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2+1 ROAD WITH BARRIER
Evaluation of the Feasibilty of Deployment of Swedish 2+1 Road with Barrier in Colorado

APPLIED INNOVATION
& RESEARCH BRANCH

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16. Abstract
Deployment of 2+1 Road with Barrier in Colorado certainly has potential to improve safety. How much safety benefit to expect, however, is, so far, somewhat uncertain. The Swedish design is widely implemented and has a record of success, so proposed Colorado Design is substantially based on it, with some modifications recommended to better reflect US driver expectancy. Study developed criteria for identifying locations with potential for implementation, screened Colorado highway network for such locations, identified 11 of them, estimated safety benefits and construction costs and ranked projects by B/C. Existing access is a challenge with introducing median barrier. This report examines proposed project locations including both the existing safety problem and the problem of existing access, and proposes possible resolutions to the access concerns. 2+1 Road with Barrier was found likely to be feasible at all 11 locations, with B/C varying between 1.56 and 9.51.

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EXECUTIVE SUMMARY

Extensive experience with deployment of 2+1 Road with Barrier in Sweden has shown that it has potential to improve safety in Colorado. Providing passing opportunities while substantially preventing head on and sideswipe opposite crashes is sure to produce safety benefits. Exactly how much safety benefit to expect, however, is so far somewhat uncertain: A recent study by Vadeby[1] uses limited empirical Bayesian methodology to estimate a Crash Reduction Factor (CRF), but has a short after period to the extent that the standard error suggests a non-negligible degree of uncertainty around the mean CRF estimate. Additionally, it is possible that crash reduction associated with 2+1 Road with Barrier varies depending on the volume and on characteristics of the existing segment. This variability in the CRF suggests that development and introduction of a crash reduction function instead of a crash reduction factor may be appropriate. A possible explanation for the variability of CRF may be that crash reduction effectiveness of passing lanes and a barrier on congested 2 lanes is greater than on less congested similar facilities.

Despite variability in its CRF, the Swedish design is widely implemented and has an overall record of success in Sweden, so the proposed Colorado design is substantially based on Swedish design, with some modifications recommended to better reflect US driver expectancy: 1) US drivers expect the right "slow" lane to end at the downstream end of a passing zone, such that slower drivers moving left are responsible for finding gaps to move into. 2) Standard US lane-drop taper rates of S:1 (where is the speed limit or 85th percentile speed in mph) are slightly longer than Swedish design tapers.

In addition to the above recommend design configuration this study:

- Developed criteria for identification of locations with potential for Implementation of 2+1 Road with Barrier:

[1] Vadeby, Anna. "Traffic Safety Effects of Narrow 2+1 Roads With Median Cable Barrier in Sweden", VTI Swedish National Road and Transport Research Institute, Conference Paper presented May 4, 2016 at Road Safety on Five Continents, Downloaded from https://www.vti.se/en/publications/publication/traffic-safety-effects-of-narrow-21-roads-with-med_920845 on 1/27/2019

    - 2-lane highway
        - 1 or more injury per mile per year over 5 years, or
        - 1 or more fatality per mile in 5 years
        - Locations with high frequency of direct highway access are excluded as impractical for implementation of 2+1 Road with Barrier
- Screened Colorado Highway network for segments meeting the criteria (12 segments identified)
- Performed safety analysis and prepared planning level construction cost estimates for Benefit /Cost analysis and ranked B/C based list of projects. (See **Table EEEE,** Page 142)

Existing access is a challenge when introducing a median barrier. Limiting an existing full-movement access to right-in, right-out is always a point of contention for landowners along a route. The examination of proposed project locations includes examination of both the exiting safety problem and of existing access, and proposes possible resolutions to the access concerns.

The considered locations included in this report were all found to hold potential for cost-effective implementation of 2+1 Road with Barrier, with B/C ranging from 1.56 on the low end to 9.51 at the most promising location.

Implementation Statement

Considering variability in the CRF, we recommend that CDOT funds a limited pilot effort for design and construction of the Colorado modified 2+1 Road with Barrier projects with predicted Benefit/Cost (B/C) ratio 3:1 of greater. In addition to improving safety at the studied locations, these projects will generate important data for the observational before after studies of the effectiveness of this treatment in Colorado environment. All locations included in this report should qualify for Federal Highway Safety Improvement Program funds.

Implementation of at least some 2+1 Roads with Barrier is a necessary first step to developing more precise tools for predicting the safety benefit of the configuration, perhaps including traffic volume and other characteristics of the existing segment in determination of appropriate crash reduction factors (or crash reduction factor function). Accurate prediction of crash reduction is

critical to making the best decisions about where to spend limited funds in pursuit of maximum safety improvement.

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

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

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

STATEMENT OF PHILOSOPHY

The efficient and responsible investment of resources in addressing safety problems is a difficult task. Since crashes occur on all highways in use, it is inappropriate to say of any highway that it is safe. However, it is correct to say that highways can be built to be safer or less safe. Road safety is a matter of degree. When making decisions effecting road safety it is critical to understand that expenditure of limited available funds on improvements in places where it prevents few injuries and saves few lives can mean that injuries will occur and lives will be lost by not spending them in places where more accidents could have been prevented[2]. It is CDOT's objective to maximize accident reduction within the limitations of available budgets by making road safety improvements at locations where it does the most good or prevents the most accidents.

LITERATURE REVIEW

Rural 2-lane highway crashes tend to be of higher severity than other highway types. This is due to a combination of high speeds, in concert with less generous design reflected by narrower shoulder widths, limited clear zone, curvature, and especially separation of opposite flows of traffic, as well as a broader mix of users and uses than rural freeways. On average on 2-lane highways in Colorado in flat and rolling terrain with AADT over 8,000 vehicles per day 8.3% of all crashes are opposite direction collisions. As CDOT pursues its Moving Toward Zero Deaths initiative, there is an opportunity to make significant progress toward this important goal by improving safety of rural 2-lane highways. This literature review focuses on the experiences of other countries that have made considerable progress in improving the safety of rural 2-lane facilities by converting them to 2+1 roads, and consideration of its feasibility in Colorado.

[2] Hauer, E., (1999) Safety Review of Highway 407: Confronting Two Myths. TRB

April 2003 I Potts[3], in NCHRP Research Results Digest Number 275, reported on European 2+1 Roadway designs. A 2+1 road has a continuous 3-lane cross section, with alternating passing lanes.

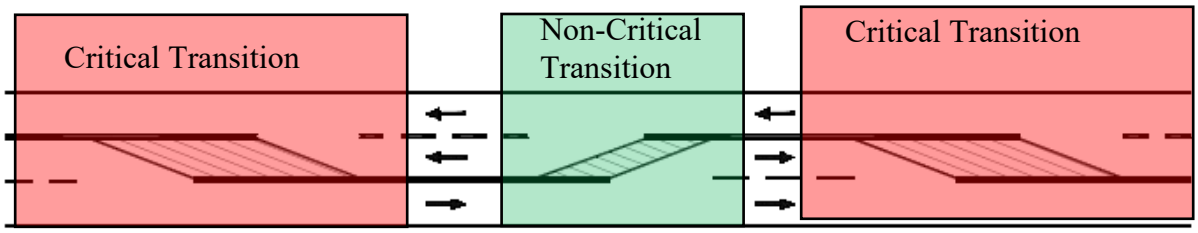

Figure 1: 2+1 Road Schematic

There are two types of transition, as shown in **Figure 1**: Critical, (in red) merging (lane drops) at end of passing lanes, where opposite direction vehicles in passing lanes are moving toward each other in the same lane; and Non-Critical, (in green above) diverging (lane adds) at beginning of passing lanes, where there is no opposite direction conflict. The report documents the state of the practice in Germany, Finland and Sweden.

GERMANY: German 2+1 roads use a 0.50m (20 inch) striped median (no barrier). All tapers are 1:1. Critical transitions are 180m (590 feet). Non-critical transitions are 30m – 50m (100 ft – 160 ft), typical length of passing is 1.0-1.4km (0.6 – 0.9 mi), never more than 2.0 km (1.2 mile). Lane drop (critical) transitions are placed where sight distance is adequate (what is adequate sight distance is not well defined). The numbers of intersections are limited. Speed limit is 100 km/h (62 mph) on segments, lowing to 70 km/h (44 mph) approaching intersections. Two-lane highways in Germany are not crowned, but have a constant cross slope, so handling the crown at transitions is not an issue. Advance signs are placed on both sides of the roadway 400m (1,300 ft) ahead of the lane drop and again 200m (650 ft) ahead of the lane drop. Merge Arrow pavement

[3] Potts, Ingrid, "Application of European 2+1 Roadway Designs" NCHRP Research Results Digest, Number 275, April 2003, Downloaded from http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rrd_275.pdf on 1/27/2019

marking also warn vehicles in the passing lane that they must merge right. 2+1 is considered the optimum roadway type for 8,000-22,000 vpd. Observed volume as high as 30,000 vpd. 2+1 roads are safer than two-lane roads, or four-lane undivided roads. The minimum length for a 2+1 road is 4km (2.5 miles). The narrow shoulders associated with the 2+1 road (0.25m (10 inches) in Germany) can be problematic for maintenance, breakdowns and crashed vehicles. A typical lane drop (critical) transition on a German 2+1 road is shown in **Figure 2**.

Figure 2: 2+1 Road in Germany

FINLAND: 2+1 roads in Finland use double striped centerline only (no barrier), but strong consideration was being given to adding a 1.7m (5' 7") flush median with a cable barrier for new construction 2+1 roads. Critical transition tapers are 200m (660 ft) (about 62:1) with a 100m (330 ft) full width buffer (500m (1,640 ft) total length including both tapers). Non-critical tapers are 25m (82 ft.) (about 7.7:1), with the two tapers back to back for a total transition length of 50m, (160 ft). 2+1 roads in Finland are controlled access (interchanges only). Typical passing lane is

1.5 km long. Advance warning signs are posted on both sides 400m (1,300 ft) ahead of the lane drop and again 50m (160 ft) ahead of the lane drop. Speed limit is 100 km/h (62 mph) for cars and 80 km/h (50 mph) for trucks. Finland has found 2+1 not much safer than ordinary 2-lane, with high head-on frequency, thus the plan to add median cable. A typical section of Finish 2+1 Road is shown in **Figure 3**.

Figure 3: 2+1 Road in Finland

SWEDEN: 2+1 roads in Sweden use cable barrier in a flush median, typically with a 1.5m (5 ft) median width. Critical transition tapers are 150m (500 feet) (about 43:1). The tapers are back-to-back with a total transition length of 300m (1,000 feet). Non-critical transitions tapers are 50m (165 feet) (about 14:1) with a total transition length of 100m (330 feet). The 2+1 section transitions to conventional 2-lane at locations with significant side road traffic or access density. Permanent openings in the median barrier, allowing for emergency/maintenance turn arounds, are located in all non-critical transition locations. Provisions for opening barrier are included in critical transition locations (at the widest point). Passing lanes are provided at least every 2km (1.2 mi). Passing zone length is variable, indicated by sign at beginning of passing lane. Advance warning signs are posted on both sides 400m (1,300 ft) ahead of the lane drop and again 50m ahead of the lane drop. Pavement marking merge arrows also alert passing drivers that they need to merge right. Delineation reflectors are incorporated in the median barrier at 100m (330 ft) spacing, decreasing to 10m (33 ft) spacing in critical transitions. The crown is located on the actual roadway centerline (thus within, but to the left of the center of the passing lane), this has not been found to cause any problems. Sweden has found 2+1 roads with barrier to be much safer than 2-lane roads, with safety very comparable to four-lane divided motorways with center barriers. 2+1 roads easily carry up to 1400-1600 vph in one direction – traffic in the opposite direction is not a factor. The speed limit is 90km/h (55 mph). A typical lane drop (critical) transition on a Swedish 2+1 road is shown in **Figure 4**.

Figure 4: 2+1 Road in Sweden, at Critical Transition

January 2009 In VTI Report 636A, A Carlsson[4] summarized the Swedish experience with 2+1 Roads with median barrier, which Sweden called "Collision Free Roads". It documents 79% reduction in fatalities compared to the two-lane roads of the same total width that they replaced, on segments away from intersections. It also finds capacity of 1600-1650 vph in one direction, with the bottleneck at the 2-lane to 1-lane transitions. The fatal crash rate for 2+1 roads with median barrier is the same as that for motorways (4-lane divided freeways with median barrier). It's important to note, however, that the fatal crash rate for 2+1 lane roads with 110 km/h (68 mph) speed limit is 60% higher than with 90 km/h (56 mph). Sweden has also tried a 2+2 road with

[4] Carlsson, Arne. "Evaluation of 2+1 Roads With Cable Barrier: Final Report", VTI Report 636A, VTI, Linkoping Sweden, January 2009

2.5m median with barrier, and found a fatal crash rate only 4% higher than 2+1 and motorway, if 2+1 has insufficient capacity, consider 2+2. Motorcyclists represent a higher proportion of fatalities and serious injuries on 2+1 roads with barriers than on 2-lane roads because of the significant reduction in all fatalities and serious injuries. In fact, for motorcyclists, 2+1 roads with barrier are safer than 2-lane roads– just not to the same degree as for cars. Median width of 1.75m (6 ft) has 20% lower barrier collisions than median width of 1.25m (4 feet) – more than 2/3 median hits are from the 1-lane side. (Perhaps offset barrier may be considered?). Flow breakdown occurs fairly suddenly at about 1,600 vph in one direction, at the 2-lane to 1-lane transition. 2+1 roadway requires more plowing, because it has more lanes. With ADT of 8,000 vehicles, the experienced barrier collision rate is 1.24/km (2.00 per mile) annually which is associated with considerable maintenance cost.

November 2014 In a presentation at Trafikverket, Ekman5 reported that 2+1 Roads with barrier were created to address the observed problem that for 2-lane roads with over 3,500 vpd head on replaced run off as the primary severe injury and fatal crash type. The network of 2+1 Roads with barrier grew from 180km in 2000 to 2,270km in 2010. Both box-beam and cable have been used for barrier, with cable very slightly outperforming box beam. 2+1 Roads are shown to have observed safety performance in terms of fatal and serious injury crashes substantially equivalent to 4-lane divided motorways.

May 2016 In a May 2016 paper presented at Road Safety of Five Continents, Vadeby, et al[6] reported that 2+1 Roads with median barrier had been implemented in Sweden address safety problems on 13m (about 42.7 ft.) wide 2-lane roads, as early as 1990. A 2+1 road with median barrier has a continuous 3-lane section with the center lane alternately assigned as a passing lane to each direction of travel, the two directions are separated by a flush median with a cable barrier.

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[5] 2+1 Roads Sweden, Lars Ekman, TRAFIKVERKET, Swedish Transport Administration 2014

[6] Vadeby, Anna. "Traffic Safety Effects of Narrow 2+1 Roads With Median Cable Barrier in Sweden", VTI Swedish National Road and Transport Research Institute, Conference Paper presented May 4, 2016 at Road Safety on Five Continents, Downloaded from https://www.vti.se/en/publications/publication/traffic-safety-effects-of-narrow-21-roads-with-med_920845 on 1/27/2019

Beginning in 2009, 2+1 with barrier was also applied on rural roads with narrower 9m – 10m (29.5 – 32.8 ft) wide roads. The narrower roads have intermittent 3rd lane added, with only about 15-35% passing opportunity for each direction, instead of about 40% for 13m roads. Before revision to 2+1 the narrow roads had speed limit of 90 km/h (56 mph), which was raised to 100 km/h (62 mph) upon conversion to 2+1. For segment (non-intersection) crashes fatalities and serious injuries decreased by 63%, which is similar to the effectiveness previously observed for 13m 2+1 conversion. (The study excluded crashes with pedestrian, bicycles, and wildlife). These results in rural road safety are comparable to 4-lane divided freeway safety (aside from intersection crashes). Vadeby used limited empirical Bayesian methodology to estimate a Crash Reduction Factor (CRF) but has a short after period to the extent that the band width of 95% confidence intervals ***(-27.0 ± 23.3 for Injury Crashes and -62.9 ± 27.2 for crashes involving Fatalities and Serious Injuries***) suggests a considerable degree of uncertainty around CRF estimate. Additionally, it is possible that crash reduction associated with 2+1 Road with Barrier varies depending on the volume and on characteristics of the existing segment. This variability in the CRF estimate suggests that development and introduction of a crash reduction function instead of a crash reduction factor may be appropriate. A possible explanation for the variability of CRF may be that crash reduction effectiveness of passing lanes and a barrier on congested 2 lanes is greater than on less congested similar facilities.

May 2017 S Cafiso, et al[7] reported on "passing relief segments" in Poland. 2+1 roads represent an alternative to a full four-lane layout providing operational and safety benefits at lower cost for AADT range of 7,000 to 25,000 vpd. Poland has implemented short stretches of 2+1 roads with less than desired lengths of passing segments (500m = 1,640 ft). Severe (Injury and Fatal)

[7] Cafiso, Salvatore, D'Agostino, Carmelo and Kiec, Mariusz. "Investigating the Influence of Passing Relief Lane Sections of Safety and Traffic Performance" Journal of Transport & Health 7 (2017) pp 38-47, UCI, London, England. Downloaded from http://dx.doi.org/10.1016/j.jth.2017.04.012 on 1/27/2019

multivehicle crashes within the segments were reduced about 47%, while crashing in adjacent (upstream and downstream) two-lane segments was basically unchanged or perhaps slightly reduced (CMF of 0.96, but 0.20 standard error means 1.00 is within the 95% confidence interval) by the presence of a nearby 2+1 segment.

BACKGROUND ON COLORADO RECOMMENDED 2+1 WITH BARRIER ROAD DESIGN

The Swedish design is widely implemented and has a record of success, so proposed Colorado design (**Figure 5**) is based on Swedish design, with some recommended modifications to better reflect US driver expectancy:

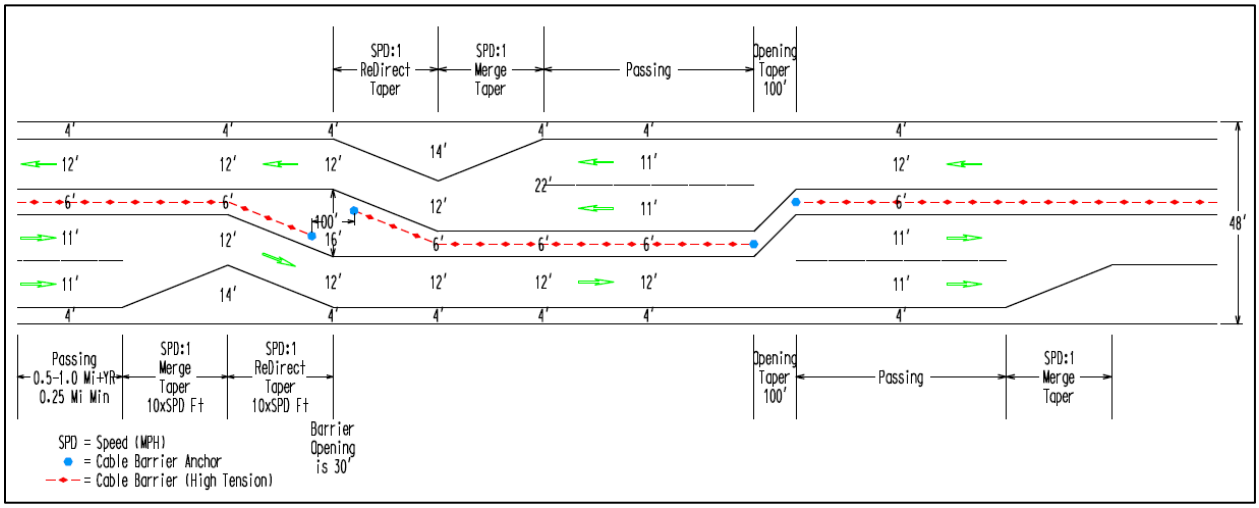


Figure 5: Sketch Layout of Proposed Colorado 2+1 With Barrier Configuration

- Cross Section: Colorado 2+1 roadway will have 4-foot outside shoulders, a 12-foot single lane, a 6-foot median (including cable barrier) two 11-foot lanes and another 4-foot shoulder, for a 48-foot typical cross section.
- Critical (Merging) Tapers: Critical tapers will be standard merging tapers of S:1 (where S is the Speed Limit or 85th percentile Speed)
    - Since we are tapering from 22-feet to 12-feet the taper will be 10 x S feet long.
    - Due to observed operational difficulties at left-lane drops in Colorado, at critical (merging) transitions the right lane should be dropped (using the S:1 merging taper) and then redirection transition (also S:1, so length = 10 x S again) should move traffic from the left (center) lane to the right.
        - This design also creates a short, wide, right-shoulder refuge which can serve as breakdown and enforcement parking at each 2-lane to 1-

lane transition. (Roughly 500 feet will have at least 10-ft shoulder width).

- Non-Critical (Diverging) Tapers: Non-critical tapers should be 100 feet.
- Intersections with significant volumes (500+ side road ADT) will include widening to accommodate auxiliary lanes so no turning traffic needs to decelerate in a thru or passing lane.
    - The center lane may serve as left turn lanes if both passing lanes can be tapered out and redirected before the intersection (right lane drop, then redirect to the right, then open a left turn auxiliary lane), barrier ends where auxiliary lane begins.
- Passing lane lengths preferred length is between ½-mile and 1-mile.
    - The absolute minimum length for a passing lane is ¼ mile.
    - Lengths over 1-mile lose efficiency, but are permissible.
- The cross section may revert to 2-lane (with barrier) in constrained locations, approaching intersections, where driveway access density is high, etc..
- The median barrier should have permanent openings at all non-critical (opening) transitions, to facilitate maintenance and emergency vehicle turn around (the median moves away from traffic in both directions in the 100-foot taper).
- Openings in the median barrier within redirect tapers can also be considered (as shown in **Figure 5**. As the median widens from 6 feet to 16 feet the barrier follows parallel to the yellow edge line. 50 feet short of where median reaches maximum width the barrier ends – the opening ends up 100-feet longitudinally with the ends offset by 8+ feet. Otherwise a continuous barrier would be placed in the center of the median (Taper rate would be 2S:1).
- Center Barrier should be a high-tension cable type, configured per manufactures specifications to achieve minimum dynamic deflection.
    - CDOT may consider specifying a dynamic deflection that only one or two configurations can meet.
    - There is a reoccurring argument that allowing dynamic deflection into a traveled way introduces unacceptable tort liability risk. This argument

seems untenable given the observed effectiveness of 2+1 Roads with Barrier:

- 2+1 Road with Barrier has a demonstrated ability to prevent, or lessen the effects of many high severity crashes, but it cannot prevent all of them. This is true of all or near all existing highway safety strategies.
- There is relatively low probability, that a center barrier rail will be deflected into an opposite direction lane and result in a collision between opposite direction vehicles (or an opposite direction vehicle and the barrier). If that unlikely event does occur, there is still a low probability that the barrier itself will be found to have increased either the likelihood or the severity of the crash (that is, the crash between opposite direction vehicles may have occurred even without the barrier, and may have been just as, or more severe).

SELECTION METHODOLOGY

The concept of 2+1 roads with barrier has originated in Sweden over 20 years ago. Since that time over 1,500 miles has been constructed, exhibiting significant safety improvements. Because of European experience, the use of 2+1 roads in the United States is recommended. A 2+1 road can serve as an effective design alternative for higher-volume, two-lane roads where the provision of a four-lane cross section is not practical due to budget constraints or environmental concerns.

Observational before and after studies conducted in Sweden over more than 20 years, show that **a 75% crash reduction in fatalities and a 50% reduction in injuries** can be expected. [3,4,5]. In addition to reducing head-on and sideswipe-opposite crashes Swedish 2+1 Section with Barrier is also effective in reducing higher severity roadway departure crashes such as overturning and fixed object collisions. **Figure 6** shows a photograph of an operating location in Sweden.

Figure 6: Example 2+1 Road with Barrier

As a general rule of thumb, for the deployment of the Swedish 2+1 Section with barrier on the rural 2 lane, segments that experience 1 or more injuries per mile per year may potentially be candidates for cost-effective implementation. Supporting B/C sensitivity analysis is provided in **Table A** using cost of construction of $500,000 per mile, cost of maintenance of $10,000 per mile annually and a CRF of ***50% for Injury*** crashes. During network screening for potential sites for deployment of Swedish 2+1 Section with Barrier, selecting segments containing fatal crashes will produce greater returns on investment, for instance observing 1 injury per mile per year, combined with 1 fatality per mile over a period of 5 years, will produce a break-even value of $4,700,000 per mile (**Table B**).

Table A: B/C Sensitivity for 2+1 Section Implementation

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

04/13/2020

Job #: 20200413163741

Location: 1A **Begin:** 0.00 **End:** 1.00 **From:** 01/01/2014 **To:** 12/31/2018

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	0		Weighted PDO:	0.00	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	5	5: Injured	Weighted INJ:	1.23	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	0	0: Killed	Weighted FAT:	0.00	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	50%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
Cost:	$ 500,000					Service Life:	20
From:	01/01/2014					Capital Recovery Factor:	0.080
To:	12/31/2018		Days: 1826			Annual Maintenance/Delay Cost:	$ 10,000

Benefit Cost Ratio: 1.21 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

Table B: B/C Sensitivity for 2+1 Section (Including Consideration of Fatalities)

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

04/13/2020

Job #: 20200413163741

Location: 1A **Begin:** 0.00 **End:** 1.00 **From:** 01/01/2014 **To:** 12/31/2018

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	0		Weighted PDO:	0.00	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	5	5: Injured	Weighted INJ:	1.23	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	1	1: Killed	Weighted FAT:	0.25	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	54%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
Cost: $ 4,700,000						Service Life:	20
From: 01/01/2014						Capital Recovery Factor:	0.080
To: 12/31/2018		Days: 1826				Annual Maintenance/Delay Cost:	$ 10,000

Benefit Cost Ratio: 1.00 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

In connection with selecting potential sites for the deployment of Swedish 2+1 Section with Barrier, it's important to keep in mind that 2 lane roads with AADT of 3,000 or more exhibit higher percentage of head-on and sideswipe opposite crashes. **Tables C** and **D** show that head-on and sideswipe opposite crashes combined on Colorado 2-Lane Rural roads with AADT between 3,000 – 8,000 account for 6.13% of all crashes, and 8.33% for 2-Lanes with AADT over 8,000. These crashes are characterized by high severity and many of them are fatal. Over 90% of them can be prevented by construction of Swedish 2+1 Section with Barrier.

Table C: Diagnostic Norms for Rural Highway on Flat and Rolling Terrain, with 2-Lanes (Undivided) and AADT from 3,000 – 8,000

Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Diagnostics Comparison Percentages Baselines

12/11/2018

Job #: 20181211160537

Highway Class: CO - Rural Flat and Rolling 2-Lane UnDivided Highways - AADT 3000 - 8000 ADT (2016)

Baseline Statistics	Statewide Average	
CATEGORY	# Crashes	%
Property Damage Only (PDO)	3,219	75.02%
Injury (INJ)	1,002	23.35%
Fatal (FAT)	70	1.63%
Persons Injured	1,475	
Persons Killed	80	
Single Vehicle Accidents	3,474	80.96%
Two Vehicle Accidents	732	17.06%
Three or More Vehicle Accidents	85	1.98%
Unknown Number of Vehicles	0	0.00%
On Road	2,637	61.45%
Off Road	1,654	38.55%
Off Road Left	732	17.06%
Off Road Right	917	21.37%
Off Road at Tee	0	0.00%
Off Road in Median	5	0.12%
Unknown Road Location	0	0.00%
Overturning	587	13.68%
Other Non Collision	57	1.33%
Vehicle Cargo or Debris	99	2.31%
Pedestrian	9	0.21%
Broadside	0	0.00%
Head On	81	1.89%
Rear End	254	5.92%
Sideswipe (Same Direction)	76	1.77%
Sideswipe (Opposite Direction)	182	4.24%

Baseline Statistics	Statewide Average	
CATEGORY	# Crashes	%
Large Boulders or Rocks	22	0.51%
Rocks in Roadway	0	0.00%
Barricade	1	0.02%
Wall or Building	1	0.02%
Crash Cushion	0	0.00%
Mailbox	26	0.61%
Other Fixed Object	36	0.84%
Involving Other Object	34	0.79%
Road Maintenance Equipment	7	0.16%
Unknown Accident Type	0	0.00%
Total Fixed Objects	1,039	24.21%
Total Other Objects	140	3.26%
Daylight	2,067	48.17%
Dawn or Dusk	362	8.44%
Dark - Lighted	27	0.63%
Dark - Unlighted	1,835	42.76%
Unknown Lighting	0	0.00%
No Adverse Weather	3,307	77.07%
Rain	111	2.59%
Snow or Sleet or Hail	578	13.47%
Fog	56	1.31%
Dust	16	0.37%
Wind	221	5.15%
Unknown Weather	2	0.05%
Dry Road	3,085	71.89%

Table D: Diagnostic Norms for Rural Highway on Flat and Rolling Terrain, with 2-Lanes (Undivided) and AADT over 8,000

Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Diagnostics Comparison Percentages Baselines

12/11/2018

Job #: 20181211161220

Highway Class: CO - Rural Flat and Rolling 2-Lane UnDivided Highways - AADT > 8000 ADT (2016)

Baseline Statistics	Statewide Average		Baseline Statistics	Statewide Average	
CATEGORY	# Crashes	%	CATEGORY	# Crashes	%
Property Damage Only (PDO)	347	68.85%	Large Boulders or Rocks	3	0.60%
Injury (INJ)	143	28.37%	Rocks in Roadway	0	0.00%
Fatal (FAT)	14	2.78%	Barricade	0	0.00%
Persons Injured	210		Wall or Building	1	0.20%
Persons Killed	15		Crash Cushion	0	0.00%
Single Vehicle Accidents	372	73.81%	Mailbox	2	0.40%
Two Vehicle Accidents	113	22.42%	Other Fixed Object	4	0.79%
Three or More Vehicle Accidents	19	3.77%	Involving Other Object	6	1.19%
Unknown Number of Vehicles	0	0.00%	Road Maintenance Equipment	2	0.40%
On Road	323	64.09%	Unknown Accident Type	0	0.00%
Off Road	181	35.91%	Total Fixed Objects	110	21.83%
Off Road Left	68	13.49%	Total Other Objects	15	2.98%
Off Road Right	109	21.63%	Daylight	239	47.42%
Off Road at Tee	0	0.00%	Dawn or Dusk	28	5.56%
Off Road in Median	4	0.79%	Dark - Lighted	3	0.60%
Unknown Road Location	0	0.00%	Dark - Unlighted	234	46.43%
Overturning	59	11.71%	Unknown Lighting	0	0.00%
Other Non Collision	8	1.59%	No Adverse Weather	391	77.58%
Vehicle Cargo or Debris	7	1.39%	Rain	15	2.98%
Pedestrian	2	0.40%	Snow or Sleet or Hail	65	12.90%
Broadside	0	0.00%	Fog	4	0.79%
Head On	19	3.77%	Dust	0	0.00%
Rear End	51	10.12%	Wind	12	2.38%
Sideswipe (Same Direction)	13	2.58%	Unknown Weather	17	3.37%
Sideswipe (Opposite Direction)	23	4.56%	Dry Road	379	75.20%

For this study existing 2-lane segments in Colorado were examined, looking for locations with at least 1 injury crash per mile per year, or at least 1 fatal crash per 10 mile in 5 years. 5 years crash history was examined. Locations with concentrations of direct accesses were excluded as impractical for construction of 2+1 roads with barrier. Safety analysis was performed, checking for susceptibility of observed crash types to implementation of 2+1 road with barrier for improvement. Planning level estimates of construction costs were estimated with some consideration of local conditions of the segment under consideration, and Benefit/Cost analysis was performed. Only segments with B/C above 1.00 are included in this report.

LOCATIONS WITH POTENTIAL FOR DEPLOYEMENT OF 2+1 ROAD WITH BARRIER CONFIGURATION

List of Locations:

- State Highway 024G MP 321.00 – 325.50, Northeast of Falcon, El Paso County
- State Highway 030A (Gun Club Road) MP 16.72 -20.33 Quincy to South of 6th Avenue, Arapahoe County
- State Highway 040A MP 151.00 – 154.00 In Routt National Forrest, Routt and Grand Counties
- State Highway 040A MP 222.00 – 226.00 North and South of Tabernash, Grand County
- State Highway 052A MP 14.93 – 18.80 East of I-25, Weld County
- State Highway 066B MP 39.30 – 40.70 West of I-25, Weld County
- State Highway 086A MP 7.79 – 13.40 East of Franktown, Douglas and Elbert Counties
- State Highway 115A MP 20.37 – 24.37 North of Penrose, Freemont County
- State Highway 160A MP 27.40 – 34.02, South of Cortez, Montezuma County
- State Highway 160A MP 197.90 – 200.90 West of Del Norte, Rio Grande County
- State Highway 160A MP 258.42 – 263.00 East of Fort Garland, Costilla County
- State Highway 285D MP 185.01 – 189.20 North of Fairplay, Park County

State Highway 024G, MP 321.00 to 325.50, Northeast of Falcon, El Paso County

Figure 7: SH 024G MP 321.00 to 325.50 Location

The observations and recommendations in this report are based on the analysis of five years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 24G (SH 024G) in El Paso County, beginning at MP 321.00 and extending to MP 325.50. The study begins just northeast of the Woodmen Intersection in Falcon and extends to the northeast towards the town of Peyton. The included distance is about 4.53 miles.

SITE CONDITIONS SH 24 is classified as an Urban Principal Arterial from MP 321.00 to MP 322.53 and a Rural Principal Arterial from MP 322.54 to MP 325.50, however it is of a rural character throughout the study section. SH 24 is primarily a 2-lane undivided highway facility with 12-foot lanes and 8-foot shoulders in the study section, but has two widened areas in the vicinity

of the two principal intersections that lie within the study limits. These widened sections each consist of one or more turn lanes as detailed in **Table E** below. This study will focus on the non-widened, 2-lane undivided portions.

Table E: Locations of Widened Sections

Begin MP	End MP	Description
321.00	322.22	2-Lane Undivided
322.23	322.80	Widened section to provide left turn lanes for Judge Orr Rd Intersection.
322.81	323.22	2-Lane Undivided
323.23	324.11	Widened section to provide left and right turn lanes for Stapleton Rd Intersection.
324.12	325.50	2-Lane Undivided

There are no rumble strips except in three short portions of the divided no-work sections. The terrain category is flat. The average annual daily traffic (AADT) from 2012 to 2015 is shown in **Table F**. 2015 is the latest year for which this data is available.

Table F: AADT by Location and Year

Begin MP	End MP	2012	2013	2014	2015
321.00	322.53	13,000	13,000	14,000	13,000
322.54	325.50	8,600	8,800	9,100	8,500

The speed limit is posted at 55 mph from the beginning of the study area until MP 322.82 and 65 mph from there on.

Table G summarizes the non-intersection related crash history for SH24G over the 5-year period from 01/01/2012 to 12/31/2016 in the three undivided sections detailed above.

Table G: Summary of Crash History SH 24G, 2012-2016

Begin MP	End MP	PDO	INJ	FAT	Total
321.00	322.22	4	9	1	14
322.81	323.22	1	2	0	3
324.12	325.50	1	6	0	7
Total		6	17	1	24

As **Table G** shows, 18 of the 24 crashes, or 75%, involved injuries or fatalities. For comparison, the statewide average for 2-lane undivided facilities in this AADT range is for only 31% of all accidents to result in injury or fatality, suggesting that an opportunity may exist to reduce the number of severe accidents in this location.

Figure 8 shows a typical section of SH 24 within project limits.

Figure 8: SH 24, MP 321.00 to 325.50 Typical View

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 9** shows the corridor SPF for the study section with the three work segments and two no-work segments identified. As the chart shows, the study section is performing worse in terms of the severity of crashes than the overall number of crashes. This is seen by the fact the line for the severity SPF plots higher than the frequency line throughout the length of the plot. It is mostly in category LOSS-III in the work segments, but is in the LOSS-IV category through the first 6/10 or so of a mile suggesting a relatively high potential for reduction of severe crashes.

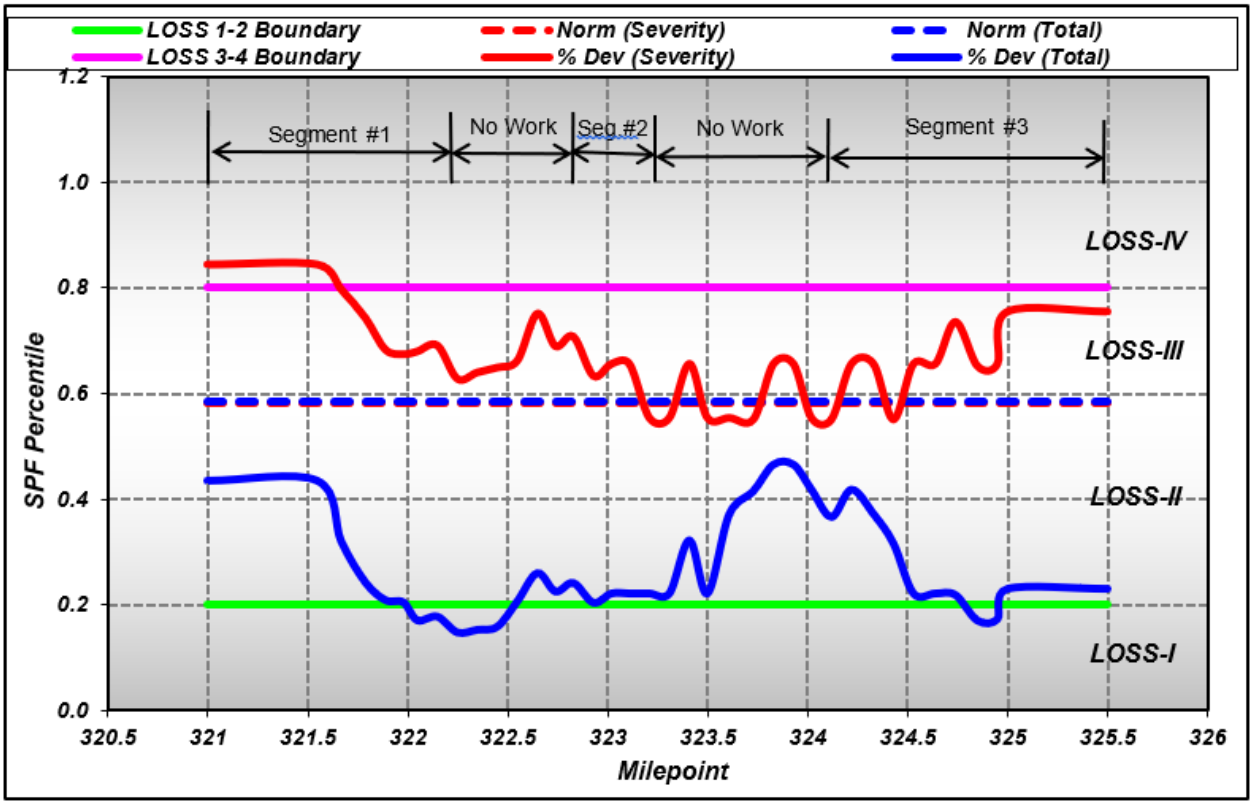


Figure 9: Corridor SPF for SH 024G MP 321.00 to 325.50

Figures 9 and **10** represent EB corrected segment safety performance analysis of SH 24 within the study limits. The three 2-lane undivided sections are each shown separately in the charts.

Figure 9 shows segment safety performance from the total crash frequency stand point. It shows that all three segments perform in the LOSS-II category in terms of total crash frequency, suggesting a low potential for a significant reduction in total number of crashes.

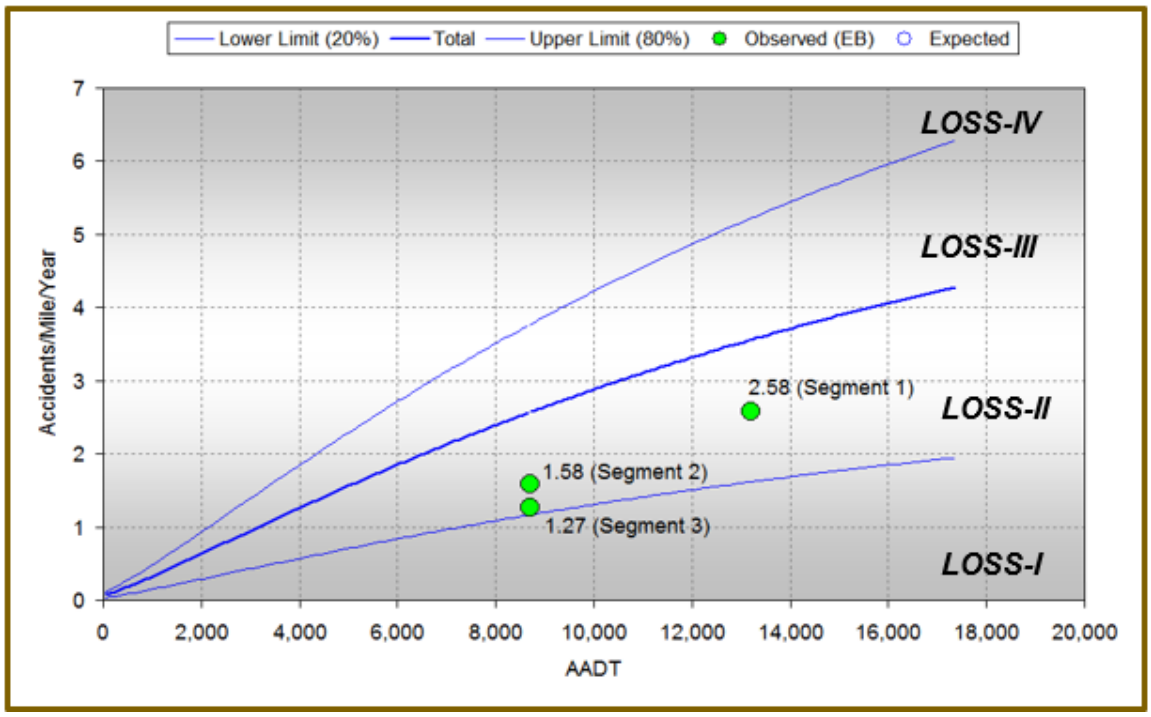


Figure 10: EB Corrected SPF for Total Crashes

Figure 11 represents segment safety performance from the standpoint of severity and considers injury and fatal crashes only. It shows all three segments perform in LOSS-III and LOSS-IV category in terms of severity, suggesting moderate to high potential for reduction of crashes involving bodily injury.

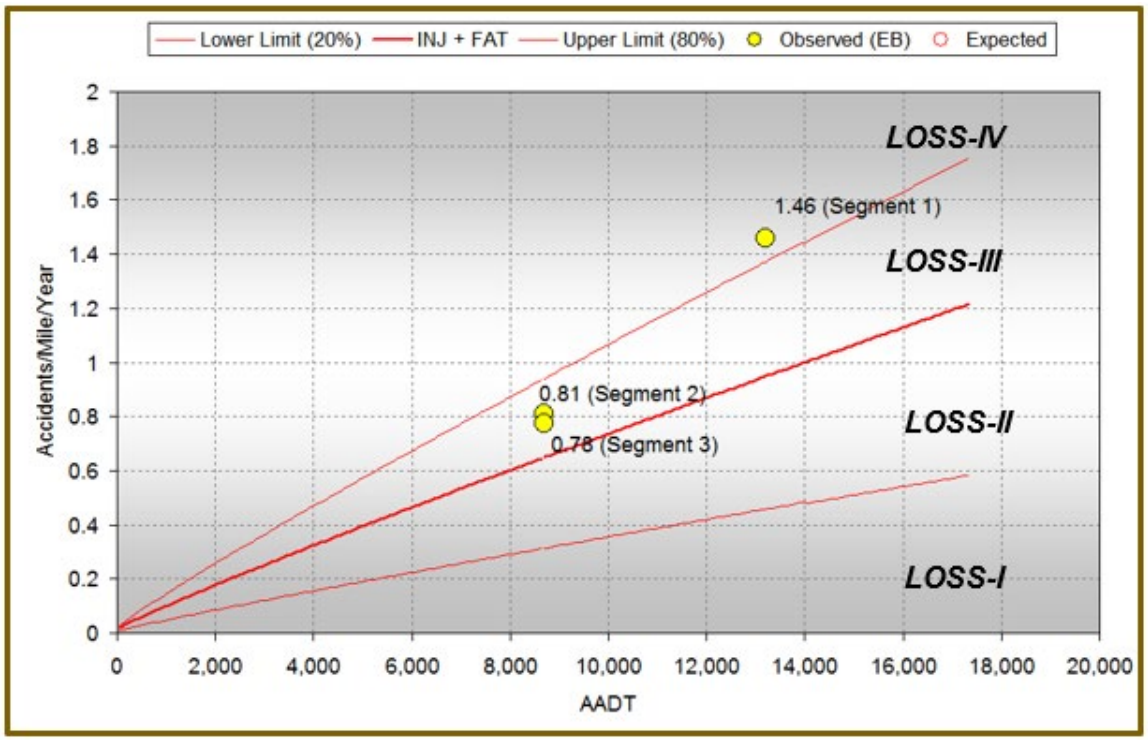


Figure 11: EB Corrected SPF for Injury and Fatal Crashes

Table H shows a summary the SPF means for the type of facility and AADT, with the observed values for this study.

Table H: SPF Data, SH 24 MP 321.00 to MP 325.50

Location	AADT	PDO	INJ	FAT	Length	Yrs	SPF Mean (I+F)	SPF Mean (Ttl)	Observed (I+F)	Observed (Ttl)
Segment 1 MP 321.00 to 322.53	8700	4	9	1	1.56	5	0.95	3.56	1.46	2.55
Segment 2 MP 322.81 to 323.22	8700	1	2	0	0.41	5	0.65	2.57	0.81	1.58
Segment 3 MP 324.12 to 325.50	13200	1	6	0	1.38	5	0.65	2.57	0.78	1.27

Types of Crashes Of the 24 non-intersection related crashes in the study section, 16 of them (67%) involved two or more vehicles compared with the statewide average rate of 26% for this type of facility.

The overall distribution by crash types within the study limits, with breakdowns for each of the three subsections, is provided in **Figure 12**. As with the previous crash related summaries, these depict only the non-intersection related crashes. As the chart for overall crashes shows, Rear End crashes were the most common, representing 29% of all crashes, but otherwise the types of crashes are spread relatively evenly amongst seven other different crash types. It is noted that the Overtaking Turn crashes were not intersection related as one would typically expect for this crash type, but were resulted when vehicles were attempting to make U-turns on the highway.

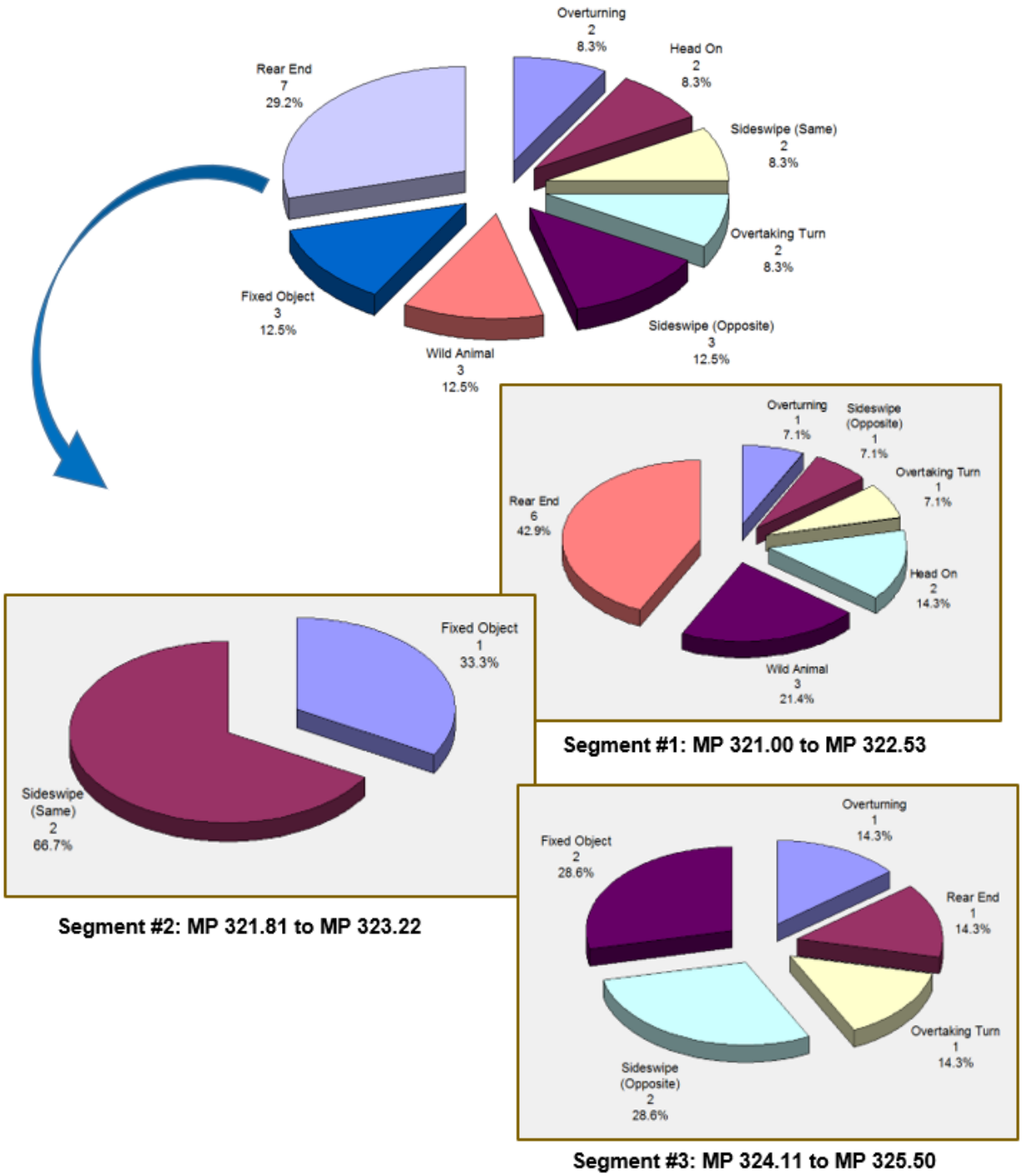
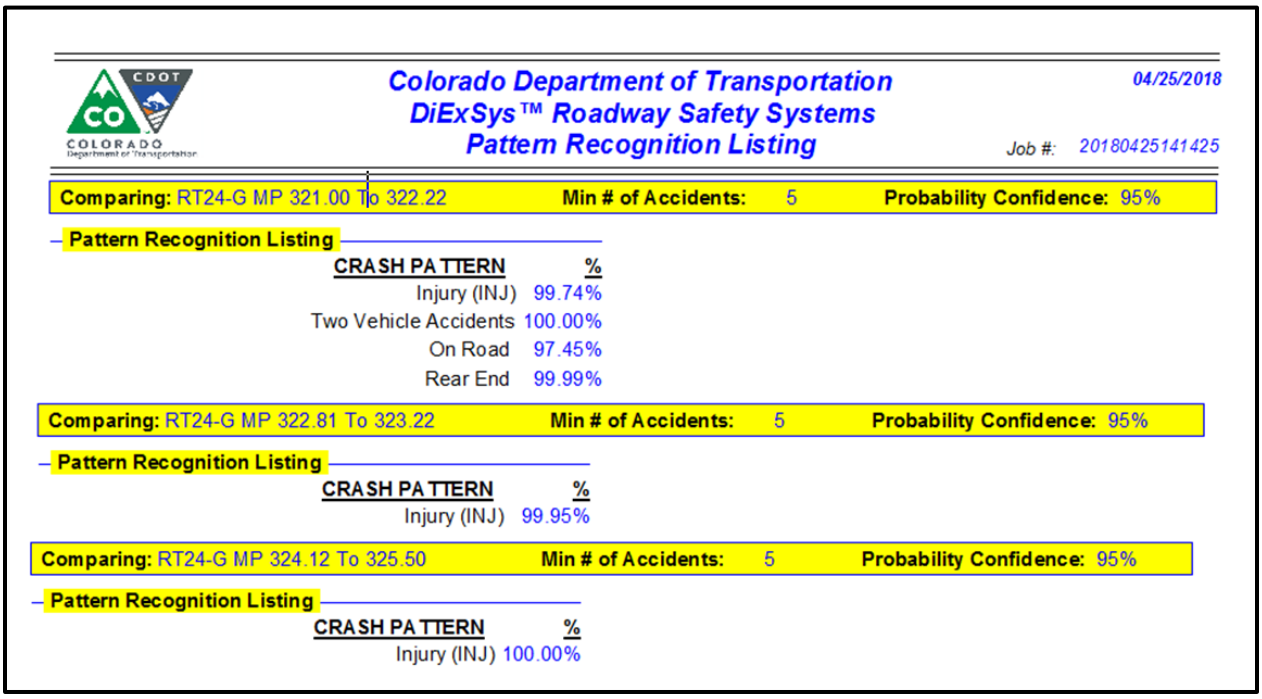


Figure 12: Crash Type Distribution SH 024G MP 321.00 – 325.50

Table I shows the results of a pattern recognition analysis each of the three segments under consideration. As the table shows, injury crashes represent patterns of notable frequency in all three of the segments. It is anticipated that many of these crashes will be circumvented with the Swedish 2+1 lane configuration. It is also expected that the frequency of On Road and Two Vehicle

crashes indicated for Segment #1 will be substantially reduced and to a lesser extent even the Rear End crashes may be reduced as a result of increased opportunities for passing.

Table I: Pattern Recognition Results for Three Segments of SH 024G



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

04/25/2018

Job #: 20180425141425

Comparing: RT24-G MP 321.00 To 322.22 **Min # of Accidents:** 5 **Probability Confidence:** 95%

Pattern Recognition Listing

CRASH PATTERN	%
Injury (INJ)	99.74%
Two Vehicle Accidents	100.00%
On Road	97.45%
Rear End	99.99%

Comparing: RT24-G MP 322.81 To 323.22 **Min # of Accidents:** 5 **Probability Confidence:** 95%

Pattern Recognition Listing

CRASH PATTERN	%
Injury (INJ)	99.95%

Comparing: RT24-G MP 324.12 To 325.50 **Min # of Accidents:** 5 **Probability Confidence:** 95%

Pattern Recognition Listing

CRASH PATTERN	%
Injury (INJ)	100.00%

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since these sections of SH 24 exhibit a much higher than expected frequency of crashes involving bodily injury, this may be a very effective location to use the 2+1 Road with Barrier configuration. The separation of oncoming lanes and the addition of a third lane is expected to substantially reduce the quantity of multi-vehicle crashes that were observed to be occurring at significantly higher rates than expected for this type of highway. Most, if not all, of the crash types occurring here are likely to be reduced by this improvement.

Table J shows an economic analysis for converting the proposed segments of SH 24 to the 2+1 Road with Barrier configuration. The analysis is based on an average cost of $800,000 per mile, for a total of $2,440,000. As the analysis shows, the expected benefit to cost ratio for this improvement is 3.12 to 1. (The analysis excludes wild animal collisions).

The cost used in this analysis is based on rough parametric estimation done using the existing cross section and terrain for this particular section of SH 024G. The actual cost is likely to vary based on more specific factors that will be determined upon final design of a project.

Table J: Economic Analysis for Conversion to 2+1 Road with Barrier (3 segments)

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

04/13/2020

Job #: 20200413233922

Location: 24G **Begin:** 321.00 **End:** 325.50 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	6		Weighted PDO:	1.47	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	15	31: Injured	Weighted INJ:	7.62	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	1	1: Killed	Weighted FAT:	0.25	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	42%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 30,100

Cost: $ 2,440,000
From: 01/01/2012
To: 12/31/2016
Days: 1827

Benefit Cost Ratio: 3.12 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 Road with Barrier cross section is adopted, decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality, some accesses may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated. **Table K** shows a list of accesses within the proposed improvement sections with some preliminary observations pertinent to their handling.

Table K: Accesses Within Improvement Segments

Location	Description	Comments	Recommendation
MP 321.25	3-Leg intersection with Blue Gill Drive on southeast side	Most convenient access for about 4 properties for EB entrance/WB exit. Alternate access is Cotton Tail Drive 0.25 miles away.	Region decision.
MP 321.50	3-Leg intersection with Cotton Tail Dive on southeast side	Serves a large number of properties.	Retain full access.
MP 323.03	3-Leg access on southeast to one business.	Nearest opportunity to turn around without making U-turn on highway is a half of a mile away.	Retain full access.
MP 324.18 to MP 324.43	Three single property accesses and one minor road (Curtis Rd)	There appears to be some redundancy between two of the single property accesses.	Retain full access at Curtis Rd and provide for U-turns at that location to facilitate reaching the other three.
MP 324.75	3-Leg access on southeast to 8 properties.		Retain full access.
MP 324.96	3-Leg access on southeast to 1 property.	This property may be part of a larger property with access at MP 325.02. To use that access when travelling in the direction that this one would be blocked would not create a significant inconvenience.	Region decision.

State Highway 030A (Gun Club Rd), MP 16.72 to 20.33, South of 6th Ave. to Quincy Ave., Arapahoe County

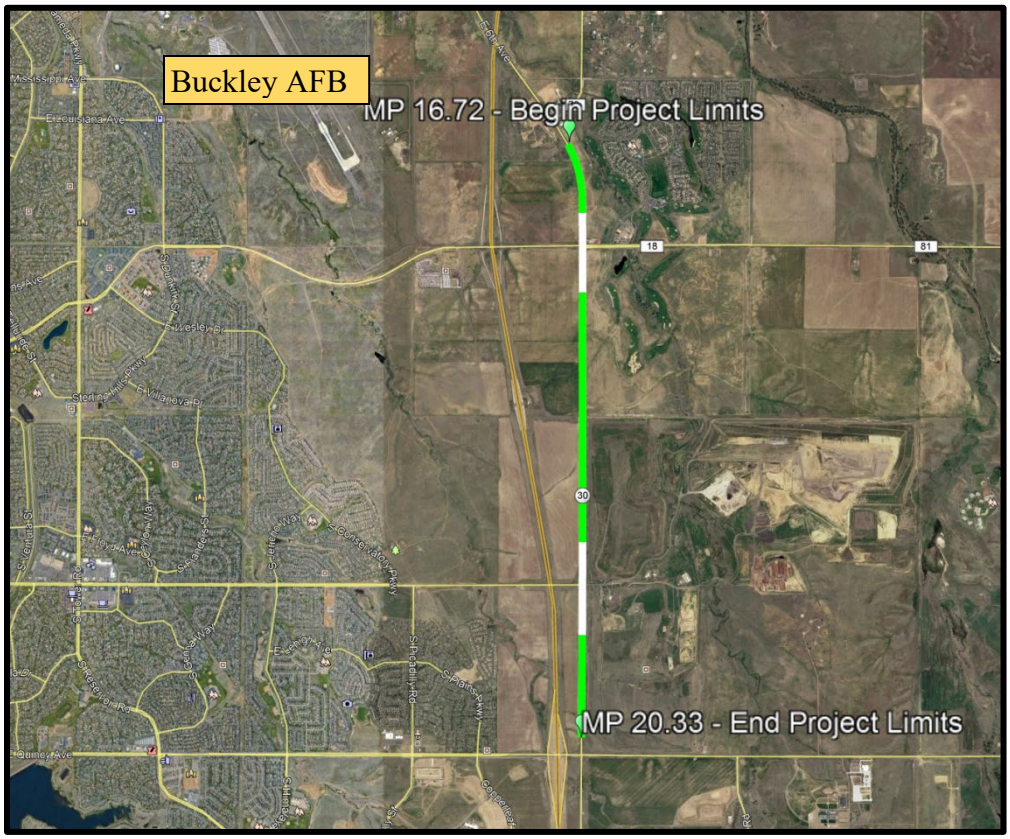


Figure 13: SH 030G MP 16.72 to 20.33 Location

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 030A (SH 030A), also known as Gun Club Road, in Arapahoe County, beginning at MP 16.72 and extending to MP 20.33. The study begins just south of 6th Ave. in Aurora and extends southerly to .09 miles north of Quincy Ave. The included distance is about 3.61 miles.

SITE CONDITIONS SH 30 is classified as an Urban Minor Arterial throughout the study section; however, it is of a rural character. SH 30 is primarily a 2-lane undivided highway facility

with 12-foot lanes with minimal shoulders in the study section, but it has two widened areas in the vicinity of principal intersections that lie within the study limits. These widened sections each consist of one or more auxiliary lanes as detailed in **Table L** below. This study will focus on the non-widened, 2-lane undivided portions.

Table L: Locations of Widened Sections

Begin MP	End MP	Length	Description
16.72	17.11	0.39	2-Lane Undivided
17.12	17.59	0.47	Widened section to provide turn lanes and acceleration lanes for Jewell Ave Intersection.
17.60	19.07	1.47	2-Lane Undivided
19.08	19.63	0.55	Widened section to provide turn lanes and NB acceleration lane for Hampden Intersection.
19.64	20.33	0.69	2-Lane Undivided

There are no rumble strips in the study section. The speed limit is posted at 55 mph throughout. The average annual daily traffic (AADT) from 2012 to 2015 is shown in **Table M**. 2015 is the latest year for which this data is available.

Table M: AADT by Location and Year

Begin MP	End MP	2012	2013	2014	2015
16.72	19.28	16,000	17,000	17,000	16,000
19.29	20.42	16,000	17,000	17,000	15,000

Table N summarizes the non-intersection related crash history for SH 30 over the 5-year period from 01/01/2012 to 12/31/2016 in the three undivided sections detailed above.

Table N: Summary of Crash History SH 30A, 2012-2016

Begin MP	End MP	PDO	INJ	FAT	Total
16.72	17.11	4	1	0	5
17.60	19.07	11	13	1	25
19.64	20.33	19	12	0	31
Total		34	26	1	61

As **Table N** shows, 27 of the 61 crashes, or 44%, involved injuries or fatalities. For comparison, the statewide average for 2-lane undivided facilities in this AADT range is for only 31% of all accidents to result in injury or fatality, suggesting that an opportunity may exist to reduce the number of severe accidents in this location.

Figure 14 shows a typical section of SH 30 within project limits.

Figure 14: SH 30, MP 18 - Typical Cross Section

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 15** shows the corridor SPF for the study section with the three work segments and two no-work segments identified. As the chart shows, the study section is performing in LOSS-II through Segment #1 suggesting relatively low potential for crash reduction. Segment #2 continues to perform in LOSS-II for much of the segment but rises sharply to finish at the boundary between LOSS-III and LOSS-IV. In terms of severity, Segment #2 performs at LOSS-III and LOSS-IV for most of the stretch suggesting a relatively high potential for reducing severe crashes. Segment #3

performs at LOSS-IV throughout both in terms of frequency and severity suggesting a high potential for crash reduction in that stretch.

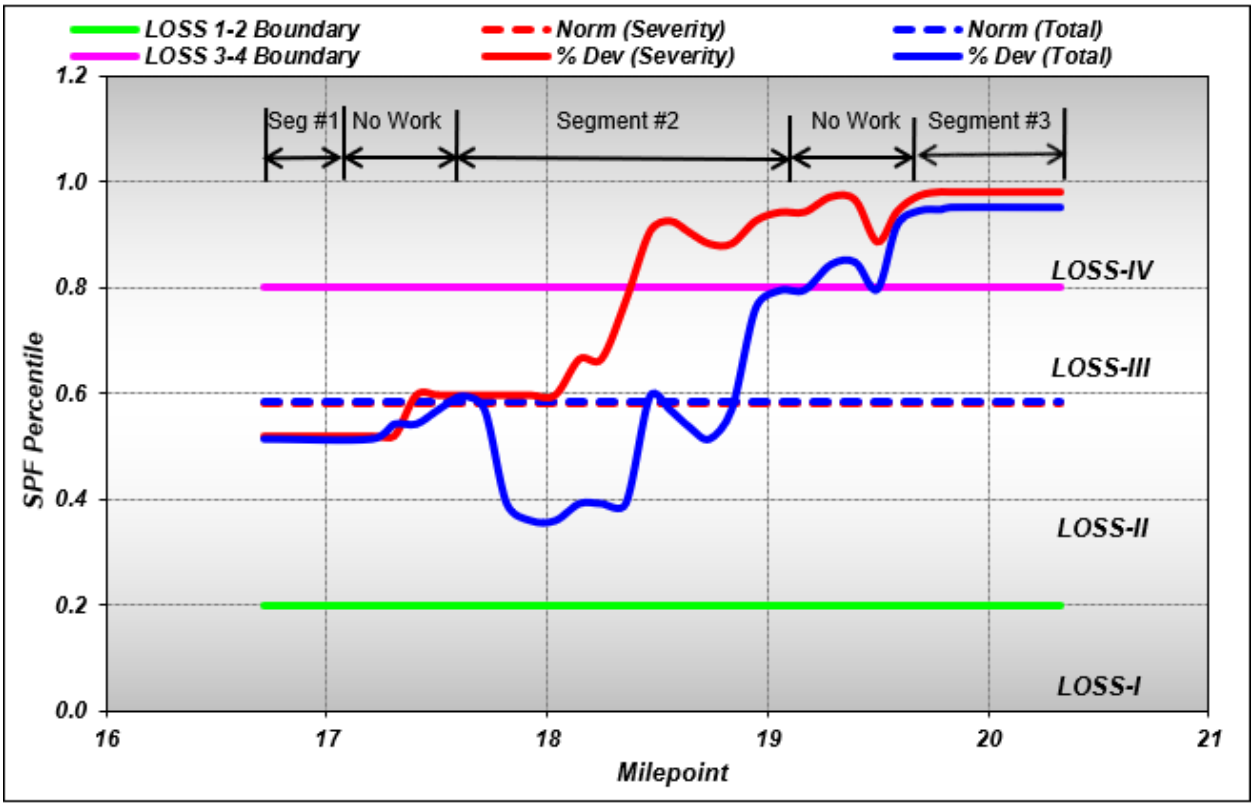


Figure 15: Corridor SPF for SH 030A MP 16.72 to 20.33

Figures 16 and **17** represent EB corrected segment safety performance analysis of SH 30 within the study limits. The three 2-lane undivided sections are each shown separately in the charts.

Figure 16 shows segment safety performance from the total crash frequency stand point. It shows that segments #1 and #2 perform in the LOSS-II category in terms of total crash frequency, suggesting a low potential for a significant reduction in total number of crashes. However, segment #3 is performing well into the LOSS-IV category suggesting a high potential for reducing the number of crashes.

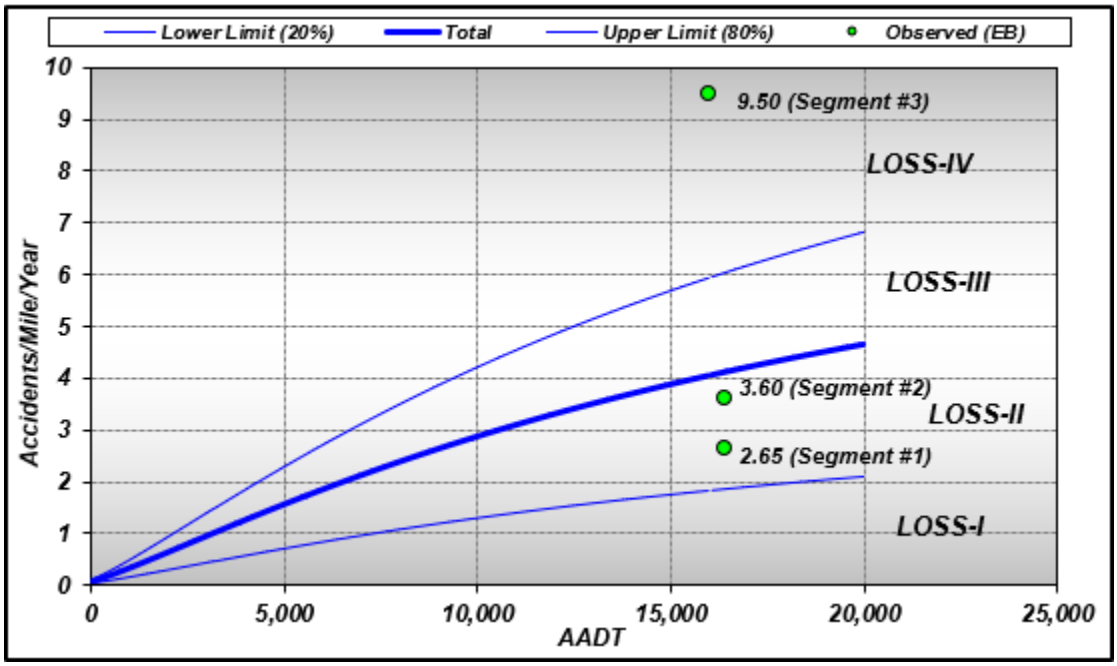


Figure 16: EB Corrected SPF for Total Crashes

Figure 17 represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. It shows that segments #2 and #3 perform in LOSS-IV category in terms of severity, suggesting moderate to high potential for reduction of crashes involving bodily injury. Segment #1 is performing in the Loss-II category indicating a relatively low potential for severe crash reduction.

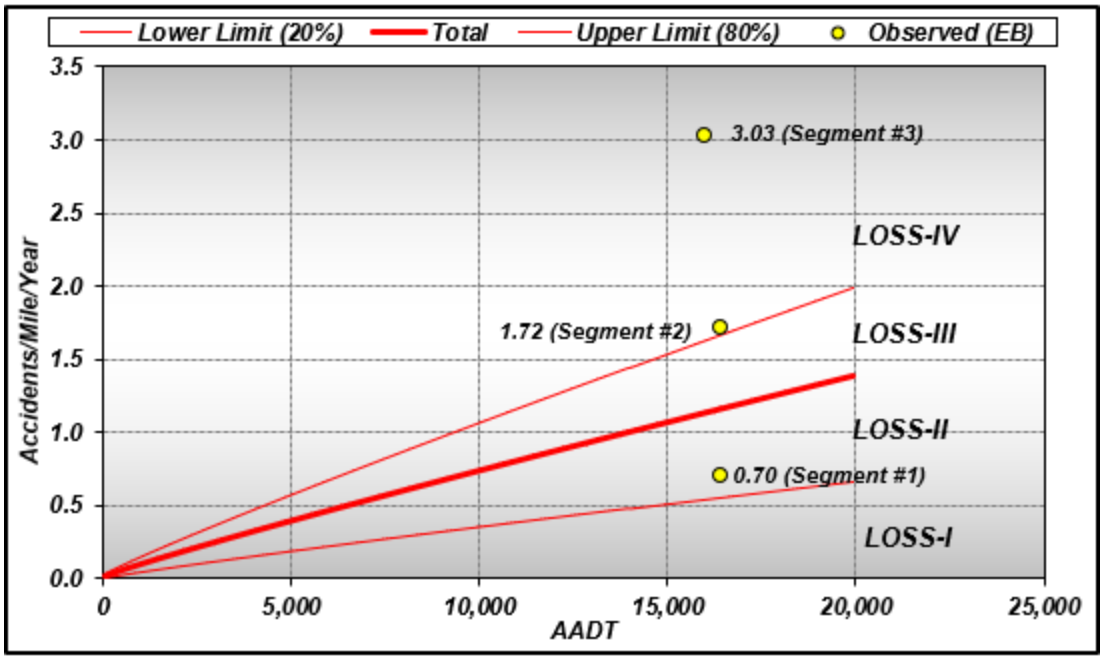


Figure 17: EB Corrected SPF for Injury and Fatal Crashes

Table O shows a summary of the SPF means for the type of facility and AADT, with the observed values for this study.

Table O: SPF Data, SH 30 MP 16.72 to MP 20.33

Location	AADT	PDO	INJ	FAT	Length	Yrs	SPF Mean (I+F)	SPF Mean (Ttl)	Observed (I+F)	Observed (Ttl)
Segment 1 MP 16.72 to 17.11	16400	4	1	0	0.39	5	1.15	4.13	0.70	2.65
Segment 2 MP 17.60 to 19.07	16400	11	13	1	1.47	5	1.15	4.13	1.72	3.60
Segment 3 MP 19.64 to 20.33	16000	19	12	0	0.69	5	1.13	4.06	3.03	9.50

Types of Crashes Of the 61 non-intersection related crashes in the study section, 42 of them (70%) involved two or more vehicles compared with the statewide average rate of 26% for this type of facility.

Forty-four (44) or 72% of the 61 crashes in the study section occurred on the roadway. Of the 17 crashes that were off-roadway crashes, 14 (23%) of them were off right and 3 (5%) were off left. The percentage of on-road crashes is somewhat higher than the statewide average of 64% for this type of facility. The adoption of the Swedish 2+1 design can be expected to reduce this number by eliminating the opposite direction multi-vehicle crashes.

The overall distribution by crash types within the study limits, with breakdowns for each of the three subsections, is provided in **Figure 18**. As with the previous crash related summaries, these depict only the non-intersection related crashes. As the chart for overall crashes shows, Rear End crashes were the most common, representing 43% of all crashes. Fixed Object crashes were the second most common crash type representing 23% of all crashes. The other relatively common crash types were Opposite Side Sideswipes comprising 11% of the crashes, with Overturning and Head Ons each comprising 8%. The four "Other" types of crashes shown in the chart were one Same Direction Sideswipe, one Overtaking Turn, one Parked Motor Vehicle and one crash involving spilled cargo on the roadway.

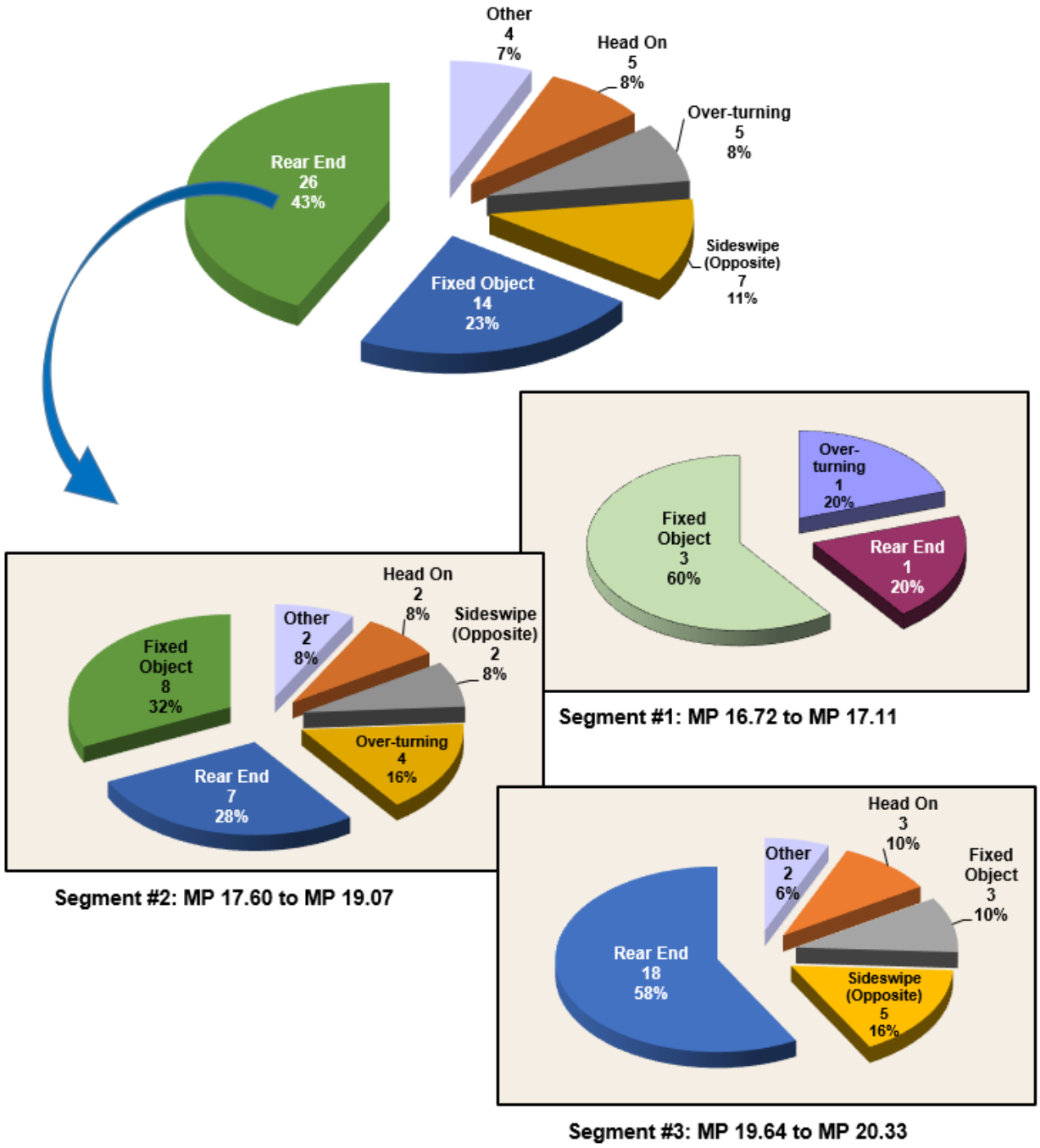
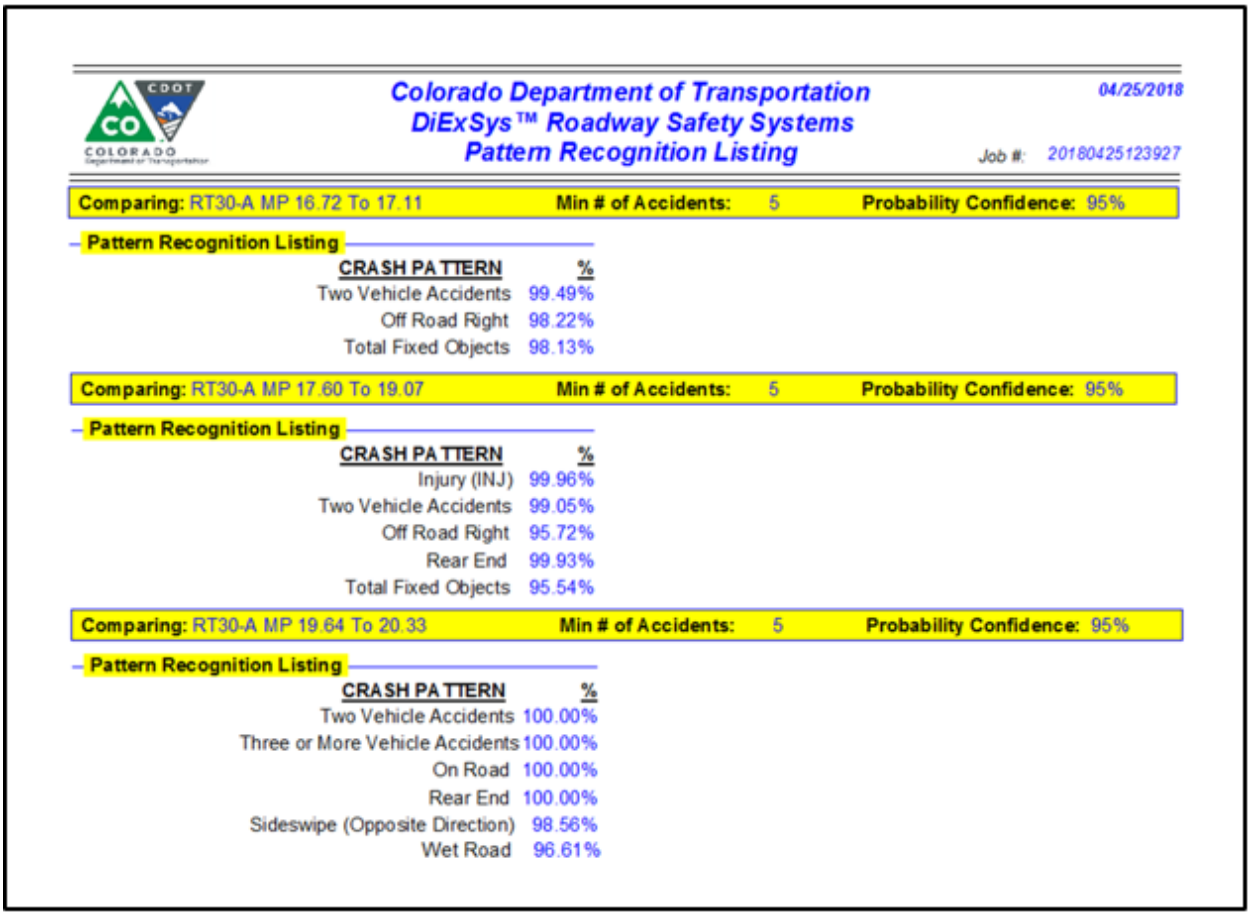


Figure 18: Crash Type Distribution SH 030A MP 16.72 – 20.33

Table P shows the results of a pattern recognition analysis each of the three segments under consideration. As the table shows, multi-vehicle crashes represent patterns of notable frequency in all three of the segments. It is anticipated that many of these crashes will be circumvented with the Swedish 2+1 lane configuration. It is also expected that the frequency of On Road and Opposite

Direction Sideswipe crashes indicated for Segment #3 will be substantially reduced, and to a lesser extent even the Rear End crashes may be reduced as a result of increased opportunities for passing.

Table P: Pattern Recognition Results for Three Segments of SH 030A



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

04/25/2018

Job #: 20180425123927

Comparing: RT30-A MP 16.72 To 17.11 **Min # of Accidents:** 5 **Probability Confidence:** 95%

Pattern Recognition Listing

CRASH PATTERN	%
Two Vehicle Accidents	99.49%
Off Road Right	98.22%
Total Fixed Objects	98.13%

Comparing: RT30-A MP 17.60 To 19.07 **Min # of Accidents:** 5 **Probability Confidence:** 95%

Pattern Recognition Listing

CRASH PATTERN	%
Injury (INJ)	99.96%
Two Vehicle Accidents	99.05%
Off Road Right	95.72%
Rear End	99.93%
Total Fixed Objects	95.54%

Comparing: RT30-A MP 19.64 To 20.33 **Min # of Accidents:** 5 **Probability Confidence:** 95%

Pattern Recognition Listing

CRASH PATTERN	%
Two Vehicle Accidents	100.00%
Three or More Vehicle Accidents	100.00%
On Road	100.00%
Rear End	100.00%
Sideswipe (Opposite Direction)	98.56%
Wet Road	96.61%

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since these sections of SH 30 exhibit a higher than expected frequency of crashes involving bodily injury, this may be a very effective location to use the 2+1 Road with Barrier configuration. Conversion of these 2-lane undivided segments into the 2+1 Road with Barrier configuration would reduce the frequency of most of the crash types we are seeing, especially the types that are most frequently severe in terms of bodily injury, i.e. those involving two or more vehicles travelling in opposite directions. In particular, it is noted that head on and opposite direction sideswipe crashes accounted for 10 (38%) of the 26 injury crashes and for the fatal crash that occurred during the 5-year study period. Virtually all of these types of

crashes can be expected to be eliminated or at the least converted into collisions with the cable rail which are typically much less severe in nature.

Table Q shows an economic analysis for converting the proposed segments of SH 30 to the 2+1 Road with Barrier configuration. The analysis is based on an average cost of $1,200,000 per mile of the 2.35 miles of proposed work segments, for a total of $2,820,000. As the analysis shows, the expected benefit to cost ratio for this improvement is 3.08 to 1.

The cost used in the above analysis is based on rough parametric estimation done using the existing cross section and terrain for this particular section of SH 030A. The actual cost is likely to vary based on more specific factors that will be determined upon final design of a project.

Table Q: Economic Analysis for Conversion to 2+1 Road with Barrier (All 3 Segments)

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

04/13/2020

Job #: 20200413172514

Location: 30A **Begin:** 16.72 **End:** 20.33 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	34		Weighted PDO:	8.35	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	26	35: Injured	Weighted INJ:	8.60	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	1	1: Killed	Weighted FAT:	0.25	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	33%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
Cost: $ 2,820,000						Service Life:	20
From: 01/01/2012						Capital Recovery Factor:	0.080
To: 12/31/2016		Days: 1827				Annual Maintenance/Delay Cost:	$ 23,500

Benefit Cost Ratio: 3.08 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

Since Segment #1 was shown to have minimal potential for crash reduction in both the frequency and severity realms, we have done an additional economic analysis based on providing the proposed improvements to only segments #2 and #3. The total projected cost for the included length of 1.96 miles is $2,350,000. As the analysis in **Table R** shows, the resulting benefit to cost ratio is somewhat increased from that for all three segments at 3.62 to 1.

Table R: Economic Analysis for Conversion to 2+1 Road with Barrier (Segments #2 and #3)

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

04/13/2020

Job #: 20200413175647

Location: 30A **Begin:** 17.60 **End:** 20.33 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	30		Weighted PDO:	7.37	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	25	34: Injured	Weighted INJ:	8.35	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	1	1: Killed	Weighted FAT:	0.25	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	34%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 19,600

Cost: $ 2,350,000
From: 01/01/2012
To: 12/31/2016
Days: 1827

Benefit Cost Ratio: 3.62 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 Road with Barrier configuration is adopted, then decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality, some accesses may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated. **Table S** shows a list of accesses within the proposed improvement sections with some preliminary observations pertinent to their handling.

Table S: Accesses Within Improvement Segments

Location	Description	Comments	Recommendation
MP 16.84	Minor paved access serving one property on east side.	Nearest turnaround point is about 1/4 miles north.	Region decision
MP 16.95	Very minor unpaved access serving a field on west side.	Condition of field grass at access suggests this is rarely used.	Do not accommodate
MP 18.31	Paved road serving what appears to be a pit on east side.	Nearest alternate access is Hampden Ave about 1 mile south.	Retain full access.
MP 18.92	Gated unpaved access to field on east side.	If a road exists, it's completely overgrown at time of photometry, indicating rare usage. Nearest turnaround is Hampden Ave 4/10 miles south.	Do not accommodate.

Table T: Accesses Within Improvement Segments

State Highway 040A, MP 112.98 to 116.00, East of Hayden, Routt County

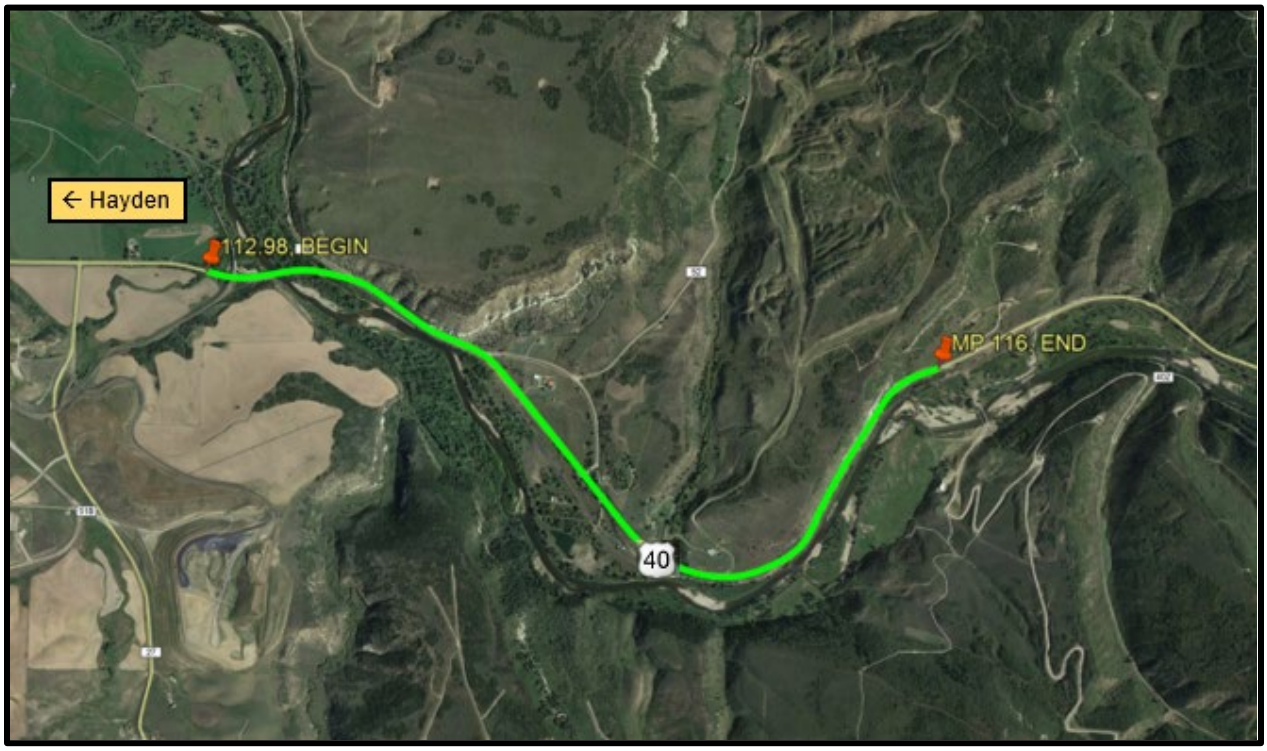


Figure 19: SH 040A MP 112.98 to 116.00 Location

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 040A (SH 040A) extending from MP 112.98 to MP 116.00 in Routt County. The study section begins about 5 miles east of the Town of Hayden and extends 3.02 miles east.

SITE CONDITIONS SH 40 is classified as a Rural Principal Arterial throughout the study section. The terrain is classified as flat throughout the study section, but although the grade is very mild, the terrain beside the road is of a mountainous nature at some places, with slopes that are often quite steep and high. From MP 115.15 to MP 115.83 (0.68 mi.) and from MP 113.67 to MP 113.78 (0.11 mi.), the left embankment is solid vertical rock that begins only a few feet from the

edge of pavement. The right side of the roadway is characterized by a downslope to a railroad track through portions of the study section. In these sections this will make widening to right unfeasible so any required widening will need to occur on the left side. SH 40 is a 2-lane undivided highway with 12-foot lanes. The shoulders vary in width from 2 feet to 8 feet as outlined in **Table U**.

Table U: SH 040A Shoulder Widths

MP	Right	Left
112.98 to 115.00	8’	6’
115.00 to 116.00	2’	2’

The total pavement width ranges from 28 to 38 feet. Centerline and shoulder rumble strips appear to exist throughout the study section. There are several minor intersections and accesses throughout the study section. These will be discussed in more detail later in the report.

The speed limit on SH 040A varies between 55 mph and 65 mph throughout the study section as summarized in **Table V** below.

Table V: Summary of Posted Speed Limits on SH 040A

EB MP	Posted Speed
112.98 – 114.31	65
114.31 – 116.00	55

WB MP	Posted Speed
112.98 – 114.54	65
114.54 – 116.00	55

The average annual daily traffic (AADT) from 2012 to 2015 ranged from 4,600 vpd to 4,900 vpd as shown in **Table W**. 2015 is the latest year for which this data is available.

Table W: SH 040A AADT by Year

2012	2013	2014	2015
4800	4900	4600	4800

Figures 20 and **21** are typical views of SH 40 within project limits. The photo in **Figure 20**, showing one of the milder portions of the study section, was taken from the OTIS photo log at approximately MP 114.3 and the photo in **Figure 21**, showing the rock cut on the left and downslope on the right, was taken at approximately MP 115.30.

Figure 20: SH 040A Typical Cross Section

Figure 21: SH 040A Cross Section in Rock Cut Area

There were 59 crashes in total in the study section during the 5-year study period. 14 crashes involved injuries, resulting in injury to a total of 24 people. Forty-five (45) of the crashes were property damage only and there were no fatalities. This is summarized by year in **Table X**.

Table X: Summary of Crashes by Year

Year	Total Crashes	PDO	Injury	Fatal	Injuries	Fatalities
2012	11	9	2	0	4	0
2013	11	7	4	0	6	0
2014	14	12	2	0	4	0
2015	10	7	3	0	5	0
2016	13	10	3	0	5	0
Total	59	45	14	0	24	0

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 22** shows the corridor SPF for the study section. As the chart shows the entire study section is performing the LOSS-IV category throughout the study section in terms of crash frequency and throughout all but the last ½ mile in terms of crash severity, suggesting high potential for accident reduction in both categories.

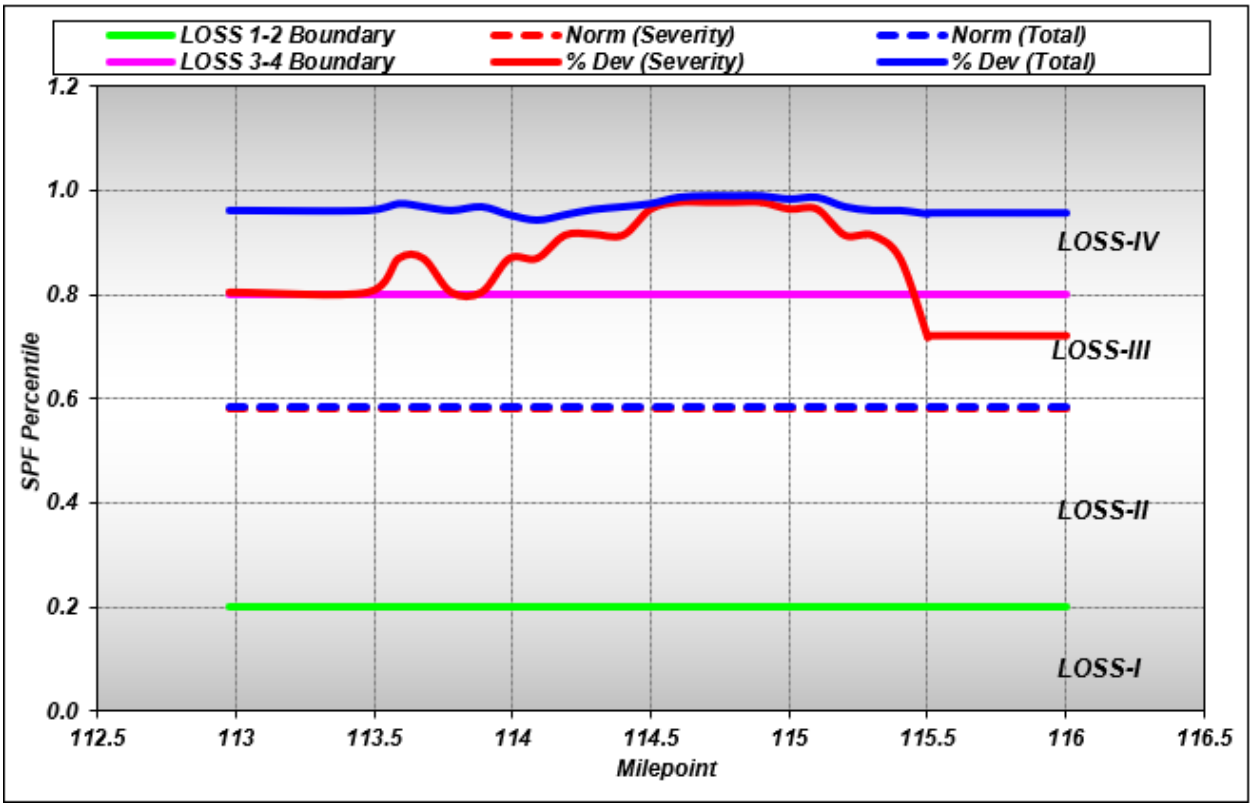


Figure 22: Corridor SPF for SH 040A MP 112.98 to 116.00

Figures 23 and **24** represent EB corrected segment safety performance analysis of SH 040A within the study limits. **Figure 19** shows segment safety performance from the total crash frequency stand point and **Figure 20** represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. Both charts show that the study section overall is performing in the LOSS-IV category, suggesting a high potential for a significant reduction in total number of crashes as well as the number of injury related crashes.

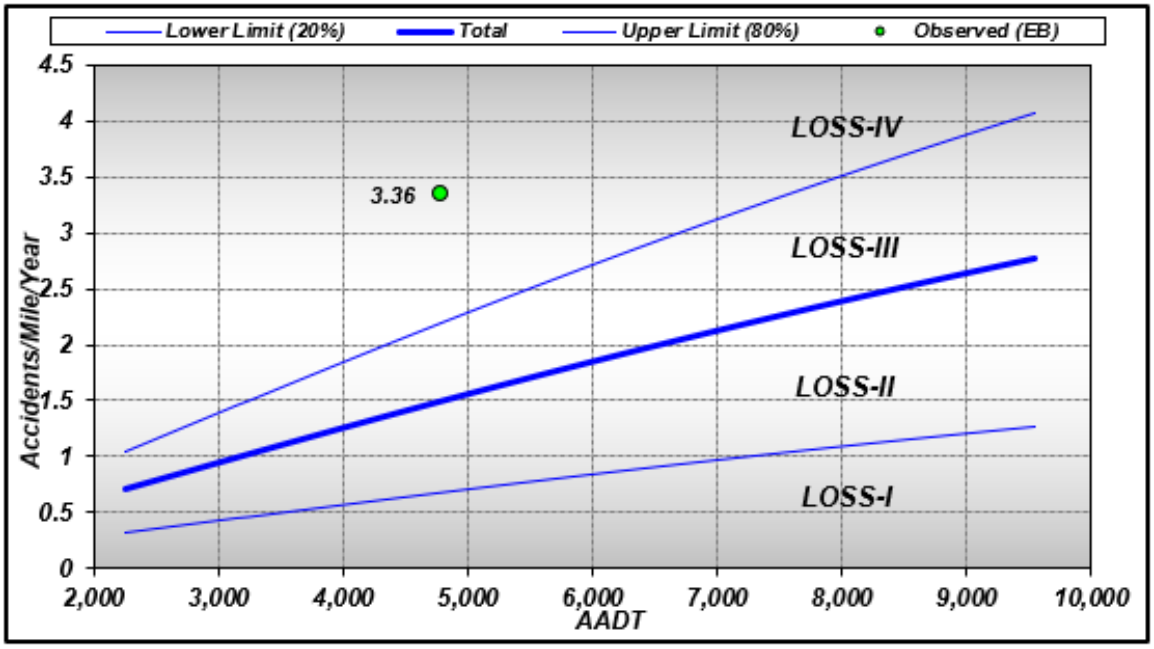


Figure 23: EB Corrected SPF for Total Crashes

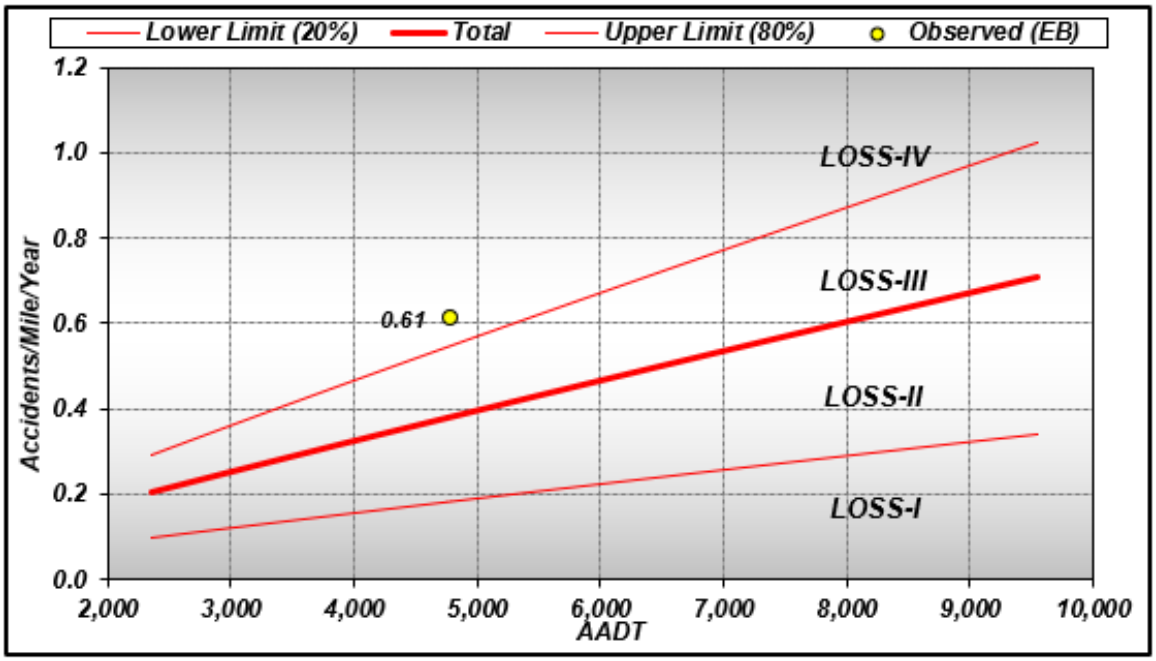


Figure 24: EB Corrected SPF for Injury and Fatal Crashes

Types of Crashes The overall distribution by crash type for all non-intersection related crashes within the study limits is provided in **Figure 25**. As the chart shows, the most common crash type was with Wild Animal, accounting for 44% of all crashes. Fixed Objects crashes were the next most common accounting for 41% of the crashes. There were no other prevalent crash types in the remaining 15% of crashes.

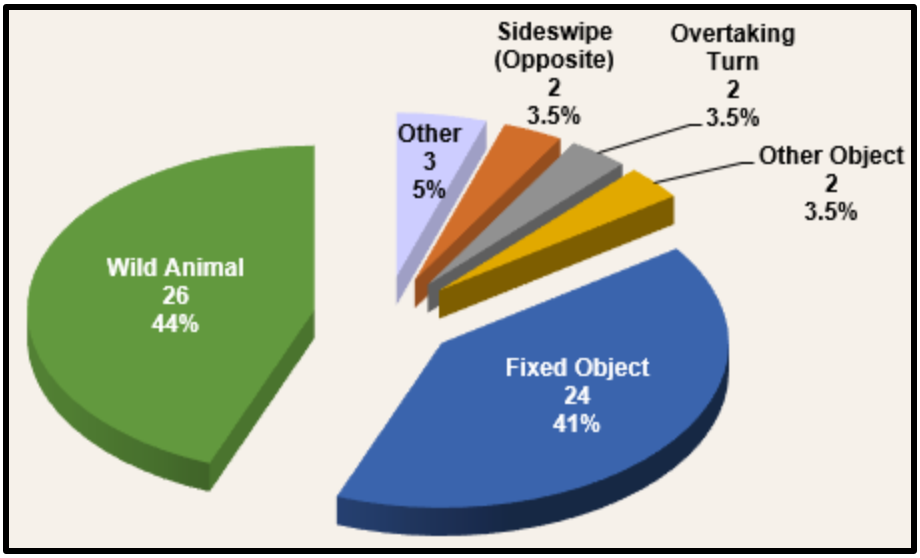


Figure 25: Crash Type Distribution SH 040A MP 112.98 to 116.00

Table Y shows the results of a pattern recognition analysis the study section using criteria of a minimum of five (5) qualifying crashes with a minimum probability confidence of 95%.

Table Y: Pattern Recognition Results for SH 040A MP 112.98 to 116.00

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

05/29/2018

Job #: 20180529165257

Comparing: RT40-A MP 112.98 To 116.00 **Min # of Accidents:** 5 **Probability Confidence:** 95%

Pattern Recognition Listing

CRASH PATTERN	%
Single Vehicle Accidents	99.22%
On Road	96.39%
Off Road	97.50%
Off Road Left	97.61%
Off Road Right	99.89%
Wild Animal	97.25%
Embankment	100.00%
Total Fixed Objects	99.98%
Daylight	95.90%
Dawn or Dusk	99.41%
Snow or Sleet or Hail	99.41%
Wet Road	99.97%
Icy Road	99.59%
Driver 1 - No Apparent Contributing Fact	95.21%
Driver 1 - No Impairment Suspected	100.00%

Of the patterns shown in this analysis, the “off road” patterns are the ones generally associated with the highest potential for mitigation with the proposed improvements. The centerline cable rail

will preclude the possibility of "off left" crashes and the increased lane delineation and security from oncoming traffic may induce drivers to have significantly less potential to leave the roadway in general, reducing the likelihood of fixed object crashes as well.

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since these sections of SH 40 exhibit a higher than expected frequency of crashes involving bodily injury, this may be a very effective location to use the Swedish 2+1 configuration.

We believe that the conversion of these 2-lane undivided segments into the "Swedish 2+1" configuration would reduce the frequency of some of the crashes that have occurred in the study section. The railing is not expected to affect the likelihood of wild animal crashes (the most common crash type).

As we discussed earlier in the report, there are sections in the study section where the proximity of rock embankment would preclude an affordable conversion to the Swedish 2+1 cross section. We are proposing that the spacing of the directional intervals be planned such that these locations coincide with switchovers and that only one lane in each direction, with cable rail in between, be provided where the widening is not feasible. This applies to 113.67 to MP 113.78 (0.11 mi.) and to MP 115.15 to MP 115.83 (0.68 mi.). The benefit of the cable rail alone could thereby be evaluated through these stretches and while the benefit of the passing lane would not be continuous, we believe the opportunity for safe passing would still be frequent enough to be effective. With these special parameters in place, this could potentially serve as a good study case for similar situations where the benefit exists but uninterrupted widening is not feasible.

Table Z shows an economic analysis for converting the proposed portion of SH 040A to the 2+1 Road with Barrier configuration. The cost of construction will vary throughout the study section as the existing pavement width and terrain vary, and some portions will not be widened at all. Using a parametric estimating algorithm for several subsections of the stretch, we arrived at a cost of about $2,500,000 for the 3.02 miles of work section, for the purpose of this preliminary benefit to cost analysis. The actual cost and resultant B/C ratio are likely to vary based on more specific factors that will be determined upon final design of a project. As the analysis shows, the expected

benefit to cost ratio for this improvement is 1.10 to 1. (Wild Animal collisions were excluded from the analysis).

Table Z: Economic Analysis for Conversion to 2+1 Road with Barrier

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

04/13/2020

Job #: 20200413222455

Location: 40A **Begin:** 112.98 **End:** 116.00 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	22		Weighted PDO:	5.40	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	11	20: Injured	Weighted INJ:	4.91	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	0	0: Killed	Weighted FAT:	0.00	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
		B/C Weighted Year Factor:		5.00	30%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
		Cost: $ 2,500,000				Service Life:	20
		From: 01/01/2012				Capital Recovery Factor:	0.080
		To: 12/31/2016	Days: 1827			Annual Maintenance/Delay Cost:	$ 30,000

Benefit Cost Ratio: 1.10 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 Road with Barrier configuration is adopted, then decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality of the more significant access points, some accesses may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated. **Table AA** shows a list of accesses within the study section with some preliminary observations pertinent to their handling. We have recommended retaining full access at the more prominent roads and provided descriptions for other less prominent accesses. The Region should review this list in the context of more specific information relative to their usage and determine which ones will need to be retained prior to design of a project.

Table AA: Accesses on SH 040A MP 112.98 to 116.00

Location	Side	Description	Comments
113.01	S	Access to field. Appears to get regular usage.	Would need to know how frequently this is used. If full access is required, project limits would be adjusted to start just beyond since it is only 150' from current limits.
113.07	N	Access to a parking area for what appears to be rafting access to Yampa River. There are a couple of buildings here.	May need to retain access depending on frequency and volume of usage. CDOT decision.
113.33	S	Short (0.2 miles) unimproved road down along ditch to river.	This is probably minor enough to not provide full access. Users of this road can turn around at MP 113.07.
113.42	N	County Road 70.	Retain full access.
113.90	N	Short loop road that provides access to County Road 52.	Retain full access.
114.06	N	Access to house with several outbuildings.	Although this is a single private property, it may have enough activity to warrant full access. Nearest turnaround would be at MP 114.37 (0.31 miles). CDOT Decision.
114.37	Both	This is the east end of the loop road at MP 113.90 on the north side. On the south side it is the west end of a smaller loop road	Retain full access.
114.72	Both	Access to one property on the north side. East end of the smaller loop road at MP 114.37 on the south side.	There are alternative access points for both of the properties. However, it may be more effective to retain access here than at MP 114.87 (below), which is the alternate access for the north side property. CDOT Decision.
114.87	N	Access to land on north side of highway. Not clear whether it is all private or whether it is single or multiple properties.	If all of this land is part of the property served by access at MP 114.72, then providing full access at MP 114.72 would be sufficient. If this serves other purposes then full access

State Highway 040A, MP 151.00 to 154.00, In Routt National Forest, Routt and Grand Counties

Figure 26: SH 040A MP 151.00 to 154.00 Location

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 040A (SH 040A) in Routt and Grand Counties, beginning at MP 151.00 and extending to MP 154.00. The study begins in the Medicine Bow-Routt National Forest about 18 miles southeast of Steamboat Springs and extends easterly for 3 miles.

SITE CONDITIONS SH 040A is classified as a Rural Principal Arterial in mountainous terrain throughout the study section. SH 040A is primarily a 2-lane undivided highway facility with 12-foot lanes in the study section, but it has a widened section with a westbound passing lane from about MP 152.85 to 153.35. The shoulders vary in width throughout the study section. The approximate total pavement widths are summarized in **Table BB**.

Table BB: Locations of Widened Sections

Begin MP	End MP	Length	Total Pavement and Roadbed Width
151.00	151.81	0.81	40
151.82	152.00	0.19	32
152.01	152.72	0.72	36
152.85	153.35	0.50	50
153.36	154.00	0.63	40

Rumble strips appear throughout the study section in 2017 video log on OTIS, but were difficult to detect in earlier logs. The pavement condition, while still exhibiting some cracking, is much improved in the 2017 video log compared to prior years' logs as well, indicating that a recent overlay has been performed. The speed limit is posted at 65 mph throughout. The average annual daily traffic (AADT) from 2012 to 2015 is shown in **Table CC**. 2015 is the latest year for which this data is available.

Table CC: AADT by Location and Year

Begin MP	End MP	2012	2013	2014	2015
151.00	153.67	3900	3800	4300	4500
153.68	154.00	2300	2300	2400	2500

A total of 74 crashes were recorded for the 5-year study period. There were 20 crashes that involved injuries and one that resulted in a fatality. 36 people were injured in addition to the one killed. This is summarized by year in **Table DD**.

Table DD: Summary of Crashes by Year

Year	Total Crashes	PDO	Injury	Fatal	Injuries	Fatalities
2012	14	8	6	0	12	0
2013	19	15	4	0	8	0
2014	16	12	3	1	4	1
2015	9	7	2	0	4	0
2016	16	11	5	0	8	0
Total	74	53	20	1	36	1

Figures 27 and 28 show typical sections of SH 40 within project limits. **Figure 27** shows a 2-lane location that is typical for most of the study section and **Figure 28** shows the section with the westbound passing lane at about MP 153.06.

Figure 27: SH 040A MP 152.50 Typical Cross Section

Figure 28: SH 040A MP 153.06 Cross Section with Passing Lane

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 29** shows the corridor SPF for the study section. As the chart shows the entire study section is performing at the LOSS-III and LOSS-IV category for both frequency and severity of crashes suggesting high potential for reduction in both categories. The chart also shows that the LOSS appears to improve upon encountering the westbound passing lane.

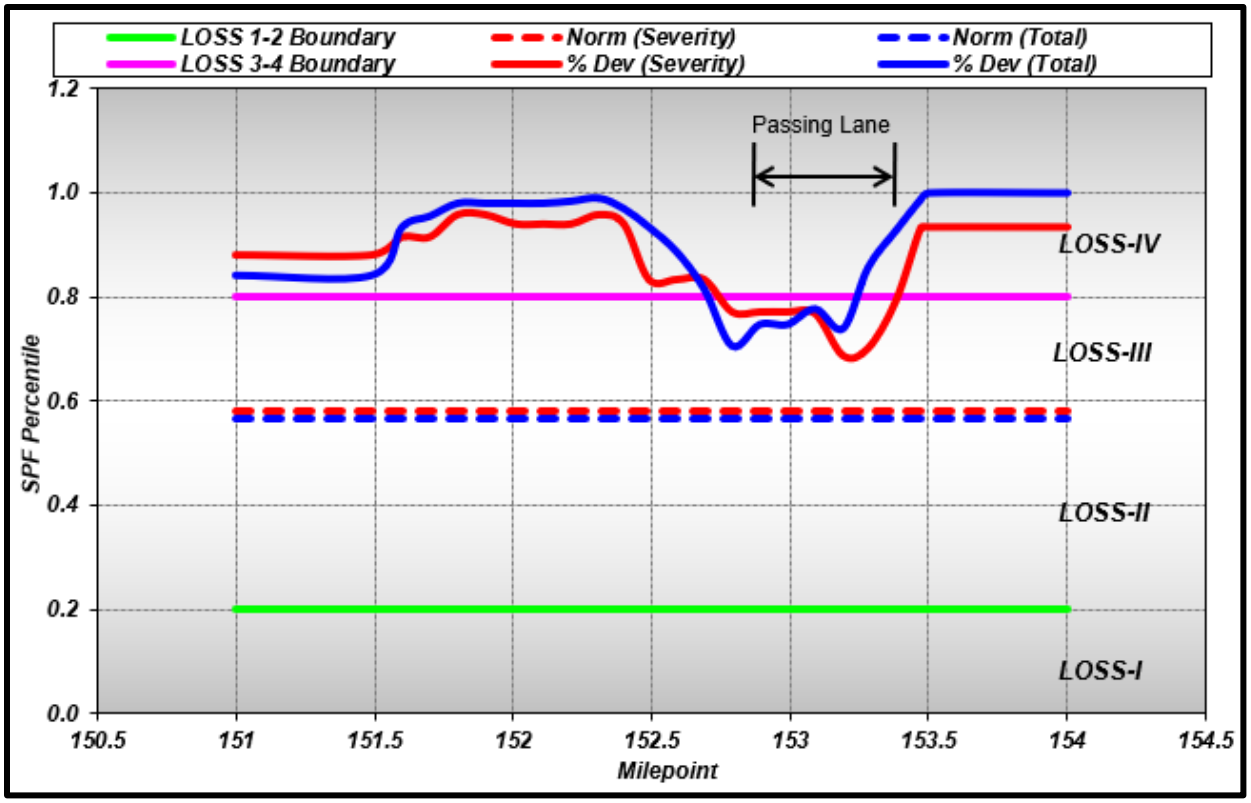


Figure 29: Corridor SPF for SH 040A MP 151.00 to 154.00

Figures 30 and **31** represent EB corrected segment safety performance analysis of SH 40 within the study limits. **Figure 30** shows segment safety performance from the total crash frequency stand point. It shows that the study section is performing in the LOSS-IV category in terms of total crash frequency, suggesting a high potential for a significant reduction in total number of crashes.

Figure 31 represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. It shows that the study section performs in the LOSS-IV category in terms of severity as well, suggesting high potential for reduction of crashes involving bodily injury.

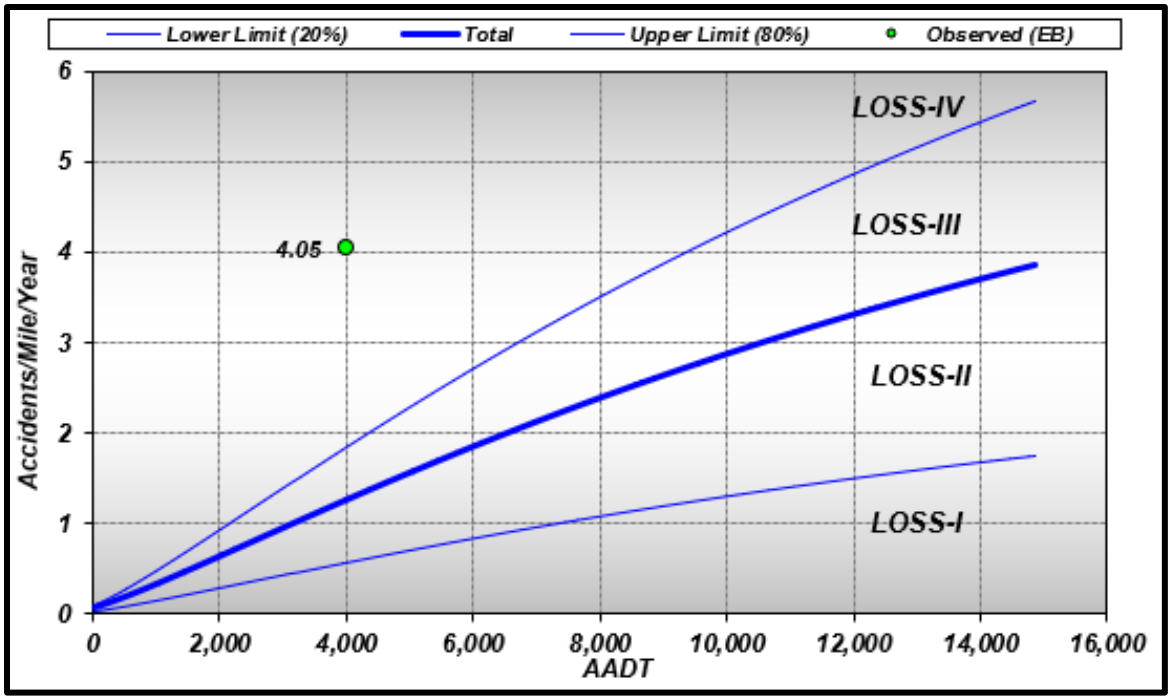


Figure 30: EB Corrected SPF for Total Crashes

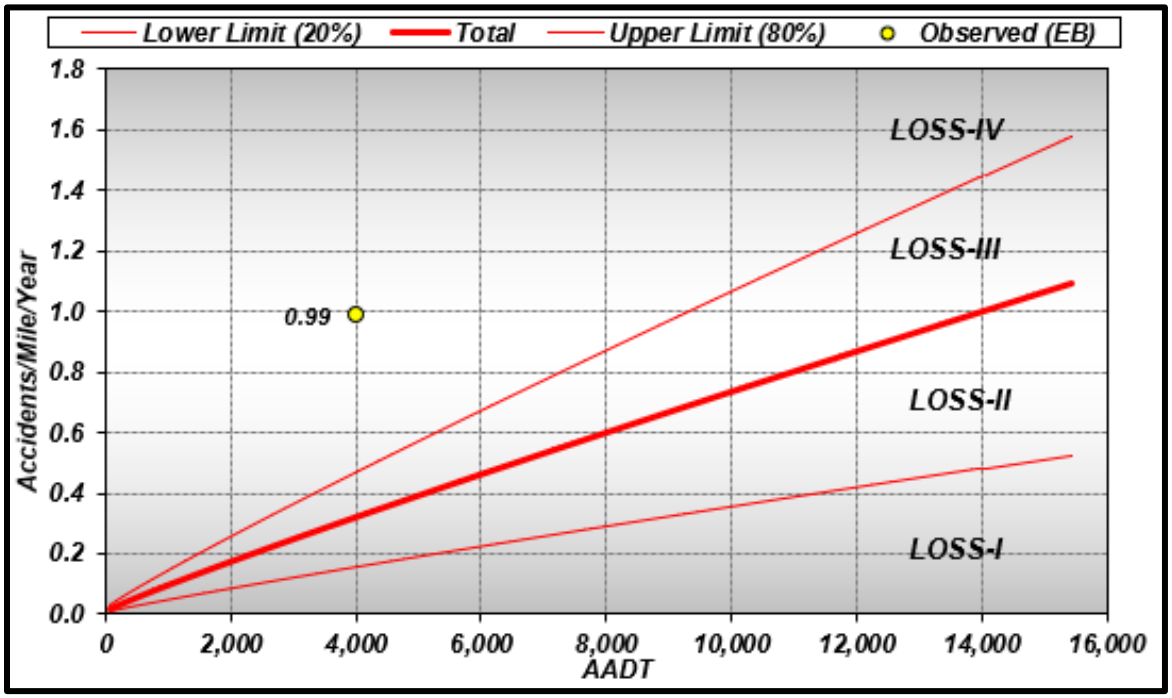


Figure 31: EB Corrected SPF for Injury and Fatal Crashes

Types of Crashes The overall distribution by crash type for all non-intersection related crashes within the study limits is provided in **Figure 32**. As the chart shows, Fixed Object crashes were

the most common, representing 36% of all crashes. The lower chart in **Figure 32** shows a breakdown of the objects that were involved in those crashes, showing that Embankment was the predominant object accounting for 78% of those crashes. Overturning crashes were the second most common crash type representing 27% of all crashes, and Wild Animals were the third most common type accounting for 22%. All other crash types were relatively infrequent.

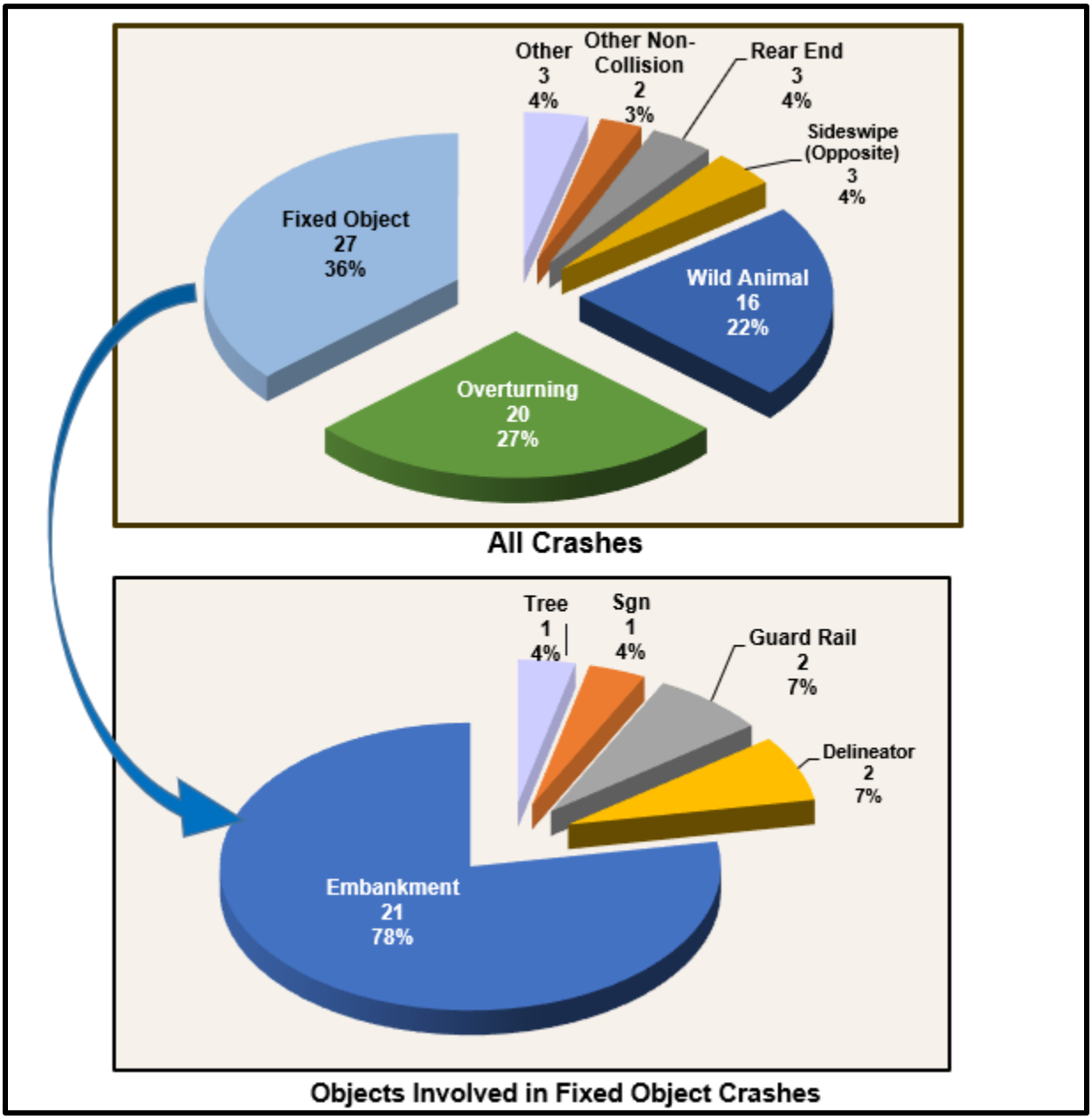


Figure 32: Crash Type Distribution SH 040A MP 151.00 to 154.00

Of the 74 non-intersection related crashes in the study section, 64 of them (86%) were single vehicle crashes which is very close to the statewide average of 84% for this type of facility.

Fifty (50) or 68% of the 74 crashes in the study section were Off-Road crashes which is somewhat higher than the statewide average of 50% for similar facilities. Of the 50 crashes that were off-roadway crashes, 33 (67%) of them were off right and 17 (33%) were off left.

The chart in **Figure 33** shows a breakdown of the 74 accidents by the condition of the roadway. As the chart shows, about two thirds, or 66%, of all accidents occurred when the road was icy, snowy or wet. The statewide average for this type of facility is for about 28% of all crashes to occur under during these road conditions.

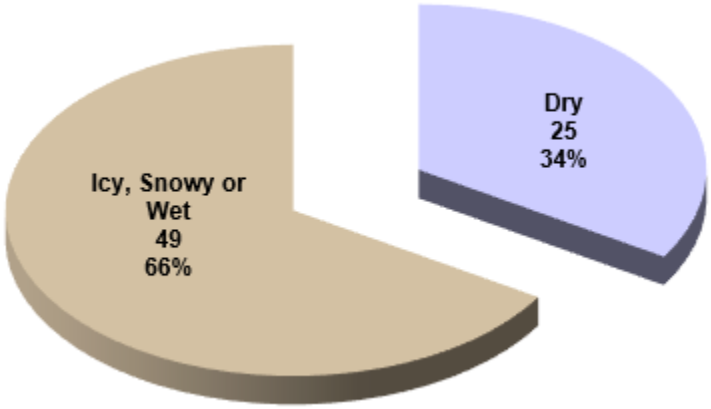


Figure 33: Distribution of Crashes by Road Condition SH 040A MP 151.00 to 154.00

Table EE shows the results of a pattern recognition analysis the study section.

Table EE: Pattern Recognition Results for SH 040A MP 151.00 – 154.00

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

04/27/2018

Job #: 20180427091824

Comparing: RT40-A MP 151.00 To 154.00 | Min # of Accidents: 5 | Probability Confidence: 95%

Pattern Recognition Listing

CRASH PATTERN	%
Single Vehicle Accidents	99.41%
Two Vehicle Accidents	97.04%
Off Road	99.96%
Off Road Left	96.37%
Off Road Right	99.98%
Overturning	99.99%
Embankment	99.98%
Daylight	99.72%
Dawn or Dusk	99.93%
Snow or Sleet or Hail	99.94%
Wind	99.98%
Snowy Road	99.67%
Icy Road	99.76%

As the table shows, patterns were found for both single-vehicle and two-vehicle crashes. The pattern for single-vehicle crashes was throughout the first two miles of the study section, while two-vehicle crashes gained prevalence through the final mile.

Also shown in the table are patterns of Off-Road, Embankment, Overturning and inclement weather and road conditions.

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since this section of SH 040A exhibits a higher than expected frequency of crashes involving bodily injury, this may be a very effective location to use the 2+1 Road with Barrier configuration. Conversion of these 2-lane undivided segments into 2+1 Road with Barrier configuration would reduce the frequency of some of the crash types we are seeing. There were only four crashes involving two vehicles travelling in opposite directions, but those crashes resulted in one fatality and seven (7) injuries. Those types of crashes would not be likely to occur with 2+1 Road with Barrier. Different outcomes would also be expected for the 17 Off-Left crashes that resulted in seven (7) injuries. In addition to those specific situations, some reduction across some of the other crash scenarios is expected as well.

Table FF shows an economic analysis for converting the proposed portion of SH 040A to the 2+1 Road with Barrier configuration. The cost of construction will vary throughout the study section as the existing pavement width and terrain vary. Using a parametric estimating algorithm for several subsections of the stretch, we arrived at an average cost estimate of $800,000 per mile, or $2,400,000 for the 3-mile stretch, for the purpose of this preliminary benefit to cost analysis. The actual cost and resultant B/C ratio are likely to vary based on more specific factors that will be determined upon final design of a project. As the analysis shows, the expected benefit to cost ratio for this improvement is 3.30 to 1. (Wild animal collisions were excluded from the analysis).

Table FF: Economic Analysis for Conversion to 2+1 Road with Barrier

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

04/13/2020
Job #: 20200413223334

Location: 40A **Begin:** 151.00 **End:** 154.00 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	39		Weighted PDO:	9.58	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	18	32: Injured	Weighted INJ:	7.86	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	1	1: Killed	Weighted FAT:	0.25	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
		B/C Weighted Year Factor:		5.00	30%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
		Cost: $ 2,400,000				Service Life:	20
		From: 01/01/2012				Capital Recovery Factor:	0.080
		To: 12/31/2016	Days: 1827			Annual Maintenance/Delay Cost:	$ 30,000

Benefit Cost Ratio: 3.30 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 Road with Barrier cross section is adopted, decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality, some accesses may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated. **Table GG** shows a list of accesses within the proposed improvement sections with some preliminary observations pertinent to their handling.

Table GG: Accesses Within Improvement Section

Location	Description	Comments	Recommendation
MP 151.46	CR 302 serves 3 properties on south side.	Turnaround points within half mile both directions. Two lots have houses and one is vacant.	Region decision
MP 152.06	Access to commercial property on north side.	Many vehicles visible on the property in satellite photo.	Retain full access.
MP 152.72	CR 199 provides access to several properties on north side.	This access is presently blockaded with boulders and Buffalo Park Trail provides access to these locations.	Do not accommodate.
MP 153.05	Buffalo Park Trail (CR 251) provides access to multiple locations north and south.	This appears to be a principal access point for various park usages.	Retain full access.
MP 153.45	Unnamed access to locations on north side.	This access is presently blockaded with boulders and Buffalo Park Trail provides access to these locations.	Do not accommodate.
MP 153.68	CR 19 (Buffalo Road). Park access north and south of highway.	There is a fairly large parking area to the north and a few forks on the south indicating relatively high usage.	Retain full access.

State Highway 040A, MP 222.00 to 226.00, North and South of Tabernash, Grand County

Figure 34: SH 040A MP 222.00 to 226.00 Location

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 040A (SH 040A) in Grand County, beginning at MP 222.00 and extending to MP 226.00. The study begins about one mile northwest of the town of Tabernash and ends about 2.5 miles south of Tabernash. The included distance is 4.0 miles. SH 040A is primarily east-west, with mileposts increasing to the east. Locally the alignment is more nearly north-south, with south as the increasing milepost direction.

SITE CONDITIONS SH 040A is classified as a Rural Principal Arterial in rolling terrain throughout the study section. SH 040A is primarily a 2-lane undivided highway facility with 12-foot lanes and 8-foot shoulders in the study section, with a few widened sections to accommodate turning lanes for intersecting roads. The frequency of intersections through the town of Tabernash (MP 222.95 to 223.60) make that stretch unsuitable for the proposed Swedish 2+1 design so that stretch will be designated as a no work section. There is also a shorter no work section from MP 224.02 to 224.22 which is a widened area with auxiliary lanes to accommodate traffic turning to and from Devils Thumb Road (CR 83). **Table HH** summarizes the proposed work and no work sections. The total length of expected work sections is 3.13 miles.

Table HH: Locations of Work Sections

Begin MP	End MP	Length	Description
222.00	222.94	0.94	Work Section
222.95	223.60	0.66	Town of Tabernash (No Work)
223.61	224.01	0.41	Work Section
224.02	224.22	0.21	Major Intersection with CR 83 (No Work)
224.23	226.00	1.78	Work Section

SH 040A is elevated for approximately ¼ mile to cross over the D&RGW Railroad at MP 223.88. The pavement width on the structure is approximately 44 feet, which is sufficient for the proposed cross section for lanes a median, with narrowed outside shoulders (to 2-foot) across the bridge.

Shoulder rumble strips appear throughout the study section. The speed limit is posted at 65 mph throughout the major portion of the study section with step-downs to 40 MPH through the town of Tabernash. This is summarized in **Table II**.

Table II: Summary of Posted Speed Limits

SB MP	Posted Speed
222.00	65
222.81	50
222.92	40
223.68	65

NB MP	Posted Speed
226.00	65
223.67	50
223.43	40
222.96	65

The average annual daily traffic (AADT) from 2012 to 2015 is shown in **Table JJ**. 2015 is the latest year for which this data is available.

Table JJ: AADT by Location and Year

Begin MP	End MP	2012	2013	2014	2015
222.00	223.02	8800	8900	9300	10000
223.03	223.99	7000	7200	6600	8000
224.00	226.00	7000	7200	7400	7300

A total of 44 crashes occurred during the 5-year study period within the proposed work segments. There were 15 crashes that involved injuries and one that resulted in a fatality. In total, 18 people were injured. This is summarized by year in **Table KK** below.

Table KK: Summary of Crashes by Year

Year	Total Crashes	PDO	Injury	Fatal	Injuries	Fatalities
2012	9	4	4	1	5	1
2013	6	4	2	0	4	0
2014	12	7	5	0	5	0
2015	11	8	3	0	3	0
2016	6	5	1	0	1	0
Total	44	28	15	1	18	1

Figure 35 is a typical view of SH 40 within project limits. This photo was taken from the OTIS photo log at approximately MP 224.50.

Figure 35: SH 040A MP 224.50 – Typical Cross Section

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 36** shows the corridor SPF for the study section with the three work segments and two no-work segments identified. As the chart shows much of Segment #3 is performing the LOSS-IV category suggesting high potential for accident reduction.

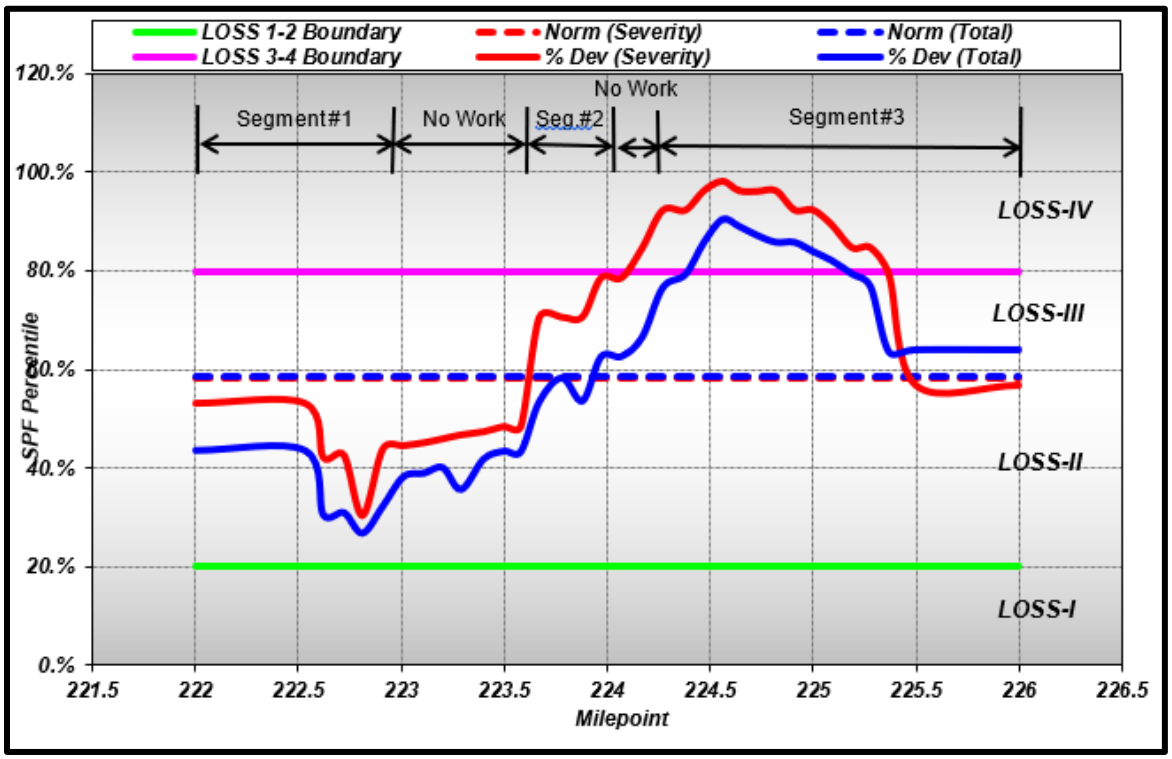


Figure 36: Corridor SPF for SH 040A MP 222.00 to 226.00

Figures 37 and **38** represent EB corrected segment safety performance analysis of SH 40 within the study limits. **Figure 37** shows segment safety performance from the total crash frequency stand point. It shows that the study section is performing in the LOSS-II category for Segments #1 and #2, and in the LOSS-III category for Segment #3 in terms of total crash frequency, suggesting a fairly high potential for a significant reduction in total number of crashes in Segment #3 but a somewhat lower potential in Segments #1 and #2.

Figure 38 represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. It shows that the study section is performing in very close to the norm for Segments #1 and #2, and in the LOSS-IV category for Segment #3 in terms of severe crash frequency, suggesting a high potential for a significant reduction in severe crashes in Segment #3 and a somewhat lower potential in Segments #1 and #2.

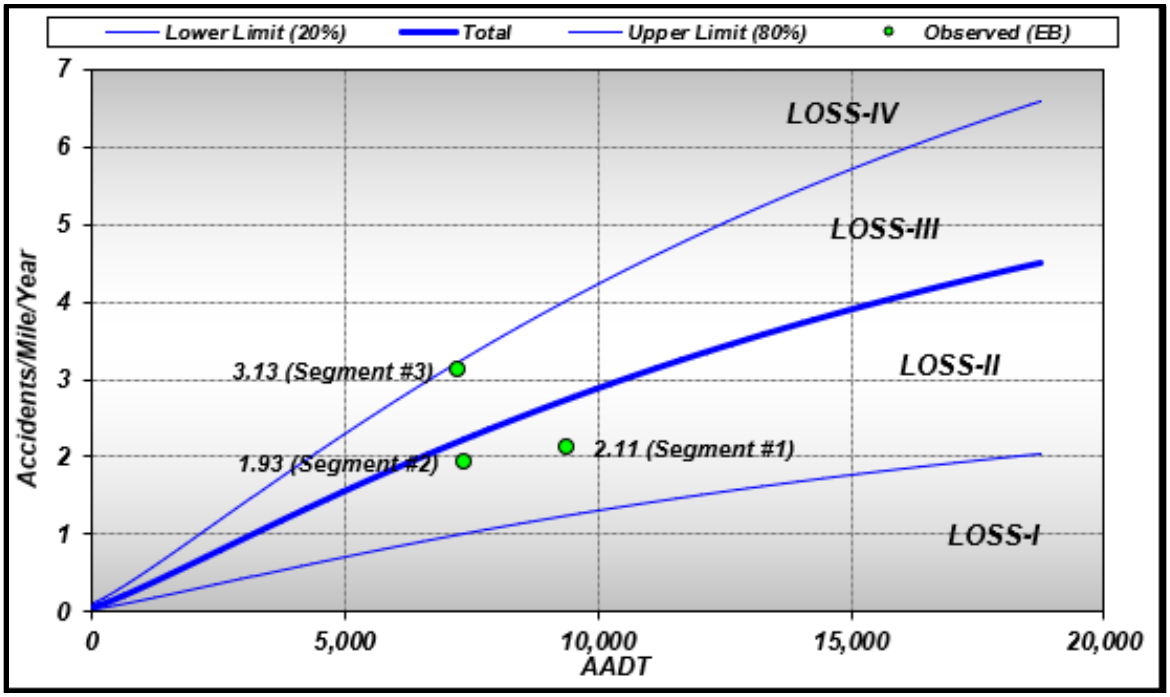


Figure 37: EB Corrected SPF for Total Crashes

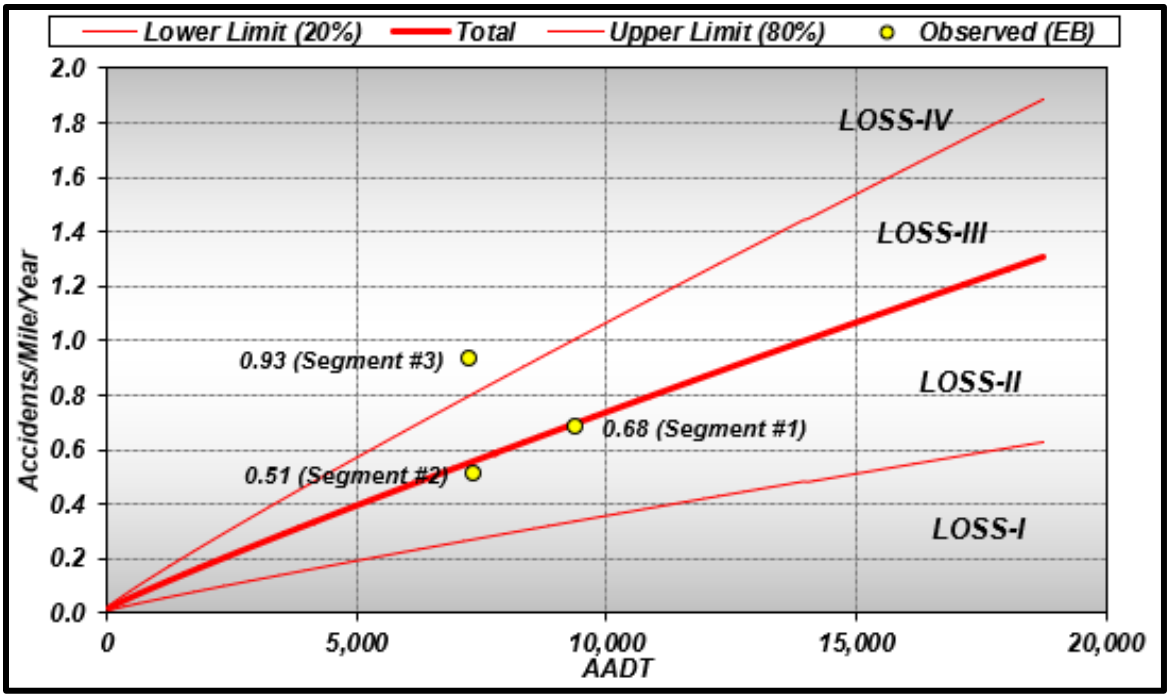


Figure 38: EB Corrected SPF for Injury and Fatal Crashes

Types of Crashes The overall distribution by crash type for all non-intersection related crashes within the study limits is provided in **Figure 39**. As the chart shows, Fixed Object crashes were the most common, representing 32% of all crashes. The lower chart in **Figure 39** shows a breakdown of the objects that were involved in those crashes, showing that Embankment was the most common object accounting for 43% of those crashes. Overturning crashes were the second most common crash type representing 23% of all crashes, Wild Animals were the third most common type accounting for 18%, and Opposite Direction Sideswipes were the fourth most common type accounting for 11% of the crashes. All other crash types were relatively infrequent but it is perhaps worth noting that two (2) head on crashes occurred which accounted for three (3) of the 18 injuries.

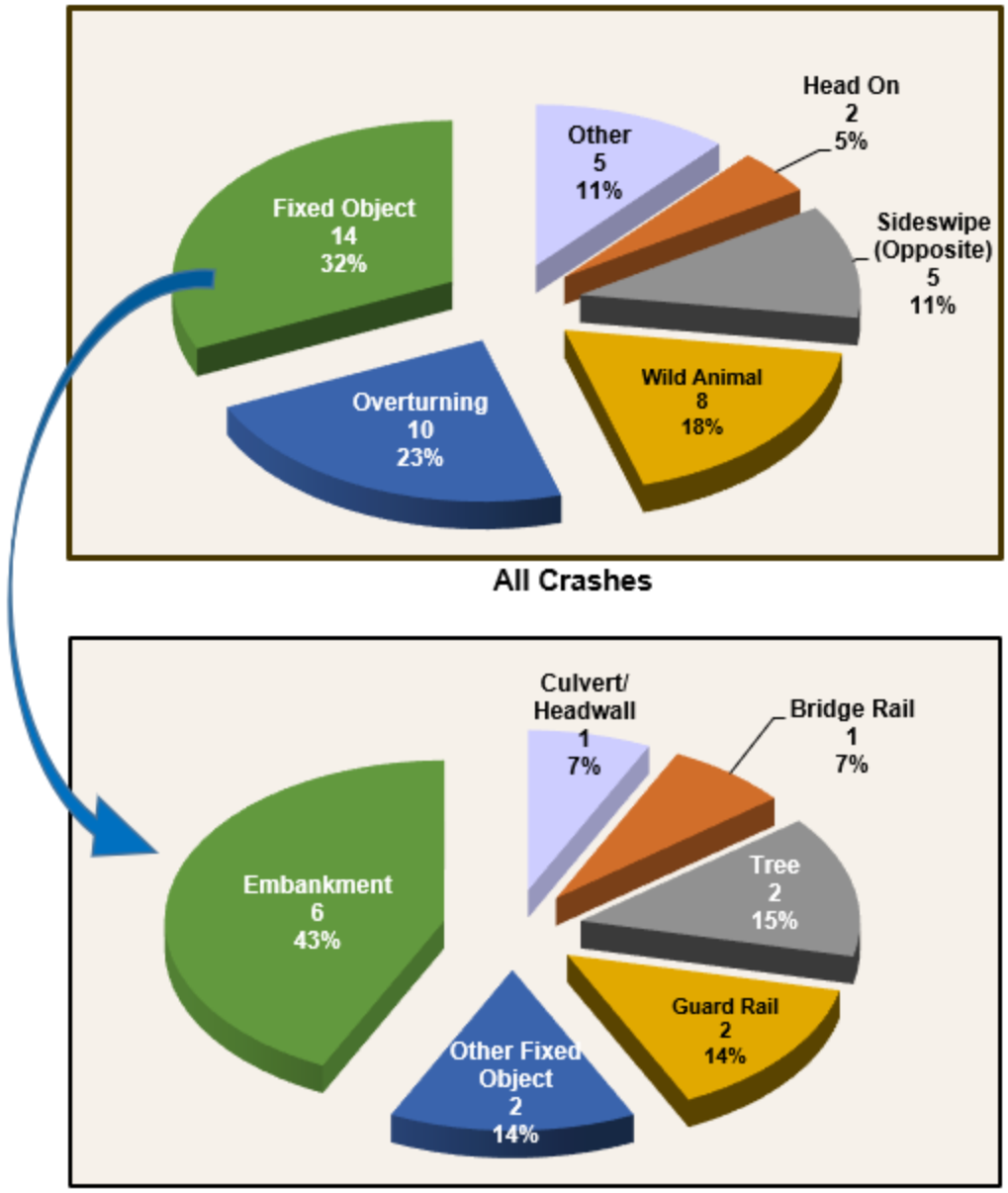


Figure 39: Crash Type Distribution SH 040A MP 222.00 – 226.00

Of the 44 non-intersection related crashes in the study section, 10 of them (23%) were multiple vehicle crashes which is somewhat higher than the statewide average of 15% for this type of facility.

The chart in **Figure 40** shows a breakdown of the 44 accidents by the condition of the roadway. As the chart shows, 68% of all accidents occurred when the road was icy, snowy or wet. The statewide average for this type of facility is for about 26% of all crashes to occur under during

these road conditions. This higher frequency is likely due in most part to the high elevation of this location, which results in snow and ice persisting on the road for longer durations than at most lower elevations. However, the combination of this prevalence and the more frequent multi-vehicle collisions suggests that the separation between oncoming traffic provided by the Swedish 2+1 design could be particularly beneficial in this area in terms of reducing the number of severe crash types.

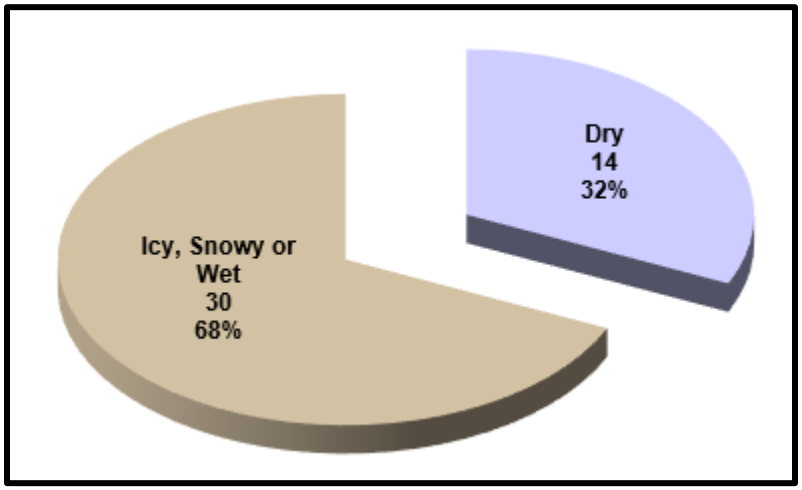
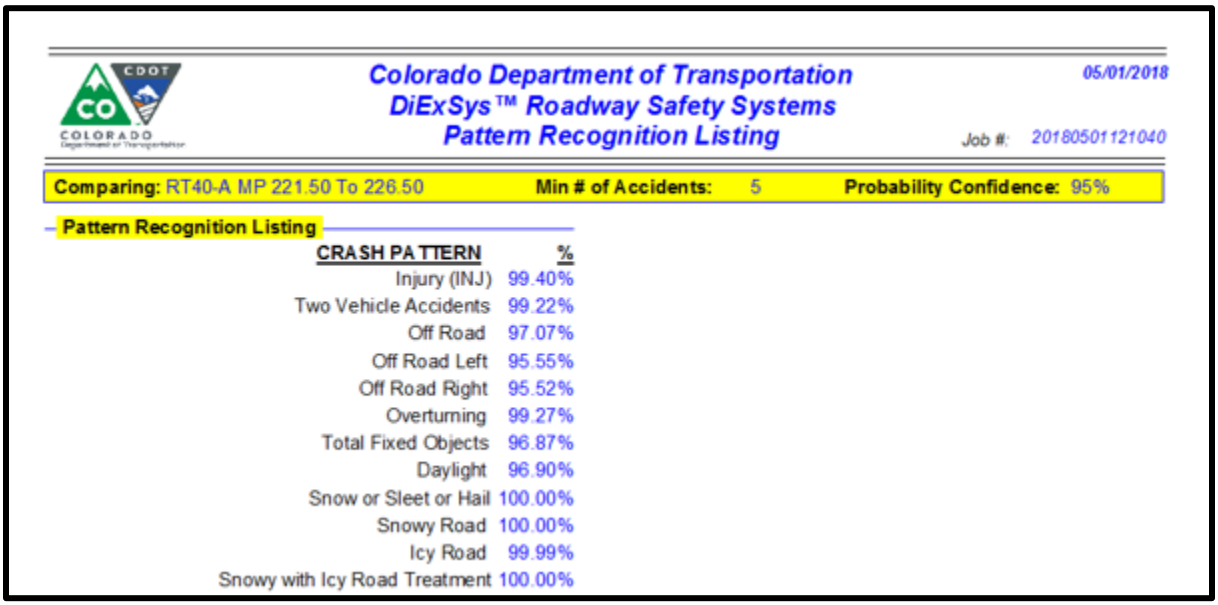


Figure 40: Distribution of Crashes by Road Conditions SH 040A MP 222.00 – 226.00

Table LL shows the results of a pattern recognition analysis the study section using criteria of a minimum of five (5) qualifying crashes with a minimum probability confidence of 95%.

Table LL: Pattern Recognition Results for SH 040A MP 221.50 – 226.50



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

05/01/2018

Job #: 20180501121040

Comparing: RT40-A MP 221.50 To 226.50 | Min # of Accidents: 5 | Probability Confidence: 95%

Pattern Recognition Listing

CRASH PATTERN	%
Injury (INJ)	99.40%
Two Vehicle Accidents	99.22%
Off Road	97.07%
Off Road Left	95.55%
Off Road Right	95.52%
Overturning	99.27%
Total Fixed Objects	96.87%
Daylight	96.90%
Snow or Sleet or Hail	100.00%
Snowy Road	100.00%
Icy Road	99.99%
Snowy with Icy Road Treatment	100.00%

As the table shows, patterns were found for crashes with injuries, two-vehicle crashes, off-road crashes, wintry weather and icy road conditions.

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since these sections of SH 040A exhibit a higher than expected frequency of crashes involving bodily injury, this may be a very effective location to use the 2+1 Road with Barrier configuration. Conversion of these 2-lane undivided segments into 2+1 Road with Barrier configuration would reduce the frequency of some of the crash types we are seeing. There were seven crashes involving vehicles travelling in opposite directions which accounted for 13 of the 18 (72%) people that were injured during the study period. While what the outcomes might have been with a different configuration is speculative, we can say with certainty that the vehicles would not have crossed into the opposing traffic lanes. Furthermore, given the much lower injury rate for crashes that did not involve opposing vehicles, it is almost certain that the number of injuries would be reduced by implementation of the 2+1 Road with Barrier. Different outcomes would also be expected for the six additional off-left crashes that resulted in two overturns and four fixed object crashes and one injury. In addition to those specific situations, some reduction across some of the other crash scenarios is expected as well.

Table MM shows an economic analysis for converting the proposed portion of SH 40 to the 2+1 Road with Barrier configuration. The cost of construction will vary throughout the study section as the existing pavement width and terrain vary. Using a parametric estimating algorithm for several subsections of the stretch, we arrived at a cost estimate of $2,500,000 for the 3.13 miles of work section, for the purpose of this preliminary benefit to cost analysis. The actual cost and resultant B/C ratio are likely to vary based on more specific factors that will be determined upon final design of a project. As the analysis shows, the expected benefit to cost ratio for this improvement is 2.29 to 1. (Analysis excluded wild animal collisions).

Table MM: Economic Analysis for Conversion to 2+1 Road with Barrier

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

04/13/2020

Job #: 20200413223915

Location: 40A **Begin:** 222.00 **End:** 226.00 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	22		Weighted PDO:	5.40	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	13	16: Injured	Weighted INJ:	3.93	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	1	1: Killed	Weighted FAT:	0.25	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	32%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 31,300

Cost: $ 2,500,000
From: 01/01/2012
To: 12/31/2016
Days: 1827

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

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 Road with Barrier configuration is adopted, then decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality, some accesses may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated. **Table NN** shows a list of accesses within the proposed improvement sections with some preliminary observations pertinent to their handling. The Region

should review these recommendations in the context of more specific information relative to their usage.

Table NN: Accesses Within Improvement Work Sections

Location	Description	Comments	Recommendation
MP 222.58	CR 522 serves many residential properties.	Principal access for around 100 homes	Retain full access.
MP 225.01	Access to private land on north side.	There is a corral here that had no animals in it in any of the various photo logs suggesting relatively infrequent usage but access itself appears quite well worn. Nearest turnaround would be about a mile away.	Retain full access.
MP 225.36	Access to railroad box on south side.	Probably used less than once per day. If access at MP 225.01 is retained then it would be relatively easy to get to.	Do not accommodate.
MP 225.46	Access to private land on north side.	Not the only access to the property. Turnaround points will be within half a mile in both directions.	Do not accommodate.

State Highway 052A, MP 14.93 to 18.80, East of Interstate 25, and State Highway 066B, MP 39.30 to MP 40.70, West of Interstate 25, Weld County

Figure 41: SH 052A MP 14.93 to 18.80 and SH 066B MP 39.30 to 40.70 Locations

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 052A (SH 052A) extending from MP 14.93 to MP 18.80, and State Highway 066B (SH 066B) extending from MP 39.30 to MP 40.70 in Weld County. The study section on SH 052A begins about 0.8 mile east of the Town of Firestone and extends 3.87 miles easterly. The portion on SH 066B begins just west of the City of Longmont and extends 1.4 miles easterly. The total included distance is 5.37 miles.

SITE CONDITIONS SH 052A is classified as an Urban Principal Arterial in rolling terrain from MP 14.93 to MP 17.43 and as a Rural Principal Arterial from MP 17.44 to MP 18.80 and SH 066B

is classified as a Rural Principal Arterial throughout the study section. The terrain is classified as Rolling throughout on both highways. Both highways are primarily 2-lane undivided highway facilities with 12-foot lanes and 10-foot shoulders in the study section, with a few small variations in shoulder widths as listed in **Table OO**.

Table OO: Roadway and Shoulder Widths

SH	Beg MP	End MP	Left Shoulder	Travel Lanes	Right Shoulder	Total Width
052A	14.93	14.99	11'	12'	11'	46'
052A	15.00	15.35	10'	12'	10'	44'
052A	15.36	15.99	9'	12'	9'	42'
052A	16.00	16.41	12'	12'	10'	46'
052A	16.42	16.49	10'	12'	8'	42'
052A	16.50	18.43	10'	12'	10'	44'
052A	18.44	18.80	12'	12'	12'	48'
066B	39.30	40.70	10'	12'	10'	44'

There are frequent minor intersections and accesses throughout both stretches of highway. These will be discussed in more detail later in the report.

Shoulder rumble strips appear to exist on portions of SH 052A in the study section but are either too worn to see in the video logs or have not been installed through the more easterly portion. Shoulder rumble strips do not appear to be present on SH 066B in the study section.

The speed limit on SH 052A is posted at 65 mph throughout the major portion of the study section with a reduction to 55 mph through and approaching the curve on the west end. This is summarized in **Table PP**. The posted speed on SH 066B is 60 mph throughout.

Table PP: Posted Speed Limits on SH 052A

EB MP	Posted Speed
SH 052A, 14.93	55
SH 052A, 15.80	65

WB MP	Posted Speed
SH 052A, 18.80	65
SH 052A, 16.40	55

SH 052A MP 14.93 – 18.80 and SH 066B MP 39.30 – 40.70

The average annual daily traffic (AADT) from 2012 to 2015 is shown in **Table QQ**. 2015 is the latest year for which this data is available.

Table QQ: AADT by Location and Year

SH	Begin MP	End MP	2012	2013	2014	2015
052A	14.93	18.43	11,000	11,000	12,000	12,000
052A	18.44	18.80	8,900	9,000	10,000	11,000
066B	39.30	40.70	16,000	16,000	19,000	19,000

A total of 55 crashes occurred during the 5-year study period within the proposed work segments. Thirty-four (33) of them were on SH 052A and 22 of them were on SH 066B. There were 20 crashes that involved injuries and four (4) that resulted in fatalities. In total, 31 people were injured and four (4) were killed. A more detailed summary by year and highway is provided in **Table RR** below.

Table RR: Summary of Crashes by Year and Highway

Year	Total Crashes		PDO		Injury		Fatal		Injuries		Fatalities	
	SH 052A	SH 066B	SH 052A	SH 066B	SH 052A	SH 066B	SH 052A	SH 066B	SH 052A	SH 066B	SH 052A	SH 066B
2012	3	7	2	3	0	3	1	1	1	7	1	1
2013	7	2	3	0	3	2	1	0	3	3	1	0
2014	8	4	7	2	1	2	0	0	2	2	0	0
2015	7	1	3	1	3	0	1	0	6	0	1	0
2016	8	8	7	3	1	5	0	0	2	5	0	0
Total	33	22	22	9	8	12	3	1	14	17	3	1

It is noted that the percentage of injury related crashes was 36% which is significantly higher than the statewide average of 27% for similar facilities and the percentage of fatal crashes was 7.3% compared to 1.9% for similar facilities.

Figure 42 is a typical view of the roadway cross sections within study limits. This photo was taken from the OTIS photo log on SH 066B at approximately MP 40.50. The side road shown on the left is fairly typical of the many minor side roads that will be discussed later.

Figure 42: SH 066B MP 40.50 – Typical Cross Section

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 43** shows the corridor SPF for the SH 052A portion of the study section. As the chart shows the study section is performing in the LOSS-III in terms of severity for most of the first mile suggesting moderate potential for a reduction in severe crashes through that stretch. Otherwise, SH 052A is performing at LOSS-II and even dropping into LOSS-I suggesting relatively low potential for accident reduction in both categories.

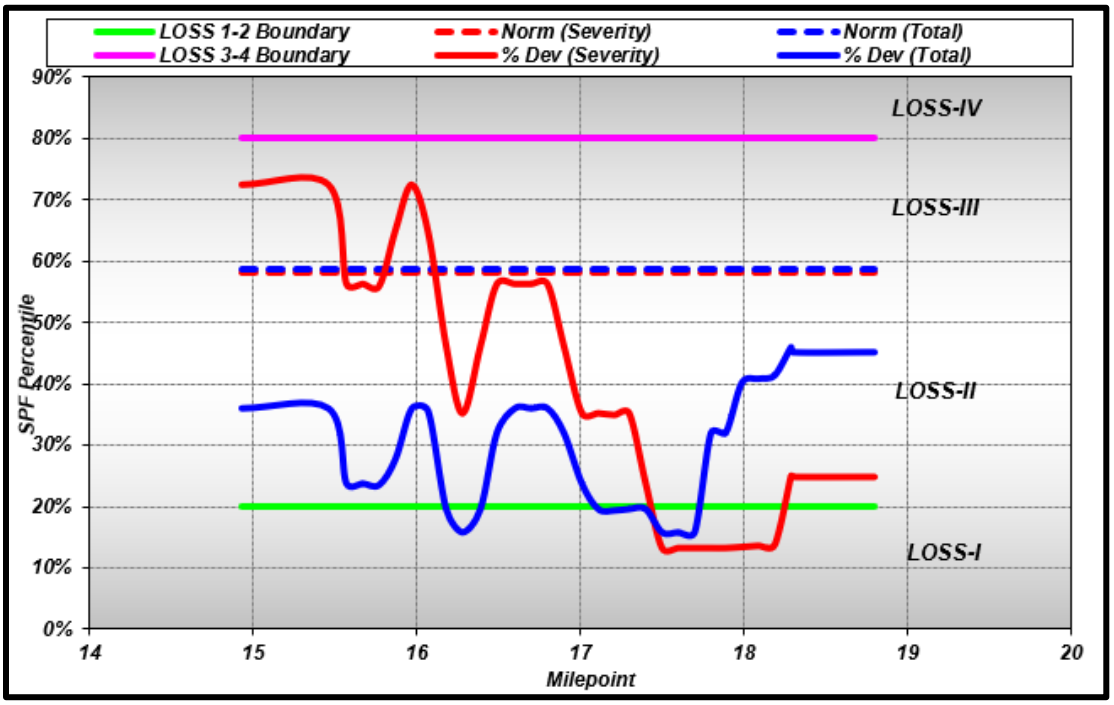


Figure 43 Corridor SPF for SH 052A

The chart in **Figure 44** shows the corridor SPF for the SH 066B portion of the study section. As the chart shows SH 066B is performing near the boundary of LOSS-III and LOSS-IV in terms of severity through most of the study section suggesting a relatively high potential for a reduction in severe crashes through the stretch. In terms of crash frequency, it is performing at LOSS-II throughout suggesting relatively low potential for a significant reduction in total number of crashes.

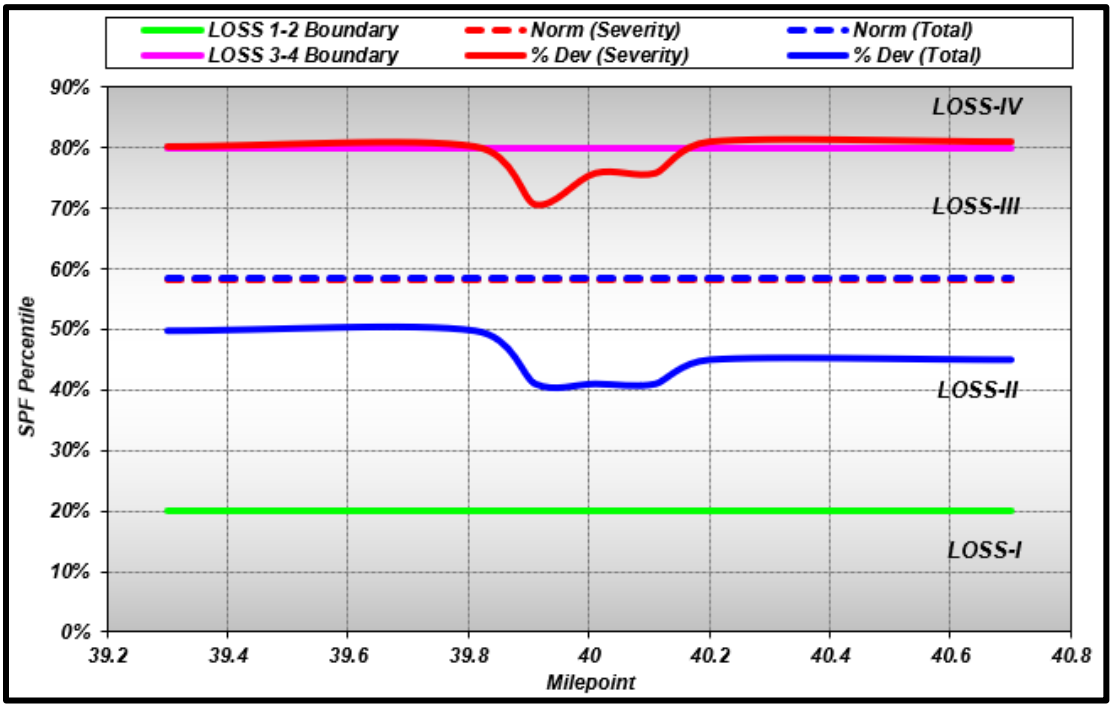


Figure 44: Corridor SPF for SH 066B

Figures 45 and **46** represent EB corrected segment safety performance analysis of SH 052A and SH 066B within the study limits. **Figure 45** shows segments safety performance from the total crash frequency stand point. It shows that both segments are performing in the LOSS-II category in terms of total crash frequency, suggesting a relatively low potential for a significant reduction in total number of crashes.

Figure 46 represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. It shows that the SH 052A segment performs in the LOSS-II category in terms of severity, suggesting relatively low potential for reduction of crashes involving bodily injury while the SH 066B segment is performing in LOSS-III category suggesting a higher potential for reduction of crashes involving bodily injury.

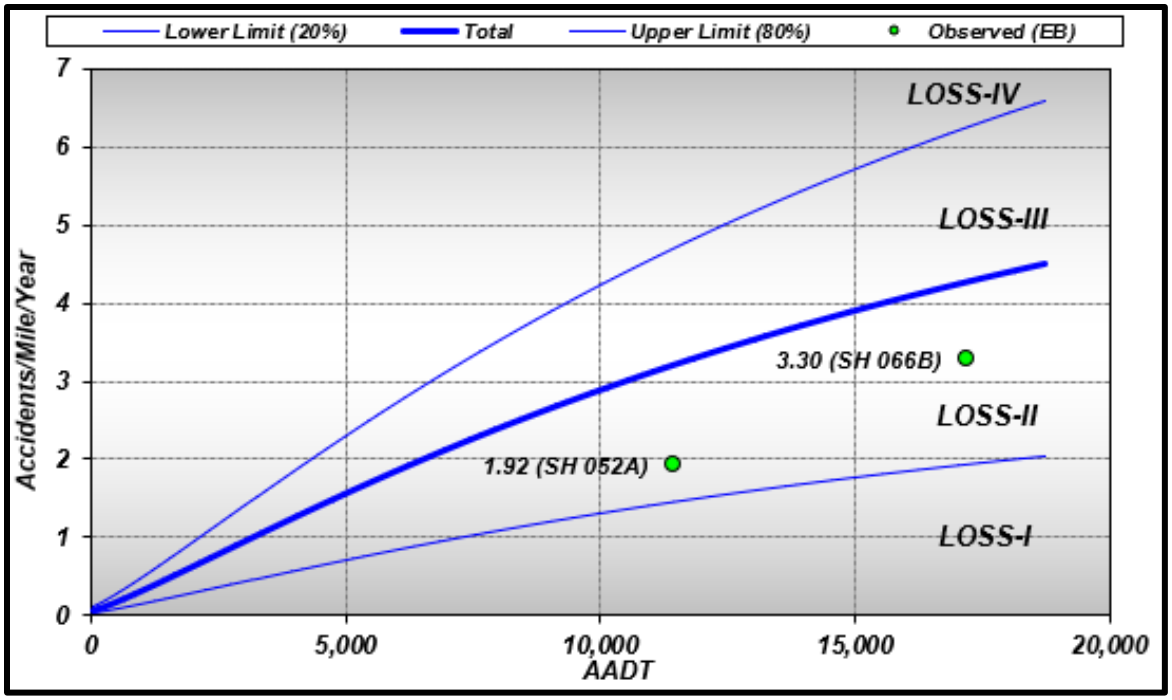


Figure 45: EB Corrected SPF for Total Crashes

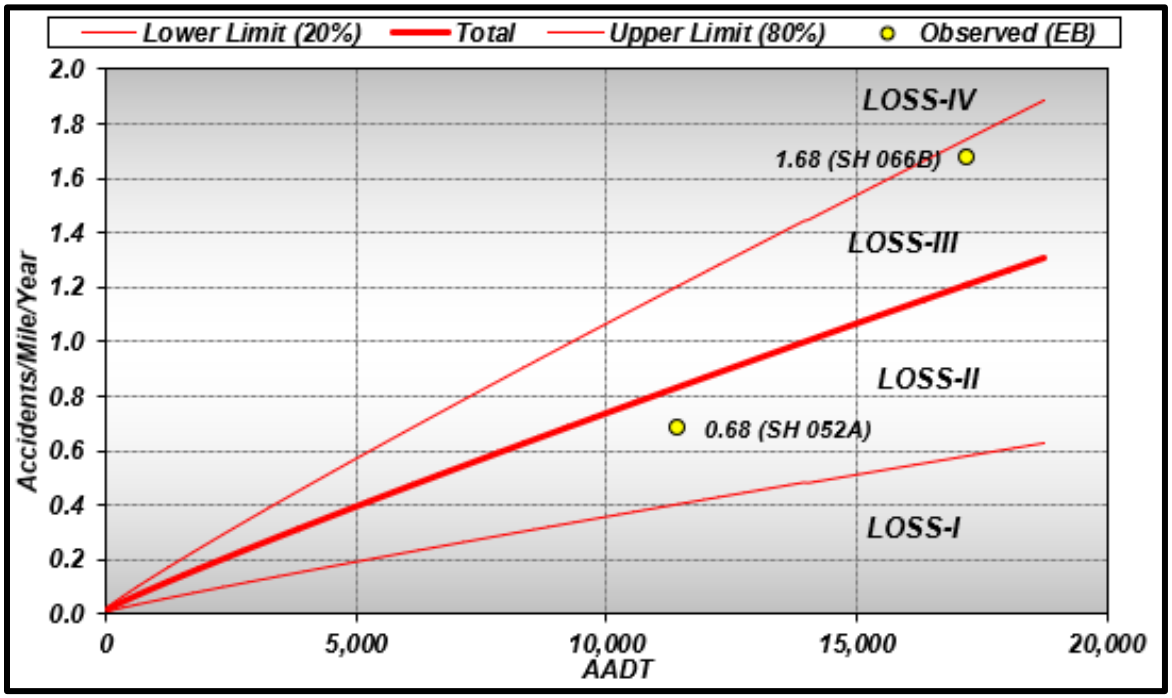


Figure 46: EB Corrected SPF for Injury and Fatal Crashes

Types of Crashes The overall distribution by crash type for all non-intersection related crashes within the study limits is provided in **Figure 47** with breakouts for each of the two highways. As

the chart shows, Rear End crashes were the most common, representing 29% of all crashes. Fixed Object crashes were the second most common crash type representing 26% of all crashes followed by Head Ons (11%), Opposite Side Sideswipes (9%) and Overturning (9%). Wild Animal and other miscellaneous type made up the remaining 16% of crashes.

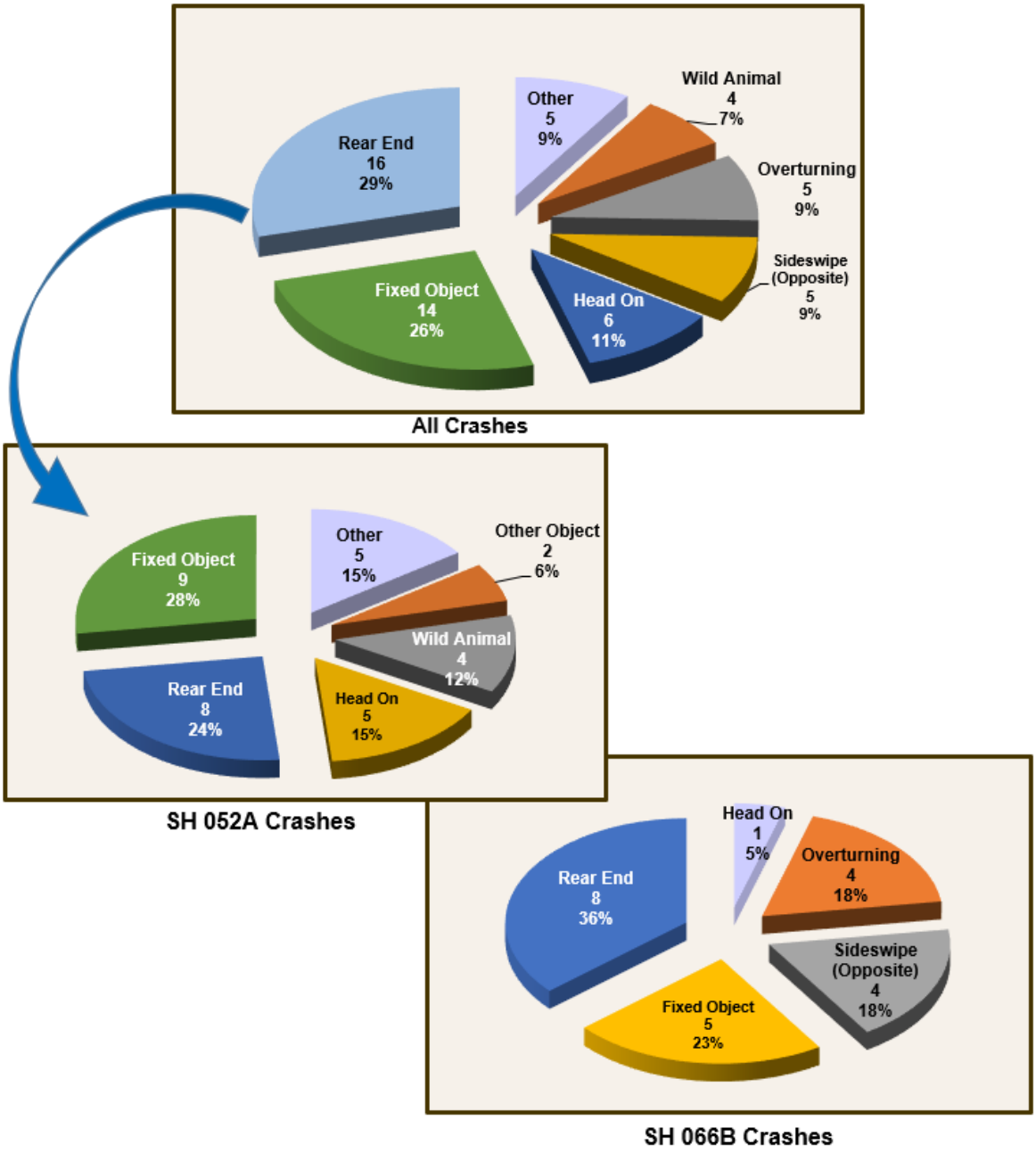
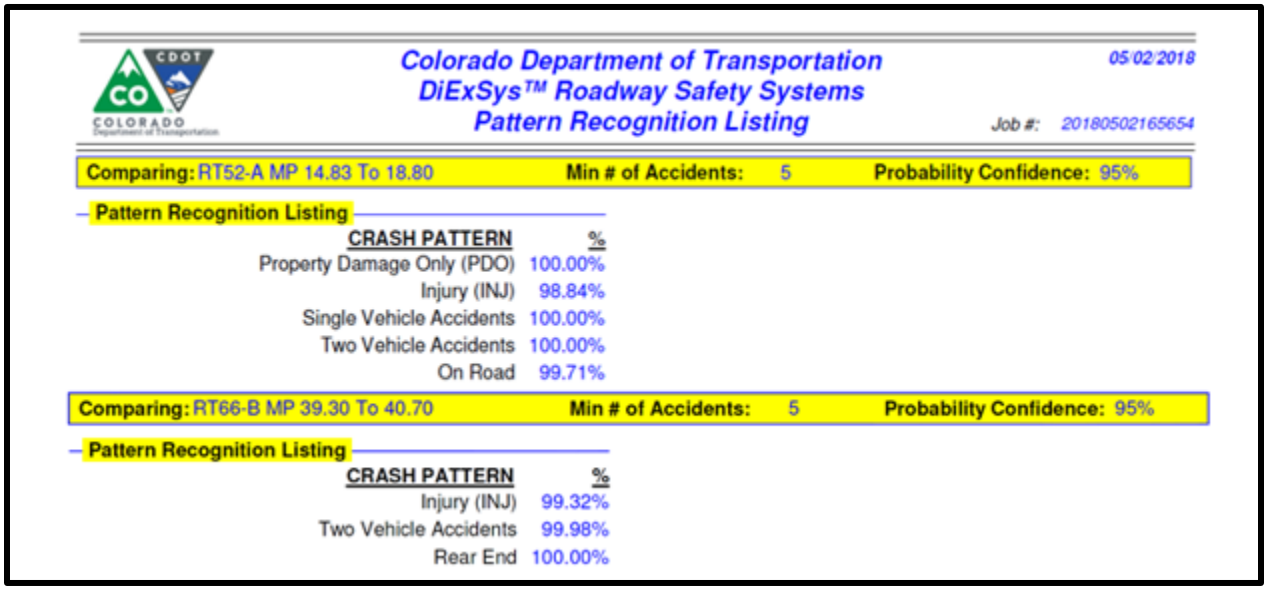


Figure 47: Crash Type Distribution, SH 052A MP 14.93 – 18.80 and SH 066B MP 39.30 – 40.70

As the charts show, there were 11 crashes that involved vehicles travelling in opposite directions (head ons and opposite directions sideswipes). These 11 crashes accounted for 12 of the injuries and two (2) of the fatalities. The construction of 2+1 Road with Barrier would effectively remove the possibility for these types of outcomes. Rear end crashes accounted for 10 of the injuries in the study period. While we do not expect the proposed modifications to eliminate this crash type, the increased passing opportunities afforded by additional lane may result in fewer impatient drivers following at dangerously close distances and thereby reduce the frequency of rear end crashes.

Table SS shows the results of a pattern recognition analysis the study section using criteria of a minimum of five (5) qualifying crashes with a minimum probability confidence of 95%. As the table shows, patterns were found for crashes with injuries, single vehicle and two-vehicle crashes, on-road crashes and rear ends.

Table SS: Pattern Recognition Results
SH 052A MP 14.93 – 18.80 and SH 066B MP 39.30 – 40.70



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

05/02/2018

Job #: 20180502165654

Comparing: RT52-A MP 14.83 To 18.80 | Min # of Accidents: 5 | Probability Confidence: 95%

Pattern Recognition Listing

CRASH PATTERN	%
Property Damage Only (PDO)	100.00%
Injury (INJ)	98.84%
Single Vehicle Accidents	100.00%
Two Vehicle Accidents	100.00%
On Road	99.71%

Comparing: RT66-B MP 39.30 To 40.70 | Min # of Accidents: 5 | Probability Confidence: 95%

Pattern Recognition Listing

CRASH PATTERN	%
Injury (INJ)	99.32%
Two Vehicle Accidents	99.98%
Rear End	100.00%

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since these sections of SH 052A and SH 066B exhibit a higher than expected frequency of crashes involving bodily injury, and because many of the crash types involved in the more severe crashes are particularly likely to be mitigated by the proposed improvement, this may be a very effective location to use the 2+1 Road with Barrier

configuration. Conversion of these 2-lane undivided segments into 2+1 Road with Barrier configuration would effectively eliminate head on and opposite direction sideswipe crashes and substantially reduce the number of non-intersection rear ends. This group of crashes accounted for 71% of all injuries and 50% of the fatalities during the study period. Different outcomes would also be expected for the 11 additional off-left crashes that resulted in four (4) injuries and one (1) fatality.

Tables TT and **UU** show economic analyses for converting the proposed portions of SH 052A and SH 066B to the 2+1 Road with Barrier configuration. The cost of construction will vary throughout the study section as the existing pavement width and terrain vary. Using a parametric estimating algorithm for several subsections of the stretch, we arrived at an average cost estimate of $700,000 per mile or $2,710,000 for the 3.87-mile stretch on SH 052A and $980,000 for the 1.4-mile stretch on SH 066B. The actual costs and resultant B/C ratios are likely to vary based on more specific factors that will be determined upon final design of a project. As the analyses show, the expected benefit to cost ratio for this improvement is 4.51 to 1 for the SH 052A portion (**Table TT**) and 5.79 to 1 for the SH 066B portion (**Table UU**). (Analyses excluded wild animal crashes).

Table TT: Economic Analysis for Conversion to 2+1 Road with Barrier on SH 052A

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

04/13/2020
Job #: 20200413225200

Location: 52A **Begin:** 14.93 **End:** 18.80 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	18		Weighted PDO:	4.42	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	8	14: Injured	Weighted INJ:	3.44	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	3	3: Killed	Weighted FAT:	0.74	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
		B/C Weighted Year Factor:		5.00	33%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
		Cost: $ 2,710,000				Service Life:	20
		From: 01/01/2012				Capital Recovery Factor:	0.080
		To: 12/31/2016	Days: 1827			Annual Maintenance/Delay Cost:	$ 38,700

Benefit Cost Ratio: 4.51 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

Table UU: Economic Analysis for Conversion to 2+1 Road with Barrier on SH 066B

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

04/13/2020

Job #: 20200413225735

Location: 66B **Begin:** 39.30 **End:** 40.70 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	9		Weighted PDO:	2.21	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	12	17: Injured	Weighted INJ:	4.18	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	1	1: Killed	Weighted FAT:	0.25	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	38%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 14,000

Cost: $ 980,000
From: 01/01/2012
To: 12/31/2016
Days: 1827

Benefit Cost Ratio: 5.79 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 with Barrier configuration is adopted, then decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality at significant intersections, some may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated. **Tables VV** and **WW** show lists of accesses within the study sections with some preliminary observations pertinent to their handling. Because of the large number of accesses, we have not provided specific recommendation for all of them. We have recommended retaining full access at a few of the more prominent roads and provided descriptions for other less prominent accesses. The Region should review this list in the context of more specific information relative to their usage and determine which ones will need to be retained prior to design of a project. If too many of them need to be retain access to both directions of traffic the feasibility of the improvement may be compromised.

Table VV: Accesses on SH 052A MP 14.93 – 18.80

Location	Side of Road	Description	Comments
14.98	N	Unimproved road	Shortcut across grass from CR 14
14.99	S	Unimproved road	Access to crop area
15.00	N	Road across field	Shortcut across field from CR 14. Very near alternate routes exist.
15.16	N	3-leg intersection with CR 17	Small collector. Retain full usage.
15.36	S	3-leg intersection with CR 17	Small collector. Retain full usage.
15.55	S	Unimproved road	Shortcut across field from CR 12.5. Very near alternate routes exist.
15.67	S	3-leg intersection with CR 12.5	Non-treatment would only affect WB traffic on CR 12.5 that wanted to stay on CR 12.5 which is probably uncommon. The alternate route would add 0.2 mile.
15.70	N	Field access	Access to crop area on north side of highway. No structures.
15.72	S	Farm house access	House and a few out buildings and pasture.
15.78	S	Field access	Access to crop area on south side of highway. No structures.
15.92	N & S	Dirt road	Road provides sole access to one property on the south and redundant access to two properties on north.
16.42	N & S	4-leg intersection with CR 19	Retain full usage at this road.
16.55	S	Field access	CR 19 provides turnaround point 1/8 mile away. There is also access from other roads.
16.68, 16.73	N	2 Accesses to same property	Residence and farm property
16.76	S	Minor road	Access to fields only.
16.93	S	Private access	Serves one property with a few buildings.
17.04	N	Field access	Access to fields only.
17.24	N & S	Private Access	Access to one residence on the north side and a larger dairy farm on the south side.
17.42	N & S	4-leg intersection with CR 21	Small collector. Retain full usage.
17.60	N	Private access	Serves one property with several buildings.
17.67	S	Minor road	Access to fields only.
17.71	S	Private access	Serves one property with several buildings.

Table WW: Accesses on SH 066B MP 39.30 – 40.70

Location	Side of Road	Description	Comments
39.34	S	Elmore Rd	Sole access to 26 homes
39.37	N	Single Drive	Farm that appears to sell earthworms to the public
39.44	S	Nesting Crane Lane	Sole access to 8 homes
39.59	S	Private access	1 Home horse property. Doesn't appear commercial.
39.66	S	Private access	1 Home horse property. Doesn't appear commercial.
39.69	S	Private access	1 Home horse property. Doesn't appear commercial.
39.73	S	Private access	Horse property with several out buildings and stables. Probably some commercial use.
39.91	N & S	County Road 3	4-leg Stop sign controlled intersection with County Road
40.01	S	Private access	Access to 1 home with a few out buildings
40.05	S	Private access	Access to 1 home with a few out buildings
40.06	N	Field access	Unimproved track across field to crop area
40.12	S	Private access	1 home
40.21	S	Residential access	Access to 8 homes.
40.25	N	Field access	Unimproved path across field to crop area
40.34	S	Unimproved road	Some possibly abandoned structures nearby, access to same fields as MP 40.53. Possible back route to other
40.44	N	Farm access	Single property with house and farm buildings
40.53	2N, 1S	3 Farm accesses	The one on the south side is to fields only. The north is a double access to the one farm property that is also served by access at MP 40.44

State Highway 086A, MP 7.79 to 13.40, East of Franktown, Douglas and Elbert Counties

Figure 48: SH 086A MP 7.79 to 13.40 Location

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 086A (SH 086A) in Douglas and Elbert Counties, beginning at MP 7.79 and extending to MP 13.40. The study begins about a mile east of Franktown and extends easterly for 5.61 miles, ending about 1½ miles west of Elizabeth.

SITE CONDITIONS SH 086A is classified as a Rural Minor Arterial in rolling terrain throughout the study section. SH 086A is primarily a 2-lane undivided highway facility with 12-foot lanes in the study section, but it has four sections that have been widened to accommodate turn lanes at the more prominent intersections. The shoulders 8 feet wide from MP 7.79 to MP 12.29 were they become 6 feet wide through the remainder of the study section. The approximate total pavement widths are summarized in **Table XX**.

SH 086A MP 7.79 to 13.40

Table XX: Locations of Widened Sections

Begin MP	End MP	Length	Total Pavement and Roadbed Width	Description
7.79	10.09	2.30	40	Normal 2-Lane stretch (8' Shoulders)
10.10	10.41	0.32	40-54	Widening for Deer Path Road Intersection
10.42	10.95	0.54	40	Normal 2-Lane stretch (8' Shoulders)
10.96	11.40	0.45	40-64	Widening for Flintwood Road Intersection
11.41	12.00	0.60	40	Normal 2-Lane stretch (8' Shoulders)
12.01	12.11	0.11	40-50	Widening for Rock Cliff Trail Intersection
12.12	12.29	0.18	40	Normal 2-Lane stretch (8' Shoulders)
12.30	12.55	0.26	36	Shoulders change from 8' to 6'.
12.56	12.96	0.41	40-64	Widening for Legacy Ridge St. Intersection
12.97	13.40	0.44	36	Normal 2-Lane stretch (6' Shoulders)

Shoulder rumble strips appear throughout the study section in 2017 video log on OTIS, but were very worn down in the eastern portion. The speed limit is posted at 55 mph throughout.

The average annual daily traffic (AADT) from 2012 to 2015 is shown in **Table YY**. 2015 is the latest year for which this data is available.

Table YY: AADT by Location and Year

Begin MP	End MP	2012	2013	2014	2015
7.79	11.18	9500	11000	12000	11000
11.18	11.27	8600	8700	9100	8300
11.27	13.40	8600	7900	8200	9000

A total of 60 crashes occurred during the 5-year study period. Thirty-eight (38) of the crashes were property damage only. There were 20 crashes that involved injuries and two (2) fatal crashes. In total, 28 people were injured and two (2) people were killed. This is summarized by year in **Table ZZ**.

Table ZZ: Summary of Crashes by Year

Year	Total Crashes	PDO	Injury	Fatal	Injuries	Fatalities
2012	14	8	6	0	9	0
2013	16	10	5	1	8	1
2014	12	9	3	0	3	0
2015	9	4	4	1	6	1
2016	9	7	2	0	2	0
Total	60	38	20	2	28	2

Figure 49 shows a typical section of SH 086A within project limits.

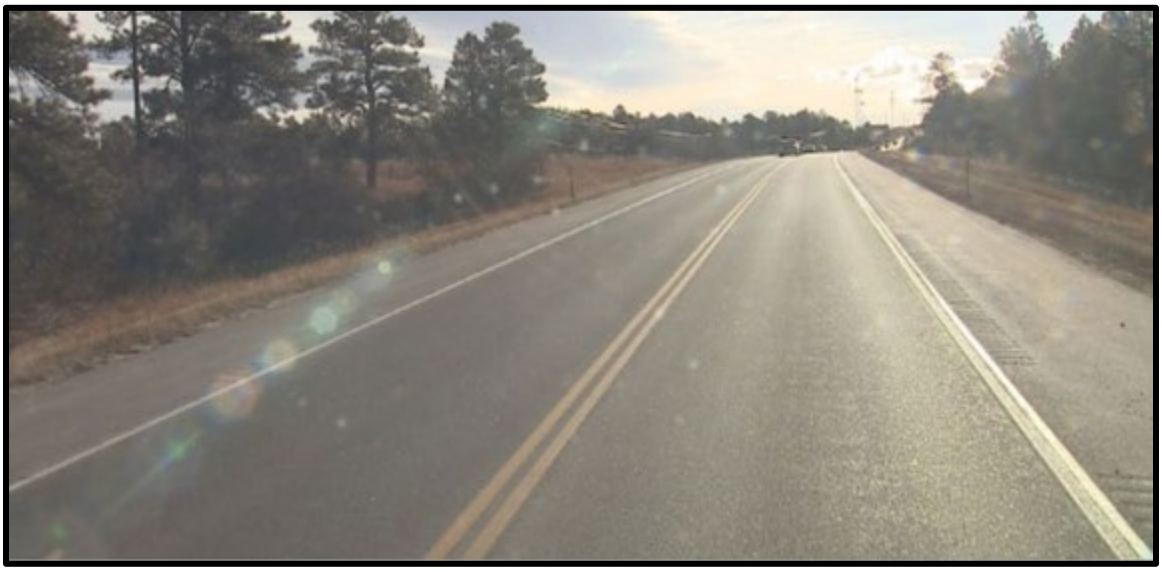


Figure 49: SH 086A MP 10.60 – Typical Cross Section

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 50** shows the corridor SPF for the study section. The chart shows that the study section is performing at the LOSS-II and LOSS-III category for both frequency and severity of crashes for almost all of the study section suggesting moderate potential for reduction in both categories. The LOSS for severity of crashes is higher than the LOSS for frequency of crashes suggesting somewhat higher potential for reduction of crashes resulting in bodily injury.

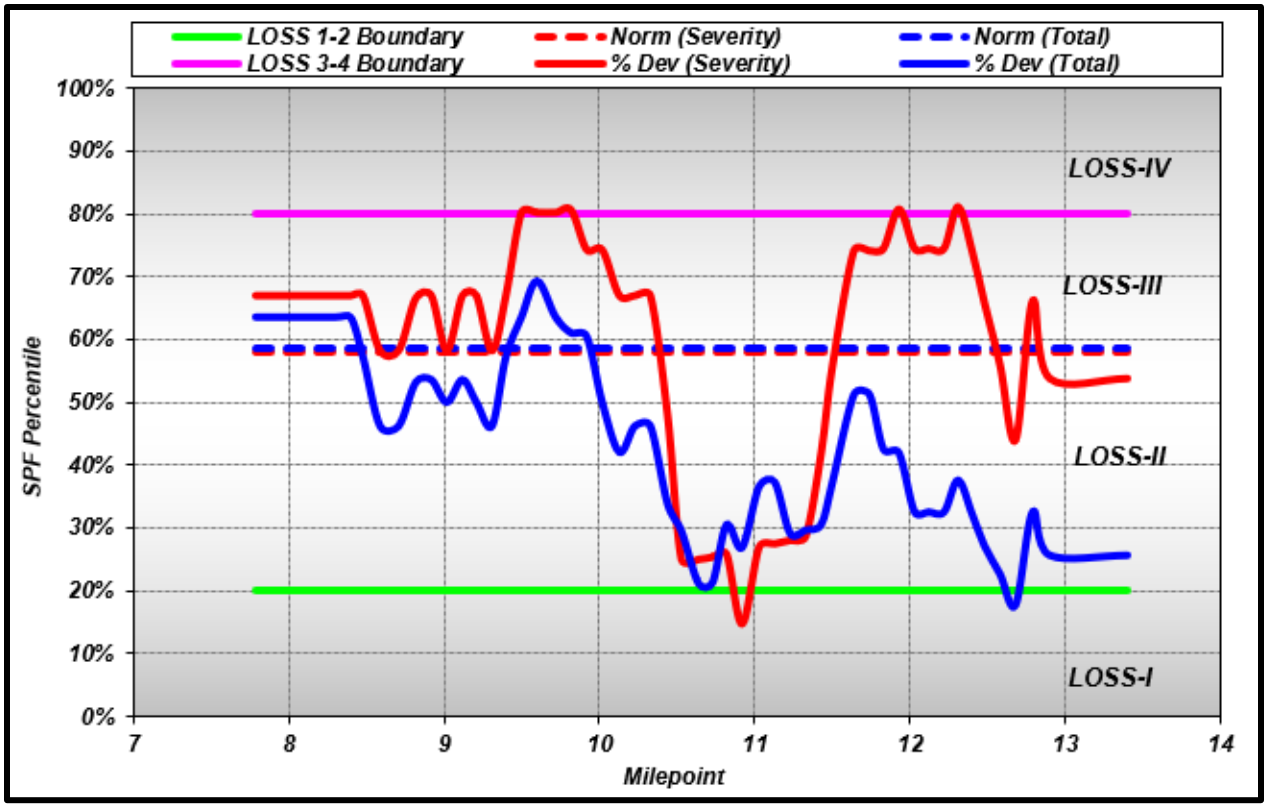


Figure 50: Corridor SPF for SH 086A

Figures 51 and **52** represent EB corrected segment safety performance analysis of SH 086A within the study limits. **Figure 51** shows segment safety performance from the total crash frequency stand point. It shows that the study section is performing in the LOSS-II category in terms of total crash frequency, suggesting a relatively low potential for a significant reduction in total number of crashes.

Figure 52 represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. It shows that the study section performs in the LOSS-III category just slightly above the boundary between LOSS-II and LOSS-III in terms of severity, suggesting moderate potential for reduction of crashes involving bodily injury.

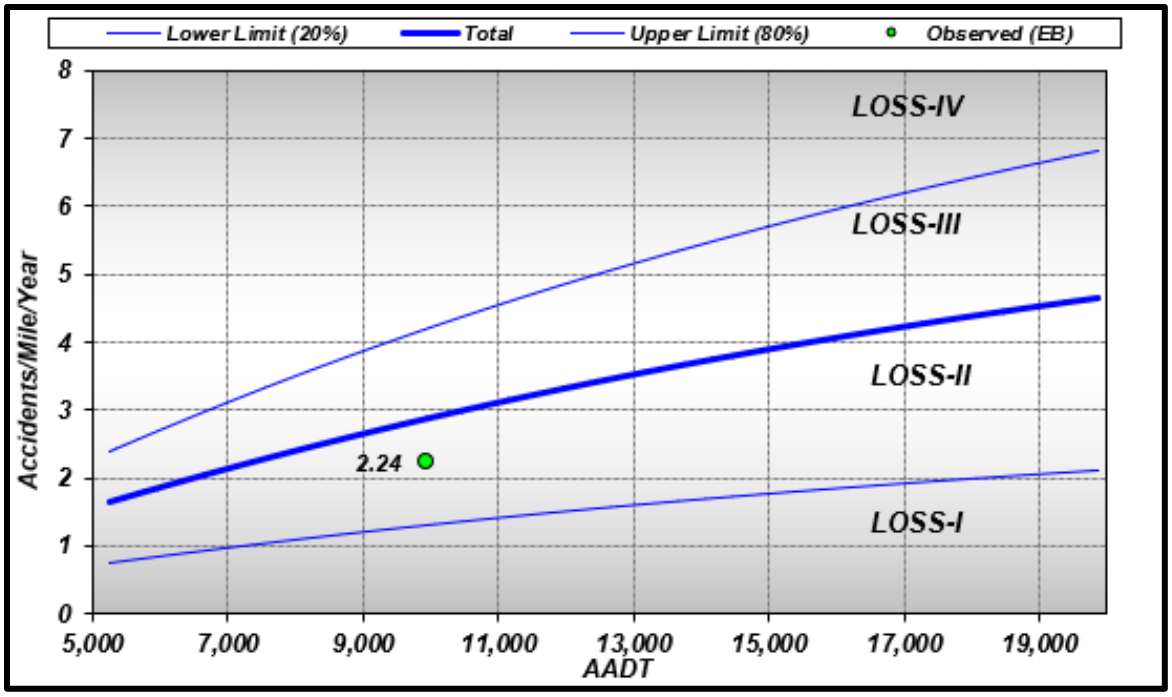


Figure 51: EB Corrected SPF for Total Crashes

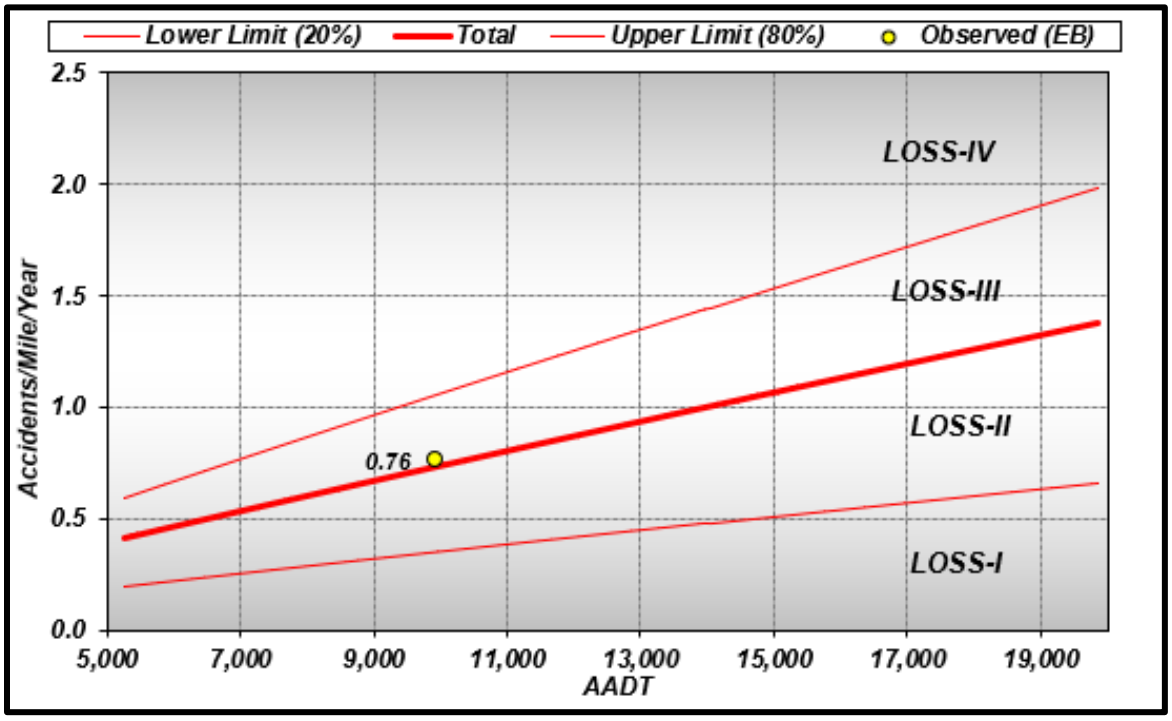


Figure 52: EB Corrected SPF for Injury and Fatal Crashes

Types of Crashes The overall distribution by crash type for all non-intersection related crashes within the study limits is provided in **Figure 53**. As the chart shows, Wild Animal crashes were

the most common, representing 46% of all crashes. Rear End crashes were the second most common crash type representing 15% of all crashes, followed by Fixed Objects at 13%, Overturning at 12% and Head Ons at 7%. All other crash types were relatively infrequent. Of these crash types, the head on and overturning crashes have the most potential for reduction in frequency from adopting the 2+1 Road with Barrier configuration.

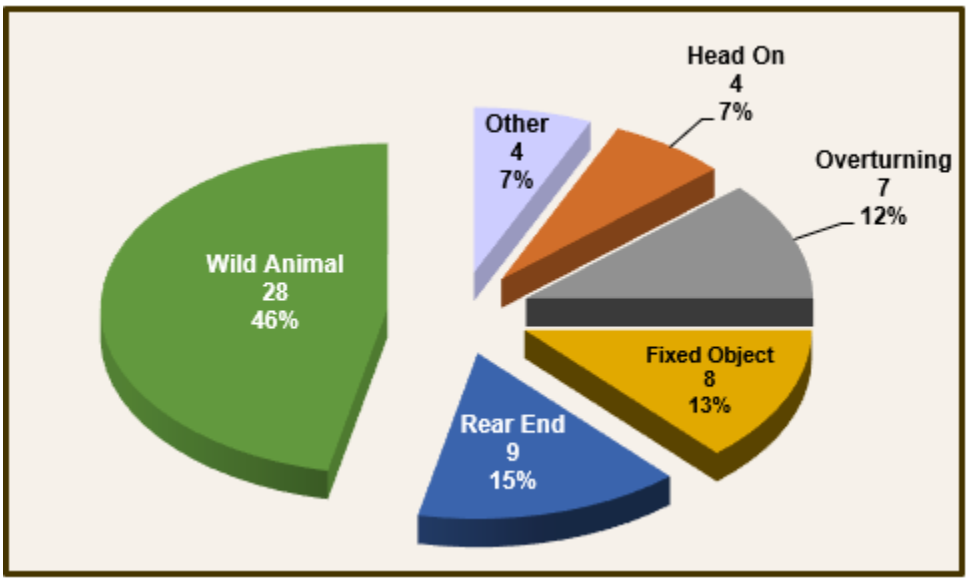
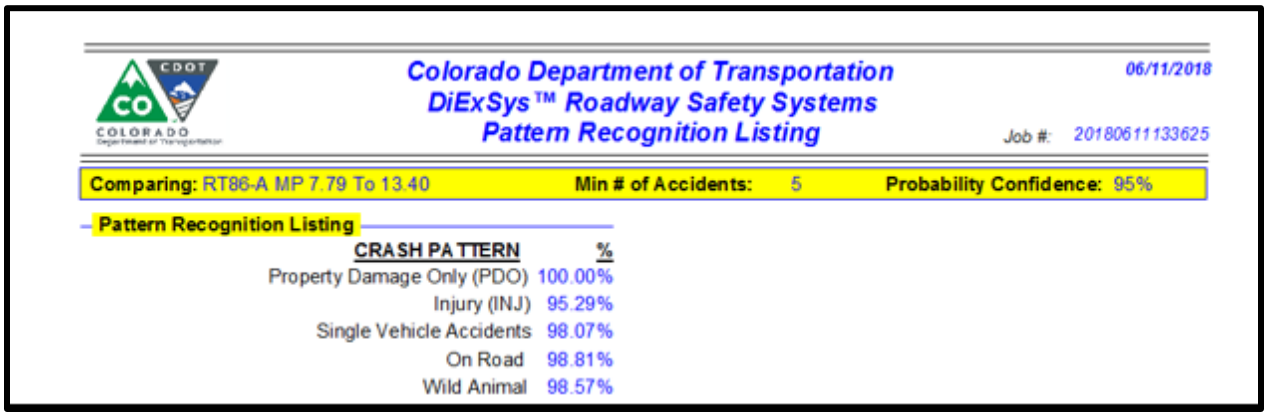


Figure 53: Crash Type Distribution SH 086A MP 7.79 – 13.40

Forty-six (46) or 76% of the 60 crashes in the study section were On-Road crashes, which is somewhat higher than the statewide average of 64% for similar facilities. The higher than average rate of on-road crashes is a result of the higher than normal percentage of wild animal related crashes, all of which occur on the roadway.

Table AAA shows the results of a pattern recognition analysis the study section.

Table AAA: Pattern Recognition Results



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

06/11/2018

Job #: 20180611133625

Comparing: RT86-A MP 7.79 To 13.40 | Min # of Accidents: 5 | Probability Confidence: 95%

Pattern Recognition Listing

CRASH PATTERN	%
Property Damage Only (PDO)	100.00%
Injury (INJ)	95.29%
Single Vehicle Accidents	98.07%
On Road	98.81%
Wild Animal	98.57%

Of the five patterns shown in the list, all of them except that for Injury can be attributed to the high frequency of wild animal related crashes. The pattern for Injury crashes is in the vicinity of MP 12 and corresponds to a group of five (5) off-road injury/fatality crashes, three of which involved overturning.

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since this section of SH 086A exhibits a higher than expected frequency of crashes involving bodily injury, this may be an effective location to use the 2+1 Road with Barrier configuration. Conversion of this 2-lane undivided segment into the 2+1 Road with Barrier configuration could reduce the frequency of some of the crash types we are seeing. There were five crashes involving two vehicles travelling in opposite directions and four of those crashes resulted injuries. There were also four off-left crashes that resulted in one injury and one fatality that would have likely had less severe outcomes with the 2+1 Road with Barrier configuration. In addition to those specific situations, some reduction across some of the other crash scenarios is expected as well.

Table BBB shows an economic analysis for converting the proposed portion of SH 086A to the 2+1 Road with Barrier configuration. The cost of construction will vary throughout the study section as the existing pavement width and terrain vary. Using a parametric estimating algorithm for several subsections of the stretch, we arrived at an average cost estimate of $800,000 per mile, or $4,500,000 for the 5.61-mile stretch, for the purpose of this preliminary benefit to cost analysis. The actual cost and resultant B/C ratio are likely to vary based on more specific factors that will

be determined upon final design of a project. As the analysis shows, the expected benefit to cost ratio for this improvement is 2.27 to 1. (Analysis did not include wild animal crashes).

Table BBB: Economic Analysis for Conversion to 2+1 Road with Barrier

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

04/13/2020

Job #: 20200413230115

Location: 86A **Begin:** 7.79 **End:** 13.40 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	12		Weighted PDO:	2.95	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	18	24: Injured	Weighted INJ:	5.90	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	2	2: Killed	Weighted FAT:	0.49	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	40%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
		Cost: $ 4,500,000				Service Life:	20
		From: 01/01/2012				Capital Recovery Factor:	0.080
		To: 12/31/2016	Days: 1827			Annual Maintenance/Delay Cost:	$ 56,100

Benefit Cost Ratio: 2.27 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 with Barrier configuration is adopted, then decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality, some accesses may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated.

There are four intersections in the study section that are major enough to already have turn lanes. These were referenced earlier in the report when we discussed pavement widths, but are listed again in **Table CCC**. These intersections will need to retain their existing level of functionality in terms of turn lanes and ability to make left turns onto and off of the side roads.

Table CCC: Intersections within the Study Section

Location	Description	Comments
MP 10.30	Deerpath Rd. Three-leg Intersection on north side of SH 86.	Left turn lane for EB traffic on SH 86 will need to be retained.
MP 11.18 and 11.27	Two offset three-leg intersections. Deerfield Rd on the south side and Flintwood Ave on the north side.	Both intersections have left turn lanes from SH 86. Deerfield Rd also has a right turn lane from SH 86. All of the lanes will need to remain in place.
MP 12.06 and 12.11	Slightly offset three-leg intersection with Rocky Cliff Rd on the north side of SH 86 and Conestoga Rd on the south side.	SH 86 has short right turn lanes and short acceleration lanes for each of these roads. These lanes should be retained and doing so should have no impact on project cost. CDOT will need to determine whether left turn functionality must be retained here.
MP 12.78	Four-leg intersection with CO Rd 3 on north side of SH 86, and Legacy Rd. on the south side.	There are left turn lanes in place for both directions. There is a right turn lane and an acceleration lane for westbound SH 86 traffic. All existing functionality will need to be retained at this intersection.

In addition to these four intersections, there are approximately 27 minor side roads or driveway accesses on SH 86 in the study section. This frequency of accesses will have an impact on the feasibility of converting this stretch of highway to 2+1 Road with Barrier. We recommend that CDOT evaluate the acceptability of eliminating left turn access at some of these locations to determine whether this stretch is a viable candidate for conversion to 2+1 Road with Barrier. Accesses with significant volumes will need auxiliary lanes to preserve the benefits of 2+1 Road with Barrier.

State Highway 115A, MP 20.37 to 24.37, North of Penrose, Fremont County

Figure 54: SH 115A MP 20.37 to 24.37 Location

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 115A (SH 115A) extending from MP 20.37 to MP 24.37 in Fremont County. The study section begins about 4 miles north of the Town of Penrose and extends 4.00 miles north.

SITE CONDITIONS SH 115A is classified as a Rural Minor Arterial through rolling terrain throughout the study section. SH 115A is a 2-lane undivided highway with 12-foot lanes and 10-foot paved shoulders in the study section. The total pavement width is 44 feet. There are a few

minor intersections and several accesses throughout the study section. These will be discussed in more detail later in the report. The highway is characterized by mild grades (less than 3%) and mild curves. The speed limit on SH 115 is posted at 60 mph throughout the study section. There are both shoulder and centerline rumble strips throughout the study section.

The average annual daily traffic (AADT) from 2012 to 2015 ranged from 7,300 vpd to 8,200 vpd as shown in **Table DDD**. 2015 is the latest year for which this data is available.

Table DDD: AADT by Year SH 115A MP 20.37 – 24.37

2012	2013	2014	2015
7300	7400	7800	8200

Figure 55 is a typical view of SH 115A within project limits, taken at approximately MP 22.04.

Figure 55: SH 115A MP 22.04 – Typical Cross Section

A total of 39 crashes occurred in the study section during the 5-year study period. Twenty-four (24) of the crashes were property damage only. There were 14 crashes that involved injuries, resulting in injury to a total of 22 people. There was one crash that resulted in a fatality. This is summarized by year in **Table EEE**.

Table EEE: Summary of Crashes by Year

Year	Total Crashes	PDO	Injury	Fatal	Injuries	Fatalities
2012	9	7	1	1	4	1
2013	9	5	4	0	8	0
2014	8	4	4	0	4	0
2015	8	6	2	0	2	0
2016	5	2	3	0	4	0
Total	39	24	14	1	22	1

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 56** shows the corridor SPF for the study section. As the chart shows the study section is performing the LOSS-I and LOSS-II categories from the beginning of the study section to MP 22, and then performs at LOSS-III and LOSS-IV for the remainder of the study section in terms of both crash frequency and crash severity. This suggests the potential for reduction in crash frequency and severity is relatively low until MP 22 and relatively high beyond MP 22. We will discuss this result in terms of economic analysis and choice of project limits later in the report.

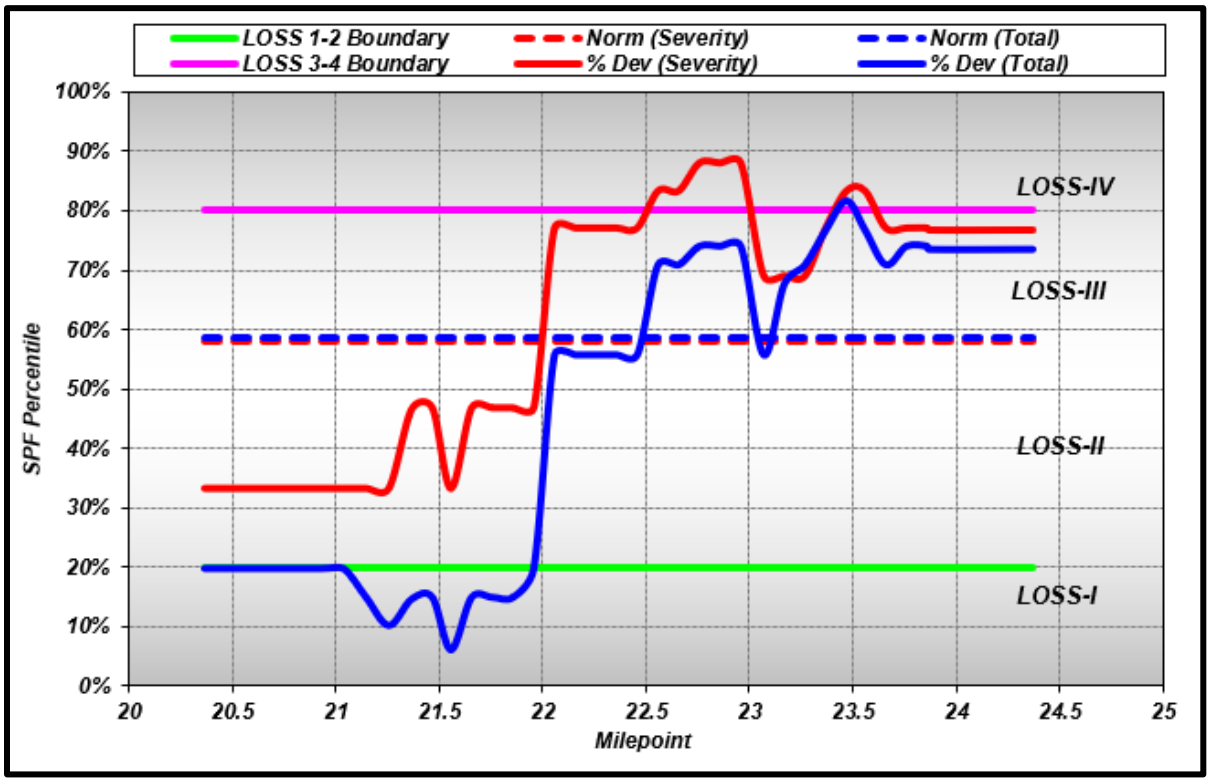


Figure 56: Corridor SPF for SH 115A

Figures 57 and **58** represent EB corrected segment safety performance analysis of SH 115 within the study limits. **Figure 57** shows segment safety performance from the total crash frequency stand point and **Figure 58** represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. The charts show that the study section is performing in the LOSS-II category in terms of overall crash frequency and in the LOSS-III category for crash severity. This suggests a moderately low potential for improvement in the frequency category and a relatively high potential for reducing the number of injury and fatality related crashes.

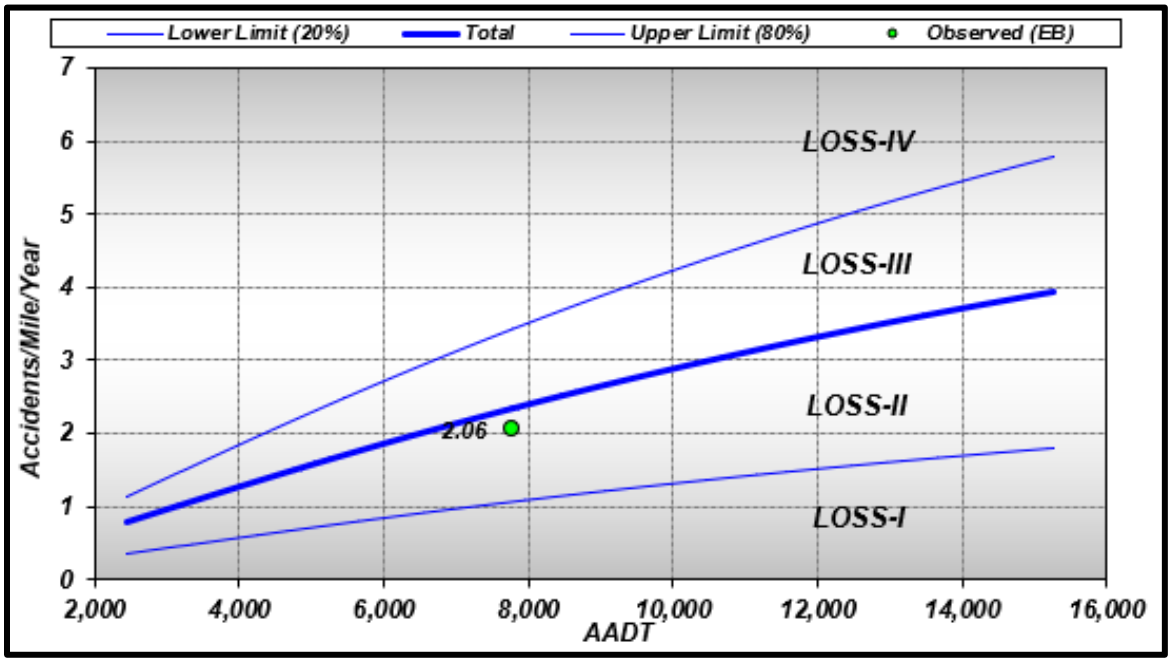


Figure 57: EB Corrected SPF for Total Crashes

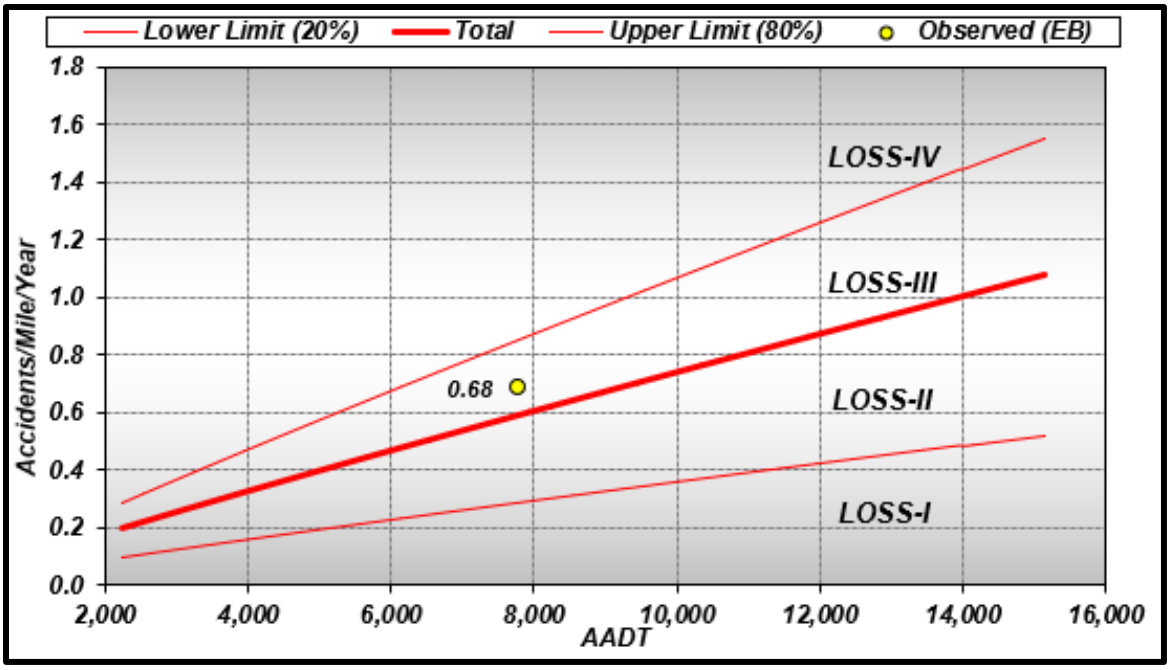


Figure 58: EB Corrected SPF for Injury and Fatal Crashes

Types of Crashes The overall distribution by crash type for all non-intersection related crashes within the study limits is provided in **Figure 59**.

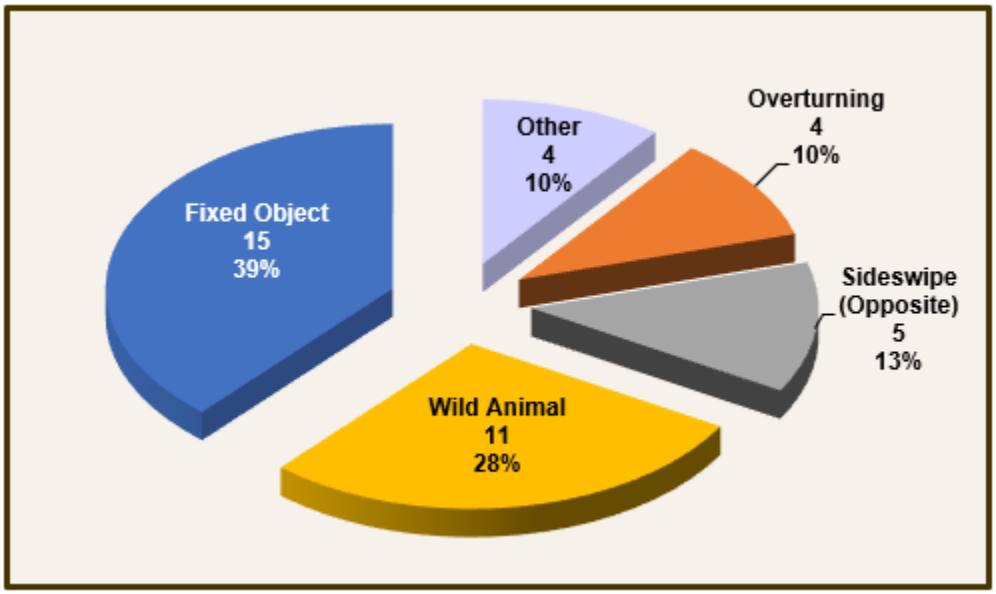


Figure 59: Crash Type Distribution SH 115A MP 20.37 – 24.37

As the chart shows, the most common crash type was with Fixed Objects, accounting for 38% of all crashes. Wild Animal crashes were the next most common accounting for 28% of the crashes. Opposite Direction Sideswipes accounted for 13% and Overturning accounted for 10%. With exception of the wild animal related crashes, the 2+1 Road with Barrier configuration is expected to be effective in reducing the frequency of all of the most common crash types shown in the chart.

Table FFF shows the results of a pattern recognition analysis the study section using criteria of a minimum of five (5) qualifying crashes with a minimum probability confidence of 95%.

Table FFF: Pattern Recognition Results

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

05/31/2018

Job #: 20180531191416

Comparing: RT115-A MP 20.37 To 24.37 | Min # of Accidents: 5 | Probability Confidence: 95%

Pattern Recognition Listing

CRASH PATTERN	%
Injury (INJ)	98.18%
Off Road	99.56%
Off Road Left	99.25%
Total Fixed Objects	99.37%
Snow or Sleet or Hail	99.70%
Icy Road	99.83%

The crash characteristics represented by these patterns are those that suggest relatively high effectiveness from the 2+1 Road with Barrier configuration. Eleven of the 39 crashes (28%) were off left. Among those crashes were 5 Injury and the one fatality crash. Since the possibility of crossing the centerline and going off the side of the roadway is eliminated with 2+1 Road with Barrier design, we expect less severe outcomes in cases like these.

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since these sections of SH 115A exhibit a higher than expected frequency of crashes involving bodily injury, this may be an effective location to use the 2+1 Road with Barrier configuration. Conversion of these 2-lane undivided segments into the 2+1 Road with Barrier configuration would reduce the frequency of some of the crashes that have occurred in the study section.

Table GGG shows an economic analysis for converting the proposed portion of SH 115A to the 2+1 Road with Barrier configuration. The cost of construction should be fairly consistent throughout the study section. Using a parametric estimating algorithm, we arrived at a cost of about $650,000 per mile, or $2,600,000 for the 4.0 miles of work section, for the purpose of this preliminary benefit to cost analysis. The actual cost and resultant B/C ratio are likely to vary based on more specific factors that will be determined upon final design of a project. As the analysis shows, the expected benefit to cost ratio for this improvement is 2.48 to 1. (Analysis excluded wild animal collisions).

Table GGG: Economic Analysis for Conversion to 2+1 Road with Barrier

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

04/13/2020

Job #: 20200413230444

Location: 115A **Begin:** 20.37 **End:** 24.37 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	14		Weighted PDO:	3.44	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	13	20: Injured	Weighted INJ:	4.91	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	1	1: Killed	Weighted FAT:	0.25	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	35%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 40,000

Cost: $ 2,400,000
From: 01/01/2012
To: 12/31/2016
Days: 1827

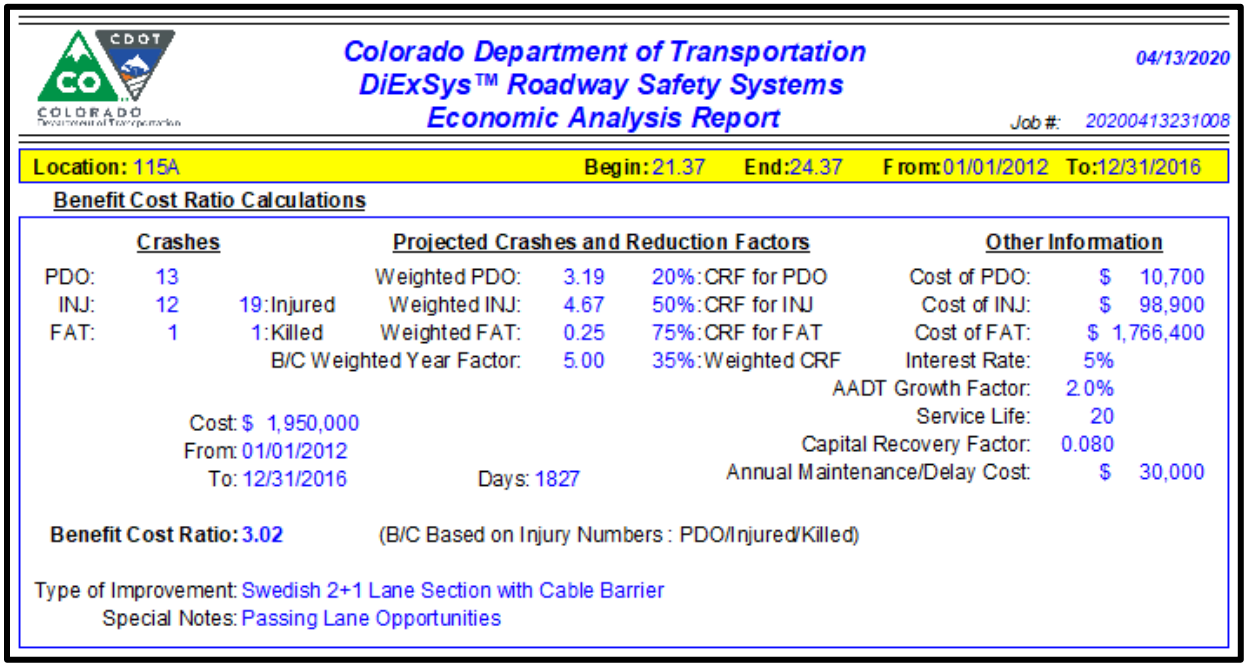
Benefit Cost Ratio: 2.48 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

As we mentioned in the discussion of the corridor SPF analysis, the south end of the study section was performing at LOSS I and II, suggesting low potential for crash reduction. Specifically, for the 5-year study period the crash frequency for the north 2.5 miles was five times as high as that for the first 1.5 miles. However, the study section limits were selected because those are the locations where the roadway changes from three lanes to two lanes. Furthermore, there is no evident difference in the nature of the highway that would account for the lesser crash rate on the south end so we believe it is preferable to build the 2+1 Road with Barrier configuration throughout rather than to leave an unimproved gap. Nonetheless, we have prepared an economic analysis for

just the north three miles of the study section for purposes of comparison, in case CDOT decides to focus the available funding on those stretches with the highest potential for crash reduction. As the economic analysis in **Table HHH** shows, the benefit cost ratio for this 3-mile stretch is projected to be 3.02 to 1 compared to 2.48 to 1 for the entire 4-mile stretch. (Analysis excluded wild animal collisions).

Table HHH: Economic Analysis for Conversion to 2+1 Road with Barrier, North 3-Miles Only



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

04/13/2020

Job #: 20200413231008

Location: 115A **Begin:** 21.37 **End:** 24.37 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	13		Weighted PDO:	3.19	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	12	19: Injured	Weighted INJ:	4.67	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	1	1: Killed	Weighted FAT:	0.25	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	35%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 30,000

Cost: $ 1,950,000
From: 01/01/2012
To: 12/31/2016
Days: 1827

Benefit Cost Ratio: 3.02 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 Road with Barrier configuration is adopted, then decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality of the more significant access points, some accesses may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated.

Table III shows lists of accesses within the study sections with some preliminary observations pertinent to their handling. We have made some preliminary recommendations but the Region should review this list in the context of more specific information relative to their usage and determine which ones will need to be retained prior to design of a project.

Table III: Accesses on SH 115

Location	Side	Description	Comments
20.58	Both	Access to County Road F-45 on the west side and to private property on east side.	Since there are accesses on both sides and one of them serves a County Road (although there is another access to CR F-45 at MP 19.97), this one should probably retain full access.
20.77	E	Access to private property. This appears to serve a single ranch.	This property can also be reached from the access at MP 20.58, so it may be feasible to not provide access from the southbound lane.
21.23	Both	Only one house with a few out buildings is served by this access, but there is a rather extensive network of unimproved roads on both sides that is reachable from here.	It's difficult to assess how much use these back roads are getting. If it is significant full access may be necessary.
22.84	W	This appears to be a pullout for access to jeep and/or hiking trails.	These four pullouts appear to be connected by a crude road that runs parallel to the highway. It may feasible to provide full access to the center pair and allow the rail to continue uninterrupted at the other two.
23.5	W	There are two pullouts here which appears to access jeep trails.	
24.17	W	This is a pullout which appears to access jeep trails.	

It may be worth noting that the three most significant accesses lie within the stretch that would be eliminated from construction if the 3-mile option were taken. This could be an additional incentive to choose that course.

State Highway 160A, MP 27.40 to 34.02, South of Cortez, Montezuma County

Figure 60: SH 160A MP 27.40 to 34.02 Location

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 160A (SH 160A) extending from MP 27.40 to MP 34.02 in Montezuma County. The study section begins about 1 mile north of the turnoff to the Town of Towaoc and extends 6.62 miles northerly terminating just south of the Town of Cortez. Although SH 160A is designated as an east-west highway, at the study location, the

alignment is predominately north-south, with local northbound corresponding to the eastbound increasing milepost direction.

SITE CONDITIONS SH 160A is classified as a Rural Principal Arterial in rolling terrain throughout the study section. SH 160A is a 2-lane undivided highway with 12-foot lanes, 6-foot paved shoulders on the left and 8-foot paved shoulders on the right in the study section. The total pavement width is 38 feet. Centerline and shoulder rumble strips appear to exist throughout the study section

There are frequent minor intersections and accesses throughout the study section. These will be discussed in more detail later in the report.

The speed limit on SH 160A is posted at 65 mph throughout the study section with the exception of a speed reduction related to the turnoffs for the Town of Towaoc and the Ute Mountain Casino and Hotel just south of the study section. The speed is posted at 55 mph for the southbound lanes from MP 27.99 south to the beginning of the study section (MP 27.40) and it's posed at 45 mph for the northbound lanes from MP 27.40 to MP 27.85

The average annual daily traffic (AADT) from 2012 to 2015 ranged from 6,300 vpd to 7,000 vpd as shown in **Table JJJ**. 2015 is the latest year for which this data is available.

Table JJJ: SH 160A AADT by Year

2012	2013	2014	2015
6,500	6,300	6,800	7,000

A total of 91 crashes occurred during the 5-year study period within the study section. There were 26 crashes that involved injuries and two (2) that resulted in fatalities. In total, 38 people were injured and four (4) were killed. This is summarized by year in **Table HHH**.

Table KKK: Summary of Crashes by Year

Year	Total Crashes	PDO	Injury	Fatal	Injuries	Fatalities
2012	16	10	6	0	7	0
2013	24	15	7	2	12	4
2014	16	13	3	0	4	0
2015	19	11	8	0	10	0
2016	16	14	2	0	5	0
Total	91	63	26	2	38	4

Figure 61 is a typical view of SH 160 within project limits, taken at approximately MP 27.50.

Figure 61: SH 160A MP 27.50 – Typical Cross Section

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 62** shows the corridor SPF for the study section. As the chart shows the study section is performing the LOSS-III and LOSS-IV categories for severity of crashes through most of the study section. The only exception is from approximately MP32.3 to MP 32.8 where it performs in the LOSS-II category. This suggests a fairly high potential for reducing crash severity in most of the study section. The study section performed at or very close to LOSS-III throughout, suggesting a moderate potential for reducing the total number of crashes.

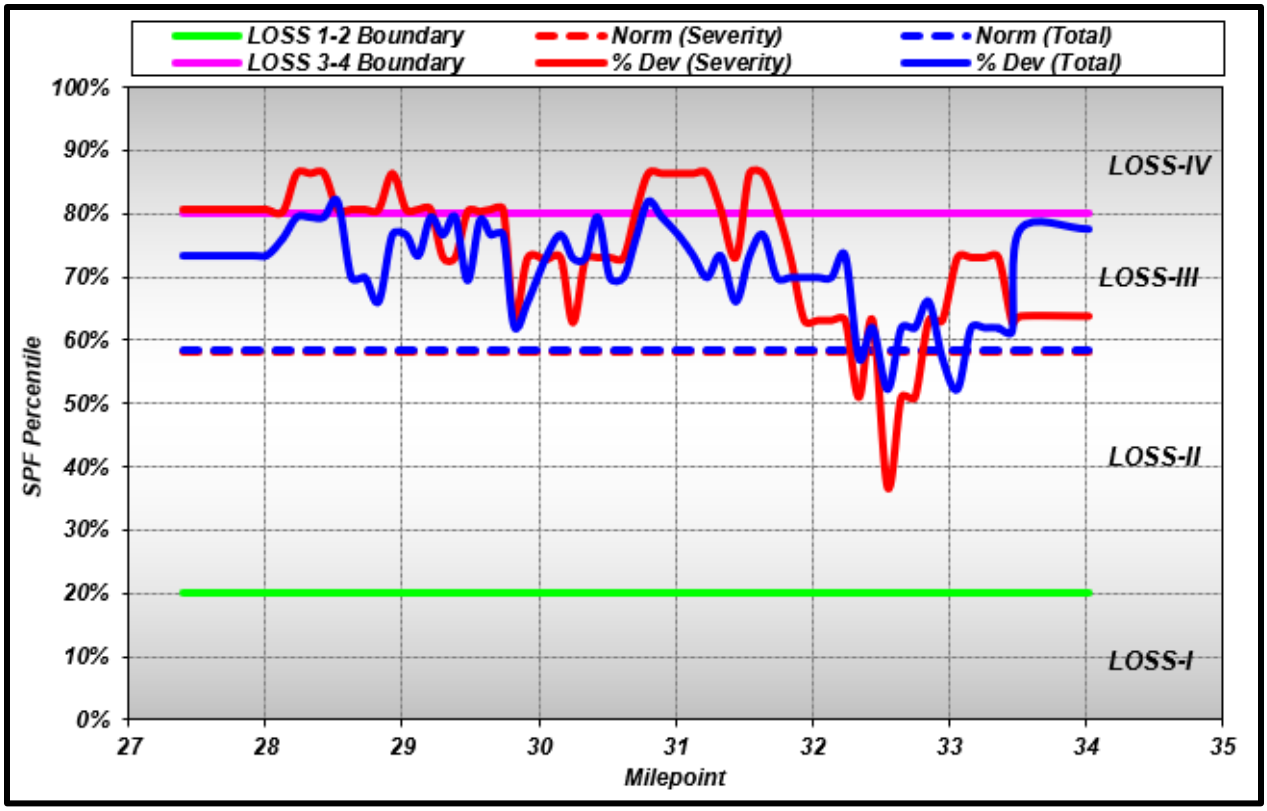


Figure 62: Corridor SPF for SH 160A

Figures 63 and 6**4** represent EB corrected segment safety performance analysis of SH 160 within the study limits. **Figure 63** shows segment safety performance from the total crash frequency stand point. It shows that the study section is performing in the LOSS-III category in terms of total crash frequency, suggesting a moderate to high potential for a significant reduction in total number of crashes. **Figure 64** represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. It shows that the study section performs in the LOSS-III category in terms of severity as well, suggesting moderate to high potential for reduction of crashes involving bodily injury.

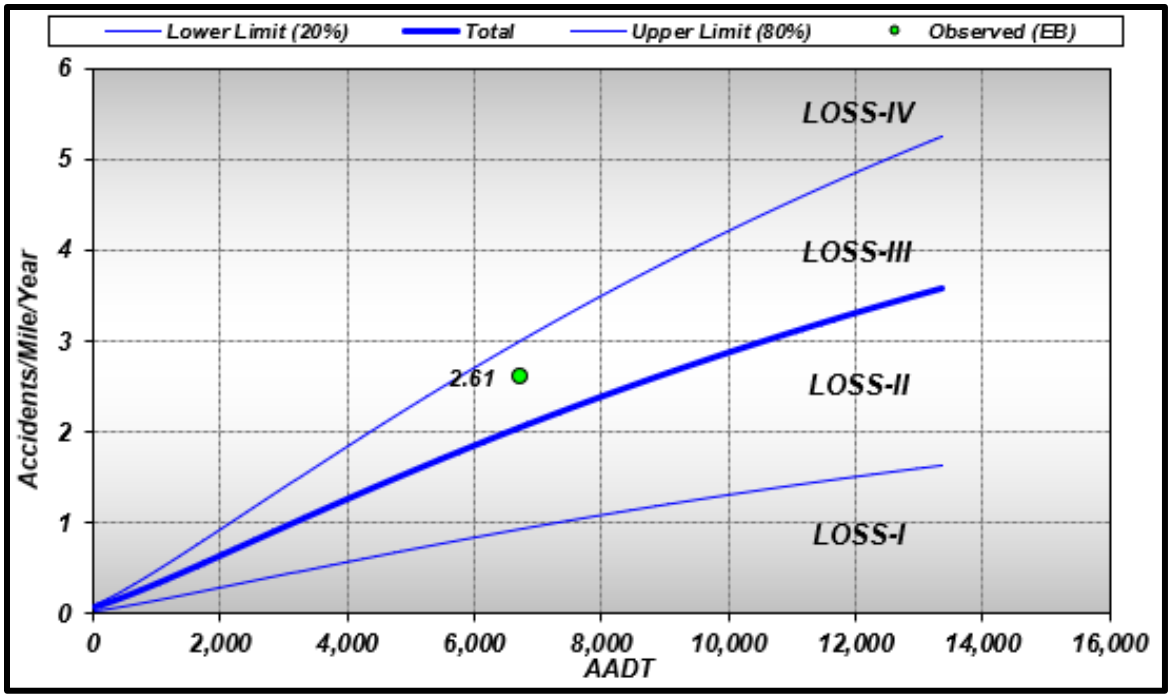


Figure 63: EB Corrected SPF for Total Crashes

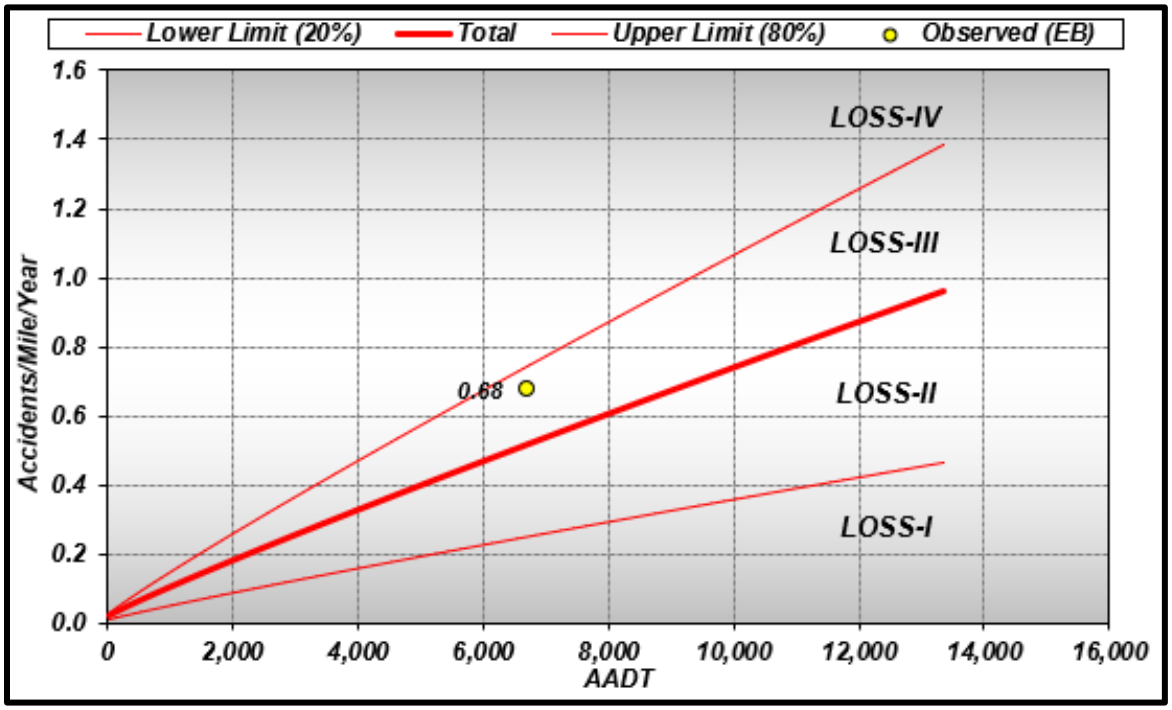


Figure 64: EB Corrected SPF for Injury and Fatal Crashes

Types of Crashes The overall distribution by crash type for all non-intersection related crashes within the study limits is provided in **Figure 65**.

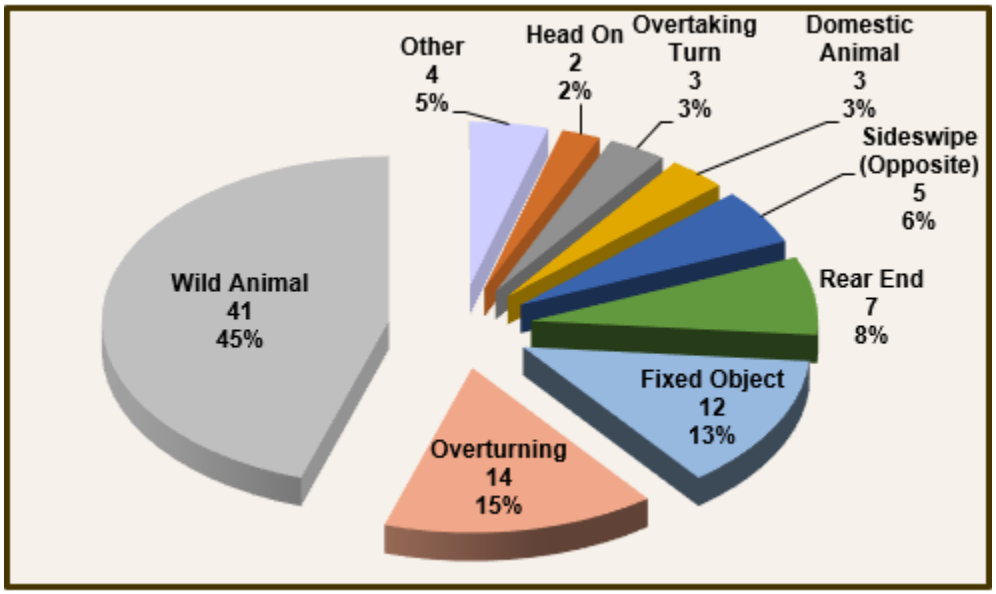


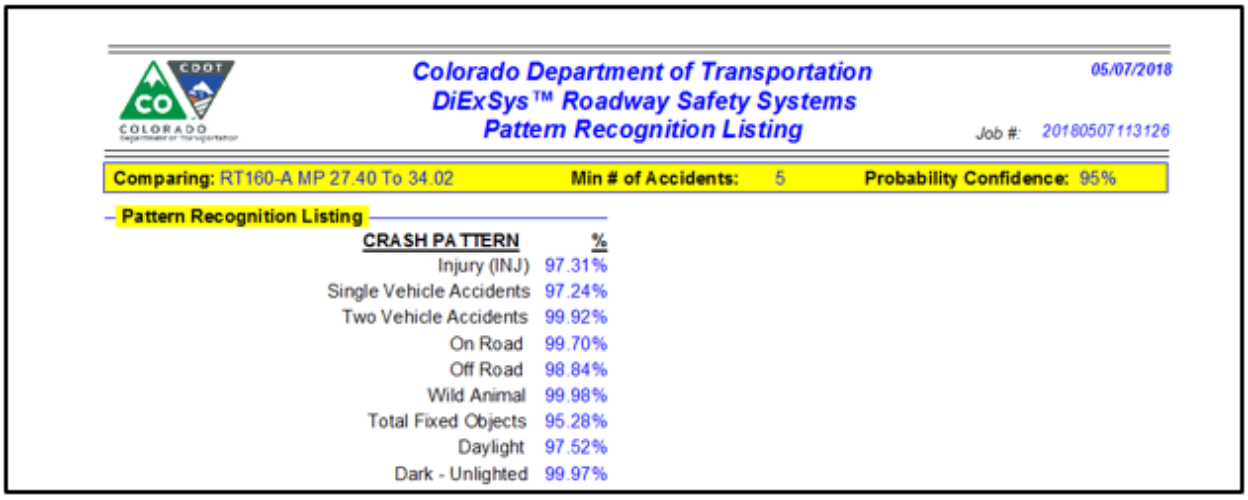
Figure 65: Type Distribution SH 160A MP 27.40 – 34.02

As the chart shows, Wild Animal crashes were the most common, representing 45% of all crashes. The next most common types of accidents were Overturning (15%), Fixed Objects (13%), Rear End (8%) and Opposite Direction Sideswipes (6%).

Although wild animal related crashes were the most common type by far, they accounted for a comparatively low percentage (14%) of the bodily injuries that occurred during the study period and are not expected to be substantially influence by the proposed construction. Opposite direction sideswipes and head ons, on the other hand, while accounting for only 8% of all accidents accounted for 26% of the injuries and 100% of the fatalities experienced during the study period. As these two types of accidents involve vehicles crossing the centerline, they are expected to be the most mitigated by the improvements.

Table LLL shows the results of a pattern recognition analysis the study section using criteria of a minimum of five (5) qualifying crashes with a minimum probability confidence of 95%.

Table LLL: Pattern Recognition Results



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

05/07/2018

Job #: 20180507113126

Comparing: RT160-A MP 27.40 To 34.02 | Min # of Accidents: 5 | Probability Confidence: 95%

Pattern Recognition Listing

CRASH PATTERN	%
Injury (INJ)	97.31%
Single Vehicle Accidents	97.24%
Two Vehicle Accidents	99.92%
On Road	99.70%
Off Road	98.84%
Wild Animal	99.98%
Total Fixed Objects	95.28%
Daylight	97.52%
Dark - Unlighted	99.97%

As the table shows, patterns were found for crashes with injuries, both single and two-vehicle crashes, both on road and off-road crashes, wild animals, fixed objects and dark unlighted conditions. Most of these are not the specific crash types for which the 2+1 Road with Barrier is notably effective, however some reduction may be seen in the injury rate, two-vehicle crashes and on road crashes.

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since these sections of SH 160A exhibit a higher than expected frequency of crashes involving bodily injury, this may be an effective location to use the 2+1 Road with Barrier configuration.

We believe that the conversion of this 2-lane undivided segment into 2+1 Road with Barrier configuration would reduce the frequency of some of the crash types we are seeing. As mentioned earlier, head on crashes and opposite direction sideswipes, although not showing up among the frequency patterns, represented a higher than expected portion of crashes, and of the most serious crash outcomes. There were also 11 additional crashes where the vehicle went off the left side of the roadway. Three (3) of those crashes were overturns that resulted in injuries. These crashes would all likely have had different outcomes with the center cable rail of the 2+1 Road with Barrier design present.

Table MMM shows an economic analysis for converting the proposed portion of SH 160A to the 2+1 Road with Barrier configuration. The cost of construction will vary throughout the study section as the existing pavement width and terrain vary. Using a parametric estimating algorithm for several subsections of the stretch, we arrived at an average cost of about $1,025,000 per mile or $6,800,000 for the 6.63 miles of work section, for the purpose of this preliminary benefit to cost analysis. The actual cost and resultant B/C ratio are likely to vary based on more specific factors that will be determined upon final design of a project. As the analysis shows, the expected benefit to cost ratio for this improvement is 2.94 to 1.

Table MMM: Economic Analysis for Conversion to 2+1 Road with Barrier

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

04/13/2020

Job #: 20200413231928

Location: 160A **Begin:** 27.40 **End:** 34.02 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	63		Weighted PDO:	15.48	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	26	38: Injured	Weighted INJ:	9.34	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	2	4: Killed	Weighted FAT:	0.98	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	29%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 66,300

Cost: $ 6,800,000
From: 01/01/2012
To: 12/31/2016
Days: 1827

Benefit Cost Ratio: 2.94 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

Since there is such a high percentage of Wild Animal related accidents that are expected to be unaffected by the proposed modifications, we did an addition economic analysis that removes those crashes from the analysis. This is shown in **Table NNN**. As the analysis shows, even with those crashes removed from consideration, the benefit to cost ratio is still estimated at 2.79 to 1.

Table NNN: Economic Analysis for Conversion to 2+1 Road with Barrier (Wild Animal Crashes Excluded)

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

04/13/2020

Job #: 20200413232114

Location: 160A **Begin:** 27.40 **End:** 34.02 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	27		Weighted PDO:	6.63	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	21	32: Injured	Weighted INJ:	7.86	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	2	4: Killed	Weighted FAT:	0.98	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	34%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 66,300

Cost: $ 6,800,000
From: 01/01/2012
To: 12/31/2016
Days: 1827

Benefit Cost Ratio: 2.79 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 Road with Barrier configuration is adopted, then decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality of the more significant access points, some accesses may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated.

There approximately 50 points of access within the study section. Many of these are private drives that serve one or just a few homes, while others serve small roads that lead to many destinations. It is not possible to assess the likely traffic volumes at all of these individual accesses in the scope of this report. We therefore recommend that if CDOT finds this to be an otherwise desirable location for a Swedish 2+1 section, they do a systematic study of the accesses within the study section to determine which ones must retain full access. If too many are deemed to require full access, it may not be a feasible location for the improvement.

State Highway 160A, MP 197.90 to 200.90, West of Del Norte, Rio Grande County

Figure 66: SH 160A MP 197.90 to 200.90 Location

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 160A (SH 160A) extending from MP 197.90 to MP 200.90 in Rio Grande County. The study section begins about 4 miles west of the Town of Del Norte and extends 3.00 miles east

SITE CONDITIONS SH 160 is classified as a Rural Principal Arterial through rolling terrain throughout the study section. SH 160A is a 2-lane undivided highway with 12-foot lanes and 10-foot paved shoulders in the study section. The total pavement width is 44 feet. There are a few minor intersections and several accesses throughout the study section. These will be discussed in more detail later in the report.

The highway is characterized by a grade of less than 1% through the study section with the exception of a very short (~300') section near MP 198.6 where the grade is perhaps as much as 4%. This is also the only location where there are any cut slopes. The rest of the study section has very minimal slopes. The speed limit on SH 160 is posted at 60 mph throughout the study section. There do not appear to be either shoulder or centerline rumble strips in the study section.

The average annual daily traffic (AADT) from 2012 to 2015 ranged from 4,400 vpd to 5,100 vpd as shown in **Table OOO**. 2015 is the latest year for which this data is available.

Table OOO: AADT by Year for SH 160A MP 197.90 – 200.90

2012	2013	2014	2015
4800	4900	5100	4400

Figure 67 is a typical view of SH 160A within project limits taken at approximately MP 199.20 showing the generally flat nature of the surrounding terrain.

Figure 67: SH 160A MP 199.20 – Typical Cross Section

Figure 68 is a view of SH 160A at approximately MP 198.50 showing the cut section described above. This is the only place within the project limits in significant cut or fill and the only place where the grade was estimated to exceed 1%.

Figure 68: SH 160A MP 198.50 – Cross Section at Cut

A total of 24 crashes occurred in the study section during the 5-year study period. Sixteen (16) of the crashes were property damage only. There were eight (8) crashes that involved injuries resulting in injury to a total of 10 people. Three of those crashes involved fatalities with a total of five (5) people killed. This is summarized by year in **Table PPP**.

Table PPP: Summary of Crashes by Year

Year	Total Crashes	PDO	Injury	Fatal	Injuries	Fatalities
2012	3	2	1	0	1	0
2013	4	2	1	1	3	3
2014	4	2	2	0	4	0
2015	8	7	0	1	0	1
2016	5	3	1	1	2	1
Total	24	16	5	3	10	5

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 69** shows the corridor SPF for the study section. As the chart shows the study section is performing the LOSS-II and LOSS-III categories throughout the study section in terms of both crash frequency and crash severity. This suggests moderate potential for reduction in crash frequency and severity.

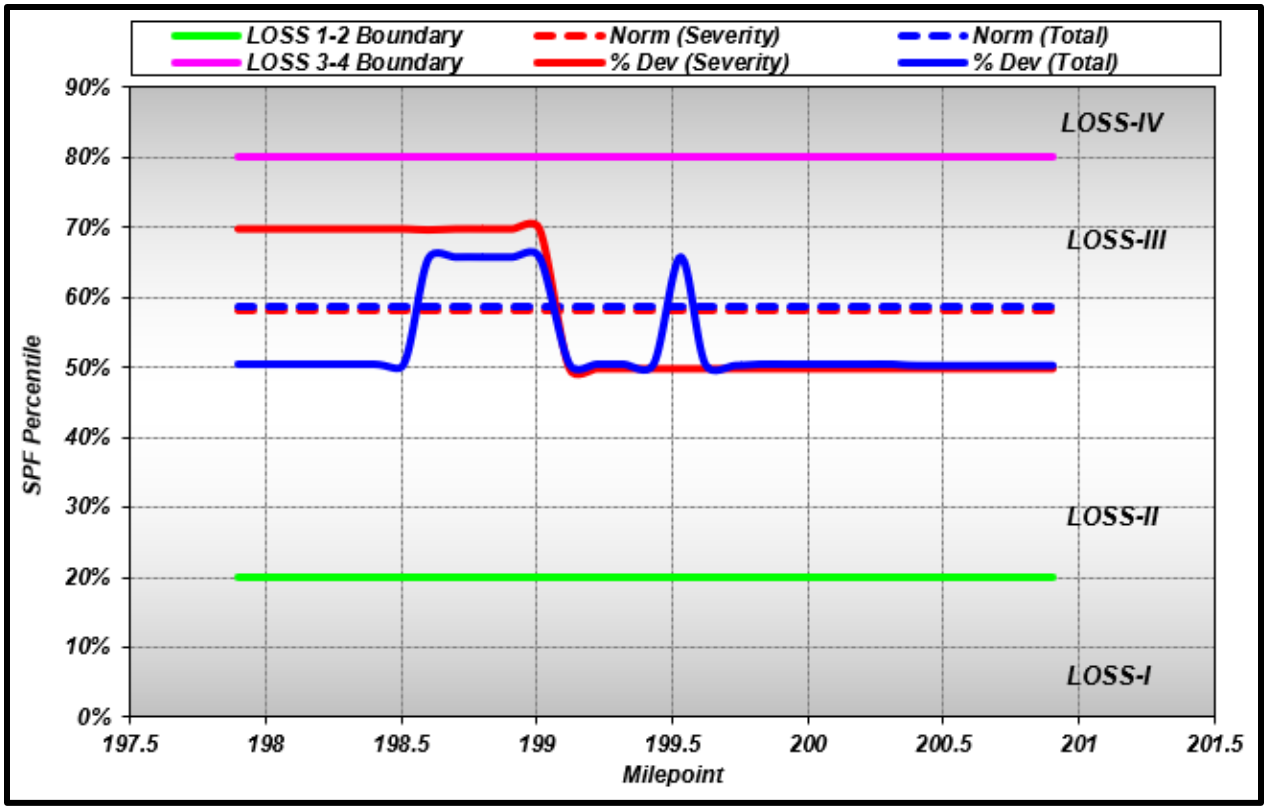


Figure 69: Corridor SPF for SH 160A

Figures 70 and **71** represent EB corrected segment safety performance analysis of SH 160A within the study limits. **Figure 70** shows segment safety performance from the total crash frequency stand point and **Figure 71** represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. These charts show that the study section is performing in the LOSS-III category in terms of overall crash frequency and for crash severity. This suggests a moderately high potential for reducing the number of crashes, including those that have resulted in injury and death.

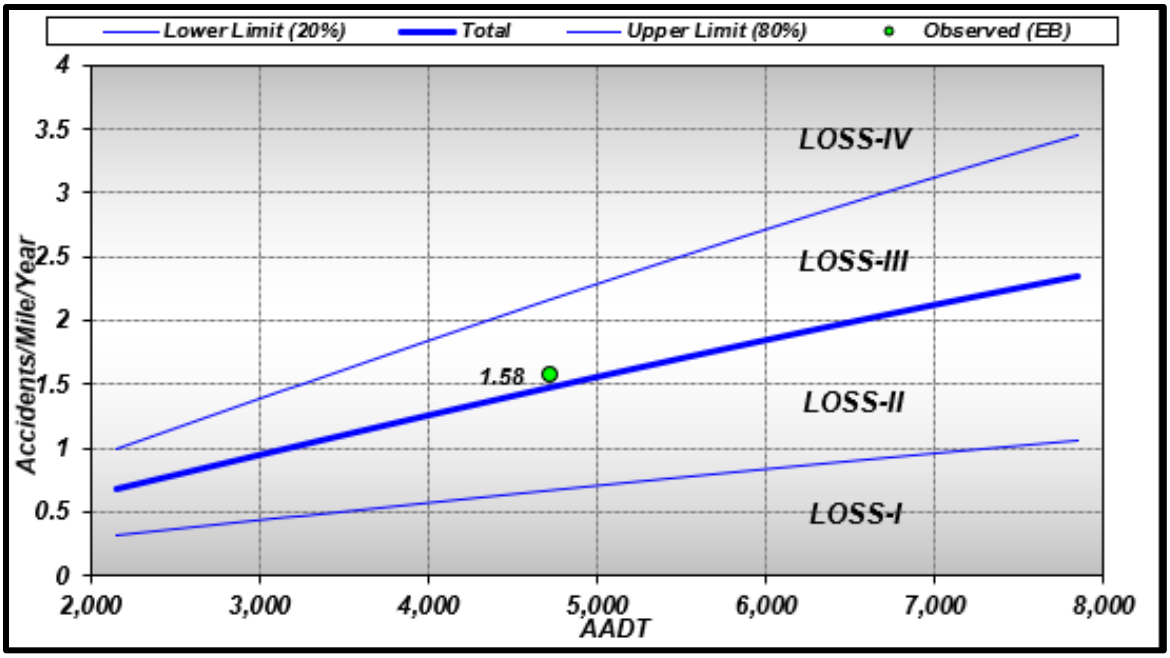


Figure 70: EB Corrected SPF for Total Crashes

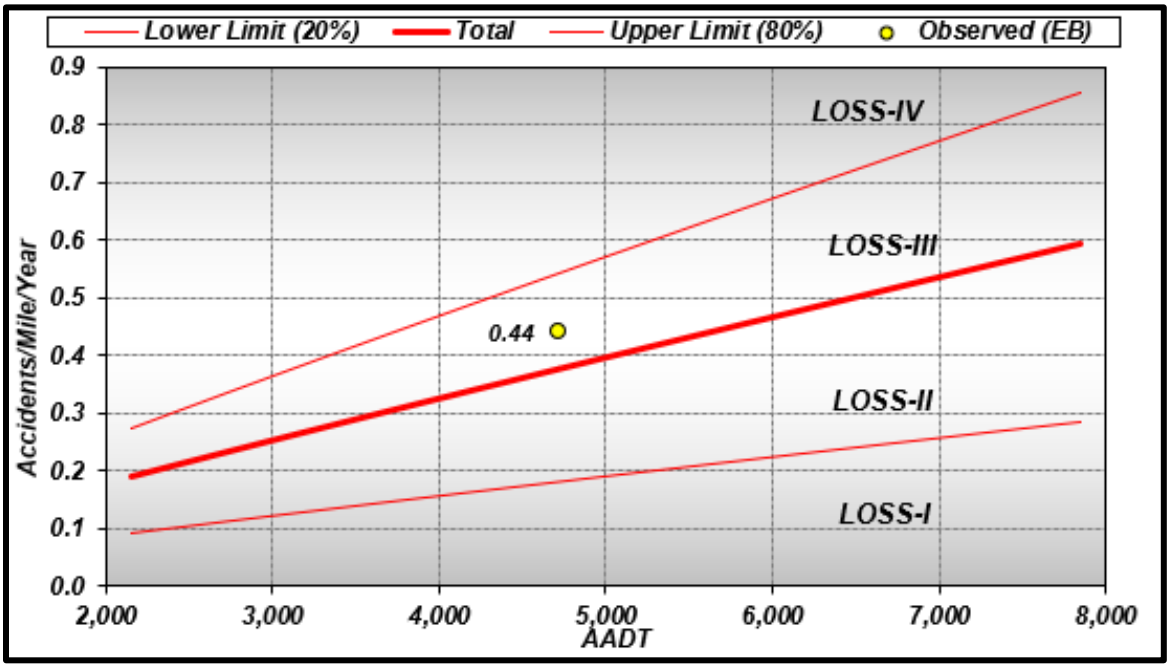


Figure 71: EB Corrected SPF for Injury and Fatal Crashes

Types of Crashes The overall distribution by crash type for all non-intersection related crashes within the study limits is provided in **Figure 72**.

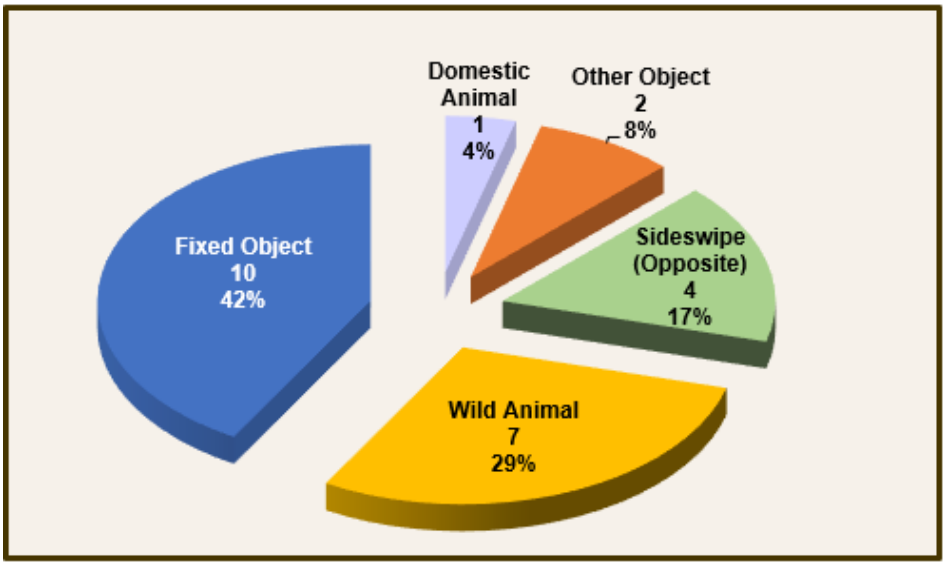


Figure 72: Crash Type Distribution SH 160A MP 197.70 – 200.90

As the chart shows, the most common crash type was with Fixed Objects, accounting for 42% of all crashes. Wild Animal crashes were the next most common accounting for 29% of the crashes. Opposite Direction Sideswipes accounted for 17% and other types accounted for the remaining 10%.

The chart in **Figure 73** shows the breakdown of crash types for just those crashes that resulted in injuries or fatalities.

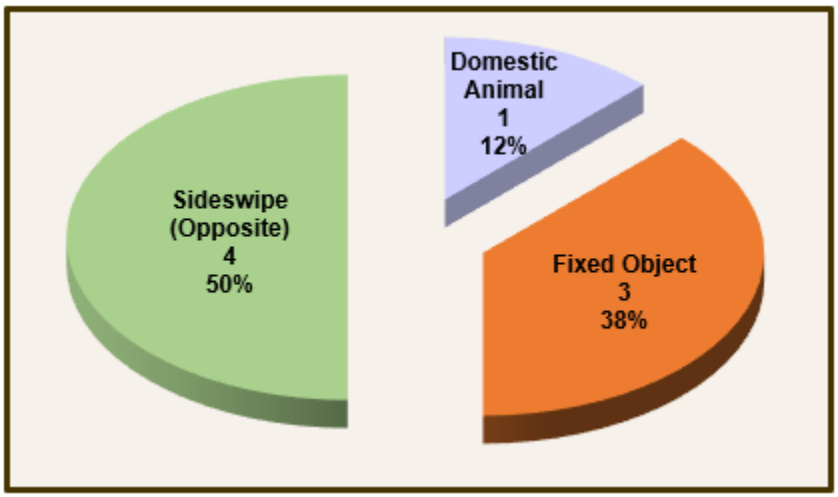


Figure 73: Crash Type Distribution of Injury and Fatal Crashes

As these charts show, opposite direction sideswipes, while accounting for only 17% of total crashes, accounted for half of the injury and fatality related crashes. In fact, *all* of the fatal crashes were opposite direction sideswipes.

We analyzed the crash history in the study section from a pattern recognition perspective using criteria of a minimum of five (5) qualifying crashes with a minimum probability confidence of 95%. There were no specific crash characteristics that met these criteria.

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since these sections of SH 160A exhibit a higher than expected frequency of crashes involving bodily injury, this may be an effective location to use the 2+1 Road with Barrier configuration. The fact that opposite direction sideswipes contributed to the severity of crashes in the study section (all of the fatalities and 30% of the injuries) makes the implementation of the 2+1 Road with Barrier configuration particularly appealing at this location, as this type of crash would be virtually eliminated. Three vehicles were observed pulling onto the shoulder to allow other vehicles to pass in the video log, one of which was a tractor. Usage of the shoulder to allow vehicles to pass can increase the probability of these opposite direction sideswipes and other harmful outcomes. If this is a common occurrence in this farming and ranching community, the periodic provision of a passing lane would be very beneficial in terms of alleviating the incentive for drivers to engage in these riskier maneuvers. In addition, there were five crashes in which the vehicle went off the left side of the roadway, in which two people were injured. The center barrier, while not preventing some sort of crash from occurring, would have at least prevented these vehicles involved from crossing over the roadway and thereby being exposed to as high of probability of severe outcomes.

Table QQQ shows an economic analysis for converting the proposed portion of SH 160A to the 2+1 Road with Barrier configuration. The cost of construction should be fairly consistent throughout the study section. Using a parametric estimating algorithm, we arrived at a cost of about $750,000 per mile, or $2,250,000 for the 3.0 miles of work section, for the purpose of this preliminary benefit to cost analysis. The actual cost and resultant B/C ratio are likely to vary based on more specific factors that will be determined upon final design of a project. As the analysis

shows, the expected benefit to cost ratio for this improvement is 8.33to 1. (Analysis excludes wild animal collisions).

Table QQQ: Economic Analysis for Conversion to 2+1 Road with Barrier

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

04/13/2020

Job #: 20200413232300

Location: 160A **Begin:** 197.90 **End:** 200.90 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	9		Weighted PDO:	2.21	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	5	10: Injured	Weighted INJ:	2.46	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	3	5: Killed	Weighted FAT:	1.23	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	38%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
		Cost: $ 2,250,000				Capital Recovery Factor:	0.080
		From: 01/01/2012				Annual Maintenance/Delay Cost:	$ 30,000
		To: 12/31/2016	Days: 1827				

Benefit Cost Ratio: 8.33 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 Road with Barrier configuration is adopted, decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality of the more significant access points, some accesses may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated.

Table RRR shows a list of accesses within the study section. Only one of the accesses listed is an intersection with a continuing road. This is at MP 199.08 and is a 3-leg intersection with right turn deceleration and acceleration lanes. The side road is Off Lane, which runs south to connect with County Road 14A. Full access should be provided for this intersection, including left turn deceleration lane to maintain the benefits of the 2+1 Road configuration.

The remainder are all either private driveways, extended driveways that serve a few properties or field accesses. The two accesses at MP 200.62 and 200.87 are the only two that appear as though

they might generate frequent interactions. CDOT should review this list in the context of more specific information relative to their usage and determine which ones will need to be retained prior to design of a project.

Table RRR: Accesses on SH 160A

Location	Side	Description
198.75	Both	The north side is access to field. The south side is access for Valle Vista which appears to consist of three residences.
198.81	South	Access for Haefeli's Honey Farms. This is a horseshoe type drive with another access point at MP 198.91
198.86	North	Access for Wilson Rio Grande Ranch.
198.91	South	Access for Haefeli's Honey Farms. This is a horseshoe type drive with another access point at MP 198.81
199.05	South	Driveway for one residence. It is horse property, possibly farm or ranch.
199.08	South	Intersection with Off Lane
199.40	Both	North side is another access point to the Wilson Rio Grande Ranch. The south side is a single residence.
199.43	South	One residential structure and a second building that may be stables. It appears some type of business operates on the property as evidenced by signage at the gate that is not readable in the video.
199.63	South	Driveway for a group of buildings that are probably for a single ranch.
199.65	South	Extended drive that serves three or four properties.
199.91	Both	Driveway for one property on the north and completely overgrown field access on the south side.
199.99	North	Driveway for one property.
200.15	South	Indian Head Drive which is a road for five homes that lie just over a tenth of a mile from the highway.
200.19	South	Driveway for one property.
200.42	Both	Driveway for one property on north side and a field road on the south side.
200.62	North	Driveway for West Side Storage which is storage sheds and trailers.
200.87	North	Access for several small businesses including an alternate access for West Side Storage (above)

State Highway 160A, MP 258.42 to 263.00, East of Fort Garland, Costilla County

Figure 74: SH 160A MP 258.42 to 263.00 Location

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 160A (SH 160A) extending from MP 258.42 to MP 263.00 in Costilla County. The study section begins just east of the Town of Fort Garland and extends 4.58 miles east.

SITE CONDITIONS SH 160A is classified as a Rural Principal Arterial throughout the study section. The terrain is classified as rolling from MP 258.42 to 260.00 and as mountainous from MP 260.00 to 263.00. Although the eastern portion of the study section is classified as mountainous, it is characterized by flat terrain in the vicinity of the roadway with grades at or below 2%.

SH 160A MP 258.42 – 263.00

SH 160A is a 2-lane undivided highway with 12-foot lanes, 6-foot paved shoulders in the study section. The total pavement width is 36 feet. Shoulder rumble strips appear to exist throughout the study section. No centerline rumbles are apparent. There are frequent minor intersections and accesses throughout the study section. These will be discussed in more detail later in the report.

The speed limit on SH 160A is posted at 65 mph throughout the study section with the exception of speed reductions near the Town of Fort Garland. The posted speed for eastbound traffic leaving Fort Garland is 35 mph until MP 258.55 where it resumes 65 mph. The westbound traffic speed drops to 50 mph at MP 258.70 and drops again to 35 mph at MP 258.44. This is summarized in **Table SSS** below.

Table SSS: Summary of Posted Speed Limits on SH 160A

EB MP	Posted Speed
258.42 – 258.55	35
258.55 – 263.00	65

WB MP	Posted Speed
258.42 – 258.44	35
258.44 – 258.70	55
258.70 – 263.00	65

The average annual daily traffic (AADT) from 2012 to 2015 ranged from 3,700 vpd to 4,600 vpd as shown in **Table TTT**. 2015 is the latest year for which this data is available.

Table TTT: SH 160A MP 258.42 – 263.00 by Year

2012	2013	2014	2015
3,700	4,500	4,600	4,100

Figure 75 is a typical view of SH 160 within project limits.

Figure 75: SH 160A MP 259.60 – Typical Cross Section

A total of 106 crashes occurred in the study section during the 5-year study period. There were 15 crashes that involved injuries and two (2) that resulted in fatalities. In total, 34 people were injured and three (3) were killed. This is summarized by year in **Table UUU**. Summary of Crashes by Year

Table UUU:

Year	Total Crashes	PDO	Injury	Fatal	Injuries	Fatalities
2012	18	17	1	0	11	0
2013	25	20	5	0	5	0
2014	19	17	2	0	3	0
2015	22	15	6	1	13	2
2016	22	20	1	1	2	1
Total	106	89	15	2	34	3

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 76** shows the corridor SPF for the study section. As the chart shows the entire study section is performing the LOSS-IV category in terms of crash frequency suggesting high potential for accident reduction in total number of crashes throughout the study section. In terms of crash severity, the study section performs at LOSS-IV for a significant portion of the study, and at LOSS-II and LOSS-III at other locations. This suggests there is a high potential for reducing crash severity in some locations, with moderate potential at other locations.

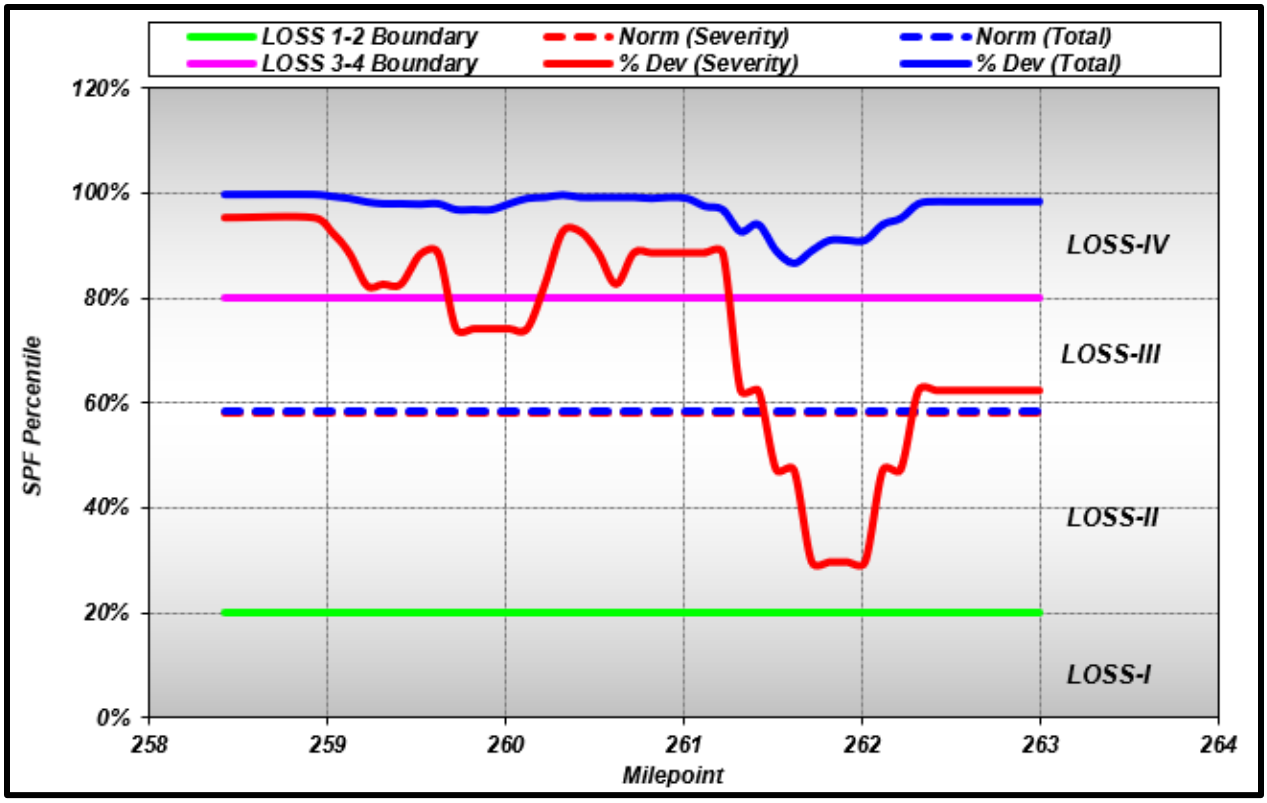


Figure 76: Corridor SPF for SH 160A

Figures 77 and **78** represent EB corrected segment safety performance analysis of SH 160A within the study limits. **Figure 77** shows segment safety performance from the total crash frequency stand point. It shows that the study section is performing in the LOSS-IV category in terms of total crash frequency, suggesting a high potential for a significant reduction in total number of crashes. **Figure 78** represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. It shows that the study section performs on the boundary between the LOSS-III and LOSS-IV categories in terms of severity, suggesting fairly high potential for reduction of crashes involving bodily injury.

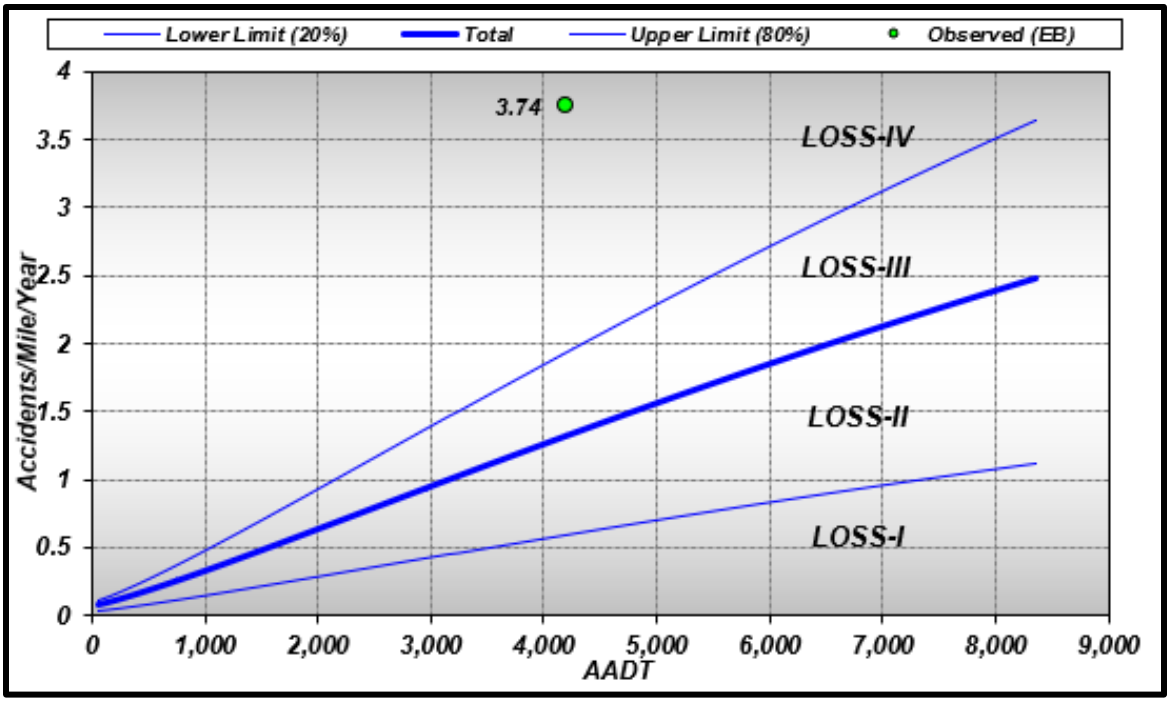


Figure 77: EB Corrected SPF for Total Crashes

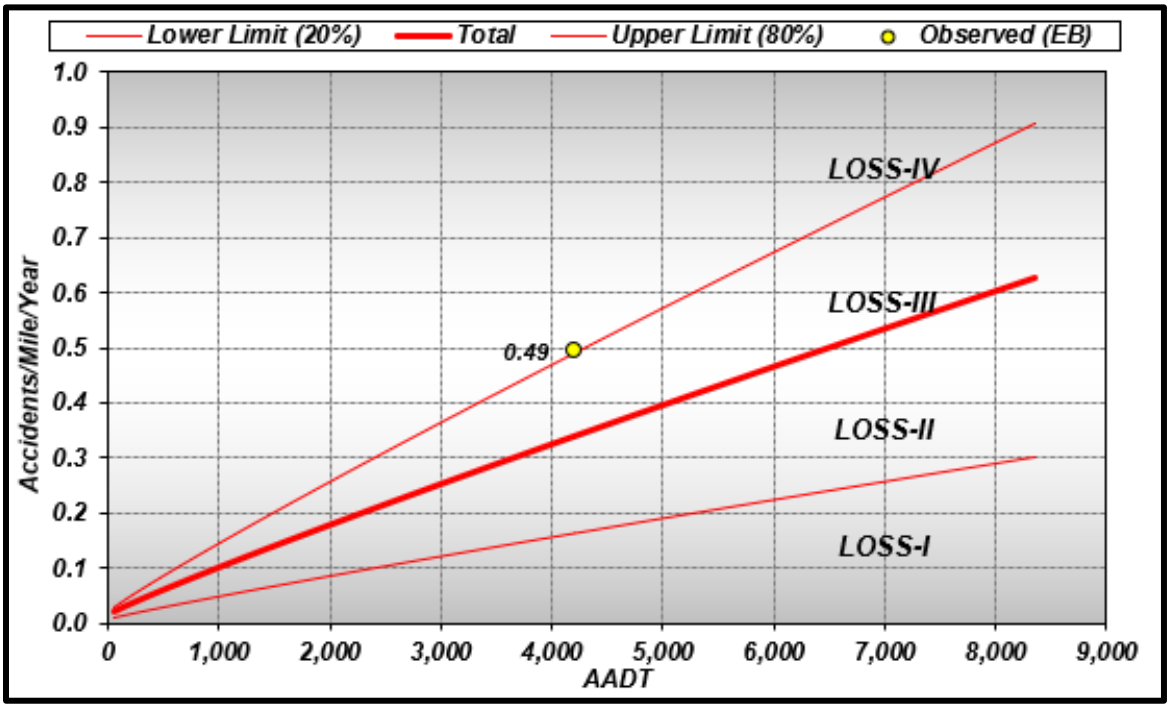


Figure 78: EB Corrected SPF for Injury and Fatal Crashes

Types of Crashes The overall distribution by crash type for all non-intersection related crashes within the study limits is provided in **Figure 79**.

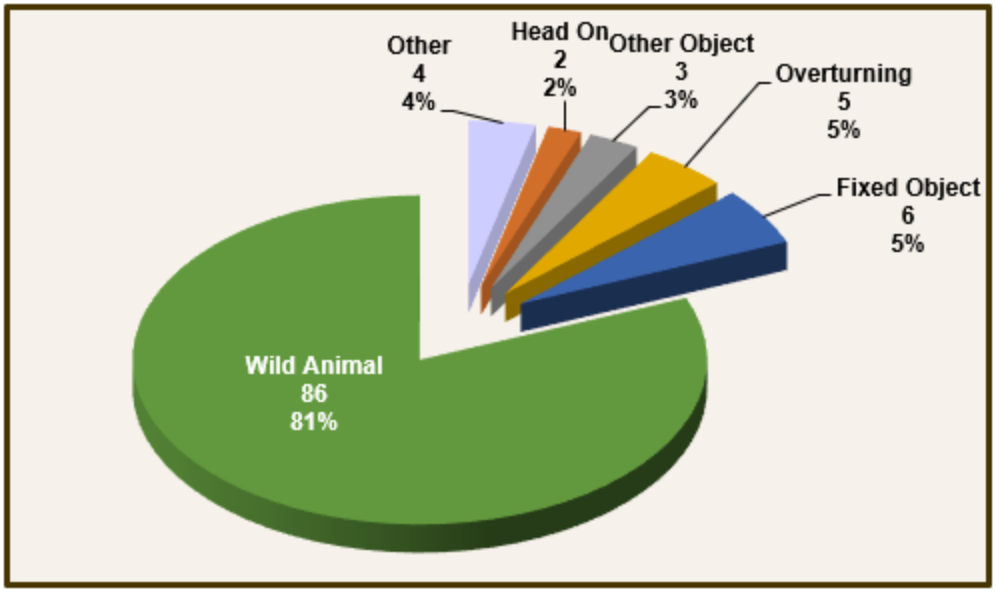


Figure 79: Crash Type Distribution SH 160A MP 258.42 – 263.00

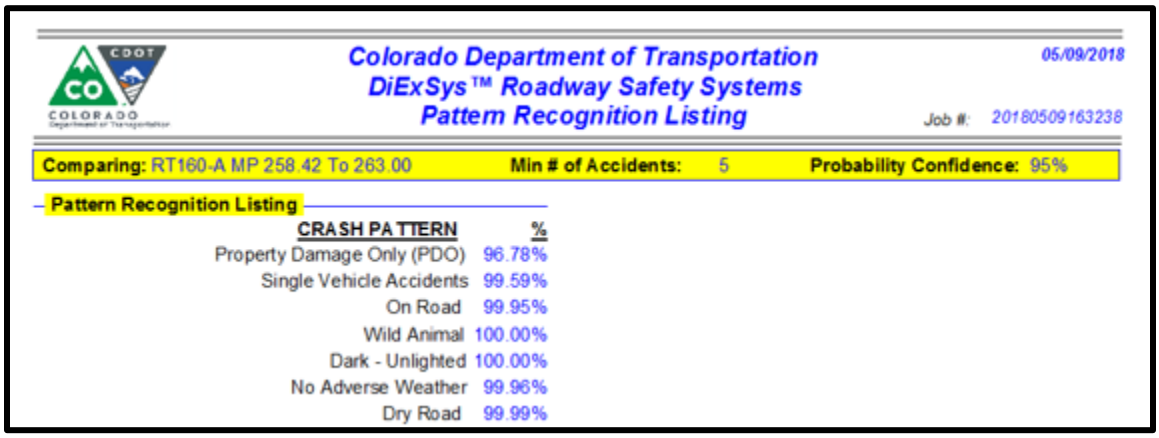
As the chart shows, Wild Animal crashes accounted for the majority of crashes, representing 81% of all crashes. The next most common types of accidents were Fixed Objects (6%), Overturning (5%), Other Objects (3%) and Head Ons (2%) with assorted types accounting for the remaining 4%.

Wild animal crashes accounted for 24 of the 34 (70%) injuries. The remaining 10 injuries occurred in three (3) overturning, two (2) fixed object and one (1) opposite direction sideswipe. Additionally, at least six (6) of the injuries attributed to wild animal crashes occurred when the vehicle subsequently crossed the centerline and collided with an oncoming vehicle. Both of the fatalities were head on crashes.

On closer inspection of the crash data, it was found that one wild animal related crash accounted for 11 of 34 (32%) injuries during the 5-year study period. This crash occurred at MP 262.60. The highly anomalous nature of this data point will be taken into account during the economic analysis later in the report.

Table VVV shows the results of a pattern recognition analysis the study section using criteria of a minimum of five (5) qualifying crashes with a minimum probability confidence of 95%.

Table VVV: Pattern Recognition Results



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

05/09/2018

Job #: 20180509163238

Comparing: RT160-A MP 258.42 To 263.00 **Min # of Accidents:** 5 **Probability Confidence:** 95%

Pattern Recognition Listing

CRASH PATTERN	%
Property Damage Only (PDO)	96.78%
Single Vehicle Accidents	99.59%
On Road	99.95%
Wild Animal	100.00%
Dark - Unlighted	100.00%
No Adverse Weather	99.96%
Dry Road	99.99%

As we found earlier, the large majority of crashes were wild animal crashes. Most, if not all, of the patterns seen in the above list are most likely a result of the frequent wild animal crashes. These are typically single vehicle, on road, property damage only crashes. Their frequency is not generally correlated strongly with adverse road, weather or lighting conditions, which accounts for the most common and benign conditions to appear as over-represented as they are seen to be in the list. The patterns found in this analysis do not suggest that 2+1 Road with Barrier would be highly effective for reducing crashes in the study section. However, since this type of analysis is based on percentages, the overwhelming number of wild animal crashes may tend to conceal other things that could be occurring. Therefore, it is worth examining the data from other perspectives as well.

2+1 Road with Barrier Conversion of these 2-lane undivided segments into 2+1 Road with Barrier configuration would be expected to reduce the frequency of some of the crashes that have resulted in the more serious consequences in the study section. As mentioned earlier, head on crashes and opposite direction sideswipes, although not showing up among the frequency patterns, represented a high portion of the most serious crash outcomes. There were also at least six (6) injuries from wild animal crashes that were attributable to a secondary event where the vehicle crossed the centerline and had a head on collision. These crashes would likely all have had different outcomes with the center cable rail of the 2+1 Road with Barrier design present.

Table WWW shows an economic analysis for converting the proposed portion of SH 160A to the 2+1 Road with Barrier configuration. Due to the unusual number of injury wild animal crashes,

we have excluded property damage only wild animal crashes from this analysis since the frequency of those events are not expected to be reduced, but we have included those wild animal crashes which included subsequent travel across the centerline and injury. However, we have not included the eleven injuries that occurred in one single wild animal crash since we view this as an anomalous occurrence that would unreasonably skew the outcome of the analysis.

The cost of construction may vary throughout the study section as the existing pavement width and terrain vary. Using a parametric estimating algorithm for several subsections of the stretch, we arrived at an average cost of about $900,000 per mile or $4,100,000 for the 4.59 miles of work section, for the purpose of this preliminary benefit to cost analysis. The actual cost and resultant B/C ratio are likely to vary based on more specific factors that will be determined upon final design of a project. As the analysis shows, the expected benefit to cost ratio for this improvement is 3.37 to 1.

Table WWW: Economic Analysis for Conversion to 2+1 Road with Barrier

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

04/13/2020

Job #: 20200413232630

Location: 160A **Begin:** 258.42 **End:** 263.00 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	12		Weighted PDO:	2.95	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	15	23: Injured	Weighted INJ:	5.65	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	2	3: Killed	Weighted FAT:	0.74	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	39%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
Cost: $ 4,100,000						Service Life:	20
From: 01/01/2012						Capital Recovery Factor:	0.080
To: 12/31/2016		Days: 1827				Annual Maintenance/Delay Cost:	$ 45,900

Benefit Cost Ratio: 3.37 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 Road with Barrier configuration is adopted, then decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality of the more significant access points, some accesses may be

sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated.

Table XXX shows lists of accesses within the study sections with some preliminary observations pertinent to their handling. We have recommended retaining full access at a few of the more prominent roads and provided descriptions for other less prominent accesses. The Region should review this list in the context of more specific information relative to their usage and determine which ones will need to be retained prior to design of a project.

Table XXX: Accesses on SH 160A

Location	Side of Road	Description	Comments
260.05	S	Trinchera Ranch Rd.	Paved public road. Retain full usage.
260.31	N	Unimproved private road.	Grass between road and the gate shows no evidence of frequent usage. Do not
262.14	N	Two picnic tables in widened area on the side of the road.	Retain full access. See comment for access at MP 262.22.
262.22	S	Public road that accesses a network of dirt roads south of the highway.	Retain full usage. Since this is so close to the picnic tables (above), this opening can be made wide enough to accommodate both.
262.71	N	Unimproved private road.	Grass between road and the gate shows no evidence of frequent usage. Do not

State Highway 285D, MP 185.01 to 189.20, North of Fairplay, Park County

Figure 80: SH 285D MP 185.01 to 189.20 Location

The observations and recommendations in this report are based on the analysis of 5 years of accident history, review of Google Earth photometry, other relevant project data provided by CDOT. CDOT is advised to verify the observations made in this report regarding physical features, roadside characteristics, and traffic control devices in the study area.

SITE LOCATION This study addresses State Highway 285D (SH 285D) extending from MP 185.01 to MP 189.20 in Park County. The study section begins about 1.75 miles north of the Town of Fairplay and extends 4.19 miles north.

SITE CONDITIONS SH 285D is classified as a Rural Principal Arterial through rolling terrain throughout the study section.

SH 285D is a 2-lane undivided highway with 12-foot lanes, 3-foot paved shoulders in the study section. There is a southbound climbing/passing lane from MP 186.42 to MP 188.00. The total pavement width ranges from 30 to 42 feet. Centerline rumble strips appear to exist throughout the study section although they appear to be too worn to still be effective. No shoulder rumbles are apparent. There are several minor intersections and accesses throughout the study section. These will be discussed in more detail later in the report.

The speed limit on SH 285D varies between 55 mph and 65 mph throughout the study section as summarized in **Table YYY**.

Table YYY: Summary of Posted Speed Limits on SH 285D

NB MP	Posted Speed
185.01 - 186.14	65
186.14 - 89.20	55

SB MP	Posted Speed
185.01 – 186.34	65
186.34 – 187.21	55
187.21 – 189.20	65

The average annual daily traffic (AADT) from 2012 to 2015 ranged from 3,500 vpd to 5,500 vpd as shown in **Table ZZZ**. 2015 is the latest year for which this data is available.

Table ZZZ: SH 285D AADT by Year

2012	2013	2014	2015
3500	4200	4400	5500

Figures 81 and **82** are typical views of SH 285 within project limits. The photo in **Figure 91**, showing a section in the 2-lane portion of the study section, and the photo **in Figure 82**, showing a section in the 3-lane portion of the study section. Both photos show the worn centerline rumble strips.

Figure 81: SH 285D MP 185.20 – Typical 2-Lane Cross Section

Figure 82: SH 285D MP 187.00 – Typical 3-Lane Cross Section

A total of 109 crashes occurred in the study section during the 5-year study period. 27 crashes involved injuries and five (5) crashes resulted in fatalities. A total of 47 people were injured and five (5) were killed. This is summarized by year in **Table AAAA**.

Table AAAA: Summary of Crashes by Year

Year	Total Crashes	PDO	Injury	Fatal	Injuries	Fatalities
2012	15	12	3	0	3	0
2013	26	19	7	0	9	0
2014	26	17	7	2	14	2
2015	21	12	8	1	15	1
2016	21	17	2	2	6	2
Total	109	77	27	5	47	5

SAFETY PERFORMANCE ANALYSIS AND DIAGNOSTIC EXAMINATION The chart in **Figure 83** shows the corridor SPF for the study section. As the chart shows the entire study section is performing the LOSS-IV category in terms of both crash frequency and crash severity, suggesting high potential for accident reduction in both categories. It is noted that even through the section that has the additional lane (MP 186.42 to 188.00) the performance remains at LOSS-IV, making this a good location to compare the effect of the centerline cable rail to an otherwise similar cross section.

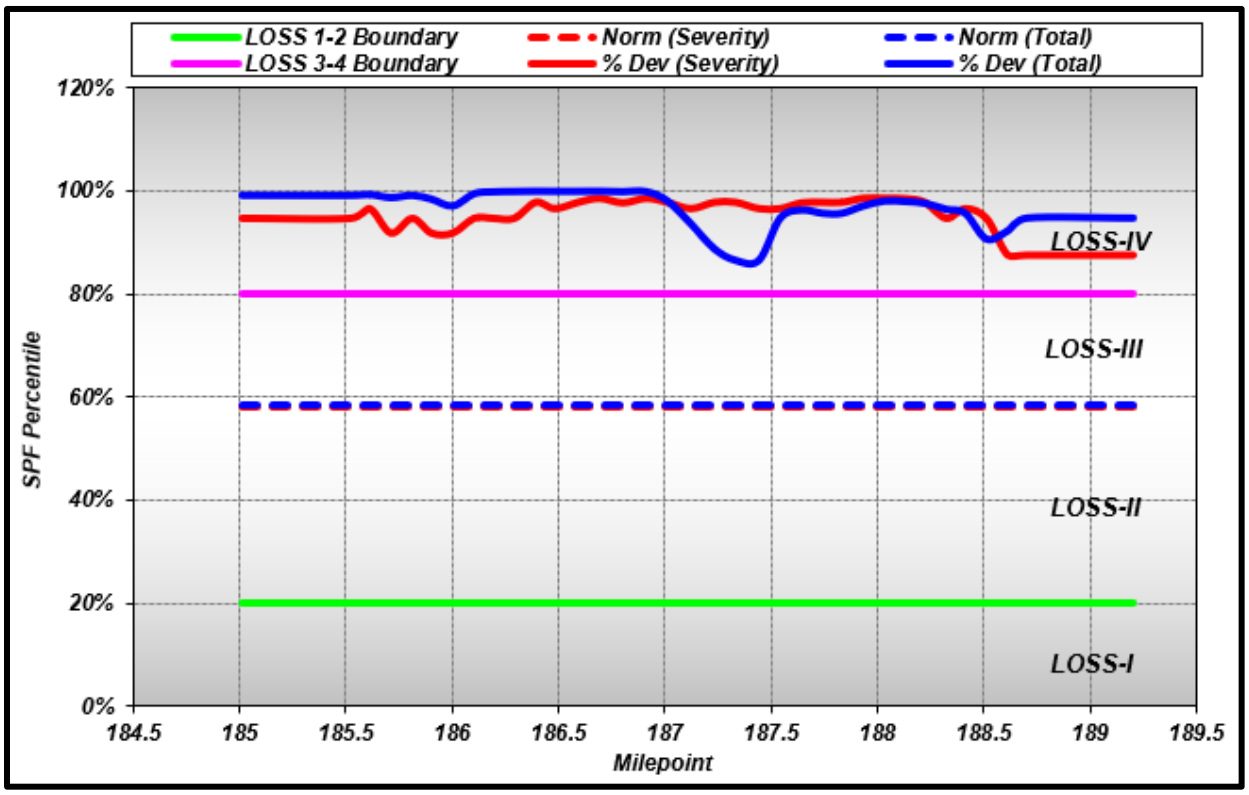


Figure 83: Corridor SPF for SH 285D

Figures 84 and **85** represent EB corrected segment safety performance analysis of SH 285D within the study limits. **Figure 84** shows segment safety performance from the total crash frequency stand point and **Figure 85** represents segment safety performance from the stand point of severity and considers injury and fatal crashes only. Both charts show that the study section overall is performing in the LOSS-IV category, suggesting a high potential for a significant reduction in total number of crashes as well as the number of injury and fatality related crashes.

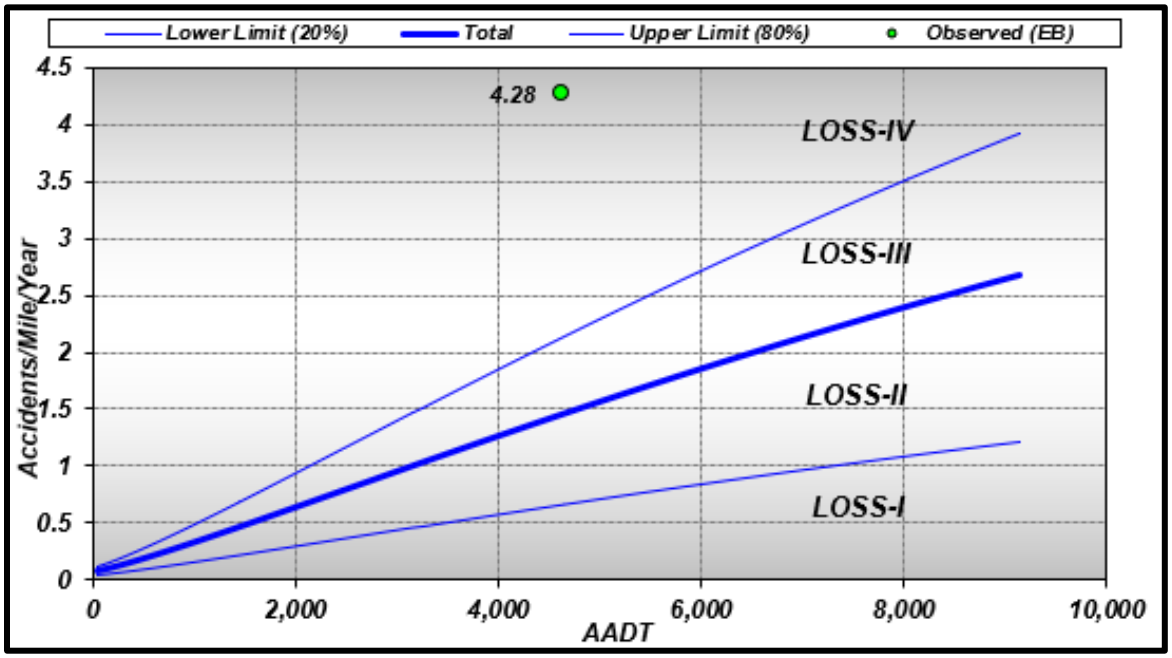


Figure 84: EB Corrected SPF for Total Crashes

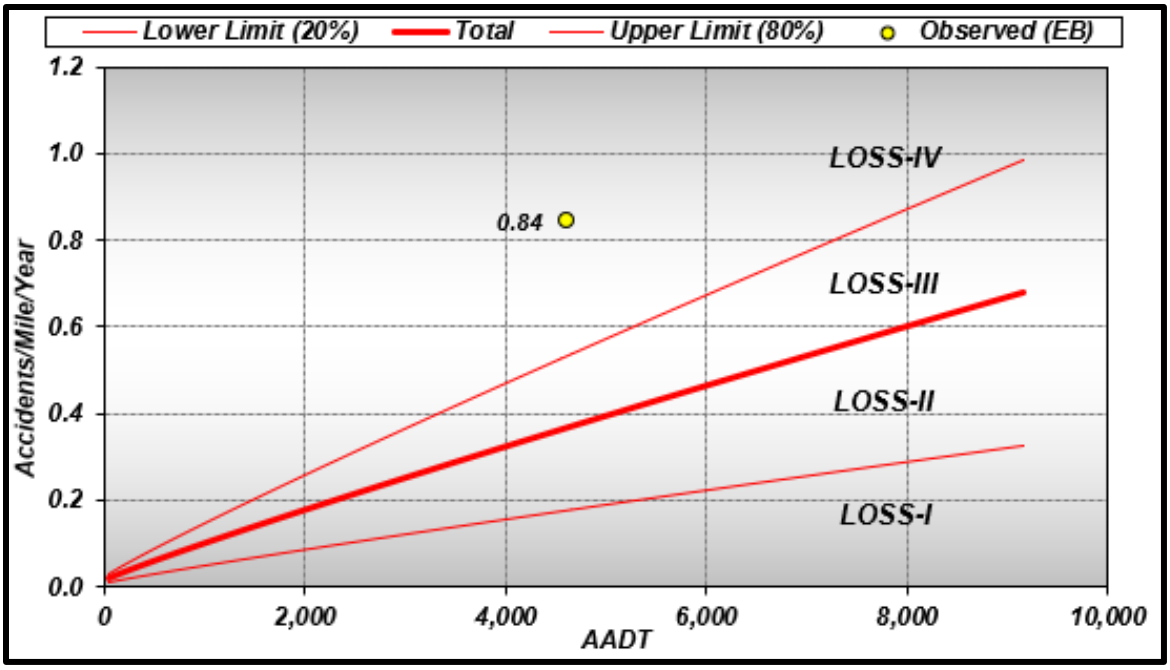


Figure 85: EB Corrected SPF for Injury and Fatal Crashes

Types of Crashes The overall distribution by crash type for all non-intersection related crashes within the study limits is provided in **Figure 86**.

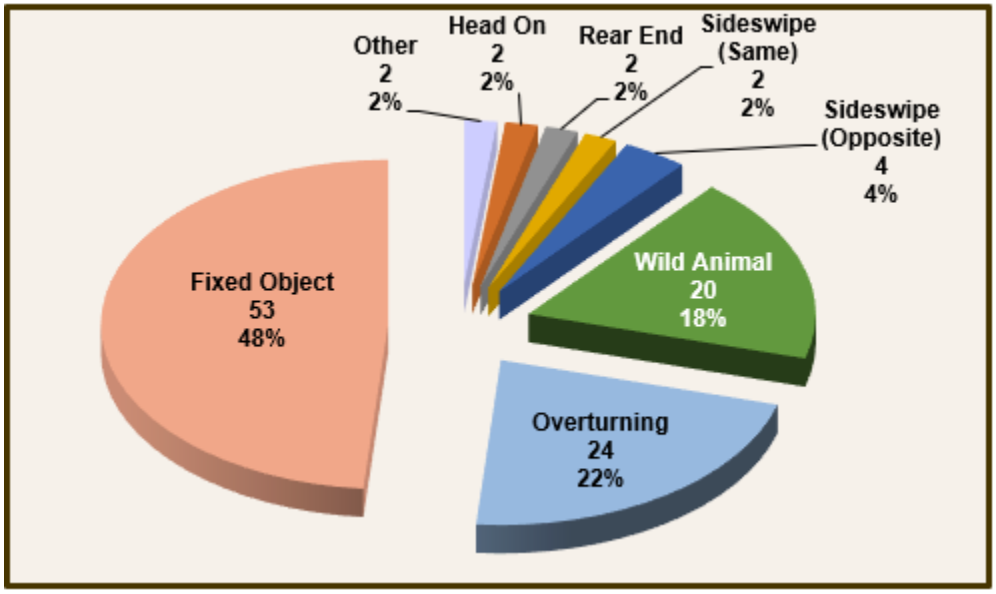


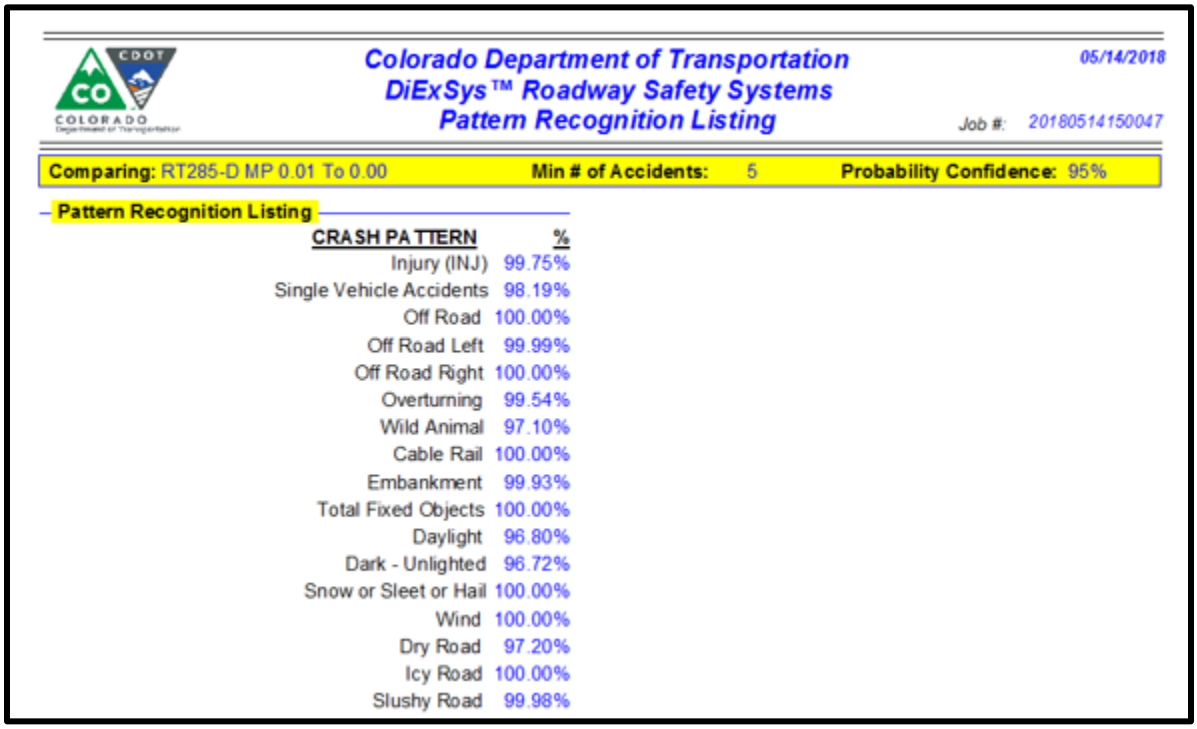
Figure 86: Crash Type Distribution SH 285D MP 185.01 – 189.20

As the chart shows, the most common crash type was with Fixed Objects, accounting for 48% of all crashes. Overturning crashes at 22% and Wild animal crashes at 18% were also common in the

study section. All other crash types were relatively uncommon. It is worth noting that although head on and opposite direction sideswipe crashes on accounted for a total of 6% of all crashes, they accounted for nine (9) injuries and two (2) of the fatalities during the 5-year study period.

Table BBBB shows the results of a pattern recognition analysis the study section using criteria of a minimum of five (5) qualifying crashes with a minimum probability confidence of 95%.

Table BBBB: Pattern Recognition Results



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

05/14/2018

Job #: 20180514150047

Comparing: RT285-D MP 0.01 To 0.00 | Min # of Accidents: 5 | Probability Confidence: 95%

Pattern Recognition Listing

CRASH PATTERN	%
Injury (INJ)	99.75%
Single Vehicle Accidents	98.19%
Off Road	100.00%
Off Road Left	99.99%
Off Road Right	100.00%
Overturning	99.54%
Wild Animal	97.10%
Cable Rail	100.00%
Embankment	99.93%
Total Fixed Objects	100.00%
Daylight	96.80%
Dark - Unlighted	96.72%
Snow or Sleet or Hail	100.00%
Wind	100.00%
Dry Road	97.20%
Icy Road	100.00%
Slushy Road	99.98%

It is noted that the most likely reason that Cable Rail appears on the list is simply that some exists at this location. Since cable rail is only present at a small percentage of the locations that contribute to the statewide averages, a normal amount of crashes involving the rail will result in a higher than average rate when compared to averages that include locations without it.

The patterns on the list of most interest in terms of having the highest potential for mitigation with the proposed improvements are Injury, Off Road Left and Overturning.

2+1 Road with Barrier Data suggest that this configuration can reduce the quantity of injury related crashes by 50% and fatalities by 75%. Since these sections of SH 285D exhibit a higher

than expected frequency of crashes involving bodily injury, this may be a very effective location to use the 2+1 Road with Barrier configuration. Conversion of these 2-lane undivided segments into the 2+1 Road with Barrier configuration would likely reduce the frequency of some of the crashes that have resulted in the more serious consequences in the study section. As mentioned earlier, head on crashes and opposite direction sideswipes, although not showing up among the frequency patterns, represented a comparatively high portion of the most serious crash outcomes. Additionally, crashes categorized as Off Left resulted in 10 injuries and one (1) fatality. These crashes would likely have had different outcomes with the center cable rail of the 2+1 Road with Barrier design present. The 2+1 Road with Barrier configuration has also been shown to be effective in reducing the number of overturning crashes which resulted in 14 of the injuries in the study section.

Table CCCC shows an economic analysis for converting the proposed portion of SH 285 to the Swedish 2+1 configuration. The cost of construction will vary throughout the study section as the existing pavement width and terrain vary. Using a parametric estimating algorithm for several subsections of the stretch, we arrived at an average cost of about $910,000 per mile or $3,800,000 for the 4.19 miles of work section, for the purpose of this preliminary benefit to cost analysis. The actual cost and resultant B/C ratio are likely to vary based on more specific factors that will be determined upon final design of a project. As the analysis shows, the expected benefit to cost ratio for this improvement is 6.26 to 1. (Analysis excludes wild animal collisions).

Table CCCC: Economic Analysis for Conversion to 2+1 Road with Barrier

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

04/14/2020

Job #: 20200414000603

Location: 285D **Begin:** 185.01 **End:** 189.20 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	61		Weighted PDO:	14.99	20%: CRF for PDO	Cost of PDO:	$ 10,700
INJ:	23	42: Injured	Weighted INJ:	10.32	50%: CRF for INJ	Cost of INJ:	$ 98,900
FAT:	5	5: Killed	Weighted FAT:	1.23	75%: CRF for FAT	Cost of FAT:	$ 1,766,400
			B/C Weighted Year Factor:	5.00	30%: Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
Cost: $ 3,800,000						Capital Recovery Factor:	0.080
From: 01/01/2012						Annual Maintenance/Delay Cost:	$ 41,800
To: 12/31/2016		Days: 1827					

Benefit Cost Ratio: 6.26 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Swedish 2+1 Lane Section with Cable Barrier
Special Notes: Passing Lane Opportunities

If the 2+1 Road with Barrier configuration is adopted, then decisions will need to be made as to what accommodations will be made for any existing accesses whose current accessibility could become compromised. While breaks in the center cable rail will generally be necessary to retain the existing level of functionality of the more significant access points, some accesses may be sufficiently minor or may have a sufficient degree of redundancy as a result of being very close to another access point, that they needn't be specifically accommodated.

Table DDDD shows a list of accesses within the study sections with some preliminary observations pertinent to their handling. We have recommended retaining full access at the more prominent roads and provided descriptions for other less prominent accesses. The Region should review this list in the context of more specific information relative to their usage and determine which ones will need to be retained prior to design of a project.

Table DDDD: Accesses on SH 285D

Location	Side of Road	Description	Comments
185.78	W	Silver Heels Ranch Rd. Fairly large ranch which probably has employees.	Retain full usage.
187.90	S	Access to range, no structures.	Usage is probably occasional and probably doesn't need access from both sides. CDOT decision.
188.01	N	Access to range, no structures.	Usage is probably occasional and probably doesn't need access from both sides. CDOT decision.
188.17 and 188.19	N & S	Openings in fence to access land. No road visible beyond access.	These appear to be rarely used. We recommend not making accommodations for these.
188.57 and 188.62	N & S	188.57 is access to a home and ranch land on the south side and 188.62 to ranch buildings on the north side.	Due to their proximity to one another, they can both be served with a single break. Retain full access.

CONCLUSIONS

Deployment of 2+1 Road with Barrier in Colorado certainly has potential to improve safety where it replaces conventional 2-lane highways, primarily by preventing head on and sideswipe opposite crashes. The Swedish design is most widely implemented and has a record of success, so Colorado should adopt a similar design, with some well-considered modifications to better reflect that US drivers expect the "slow" lane to be the ending lane, and somewhat gentler tapers than Sweden employs. (Details are in the "Background on Colorado Recommended 2+1 with Barrier Road Design" section of this report).

Locations where 1 or more injuries per mile, per year may potentially be candidates for cost-effective implementation of 2+1 Road with Barrier, and any fatal crashes improve the expected return on investment. For this study, 2-lane segments in Colorado were examined, looking for locations with at least 1 injury crash per mile per year in a 5-year crash history. Locations which were found to have concentrations of direct access points were excluded as impractical for construction of 2+1 Road with Barrier. Planning level estimates of construction costs were estimated with some consideration of local conditions of the segment under consideration, and Benefit/Cost analysis was performed. Only segments with B/C above 1.00 are included in this report, and ranked in order of cost effectiveness in priority order. They appear in order of Highway Number and Mile Post in the body of the report, and in ranked order in **Table EEEE**, on the next page.

Ranked List of Proposed Projects

Table EEEE: Projects Ranked in Priority Order

Rank	Location	PDO	INJ	Injured	FAT	Killed	Total	Ttl LOSS	Sev LOSS	Cost	B/C
1	SH 160A MP 197.90-200.90	9	5	10	3	5	17	III	III	$2,250,000	8.33
2	SH 285D MP 185.01-189.20	61	23	42	5	5	89	IV	IV	$3,800,000	6.26
3	SH 066B MP 39.30-40.70	9	12	17	1	1	22	II	III	$980,000	5.79
4	SH 052A MP 14.93-18.80	18	8	14	3	3	29	II	II	$2,710,000	4.51
5	SH 030A MP 16.72-20.33 (Segments 2 and 3)	30	25	34	1	1	56	IV	IV	$2,350,000	3.62
6	SH 160A MP 258.42-263.00	12	15	23	2	3	29	IV	IV	$4,100,000	3.37
7	SH 024G MP 321.00-325.50 (3 segments)	6	15	31	1	1	22	II	III	$ 2,440,000	3.12
8	SH 030A MP 16.72-20.33 (3 Segments)	34	26	35	1	1	61	IV	IV	$2,820,000	3.08
9	SH 115A MP 21.37-24.37 (Northern 3 miles)	13	12	19	1	1	26	III	III	$1,950,000	3.02
10	SH 160A MP 27.40-34.02	27	21	32	2	4	50	III	III	$6,800,000	2.79
11	SH 040A MP 151.00-154.00	39	18	32	1	1	58	IV	IV	$2,400,000	2.75
12	SH 115A MP 20.37-24.37 (Whole)	14	13	20	1	1	28	II	III	$2,600,000	2.48
13	SH 040A MP 222.00-226.00	22	13	16	1	1	36	III	III	$2,500,000	2.29
14	SH 086A MP 7.79-13.40	12	18	24	2	2	32	II	III	$4,500,000	2.27
15	SH 040A MP 112.98-116.00	22	11	20	0	0	33	IV	IV	$2,500,000	1.10

Note that some projects (indicated with notes in parentheses) do not consist of the entire segment between the indicated end points. Also note that two alternatives each are considered for SH 030A MP 16.72-20.33 and for 115A MP 20.37-24.37. In each case one alternative is a subset of the other – the shorter alternative has a higher B/C, but the longer alternative would still be worth doing, just not as highly ranked. There are 13 studied locations.

RECOMMENDATIONS

Considering variability in the CRF we recommend that CDOT funds a limited pilot effort for design and construction of the Colorado modified 2+1 Road with Barrier projects with predicted Benefit/Cost (B/C) ratio 3:1 of greater. In addition to improving safety at the studied locations, these projects will generate important data for the observational before after studies of the effectiveness of this treatment in Colorado environment. All locations included in this report should qualify for Federal Highway Safety Improvement Program funds.