APPENDIX A3

TRANSPORTATION TECHNICAL MEMORANDUM

Appendix A3

I-70 West Vail Pass Auxiliary Lanes Transportation Technical Memorandum

April 2020
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Introduction and Background

The Interstate 70 (I-70) West Vail Pass Auxiliary Lanes project (Project) is located in Eagle and Summit Counties, with the eastern terminus just east of the Vail Pass Rest Area and the western terminus in the Town of Vail. The project study limits include eastbound (EB) and westbound (WB) I-70 from mile post (MP) 179.5 to MP 191.5. The project location and approximate study area are shown in **Figure 1**.

As part of the intial National Environmental Policy Act (NEPA) analysis, a Tier 1 Environmental Impact Statement (EIS) for the I-70 Mountain Corridor (C-470 to Glenwood Springs) was completed in 2011. This EIS, the *I-70 Mountain Corridor Programmatic Final Environmental Impact Statement* (PEIS) and subsequent Record of Decision (ROD), recommended the addition of auxiliary lanes EB and WB on the west side of Vail Pass from MP 180-190 as part of the Preferred Alternative's Minimum Program of Improvements. A follow-up Advance Guideway System (AGS) Feasibility Study in 2014 analyzed potential alignments and costs for an AGS system and determined there were three feasible alignments for future AGS. While an AGS is not part of the West Vail Pass Auxiliary Lanes project, the AGS Feasibility Study was used to ensure the project did not preclude the favored alignment.

A Tier 2 NEPA analysis is the next step required to move highway improvements forward. The project is following the Colorado Department of Transportation (CDOT) and Federal Highway Administration (FHWA) NEPA process to confirm the needs for improvements to West Vail Pass, identify a Proposed Action, investigate the anticipated benefits and impacts of the proposed improvements (through an Environmental Assessment), produce conceptual design plans, and make funding, scheduling, and phasing recommendations.

This memorandum describes the transportation affected environment and potential impacts on transportation resources within the study area.

I-70 Final PEIS and Record of Decision Analysis

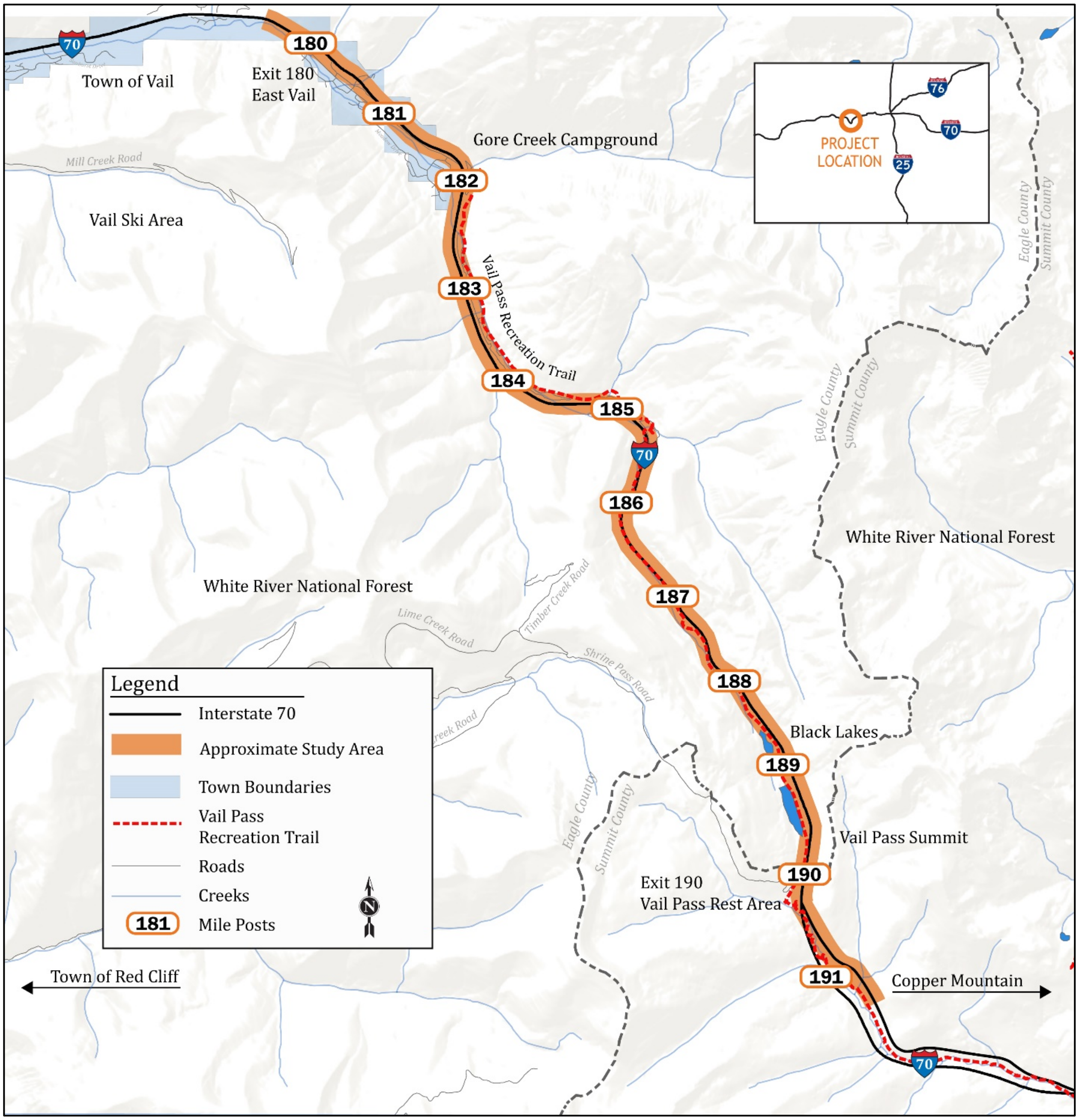
The I-70 Final PEIS and the *I-70 Mountain Corridor PEIS Travel Demand Technical Report* (CDOT 2010) provide information about existing and future transportation conditions in the study area. Some of the key findings of the I-70 Final PEIS that are relevant to the West Vail Pass Auxiliary Lanes study area are safety and operational issues related to speed differentials due to slow-moving vehicles.

These key findings are generally consistent with new analysis that was conducted for this Tier 2 process.

Study Area

The study area (**Figure 1**) extends from the Town of Vail (MP 179.5) east to the top of Vail Pass (MP 191.5) in Eagle and Summit Counties, Colorado. The study area was established early in the planning process and extends approximately 200 feet on both sides of I-70. The project extent was later established to include the potential limits of disturbance resulting from the Proposed Action and was utilized for impact analyses.

Figure 1. Project Location and Study Area



Source: DEA Project Team

PURPOSE AND NEED

The purpose of the project is to improve safety and operations on EB and WB I-70 on West Vail Pass.

This project is needed to address safety concerns and operational issues due to geometric conditions (steep grades and tight curves) and slow-moving vehicle and passenger vehicle interactions that result in inconsistent and slow travel times along the corridor. The I-70 Mountain Corridor PEIS identified safety and mobility issues on West Vail Pass related to speed differentials due to slow-moving vehicles. *(Mobility is defined as the ability to travel along the I-70 Mountain Corridor safely and efficiently in a reasonable amount of time.)*

- Safety Concerns: A high number of crashes occur along the corridor related to speed, tight curves, narrow roadway area, and inclement weather/poor road conditions. Speed differentials between passenger vehicles and slow-moving vehicles cause erratic lane changes and braking maneuvers resulting in crashes and spin outs. Emergency response is hampered by vehicular speeds and lack of roadway width to provide room for emergency vehicles to pass.
- Operational Issues: The steep grades and resulting speed differentials causes slow and unreliable travel times through the corridor. Tight curves also cause drivers to slow down. The corridor is frequently closed by vehicle incidents, due to lack of width to maintain a single lane of traffic adjacent to emergency responders, resulting in substantial traffic backups and delays. During winter months, the travel lanes and shoulders are severely impacted by snow accumulation, impacting the overall capacity of the corridor. *(Operations is defined as the optimal flow of traffic taking into consideration geometric and weather conditions.)*

NO ACTION ALTERNATIVE

The No Action Alternative is included as a baseline for comparison to the action alternative. Under the No Action Alternative, only programmed projects that are planned and funded by CDOT or other entities would be completed. Currently, there are no large-scale transportation projects to add safety improvements, operational improvements, vehicular capacity, and multimodal facilities along I-70 within the project area. The No Action Alternative would leave West Vail Pass as it currently is configured and would not provide substantial improvements beyond typical current maintenance (e.g. resurfacing and plowing) activities. The roadway would remain the same, with 2 EB and 2 WB lanes (each 12 feet in width), an inside shoulder typically 4 feet in width, and an outside shoulder typically 10 feet in width.

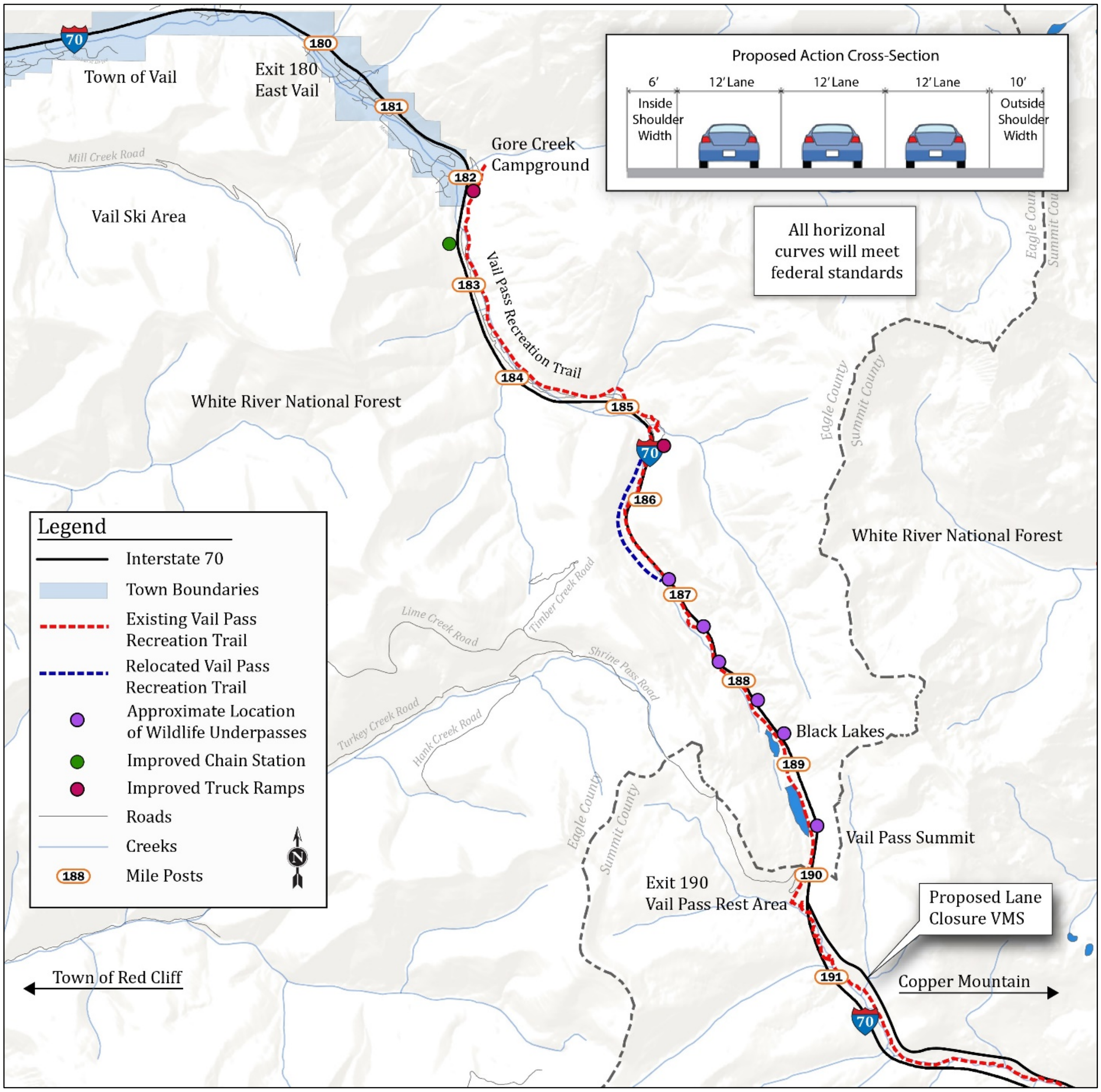
PROPOSED ACTION ALTERNATIVE

The Proposed Action (**Figure 2**) will add a 12-foot auxiliary lane, both EB and WB, for 10 miles from approximately the EB I-70 on-ramp in East Vail (MP 180) to the WB off-ramp at the Vail Pass Rest Area exit (MP 190). Existing lanes will be maintained at 12 feet and the shoulders would be widened to a minimum of 6 feet for inside shoulders and maintained at 10 feet for outside shoulders. All existing curves will be modified as needed to meet current federal design standards.

Intelligent Transportation System (ITS) equipment will also be installed along the I-70 project corridor, consistent with recent study recommendations. Additional variable message signs (VMSs) will be installed at key locations to warn drivers of upcoming curves, grades, and incidents.

Additional variable speed limit signs will be installed to manage driver speeds to conditions. Automated lane closure signage will be installed approaching the East Vail exit on EB I-70 and approaching the WB I-70 Vail Pass Rest Area exit to quickly and efficiently close lanes when needed.

Figure 2. I-70 West Vail Pass Auxiliary Lanes Proposed Action Alternative



Source: DEA Project Team

Additional elements of the Proposed Action include:

- The Vail Pass Recreation Trail will be directly impacted by the addition of the I-70 auxiliary lane and therefore relocated for approximately two miles from MP 185 to MP 187.
- Existing emergency truck ramps, located at approximately MP 182.2 and 185.5, will be upgraded to current design standards.
- Six wildlife underpasses and wildlife fencing will be constructed throughout the corridor.
- Additional capacity will be added to the existing commercial truck parking area at the top of Vail Pass.
- Widened shoulders (minimum of eight feet of additional width beyond the 10' shoulder) at multiple locations to accommodate emergency pull-offs, emergency truck parking, and staging for tow trucks.
- Improved median emergency turnaround locations to accommodate emergency and maintenance turnaround maneuvers.
- Improved chain station located at approximately MP 182.5 with additional parking, signage, lighting, and separation from the I-70 mainline.
- Avalanche protection located at approximately MP 186.

Methodology

Travel Demand Forecasts

The CDOT statewide travel demand model forecasts traffic volumes for the year 2045. The I-70 Final PEIS forecasted traffic volumes for 2035 as the design year and also included long-range forecasts for 2050. Based the current statewide travel demand model and updates to the I-70 Final PEIS traffic forecasts, 2045 was selected as the future design year for the traffic evaluation.

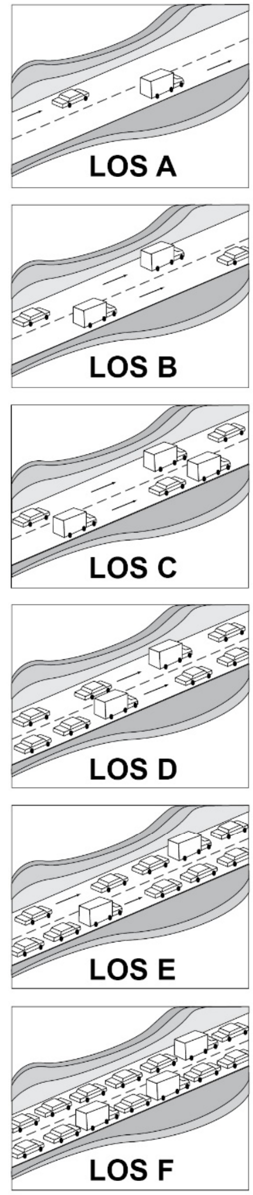
Various traffic growth rates have been used by other studies along the I-70 Mountain Corridor. These sources, including the I-70 Final PEIS, historical growth rates for the study corridor, and the population forecasts for the surrounding counties were used to estimate the traffic growth rate for the project.

Traffic Operations Analysis

Traffic operations were evaluated using Level of Service (LOS) methodologies documented in the *Highway Capacity Manual 6th Edition*, Transportation Research Board, 2016, using Highway Capacity Software version 7.7. LOS is a qualitative measure of traffic operational conditions based on roadway capacity and vehicle density. LOS is described by a letter designation ranging from A to F, with LOS A representing the best possible free-flow operation conditions and LOS F representing over-capacity or breakdown and gridlock conditions. Density as passenger cars per mile per lane (pc/pm/pl) and LOS are provided as representation of the corridor segment travel conditions. The operating conditions at each LOS are illustrated in **Figure 3**.

Figure 3. Freeway Level of Service Description

Level of Service	Description
A	Free-flow operations with low traffic density.
B	Reasonably free-flow traffic operations. Ability to maneuver is only slightly restricted.
C	Speed at or near free-flow operations. Stable conditions with movements somewhat restricted with higher volumes
D	Density increases more quickly. Freedom to maneuver is more noticeably limited. Minor incidents create queuing.
E	Operation near or at capacity. Vehicles closely spaced. Operations extremely volatile. Any disruption causes queuing.
F	Breakdown in traffic flow with gridlock. Demand exceeds capacity.



Source: Highway Capacity Manual, 6th Edition

The traffic operations analysis included the following assumptions:

- Traffic volumes represent the peak hours for an average Summer Weekday (Monday-Thursday) and Summer Sunday
- Peak hour factor: assumed to be 0.95 in the EB lanes and 0.85 in the WB lanes, as was used in the I-70 Final PEIS.

- Heavy vehicle peak hour percentage (summer): assumed to be 6% heavy trucks and 8% medium trucks/recreational vehicles as shown in the I-70 Final PEIS for summer weekend forecasts.
- Ramp truck percentage was assumed to correspond with I-70 truck percentage splits.
- Roadway grades utilized were from the *Safety Assessment Report I-70: MP 179.00 to MP 191.00 West Vail Pass Auxiliary Lanes Environmental Assessment* (January 2018).
- Driver population assumed "Balanced Mix" as I-70 carries local, visitor, and commercial through traffic.

Safety

Crash History

CDOT completed the *Safety Assessment Report I-70: MP 179.00 to MP 191.00 West Vail Pass Auxiliary Lanes Environmental Assessment* (January 2018) to evaluate crash data for the I-70 study corridor for a three-year period from January 1, 2014 through December 31, 2016. The report is included in **Appendix A**.

CDOT has developed Highway Segment Safety Performance Functions (SPFs) to estimate the average crash frequency for a specific site type as it relates to the annual average daily traffic of the segment. These SPFs are used to predict the potential that a corridor has for crash reduction based on the observed versus the predicted crash frequency, which is called the Level of Service of Safety (LOSS). The LOSS reflects how the roadway segment is performing in regards to its expected crash frequency and severity at a specific level of Average Daily Traffic. It provides a crash frequency and severity comparison with the expected norm:

- LOSS I – Below 20th Percentile
  - Substantially better than average daily record; indicates a low potential for crash reduction
- LOSS II – 20th Percentile to Mean
  - Indicates a low to moderate potential for crash reduction
- LOSS III – Mean to 80th Percentile
  - Indicates a moderate to high potential or crash reduction
- LOSS IV – Above 80th Percentile
  - Substantially worse than average safety record; indicates high potential for crash reduction

Predictive Crash Safety Evaluation

The safety evaluation methodology utilized the Colorado-based SPFs to estimate the baseline expected crashes. Crash rates predicted from CDOT's program are based exclusively on equivalent Colorado facilities so they are more representative of the conditions found on West Vail Pass than baseline crash rates derived from other modeling packages. The specific methodology used for this study was developed in consultation with the CDOT Safety & Traffic Engineering Branch.

Primarily, the evaluation for the study corridor incorporated the Rural Mountainous 4-Lane Divided Freeways SPF for the baseline conditions. The methodology closely matched Method 3 as described in the *Highway Safety Manual* (Part C.7). The methodology was as follows:

1. Determine the evaluation period of interest.
2. Collect observed crashes and annual average daily traffic (AADT) within the defined study period.
3. Develop individual corridor segments/sites within the 10-mile corridor for the evaluation.
   - » Option 1: Segmentation based on geometric features (e.g., tangents, curves, structures).
   - » Option 2: Segmentation based on crash patterns/clustering.
4. Option 1 was used to ultimately segment the corridor, but crash locations were overlaid on the segments to ensure crash clusters were not split between segments.
5. Assign the crashes and AADT to appropriate corridor segments.
6. Use the VZS software to calculate the expected average crash frequency for the baseline condition on each segment.
7. Apply the appropriate crash modification factors (CMFs) that are associated with the specific geometric considerations and design options (e.g., shoulder width adjustment, curve modifications, etc.).
8. Predicted average crash frequency will be calculated using Colorado-developed SPFs through the VZS (disabling Empirical Bayes from VZS)
9. Calculate the predicted crash frequencies for No Action and Proposed Action scenarios and compare for the resulting Proposed Action scenario crash reduction.

The *West Vail Pass Predictive Crash Safety Evaluation Memorandum* in **Appendix B** provides the details on the development of the CMFs that fit within the context of the I-70 West Vail Pass corridor. The CMFs considered in the calculation of the potential crash reductions were for changes in horizontal curvature, increase in inside shoulder width, and the addition of an auxiliary lane.

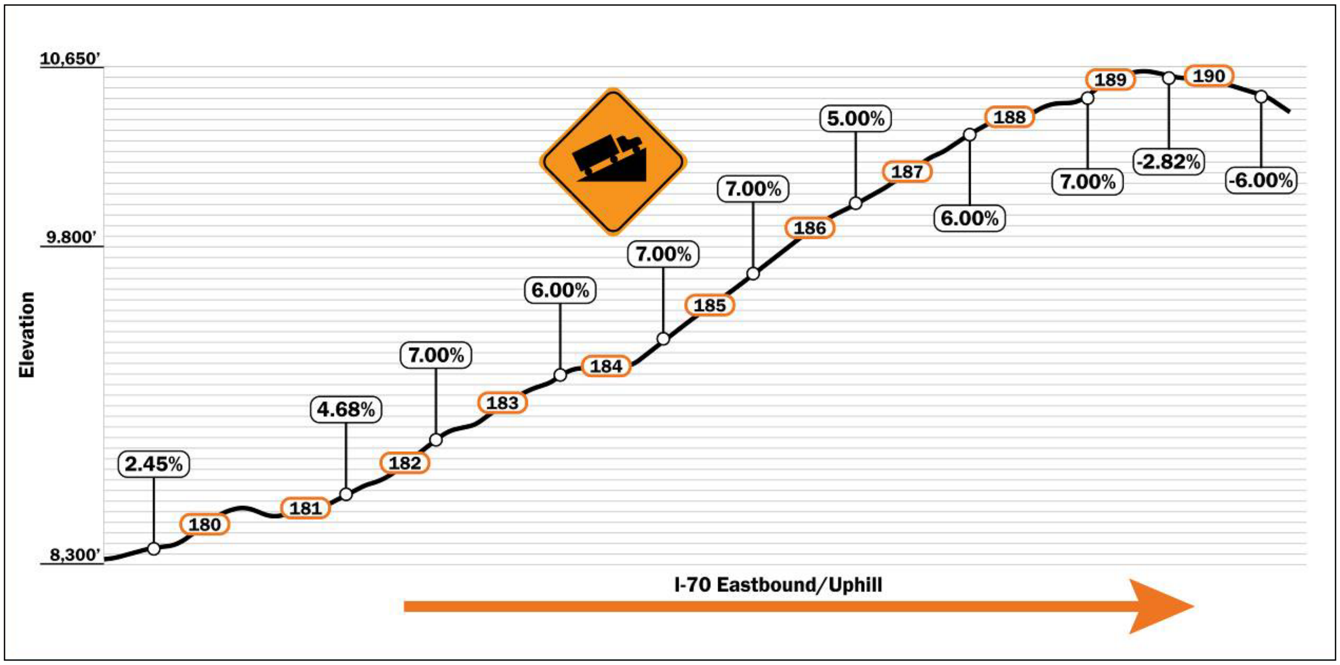
Existing Conditions

The I-70 Mountain Corridor is a critical part of the Primary Highway Freight System and I-70 is Colorado's only east-west interstate, providing a critical interstate commerce link for Colorado and the country. It also provides the only direct route between the Front Range and western Colorado. Area residents and visitors travel the corridor to access growing mountain communities, as well as local and regional recreational opportunities.

The West Vail Pass segment of the I-70 Mountain Corridor experiences safety and mobility issues related to speed differentials due to the steep grades and trucks and other slow-moving vehicles. A high number of crashes occur along the corridor related to speed, tight curves, limited roadway area (lanes and shoulder width for drivers losing control), and inclement weather/poor road conditions. Speed differentials between passenger vehicles and trucks cause erratic lane changes and braking maneuvers resulting in crashes and spin outs.

There are steep and relatively long grades along West Vail Pass (see **Figure 4**) that exceed the standard maximum grade of five percent. The steep grades and resulting speed differentials between different types of vehicles cause slow and unreliable travel times through the corridor. Tight curves also cause drivers to slow down. The corridor is frequently closed by vehicle incidents, due to lack of width to maintain a single lane of traffic adjacent to emergency responders, resulting in substantial traffic backups and delays. The wide speed variations with no pull-off area for incidents and response and no breakdown area for uphill drivers creates turbulence in traffic flow and drivers cannot travel with free-flow conditions. In the downhill direction, the combination of steep grades with tight curves create issues for heavy vehicles with hot brakes and trucks pull over in the areas of MP 181, MP 182, and MP 184.

Figure 4. I-70 Grade on West Vail Pass



The speed limit is posted at 65 mph with a 45 mph truck speed limit in the WB (downhill) direction. The West Vail Pass study corridor has an existing (2017) Annual Average Daily Traffic (AADT) of approximately 22,000 vehicles per day.

Traffic Operations

CDOT collects a significant amount of field data in the I-70 Mountain Corridor using electronic devices. These data are valuable in recording hour-by-hour status of traffic operations in the corridor. Automatic Traffic Recorders (ATR) record volumes, speeds, and vehicle classifications on an hourly basis. The information is available from CDOT for each day of the year. There is an ATR located west of the US 24 (Copper Mountain) interchange at MP 195, east of the Project area.

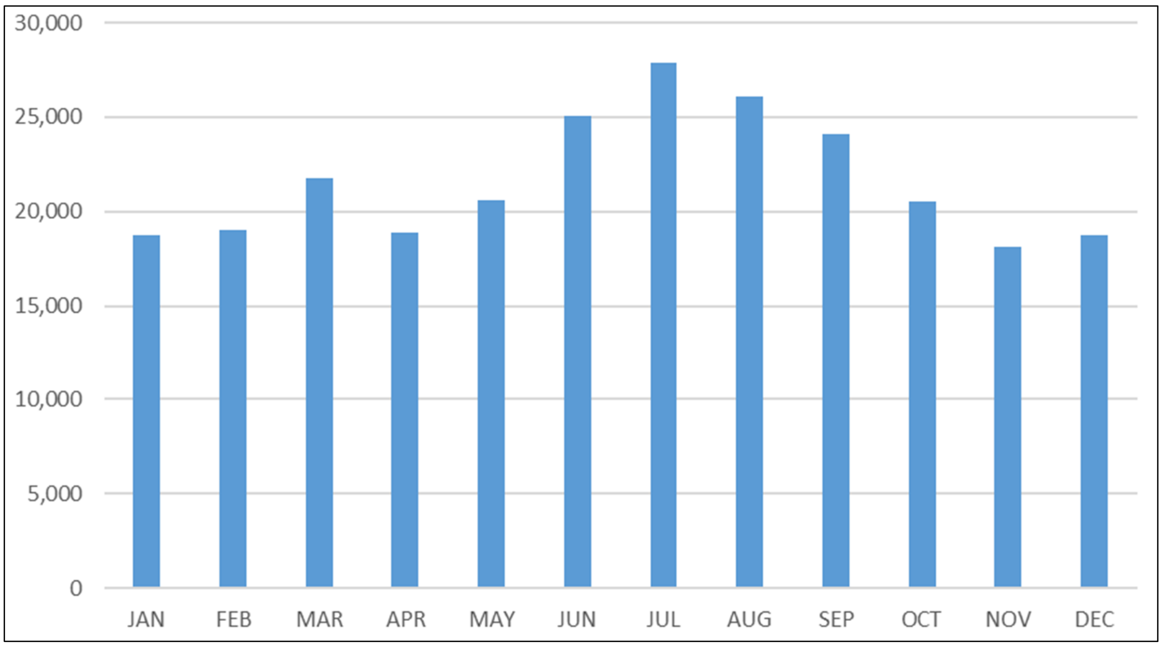
Microwave Vehicle Radar Detection (MVRD) devices use radar to record volume, occupancy, speed, and classification of each vehicle. They are typically located on poles along the road and can also record data for each lane of a multi-lane facility. There are two MVRD devices in the project area, located at MP 182.0 and MP 183.6.

INRIX gathers real-time traffic data from commercial fleets, GPS, cell towers, mobile devices, and cameras and determines travel times and speed of vehicles through the I-70 corridor. INRIX data is available for the study segment.

Seasonal Traffic Patterns

Figure 5 shows the average daily traffic volumes in both directions of I-70 on Vail Pass for each month of the year over the last five years (January 1, 2015 – December 31, 2019). These monthly volumes establish that the summer season (June through September) experiences the highest daily volumes. The traffic volumes during other months of the year are notably lower, although March experiences the next highest volume, as a result of the winter vacation activities in the mountains.

Figure 5. Average Daily Traffic Volumes by Month (2015 – 2019)



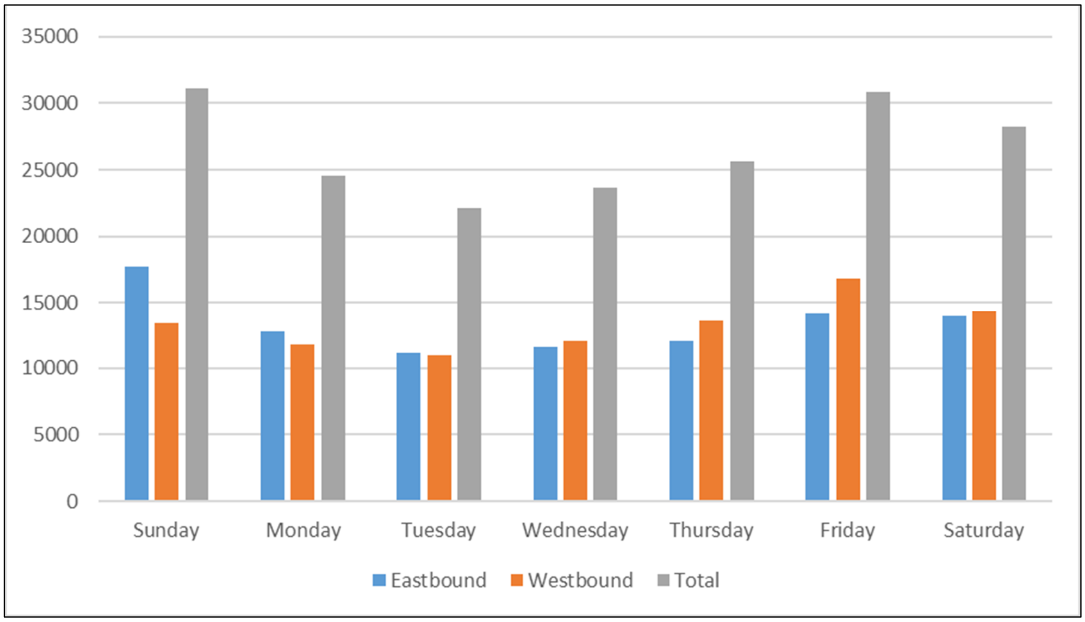
Source: CDOT ATR 000119

Daily Traffic Patterns

I-70 at West Vail Pass is used primarily for recreation on weekends. Daily traffic during both the summer and winter seasons are highest on Friday through Sunday. The summer volumes traveling the corridor in 2019 are shown for each day of the week in **Figure 6**. As shown, WB traffic is highest on Fridays as people drive from the Front Range through the mountain areas for recreational activities. There is less WB traffic on Saturdays, but it is still the second-highest volume day of the week. Sundays have the highest EB volumes of the week, as visitors return to the Front Range area.

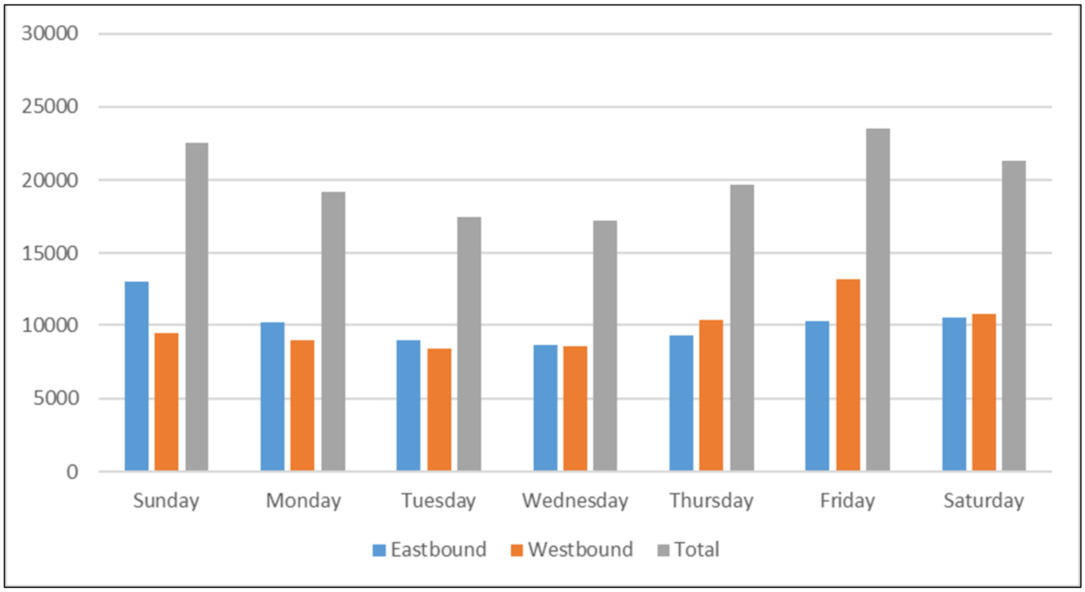
Winter season traffic volumes are overall lower than in summer. The peak daily traffic patterns in winter are similar to summer, as shown in **Figure 7**.

Figure 6. Summer Daily Traffic Patterns (2019 - June through September)



Source: CDOT ATR 000119

Figure 7. Winter Daily Traffic Patterns (2019 - December through March)



Source: CDOT ATR 000119

TRUCK VOLUMES AND OPERATIONS

Trucks make up almost 12 percent of the average daily traffic on I-70 at West Vail Pass. There is a notable 10 to 20 miles per hour (mph) speed differential between passenger vehicles and heavy trucks and/or recreational vehicles on the steep grades. These wide speed variations with limited recovery and break down areas creates turbulence in traffic flow.

There is a chain up station located along EB I-70 at MP 178, just west of the project area. Two chain-up stations are located along EB I-70 within the project area at MP 182.6 and MP 184.2. The major chain-up station is at MP 178, and the other two are much smaller and are not used as much. However, vehicles carrying Hazardous Materials are directed to go to the station at MP 182.6 to chain-up. West of Vail Pass, there is only one official chain-down station and it is just west of the study area and the interchange at Exit 180.

There are two truck emergency ramps located along WB I-70 within the project area at MP 185.7 (upper Vail Pass) and MP 182.2 (lower Vail Pass). From January 2016 to December 2019, the upper truck emergency ramp was used 12 times and the lower ramp was used 18 times. The total truck ramp use over the last four years by month is summarized in **Table 1**. It should be noted that this data may not capture runaway trucks that crashed outside of the ramp (on I-70, before or after the ramp), so it is not a complete picture of truck safety.

Table 1. West Vail Pass Truck Emergency Ramp Use (2016 – 2019)

Month	Year				Total
	2016	2017	2018	2019	
January	0	1	0	0	1
February	0	0	0	0	0
March	0	1	2	2	5
April	0	2	1	0	3
May	0	1	2	0	3
June	0	0	0	0	0
July	1	2	0	0	3
August	0	0	0	1	1
September	4	3	0	1	8
October	1	2	1	0	4
November	0	1	0	0	1
December	0	0	1	0	1
Total	6	13	7	4	

Source: CDOT

Lane Utilization and Speed Differential

Table 2 summarizes the average speed differential and lane utilization collected at the two MVRD devices along West Vail Pass in January and June 2016. As shown, speed differences between the left and right lane are up to 9 mph. With slow-moving vehicles in the right lane, the majority of traffic travels in the left lane. As shown, around 60 percent of the traffic traveled in the left lane. There does not appear to be a difference between January and June.

Table 2. Lane Utilization and Speeds

Data Collected	MP 182.0		MP 183.6	
	Eastbound	Westbound	Eastbound	Westbound
Average Speed Differential (between left and right lane)	Jan: + 5 mph July: + 7 mph	Jan: + 4 mph July: + 9 mph	Jan: + 6 mph July: + 5 mph	Jan: + 4 mph July: + 6 mph
Average Lane Utilization (left lane/right lane)	Jan: 59% / 41% July: 59% / 41%	Jan: 64% / 36% July: 56% / 44%	Jan: 56% / 44% July: 57% / 43%	Jan: 61% / 39% July: 65% / 35%

Source: CDOT MVRD

Design Day and Peak Period

Table 3 compiles the highest 20 days for total daily traffic on I-70 on West Vail Pass over the most recent three-year period (January 1, 2017 – December 31, 2019). The majority of the top 20 daily volumes occurred on a Sunday. The top 60 days over the three years occurred during the summer season. The third Sunday in July was chosen to represent the peak day for the project evaluation since it is not a holiday weekend and it is generally closest to the average of the top 20 days.

Table 3. I-70 Daily Traffic Volumes (2015 – 2017)

Rank	Date	Day	Daily Volume
1	7/7/2019	Sunday	35,217
2	7/28/2019	Sunday	34,315
3	7/23/2017	Sunday	33,879
4	8/30/2019	Friday	33,661
5	8/6/2017	Sunday	33,575
6	8/4/2019	Sunday	33,574
7	7/21/2019	Sunday	33,539
8	7/3/2019	Wednesday	33,498
9	7/6/2019	Saturday	33,474
10	7/1/2017	Saturday	33,352
11	8/2/2019	Friday	33,204
12	6/30/2017	Friday	32,927
13	8/9/2019	Friday	32,878
14	7/19/2019	Friday	32,825
15	9/2/2019	Monday	32,819
16	8/11/2019	Sunday	32,773
17	7/30/2017	Sunday	32,770
18	6/18/2017	Sunday	32,410
19	7/14/2019	Sunday	32,386
20	6/10/2018	Sunday	32,382

Source: CDOT ATR 000119

Travel Times

Travel times on West Vail Pass are impacted by recurring congestion in the EB direction as well as incident-based delays in both directions. EB recurring congestion takes two forms: everyday backups from slow-moving vehicles traversing the ten miles of steep uphill grades (typically in the right lane but sometimes overtaking slower vehicles from the left lane), and Sunday afternoon congestion from recreational traffic returning to the Front Range from the mountains. Under existing traffic volumes, EB trucks traveling uphill decelerate by as much as 30 mph under the speed limit and all traffic slows as much as 15 mph under the speed limit when a truck is traversing the pass on EB I-70.

Regular congestion occurs throughout the year on weekends as EB I-70 Front Range-bound traffic returns from recreational activities in the mountains. This congestion along West Vail Pass peaks in the summer months but occurs throughout the year. A review of INRIX data on West Vail Pass found that the average weekend in 2019 recorded more than 3.6 hours with EB I-70 delay and this delay is expected to increase with traffic volumes through the I-70 Mountain Corridor.

Level of Service

Existing operations analysis for the peak hours of Summer Weekday and Summer Sunday were developed for study corridor. The results of the operations evaluation are shown in **Table 4**, including both freeway and ramp merge/diverge operations.

Table 4. Existing Conditions Operations Analysis

Name/Location	Type	Direction	Summer Weekday		Summer Sunday	
			Density[1]	Level of Service (LOS)	Density[1]	LOS
East Vail Interchange – On Ramp	Merge	EB	10	A	20.8	B
East Vail to Rest Area	Basic	EB	10.5	A	21.5	C
Rest Area Interchange – Off Ramp	Merge	EB	11	B	24.1	C
Rest Area Interchange – On Ramp	Merge	WB	9.9	A	12.9	B
Rest Area to East Vail	Basic	WB	9.1	A	11.8	B
East Vail Interchange – Off Ramp	Diverge	WB	9.6	A	12.2	B

[1] Passenger cars per mile per lane (pc/pm/pl)

Highway Closures and Traffic Management

I-70 at West Vail Pass experiences relative frequent partial (one-lane) or full highway closures due to crashes, weather, vehicle breakdowns, and other incidents. When incidents force a full closure of the 24 miles between Copper Mountain and Vail (including West Vail Pass), the detour route is 54 miles long and follows SH 91 and US 24 via Leadville, traveling off of I-70 between the interchanges at Copper Mountain (MP 195) and Minturn (MP 171). This route is entirely on high-elevation two-lane highways with non-freeway design thresholds and speed limits between 25 and 65 mph. Additionally, when Vail Pass full closures are weather-related, the detour route typically experiences similar weather conditions. This detour route has much higher impacts to detoured traffic, both in travel time and crash rates, than a detour route in a typical urban or suburban environment with multiple alternate routes of a similar roadway classification.

CDOT maintains datasets documenting partial and full closures with date, location, duration, and type (reason for closure). **Table 5** shows a summary for duration of closures from 2014 through 2017. In recent years CDOT has implemented a more proactive incident management strategy to close the highway, called a "safety closure" when crashes occur and during weather events to reduce secondary crashes and to provide more space and time for emergency response along the corridor. The number of highway closures each year has increased, but the overall duration of closures has been reduced.

Table 5. Closures due to Incidents 2014 - 2017

Year	Number of Full Closures	Number of Partial Closures	Duration of Closures (hours)
2014	15	25	400.0
2015	33	98	476.7
2016	71	144	307.9
2017	91	163	363.5
Total	210	430	1,548.1

Source: CDOT

Table 6 summarizes the types of incidents documented for full closures on I-70 at West Vail Pass from 2014 through 2017. Over those years, 61 of the 210 incident full closures involved trucks/commercial motor vehicles.

Table 6. Types of Incidents for Full Closures 2014 - 2017

Type of Incident	Number of Full Closures
Crash	86
Avalanche Control	3
Blocked	1
Closed	13
Disabled Semi Trailer	1
Jackknifed Semi Trailer	1
Mechanical	6
Outside Agency Activity	2
Runaway Ramp Closure	6
Safety Closure	82
Spun Out/Slide Off	9

Source: CDOT

Full closure data for West Vail Pass was compared with closures for I-70 at the Straight Creek segment between Silverthorne (elevation about 9,035 feet) and the Eisenhower-Johnson Memorial Tunnel (elevation about 11,013 feet). The elevations are similar to the West Vail Pass segment and winter weather conditions are roughly similar. The average grade along Straight Creek is 4.6 percent, compared to 3.4 percent for West Vail Pass. I-70 at Straight Creek has three lanes in each direction with relatively narrow shoulders while I-70 at West Vail Pass has two lanes in each direction with standard shoulders. In 2017, West Vail Pass had 91 full closures lasting 114 hours while Straight Creek had only 19 full closures lasting 36 hours. Even with narrower shoulders, the Straight Creek segment with three lanes in each direction experienced substantially less full closures.

Heavy Tow

For winter weather events and busy summer weekends, heavy tows are staged along the corridor to mitigate partial and full closures. In winter 2017 (October 2016 – April 2017), there were 44 heavy tow relocations with 20 of those relocations occurring in December (**Table 7**).

Table 7. I-70 West Vail Pass Heavy Tow Relocations – Winter 2016/2017

Month	Relocations
October	0
November	5
December	20
January	7
February	12
March	0
April	0
TOTAL	44

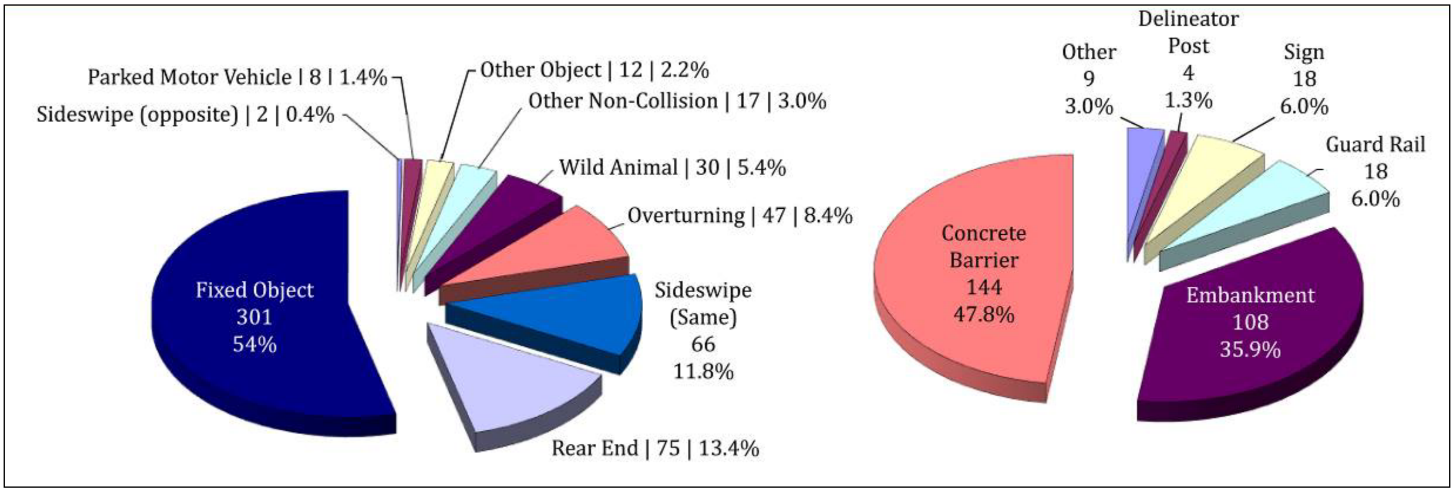
Source: CDOT

Safety

The following findings were taken from the *Safety Assessment Report I-70: MP 179.00 to MP 191.00 West Vail Pass Auxiliary Lanes Environmental Assessment* (January 2018). The safety assessment focused on crashes that occurred from January 1, 2014 through December 31, 2016 on I-70 between MP 179 and 191.

A total of 566 crashes were reported during the three-year time period, including mainline, ramp, and ramp terminal crashes. Of these crashes, there were 121 injury crashes with 205 injured. There were a total of 558 mainline crashes in the corridor. Fixed object crashes were the most common crash type (54 percent), followed by rear end (13.4 percent) and sideswipe same direction crashes (11.8 percent). **Figure 8** shows the crash distribution by type and the breakdown of the fixed object crashes for mainline I-70.

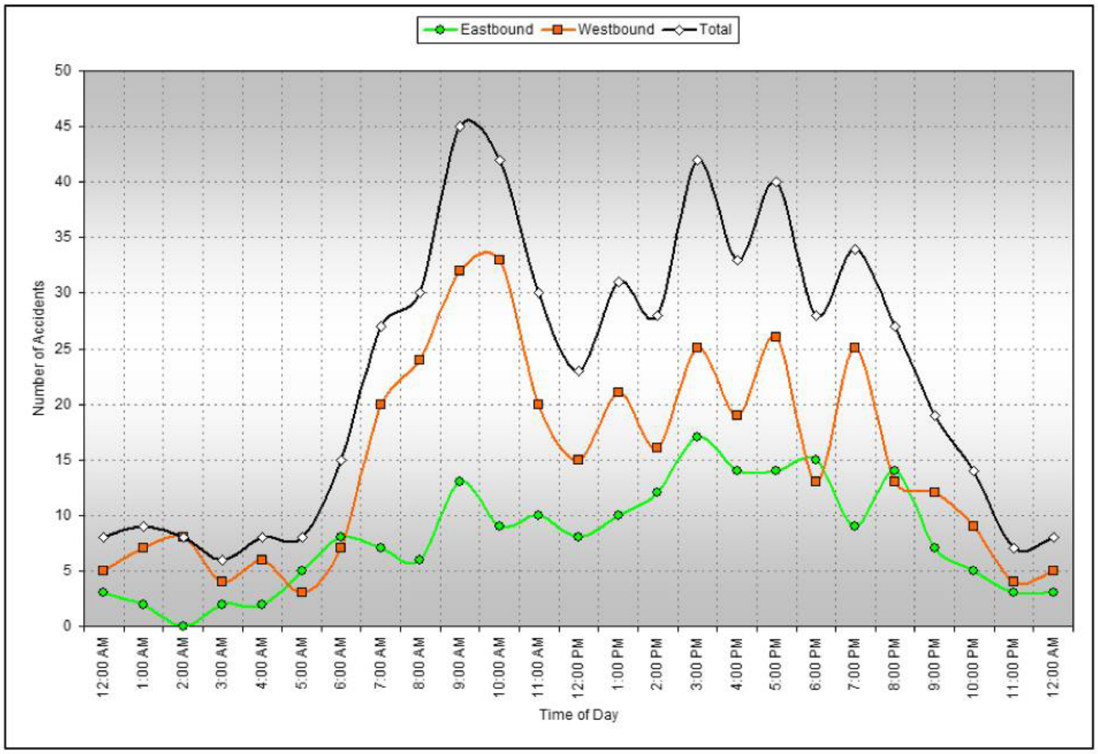
Figure 8. Mainline Crash Distribution Type (2014 – 2016)



Source: CDOT Safety Assessment Report I-70: MP 179.00 – MP 191.00 (January 2018)

Figure 9 provides the breakdown of the mainline crashes by time of day and direction. As shown, there are more crashes occurring in the WB direction. Approximately 65 percent of crashes are WB and 35 percent are EB. The EB has a slight increase in crashes during the PM peak period of 3:00 PM to 6:00PM. The WB direction has an increase in crashes during the AM peak period between 9:00 AM and 11:00 AM.

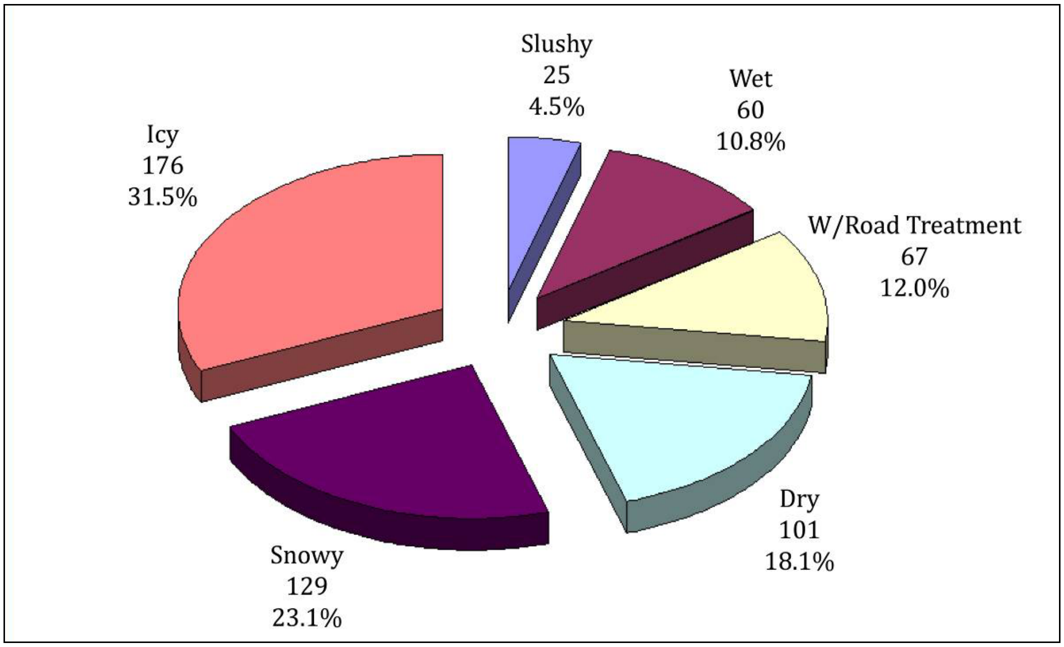
Figure 9. I-70 Mainline Crashes by Time of Day and Direction



Source: CDOT Safety Assessment Report I-70: MP 179.00 – MP 191.00 (January 2018)

Figure 10 provides the crashes by road condition. As shown, 59 percent of crashes occur on icy, slushy, or snowy roads,while only 18 percent of the crashes occur on dry roads. Road conditions appear to be a significant factor in crashes, shown by number of crashes occurring in poor road conditions and occurring during winter months.

Figure 10. I-70 Mainline Crashes Road Condition



Source: CDOT Safety Assessment Report I-70: MP 179.00 – MP 191.00 (January 2018)

To facilitate a more detailed crash analysis, the corridor was divided into segments based on interchange locations, curve locations, and grades. The non-intersection crashes within the study corridor were tested for the presence of patterns related to crash type, severity, direction of travel, road conditions, spatial distribution, time of day, and behavioral attributes. The analysis was performed using normative percentages for diagnostics of safety problems for a four-lane rural mountainous divided freeway.

Table 8 provides an overall summary by segment of the crashes and crash patterns found. As shown, the predominant crash type across all segments is fixed object. In Segments 1 through 3, the predominant crash type is concrete barrier, while it is embankment in Segment 4. The highest crash rate is found in Segment 3, which also has the largest number of poor road condition crashes, the steepest grades in the WB direction, and a high percentage of WB crashes. For the frequency of total crashes, Segment 1 had moderate to high potential for crash reduction. Segments 2, 3, and 4 were in the LOSS IV category, indicating high potential for crash reductions.

Notable crash patterns within shorter sections of the corridor include:

- MP 181-181.6: Wild animal crashes (deer, May through August, dawn until dusk)
- MP 181.8-182: Concrete barrier/embankment crashes during inclement road conditions
- MP 182-182.7: Rear-end crashes due to speed differentials

- MP 182.5-184: Side swipe same direction crashes due to speed differentials or losing control in adverse weather conditions
- MP 184-184.5: Concrete barrier crashes on bridges during inclement road conditions (mostly westbound)
- MP 185.5-186.1: Concrete barrier/embankment crashes during inclement road conditions with inexperienced/unfamiliar drivers (mostly westbound)
- MP 187-187.5: Side swipe same direction crashes due to losing control in adverse weather conditions
- MP 188.6-189.1: Overturning crashes during inclement road conditions (mostly westbound)

Table 8. I-70 Segment Safety Summary (2014-2016)

DATA	SEGMENT 1	SEGMENT 2	SEGMENT 3	SEGMENT 4
MP	179.00 – 182.00	182.01 – 184.50	184.51 – 186.50	186.51 – 191.00
Elevation	8,320 – 8,700 ft	8,700 – 9,270 ft	9,270 – 10,000 ft	10,000 – 10,590 ft
Average Grade	2.4%	4.3%	6.9%	4.6% west of top 2.9% east of top
Maximum Grade	-	6.8%	7.0%	7.4%
Total Crashes	74	101	135	248
PDO[1] Crashes	63	82	104	189
INJ[2] Crashes	11	19	31	59
Crashes/Mile	21.0	40.4	67.5	55.1
Level of Service of Safety – Total Crashes	LOSS III	LOSS IV	LOSS IV	LOSS IV
Predominant Crash Type	Fixed Object (39%)	Fixed Object (55%)	Fixed Object (59%)	Fixed Object (56%)
Direction	EB 40% WB 60%	EB 61% WB 39%	EB 27% WBd 73%	EB 26% WB 74%
Percent Inclement Road Conditions	68%	76%	88%	85%
Crashes Caused by Trucks (percent of total crashes)	8 crashes (11%)	15 crashes (15%)	23 crashes (17%)	23 crashes (9%)
Crash Patterns	Wild Animal Concrete Barrier Embankment	Rear-End Sideswipe Same Concrete Barrier Total Fixed Objects	Concrete Barrier Embankment Total Fixed Objects	Off Road Overturning Sideswipe Same Sign Concrete Barrier Embankment Total Fixed Objects

Source: CDOT Safety Assessment Report I-70: MP 179.00-MP191.00 (January 2018)

[1] PTO = Property Damage Only crash

[2] INJ = Injury crash

In the context of Vail Pass and the adverse road conditions that are regularly experienced in the winter, losing control and hitting another car (instead of a fixed object) are indicative of conditions where lane departures cannot be avoided. Fixed object crashes are indicative of vehicles losing control, which in this corridor is often found to be related to grade, bridges, sharp curves, and inclement road conditions.

From MP 182.01 to MP 186.5, trucks are involved in a higher percentage of corridor crashes (16%) than the percentage of trucks in the overall traffic volumes (12%), which indicates potential safety issues related to truck interactions. They are more than twice as likely to be involved in multi-vehicle crashes as other vehicles; and slightly more likely than other vehicles to be involved in dry road crashes. These patterns reinforce the obvious notion that larger vehicles take up more space and are not as nimble as smaller vehicles, thus being involved in more crashes with other vehicles. The general recommendations that would provide more lateral space (wider shoulders and an additional lane) to better accommodate all vehicles, particularly in harsh winter conditions.

A comparison of the crash history along West Vail Pass was made with the I-70 at Straight Creek segment. On Straight Creek, the total number of mainline crashes for the three-year period was 335 crashes, resulting in a LOSS III for total crashes and a crash rate of 1.16 crashes per million vehicle-miles. West Vail Pass had 558 mainline crashes, resulting in a LOSS IV for total crashes and a crash rate of 1.93 crashes per million vehicle-miles. Thus, safety on West Vail Pass is worse when both are compared in terms of crash rates and LOSS. The main difference between Straight Creek and West Vail Pass is that Straight Creek has three lanes in each direction and West Vail Pass has two.

Future Conditions

Traffic Forecasts

Annual traffic growth for future years was developed based on the CDOT statewide travel demand model (2045), previous travel demand estimates from the I-70 Final PEIS versus actual traffic volumes in the corridor, and historic and future population data for surrounding counties.

Various traffic growth rates have been used by studies along the I-70 Mountain Corridor. The I-70 Final PEIS developed a travel demand model that projected future weekend traffic demand on the corridor. That model indicated the corridor would experience an annual traffic growth rate of 2.20 percent on Summer Sundays. However, historical traffic growth along the study corridor between 2000 and 2019 shows peak Summer Sunday traffic has grown at a rate of 0.70 percent per year.

CDOT publishes a 20-year growth factor for each segment of the state highway system and projects a 1.04 percent annual growth for both weekday and weekend traffic along the study corridor. The CDOT statewide travel demand model projects a 1.95 percent annual growth rate for weekday traffic on the corridor.

The 2.20 percent annual growth rate from the I-70 Final PEIS travel demand model is based on population and land use forecasts that are somewhat dated (last updated in 2011). Recent data and forecasts from the Colorado State Demography Office for the period from 2017 to 2045 show that population in Eagle and Summit Counties will grow with annual growth rates between 1.60 and 1.70 percent.

Considering all of these traffic forecast sources, the 2045 traffic for this project is based on the middle range of 1.95 percent annual growth rate, which is an average of the PEIS growth rate for weekends, the CDOT statewide travel demand model growth rate for weekday travel, and the population forecasts for the surrounding counties. Use of the higher percent annual growth rate of 1.95 percent compared to the CDOT growth factor and historical traffic growth supports the possibility of traffic growth that may be induced by improvements to I-70 outside the study corridor and the possibility of higher traffic flows due to connected and/or autonomous vehicles. There is uncertainty on the timing of future vehicle fleet adoption for these new technologies, but a higher traffic growth rate with the use of connected and/or autonomous vehicles is a real possibility.

This growth rate results in a 2045 AADT forecast of 37,400 vehicles per day (two-way) with a Summer Sunday experiencing approximately 52,000 vehicles per day and an average Summer Weekday experiencing about 40,000 vehicles per day. Future travel demand estimates are expected to remain the same with or without the project.

Impacts

No Action Alternative

The No Action Alternative does not meet the purpose and need of the Project. Traveler safety and operational efficiency would not be improved along West Vail Pass. Other than routine maintenance (e.g. resurfacing and plowing) to keep I-70 in good condition, the interstate would not be improved beyond those activities.

Level of Service

Table 9 presents the existing conditions and 2045 No Action conditions for the peak hours of Summer Weekday and Summer Sunday. Traffic growth results in increased density and degraded traffic operations along the study corridor by 2045, particularly in the EB (uphill) direction where the corridor operates at LOS F, which equals traffic gridlock, in 2045.

Table 9. Existing and 2045 No Action Operations Analysis

Name/Location	Direction	Summer Weekday				Summer Sunday			
		Existing		2045 No Action		Existing		2045 No Action	
		Density[1]	LOS	Density[1]	LOS	Density[1]	LOS	Density[1]	LOS
East Vail Interchange – On Ramp	EB	10	A	17.3	B	20.8	B	38.1	D
East Vail to Rest Area	EB	10.5	A	18	B	21.5	C	-[2]	F
Rest Area Interchange – Off Ramp	EB	11	B	19.1	B	24.1	C	-[2]	F
Rest Area Interchange – On Ramp	WB	9.9	A	17.1	B	12.9	B	22.3	B
Rest Area to East Vail	WB	9.1	A	15.6	B	11.8	B	20.3	C
East Vail Interchange – Off Ramp	WB	9.6	A	16.5	B	12.2	B	21.1	C

[1] Passenger cars per mile per lane (pc/pm/pl)
[2] Maximum density too high to report per the Highway Capacity Software

Safety

The results of the predicted crash modeling for the No Action Alternative are shown in **Table 10**. There are two sets of baseline annual crash rates for the No Action 2045 model – a predicted and an expected crash rate. Changes in site conditions and crash history make future baseline predictions challenging, so both crash rates are presented. The variance between the predicted (derived from the four-lane freeway SPF) and the expected (calculated from the predicted modified by site conditions) crash rates are fairly substantial and the number of crashes per year with the No Action conditions would likely be somewhere between the recent crash history of 186 crashes/year and a 34 percent increase to 250 crashes/year. Both results were used as baselines for evaluating potential crash reduction with potential project elements.

Table 10. No Action Alternative Predicted Crashes

I-70 Segment Mileposts	Predicted 2045 No Action Crashes/Year	Expected 2045 No Action Crashes/Year
Segment 1 MP 180.10 – 181.50	18.89	16.30
Segment 2 MP 181.51 – 182.66	15.65	23.86
Segment 3 MP 182.67 – 184.43	23.88	36.10
Segment 4 MP 184.44 – 185.79	18.35	38.07
Segment 5 MP 185.80 – 186.66	11.74	36.08
Segment 6 MP 186.67 – 188.13	19.83	56.83
Segment 7 MP 188.14 – 189.90	23.88	48.92
Total Corridor Crashes/Year	129.07	250.09

Source: I-70 West Vail Pass Auxiliary Lanes Predictive Crash Safety Evaluation Memo, Apex Design

In the future No Action condition, response by emergency vehicles would continue to be challenging due to limited areas to access crashes or respond to disabled vehicles. I-70 at West Vail Pass would continue to experience relative frequent partial (one-lane) or full highway closures due to crashes, weather, vehicle breakdowns, and other incidents. The number of full I-70 closures at West Vail Pass would continue to increase with the expected increase in crashes and the need to implement safety closures to provide more space and time for emergency response.

Proposed Action Alternative

Overall, the Proposed Action addresses safety issues related to tight curves and narrow roadway area, with crash modification factors developed for the inside shoulder widening, curve radius modifications, and auxiliary lane predicting a substantial reduction in crashes experienced along the corridor. The added auxiliary lane addresses the uphill speed differentials along the steepest sections of the pass, improving travel time reliability. Turbulence in the overall corridor traffic flow is reduced and drivers will experience more free-flow conditions. Breakdown areas with widened area beyond the ten-foot outside shoulders are provided in the downhill direction where there are notable hot spots for hot brakes with trucks pulling over. The Proposed Action also provides travel time savings with reduced delay and reduced crash risk from fewer/shorter West Vail Pass full closures.

Emergency response would improve with reduced crashes and increased area for disabled vehicles to be moved out of the travel lanes and into the shoulder. Shoulders and auxiliary lanes would also provide more space for first responders and law enforcement to access crashes or disabled vehicles/breakdowns.

ITS applications would increase the effectiveness and reduce the overall duration of highway closures due to weather events and other incidents. Highway closures due to minor crashes and vehicle breakdowns would be reduced because vehicles could use the shoulder as a refuge area with the auxiliary providing more space while keeping at least one lane of traffic open.

The Proposed Action alignment would closely follow the existing roadway profile and would continue to have grades exceeding the standard maximum five percent grade, requiring design exceptions. However, the chain station improvements, truck emergency ramp improvements, added auxiliary lane in each direction, improved curve radii and superelevation, and improved signage with dynamic and enhanced advance curve signs will minimize the safety impacts of maintaining the existing I-70 grades.

The Proposed Action design includes concrete median and outside barrier that would limit the sight distance on some curves below the standard, requiring design exceptions, but the six-foot inside shoulders, wider outside shoulder width at several locations, added auxiliary lane in each direction, improved curve radii and superelevation, and enhanced advance curve signs will minimize the minimal safety impacts of the reduced sight distance.

There are areas where there is both a highway grade and sight distance design exception needed. These areas will mainly occur in the curves from approximately MP 186 to MP 188 due to the use of glare screen on the median barrier and grades of six to seven percent. For most of the corridor, the median barrier is at a standard height of 36 inches tall. From MP 185.5 to MP 188.7, the median is narrow, so the barrier is continuous and will have glare screen, which is 56 inches tall. The taller barrier affects the sight distance since drivers cannot see over it. However, CDOT has found that adding glare screen on I-70 in other mountain areas improved overall safety with a reduction in crashes. The number and types of crashes in the existing areas of substandard sight distance with grades do not indicate safety issues related to sight distance. The Proposed Action includes widening the inside shoulder to six feet, maintaining the outside shoulders at ten feet wide, and curve modifications, which will mitigate many of the crash types experienced at these locations.

Level of Service

Auxiliary lanes would greatly reduce travel delays caused by slow-moving vehicles by providing another lane for passing maneuvers. **Table 11** presents the 2045 No Action and Proposed Action conditions for the peak hours of Summer Weekday and Summer Sunday. Even with the expected traffic growth, traffic operations would remain at LOS C or better in both directions during Summer Sunday peak hours in 2045.

Table 11. 2045 No Action and Proposed Action Operations Analysis

Name/Location	Direction	Summer Weekday				Summer Sunday			
		2045 No Action		2045 Proposed Action		2045 No Action		2045 Proposed Action	
		Density[1]	LOS	Density[1]	LOS	Density[1]	LOS	Density[1]	LOS
East Vail Interchange – On Ramp	EB	17.3	B	11.2	A	38.1	D	23.5	B
East Vail to Rest Area	EB	18	B	12	B	- [2]	F	24.8	C
Rest Area Interchange – Off Ramp	EB	19.1	B	12	B	- [2]	F	25.7	C
Rest Area Interchange – On Ramp	WB	17.1	B	11	B	22.3	B	14.4	B
Rest Area to East Vail	WB	15.6	B	10.4	A	20.3	C	13.5	B
East Vail Interchange – Off Ramp	WB	16.5	B	10.4	B	21.1	C	13.3	B

[1] Passenger cars per mile per lane (pc/pm/pl)
[2] Maximum density too high to report per the Highway Capacity Software

Safety

The safety assessment recommended the following efforts to enhance safety along the study corridor, which are included in the Proposed Action:

- Widening the roadway to three lanes in each direction to give vehicles more space to avoid slower-moving vehicles and to make evasive maneuvers, reduce congestion that may occur during peak periods, and reduce rear-end and sideswipe same direction type crashes.
- Enhanced ITS infrastructure installing variable speed limit signs, dynamic speed display sign, and variable message signs to provide current information about road and weather conditions and traffic congestion.
- Installing wildlife fencing and warning signs, "bridge ices before road" signs, and advanced curve warning signs at appropriate locations.
- Flattening tight curves to decrease fixed object crashes.

The results of the predicted crash modeling for the No Action and Proposed Action are shown in **Table 12**. Regardless of what baseline No Action crash rate (predicted or expected) ultimately is in 2045, the predicted crash reduction is in the range of 37 – 41 percent, which equates to as much as 100 less crashes occurring along the study corridor every year.

Table 12. No Action and Proposed Action Predictive Crash Reduction Summary

I-70 Segment Mileposts		Predicted 2045 No Action Crashes/Year	Expected 2045 No Action Crashes/Year	Crash Reduction	
				Predicted	Expected
Segment 1	MP 180.10 – 181.50	18.89	16.30	4.75	4.10
Segment 2	MP 181.51 – 182.66	15.65	23.86	4.72	7.19
Segment 3	MP 182.67 – 184.43	23.88	36.10	7.11	10.76
Segment 4	MP 184.44 – 185.79	18.35	38.07	5.64	11.69
Segment 5	MP 185.80 – 186.66	11.74	36.08	6.90	21.22
Segment 6	MP 186.67 – 188.13	19.83	56.83	9.99	28.62
Segment 7	MP 188.14 – 189.90	23.88	48.92	8.97	18.38
Total Corridor Crashes/Year		129.07	250.09	48.08	101.96
Corridor-wide Percent Crash Reduction				37%	41%

Source: I-70 West Vail Pass Auxiliary Lanes Predictive Crash Safety Evaluation Memo, Apex Design

Mitigation Measures and Best Management Strategies

The mitigation measures in **Table 13** will be implemented should the Proposed Action be constructed.

Table 13. Resource Mitigation Measures

<table>
<tr><th colspan="4">CONTEXT</th></tr>
<tr><td colspan="4">I-70 is Colorado's only east-west interstate, providing a critical interstate commerce link for the country. West Vail Pass experiences traffic operation issues with disruptions to travel caused by geometric challenges, slow-moving vehicle volumes and interactions, and speed differentials resulting in conflicts and erratic driver behavior (lane changing and sudden braking).
There are steep and relatively long grades along West Vail Pass that create wide variations in speeds between different types of vehicles. Sharp curves at MP 186 contribute to safety issues in the WB direction (downhill) and speed differentials. In the EB (uphill) direction, winter snow storage results in narrow driving area with limited to no shoulders. This disrupts traffic flow with no pull-off area for incidents and response and no breakdown area for uphill drivers. In the downhill direction, the combination of steep grades with tight curves create issues for heavy vehicles and there is no pull-off area for hot brakes to cool.
The speed limit is posted at 65 mph with a 45 mph truck speed limit in the WB (downhill) direction. The corridor's Annual Average Daily Traffic is approximately 22,000 vehicles per day.</td></tr>
<tr><th>IMPACT TYPE</th><th>NO ACTION ALTERNATIVE</th><th>PROPOSED ACTION ALTERNATIVE</th><th>MITIGATION</th></tr>
<tr><td>Transportation – Travel Delays</td><td><u>Permanent Impacts:</u>
• Travel delays due to backups from slow-moving vehicles would increase as volumes increase, particularly in the peak travel periods.
• I-70 drivers would experience increasingly unreliable travel times as interactions with slow-moving vehicles increase.</td><td><u>Permanent Impacts:</u>
• Auxiliary lanes would reduce travel delays caused by slow-moving vehicles by providing another lane for passing maneuvers.
• Delays due to incidents blocking a lane or shoulder would be reduced with more space for passing.

<u>Temporary Impacts:</u>
• Traffic delays and backups may increase during construction with lane shifts, restrictions, and closures.</td><td><u>Permanent</u>:
None

<u>Temporary</u>:
• Extensive warning signage for work zone will warn drivers of downstream traffic delays and backups.
• CDOT will work with the contractor to avoid closures to the greatest extent possible during peak periods.
• Short-term lane closures will be consistent with the CDOT Region 3 Lane Closure Strategy to minimize construction delays.</td></tr>
</table>

Impact Type	No Action Alternative	Proposed Action Alternative	Mitigation
Transportation – Emergency Response	**Permanent Impacts:** • Emergency response would continue to remain challenged with limited area to access crashes or disabled vehicles.	**Permanent Impacts:** • Emergency response would improve with reduced crashes and increased area for disabled vehicles to me moved out of the travel lanes and into the shoulder. • Shoulders and auxiliary lanes would provide more space for first responders and law enforcement to access crashes or disabled vehicles/breakdowns. **Temporary Impacts:** • First responders and law enforcement may have limited shoulder area for emergency response during construction.	**Permanent**: None **Temporary**: • CDOT will work with the contractor to maximize the number and frequency of emergency pull-off areas to the greatest extent possible through the work zone.
Transportation – Highway Closures	**Permanent Impacts:** • Partial and full highway closures would be expected to increase as more crashes and other incidents occur.	**Permanent Impacts:** • ITS applications would increase the effectiveness and reduce the overall duration of highway closures due to weather events and other incidents. • Highway closures due to minor crashes and vehicle breakdowns would be reduced because vehicles and trucks could use the shoulder as a refuge area with the auxiliary providing more space while keeping at least one lane of traffic open. **Temporary Impacts:** • Traffic delays and backups may increase during construction with partial and full highway closures.	**Permanent**: None **Temporary**: • CDOT will work with the contractor to avoid closures to the greatest extent possible during peak periods. • CDOT and the contractor will notify emergency service providers of the timing of impending highway closures during construction.

Impact Type	No Action Alternative	Proposed Action Alternative	Mitigation
Transportation - Safety	**<u>Permanent Impacts:</u>** • Safety issues would persist and worsen as volumes increase along the corridor. • I-70 would continue to have segments with grades exceeding the standard maximum five percent grade.	**<u>Permanent Impacts:</u>** • Auxiliary lanes, wider shoulders, ITS improvements, improved signage, and curve modifications would improve driver safety and reduce fixed object, rear-end, and sideswipe same direction type crashes. The overall predicted crash reduction is in the range of 37 – 41 percent, which equates to as much as 100 less crashes occurring along the study corridor every year. • Concrete median and outside barrier would limit the sight distance on some curves below the standard, requiring FHWA design exceptions, but would improve sight distance over existing conditions. • The I-70 alignment would closely follow the existing roadway profile and segments would continue to have grades exceeding the standard maximum five percent grade, requiring an FHWA design exception. **<u>Temporary Impacts:</u>** • Construction delays and lane restriction may increase potential for crashes during construction.	**<u>Permanent</u>**: • Providing six-foot inside shoulders, wider outside shoulder width at several locations, the added auxiliary lane in each direction, improved curve radii and superelevation, and improved signage with dynamic and enhanced advance curve signs will minimize the minimal safety impacts of the reduced sight distance. • Providing lower truck chain station improvements, truck emergency ramp improvements, the added auxiliary lane in each direction, improved curve radii and superelevation, and improved signage with dynamic and enhanced advance curve signs will minimize the safety impacts of maintaining the existing I-70 grades. **<u>Temporary</u>**: • Extensive warning signage for work zone will warn drivers of downstream traffic delays and backups and provide information on appropriate speeds. • Work requiring lane closures will be conducted at night as much as possible. CDOT will work with the contractor to avoid closures to the greatest extent possible and closures will be minimized to the greatest extent possible during peak periods.

Permits

During construction, several permits may be required for access, lane closures, and construction traffic control procedures. Construction access permits are required to be obtained by the construction contractor for detours and lane closures. The construction contractor will also be required to contact CDOT Traffic Section for any additional permitting required within CDOT right-of-way as design is finalized.

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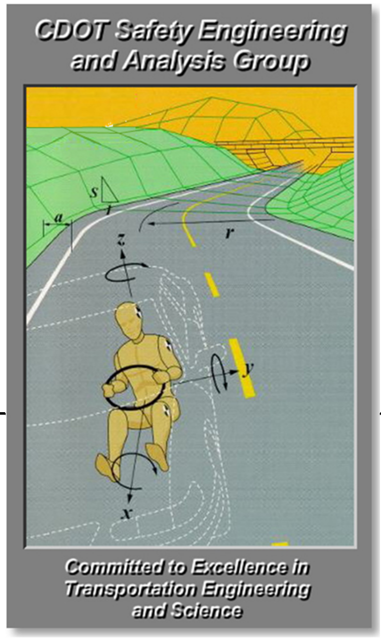
Appendix A

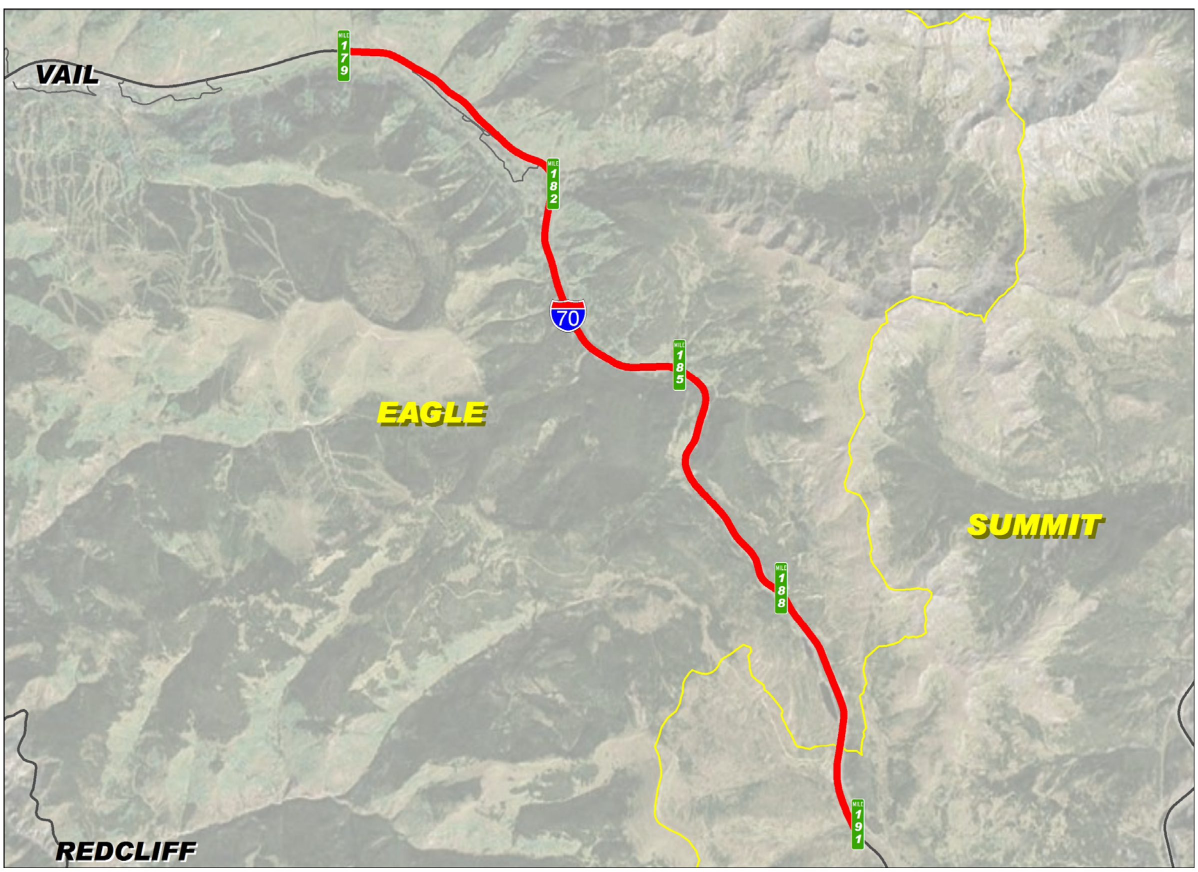
Safety Assessment Report



Safety Assessment Report

I-70: MP 179.00 to MP 191.00
West Vail Pass Auxiliary Lanes
Environmental Assessment
January 2018

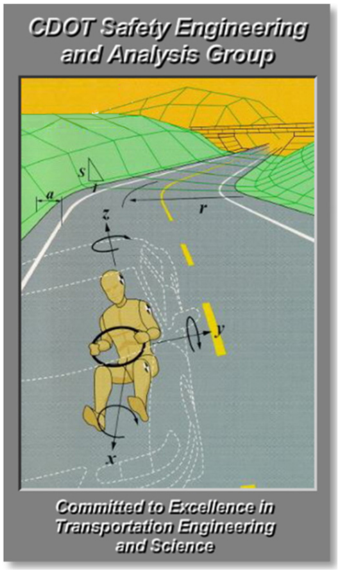
Prepared by Felsburg Holt & Ullevig under the direction of:
The Colorado Department of Transportation
HQ Safety and Traffic Engineering Branch
4201 E. Arkansas Ave, 3rd Floor
Denver, Colorado 80222



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 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 subjected 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.



A 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 the 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 crashes could have been prevented.[1] It is CDOT's objective to maximize crash reduction within the limitations of available budgets by making road safety improvements at locations where it does the most good or prevents the most crashes.

Introduction

The purpose of this safety assessment is to identify current safety issues and potential improvements to improve safety along Interstate 70 (I-70) between milepost (MP) 179.00 to MP 191.00 as part of the I-70 West Vail Pass Auxiliary Lanes Environmental Assessment. This study identifies crash patterns for both the eastbound and westbound directions of travel along I-70 as well as at the interchanges within the study area. This study also provides general safety improvements to be considered.

The scope of this report is as follows:

- Assess the magnitude and nature of the safety problem within the project limits.
- Relate crash causality to roadway geometrics, roadside features, traffic control devices, traffic operations, driver behavior, and vehicle type.
- Suggest cost effective counter measures to address identified problems.
- Provide guidance on how to maximize crash reduction.

This report is based on the comprehensive analysis of three years of crash history (2014-2016) and video log review. The Region is advised to verify through field survey, the information included in this report regarding physical features and roadside characteristics in the study area.

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

Site Locations and Conditions

This study addresses a section of I-70 in Eagle County that extends into Summit County beginning at MP 179.00, west of East Vail interchange, and extending to MP 191.00, east of the Vail Pass/Shrine Pass Road interchange and rest area. The study area is mostly in Eagle County with approximately 1 mile in Summit County. The included distance is approximately 12 miles.

I-70 is classified as a rural interstate through the study section. I-70 is a four-lane divided facility through a mountainous environment with a depressed median. There are two interchanges in the study section, including: East Vail (Exit 180 – MP 179.9) and Vail Pass (Exit 190 – MP 189.9). The 2016 average daily traffic (ADT) for the corridor is 22,000 vehicles per day (VPD). There are approximately 11% trucks on the corridor.

Crash Summary

The crash history for the period of January 1, 2014 through December 31, 2016 was examined to locate crash clusters and identify collision causes. Within the study period, 566 crashes were reported along I-70 between MP 179.00 and MP 191.00 including mainline, ramp, and ramp terminal crashes. Of these, there were 121 injury collisions with 205 injured. **Table 1** summarizes the crash totals for this segment of I-70 over the three-year study period.

Table 1: Crash Totals for I-70 (MP 179.00 to MP 191.00)

Year	PDO* Crashes	Injury Crashes	Injuries	Fatal Crashes	Fatalities	Total
2014	163	54	98	0	0	217
2015	143	28	46	0	0	171
2016	139	39	61	0	0	178
Total	**445**	**121**	**205**	**0**	**0**	**566**
Average/Year	**148**	**40**	**68**	**0**	**0**	**189**

*PDO – Property Damage Only crashes

Mainline Crash History

Figure 1 shows the crash distribution by crash type for mainline I-70. There was a total of 558 mainline crashes in the corridor. Fixed object crashes were the most common crash type (54 percent), followed by rear end (13.4 percent) and sideswipe same direction crashes (11.8 percent).

Figure 1: I-70 Mainline Crash Distribution by Type

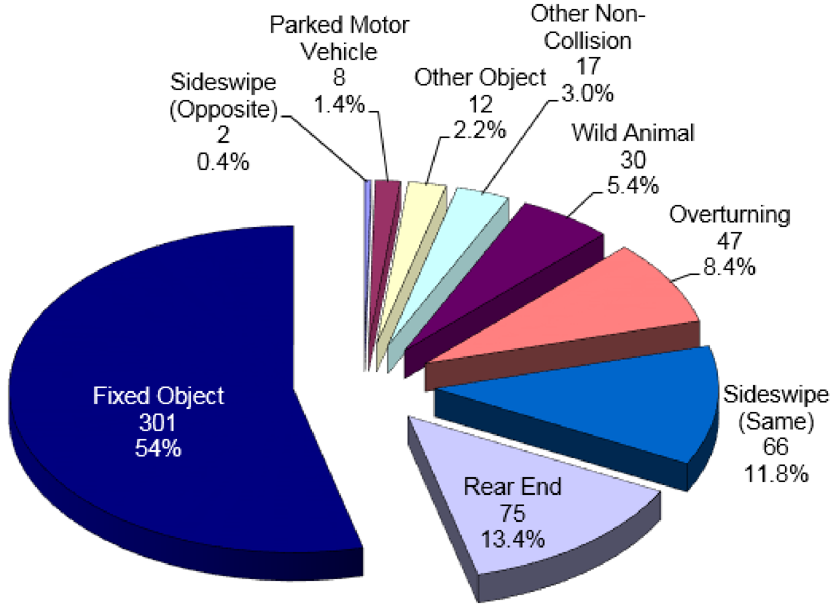


Figure 2 shows the breakdown of the fixed object crashes. Concrete barrier crashes accounted for the majority of fixed object crashes (47.8 percent), followed by embankment crashes (35.9 percent).

Figure 2: I-70 Mainline Fixed Object Crash Distribution by Type

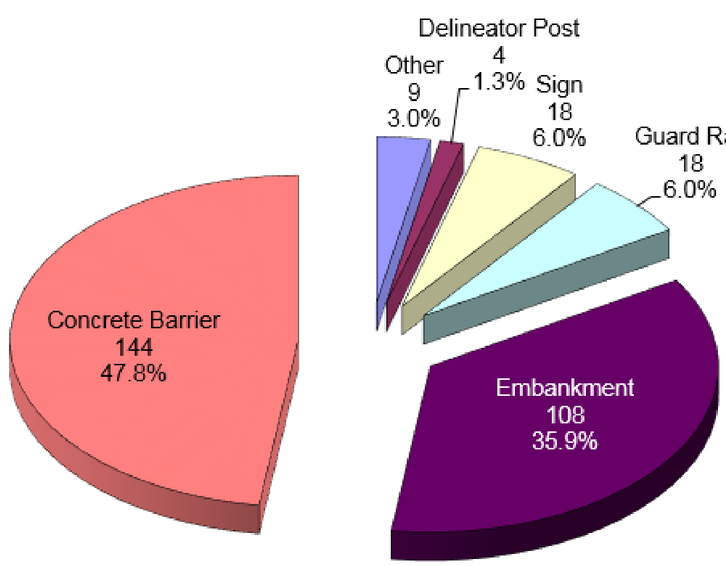


Figure 3 provides the breakdown of the mainline crashes by time of day and direction. As shown there are more crashes occurring in the westbound direction. Approximately 65 percent of crashes are westbound and 35 percent are eastbound. The eastbound direction has a slight increase in crashes during the PM peak period of 3:00 PM to 6:00 PM. The westbound direction has an increase in crashes during the AM peak period between 9:00 AM and 11:00 AM.

Figure 3: I-70 Mainline Crashes by Time of Day and Direction

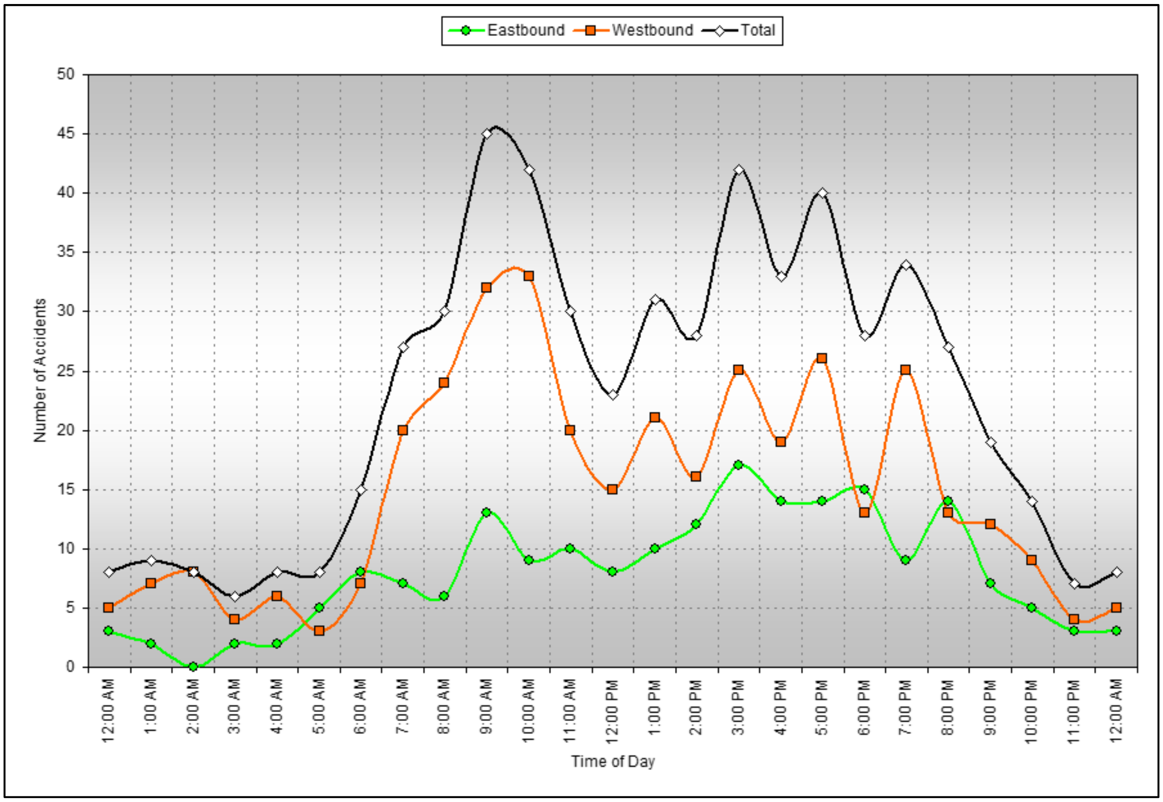


Figure 4 provides the breakdown of the mainline crashes by the day of week. As shown, Friday has the highest number of crashes. This peak on Friday corresponds to a peak in average daily traffic (ADT) westbound on Fridays, as shown in **Figure 5**. As was shown earlier, the westbound direction has a higher number of crashes, which is why the westbound ADT peak corresponds to the crash peak.

Figure 4: I-70 Mainline Crashes by Day of Week

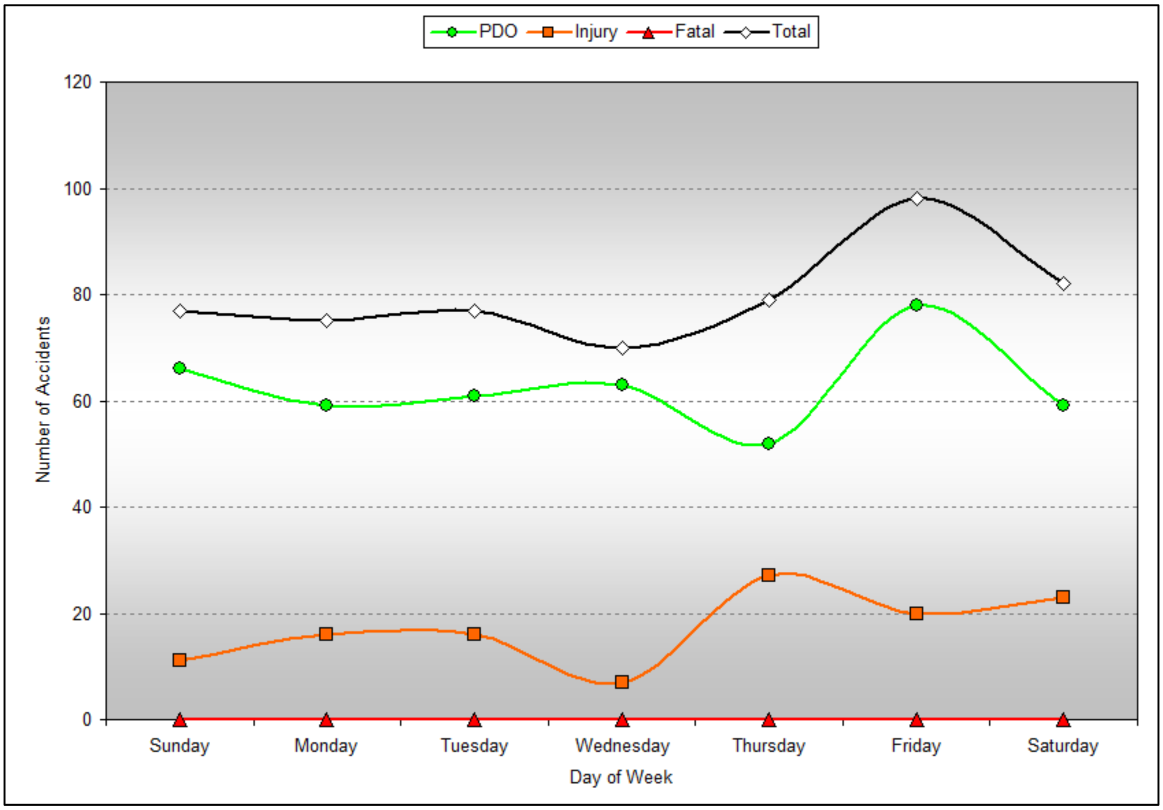


Figure 5: I-70 2016 ADT by Day of Week

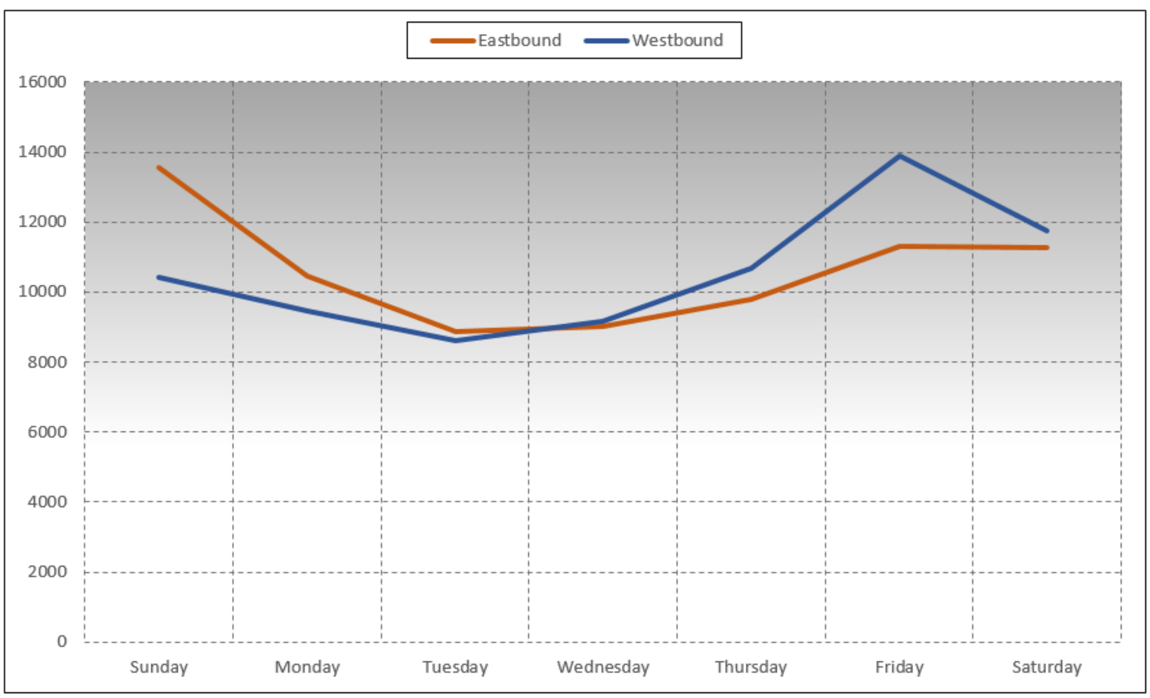


Figure 6 shows the crashes occurring by month of the year. As shown, there are significantly more crashes occurring during winter months, with the peak in January and February with over 80 crashes per month on average. During the summer months of July through October there are less than 25 crashes occurring per month on average.

Figure 6: I-70 Mainline Crashes by Month

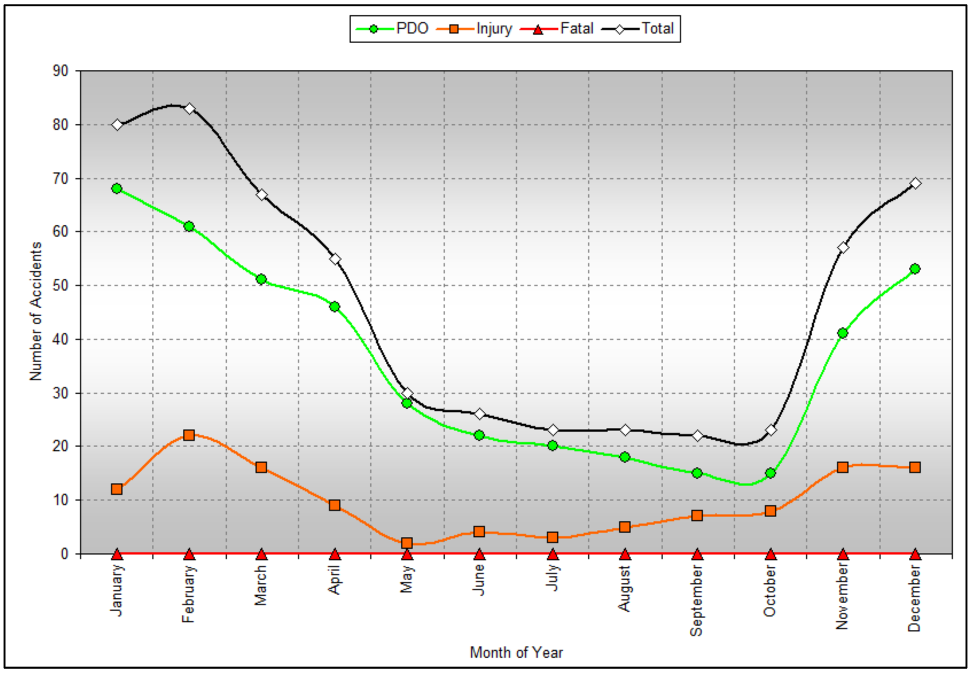
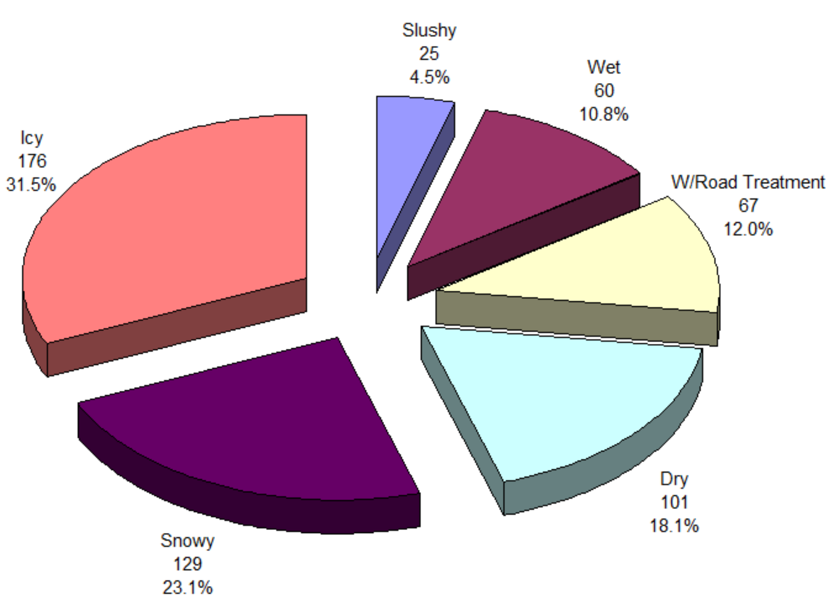


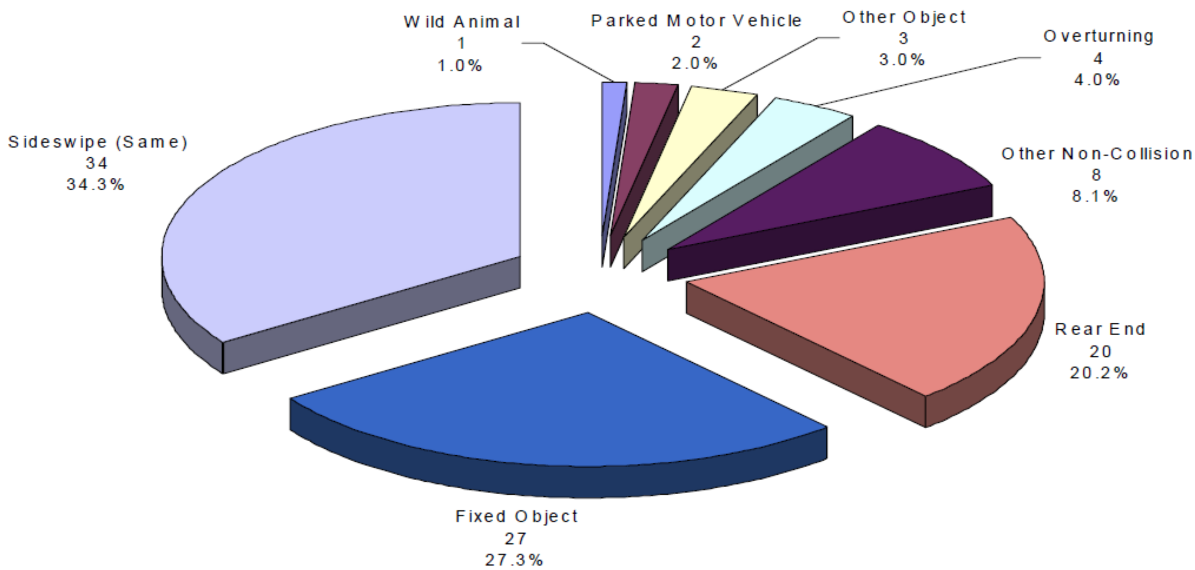
Figure 7 provides the crashes by road condition. As shown, 59 percent of crashes occur on icy, slushy, or snowy roads. While only 18 percent of the crashes occur on dry roads. Road conditions appear to be a significant factor in crashes, shown by number of crashes occurring in poor road conditions and occurring during winter months.

Figure 7: I-70 Mainline Crashes Road Condition



There was total of 99 crashes in the corridor that involved heavy trucks, and 69 (12.4 percent) of these were caused by these heavy vehicles. Trucks caused slightly more crashes than their overall proportion of total traffic (10.8 percent). **Figure 8** provides a summary of the types of crashes that involved trucks. Crashes involving at least two vehicles (sideswipe [same] and rear end) represent over half (54.5 percent) while fixed objects (27.3 percent) are half this proportion. This is just about the opposite proportions as found for all crashes (see **Figure 1**). Also by way of comparison, a higher proportion of truck crashes (25 – 25.2 percent) occur on dry roads; higher than the proportion for all traffic (18.1 percent). Finally, approximately 70 percent of the crashes involving trucks were westbound which slightly higher than the proportion for overall traffic (65 percent).

Figure 8: I-70 Mainline Crashes Involving Trucks

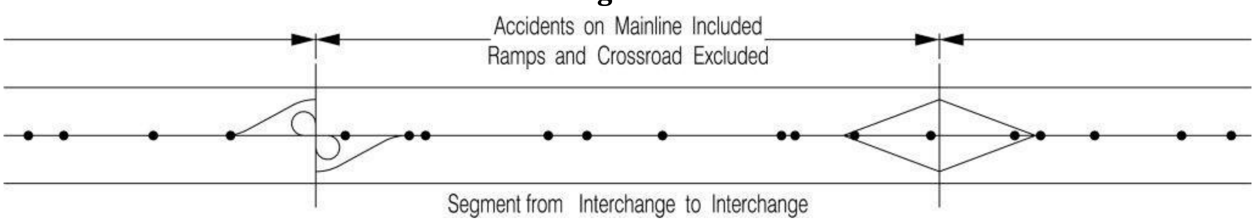


Safety Performance Functions

We have refined the assessment of the magnitude of safety problems on highway segments through the use of Safety Performance Functions (SPF). The SPF reflects the complex relationship between traffic exposure, measured in average daily traffic (ADT), and crash count for a unit of road section measured in crashes per mile per year. The SPF models provide an estimate of the normal or expected crash frequency and severity for a range of ADT among similar facilities. Two kinds of Safety Performance Functions were calibrated. The first one addresses the total number of crashes and the second one looks only at crashes involving an injury or fatality. It allows us to assess the magnitude of the safety problem from the frequency and severity standpoint.

All of the dataset preparation was performed using the Colorado Department of Transportation (CDOT) crash databases. Crash history for each facility was prepared using the most recent 10 years of available crash data. The ADT for each roadway segment for each of the 10 years was entered into the same dataset. Each dataset is corrected for the regression to the mean bias using the Empirical Bayes (EB) procedure. **Figure 9** illustrates how the dataset was prepared for interstates.

Figure 9



Development of the SPF lends itself well to the conceptual formulation of the Level of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance. If the level of safety predicted by the SPF will represent a normal or expected number of crashes at a specific level of ADT, selected percentiles within the frequency distribution can be stratified to represent specific levels of safety.

- LOSS I – Indicates a low potential for crash reduction
  (below 20^{th} percentile)
- LOSS II – Indicates a low to moderate potential for crash reduction
  (20^{th} percentile to mean)
- LOSS III – Indicates a moderate to high potential for crash reduction
  (mean to 80^{th} percentile)
- LOSS IV – Indicates a high potential for crash reduction
  (above 80^{th} percentile)

LOSS reflects how the roadway segment is performing in regard to its expected crash frequency and severity at a specific level of ADT. It only provides a crash frequency and severity comparison with the expected norm. It does not, however, provide any information related to the nature of the safety problem itself. If the safety problem is present, LOSS will only describe its magnitude from the frequency and severity standpoint. The nature of the problem is determined through diagnostic analysis using direct diagnostic and pattern recognition techniques.

The corridor was divided into segments based on interchange locations, curve locations, and grades. Below are the segments with descriptions:

- Segment 1 – MP 179.00 to MP 182.00
- Segment 2 – MP 182.01 to MP 184.50
- Segment 3 – MP 184.51 to MP 186.50
- Segment 4 – MP 186.51 to MP 191.00

Figure 10 shows the safety performance of the highway from a total frequency standpoint by segment. As shown, Segment 1 falls into the LOSS III category for the frequency, indicating moderate to high potential for crash reduction. Segments 2, 3, and 4 fall into the LOSS IV category, indication high potential for crash reduction.

Figure 11 shows the safety performance of the highway from a severe crash standpoint. Segments 1 and 2 fall into the LOSS II or LOSS III categories, indicating moderate potential for crash reduction. Segments 3 and 4 fall into the LOSS IV category, indicating high potential for crash reduction.

Figure 10: Rural, Mountainous 4-Lane Divided Interstate – Total Crashes

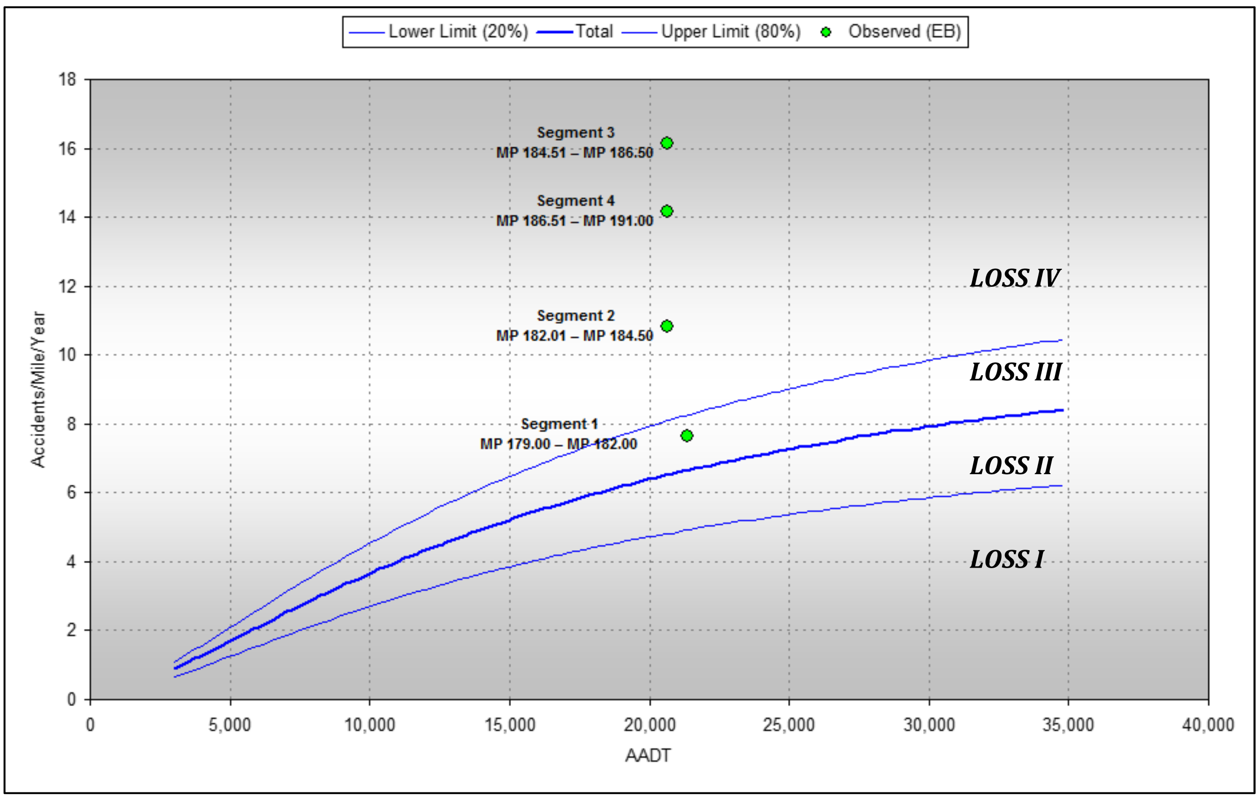
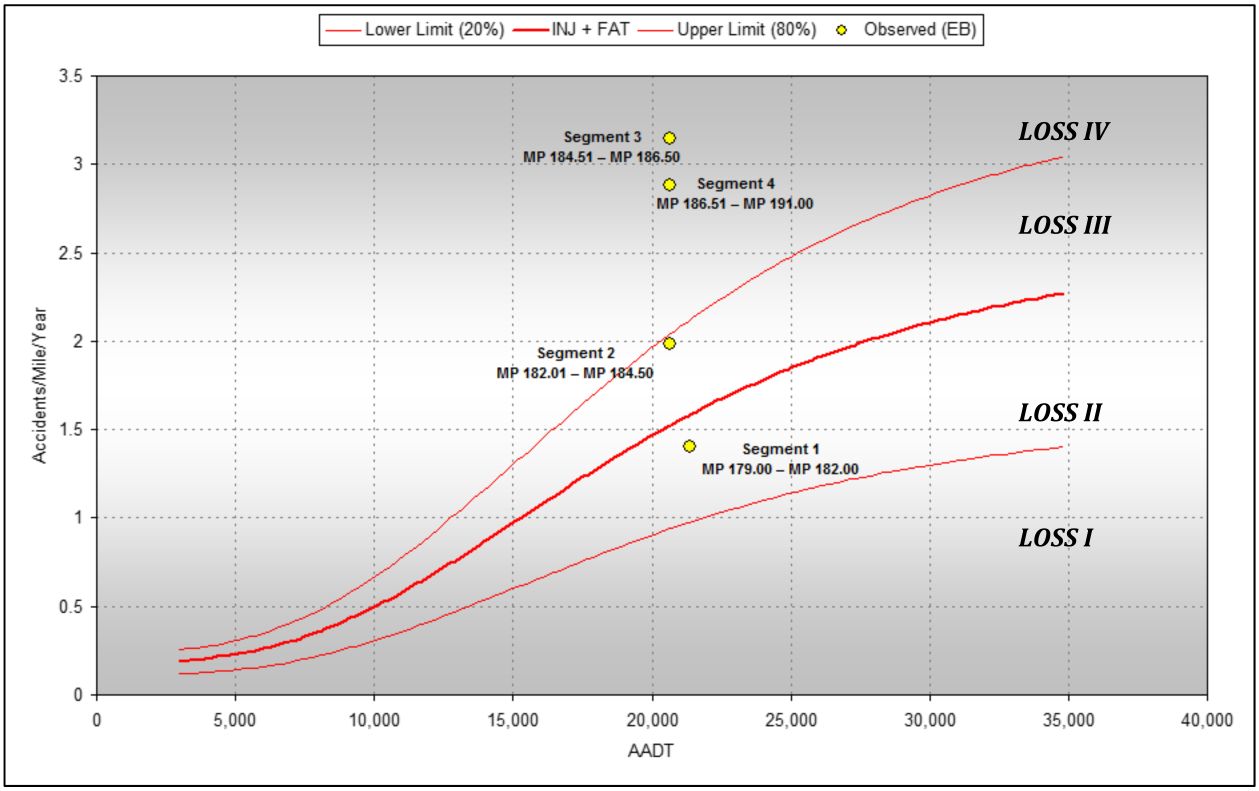


Figure 11: Rural, Mountainous 4-Lane Divided Interstate – Severe Crashes



Pattern Recognition Analysis

The non-intersection crashes within the project limits were tested for the presence of patterns related to accident type, severity, direction of travel, road conditions, spatial distribution of accidents, time of day and behavioral attributes. Pattern recognition analysis for I-70 was performed using normative percentages for diagnostics of safety problems for a 4-lane rural mountainous divided freeway. These diagnostic norms were developed using the same data points as those graphed in the SPF analysis. This section covers notable accident types and conditions over the study period within the project limits. Anything exceeding 95 percent probability is considered to be a pattern. Both directions were analyzed when detecting patterns. **Table 2** provides an overall summary by segment of the crashes and crash patterns found.

Table 2: I-70 Segment Summary

	Segment 1	**Segment 2**	**Segment 3**	**Segment 4**
MP	179.00 - 182.00	182.01 - 184.50	184.51 - 186.50	186.51 - 191.00
Elevation	8,320' – 8,700'	8,700' – 9,270'	9,270' – 10,000'	10,000' – 10,590'
Average Grade	2.4%	4.3%	6.9%	4.6% w/o top 2.9% e/o top
Maximum Grade	-	6.8%	7.0%	7.4%
Total Crashes	74	101	135	248
PDO Crashes	63	82	104	189
INJ Crashes	11	19	31	59
Crashes/Mile	21.0	40.4	67.5	55.1
Predominant Crash Type	Fixed Object (39%)	Fixed Object (55%)	Fixed Object (59%)	Fixed Object (56%)
Predominant Fixed Object Crash Type	Concrete Barrier (52%)	Concrete Barrier (56%)	Concrete Barrier (61%)	Embankment (49%)
Direction	Eastbound 40 % Westbound 60 %	Eastbound 61 % Westbound 39 %	Eastbound 27 % Westbound 73 %	Eastbound 26 % Westbound 74 %
% Inclement Road Conditions	68%	76%	88%	85%
Crashes Caused by Trucks (% of total crashes)	8 Crashes (11%)	15 Crashes (15%)	23 Crashes (17%)	23 Crashes (9%)
Crash Patterns	Wild Animal Concrete Barrier Embankment	Rear-End Sideswipe Same Concrete Barrier Total Fixed Objects	Concrete Barrier Embankment Total Fixed Objects	Off Road Overturning Sideswipe Same Sign Concrete Barrier Embankment Total Fixed Objects

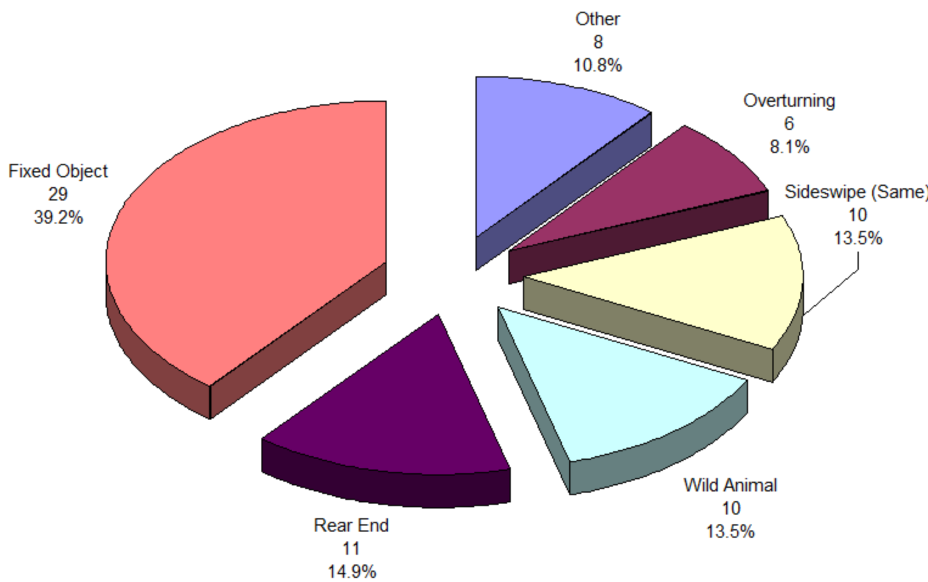
As shown in **Table 2**, the predominant crash type across all segments in fixed object. In Segments 1 through 3, the predominant fixed object crash type is concrete barrier, while it is embankment in Segment 4.

It should be noted, that the highest crash rate is found in Segment 3, which also has the largest number of poor road condition crashes, the steepest grades in the westbound direction, and a high percentage of westbound crashes. The following sections will discuss the patterns by segment in more detail.

Segment 1: MP 179.00 – 182.00

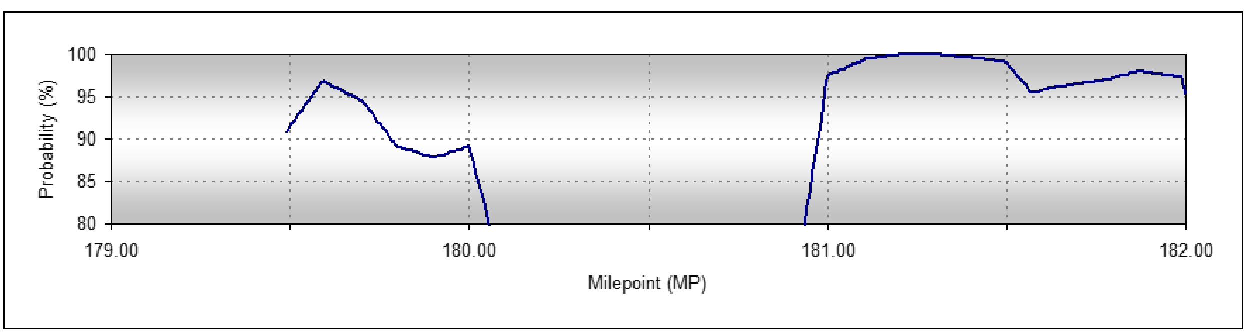
Segment 1 is at an elevation of 8,320 feet on the west end and 8,700 feet on the east end. The average grade over the segment is 2.4 percent. There is a relatively sharp curve (involving a large bridge over Gore Creek and Bighorn Road) between MP 181.70 and MP 182.00 in this segment. **Figure 12** contains a breakdown of crash types in Segment 1. Significant crash patterns found along the Segment 1 included wild animal, concrete barrier, and embankment.

Figure 12: Segment 1 Crash Distribution by Type



Wild Animal Crashes

Figure 13: Location Pattern of Wild Animal Crashes

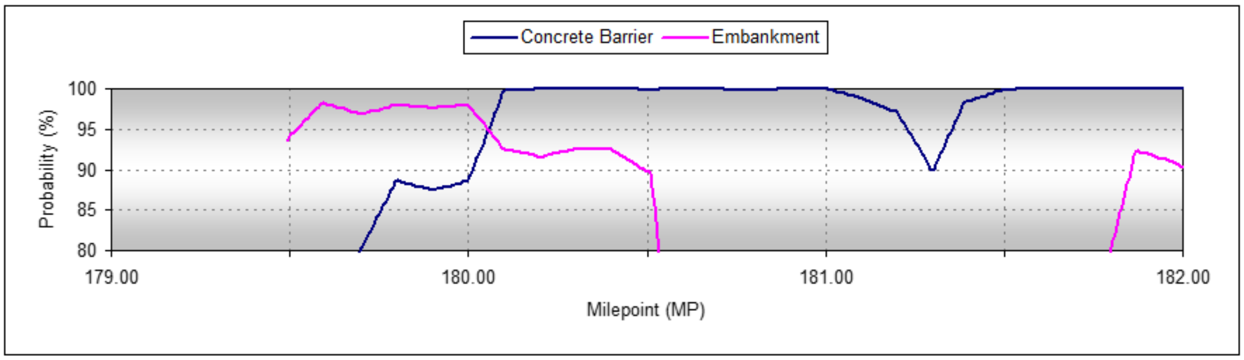


Total: 10 Crashes (2014-2016)
Severity: 10 PDO
Direction: 2 Eastbound, 8 Westbound
Causal Factor: Most of the crashes (9 of 10) were with deer, although one instance involved a bear. Of the 10 crashes, 8 occurred in the westbound direction and 2 occurred in the eastbound direction. All of the wildlife crashes occurred in the summer months (May-October). Nearly all of these crashes were in dry conditions and occurred during dark lighting conditions (9 of 10). All crashes occurred between 6:00 PM and 6 AM, with most during the hours of dawn and dusk. Six of the crashes occurred between MP 181.00 and MP 181.60.

Recommendation: Consideration should be given to installing deer warning signs for the segment of MP 181.00 and MP 181.60 westbound. Alternatively, consider using VMS signs to warn of wildlife during peak wildlife crash times (May – August, dawn and dusk).

Concrete Barrier/Embankment Crashes

Figure 14: Location Pattern of Concrete Barriers/Embankment Crashes



Total: 15 Concrete Barrier Crashes (2014-2016)
8 Embankment Crashes
Severity: Concrete Barrier Crashes - 12 PDO, 3 Injury (3 Injured)
Embankment Crashes - 5 PDO, 3 Injury (4 injured)
Causal Factor: Figure 15 provides the location of the concrete barrier and embankment crashes. As shown, there is a cluster between MP 181.80 and MP 182.00. There is a large curve between MP 181.70 and MP 182.00. In addition, there is a bridge over Gore Creek and Bighorn Road on the curve between MP 181.80 and MP 181.95. All but one of the crashes in this cluster occurred during inclement road conditions.

Figure 15: Location of Concrete Barriers/Embankment Crashes

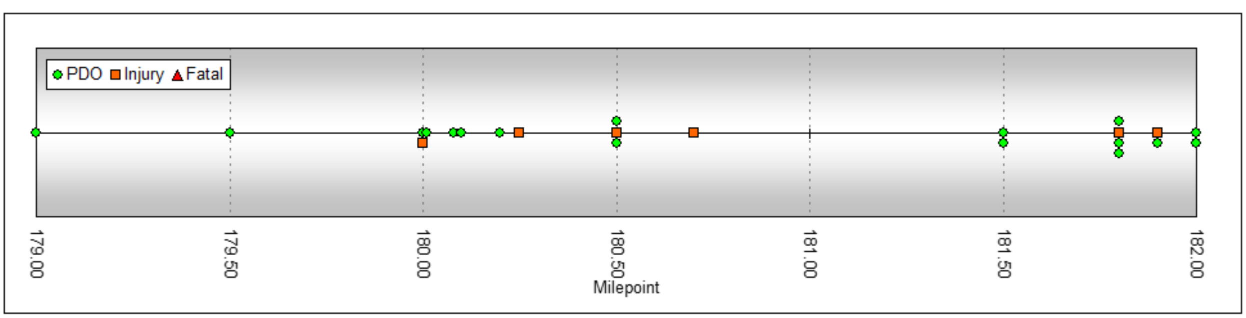


Table 3 shows the lighting and roadway conditions present for the concrete barrier/embankment crashes by direction for this segment. As can be seen in the table, these crashes occurred in both directions. They occurred mostly in the day and primarily on inclement road conditions. In the westbound direction, all of the crashes occurred during inclement road conditions.

Table 3: Lighting and Road Conditions for Concrete Barrier/Embankment Crash Types

Lighting Condition	Eastbound			Westbound		
	Dry	Inclement Road Conditions	Total	Dry	Inclement Road Conditions	Total
Daylight	3	5	8	0	6	6
Dawn/Dusk	0	1	1	0	1	1
Night	0	4	4	0	3	3
Total	3	10	13	0	10	10

Recommendation: Consider installing variable speed limit signs (VSL) as well as dynamic speed display signs (DSDS) in both directions in the vicinity of MP 180.00 eastbound and MP 182.00 westbound and varying the speed based on weather conditions. Consider installing the warning sign BRIDGE ICES BEFORE ROAD (W8-13) on both approaches to the Gore Creek bridge. Consider widening the roadway to three lanes to give vehicles more space to avoid slower moving vehicles and to make evasive maneuvers to help reduce the number of rear end and sideswipe (same) crashes. Consider widening the inside and outside shoulder widths to 12 feet to allow for drivers that leave the travel lane more time to correct before hitting a barrier.

Truck Involved Crashes

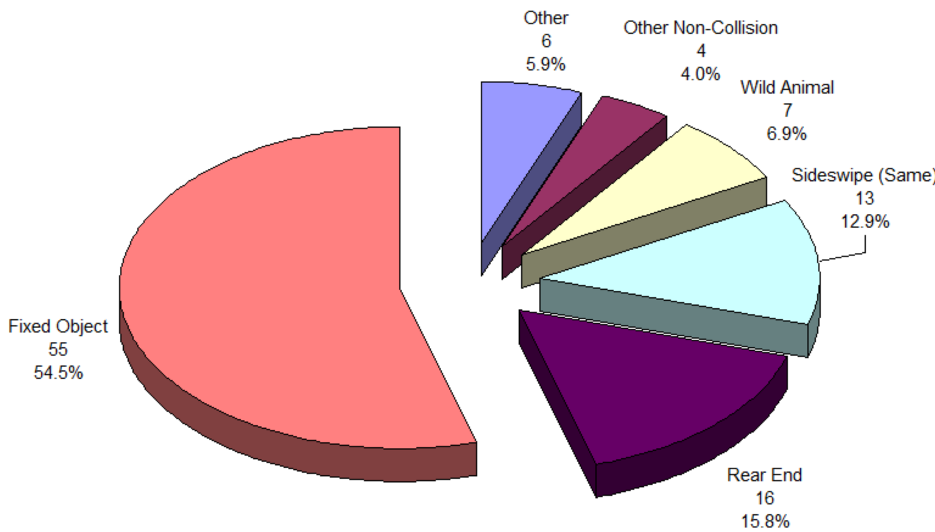
Total: 13 Crashes (2014-2016)
Severity: 12 PDO, 1 INJ (1 injured)
Direction: 4 Eastbound, 9 Westbound
Crash Types: Rear end (4), Sideswipe [same] (6), Fixed object (2), Overturning (1)
Crashes Caused by Trucks: 8 Crashes, 2 Eastbound, 6 Westbound
Causal Factor: Most of the crashes (10 of 13) involved another vehicle (rear end or sideswipe [same]), and 9 out of 13 were westbound. Only 4 of the crashes occurred during dry roadway conditions. These patterns lead to the conclusion that trucks (as well as other vehicles) are having difficulty maneuvering to avoid other vehicles or departing from their lane.

Recommendation: Consider widening the roadway to three lanes to give vehicles more space to avoid slower moving vehicles and to make evasive maneuvers to help reduce the number of rear end and sideswipe (same) crashes. Consider widening the inside and outside shoulder widths to 12 feet to allow for drivers that leave the travel lane more time to correct before hitting a barrier.

Segment 2: MP 182.01 – 184.50

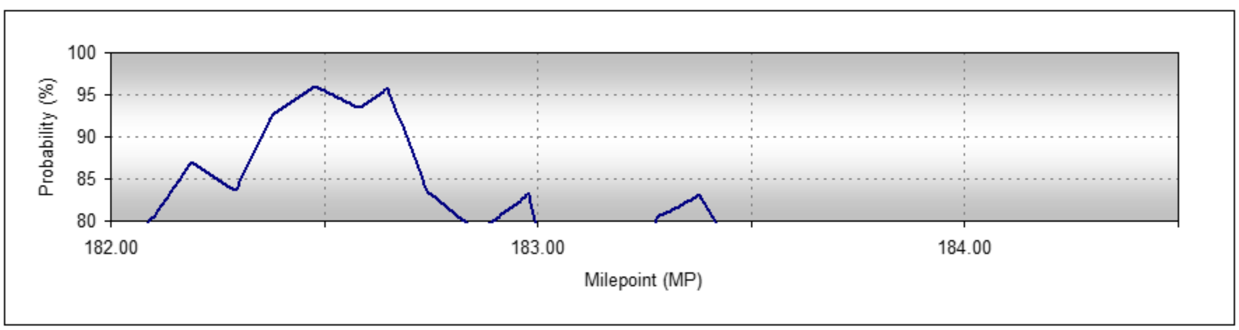
Segment 2 is at an elevation of 8,700 feet on the west end and 9,270 feet on the east end. The average grade over the segment is 4.3 percent. There is a westbound runaway truck ramp at approximately MP 182.10. **Figure 16** contains a breakdown of crash types in Segment 2. Patterns found along the Segment 2 included rear-end, sideswipe same direction, concrete barrier, and fixed objects.

Figure 16: Segment 2 Crash Distribution by Type



Rear-End Crashes

Figure 17: Location Pattern of Rear-End Crashes

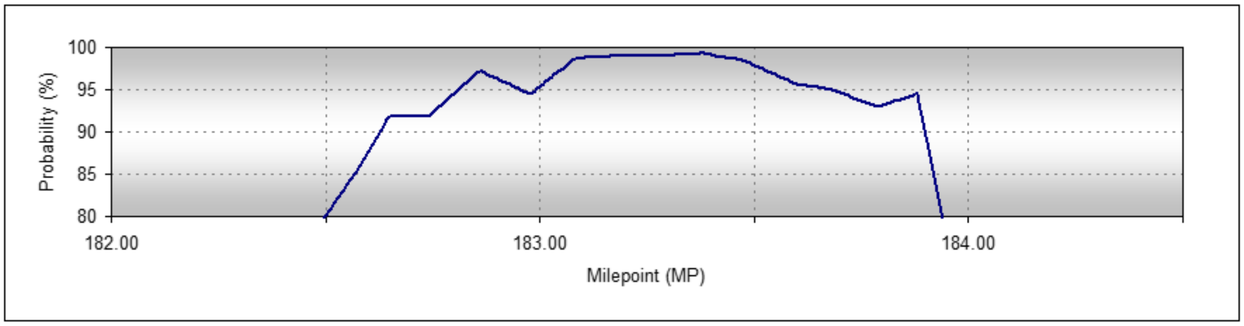


Total: 16 Crashes (2014-2016)
Severity: 10 PDO, 6 Injury (10 injured)
Causal Factor: These crashes occurred equally in both the eastbound and westbound directions. These crashes occur mostly during the day with some occurring on inclement road conditions (6 of 16) and most occurring during the winter (11 of 16). Traffic congestion is normally a primary factor for rear-end crashes. Through this segment, speed differentials due to the adverse road conditions may also be a significant contributing factor.

Recommendation: Consider using variable message signs (VMS) to warn driver in advance if there is slowing traffic and poor weather conditions. Widening to three lanes in each direction would provide more space to avoid slower moving vehicles and to make evasive maneuvers (and to reduce peak skier congestion) in order to help reduce rear-end crashes.

Sideswipe Same Direction Crashes

Figure 18: Location Pattern of Sideswipe Same Direction Crashes

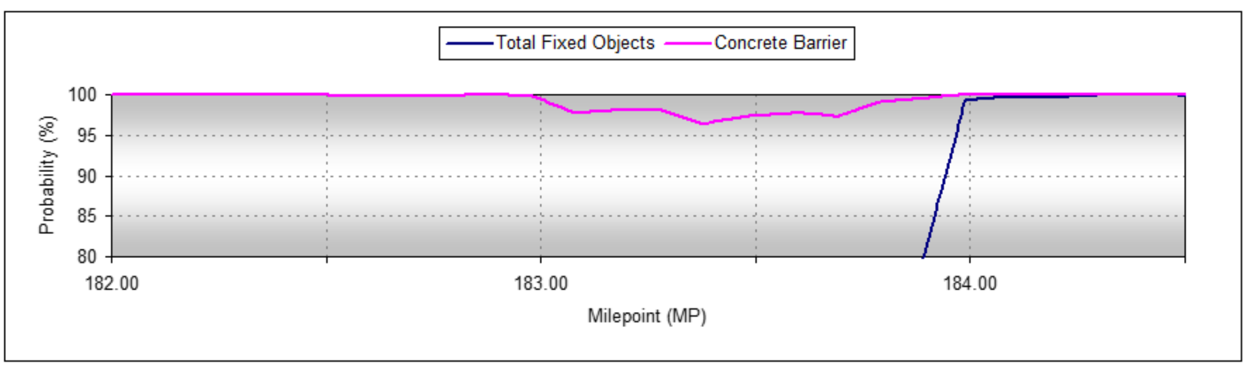


Total: 13 Crashes (2014-2016)
Severity: 11 PDO, 2 Injury (2 injured)
Causal Factor: The sideswipe same direction type crashes occurred in both the eastbound (7 crashes) and westbound directions (6 crashes) The largest number of crashes occurred in the morning and afternoon peak periods. These crashes occur mostly in the day with many occurring on inclement road conditions (8 of 13). Traffic congestion is normally a primary factor for sideswipe same direction crashes. In the context of Vail Pass and the adverse road conditions that are regularly experienced in the winter, losing control and hitting another car (instead of a fixed object) are indicative of conditions where lane departures cannot be avoided.

Recommendation: Consider using variable message signs (VMS) to warn driver in advance if there is slowing traffic and poor weather conditions. Consider widening to three lanes in each direction to provide more space to avoid slower moving vehicles and to make evasive maneuvers (and reduce any peak skier congestion) to help reduce sideswipe same direction crashes.

Fixed Object/Concrete Barrier Crashes

Figure 19: Location Pattern of Fixed Object/Concrete Barrier Crashes



Total: 55 Fixed Object Crashes (Includes Concrete Barrier Crashes) (2014-2016)
31 Concrete Barrier Crashes
Severity: Fixed Object Crashes - 44 PDO, 11 Injury (21 Injured)
Concrete Barrier Crashes - 25 PDO, 6 Injury (8 injured)
Causal Factor: Although the concrete barrier crash pattern is present throughout this segment of the corridor, in **Figure 20** it is shown that most of the fixed object and concrete barrier crashes occur

between MP 184.00 and MP 184.50. There is a large curve through this portion of the segment that contributes to the fixed object crashes. There is a bridge on this curve from approximately MP 184.40 to MP 184.50 over the Black Gore Creek.

Figure 20: Location of Fixed Object Crashes

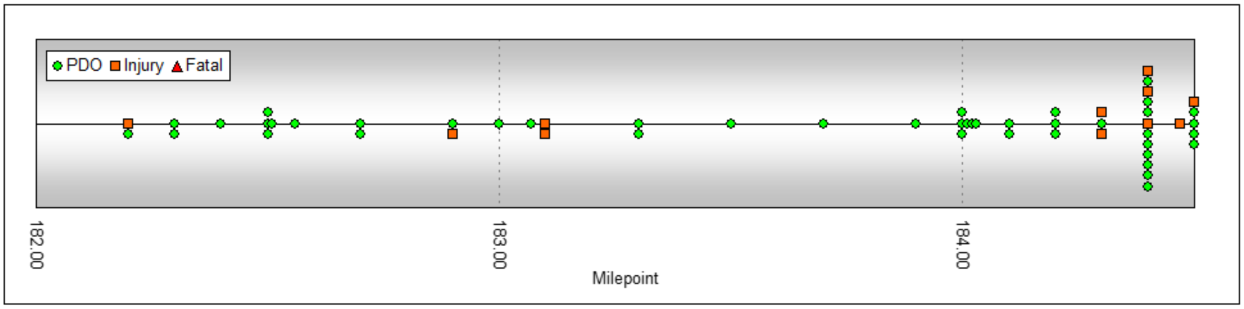


Table 4 shows the lighting and roadway conditions present for the fixed object crashes by direction.

Table 4: Lighting and Road Conditions for Fixed Object Crash Type

Lighting Condition	Eastbound			Westbound		
	Dry	Inclement Road Conditions	Total	Dry	Inclement Road Conditions	Total
Daylight	1	17	18	3	8	11
Dawn/Dusk	0	4	4	0	1	1
Night	0	16	16	2	3	5
Total	1	37	38	5	12	17

As can be seen in the table, the majority of fixed object crashes occurred in the eastbound direction in this segment. These crashes were split between day and night with virtually all crashes occurring on adverse road conditions. In the westbound direction, majority of the crashes also occurred during inclement road conditions (12 of 17).

The fixed object crashes were split between off-road left (33 of 55) and off-road right crashes (22 of 55). Many of these crashes were the result of driving carelessly for conditions. In the eastbound direction, there was a cluster of crashes on the Black Gore Creek bridge due to icy conditions. For eastbound drivers, the road is relatively straight and level, and vehicles may be gaining speed for the remainder of the push up to the top of the pass.

Recommendation: Consider installing the warning sign BRIDGE ICES BEFORE ROAD (W8-13) on the eastbound approach to the Black Gore Creek bridge. Also for eastbound drivers, consider installing variable speed limit (VSL) signs as well as dynamic speed display signs (DSDS) to vary speeds based on road conditions. Consider widening the inside and outside shoulder widths to 12 feet to allow for drivers that leave the travel lane more time to correct before hitting a barrier. Consider widening to three lanes in each direction would provide more space to avoid slower moving vehicles and to make evasive maneuvers.

Truck Involved Crashes

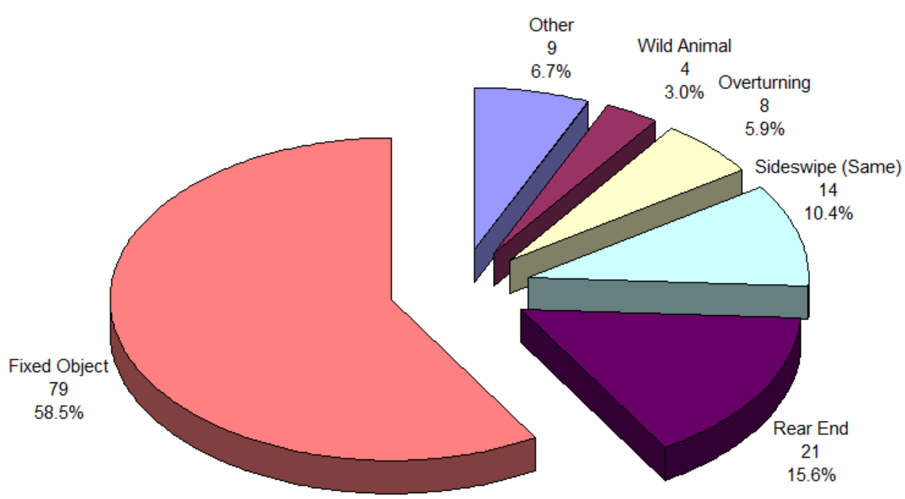
Total: 26 Crashes (2014-2016)
Severity: 23 PDO, 3 INJ (5 injured)
Direction: 12 Eastbound, 14 Westbound
Crash Types: Rear end (7), Sideswipe [same] (9), Fixed object (8), Other object (2)
Crashes Caused by Trucks: 15 Crashes, 8 Eastbound, 7 Westbound
Causal Factor: Most of the crashes (16 of 26) involved another vehicle (rear end or sideswipe [same]), and a slight majority (14 out of 26) were eastbound. Only 9 of the crashes occurred during dry roadway conditions. These patterns lead to the conclusion that trucks (as well as other vehicles) are having difficulty maneuvering to avoid other vehicles or departing from their lane.

Recommendation: Consider widening the roadway to three lanes to give vehicles more space to avoid slower moving vehicles and to make evasive maneuvers to help reduce the number of rear end and sideswipe (same) crashes. Consider widening the inside and outside shoulder widths to 12 feet to allow for drivers that leave the travel lane more time to correct before hitting a barrier.

Segment 3: MP 184.51 – 186.50

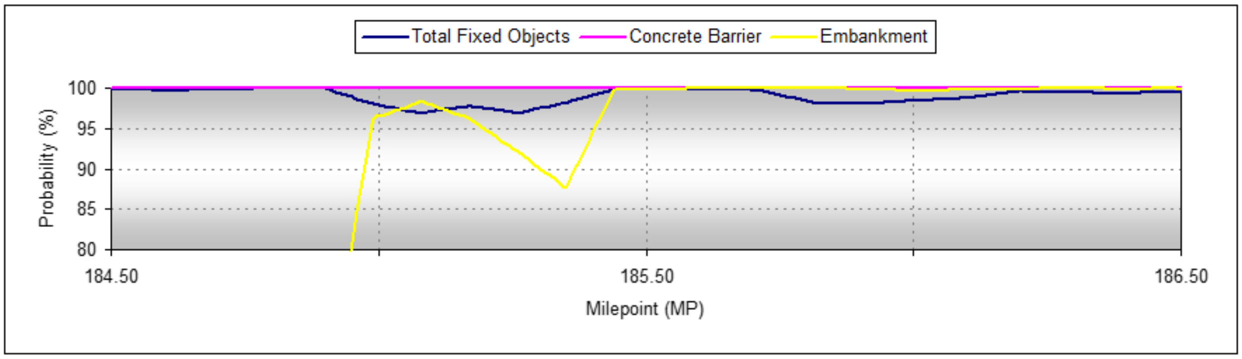
Segment 3 is at an elevation of 9,270 feet on the west end and 10,000 feet on the east end. The average grade over the segment is 6.9 percent and is fairly consistent. This segment has significant downgrades in the westbound direction and is at higher elevations than Segment 2. There is a westbound runaway truck ramp at approximately MP 185.6. There are a series of sharp curves through most of this segment. **Figure 21** contains a breakdown of crash types in Segment 3. Patterns found along the Segment 3 included concrete barrier, embankment, and fixed objects.

Figure 21: Segment 3 Crash Distribution by Type



Fixed Object/ Concrete Barrier/ Embankment Crashes

Figure 22: Location Pattern of Fixed Object/Concrete Barriers/Embankment Crashes



Total: 79 Fixed Object Crashes (Includes Concrete Barrier and Embankment Crashes) (2014-2016)
48 Concrete Barrier Crashes
22 Embankment Crashes
Severity: Fixed Object Crashes - 63 PDO, 16 Injury (20 Injured)
Concrete Barrier Crashes - 43 PDO, 5 Injury (6 injured)
Embankment Crashes - 12 PDO, 10 Injury (13 injured)
Causal Factor: Figure 23 shows the locations of the fixed object crashes through the corridor. As shown, there are clusters around MP 185.50 (the vicinity of the Polk Creek bridge which is situated on a curve) and between 185.80 and 186.10 (where there is a sharp curve). Of the 42 fixed object crashes that occurred in these two clusters, 39 occurred during inclement road conditions. Ten of the crashes occurred in the eastbound direction with 32 in the westbound direction.

Figure 23: Location of Fixed Object Crashes

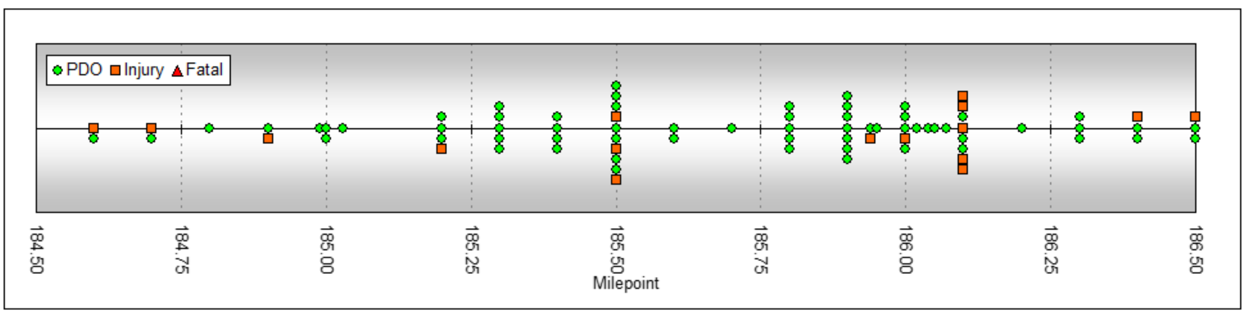


Table 5 shows the lighting and roadway conditions present for the fixed object crashes by direction. As can be seen in the table, the majority of fixed object crashes occur in the westbound direction (57 of 79) during the day and primarily occurring on inclement road conditions. Many of these crashes were noted as being the result of driver inexperience or the driver is unfamiliar with the area.

Table 5: Lighting and Road Conditions for Fixed Object Crash Types

Lighting Condition	Eastbound			Westbound		
	Dry	Inclement Road Conditions	Total	Dry	Inclement Road Conditions	Total
Daylight	0	9	9	3	40	43
Dawn/Dusk	0	2	2	0	4	4
Night	0	7	7	1	13	14
Total	0	18	18	4	57	61

Recommendation: Consider installing variable speed limit (VSL) signs as well as dynamic speed display signs (DSDS) in order to vary speeds based on road conditions. Consider using variable message signs (VMS) to warn driver in advance if there is slowing traffic and poor weather conditions. Consider installing the warning sign BRIDGE ICES BEFORE ROAD (W8-13) on the approaches to the Polk Creek bridge. Also consider widening the inside and outside shoulder widths to 12 feet to allow for drivers that leave the travel lane more time to correct before hitting a barrier. Consider widening to three lanes in each direction to provide more lateral space for evasive maneuvers. Flattening the curve between MP 185.85 and MP 186.45 could decrease fixed object crashes along the segment.

Truck Involved Crashes

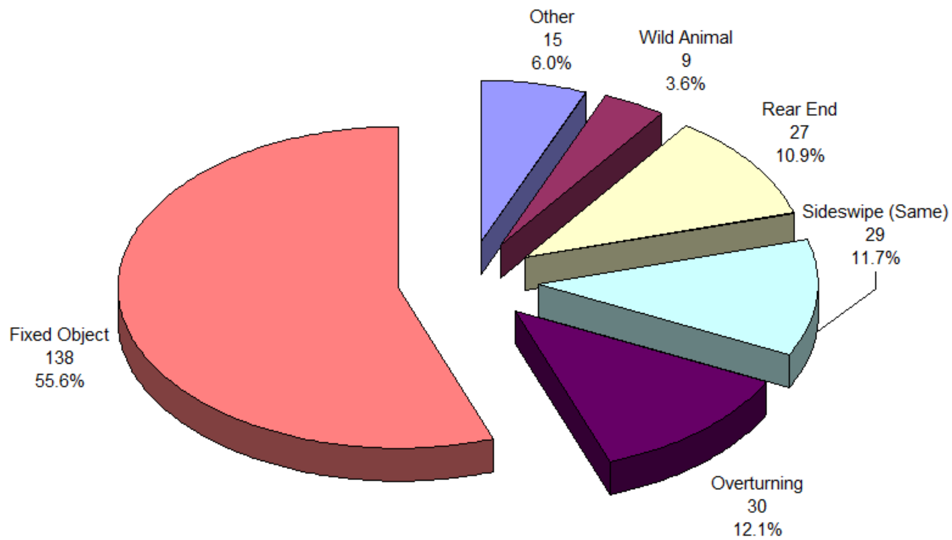
Total: 28 Crashes (2014-2016)
Severity: 19 PDO, 9 INJ (17 injured)
Direction: 5 Eastbound, 23 Westbound
Crash Types: Rear end (7), Sideswipe [same] (4), Fixed object (10), Other object (4), Overturning (1), Parked vehicle (2)
Crashes Caused by Trucks: 23 Crashes, 3 Eastbound, 20 Westbound
Causal Factor: A significant number of crashes involved multiple injuries. The most prevalent type of crash (11 of 28) involved another vehicle (rear end or sideswipe [same]), while the next prevalent type of crash (10 out of 26) involved leaving the roadway and hitting a fixed object. The vast majority of crashes (23 of 28) were westbound on the steep downhill grade. Only 4 of the crashes occurred during dry roadway conditions. These patterns lead to the conclusion that trucks (as well as other vehicles) are having difficulty staying in their own lane to avoid hitting fixed objects or other vehicles.

Recommendation: Consider widening the roadway to three lanes to give vehicles more space to avoid slower moving vehicles and to make evasive maneuvers to help reduce the number of rear end and sideswipe (same) crashes. Consider widening the inside and outside shoulder widths to 12 feet to allow for drivers that leave the travel lane more time to correct before hitting a barrier.

Segment 4: MP 186.51 – 191.00

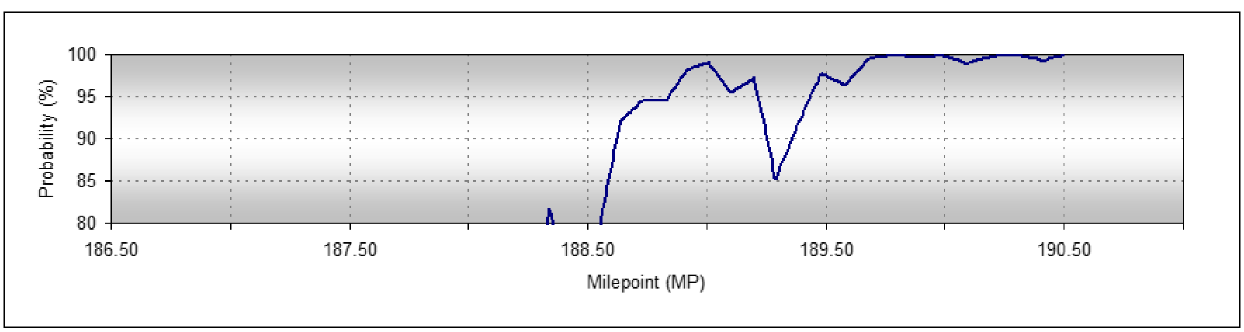
Segment 4 is at an elevation of 10,000 feet on the west end and 10,430 feet on the east end. This segment is at the highest elevations of the study corridor with a peak at the top of Vail Pass (MP 189.90) at an elevation of 10,600 feet. As a result, this segment experiences the most severe adverse weather and road conditions due to the relatively open terrain. The average grade west of the top of the pass is 4.6% and 2.9% east of the pass. **Figure 24** contains a breakdown of crash types in Segment 4. Patterns found along the Segment 4 included overturning, sideswipe same direction, concrete barrier, embankment, sign, and fixed objects. Because so many fixed object type crashes came up in this segment, they will be grouped under fixed objects rather than evaluated separately.

Figure 24: Segment 4 Crash Distribution by Type



Overturning Crashes

Figure 25: Location Pattern of Overturning Crashes



Total: 30 Crashes (2014-2016)
Severity: 22 PDO, 8 Injury (15 injured)
Causal Factor: The overturning crashes were seen through the segment, with a small cluster between MP 188.60 and MP 189.10 and another between MP 189.90 and MP 190.10. There is a fairly significant grade in the area of the first cluster as well as several curves. The second cluster occurs at the top of Vail Pass.

Figure 26: Location of Overturning Crashes

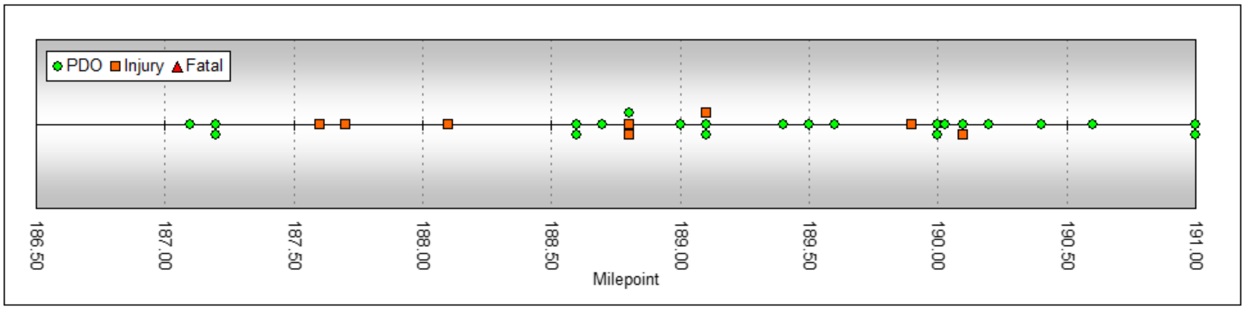


Table 6 shows the lighting and roadway conditions present for the overturning crashes by direction.

Table 6: Lighting and Road Conditions for Overturning Crash Type

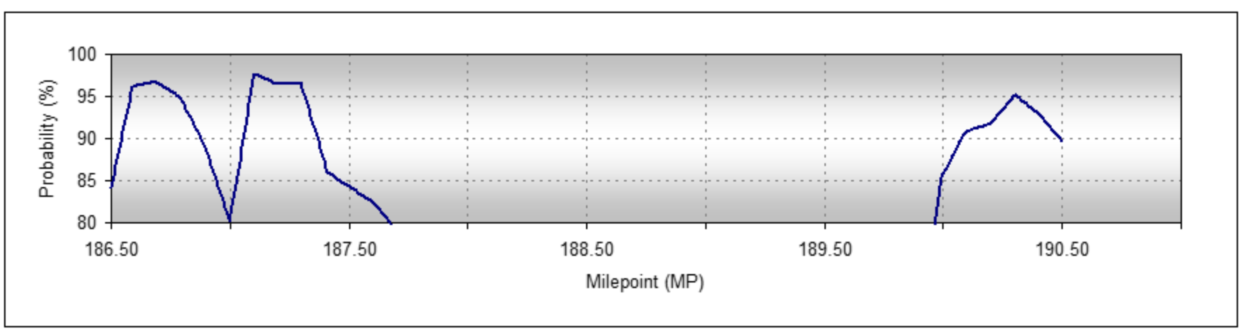
Lighting Condition	Eastbound			Westbound		
	Dry	Inclement Road Conditions	Total	Dry	Inclement Road Conditions	Total
Daylight	2	4	6	3	9	12
Dawn/Dusk	0	1	1	1	3	4
Night	0	2	2	1	4	5
Total	2	7	9	5	16	21

As can be seen in the table, most overturning crashes occur in the westbound direction (21 of 30) in the day and primarily occur on inclement road conditions.

Recommendation: Consider using variable message signs (VMS) to warn driver in advance if there are poor weather conditions ahead. Consider installing variable speed limit (VSL) signs as well as dynamic speed display signs (DSDS) in order to vary speeds based on road conditions. Consider increasing the inside and outside shoulder width to 12 feet to allow drivers more time to correct if they leave the travel lane.

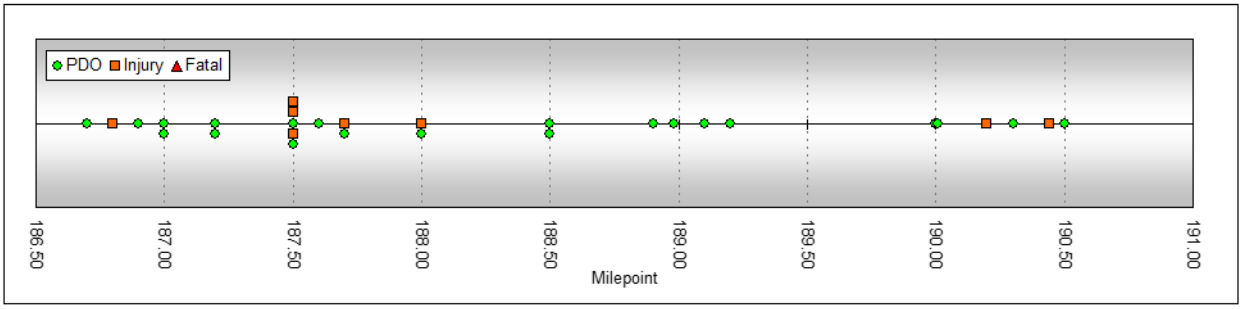
Sideswipe Same Direction Crashes

Figure 27: Location Pattern of Sideswipe Same Direction Crashes



Total: 29 Crashes (2014-2016)
Severity: 21 PDO, 8 Injury (24 injured)
Causal Factor: As shown in **Figure 28**, there is a cluster of sideswipe same direction crashes around MP 187.50. All of these crashes occurred in the westbound direction in inclement road conditions. At this location, there is an S-curve with a fairly large downgrade. Traffic congestion is normally a primary factor for sideswipe same direction crashes. In the context of Vail Pass and the adverse road conditions that are regularly experienced in the winter, losing control and hitting another car (instead of a fixed object) are indicative of conditions where lane departures cannot be avoided.

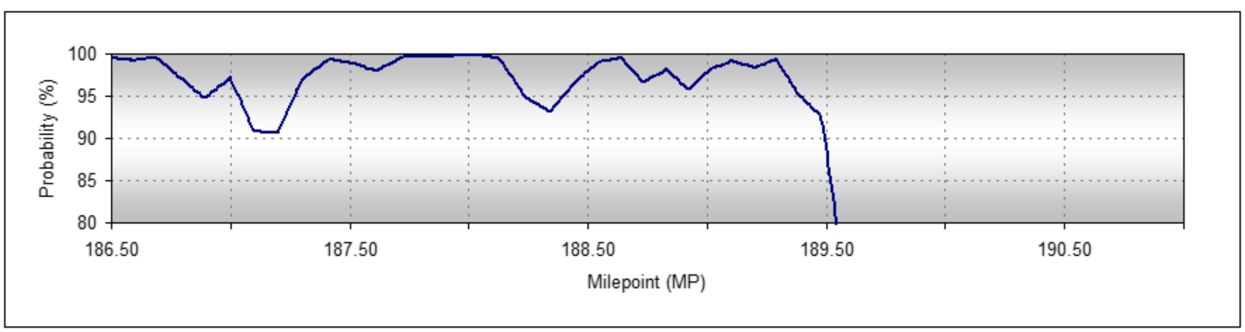
Figure 28: Location of Sideswipe Same Direction Crashes



Recommendation: Consider using variable message signs (VMS) to warn driver in advance if there are poor weather conditions ahead. Consider installing variable speed limit (VSL) signs as well as dynamic speed display signs (DSDS) in order to vary speeds based on road conditions. Consider increasing the inside and outside shoulder width to 12 feet to allow drivers more time to correct if they leave the travel lane. Consider widening to three lanes in each direction to provide more space to avoid slower moving vehicles and to make evasive maneuvers (and reduce any peak skier congestion) to help reduce sideswipe (same) crashes.

Fixed Object Crashes

Figure 29: Location Pattern of Fixed Object Crashes



Total: 138 Crashes (2014-2016)
Severity: 111 PDO, 27 Injury (36 injured)
Causal Factor: Table 7 shows the lighting and roadway conditions present for the fixed object crashes by direction. As shown in the table, the majority of fixed crashes occur in the westbound direction (102 of 138) primarily occurring on inclement road conditions.

Table 7: Lighting and Road Conditions for Fixed Object Crash Type

Lighting Condition	Eastbound			Westbound		
	Dry	Inclement Road Conditions	Total	Dry	Inclement Road Conditions	Total
Daylight	2	23	25	3	70	73
Dawn/Dusk	0	1	1	0	2	2
Night	1	9	10	3	24	27
Total	3	33	36	6	96	102

Recommendation: Consider using variable message signs (VMS) to warn driver in advance if there are poor weather conditions. Consider installing variable speed limit (VSL) signs as well as dynamic speed display signs (DSDS) to vary speeds based on road conditions. Consider widening the inside and outside shoulders to 12 feet to give drivers more time to correct if they lose control or leave the lane of travel. Consider widening the roadway to three lanes to give vehicles more space to avoid slower moving vehicles and to make evasive maneuvers.

Truck Involved Crashes

Total: 32 Crashes (2014-2016)
Severity: 24 PDO, 8 INJ (18 injured)
Direction: 9 Eastbound, 23 Westbound
Crash Types: Rear end (2), Sideswipe [same] (15), Fixed object (8), Other object (4), Overturning (2), Wild animal (1)
Crashes Caused by Trucks: 23 Crashes, 7 Eastbound, 16 Westbound
Causal Factor: A significant number of crashes involved multiple injuries. The most prevalent type of crash (17 of 32) involved another vehicle (rear end or sideswipe [same]), while the next prevalent type of crash (8 out of 32) involved leaving the roadway and hitting a fixed object. The vast majority of crashes (23 of 28) were westbound on the steep downhill grade. Only 8 of the crashes occurred during dry roadway conditions. These patterns lead to the conclusion that trucks (as well as other vehicles) are having difficulty staying in their own lane to avoid hitting fixed objects or other vehicles.

Recommendation: Consider widening the roadway to three lanes to give vehicles more space to avoid slower moving vehicles and to make evasive maneuvers to help reduce the number of rear end and sideswipe (same) crashes. Consider widening the inside and outside shoulder widths to 12 feet to allow for drivers that leave the travel lane more time to correct before hitting a barrier.

Ramp and Ramp Terminal Collision Analysis

Crashes that occurred on the ramps or at the ramp terminals for each interchange within the corridor were analyzed for correctable patterns. However, analysis showed that no ramp or ramp terminal had above four crashes and no fatalities occurred at any of the interchanges. Therefore, no crash patterns were able to be identified at the ramps or ramp terminals in the corridor.

Conclusion and Recommendations

These conclusions and recommendations are based on the analysis of three years of crash history and review of video log. The Region is advised to verify through field survey, the observations made in this report regarding physical features, roadside characteristics and traffic control devices.

There were 566 crashes reported along I-70 between MP 179.00 and MP 191.00 from January 1, 2014 through December 31, 2016 including mainline, ramp, and ramp terminal crashes. There were 121 crashes that caused injuries (205 injured).

Mainline Crashes

The corridor was divided into four segments for LOSS analysis:

- Segment 1 – MP 179.00 to MP 182.00
- Segment 2 – MP 182.01 to MP 184.50
- Segment 3 – MP 184.51 to MP 186.50
- Segment 4 – MP 186.51 – MP 191.00

For the frequency of crashes, Segment 1 had moderate to high potential for crash reduction. Segments 2, 3, and 4 were in the LOSS IV category indicating high potential for crash reduction.

For the severity of crashes, Segment 1 had low to moderate potential for crash reduction. Segment 2 had moderate to high potential, while Segments 3 and 4 were in the LOSS IV category indicating high potential for crash reduction.

Fixed object, rear-end, and sideswipe same direction type crashes were the most common mainline crash types along I-70 with 54 percent, 13 percent, and 12 percent of total mainline crashes, respectively. Rear-end and sideswipe same direction crash types are normally indicative of traffic congestion. In the context of Vail Pass and the adverse road conditions that are regularly experienced in the winter, losing control and hitting another car (instead of a fixed object) are indicative of conditions where lane departures cannot be avoided. Fixed object crashes are indicative of vehicles losing control, which in this corridor was often found to be related to grade, bridges, and inclement road conditions.

Trucks are involved in slightly more crashes than their proportion of overall traffic. They are more than twice as likely to be involved in multi-vehicles crashes as other vehicles; and slightly more likely than overall to be involved in dry road crashes. These patterns reinforce the obvious notion that larger vehicles take up more space and are not as nimble as smaller vehicles, thus being involved in more crashes with other vehicles. The general recommendations that would provide more lateral space (wider shoulders and an additional lane) to better accommodate all vehicles, particularly in harsh winter conditions.

A rough comparison of crash history can be made with the Straight Creek Segment of I-70 between Silverthorne (elevation – ~9,035') and the Eisenhower-Johnson Memorial Tunnels (11,013'). The elevations are roughly similar to the West Vail Pass segment of I-70 (8,320' to 10,590'), and since the highpoints are approximately 24 miles apart along I-70, the winter weather conditions are also roughly similar. The average grade along Straight Creek is 4.6% compared to 3.4% for West Vail Pass. On Straight Creek, the total number of mainline crashes of the three-year period was 335 crashes. This results in a LOSS III for total crashes (with regression to the mean correction) of 12.95 Crashes per Mile per Year (CPMPY) compared to a mean value of 12.18 CPMPY – a ratio of 1.06. West Vail Pass had 558 mainline crashes which results in a LOSS IV for total crashes (with regression to the mean correction) of 14.08 CPMPY with a mean of 7.91 CPMPY – a ratio of 1.78. Thus, safety on West Vail Pass is worse when both are compared to their respective means. The main difference between Straight Creek and West Vail Pass is that Straight Creek has three lanes in each direction and West Vail Pass has two. Based on current volumes and Straight Creek crash history, West Vail Pass crash record might improve to 11.05 CPMPY if it were reconstructed to 6 lanes. This would be a decrease in total crashes over a 3-year period of approximately 110 crashes. This benefit should be experienced by all vehicles, including trucks. Additional safety benefits could result from the recommended shoulder widening and ITS infrastructure.

Mainline Recommendations include:

Overall Corridor

- Consider widening the roadway to three lanes in each direction to give vehicles more space to avoid slower moving vehicles and to make evasive maneuvers, reduce congestion that may occur during peak skier periods, and reduce rear-end and sideswipe same direction type crashes.
- Consider widening the inside and outside shoulder to 12 feet through the corridor to reduce fixed object and overturning crashes.
- Consider enhanced ITS infrastructure including installing variable speed limit (VSL) signs, dynamic speed display signs (DSDS), and variable message signs to provide current information about road and weather conditions and traffic congestion.

Segment 1 (MP 179.00 – MP 182.00)

- Consider installing deer warning signs for westbound vehicles approaching MP 181.00. Alternatively, consider using VMS warning signs during peak wildlife crash times (May – August, dawn and dusk) to warn vehicles of wildlife.
- Consider installing a BRIDGE ICES BEFORE ROAD (W8-13) on both approaches to the Gore Creek bridge.

Segment 2 (MP 182.01 – MP 184.50)

- Consider installing a BRIDGE ICES BEFORE ROAD (W8-13) on eastbound approach to the Black Gore Creek bridge.

Segment 3 (MP 184.51 – MP 186.50)

- Consider installing a BRIDGE ICES BEFORE ROAD (W8-13) on both approaches to the Polk Creek bridge.

- Consider flattening the curve between MP 185.85 and MP 186.45 to decrease fixed object crashes along the segment.
- Westbound Segment 3 has the worst safety record and should be considered for initial safety improvement implementation.

Segment 4 (MP 186.51 – MP 191.00)

- No additional recommendations.
- Westbound Segment 4 has the second worst safety record and should be considered next after Segment 3 for safety improvements.

Additional Safety Features

The following features should be provided as part of any improvement projects:

- Good skid resistance and drainage of the roadway surface.
- Adjustment, repair, and upgrade of existing guardrail to meet current standards.
- Elimination of pavement edge drop-offs (Safety Edge Application).
- Super-elevation and crown correction where required.
- Appropriate pavement markings (highly reflective and durable), signing and delineation.
- Appropriate advance warning signing of curves.
- Replace all button reflectors and guardrail reflectors to insure good nighttime and inclement weather (fog, snow, rain, etc.) delineation.

Appendix B

Safety Evaluation Memo

WEST VAIL PASS
PREDICTIVE CRASH SAFETY EVALUATION

This memorandum summarizes the crash prediction evaluation for the I-70 West Vail Pass Auxiliary Lanes Environmental Assessment (EA). This safety evaluation compared the No Build and Build scenarios for the EA. The analysis also provided input for the evaluation of benefits and impacts for potential localized design options along the corridor, such as narrowed shoulders in areas to avoid physical and/or environmental impacts.

The safety evaluation methodology utilized Colorado-based Safety Performance Functions (SPFs) from CDOT's Vision Zero Suite (VZS) to estimate the baseline expected crashes. VZS-predicted crash rates are based exclusively on equivalent Colorado facilities so they are more representative of the conditions found on West Vail Pass than baseline crash rates derived from other modeling packages (notably FHWA's Interactive Highway Safety Design Model). This methodology was developed in consultation with the CDOT HQ Safety & Traffic Engineering Branch.

Primarily, the evaluation for the study corridor incorporated the Rural Mountainous 4-Lane Divided Freeways SPF for the baseline conditions. The methodology closely matched *Method 3* as described in the Highway Safety Manual (Part C.7). The methodology was as follows:

1. Determine the evaluation period of interest.
2. Collect observed crashes and annual average daily traffic (AADT) within the defined study period.
3. Develop individual corridor segments/sites within the 10-mile corridor for the evaluation.
    - Option 1: Segmentation based on geometric features (e.g., tangents, curves, structures).
    - Option 2: Segmentation based on crash patterns/clustering.

    Option 1 was used to ultimately segment the corridor, but crash locations were overlaid on the segments to ensure crash clusters were not split between segments.
4. Assign the crashes and AADT to appropriate corridor segments.
5. Use the VZS software to calculate the expected average crash frequency for the baseline condition on each segment.
6. Apply the appropriate crash modification factors (CMFs) that are associated with the specific geometric considerations and design options (e.g., shoulder width adjustment, curve modifications, etc.).
    - Predicted average crash frequency will be calculated using Colorado-developed SPFs through the VZS (disabling Empirical Bayes from VZS)
7. Calculate the predicted crash frequencies for No Build and Build scenarios and compare for the resulting Build scenario crash reduction.

CRASH MODIFICATION FACTOR DEVELOPMENT

This section expands on Step 6 of the Predictive Crash Methodology summarized in the previous section. In order to have a meaningful predictive safety evaluation, the appropriate CMFs that fit within the context of the I-70 on West Vail Pass must be applied.

The first step was to identify applicable CMFs based on the proposed improvements. This step required extensive research efforts gathering and reviewing candidate CMFs, including a review of the research reports on which the CMFs were based. These CMFs were then narrowed down based on the initial base-line conditions from which the CMF was developed. The conditions include the quality of the CMF (FHWA star rating), roadway type, and area type at the time of the CMF research and development. Sources for various CMFs include the CMF Clearinghouse and other state departments of transportation that share similar characteristics and topography (Wyoming, Oregon, Utah, etc.). The overall list of CMFs that were found is provided as an attachment.

The selected CMFs are categorized within advanced technology and ITS, horizontal curvature improvements, and additional lanes. More specifically, these include change in horizontal curvature, increase in inside shoulder width, and the addition of an auxiliary lane.

Horizontal Curve CMF

The CMF for change in horizontal alignment came out of a Washington State-based crash study from the CMF Clearinghouse:

Source	Location/Facilities	CMF Function
Banihashemi, M, "Is Horizontal Curvature a Significant Factor of Safety in Rural Multilane Highways?" (2015)	Washington State, all road types	$CMF = e^{(273.899 \cdot (\frac{1}{R2} - \frac{1}{R1}))}$ For a tangent section, the radius can be considered infinity

This study resulted in CMF functions that were based on the difference in curve radii (existing curve to proposed curve) only. It was rated three-star (fair rating) by the Clearinghouse and came from a region with geography and weather similar to western Colorado. Several pairs of existing and proposed horizontal curves (both increased and decreased radii in the proposed geometry) on I-70 were tested in using the CMF equation and the resulting CMFs were consistently intuitive based on the magnitude of change from existing to proposed, as noted in Table 1 on the following page.

Table 1: Select Curve Modification CMFs

Existing Curve MP / Direction	Existing Radius (ft)	Proposed Radius (ft)	CMF (Banihashemi)
183.78 / Left	2,865	3,100	0.98
184.85 / Right	1,910	1,750	1.04
185.86 / Right	1,273 (compound)	1,696	0.84
188.19 / Left	3,820	4,614	0.96
189.5 / Right	1,763	1,850	0.98
Minimum radius, 65mph design speed (AASHTO Green Book) = 1,485 ft			

It is important to note that the CMF for horizontal curve modifications used an equation that produces a different value for each modified curve in the corridor. There were multiple curves within each of the seven defined analysis segments for both the westbound and eastbound direction, as referenced in the previous memorandum. Using the function-based CMF, multiple CMFs were calculated within each segment. To move forward with a segment based analysis, a segment-level CMF was estimated by taking the average of each of the individual horizontal curve modification CMFs within the appropriate segment. As a result, seven segment-level CMFs were calculated.

Inside Shoulder CMF

The CMF for increasing inside shoulder width came from an amalgamated NCHRP report of rural multilane highways within the CMF Clearinghouse:

Source	Location/Facilities	CMF
Graham et al. "NCHRP Report 794: Median Cross-Section Design for Rural Divided Highways" (2014)	California, Missouri, North Carolina, Ohio, Pennsylvania, Washington State, rural divided roads	0.626 (0.791 over 2 ft) *median crashes only*

Colorado data was not included; however, impacts from a widened shoulder are not likely to vary much across environments and driver populations in locations different than West Vail Pass. As well, driving conditions in California and Washington State could be very similar.

When forecasting the future build-year predicted and expected crash rates, specific crash types such as center median crashes were not broken out. In order to account for just those crashes within the build-year crash rates, the proportion of center median crashes from the 2014-2016 crash history was assumed to apply to the future analysis year as well. Table 2, on the next page, summarizes the segment-by-segment crash distribution that will be assumed when applying the CMF to the predicted crash evaluation.

Table 2: Center Median Crash Distribution

Segment	Total Crash History (2014 - 2016)	Center Median Crashes (Number)	Center Median Crashes (Percent)
1	28	5	18%
2	45	11	24%
3	68	29	43%
4	74	24	32%
5	72	29	40%
6	113	40	35%
7	95	39	41%

Auxiliary Lane CMF

The inclusion of the auxiliary lane in both directions over the pass is the central improvement of the West Vail Pass project. However, research showed that the available published nationwide CMFs for auxiliary lanes do not closely match the unique characteristics of the I-70 corridor, which includes the mountainous environment, weather, and traffic mix. A summary of safety data for added freeway lanes (not specific to auxiliary lanes) is included below:

Table 3: Nationwide Crash Modification Factors for Added Lanes

Source	CMF	Notes
Florida DOT, Update of Florida CMFs and Countermeasures to Improve the Development of District Safety Improvement Projects (2005) www.lctr.org/Documents/CRFFinalReport.pdf	0.78	Unknown facilities; average from DOTs in AZ, IA, IN, MO, MT, and NY
Virginia DOT, Smart Scale/HB2 Expected Roadway Project Crash Reductions (2016) vasmartscale.org/documents/ss_planning_level_cmfs_092116.pdf	0.70	Unknown facilities
West Virginia DOT/USDOT, I-81 Phase 2 Project (2018) www.mdot.maryland.gov/newMDOT/Planning/BUILD/Documents%20and%20Images/Narrative.pdf (p. 28)	0.60	Rural rolling hills
Idaho DOT, Safety Evaluation Instruction Manual (1999)	0.90	reference Florida DOT above
Arizona DOT, Accident Rate Reduction Levels, Which May Be Attainable From Various Safety Improvements (1991)	0.75	reference Florida DOT above
Montana DOT, Safety Engineering Improvement Program—Accident Reduction Factors	0.80	reference Florida DOT above
Interactive Highway Safety Design Model (IHSDM), 4- to 6-lane rural general freeway SPF	0.93	Note that CMF decreases with increased volumes (assumed design 38k ADT)

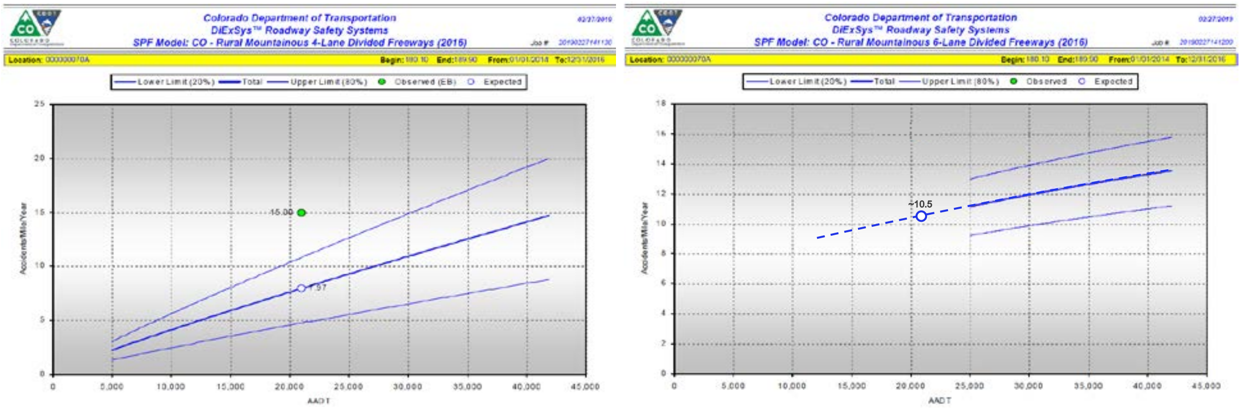
Colorado DOT, Vision Zero Suite, 4- to 6-lane "generic" mountainous freeway SPF	1.58	Note that CMF varies with increased volumes (assumed design 38k ADT) *See below for further discussion*
CMF Clearinghouse (Texas) *www.cmfclearinghouse.org/study_detail.cfm?stid=464*	*0.75*	*Urban freeways; for information only*
Colorado DOT, Relationships Between Safety and Both Congestion and Number of Lanes on Urban Freeways *www.diexsys.com/PDF/2083-004.PDF*	*1.25*	*Urban freeways; for information only*
CMF Clearinghouse (Florida) *www.cmfclearinghouse.org/study_detail.cfm?stid=438*	*0.85*	*Urban freeways; for information only*

The national research suggests a CMF for freeway lane additions of between 0.60 and 0.96, although many of these studies come from a variety of environments that do not closely match up with the conditions on West Vail Pass. Several of the CMFs also come from urban freeways, which typically experience higher traffic volumes and different crash causal factors. These urban CMFs suggest a divergent impact of adding freeway lanes, with some increasing and some decreasing crashes. Due to their substantially different background, they are not being considered for comparison.

To adapt the safety evaluation to West Vail Pass, a secondary methodology was developed to derive a more meaningful CMF that would be applicable to the corridor's environmental conditions. The CMF was derived by utilizing the Colorado-based SPFs within the VZS models. As noted above, when comparing Predicted Crash Rate (those calculated based on a non-location-specific Colorado freeway SPF), 6-lane mountainous freeways in Colorado have a higher crash rate than 4-lane freeways. This is likely due in part to the higher volumes on 6-lane freeways and the small number of 6-lane mountainous segments in Colorado. There are only two segments of 6-lane mountain freeway in Colorado with sufficient crash history (i.e., the I-70 peak period shoulder lane is not included yet): I-70 west of Eisenhower Tunnel (7.7 miles long) and I-70 east of Floyd Hill (12.8 miles long). These two segments also likely see faster speeds as they are immediately downstream of more congested 4-lane segments and motorists are able to travel on the 6-lane segments at their desired higher speeds.

As West Vail Pass has an abnormally high crash rate, the Expected Crash Rate (calculated by adjusting the Predicted Crash Rate based on observed crashes) at existing volumes (21,000 vpd) for this 4-lane segment is above what would be predicted for a 6-lane segment, as is shown in the two safety performance functions in Figure 1, on the next page. Thus, the additional lane CMF was calculated based on comparing the Predicted Crash Rate for a generic mountainous 6-lane segment to the Expected Crash Rate for the mountainous 4-lane segment on West Vail Pass. The resulting CMF was compared to the national CMFs to see if it fit within the range of CMFs for adding lanes in other states.

Figure 1: Vision Zero Predicted and Expected Crash Rates



To derive the CMF, the following procedure was used by utilizing the CDOT-developed SPF for 4-lane and 6-lane mountainous freeways:

1. The corridor within the project limits was segmented based on geometry such as horizontal curves, with a more detailed inspection to confirm that the segments did not overlap on major structures.

2. The segments were developed to be around one mile or more in length to maintain best practice. In total, seven segments were developed, truncating the corridor from the Exit 180 onramp to the Exit 190 offramp. The historic observed crashes from 2014 to 2016 were associated with each segment based on the beginning and ending mileposts. The segmentation of the study corridor is provided in Table 4 below:

Table 4: Corridor Segmentation

Segment	Mileposts		Length (mi)	Observed Crashes (2014 – 2016)
1	180.10	181.50	1.40	28
2	181.51	182.66	1.16	45
3	182.67	184.43	1.77	68
4	184.44	185.79	1.36	74
5	185.80	186.66	0.87	72
6	186.67	188.13	1.47	113
7	188.14	189.90	1.77	95

3. The observed crashes and the projected design year average daily traffic (ADT) were input into the CDOT interactive SPF spreadsheet.

4. Predicted and Expected Crash Rates were calculated from the mountainous 4-lane and 6-lane freeway SPFs for each segment. The VZS software was used to output Predicted and Expected Crash Rates for the present year ADT (21,000) and a Predicted Crash Rate for the design year ADT (37,000). The Expected Crash Rate for the design year was calculated from these VZS outputs.

5. With the Predicted Crash Rate estimated for the build-year conditions of each segment, the initial auxiliary lane CMF was calculated using the formulation below:

$$\text{CMF} = \frac{Predicted\ Crash\ Rate\ (Mountainous\ 6{-}Lane\ Freeway) \times Safety\ Factor}{Expected\ Crash\ Rate\ (Mountainous\ 4{-}Lane\ Freeway)}$$

A Safety Factor of 125% was augmented to the Predicted Crash Rate (6-Lane) because it was recognized that the 6-Lane SPF alone would not fully account for the conditions inherent on West Vail Pass, thus adjusting the comparative crash rate higher.

6. For the first and last segment, being downstream and upstream respectively of interchange ramps, the above auxiliary lane CMF was not considered appropriate and a separate CMF was utilized from the CMF Clearinghouse relating to auxiliary lanes adjacent to ramps developed in Washington State:

Source	Location/Facilities	CMF
Ray et al. "NCHRP Report 169: Determining Guidelines for Ramp and Interchange Spacing" (2010)	Washington State, freeways	0.80

The overall CMFs for the auxiliary lane addition are summarized below in Table 5.

Table 5: Auxiliary Lane CMF Estimation Summary

Seg.	Mileposts		Crash History (2014 – 2016)[1]	Expected Crash Rate/Mile/Year (M4-Lane)[2]	Predicted Crash Rate/Mile/Year (M6-Lane)[2]	Seg. CMF
1	180.10	181.50	28	11.37	-	0.80[4]
2	181.51	182.66	45	20.08	12.91	0.80
3	182.67	184.43	68	19.91	12.91	0.81
4	184.44	185.79	74	27.33	12.91	0.60[3]
5	185.80	186.66	72	40.48	12.91	0.60[3]
6	186.67	188.13	113	37.74	12.91	0.60[3]
7	188.14	189.90	95	26.98	-	0.80[4]

Note 1: Crash history aligned with time period from CDOT *Safety Assessment Report, I-70: MP 179-191* (January 2018)
Note 2: Based on projected design year ADT of 37,000 and a safety factor of +25%
Note 3: CMF revised upward to 0.60 based on West Virginia study, Table 3
Note 4: CMF derived from *Ray et al* (2010) auxiliary lanes at on- and off-ramps (see above)

7. As a reasonableness check, the custom auxiliary lane CMFs were compared to other nationwide CMFs that include a similar treatment but variable environmental conditions, as detailed previously in Table 3. Some of the segment CMFs resulted in crash reductions that were considered unreasonably low or too optimistic. To address this, a floor was set to the CMF calculation such that no CMF would be lower than 0.60. This value was used as a minimum based on the lowest finding of the reviewed auxiliary lane CMFs (from the West Virginia study).

CMF Summary

The CMFs used for the safety evaluation are summarized below in Table 6.

Table 6: Crash Modification Factors Summary

Countermeasure	CMF	Crash Type / Severity	Base Conditions
Widen Inside Shoulder from 4' to 6'	0.626	Center median crashes / All	4-lane mountainous freeway
Flatten Horizontal Curve (Increase Radius)	Function *(0.84-1.04)*	All / All	4-lane mountainous freeway
Add Auxiliary Lane	By Segment *(0.60-0.81)*	All / All	4-lane mountainous freeway

The 4-lane mountainous freeway SPF was used as the base to calculate the Predicted and Expected crash rates for the No Build scenario. The above CMFs were applied to the SPF to calculate the Predicted crash frequency for the Build scenario using the following equation (2010 Highway Safety Manual, Chapter 3, Equation 3-3):

$$Crash\ Freq._{Build\ Scenario} = Crash\ Freq._{Predicted,M4-Lane} \times (CMF_{Shldr} \times CMF_{Curve} \times CMF_{AuxLn})$$

Because the horizontal curve CMF varied by curve and the auxiliary lane CMF varied by segment, the above equation was applied incrementally up the corridor to arrive at a Predicted frequency for each segment.

Safety Evaluation Results

Table 7, on the next page, summarizes the results of the predicted crash modeling for both Build and No Build scenarios. It is important to note that there are two sets of baseline annual crash rates for the No Build 2045 model – a Predicted and an Expected crash rate. Changes in site conditions and crash history make future baseline prediction challenging, so both crash rates were carried forward. The variance between the Predicted (from the 4-lane freeway SPF) and Expected (Predicted modified by site conditions) crash rate is substantial, but the predicted crash reduction from the applied CMFs is fairly close between the two baselines. Regardless of what the baseline No Build crash rate ultimately is in 2045, the predicted crash reduction is in the range of 37-41%.

Table 7: Predictive Crash Reduction Summary

Seg.	Predicted 2045 No Build Crashes/Year	Expected 2045 No Build Crashes/Year	Crash Reduction Factors			Crash Reduction	
			Horiz Geo.	Aux Lane	Shoulder	Predicted	Expected
1	18.89	16.30	0.99	0.80	0.626	4.75	4.10
2	15.65	23.86	0.95	0.80	0.626	4.72	7.19
3	23.88	36.10	1.02	0.81	0.626	7.11	10.76
4	18.35	38.07	1.30	0.60	0.626	5.64	11.69
5	11.74	36.08	0.78	0.60	0.626	6.90	21.22
6	19.83	56.83	0.93	0.60	0.626	9.99	28.62
7	23.88	48.92	0.91	0.80	0.626	8.97	18.38
					Total Crashes/Year (No Build)	*129.07*	*250.09*
					Total Predicted Crashes/Year (Build Conditions)	*80.99*	*148.12*
					Total Predicted Crash Reduction	*48.08*	*101.96*
					Corridor-Wide Percent Crash Reduction	**37%**	**41%**