COLORADO
Department of Transportation
Office of the Chief Engineer

Urban Arterial Safety Strategies

The Colorado Department of Transportation (CDOT) recently adopted the new Strategic Transportation Safety Plan (STSP) with the following vision: “The future of Colorado is zero deaths and serious injuries so all people using any transportation mode arrive at their destination safely.” The Safer Main Streets Initiative was developed by CDOT and the Denver Regional Council of Governments (DRCOG) to support infrastructure projects that improve safety and transform urban spaces, especially for vulnerable users in alignment with CDOT’s vision of zero deaths.

CDOT Traffic Engineering in collaboration with Region 1 Traffic, developed a tool box of strategies for consideration when identifying potential project locations and developing project scopes. This list compiled strategies which may mitigate specific safety issues from a variety of sources, including FHWA, AASHTO, the Highway Safety Manual, and others.

An engineering analysis is recommended for any identified location and may include some or all of the following: identification of safety concerns, crash patterns, crash severity, geometric or design issues, local knowledge, enforcement data, and traffic volumes (including pedestrians and bicycles if applicable). Project selection and scoping should be developed in collaboration with the CDOT regional offices, taking the engineering analysis into consideration.

	Strategy Type	Description	Potential Impacts
1	Access Control Plan	Develop an access control plan and subsequently implement infrastructure improvements for the corridor. Consolidate accesses points, improve alignments, add medians.	Reduce conflict points for vehicles and pedestrians with fewer accesses. Improve access alignments, improve sight distance, improve traffic flow. Requires community involvement to develop and implement a plan. Allows engineering analysis of operations and evaluation of access points to improve safety for corridor wide improvements.
2	Road Diet	Convert traditional 4-lane highway into a 3-lane segment with a two-way left turn lane in the center. Reclaimed space may be allocated for other uses, such as turn lanes, bus lanes, pedestrian refuge islands, bike lanes, sidewalks, bus shelters, parking or landscaping.	Road diets can cut total crashes 19 to 47 percent. Can provide for additional safety for bikes and peds with improved bike and/or ped facilities. Improved transit mobility when bus lanes or transit facilities are added.
3	Signal	Left Turn Lane/left turn arrow. Flashing Yellow Arrow (FYA) with full protection phase. May be Time of Day or Full time application as applicable.	Reduces left turning conflicts. Left only phasing may reduce pedestrian conflicts

4	Signal	Install new signals at a 2 way stop controlled intersection where warrants are met.	May reduce efficiency, increasing delays and/or pollution. Provide pedestrian phase for improved ped safety.
5	Signal	Add Exclusive Pedestrian Phasing; Replace Existing WALK/DON'T WALK Signals with Pedestrian Countdown Signal Heads; Implement a Leading Pedestrian Interval; Convert Permissive to Protected-Only left-Turn Phasing	Reduce Pedestrian crashes
6	Signal	Backplates with Retroreflective Borders	Backplates added to a traffic signal indication improve the visibility of the illuminated face of the signal by introducing a controlled-contrast background. The improved visibility of a signal head with a backplate is made even more conspicuous by framing it with a retroreflective border. Signal heads that have backplates equipped with retroreflective borders are more visible and conspicuous in both daytime and nighttime conditions.

7	Signal	Install snow cones to signals to increase visibility during inclement weather, specifically driving snow.	Snow cones on signals can reduce or prevent snow accumulation which blocks the signal during inclement weather conditions. May reduce red light violation crashes during inclement weather.
8	Signal	Install or Upgrade Traffic and Pedestrian Signals. This strategy includes six countermeasures: traffic signals, pedestrian signals, pedestrian signal timing, accessible pedestrian signals, signal enhancements, and right-turn-on-red restrictions.	Improved control of pedestrian and traffic flow. Improves pedestrian safety, may improve traffic flow with improved signal coordination.
9	Signal	Intersection Signal timing changes. Change timing to allow for leading pedestrian interval at signalized intersections to allow peds to walk before vehicles get a green turn signal	Increased ped visibility, reduction in conflicts and lower ped crashes up to 59%
10	Signal	Coordinate signals and develop a corridor signal timing plan and accommodations for transit operations.	Improved transit mobility and operations, reduction in congested conditions, improved ped signal operations.

11	Signal	Improve signal clearance interval. The target of this strategy is crashes related to clearance interval lengths that are too short for a particular intersection.	This strategy is proven effective in reducing multi-vehicle crashes at signalized intersections. A study of signalized intersections in one city in New York found a 9-percent reduction in multivehicle and a 12-percent reduction in injury crashes at intersections where the duration of the change intervals was lengthened to meet ITE recommendations.
12	Signal Coordination	Signal coordination has long been recognized as having beneficial effects on the quality of traffic flow along a street or arterial. Good signal coordination can also generate measurable safety benefits. Implement Green Wave Systems(Coordinated Signals). Coordinated signal timing synchronizes traffic movements and manages the progression speed of specific modes where uninterrupted flow is desired along	The ITE Traffic Safety Toolbox (Institute of Transportation Engineers, 1999b) cites two studies of coordinated signals with intersection crash frequencies that dropped by 25 and 38 percent. One of the studies showed an improvement in crash rates for midblock sections as well. Reduce a high frequency of crashes involving major street left-turning and minor street right-turning vehicles

13	Remove Unwarranted Signal	This strategy is targeted at signalized intersections where traffic volumes and safety records do not warrant a traffic signal.	Removal of an unwarranted signal will eliminate excessive delay and disobedience of the signal indicators at the targeted intersections if these conditions exist because the signal is no longer needed.
14	Transit Signal Priority System	Transit signal prioritization, as an example, freight vehicles are equipped with a device to communicate with traffic signals and extend green time to expedite freight movement and reduce stop/go conflicts in dense urban environments.	improve bus running time
15	Emergency Vehicle Preemption	Signal preemption allows emergency vehicles to disrupt a normal signal cycle in order to proceed through the intersection more quickly and under safer conditions.	A review of signal preemption system deployments in the United States shows decreases in response times between 14 and 50 percent. In addition, the study reports a 70-percent decrease in crashes with emergency vehicles in St. Paul, Minnesota. This may require signal upgrades for deployment and likely combined with additional safety improvements.

16	Lighting	Improve street lighting	Impacts nighttime crashes only, improves ped, bike and vehicle safety. Implement in spot locations or corridors as appropriate based on safety evaluation
17	Geometrics	Convert Intersection to Roundabout; Install Raised Median; Install Raised Pedestrian Crossing; Install Refuge Islands; Install Sidewalk; Provide Paved Shoulder ; Narrow Roadway Cross-Section; channelizing right turns, etc.	Reduce Pedestrian crashes, other crash types. Improvements need to be evaluated on a case by case basis.
18	Geometrics (bicycle)	There are several ways to modify the geometry of an intersection to improve bicycle safety, including: Reducing the crossing distance for bicyclists. Realigning intersection approaches to reduce or eliminate intersection skew. Modifying the geometry to facilitate bicycle movement at interchange on-ramps and off-ramps	Research by Landis et al. (2003) on intersection level of service for bicyclists indicates that bicyclists feel safer crossing shorter distances. It is reasonable to expect that raised medians would also benefit bicyclists at path/highway crossings. Raised refuge islands can also serve to calm traffic (i.e., reduce motor vehicle speeds), which is beneficial for bicyclists.

19	Geometrics	Install new roundabout at existing signal or stop controlled intersection	Ensure pedestrian facilities are sufficient for ped safety. Reduces delays, reduces speed, reduces "T-Bone" type of crashes, left turn conflicts.
20	Medians	Install hardscape medians	Reduce crossover/head on collisions, reduces conflict points by bringing vehicles to specific intersections, allows for intersection control. Allows for beautification in the medians, see South Broadway.
21	Crosswalk Improvement	Additional sidewalk area at intersections or bulb outs for lower speed applications and in conjunction with other improvements.	Reduces pedestrian crossing distance and conflicts. Provides traffic calming. Can improve slopes and turning radii for ADA accessibility at the crossing. May reduce parking.
22	Pedestrian Facilities	Add improved sidewalks such as wider sidewalks, add missing sections of sidewalks, relocate sidewalks for improved access/ease of use. Raised medians, crossing islands	

23	Crosswalk Improvement	Rectangular rapid flashing beacon installation at midblock crossings to improve driver yield behavior may be considered on a case by case basis.	Improved pedestrian crashes at midblock crossings with up to 47% decrease in crashes
24	Crosswalk Improvement	Enhanced crosswalk visibility with improved lighting, enhanced signage and pavement marking	Helps drivers detect pedestrians and reduce ped crashes 23-48%
25	Crosswalk Improvement	Install raised crosswalks. These are typical for lower volume roadways than typical urban arterials and may be more applicable	Acts as traffic calming, may reduce vehicle speeds, reduce ped crashes up to 45%
26	Crosswalk Improvement	Install Pedestrian crossing refuge or islands to provide a safe place for pedestrians to stop at the midpoint of the roadway before crossing the remaining distance	Can reduce ped crashes up to 32%
27	Crosswalk Improvement	Pedestrian hybrid beacons (PHBs) or HAWK, an intermediate option between a flashing beacon and a full pedestrian signal, provide stop control for higher speed, multilane	PHBs can reduce pedestrian crashes up to 55 percent.

		roadways with high vehicular volumes.	
28	Crosswalk Improvement	Reduce Screening by Physical Objects at Crosswalks, improve sight lines and sight distance.	Studies have shown that reducing visual screening by installing advance yielding markings can produce large reductions in motor-vehicle/pedestrian conflicts at crosswalks.
29	Reduce Vehicle Speed	Install speed humps and speed tables. These may not be applicable for mainline arterials.	Speed humps have been evaluated and found effective in many cities in terms of reducing vehicle speeds. Eight studies were reviewed for this Guide and are listed in the References section. These studies found that 85th-percentile speeds decreased by 4 to 23 mi/h after the speed humps were installed
30	Reduce Vehicle Speed	Curb radius reduction where allowable based on traffic volumes, mainline speeds, and movement counts.	Reducing the curb radius creates a tighter turn and results in motorists making right turns at lower speeds.

31	Overpass or Underpass	At path/roadway intersections, an overpass or underpass allows for uninterrupted flow for bicyclists/pedestrians and completely eliminates exposure to vehicular traffic.	These grade-separated crossings can improve safety and are desirable at some locations. Because grade-separated crossings can be quite expensive, may be considered unattractive, may become sites of crime or vandalism, and may even decrease safety if not appropriately located and designed, these types of facilities are primarily used as measures of last resort
32	Provide Vehicle Restriction/Diversion Measures	Diverters, partial street closure, full street closure, and pedestrian streets. These countermeasures are designed to reduce or eliminate motor-vehicle traffic on low-volume streets, especially cut-through traffic in neighborhoods.	Pedestrians benefit because they are exposed to fewer motor vehicles, which means less risk of a crash, fewer conflicts, and a higher perception that it is safe to walk without being hit by a vehicle. However, these countermeasures can be expensive and restrict access to emergency vehicles.

33	Geometrics	Geometric modifications to reduced Left Turn Conflicts at Intersections which may reduce through movements or relocate u-turns to another location. May also use signal timing and signal phases to modify or restrict left turn movements.	Reduced left-turn conflict intersections are geometric designs that alter how left-turn movements occur in order to simplify decisions and minimize the potential for related crashes. Two highly effective designs that rely on U-turns to complete certain left-turn movements are known as the restricted crossing U-turn (RCUT) and the median U-turn (MUT).
34	Geometrics	Left and Right Turn Lanes at Two-Way Stop-Controlled Intersections	Auxiliary turn lanes—either for left turns or right turns—provide physical separation between turning traffic that is slowing or stopped and adjacent through traffic at approaches to intersections. Turn lanes can be designed to provide for deceleration prior to a turn, as well as for storage of vehicles that are stopped and waiting for the opportunity to complete a turn.

35	Geometrics	The visibility at intersections can be enhanced by improving the sight distance/sight lines near the intersection and/or by improving the conspicuity of traffic control devices at and near intersections.	Improved visibility and awareness of traffic control information are expected to reduce conflicts related to drivers not being able to see the device well or in enough time to comply with the signal indication or sign message (such as those resulting in rear-end and right-angle crashes).
36	Restrict or Eliminate Turning Maneuvers (Including Right Turns on Red)	This strategy includes restricting or eliminating left- or right-turning maneuvers using channelization or signing and prohibiting right turns on red (RTOR).	Prohibition of RTOR can help reduce crashes related to limited sight distance and pedestrians that involve right-turning vehicles. This strategy can also help reduce the frequency and severity of crashes between vehicles turning right on red and vehicles approaching from the left on the cross street or turning left from the opposing approach.
37	Sign/Marking/Operation	Add Intersection/Segment Lighting; Improve Pavement Friction; Prohibit Right-Turn-On-Red; Prohibit Left Turns; Restrict Parking Near Intersections	Reduce Pedestrian crashes

38	Parking changes	Remove parking to enhance the roadway profile	Allows for additional space to add bike lanes, turn lanes, medians, additional thru lanes.
39	Parking changes	Add parking as a part of a comprehensive corridor plan, such as a roadway diet which includes traffic calming or other improvements	Reduces through lanes and may reduce travel speeds. May impact bike lanes.
40	Pavement Markings	Install test speed control markings	Transverse pavement markings to provide the illusion of changing speed in the driver's peripheral vision, causing drivers to slow down as the frequency of markings changes. Study results vary with the effectiveness of this treatment. If applied, it is recommended that a before and after study be completed on the effectiveness of the markings. Project may need to include additional signage for implementation. It is not recommended that markings be contained within bike lanes due to the loss of friction created by pavement markings.

41	Pavement markings	Install green bike lanes, pavement markings and additional bike lane improvements.	Helps drivers recognize bicycle facilities and improves visibility of bicyclists. Currently requires permission from FHWA before implementation.
42	Road Narrowing and Traffic Calming Measures	Roadway narrowing improvements have the objective of slowing vehicle speeds along routes where pedestrians may be crossing the street	Lower vehicle speeds are associated with shorter stopping distances. Lower-speed vehicles are also more likely and more able to yield to a pedestrian. Narrowing roadways is believed to result in slower vehicle speeds and a corresponding reduction in pedestrian crashes.
43	Geometrics (Roundabout)	Speed is a fundamental risk factor in the safety of bicyclists. Design roundabout treatments that slow traffic such as tightening entry curvature and entry width, and radial alignment of the legs of a roundabout should improve bicycle safety.	Shen et al. (2000) concluded that bicycle accident rates at roundabouts are 15 times those of motor vehicles, and surveys taken from bicyclists indicate that bicyclists find roundabouts significantly more stressful to negotiate than other forms of intersections, particularly on roads with heavy traffic.

44	Contraflow Bicycle Lanes	The contraflow bike lane is a specific bicycle facility that can be used in special situations and is intended to reduce the number of conflicts between bicycles and motor vehicles. The facility also would be intended to save time for bicyclists having to travel an extra distance if they rode with traffic.	Contraflow bicycle facilities are generally recommended in areas with numerous one-way streets or where following traffic flow would result in difficulty for bicyclists. They provide facilities that bicyclists generally consider safer, encouraging more use.
45	Provide Bicycle-Tolerable Shoulder Rumble Strips	Bicycle-tolerable rumble strips are intended to provide a safer environment for bicyclists when rumble strips are present along a roadway. They are not intended to change the behavior of bicyclists. Transverse rumblestrips and sinusoidal (low noise) rumblestrips (mumblestrips). Preferable in channelized turn lanes.	Bicycle-tolerable rumble strip patterns have been recommended to accomplish the intended goal of providing rumble strips to benefit motorists without generating excessive vibration for bicyclists who ride over the rumble strips. The actual safety effectiveness of this treatment is difficult to assess because most agencies do not have data on bicycle-only crashes or loss-of-control bicycle injuries related to rumble strip encounters.
46	Work Zone Intrusion Alarms	Technology for work zone safety to notify workers when a vehicle enters the work zone area.	reduce work zone crashes

47	Implement Automated Enforcement (approach speeds, red-light running)	Automated enforcement refers to the use of photo radar and video camera systems connected to the signal control. Such systems record vehicles proceeding through the intersection after the signal displays red or speeding while approaching an intersection. Application requires CDOT Region 1 review process and approval if within CDOT ROW.	Automated enforcement has been shown to significantly decrease violations, not only at intersections where cameras are installed, but also at other intersections in the area. However, there are many opponents to enforcement cameras. Arguments against this strategy include violation of personal privacy, violation of constitutional rights, lower effectiveness than other types of enforcement, high cost outweighing the benefits, and implementation solely to generate revenue.
48	USLIMITS2 (ITS crash Countermeasure toolbox)	Free, web-based tool designed to help practitioners assess and establish safe, reasonable, and consistent speed limits for specific segments of roadway. It is applicable to all types of facilities, from rural and local roads to residential streets and urban freeways.	Reduces the number of severe crashes at high crash locations and improves safety culture.

49	Provide Education, Outreach, and Training	Educational measures are directed at both drivers and pedestrians to improve their behavior and compliance to laws and ordinances.	The NHTSA film on WILLIE WHISTLE is aimed at grades kindergarten through 3 and teaches children the safe way to cross streets. After extensive testing in Los Angeles, Columbus, and Milwaukee, an observed reduction in dart and dash crashes by more than 30 percent among 4- to 6-year-old children was attributed to the film.
50	Revise Geometry of Complex Intersections	Some geometric problems with signalized intersections will not be remedied using signing, channelization, or signal phasing. Physical modifications to all or part of an intersection may be needed to reduce severe crash rates.	Closure of an intersection leg would be expected to eliminate crashes related to that leg. Determination of the effectiveness is site specific, due to the varying conditions at intersections where leg closure might be considered. In addition, consideration must be given to the adjacent intersections, to alternative routes onto which traffic would be diverted, and to the potential impact to safety on those routes. Where properly applied, a net safety benefit can be expected.

51	Construct Special Solutions	This strategy includes the following: providing indirect left turn, reconstructing intersections, converting intersections to roundabouts, convert two-way streets to a one-way pair, and constructing interchanges.	Signalized intersections may have such a significant crash problem that the only alternative is to change the nature of the intersection itself. These types of projects will be high cost and require substantial time for implementation. As such, they will generally not be applicable for agency programs focusing on low-cost, short-term solutions. Note that implementing these strategies will also necessitate significant public involvement and stakeholder activity. Nonetheless, these strategies are outlined here to provide a complete picture of the range of solutions to signalized intersection safety.

This list of strategies is intended to provide suggestions but should not be considered exhaustive. Applicants are encouraged to research these and other options to identify the most effective safety strategies for project locations. Strategy descriptions and safety measures were compiled from a number of sources and other strategies may be available from these sources or others. The following websites provide additional details and strategies:

https://www.fhwa.dot.gov/innovation/innovator/issue74/sneakpeek/page_02.html

https://vtechworks.lib.vt.edu/handle/10919/27759

https://safety.fhwa.dot.gov/provencountermeasures/left_right_turn_lanes/

https://safety.fhwa.dot.gov/provencountermeasures/reduced_left/

https://ops.fhwa.dot.gov/publications/fhwahop08024/chapter1.htm

https://safety.fhwa.dot.gov/provencountermeasures/blackplate/

https://www.fhwa.dot.gov/innovation/innovator/issue74/issue74.cfm

https://www.fhwa.dot.gov/innovation/everydaycounts/edc_4/step.cfm

https://safety.fhwa.dot.gov/ped_bike/step/resources/

Strategic Transportation Safety Plan (STSP):

https://www.codot.gov/safety/safetydata/safetyplanning/strategictransportationsafetyplan.pdf

Highway Safety Manual:

http://www.highwaysafetymanual.org/Pages/default.aspx

NCRHP Report 500:

http://www.trb.org/Main/Blurbs/152868.aspx

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