East 13th, 14th, 16th, and 17th Avenues Safety Study

Prepared for:
City & County of Denver

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FEHR PEERS

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Introduction

Background & Goals

The East 13th, 14th, 16th, and 17th Avenues Safety Study ("Safety Study") aims to improve long-term safety for all travel modes on East 13th, 14th, 16th, and 17th Avenues between Broadway and the eastern Denver city limits. These streets have been a long-standing concern for area residents, business owners, and other constituents. Portions of these streets are on the city's Tier 1 and Tier 2 High Injury Network according to the city's *2022 Vision Zero Action Plan*. **Table 1** shows the study streets, their limits, and the portions on the High Injury Network.

Table 1: Study Streets, Limits, and Portion on High Injury Network

Study Street	Study Limits	Portion High Injury Network	Notes
East 13th Avenue	Broadway – Yosemite Street	Broadway to Clermont Street	N/A
East 14th Avenue	Broadway – Yosemite Street	Broadway to Clermont Street	N/A
East 16th Avenue	Detroit Street – Colorado Boulevard	N/A	West of East High School, East 16th Avenue was studied or improved through other efforts
East 17th Avenue	Colorado Boulevard – Yosemite Street	Colorado Boulevard to Cherry Street	West of Colorado Boulevard, East 17th Avenue was studied through a transit Speed & Reliability Study
East 18th Avenue	N/A	N/A	East 18th Avenue was studied through a transit Speed & Reliability Study

Source: Fehr & Peers.

In addition to the long-standing concerns regarding these streets and their presence on the High Injury Network, forthcoming Bus Rapid Transit (BRT) on East Colfax Avenue is expected to change travel patterns in the area. East Colfax Avenue BRT will make significant improvements to transit between Denver Union Station and I-225 in Aurora. By repurposing two travel lanes on East Colfax Avenue, some area drivers will likely choose alternate routes on study streets. The construction of East Colfax Avenue BRT is expected to be complete by the end of 2027. This study aims to mitigate both pre-existing safety concerns on these streets as well as potential diversion effects resulting from East Colfax Avenue BRT.

Study Area

The limits of this study are highlighted in **Figure 1** and **Figure 2.**

- East 13th Avenue from Broadway to Yosemite Street
- East 14th Avenue from Broadway to Yosemite Street
- East 16th Avenue from Detroit Street to Colorado Boulevard
- East 17th Avenue from Colorado Boulevard to Yosemite Street

Figure 1: Study Area – Broadway to Colorado Boulevard

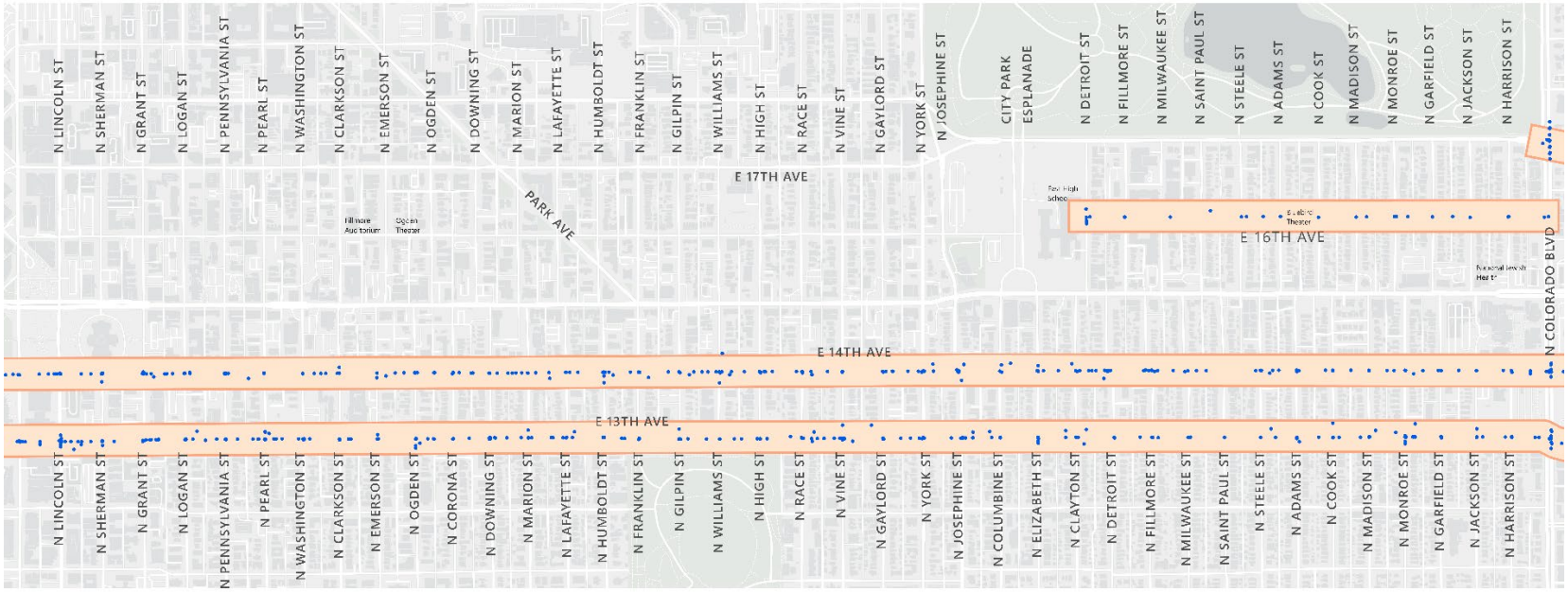
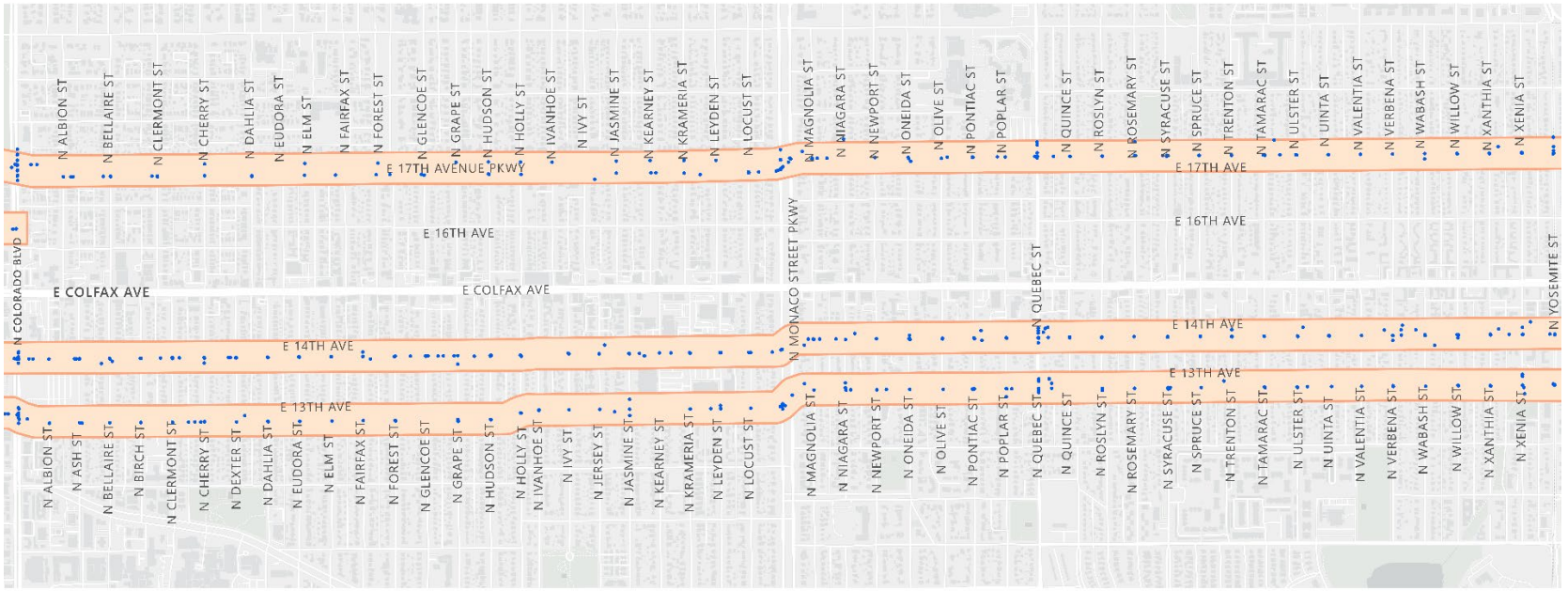


Figure 2: Study Area – Colorado Boulevard to Yosemite Street



Methodology

This study began with a safety analysis based on a review of crash history involving all travel modes, vehicle speed and volume data, and community member input. All reported crashes that occurred within the study area during 2018 to 2022 were summarized and studied in detail. Crashes were analyzed by crash type, location, severity, apparent cause, and other factors. Directional speed and volume data was collected at 16 locations, four on each street, and compiled and studied as well. Community member input in the format of map comments, survey responses, and neighborhood meetings reinforced the concerns that were noticed in the crash history and speed data.

Based on the safety concerns observed in the safety analysis, countermeasures were recommended, and a benefit-cost analysis of each countermeasure was completed. For each countermeasure, priority locations were identified based on the safety analysis and cost estimates calculated for multiple scales of implementation.

The first phase of safety improvements will include low-cost treatments and will be constructed outside of the East Colfax Avenue BRT project, but within the same construction timeframe. The second phase will involve higher cost treatments for which funding needs to be identified. Finally, this study recommends feasibility assessment of other countermeasures to address remaining uncertainties. Implementation of these countermeasures is contingent of these findings.

Safety Summary

Through the course of this study, existing safety conditions were assessed by way of crash history, speed and volume data, and community member input. The number of crashes occurring on these corridors generally exceeds the expected number. This is partially attributable to high speeds, which are consistent throughout the study area. Hundreds of comments from community members reinforced the data findings with clear concerns of speeding and frequent crashes.

Appendix A, **Appendix B**, and **Appendix C** include safety summary presentations for the study streets.

Crash History

Five years of crash data, from 2018 through 2022, were analyzed as part of this study. **Table 2** shows a detailed history of crashes on each street, including severity and top crash types. In the entire study area, there were:

- 2,383 total crashes,
- 537 crashes resulting in a fatality or injury (all severity levels), and
- 86 crashes involving a pedestrian or bicyclist.

Table 2: Crash History by Street

Street	Study Limits	Fatal Crashes	Injury Crashes	PDO Crashes*	Total Crashes	Ped/ Bike Crashes	Top Fatal/ Injury Crash Types	Top Overall Crash Types
East 13th Avenue	Broadway – Yosemite Street	3	195	711	909	35	Broadside (95) Rear-end (35) Pedestrian (20)	Broadside (276) Rear-end (184) Fixed object (170)
East 14th Avenue	Broadway – Yosemite Street	2	250	824	1,076	44	Broadside (103) Rear-end (30) Pedestrian (27)	Broadside (322) Fixed object (197) Sideswipe (same direction) (178)
East 16th Avenue	Detroit Street – Colorado Boulevard	0	7	39	46	1	Parked motor vehicle (3)	Parked motor vehicle (17) Rear-end (12) Broadside (4)
East 17th Avenue	Colorado Boulevard – Yosemite Street	1	79	272	352	6	Broadside (36) Rear-end (14) Fixed object (11)	Broadside (128) Rear-end (93) Fixed object (52)
	Total	6	531	1,846	2,383	86	N/A	N/A

*PDO, or Property Damage Only, includes crashes that resulted in no injuries or fatalities.
Source: Fehr & Peers.

Overall, the most common crash types throughout the study area were:

1) Broadside,
2) Rear-end,
3) Fixed object,
4) Sideswipe (same direction), and
5) Overtaking turn

The crash types that resulted in the most fatal and injury crashes were:

1) Broadside,
2) Rear-end,
3) Fixed object,
4) Pedestrian, and
5) Overtaking turn

Broadside crashes occur consistently throughout all four streets, but they tend to have varying root causes depending on where they happen, so mitigation strategies must account for crash context. All crashes are

exacerbated by speeds to some degree but rear-end, fixed object, and pedestrian crashes are all especially mitigable through speed reduction. The degree of severity of a crash is often influenced by the speed differential between the people or objects involved and the vulnerability of each individual. For example, sideswipe crashes in the same direction often result in property damage only because the cars are going nearly the same speed, and pedestrians are far more vulnerable than someone in a car and therefore more likely to be severely injured or killed. All these factors are critical to consider when establishing recommendations to improve safety on these streets.

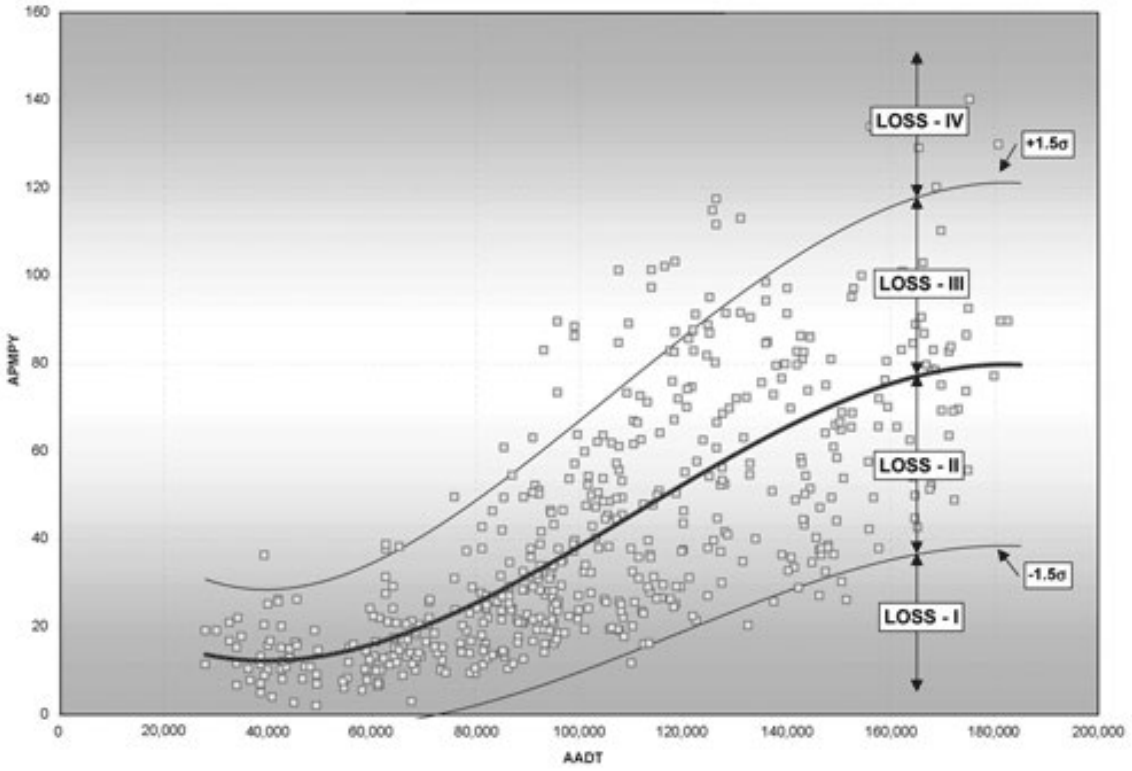
Level of Service of Safety

Level of Service of Safety (LOSS) is a quantitative way of evaluating an intersection's potential for crash reduction by estimating how many more or less crashes are happening than expected (compared to similar intersections). This is done by comparing the number and type of crashes at an intersection to the number and type of crashes at a sampling of other intersections with similar characteristics. Characteristics used to compare intersections include the number of lanes, whether the roadway is divided, and average daily traffic volume, among others. The LOSS can be calculated in terms of all crashes (LOSS Frequency) or in terms of injury crashes (LOSS Severity) and is scored on a percentile scale between LOSS I and LOSS IV where the 50th percentile is the number of crashes expected at the given type of intersection.

- LOSS IV (4) means that a location falls within the top 20th percentile for number of crashes given the intersection characteristics. LOSS 4 indicates high potential for crash reduction.
- LOSS III (3) means that a location falls between the 50th (average) and 80th percentile. LOSS 3 indicates moderate to high potential for crash reduction.
- LOSS II (2) means that a location falls between the 20th and 50th percentile (average). LOSS 2 indicates low to moderate potential for crash reduction.
- LOSS I (1) means that a location falls within the bottom 20th percentile. LOSS 1 (I) indicates low potential for crash reduction.

Figure 3 shows the percentile curves for Level of Service of Safety.

Figure 3: Level of Service of Safety Percentile Curves



Denver's goal for crashes resulting in fatality or serious injury is zero. Analyzing LOSS is not intended to dismiss or ignore crashes that occur at locations with a lower-than-average crash rate. However, analyzing LOSS and targeting LOSS 3 or LOSS 4 intersections is a strategic way to prioritize specific locations for improvement to have the greatest effect of reducing fatalities and serious injuries.

Figure 4 and **Figure 5** show LOSS Frequency and Severity scores for East 13th, 14th, and 17th Avenues. A LOSS analysis was not conducted for East 16th Avenue given the relatively low number of crashes on East 16th Avenue. Most intersections scored LOSS 1 or LOSS 2 on East 17th Avenue, indicating fewer crashes than expected. However, there are many intersections on East 13th and 14th Avenues that scored LOSS III or LOSS IV, indicating more crashes than expected.

Figure 4: East 13th, 14th, and 17th Avenues Intersection LOSS Frequency

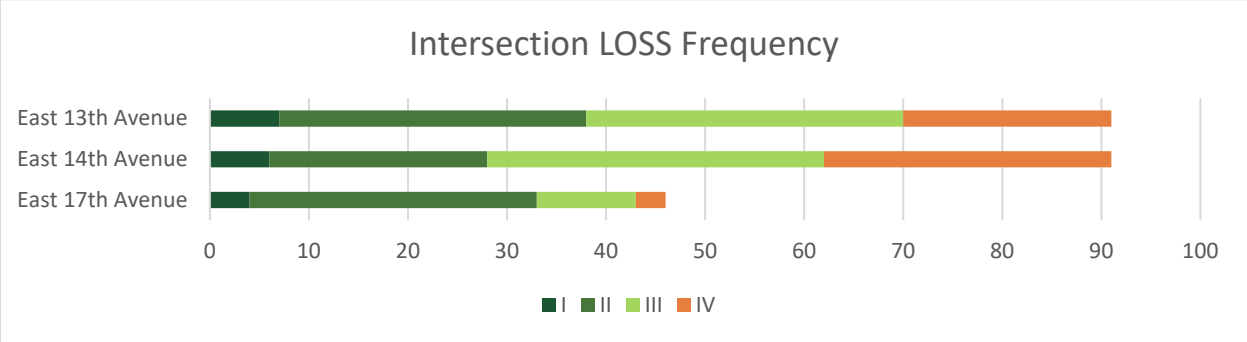


Figure 5: East 13th, 14th, and 17th Avenues Intersection LOSS Severity

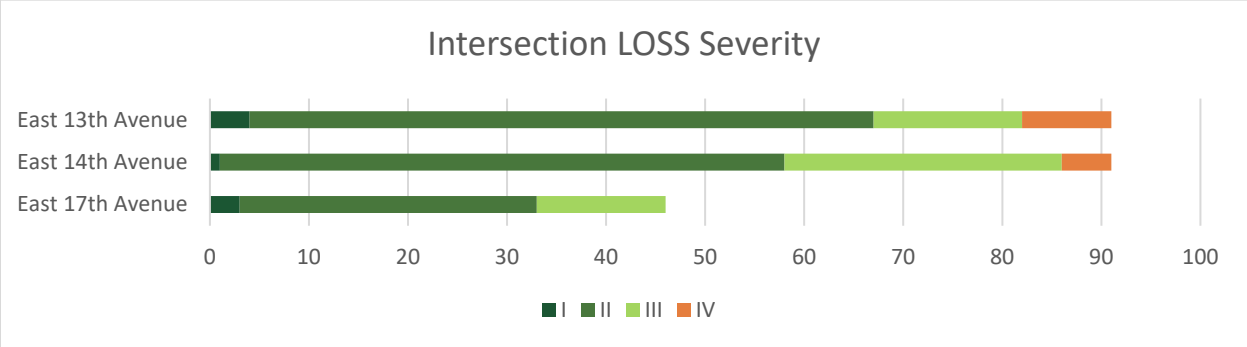


Figure 6 through **Figure 8** identify LOSS Severity III and IV intersections on the three streets. There are no LOSS Severity IV intersections on East 17th Avenue. The LOSS maps highlight several clusters of intersections that had more crashes than expected.

Appendix D includes all Level of Service of Safety calculation sheets.

Figure 6: LOSS Severity III and IV Intersections – East 13th and 14th Avenues, Broadway to Colorado Boulevard

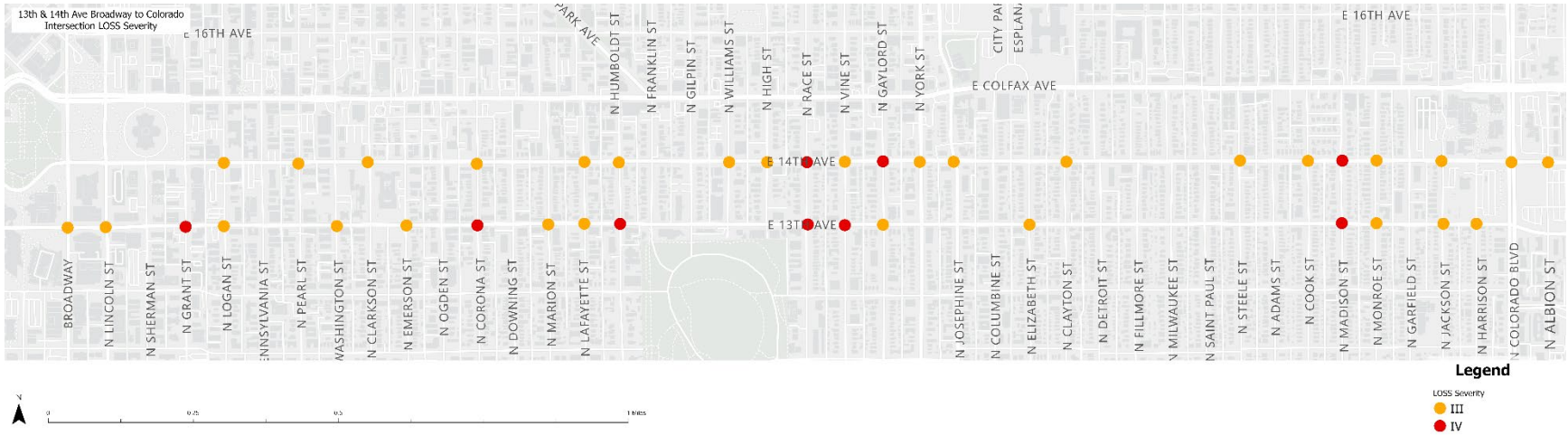
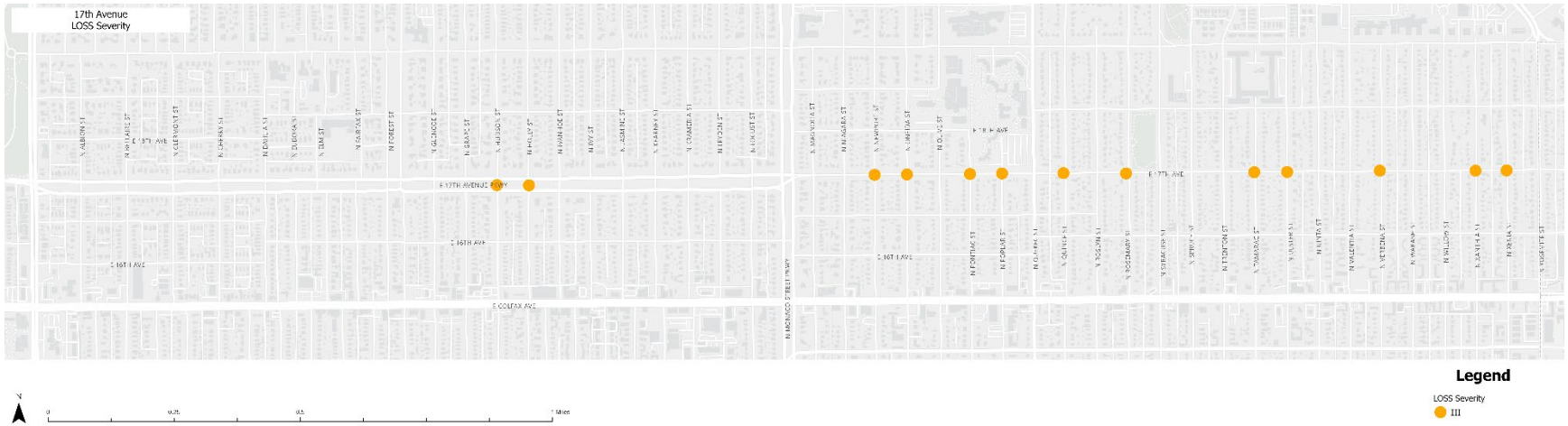


Figure 7: LOSS Severity III and IV Intersections – East 13th and 14th Avenues, Colorado Boulevard to Yosemite Street

Figure 8: LOSS Severity III and IV Intersections – East 17th Avenue, Colorado Boulevard to Yosemite Street



Corridor Speeds

Speeds throughout the entire study area are higher than the posted speed limits. High speeds are unsafe for all road users and play a role in diminishing corridor accessibility, especially for people walking or biking. **Figure 9** summarizes the percent of vehicles speeding on each street.

Figure 9: Percent of Vehicles Speeding by Street

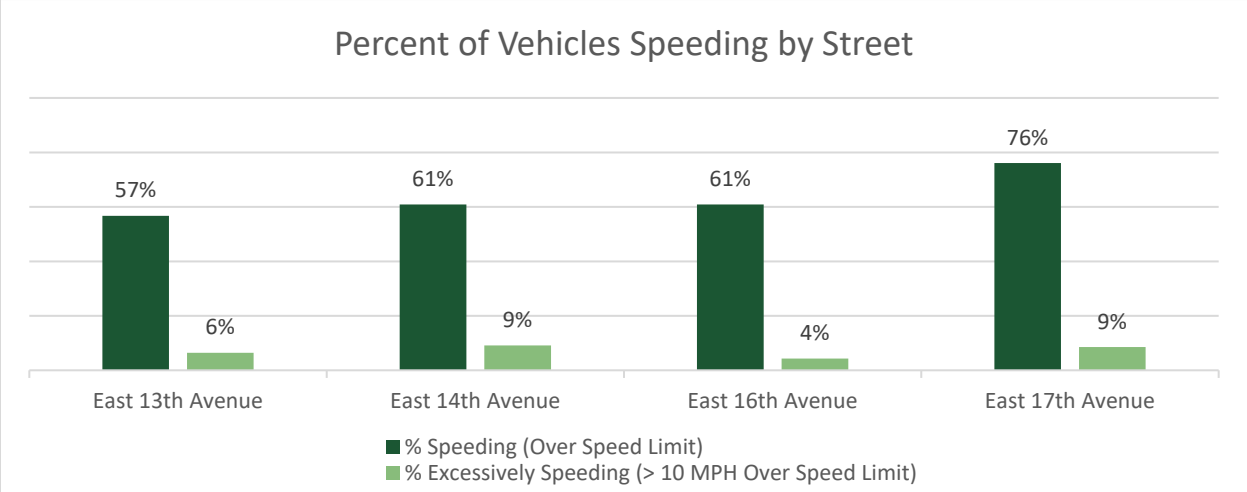


Table 3 summarizes volume and speed data collected on each street and shows that 85th percentile speeds captured throughout the study area range between 11 percent and 35 percent above the posted speed limit. On the arterial streets, East 13th, 14th, and 17th Avenues, the highest recorded speeds all exceed 50 MPH. The speed data included several observations of vehicles traveling 60 MPH or more – more than double the posted speed limit. Speeding exacerbates the frequency and severity of all crash types, so this evidence of high speeds on all four corridors presents a significant opportunity to make these corridors safer by reducing travel speeds.

Table 3: Corridor Speed Data

Corridor	Location	Average Daily Traffic	Speed Limit (MPH)	% of Vehicles Over Speed Limit	85th Percentile Speed (MPH)	Highest Speed (MPH)
East 13th Avenue	West of Lafayette Street	10,000	30	31%	33.2	55-59
East 13th Avenue	West of Milwaukee Street	8,600	30	71%	36.8	65-69
East 13th Avenue	West of Eudora Street	5,960	30	73%	37.7	70-74
East 13th Avenue	West of Tamarac Street	2,470	30	73%	38.9	60-64
East 14th Avenue	West of Lafayette Street	10,480	30	45%	34.9	55-59
East 14th Avenue	West of St Paul Street	9,170	30	80%	38.9	65-69
East 14th Avenue	West of Forest Street	6,690	30	51%	34.7	55-59
East 14th Avenue	West of Tamarac Street	3,190	30	81%	39.6	60-64
East 16th Avenue	West of St Paul Street (Westbound)	740	20	59%	26.0	35-39
East 16th Avenue	West of St Paul Street (Eastbound)	660	20	61%	26.4	40-44
East 16th Avenue	West of Harrison Street (Westbound)	450	20	60%	24.8	30-34
East 16th Avenue	West of Harrison Street (Eastbound)	510	20	63%	27.0	35-39
East 17th Avenue	West of Holly Street (Westbound)	4,340	30	88%	39.5	60-64
East 17th Avenue	West of Holly Street (Eastbound)	5,940	30	77%	37.7	80-99
East 17th Avenue	West of Uinta Street (Westbound)	2,670	30	67%	37.0	50-54
East 17th Avenue	West of Uinta Street (Eastbound)	2,970	30	66%	36.3	55-59

Source: Fehr & Peers.

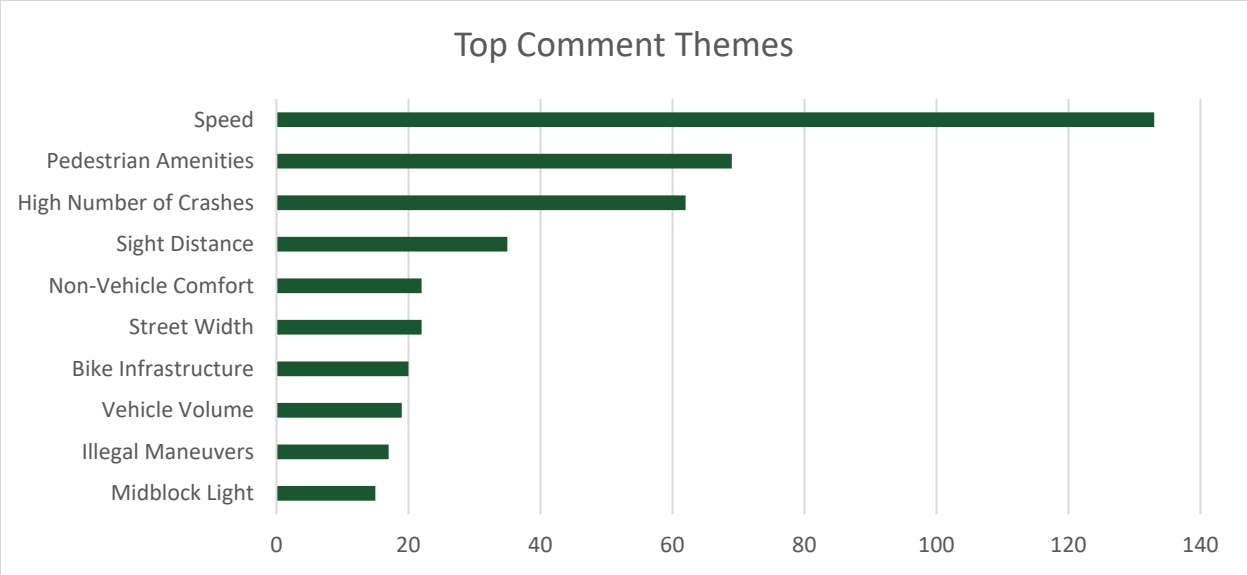
Community Member Input

The project team circulated a Web map and online survey from January 17, 2024 until July 16, 2024 through East Colfax Avenue BRT public meetings, email channels, and Registered Neighborhood Organization meetings. **Appendix E** includes the Web map comments, and **Appendix F** includes the online survey responses.

Web Map

The Web map received 818 comments in total. While comments were accepted on and between East 13th, 14th, 16th, 17th, and 18th Avenues, the study area and this report are focused on a smaller area. 504 comments were located within this study area and were relevant to the discussion of safety. **Figure 10** shows the most common themes among those comments.

Figure 10: Top Web Map Comment Themes



The map comments remain visible at this link to the web map.

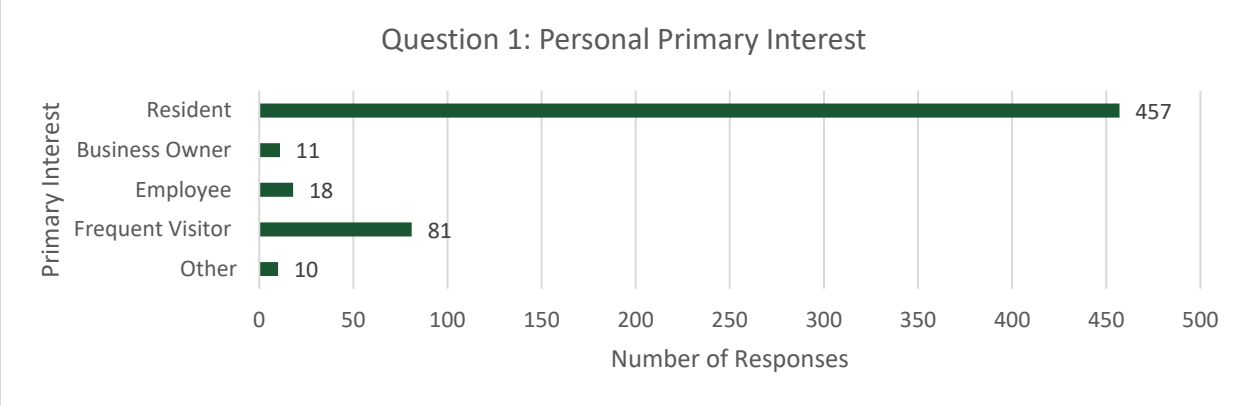
Online Survey

The online survey received 487 responses from 425 participants. The survey asked three questions:

1) Please indicate your primary interest in the corridors parallel to East Colfax Avenue (select all that apply)
2) Please select the corridor(s) that you have the biggest safety concerns for (select all that apply)
3) Please select your top three traffic safety concerns on the corridors you selected (select 3)

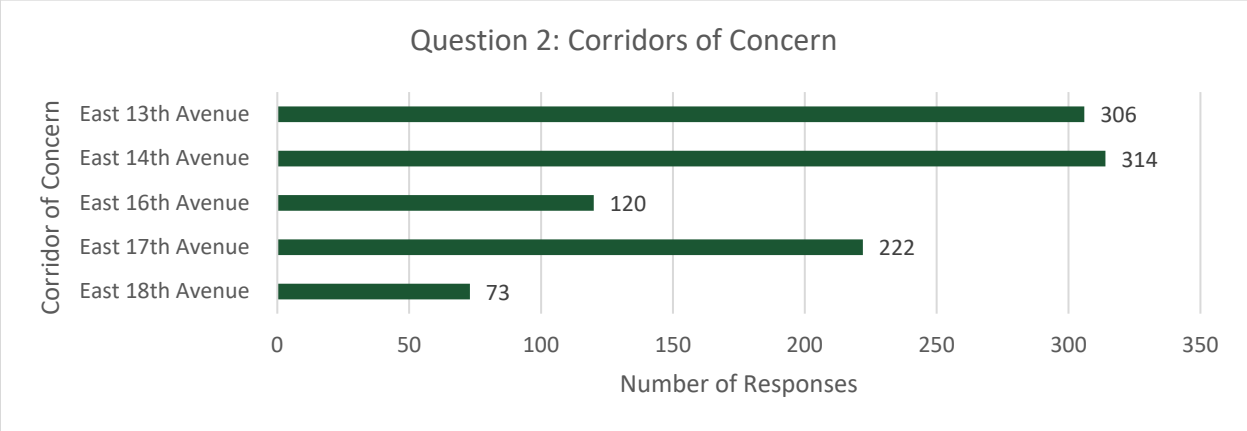
The responses are documented in **Figure 11** through **Figure 13**.

Figure 11: Online Survey Question 1 Responses



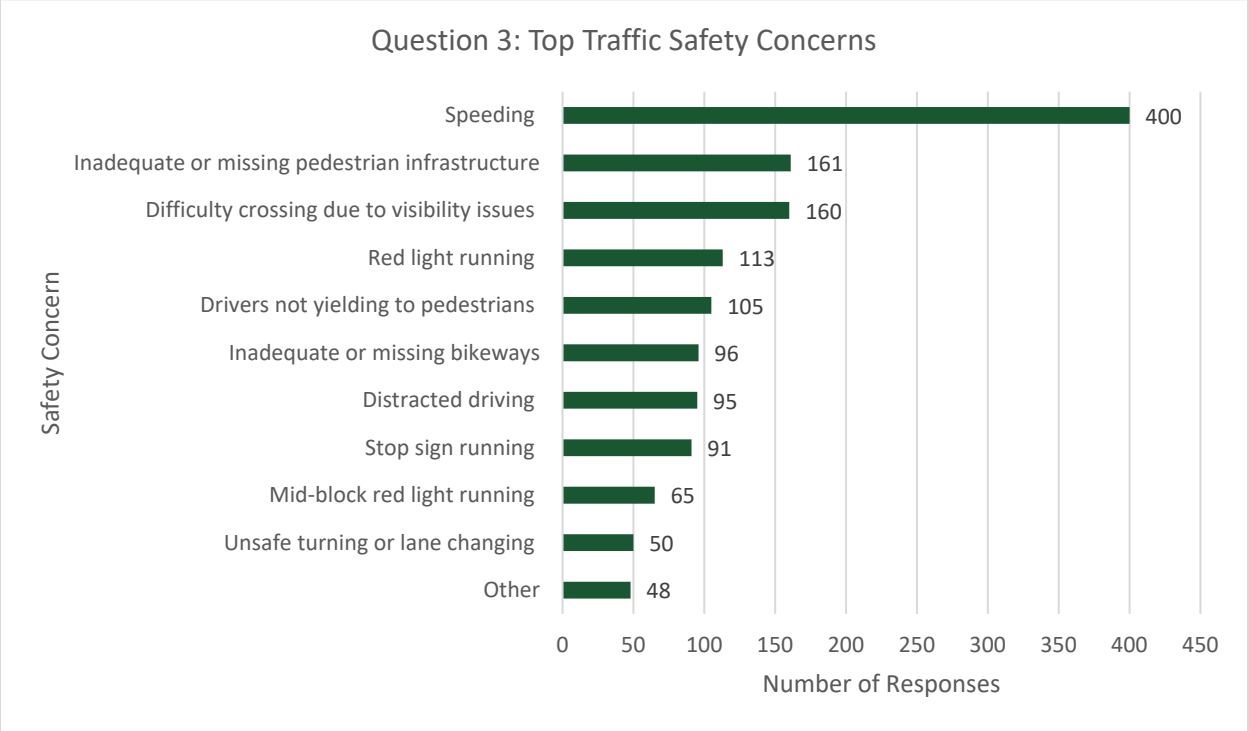
The survey appears to have reached many residents, but business owners and employees have less representation. Those who selected "other" primarily included commuters through the corridors and parents of children attending schools within the study area.

Figure 12: Online Survey Question 2 Responses



East 13th and 14th Avenues were similarly ranked. Many respondents who voted for East 13th Avenue also voted for East 14th Avenue, while the other three corridors were more often a participant's only selection.

Figure 13: Online Survey Question 3 Responses



The top safety concerns identified in the survey yielded similar results to the comment themes in the Web map, with speeding receiving the most attention by far in both formats, and pedestrian infrastructure and sight distance following behind.

Registered Neighborhood Organization Meetings

To hear directly from the neighborhoods affected by safety on these streets, this study was discussed as part of seven Registered Neighborhood Organization (RNO) meetings. They were:

- Greater Park Hill Community, March 7th, 2024
- Inter-Neighborhood Cooperation, March 14th, 2024
- South City Park Neighborhood Association, March 20th, 2024
- Capitol Hill United Neighborhoods, March 28th, 2024
- Mayfair Neighborhoods, April 1st, 2024
- East Colfax Neighborhood Association, April 16th, 2024
- Congress Park Neighbors, April 17th, 2024

The input received at these meetings reaffirmed the findings of the Web map and the online survey and helped to pinpoint specific concerns in each neighborhood.

Primary Safety Concerns & Countermeasures

The following safety concerns are paired with proven countermeasures that are recommended at various locations throughout the study area. Based on crash history, data collection, and community member input, the six primary safety concerns are:

- Broadside crashes at signalized intersections,
- Broadside crashes at unsignalized intersections,
- Crashes involving pedestrians and bicyclists,
- High speeds,
- Overtaking turn crashes, and
- Wrong-way (head-on) crashes

High speeds, although not directly attributable to any one crash type, have the effect of exacerbating the likelihood and severity of all crashes. The other five concerns collectively represent 45 percent of all crashes and 66 percent of fatal and injury crashes in the study area during 2018 to 2022. By focusing on this limited number of safety concerns, the city can have an outsized impact in reducing fatal and injury crashes.

Fehr & Peers identified recommended countermeasures for each safety concern. For each safety concern, we identified countermeasures that can be implemented with quick-build materials and already meet DOTI standards or have otherwise recently been designed/implemented elsewhere in Denver as well as additional countermeasures that have been shown to reduce crashes but are either non-standard in Denver or require technology upgrades that could be costly or require citywide prioritization for implementation. **Table 4** shows a summary of possible countermeasures and cost estimates.

Table 4: Countermeasure Summary

Safety Concern	Possible Countermeasures & Costs
Broadside crashes at signalized intersections	• Signal timing (red clearance interval) *Cost included for other countermeasures* • Detection-based red clearance extension *Cost not produced at this time* • Red light cameras *Cost not produced at this time*
Broadside crashes at unsignalized intersections	• Increase sight distance (including bulbouts) *$235,000*
Crashes involving pedestrians and bicyclists	• Signal timing (LPI) *Cost included for other countermeasures* • Bulbouts *$150,000* • Protected bike lanes *Cost not produced at this time*
High speeds	• Signal timing (coordination) *$250,000* • Bulbouts (through broadside at unsignalized and ped/bike) *Cost included for other countermeasures* • Chicanes *$245,000* • Speed tables *$460,000-$800,000* • Lane reduction *Cost not produced at this time* • Convert one-way streets to two-way where possible *Cost not produced at this time*
Overtaking turn crashes	• Arrow pavement markings *$42,000* • Lane reduction *Cost not produced at this time* • Convert one-way streets to two-way where possible *Cost not produced at this time*
Wrong way crashes	• Improve one-way signage *$41,000* • Convert one-way streets to two-way where possible *Cost not produced at this time*
Other Cross-cutting Countermeasures	• Lane reduction *Cost not produced at this time* • Convert one-way streets to two-way where possible *Cost not produced at this time* • Protected bike lanes *Cost not produced at this time*

Source: Fehr & Peers.

Table 4 shows that, in total, recommended countermeasures at priority locations will cost between $960,000 and $1.2 million, depending on whether chicanes or speed tables are preferred to address high speeds. The costs would increase to implement treatments across the entire length of each corridor, beyond just the priority locations.

Key Definitions

Crash Modification Factor

A Crash Modification Factor (CMF) is a multiplicative factor that indicates the proportion of crashes that would be expected after implementing a safety countermeasure. CMFs with a value less than 1.0 indicate an expected decrease in crashes. CMFs greater than 1.0 indicate an expected increase in crashes.

Example

An intersection is expected to experience 10 crashes per year. By installing a countermeasure with a CMF of 0.80, the expected crashes after installing the countermeasure would be 10 x 0.80 = 8 crashes per year (a 20% reduction).

Appendix G includes the details of crash modification factors applied in this study.

Benefit-Cost Ratio

While the true, human costs of crashes cannot be quantified, benefit-cost ratios are helpful for prioritizing locations and countermeasures. The cost element of the benefit-cost ratio accounts for a countermeasure's capital cost. The benefit element of the benefit-cost ratio accounts for a location's crash history, the cost of different crash severities according to CDOT, the efficacy of the countermeasure (Crash Modification Factor), the countermeasure's service life.

- Fatal: $1.5 million
- Injury: $80,700
- Property Damage Only (PDO): $9,300

Appendix H includes the benefit-cost analysis worksheet used in this study.

Broadside Crashes at Signalized Intersections

Broadside crashes at signalized intersections represented 333 crashes on East 13th, 14th, and 17th Avenues (there are no signalized intersections within the East 16th Avenue study limits) between 2018 and 2022, 127 of which resulted in fatality or injury. While it is not possible to discern from only the crash data which of these crashes are the result of red light running, it is likely that red light running is a contributor to these crashes.

Increase Red Clearance Interval

The red clearance interval is the amount of time that all signals at an intersection are red at the same time to allow traffic to clear the intersection before the next phase. Increasing red clearance time at signalized intersections has a crash modification factor (CMF) of 0.80 for all crash types, including broadside crashes. Research on increasing the red clearance interval is conflicting. Some shows safety benefit, while other research, including research that informed the *Signal Timing Manual* (NCHRP 812), suggests diminishing safety returns over time when it comes to adding red time. These studies generally addressed adding only small increments of red time; more red time (1.0 additional seconds or more) is likely necessary to address these broadside crashes.

The benefit-cost ratio of increasing red clearance time at all arterial-arterial intersections within the project limits, which would amount to 27 intersections, is estimated to be 108:1. The estimated cost of $250,000 includes updating signal timing throughout the corridors, which could be completed through DOTI work orders. Implementing this countermeasure could mitigate 0.4 fatal crashes, 42 injury crashes, and 122 PDO crashes in a 5-year period based on the 2018 to 2022 crash history. Future improvements could address non-arterial intersections as well, but the 27 arterial-arterial intersections are listed in **Table 5**. Eight priority intersections with five or more fatal and injury crashes during 2018 to 2022 are bold. Although not classified as arterials, the intersections of East 13th Avenue and Washington Street and Syracuse Street also had five fatal and injury crashes during 2018 to 2022 and should also be prioritized.

Table 5: Priority Red Clearance Interval Locations

East 13th Avenue	East 14th Avenue	East 17th Avenue
Broadway	Broadway	Colorado Boulevard
Lincoln Street	Lincoln Street	Monaco Parkway
Grant Street	Grant Street	Quebec Street
Logan Street	Logan Street	
Washington Street	**Clarkson Street**	
Clarkson Street	Corona Street	
Corona Street	Downing Street	
Downing Street	**York Street**	
York Street	Josephine Street	
Josephine Street	**Colorado Boulevard**	
Colorado Boulevard	Monaco Parkway	
Monaco Parkway	**Quebec Street**	
Quebec Street		
Syracuse Street		

Notes:
Non-bold locations are all arterial-arterial intersections.
Bold locations had five or more fatal or injury crashes from 2018 to 2022.
Source: Fehr & Peers.

Detection-based Red Clearance Extension

One method that could be deployed to reduce red light running-related crashes is to install detection-based red clearance extension. Detection-based red clearance extension uses traffic detection cameras with advanced detection zones to estimate the speed of approaching vehicles. If a vehicle is approaching at a speed and at a point in time likely to result in running the red light, the traffic signal controller can automatically extend the red clearance interval for all vehicles. While this functionality is often pre-programmed into traffic signal controllers, few agencies are using it. Unfortunately, on the study streets, most traffic signals are pre-timed and lack detection. The cost of a single detection camera is approximately $30,000. This is a strategy that the city can pilot on other streets that already have the necessary detection cameras and controllers, then apply to the study streets if successful.

Red Light Cameras

Red light cameras could be installed at high-priority locations. Denver already has red light cameras as a limited number of locations and further implementation will likely follow a citywide prioritization. Nonetheless, red light cameras reduce broadside and approach turn crashes by 25 percent in urban settings. Based on number of applicable crashes, crash severity, and proximity to one another, four priority locations on the study streets are:

- East 13th Avenue and Logan Street
- East 14th Avenue and York Street
- East 14th Avenue and Colorado Boulevard
- East 17th Avenue and Quebec Street

Broadside Crashes at Unsignalized Intersections

Broadside crashes at unsignalized intersections represented 377 crashes within the study limits between 2018 and 2022, 102 of which resulted in fatality or injury.

Increase Sight Distance

On-street parking creates the most common sight distance obstruction on these streets. "Daylighting" an intersection by prohibiting parking is a common strategy for increasing sight distance. Increasing sight distance by prohibiting parking by an additional 20 feet at unsignalized intersections has a crash modification factor (CMF) of 0.39. The benefit-cost ratio of prohibiting parking at an intersection from 20 feet (current Denver ordinance) to 40 feet at all unsignalized intersections within the study limits, which would amount to 189 intersections, is estimated to be 40:1. The estimated cost of $431,000 includes quick-build paint and delineator posts, a curb stop inside the paint, and resetting each NO PARKING sign. While resetting the NO PARKING signs is the minimum necessary to implement this countermeasure, quick-build bulbouts with paint, delineator posts, and curb stops are likely necessary to reduce instances of drivers stopping or parking in this space. Resetting signs could be completed through DOTI work orders; however, broader implementation of quick-build bulbouts would require using an on-call contractor or initiating a separate design-bid-build process. Implementing this countermeasure could mitigate 0.6 fatal crashes, 61 injury crashes, and 169 PDO crashes in a 5-year period based on the 2018 to 2022 crash history.

This countermeasure would result in the loss of one parking space on each adjacent curb that currently allows parking. **Figure 17** shows an example of the relationship between the number of parking spaces removed (20 feet per space) and the resulting CMF associated with increasing sight distance. The chart shows that removing just one parking space can have a significant effect on crash reduction potential, and

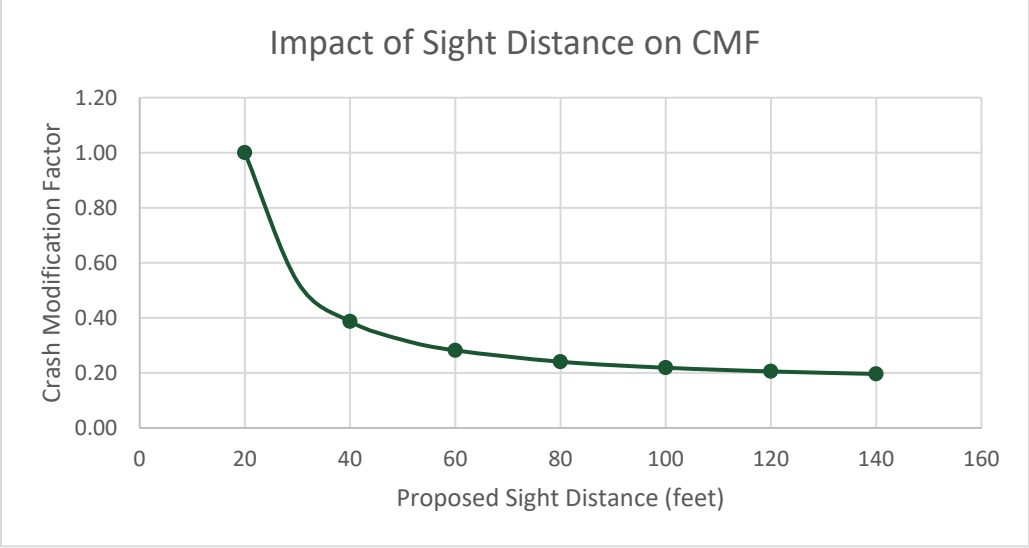


Figure 14: Crash Modification Factor versus Sight Distance Chart

There are two categories of intersections to prioritize. First, unsignalized intersections with five or more broadside crashes during 2018 to 2022. Second, intersections on East 13th Avenue, East 14th Avenue, or East 17th Avenue where the minor street has a traffic signal and allow left-turns with the East Colfax Avenue BRT project. **Table 6** shows the locations of these intersections. The cost of increasing sight distance only at these 44 priority locations is estimated to be $235,000.

Table 6: Priority Increase Sight Distance Locations

East 13th Avenue	East 14th Avenue	East 17th Avenue
Ogden Street	Ogden Street	Glencoe Street
Lafayette Street	Marion Street	Hudson Street
Race Street	Lafayette Street	Krameria Street
Vine Street	Humboldt Street	Magnolia Street
Columbine Street	Race Street	Oneida Street
Elizabeth Street	Gaylord Street	Quince Street
Adams Street	Columbine Street	Rosemary Street
Madison Street	Elizabeth Street	Uinta Street
Cherry Street	Adams Street	Xanthia Street
Dahlia Street	Clermont Street	Xenia Street
Glencoe Street	Cherry Street	Glencoe Street
Hudson Street	Eudora Street	
Ivy Street	Glencoe Street	
Uinta Street	Hudson Street	
Yosemite Street	Ivy Street	
	Uinta Street	
	Willow Street	
	Xenia Street	

Source: Fehr & Peers.

Crashes Involving Pedestrians and Bicyclists

Crashes involving pedestrians and bicyclists represented 86 crashes within the project limits between 2018 and 2022, 72 of which resulted in fatality or injury.

Leading Pedestrian Intervals

A leading pedestrian interval is a period of time when the pedestrian signal is active before the green light is activated for vehicles in the parallel movement, allowing pedestrians to enter the intersection and begin crossing before vehicles. Implementing leading pedestrian intervals (LPIs) at intersections has a crash modification factor (CMF) of 0.81 for all pedestrian crashes at a signalized intersection. The benefit-cost ratio of implementing LPIs at all signalized intersections within the project limits, which would amount to 50 intersections, is estimated to be 9:1. The estimated cost of $250,000 includes updating signal timing throughout the corridors, which could be completed through DOTI work orders. Implementing this countermeasure could mitigate 7 injury crashes and 1 PDO crash in a 5-year period based on the 2018 through 2022 crash history.

Install Bulbouts

Decreasing the curb radius from 20 feet to 10 feet by installing bulbouts at intersections has a crash modification factor (CMF) of 0.82 for all pedestrian crashes at an intersection. The benefit-cost ratio of installing bulbouts at all intersections within the project limits where a pedestrian crash has occurred during 2018 to 2022 (excluding the intersections of East 14th Avenue & Colorado Boulevard and East 17th Avenue & Colorado Boulevard given the lack of on-street parking on Colorado Boulevard), which would amount to 28 intersections, is estimated to be 14:1. The estimated cost of $150,000 includes quick-build paint and delineator posts, a small curb stop inside the paint, and resetting each NO PARKING sign. The installation of an individual bulbout could be completed through a DOTI work order but broader implementation would require using an on-call contractor or initiating a separate design-bid-build process. Implementing this countermeasure could mitigate 8 injury crashes and 2 PDO crashes in a 5-year period based on the 2018 to 2022 crash history.

For all pedestrian safety improvements, intersections that have had pedestrian and bike crashes should be prioritized and are shown in **Table 7**. The only location that has had three or more pedestrian and bike crashes during 2018 to 2022 is the intersection of Pearl Street and East 14th Avenue, which will be upgraded as part of the upcoming Pearl Street Neighborhood Bikeway project.

Table 7: Priority Bulbout Locations

East 13th Avenue	East 14th Avenue	East 17th Avenue
Ogden Street	**Pearl Street**	Xenia Street
Corona Street	Washington Street	
Downing Street	Corona Street	
Marion Street	Marion Street	
Lafayette Street	Lafayette Street	
Williams Street	Humboldt Street	
High Street	Franklin Street	
Josephine Street	High Street	
Garfield Street	Race Street	
Bellaire Street	Josephine Street	
Roslyn Street	Birch Street	
Ogden Street	Glencoe Street	
	Ivy Street	
	Krameria Street	
	Xenia Street	

Notes:
Non-bold locations are intersections with one or two pedestrian or bicyclist crashes from 2018 to 2022.
Bold locations had three or more pedestrian or bicyclist crashes from 2018 to 2022.
Source: Fehr & Peers.

High Speeds

As documented in the collected speed data and the Web map comments, speeds on these streets are higher than desired. Crash issues are exacerbated by these high speeds. Reducing the mean speed on a roadway by 15 percent has a crash modification factor (CMF) of 0.56 for fatal crashes, 0.78 for injury crashes, and 0.85 for property damage only (PDO) crashes. Reducing 85th percentile speeds on East 13th Avenue, East 14th Avenue, and East 17th Avenue closer to the posted speed limit of 30 MPH would require a speed reduction of closer to 20 percent.

Even if installed together, these countermeasures are unlikely to reduce operating speeds to the 30 MPH posted speed limit. To further reduce operating speeds, Fehr & Peers recommends considering speed tables as an additional countermeasure. Reducing the number of travel lanes or converting one-way segments of the study corridors to two-way streets where possible may also help reduce speeds.

Signal Coordination

To some extent, corridor speeds can be managed with appropriate signal coordination. Traffic signal coordination is a method of traffic signal timing that allows vehicles to move through intersections without stopping or with minimal delays. Signals on the study streets are already coordinated. Appropriately timing the offset between traffic signals for a lower target operating speed can reduce instances of speeding where close spacing of traffic signals exists; however, the effect of this strategy is limited where traffic signals are located farther apart east of Colorado Boulevard. Recommended countermeasures for other safety concerns, including increasing the red clearance interval to mitigate broadside crashes at signalized intersections and leading pedestrian intervals to mitigate pedestrian crashes at signalized intersections, could be implemented alongside appropriate signal coordination. The estimated cost of $250,000 includes updating signal timing throughout the corridors, which could be completed through DOTI work orders. Implementing this countermeasure would have a small effect on reducing corridor travel speeds.

Bulbouts

Treatments that physically narrow the roadway are associated with a four percent reduction in travel speeds (*U.S. Traffic Calming Manual*). Recommended countermeasures for other safety concerns, including bulbouts (shown in Figure 14) to increase sight distance to mitigate broadside crashes at unsignalized intersections and bulbouts to mitigate pedestrian crashes at signalized intersections, would create several narrowing treatments along the study streets. Implementing these bulbouts would build upon the 21 locations on East 13th and 14th Avenues where they were installed in 2023 to achieve a reduction in travel speeds of less than five percent.

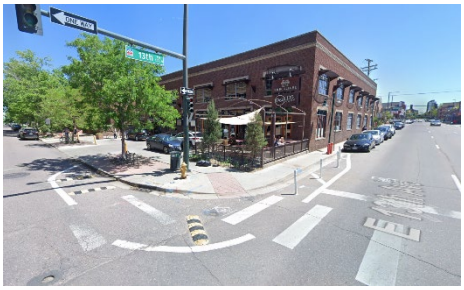


Figure 15: Paint-and-post bulbout on East 13th Avenue in Denver

Chicanes

Modifying the horizontal alignment, previously implemented or designed in Denver with chicanes, is a countermeasure that can reduce travel speeds more than treatments that only narrow the roadway (e.g., bulbouts). An example of chicanes in Denver is shown in Figure 15. Research for other horizontal alignment treatments has shown a 11 percent reduction in travel speeds (*U.S. Traffic Calming Manual*). Implementing this countermeasure may require changes in lane configurations and/or on-street parking. The estimated cost of implementing 60 chicanes throughout the extents of East 13th, 14th, and 17th Avenues (60 locations, or one chicane every four blocks) is $245,000. The installation of an individual chicane could be completed through a DOTI work order, but broader implementation would require using an on-call contractor or initiating a separate design-bid-build process.

Figure 16: Paint-and-post chicane on 30th Street in Denver

Speed Tables

Signal coordination, bulbouts, and chicanes can all be implemented with quick-build materials and already meet DOTI standards or have otherwise recently been designed/implemented elsewhere in Denver. However, their implementation is unlikely to reduce travel speeds on East 13th Avenue, East 14th Avenue, or East 17th Avenue to the currently posted speed limit of 30 MPH. An additional countermeasure for consideration is to implement speed tables rather than chicanes. Speed tables have a higher design speed than speed cushions and other agencies have installed them on higher-volume streets where speed reduction is necessary while balancing the needs of trucks and emergency vehicles. For example, the

Hawaii Department of Transportation recently and successfully installed hundreds of speed tables (with crosswalks) on higher-speed, multi-lane, state highways.

Figure 17: Speed Table

In a study of 78 applications, 22-foot speed tables produced a 20 percent reduction of speeds on average, to an average speed of 29.2 MPH (*U.S. Traffic Calming Manual*). If placed approximately every four blocks along East 13th, 14th, and 17th Avenues, the benefit-cost ratio of installing speed tables to reduce mean speeds by at least 15 percent is estimated to be 84:1. The estimated cost of $800,000 includes asphalt, labor, thermoplastic pavement markings, and warning signs for 60 speed tables. Implementing this countermeasure could mitigate more than 2.6 fatal crashes, 117 injury crashes, and 335 PDO crashes in a 5-year period based on the 2018 to 2022 crash history. The top three priority corridors for speed reduction are:

1. East 13th Avenue from Broadway to Colorado Boulevard
2. East 14th Avenue from Broadway to Monaco Parkway
3. East 17th Avenue from Monaco Parkway to Yosemite Street

The cost of installing speed tables only at the priority locations listed above is estimated to be $460,000.

Overtaking Turn Crashes

Overtaking turn crashes represented 260 crashes within the project limits between 2018 and 2022, 40 of which resulted in fatality or injury. In addition to implementing arrow pavement markings as described in the next section, converting one-way segments of the study corridors to two-way streets may help to reduce the prevalence of overtaking turn crashes.

Arrow Pavement Markings

Arrow pavement markings at intersections have a crash modification factor (CMF) of 0.85 for all injury crashes at intersections. The benefit-cost ratio of implementing arrow pavement markings at all unsignalized intersections on East 13th, 14th, and 17th Avenues where an injury overtaking turn crash has occurred, which would amount to 23 intersections, is estimated to be 7:1. The estimated cost of $42,000 includes thermoplastic pavement markings, which could be installed through DOTI work orders. Implementing this countermeasure could mitigate 4 injury crashes in a 5-year period based on the 2018

through 2022 crash history. The recommended intersections, where injury crashes have occurred during 2018 to 2022, are shown in **Table 8**.

On both East 13th and 14th Avenues, there is a concentration of overtaking turns around Colorado Boulevard – with a total of 24 crashes on East 13th Avenue between Madison Street and Colorado Boulevard, and a total of 27 crashes on East 14th Avenue between Albion Street and Clermont Street.

Table 8: Priority Arrow Pavement Marking Locations

East 13th Avenue	East 14th Avenue	East 17th Avenue
Ogden Street	High Street	Newport Street
Lafayette Street	Race Street	
Humboldt Street	Vine Street	
Race Street	Clayton Street	
Cook Street	Milwaukee Street	
Madison Street	Jackson Street	
Monroe Street	Ash Street	
Harrison Street	**Birch Street**	
Ulster Street	**Clermont Street**	
	Cherry Street	
	Leyden Street	
	Trenton Street	
	Wabash Street	

Notes:
Non-bold locations are intersections with one injury overtaking turn crash from 2018 to 2022.
Bold locations are intersections with two or more injury overtaking turn crashes from 2018 to 2022.
Source: Fehr & Peers.

Wrong Way Crashes

Wrong-way crashes represented 22 crashes within the project limits between 2018 and 2022, 11 of which resulted in fatality or injury. Wrong-way drivers are a notable concern from the perspective of community members, as they cause significant alarm to other users even when they do not cause crashes. Converting segments of the study area streets to be two-way, as discussed in more detail in later sections, would also mitigate wrong-way crashes.

Improve One-way Signage

While Fehr & Peers did not complete a detailed review of all one-way signage along the study streets, it appears that the standard one-way sign layout meets the MUTCD minimums (one ONE WAY R6-1 sign on the near-right side, and one ONE WAY R6-1 on the far-left side). The MUTCD gives the option for additional ONE WAY R6-1 signs on the far-right side. In many cases, the placement of these signs on the far-right side is likely to be more visible to drivers on the minor street given their location when judging a gap in traffic and that traffic is only approaching from one direction.

Improving one-way signage at intersections to MUTCD standards has a crash modification factor (CMF) of 0.85 for all injury crashes at intersections. The benefit-cost ratio of improving one-way signage at all named intersections within the project limits, which would amount to 226 intersections, is estimated to be 6:1. The estimated cost of $41,000 includes one-way signs, which could be installed through DOTI work orders. Implementing this countermeasure could mitigate 1.5 injury crashes in a 5-year period based on the 2018 to 2022 crash history.

Other Cross-cutting Countermeasures

Throughout the completion of this study, community members and DOTI staff inquired about more significant intervention on the study streets including reducing the number of travel lanes, implementing protected bike lanes, or converting one-way streets to two-way. While there is merit to each of these ideas, uncertainties around their cost, effects to safety, and effects to vehicle mobility in the study area suggest that thorough evaluation and community conversations are necessary before advancing them. To advance any of these ideas, DOTI should complete further study.

Lane Reduction

Reducing the number of travel lanes would be most possible on East 14th Avenue east of Grant Street (three lanes to two lanes) and on East 17th Avenue from Colorado Boulevard to Monaco Parkway (four lanes to two lanes). Reducing the number of travel lanes would reduce travel speeds during peak times by reducing passing opportunities. It would improve safety by reducing speeds, reducing exposure for pedestrians crossing the street, and possibly in other ways. However, reducing the number of lanes on East 14th Avenue and East 17th Avenue would result in a reduction of vehicle capacity on these streets and in the study area.

Protected Bike Lanes

Protected bike lanes have been previously proposed on these streets and are being further considered in the current update to Denver Moves: Bikes, including East 13th, 14th, and 17th Avenues. It has not yet been determined whether protected bike lanes would be implemented in place of travel lanes, on-street parking, or other changes to the street cross-section. While adding protected bike lanes to these streets will improve access and comfort for people biking, it is difficult to discern whether they will mitigate bicyclist crashes currently happening on these streets (some crashes are likely related to bicyclists crossing these streets rather than biking along them). Potential parking and traffic impacts of a protected bike lane were not studied as a part of this analysis.

Two-way Conversion

Converting the study streets that are currently one-way to two-way would significantly alter the function of these streets. Historically, one-way streets were installed to enable vehicles to move across long distances quickly and at high capacity. It stands to reason that converting these streets back to two-way would reduce speeds. However, the safety effects of two-way conversion are unclear: two-way streets introduce more conflict points, create potential for head-on crashes, and can be more complex for pedestrians to cross. Research on one-way to two-way conversions is limited. One available study on the Crash Modification Factor Clearinghouse from China shows a CMF greater than 1.0 (indicating an increase in crashes) while other examples have showed a crash reduction. DOTI should complete further study to understand the expected safety performance of these streets in two-way versus one-way operation.

Beyond the uncertainties of the safety outcomes, the cost of a two-way conversion may be high. Fehr & Peers estimated the cost of a two-way conversion on East 13th Avenue and East 14th Avenue between

Colorado Boulevard and Yosemite Street, the segments that would be easiest to convert. When accounting for major signal modifications at intersecting arterial streets to meet DOTI standards, signal removals at minor streets, and striping/signing changes, the cost likely exceeds $5 million. That cost may be lower if DOTI can employ creative strategies for traffic signals at intersecting arterial streets that still meet MUTCD requirements.

Traffic Effects

To understand the effects of lane reductions and two-way conversions on traffic, Fehr & Peers re-ran the TransModeler model used for the *East Colfax Avenue BRT Transportation Report* (2019 Build Mitigated scenario). These changes result in significantly more congestion within the study area network, as reflected in increases in unserved vehicles (i.e., vehicles unable to enter the model network), Vehicle Hours Traveled (VHT), and the number of level of service (LOS) E or LOS F intersections. **Table 9** and **Table 10** show the results of this analysis.

The most significant challenge occurs where East 13th Avenue and East 14th Avenue intersect with major north-south roads, primarily Colorado Boulevard and Monaco Parkway. Additional green time is needed to serve the new movements at these intersections which is challenging when these locations are already at or near capacity today. Additional study would be necessary to determine optimal signal phasing and intersection design to safely and efficiently accommodate all anticipated users at these locations.

Table 9: TransModeler Summary with Lane Reduction and Two-way Conversions (AM)

Scenario	Unserved Vehicles (6:30-9:30 AM)	Vehicle Hours Traveled (VHT) (6:30-9:30 AM)	LOS E or LOS F Intersections (6:30-9:30 AM)
2019 No Build *from East Colfax Avenue BRT Transportation Report*	30 (<0.1%)	11,100	7
2019 Build Mitigated *from East Colfax Avenue BRT Transportation Report*	50 (<0.1%)	11,800 (+6%)	10 (+3)
2019 Build Mitigated + Lane Reductions & Two-way Conversions	860 (0.8%)	14,200 (+28%)	15 (+8)

Source: Fehr & Peers.

Table 10: TransModeler Summary with Lane Reduction and Two-way Conversions (PM)

Scenario	Unserved Vehicles (4:00-7:00 PM)	Vehicle Hours Traveled (VHT) (4:00-7:00 PM)	LOS E or LOS F Intersections (4:00-7:00 PM)
2019 No Build *from East Colfax Avenue BRT Transportation Report*	10 (<0.1%)	13,400	10
2019 Build Mitigated *from East Colfax Avenue BRT Transportation Report*	780 (0.6%)	15,900 (+19%)	12 (+1)
2019 Build Mitigated + Lane Reductions & Two-way Conversions	6,900 (5.4%)	25,100 (+87%)	35 (+24)

Source: Fehr & Peers.

Other Considerations

The following countermeasures or strategies may improve safety on the study streets, but their efficacy, benefit-cost, or effects require further assessment.

Relocation of Stop-gap Signals

Within the study area on East 13th and 14th Avenues there are a total of 14 stop-gap signals, or mid-block signals that were installed with the intention of creating gaps in one-way traffic flow to reduce congestion on the intersecting minor streets. While community members express significant frustration with these signals and report seeing them disregarded by drivers, the cost of relocating them outweighs the safety benefits that would result. It would cost at least $500,000 to remove a stop-gap signal and replace it with a fully signalized intersection. Additionally, moving the stop-gap signals to intersections would likely increase traffic volumes on the intersecting minor streets. Because they are not located at intersections, these signals are not associated with a significant number of crashes, so there is little likelihood of return on investment in terms of safety.

Use of Permanent Materials for Construction

Denver has employed many quick-build materials to decrease construction costs and increase the rate at which safety, traffic calming, and other multimodal improvements can be installed. It is also a valuable way to ensure positive outcomes of treatments before spending more money on permanent infrastructure. While this method has clear benefits, it is important to note that quick-build treatments require frequent and costly maintenance to maintain efficacy. Permanent infrastructure also is received more positively by residents. As a result, quick-build treatments should be improved with permanent infrastructure as soon as is economically feasible.

Effects of Proposed Changes on Pedestrian Crossing Distances

Given the recommended changes to these streets, some existing marked crosswalks may need to be reevaluated in terms of recommended crossing treatment based on the *City and County of Denver Uncontrolled Pedestrian Crossing Guidelines*. For given traffic volumes (vehicle Average Daily Traffic) and lane configurations (roadway type), reducing the speed of a street can lessen the type and cost of treatments necessary to ensure safe and comfortable pedestrian crossings. In some cases, on the study streets, reducing the speeds may change locations that require a Pedestrian Hybrid Beacon or signal to require a Rectangular Rapid Flashing Beacon instead. Or reducing the speeds may change locations that require a Rectangular Rapid Flashing Beacon to require just markings and signing. By reducing corridor speeds, the cost of improving pedestrian crossings can be significantly reduced as well.

Figure 18: Recommended Treatment Matrix from Uncontrolled Pedestrian Crossing Guidelines

Table 4: Recommended treatment at marked crosswalks

Roadway Type	Vehicle ADT ≤9,000			Vehicle ADT >9,000 to 15,000			Vehicle ADT ≥15,000		
	≤30 mph	35 mph	40 mph	≤30 mph	35 mph	40 mph	≤30 mph	35 mph	40 mph
2 Lanes (1 lane in each direction)	A 1 2 4 6	A 4 6	B 4 6	A 4 6	A 4 6	C 4 6	B 4 6	B 4 6	C 4 6
3 lanes with raised median / Single lane one-ways (1 lane in each direction)	A 1 2 3 6	A 3 6	B 3 6	B 2 3 6	B 3 6	B 3 6	B 2 3 6	B 3 6	C 3 6
3 lanes w/o raised median (1 lane in each direction with a left-turn lane)	A 1 2 3 4 6	A 3 4 6	C 3 4 6	B 3 4 6	B 3 4 6	C 3 4 6	C 3 4 6	C 3 4 6	C 3 4 6
4+ lanes with raised median (2 or more lanes in each direction)	A 3 5 6	A 3 5 6	C 3 5 6	B 3 5 6	B 3 5 6	C 3 5 6	C 3 5 6	C 3 5 6	C 3 5 6
4+ lanes w/o raised median/ Multilane one-ways (2 or more lanes in each direction)	A 3 4 5 6	B 3 4 5 6	C 3 4 5 6	B 3 4 5 6	B 3 4 5 6	C 3 4 5 6	C 3 4 5 6	C 3 4 5 6	C 3 4 5 6

Geometric Enhancements:

1. Raised Crosswalk
2. In-street pedestrian sign
3. Advanced "yield here to" markings & signage
4. Pedestrian refuge island
5. Road diet
6. Curb Extensions

Level	Treatment
A	Markings & Signing
B	RRFB
C	PHB or Signal

Notes:

Refer to the table instructions on the previous page for more information on how to use this table, such as when exceptions may be required or permitted. Explore geometric enhancements prior to the implementation of the treatment identified in the table.

The recommendations in this table were updated based off of research summarized in the Federal Highway Administration's Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations (FHWA-SA-17-072).

When applying this table at an uncontrolled intersection leg on a signalized corridor, Level A may be upgraded to B with approval of the City Traffic Engineer. Level A may also be upgraded to B if a gap study reveals insufficient gaps to safely cross.

Local Street Traffic Calming

It is likely that the safety improvements outlined in this study will have many, mostly positive effects on the intersecting minor streets. An analysis of these effects is not included in this study, but it will be critical to monitor effects over time as improvements are implemented on East 13th, 14th, 16th, and 17th Avenues. Depending on the results of various treatments, the approach to safety improvements may need to be modified accordingly.

Appendix A: East 13th & 14th Avenues Presentation

Appendix B: East 16th Avenue Presentation

Appendix C: East 17th Avenue Presentation

Appendix D: Vision Zero Suite LOSS Results

Appendix E: Social Pinpoint Web Map Comments

Appendix F: Social Pinpoint Online Survey Results

Appendix G: Countermeasure Reports

Appendix H: Benefit-Cost Analysis Worksheet