Chapter 15
Traffic Safety and Engineering

Legend

(solid border box)	Multimodal Application Example
(dotted border box)	Context-Sensitive Solutions Application Example
(dashed border box)	Performance-Based Practical Design Application Example
(bicycle icon)	Multimodal (MM)
(mountain icon)	Context-Sensitive Solutions (CSS)
(light bulb icon)	Performance-Based Practical Design (PBPD)
(globe icon)	Web link for additional information
(AASHTO seal)	AASHTO-Specific Information

Chapter

15

15 Traffic and Safety Engineering

15.1 Introduction

The mission of CDOT's Traffic Safety and Engineering Services Branch is to strategically reduce traffic crashes and resulting deaths, injuries, and property damage; and to improve the flow of traffic through effective application of traffic engineering principles. This chapter addresses most, but not all, important design issues related to providing a safer transportation system.

15.2 Roadway Safety

Major factors affecting highway safety are the roadway geometrics and roadside features, driver ability and attentiveness, environmental and contextual factors, and vehicle characteristics. Highway safety is greatly influenced by variations among drivers (human factors), and driver expectations. The driver’s knowledge and driving experience in a given environment or roadway condition are also key determinants of a roadway’s safety performance. However, there are other factors, such as highway design, that have a tangible impact on safety.

Design consistency in terms of roadway geometrics, typical section, and hazard elimination, mitigation, or shielding should be consistent throughout a corridor to minimize unexpected conditions. Advance warnings of changing conditions should be provided as a last resort when mitigation of the hazard is not possible.

The designer should request a Traffic Operations Evaluation from the Region Traffic Representative for a safety and traffic operations analysis of their project to determine if a more detailed safety assessment report is required. The report or analysis includes recommendations for safety improvements based on evaluation of the crash data within a project’s limits. The designer should document decisions to apply or not to apply any given safety feature in accordance with the CDOT *Project Development Manual* (CDOT, [2013] 2022).

Primary references for safer designs are the AASHTO *Highway Safety Design and Operations Guide* (AASHTO, 1997), and the AASHTO *Roadside Design Guide* (AASHTO, 2011).

15.2.1 Bicycle and Pedestrian Safety

The safety of bicyclists and pedestrians should be considered during scoping and design of all new projects including resurfacing. Shoulder rumble strips are effective as a roadway departure mitigation, but on rural highways should only be used on roads with a 4-foot-wide or wider paved shoulder. Rumble strips on a narrow shoulder (less than 4 feet wide) force bicyclists into the through lanes of traffic, which creates a speed differential hazard with vehicles. Bicyclists and pedestrian traffic during construction should also be a major consideration during the design scoping of all projects to resolve access issues with the temporary conditions of the roadway.

Refer to Chapter 13 of this Guide for additional information on designing for bicyclist and pedestrian safety.

15.2.2 Animal-Vehicle Collisions

In many rural areas of Colorado, particularly on the Western Slope, animal-vehicle collisions (AVC) are frequently the highest crash type on many roadways. The designer must closely evaluate the crash data and safety analysis from the Operations Evaluation to determine if the number of AVCs warrants mitigation. Wildlife fencing can effectively mitigate these crash types. Safe passage (overpasses and underpasses) is even more effective of a collision countermeasure and may be needed where it is necessary to maintain habitat connectivity and migratory patterns. Wildlife specific signing and warning systems can also be utilized. CDOT has worked extensively with Colorado Parks and Wildlife to analyze critical habitat corridors on the Western Slope, and are expanding the analysis to include roadways on the eastern slope. Early communication with the Region Environmental Program Manager and the Region Traffic Engineer helps to identify if a project needs mitigation for AVCs.

Use this link to access CDOT's wildlife prioritization studies, data and tools:
https://www.codot.gov/programs/research/pdfs/2022/wildlife-prioritization

15.2.3 Railroad-Highway Grade Crossings

Railroad-highway grade crossings involve two distinct modes of transportation with different operating authorities and operating characteristics. A roadway and a railway may intersect at-grade, or may be grade-separated by a structure that carries the roadway over or under the railroad. Most of Colorado's railroad-highway grade crossings are at grade.

A railroad-highway grade crossing is characterized by continuous vehicular traffic, interrupted periodically by a train's passage. The intermittent nature of train operations may dull a driver's awareness to a train's possible approach. Some drivers are tempted to disregard warnings and try to beat a train through the crossing. Except in unusual circumstances, trains have the right-of-way because of their huge mass and very long stopping distances. Safety at railroad-highway grade crossings is of utmost importance. The roadway design should include appropriate features to discourage risky driver behaviors, to provide sufficient advance notice of the grade crossing and of a train's approach or presence, and, as appropriate, to physically prohibit vehicles from entering the crossing.

Railroad grade crossings and crossing requirements are administered by the Colorado Public Utilities Commission (PUC). If a project is going to modify, improve, or adversely impact a rail crossing, the project manager must advise the Region Utility Engineer and the CDOT Railroad Program Manager who may also communicate with the PUC Engineer to discuss expectations and options for a crossing modification. It is important to begin this discussion very early in the project development cycle to avoid delays to the overall project schedule.

Use this link to access more information on railroad clearances: *https://www.codot.gov/business/project-management/execute-fir-for-ad/railroad-utilities*

Strategies for improving railroad-highway grade crossing safety include upgrading warning devices and improving the geometry, sight distance, and ride quality of the crossing. Active grade crossings contain train-activated devices that warn drivers of the approach or presence of a train. When new devices, such as gate supports, are installed, they may become roadside hazards and warrant shielding from errant vehicles.

The project manager must also determine if the crossing location is also frequented by bicyclists and pedestrians. If bicycle and pedestrian activity is frequent, safety improvements may be necessary for those multimodal uses. Improvements can include trail crossing gates, truncated domes, aligning bike crossings to be perpendicular to the rails, and other warning systems. Refer to Chapter 13 of this Guide for more information.

Passive grade crossings lack warning devices and rely on signs and pavement markings to identify the crossing location. Passive grade crossings have a higher risk for crashes because there is less direct control over driver actions. Where passive grade crossings remain in place, enhanced sign systems and improved driver sight distance to see approaching trains may increase driver awareness and responsiveness.

Active railroad-highway grade crossings that are located adjacent to a signalized roadway intersection increase the complexity of signing and signals. Drivers may receive conflicting information from such closely spaced signals, or traffic stopped at the adjacent signalized intersection may queue back onto the grade crossing. Consideration should be given to interconnecting the traffic control signal with the active control system of the railroad crossing and providing a "pre-emption" sequence. With pre-emption, the approach of a train causes the traffic signals to enter a special mode to control traffic movements in coordination with the train's passage through the crossing. Traffic control signals near railroad-highway grade crossings shall conform to Section 8C.09 of the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA, [2009] 2022); and pre-emption shall conform to Section 4D.27 of the

MUTCD. A Systems Engineer Analysis can help to identify the optimal Intelligent Transportation System (ITS) and signal solution to accommodate a railroad crossing at or near a signalized intersection.

When a railroad-highway grade crossing is located within the limits of a rehabilitation project, the crossing, along with any existing devices, should be relocated or reconfigured as necessary to be compatible with changes to the highway. A safety assessment of the existing crossing should also be conducted and, to the extent feasible, the project should include any appropriate crossing safety improvements.

Closing unnecessary grade crossings improves safety by eliminating the potential for vehicle-train crashes and by concentrating limited safety funds on the remaining crossings. Guidance for eliminating and consolidating railroad-highway grade crossings is provided in AASHTO *Highway-Rail Crossing Elimination and Consolidation* (AASHTO, 1995). While closing a crossing may be the preferred option for a project, the project manager should have a thorough conversation with the Region Utility Engineer, and the Railroad Program Manager to understand the timeline and effort required to complete a crossing closing. This should be completed early in the project development process to account for negotiations, administrative hearings, and time for a final determination to be made.

All projects involving work on railroad property or adjustments to railroad facilities require a written contract between CDOT, the railroad, and any other involved local agencies. Any changes to a grade crossing's operating characteristics must be coordinated with the PUC. The CDOT Railroad and Utilities Program within the Project Development Branch administers the highway-rail grade crossing program and is CDOT's point of contact with the railroad, the PUC, and local agencies on all railroad contracts.

For additional guidance on railroad-highway grade crossing components, safety assessment, safety measures, project development, and traffic control, refer to:

- FHWA *Railroad-Highway Grade Crossing Handbook*, Third Edition (FHWA and FRA, 2019).
- FHWA *Guidance on Traffic Control Devices at Highway-Rail Grade Crossings* (FHWA, 2002).
- *Manual on Uniform Traffic Control Devices* (MUTCD) Part 8 (FHWA, [2009] 2022).
- CDOT *Railroad Manual* (CDOT, 2017).

15.2.4 Roadway Geometry Considerations

Horizontal curves typically have crash rates from 1.5 to 4 times higher than tangent sections. Crash rates tend to increase due to reduced sight distance associated with either a reduced curve radius or an increased deflection angle. Therefore, it is usually beneficial to maximize curve radii and minimize deflection angles when designing alignments. The use of spiral curves can help to mitigate some of the safety problems associated with horizontal curves by:

- Providing a safer path for the driver from a tangent position to a curve position

- Providing a location for the required length of transition from normal crown to full superelevation.

The attributes of spiral curves are explained in Section 6.2.4.2 of this Guide and Chapter 3 of the A Policy on Geometric Design of Highways and Streets (2018 AASHTO GDHS) (AASHTO, 2018).

Vertical curves can also lead to higher crash rates due to the reduced sight distance imposed by the crest of a vertical curve. Accordingly, the designer should minimize the severity of vertical curvatures in the alignment design. Intersections and roadway accesses located on or near vertical curves should be investigated thoroughly and avoided when practical alternatives can be found.

Designers should also review all existing curves on a roadway segment for large differences between posted speeds versus curve design speeds. Any major differences should warrant consideration of reduced speed limits, advisory signage, chevrons, and the addition of guardrail.

15.2.5 Intersections

Intersections are major points of conflict. Safety measures that can reduce conflict, particularly from left turns, include roundabouts, medians, offset left turns to improve driver sight distance and visibility, protected left-turn phasing of signals, and auxiliary lanes among other measures. Left-turn lanes should be designed with an offset to provide for proper sight distance to oncoming traffic when a vehicle is in the opposing left-turn lane. Safer methods for accommodating pedestrian and bicycle traffic movements through the intersection should also be considered (refer to Chapter 13 of this Guide). All-way stops or roundabouts may sometimes be desirable alternatives to traffic signals. Criteria for all-way stops are found in Section 2B of the (MUTCD) (FHWA, [2009] 2022). Further information on roundabout design is found in Chapter 9 of this Guide and the FHWA *Roundabouts: An Informational Guide* (FHWA, 2000).

“Stop Ahead” warning signs should be placed ahead of intersections where the driver may not anticipate the required stop or where sight distance is obstructed. For additional emphasis, a yellow beacon above the “Stop Ahead” sign, a red beacon above the “Stop” sign, or both can be considered. Recently the addition of embedded LED borders for stop signs or advanced warnings signs have greatly improved driver compliance at intersections. The designer should discuss if these options are appropriate with the region traffic engineering staff.

The designer must consider the corner radii and sight distances at intersections. A large corner radius can increase the roadway crossing width, making it more hazardous for pedestrian crossing, and also tends to increase vehicle speed through intersection corners. There are various options for intersection corners and shorter pedestrian crossings. Taking the time to understand the vehicles using the intersection and the corner and crossing options can help to make the intersection safer for all users. Designing a corner with too small a radius can cause maneuverability and safety problems for large vehicles and pedestrians, increasing the potential for pedestrian conflicts when large vehicles track over the adjacent curb and sidewalk.

As part of a project, traffic signals should be replaced or modified to comply with current standards, including PROWAG, and to meet design traffic demands.

It is essential to have proper application of traffic control devices to designate right of way and safe movement of all traffic, including pedestrians and bicyclists. Refer to the standards published in the latest edition of the MUTCD (FHWA, [2009] 2022).

If a designer or design team is considering a new intersection or significant changes to the operations or geometry of an intersection, a request to utilize the CDOT Intersection Control Assessment Tool or "ICAT" should be submitted to the Region and HQ Traffic Operations teams. CDOT's ICAT quantitatively evaluates several intersection control scenarios (alternatives) and ranks these alternatives based on their operational and safety performance. Implementing a performance-based procedure such as ICAT creates a transparent and consistent approach to consider intersection alternatives based on metrics such as safety, operations, cost, and social, environmental, and economic impacts.

Use this link to access more information on CDOT's Intersection Control Assessment Tool (ICAT): https://www.codot.gov/programs/maintenance-operations/tsmo-evaluation

Use this link to access more information on FHWA's Capacity Analysis for Planning of Junctions (CAP-X) Tool: https://www.fhwa.dot.gov/software/research/operations/cap-x/

15.2.6 Multimodal Traffic Control Devices

Over the last few years there has been an increased focus on safety for the most vulnerable road users—pedestrians and bicyclists. Many studies and efforts have been tested to improve driver compliance as well as pedestrian and bicyclist compliance to prevent bicycle and pedestrian crashes. Below are several types of traffic control devices specifically focused on improving bicycle and pedestrian safety at roadway crossings.

15.2.7 Pedestrian Crossing Safety Devices

There is a multitude of devices and methods to improve pedestrian safety at crossings including improved markings, signing, and lighting. Below are some additional measures that can be investigated where there is high pedestrian activity, or a safety analysis has identified the need to improve pedestrian safety at a crossing location.

- *Pedestrian flashing beacons.* Can be installed in advance of a pedestrian crossing to warn motorist of the presence of a pedestrian. These can be static flashing devices or pedestrian activated devices to provide a more dynamic warning which may increase driver compliance over the continual flashing device.

- *Rectangular Rapid Flashing Beacons (RRFB).* This is a pedestrian actuated enhancement for pedestrian crossings. RRFBs have been found to reduce pedestrian vehicle crashes by up to 47%. Typically, these are used on roadways with a posted speed limit of less than 40 MPH. On multi-lane roadways a refuge median and the addition of median RRFBs in each direction is highly recommended to maintain compliance from all lanes of traffic when pedestrians are present.

Use this link to access more information on RRFBs: *https://highways.dot.gov/safety/proven-safety-countermeasures/rectangular-rapid-flashing-beacons-rrfb*

- *Pedestrian Hybrid Beacons (PHB) -* Pedestrian hybrid beacons are a modified signal system specifically for pedestrian crossings that are activated by the pedestrian to obtain driver compliance to stop for the pedestrian crossing maneuver. PHBs are more common on high volume roadways with multiple lanes of traffic and on roadways where the posted speed limit is over 35 MPH, but they can also be used on roadways with posted speed of 35 MPH or less. Warrants for the installation of PHBs can be found in the MUTCD Chapter 4F (FHWA, [2009] 2022). PHBs have been found to reduce pedestrian crashes by up to 69% and overall crashes by 29%.

Use this link for more information on PHBs: *https://safety.fhwa.dot.gov/provencountermeasures/ped_hybrid_beacon.cfm*

- *Leading Pedestrian Interval (LPI) -* An LPI gives pedestrians the opportunity to enter the crosswalk at a signalized intersection 3-7 seconds before vehicles are given a green indication. This helps to better establish the pedestrian's presence in the intersection to the motorists making them more visible before right or left turns are made by vehicles. LPIs have shown a 13% decrease in pedestrian vehicle crashes at intersections.

Use this link for more information on LPIs: *https://safety.fhwa.dot.gov/provencountermeasures/lead_ped_int.cfm*

15.2.8 Bicycle Safety Devices

- *Bicycle shared lane markings (SLM) or "Sharrows."* Markings used to indicate a shared lane for bicyclists and motorists where there is insufficient room to add a bike lane outside of the travel lane. Typically, these are used on roadways with a posted speed of 35 mph or less in urban corridors. These should only be used if there is no other alternate location to provide bike refuge on the roadway section and the project manager shall discuss all options with the region traffic engineer before implementing this in the project design.

Use this link for more information from NACTO on SLMs:
https://nacto.org/publication/urban-bikeway-design-guide/bikeway-signing-marking/shared-lane-markings/

- *Bicycle lanes.* Most fatal and serious injury crashes with bicyclists occur at non-intersection locations where a motorist overtakes a bicycle. The speed differential along with the difference in mass between the vehicle and bicyclist can lead to serious injury or death. Providing a bike lane can reduce crashes up to 49% on urban 4-lane undivided collectors and 30% on urban 2-lane undivided collectors. The project manager should carefully investigate the presence and use of the roadway by bicyclists to determine if additional countermeasures to improve bicyclist safety are appropriate. There are also several different types of bike lanes to consider including buffered bike lanes and separated bike lanes.

Use this link for more information from FHWA on Bicycle Lanes:
https://safety.fhwa.dot.gov/provencountermeasures/bike-lanes.cfm

Use this link to access FHWA's Bikeway Selection Guide:
https://safety.fhwa.dot.gov/ped_bike/tools_solve/docs/fhwasa18077.pdf

- *Bicycle signal phasing.* There are several options to consider for bicycles at intersections.
  - *Lead bike interval.* Provides a bicyclist a three second head start crossing the intersection before vehicles receive the green indication.
  - *Exclusive bicycle phasing.* Installation of a bicycle signal head will allow fully protected bicycle phases to operate at intersections independent from the normal signal phasing for vehicles. During this type of phasing "scramble" phasing is prohibited (allowing all direction of bike traffic to move at the same time).
  - *Bicycle detection.* Bike boxes with detection for bicyclists will allow the signal to detect the presence of a bicyclist to change the signal phasing when a vehicle is not present.

Use this link to access FHWA's MUTCD Interim Approval for optional Use of a Bicycle Signal Face (IA-16):
https://mutcd.fhwa.dot.gov/resources/interim_approval/ia16/

Use this link to access ITE's Signal Timing and Phasing for Bicycles:
https://www.ite.org/technical-resources/topics/complete-streets/bicycle-signals/signal-timing-and-phasing-for-bicycles/

15.2.9 Interchanges

Interchanges do not always have the same direct conflict potential as intersections, but the vehicle merge areas often show a higher frequency of crashes.

A large portion of truck crashes occurs at interchanges. The potential for overturning of high-profile vehicles increases on circular (clover leaf) ramps. Adequate signing, careful attention to merging patterns, and ramp geometrics can mitigate these problems. These concepts are detailed in Chapter 10 of the *Highway Capacity Manual* (TRB, 2022).

If a designer or design team is considering a new interchange or significant changes to the operations or geometry of an interchange, a request to utilize the CDOT Intersection Control Assessment Tool or "ICAT" should be submitted to the Region and HQ Traffic Operations teams. CDOT's ICAT quantitatively evaluates several intersection control scenarios (alternatives) and ranks these alternatives based on their operational and safety performance. Implementing a performance-based procedure such as ICAT creates a transparent and consistent approach to consider intersection alternatives based on metrics such as safety, operations, cost, and social, environmental, and economic impacts.

Use this link for more information on CDOT's ICAT:
https://www.codot.gov/programs/maintenance-operations/tsmo-evaluation

Use this link to access more information on FHWA's Capacity Analysis for Planning of Junctions (CAP-X) Tool:
https://www.fhwa.dot.gov/software/research/operations/cap-x/

15.2.10 Context Sensitive Solutions

Safety is a challenge to be addressed on every project. It may not be the primary driver for a given project, but it should be a consideration in the development and evaluation. Context Sensitive Solutions (CSS) equally address safety, mobility, and the preservation of scenic, aesthetic, historic, environmental, and other community values. To balance these values the design process should be flexible in adherence to standards and criteria. A successful context-sensitive solution produces transportation designs that address both safety and feasibility. CSS maintains safety and mobility as a priority, yet recognizes that these are achieved in varying degrees with alternative solutions. Utilizing the CSS philosophy, CDOT design professionals determine which solution best fits, given the site's conditions and context. CSS is about making good engineering decisions within the context of the roadway and surroundings the road supports.

NCHRP Report 480, A Guide to Best Practices for Achieving Context Sensitive Solutions (CSS) (TRB, 2003) discusses two types of safety: nominal safety and substantive safety. "Nominal safety" equates adherence to standards or design policy with achieving safety and considers substandard designs to be unsafe. Under the nominal safety concept, a roadway designed to current or modern criteria would be characterized as 'safe'. However, engineers should also consider substantive safety in the design process. Substantive safety refers to the actual (or expected) crash frequency and severity for a highway or roadway.

These two types of safety should be considered when addressing a safety problem. The solution should balance cost, environment, and other stakeholder values. High-crash locations with substandard design features should be prioritized for improvement. Locations that are nominally safe, but substantively less safe also should be considered.

For every project, the setting and character of the location, the values of the community, and the needs of highway users should be balanced.

Consider the following:

- Flexibility provided within the standards.
- Design exceptions where there are environmental or contextual concerns.
- Opportunities to re-evaluate decisions made in the planning phase.
- Design speed that is appropriate for contextual area it supports.
- Flexibility to modify existing horizontal and vertical geometry, cross section, and design for resurfacing, restoration, and rehabilitation (3R) improvements where it is known that the roadway may not integrate well with the surrounding area it supports.
- Alternative standards for differing contextual corridors or scenic routes.
- Safety and operational impact of various design features and modifications.

These concepts are discussed in detail in NCHRP Report 480, A Guide to Best Practices for Achieving Context Sensitive Solutions (CSS) (TRB, 2003) and *Flexibility in Highway Design* (FHWA, 1997). Additional information on context-sensitive solutions can be found in the following references:

- NCHRP Report 480, A Guide to Best Practices for Achieving Context Sensitive Solutions (FHWA, 2003).
- NCHRP Report 374, Effect of Highway Standards on Highway Safety (TRB, 1995).
- NCHRP Project 430, Improved Safety Information to Support Highway Design (TRB, 1999).
- NCHRP Report 362, Roadway Widths for Low-Traffic-Volume Roads (TRB, 1994).
- FHWA IHSDM: Interactive Highway Safety Design Model (FHWA, n.d.).

- FHWA, Prediction of the Expected Safety Performance of Rural Two-Lane Highways (FHWA, 2000).
- CDOT Chief Engineer's Policy Memo 26, Context Sensitive Solutions (CSS) Vision for CDOT (CDOT, 2005).

15.2.11 Work Zone Safety

Proper traffic control, delineation, and channelization are critical to achieving safety in work zones. A work zone can pose additional hazards to the motorist and cause risk to workers. All traffic control devices must meet the guidelines in the AASHTO *Manual for Assessing Safety Hardware* (MASH) (AASHTO, 2016), NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features (TRB, 1993) and the MUTCD (FHWA, [2009] 2022). Refer also to Section 20.5.1 of this Guide.

15.2.12 Lane Closure Strategies

Each of the CDOT Regions has established work zone lane closure strategies that consider traffic volume throughout the day and seasonally on all roadways across the state. The designer shall carefully consider the lane closure guidance on when lane closures may be allowed or adjust their project to support night work if that is required for a closure.

Use this link to access more information on CDOT's Work Zone Safety Program and access to the individual Region Lane Closure Policies: *https://www.codot.gov/safety/traffic-safety/performance/work-zone-safety*

15.2.13 CDOT Work Zone Safety and Mobility Procedures

Refer to CDOT Procedural Directive 1502.1, Traffic Control for Planned and Unplanned Work.

The FHWA rule on Work Zone Safety and Mobility led to the development and implementation of CDOT Policy Directives, as well as new procedures, specifications, and training requirements. CDOT implemented a Transportation Management Plan that lays out a set of coordinated strategies, describes how these strategies will be used to manage the work zone impacts of a project, and details training requirements.

In 2019, CDOT updated Procedural Directive 1502.1, Traffic Control for Planned and Unplanned Work. This procedural directive applies to all engineering work on roadways. Within this procedural directive, there is a guidance table on traffic control expectations based upon anticipated duration of the closure.

Use this link for more information on CDOT's Procedural Directive 1502.1 Traffic Control for Planned and Unplanned Work: Policies and Procedures — Colorado Department of Transportation (codot.gov)

15.2.14 Temporary Speed Limit Reductions

Refer to CDOT Procedural Directive 1502.2, Temporary Reduction in Speed Limits.

Whenever a planned work zone strategy includes a reduction in the posted speed limit the project needs to submit a Form 568 to the Region Traffic Engineer for approval. Procedural Directive 1502.2 details the requirements for requesting a speed limit reduction and to whom the speed reduction needs to be distributed to. This may seem to be a task to be left to the construction project engineer but when designing detours or temporary roadway conditions this needs to be considered for proper inclusion in the temporary roadway design.

15.2.15 Smart Work Zone Deployments

A Smart Work Zone is a toolbox of technologies that assess work zone conditions to generate actionable intelligence that improves the efficiency and safety of traveling public and workers in the work zone. The toolbox can include the applications of computers, communications, sensor technology, applications, software, connected or non-connected equipment, data collection, traffic control centers, and/or automation depending on the size, needs, and complexity of the project.

Smart Work Zones, if properly designed and implemented, will:

- Better inform motorists and reduce their frustrations.
- Encourage motorists to take alternate routes.
- Reduce congestion and allow more freely flowing traffic.
- Clear incidents more quickly, thereby reducing secondary incidents.
- Make work zones safer for highway workers and motorists.

Whenever a planned work zone strategy includes smart work zone, the project team or designer needs to contact the Region and Headquarters traffic and ITS personnel as early as possible.

15.2.16 Roadway Shoulders

Refer to CDOT Policy Directive 902.0, Shoulder Policy (CDOT, 1999).

15.3 Reducing Run-Off-The-Road-Crashes

Apply the following improvements where appropriate to reduce the frequency and severity of run-off-the-road crashes:

- Removing obstacles from the roadside.
- Redesigning the obstacle.
- Relocating obstacles from the clear zone.
- Installing breakaway devices that reduce impact severity (MASH) (AASHTO, 2016) and NCHRP Report 350 (TRB, 1993).

- Shielding obstacles with guardrail that meets MASH compliance.
- Improving delineation.
- Cable rail installation.
- Upgrading guardrail to MASH compliance.
- Using rumble strips there is a minimum 4-foot shoulder.
- Applying textured shoulder treatment.
- Eliminating shoulder drop-offs, using safety edge technology.
- Correcting superelevation.
- Improving the pavement condition.
- Improving the roadway geometry.
- Flattening slopes.
- Maintaining the clear zone.

15.3.1 Rumble Strips

Studies have shown that rumble strips can reduce the frequency of run-off-the-road crashes by 36% on rural two-lane roads and up to 17% on urban freeways (FHWA Proven Safety Countermeasures). Centerline rumble strips can reduce sideswipe opposite direction crashes by up to 45% on rural two-lane roads and 64% on urban two-lane roads (FHWA Proven Safety Countermeasures). Rumble strips alert drivers when their vehicles stray onto the shoulder or over the centerline of the roadway. Rumble strips can also provide protection for pedestrians and bicyclists on the shoulder by discouraging motorists from straying onto the shoulder and provide an audible notice to pedestrians and bicyclists. Improperly installed rumble strips can force the bicyclist into the travel lane causing conflict with the motorists. Shoulder rumble strips should only be placed on shoulders with a minimum 4-foot shoulder or wider.

In more densely populated areas, the installation of rumble strips may cause noise issues with the residents. The engineer should take this into consideration using a context sensitive analysis to determine the safety benefit versus impact to the residents. In recent years, a new type of rumble strip with reduced noise impacts has been used. The modified rumble strip is a sinusoidal “football” shape that quiets the sound of the tires when contacting the indentation in the roadway. Also known as a “mumble strip,” it still creates the tactile feeling in the vehicle and some noise, but is generally not as loud as traditional rumble strips.

CDOT received approval to install rumble strips on all highways using FHWA Highway Safety Improvement Program (HSIP) funding as well as being eligible to use FASTER Safety Mitigation funding to help expedite the installation of these proven safety measures. Coordinate with the Region Traffic Engineer to inquire about possible funding for the installation of rumble strips.

Use this link to access more information from FHWA on Longitudinal Rumble Strips:
https://safety.fhwa.dot.gov/provencountermeasures/fhwasa18029/ch2.cfm

15.3.1.1 General Criteria

Refer to Standard Plan M-614-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) for rumble strip details.

To maximize a smooth shoulder surface suitable for bicycle use, rumble strips should be installed adjacent to the edge of the travel lane per CDOT Standard Plan M-614-1 (CDOT, 2019). AASHTO considers a 4-foot width on the shoulder beyond the rumble strip to be the minimum for safe bicycling. Refer to AASHTO's *Guide for the Development of Bicycle Facilities* (AASHTO, 2012).

Rumble strips should be used on rural highways at locations where run-off-the-road type crashes are most likely to occur. These locations should include:

- On long tangents to avoid lane departures and side-swipe opposite direction crashes.
- Through horizontal curves to prevent lane departures.
- Along steep fill slopes.
- At approaches to narrow bridges.
- At documented high-crash locations.

Rumble strips should not be used where guardrail is installed on shoulders that are less than 6 feet wide. When rumble strips are discontinued for guardrail or narrow shoulders, the rumble strip should end at least 250 feet prior to the beginning section of the guardrail or the narrowing of the shoulder. This will allow bicyclists room to reposition their bikes on the shoulder.

Rumble strips are not normally used in urban areas because of the noise they cause and the frequent use of the roadway shoulder for turning or parking.

Centerline rumble strips are frequently used to mitigate head-on, sideswipe opposite, and opposite side run-off-the-road crashes in areas with a history of these types of crashes, mountainous areas, or areas where sight distance is constrained. When used, centerline rumble strips should be installed in "no passing" zones but may continue into "passing" zones.

15.3.1.2 Installation on Interstate Highways

Rumble strips should be installed on the inside (left) shoulders of all rural Interstate highways and rural freeways with depressed medians as shown on Standard Plan M-614-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) and may be continuous as determined by the designer.

They should be installed on the outside (right) shoulders providing the shoulder width is 6 feet or greater.

15.3.1.3 Installation on Narrow Shoulders

Where the system-wide evaluation indicates a significant history of run-off-the-road crashes, rumble strips may be considered if bicycle traffic can still be accommodated. Consider applying edge rumble strips only in high-crash locations rather than over the entire length of the roadway.

Before installing rumble strips on narrow shoulders, the designer should weigh the benefits to motorists, versus the reduction in usable bicycle riding width. Installation of rumble strips on shoulders which are 4 feet wide or narrower will provide bicycles with less than the AASHTO recommended 4-foot clear bike path and will have a negative impact on bicycle travel.

For further information on rumble strips, refer to the FHWA Rumble Strip Web Page (FHWA, n.d.) and to NCHRP Synthesis 191 Use of Rumble Strips to Enhance Safety (TRB, 1993).

15.4 Roadside Safety

Roadside safety is improved by reducing the likelihood of a vehicle leaving the roadway and by minimizing or eliminating the hazards faced by an errant vehicle that leaves the roadway. This section discusses the methods and tools used to improve roadside safety. Additional strategies can be found at the joint AASHTO-NCHRP web site for implementing the NCHRP Project 17 – 18, Strategic Highway Safety Plan (AASHTO, 2009).

CDOT has adopted the AASHTO *Roadside Design Guide* (AASHTO, 2011) for use in determining barrier warrants, length of needed barrier, and overall roadside design considerations. Some of the items that are covered are:

- Barrier types and characteristics.
- Methods for mitigation of obstacles.
- Clear zone concept.
- Embankments and cut slopes.
- Fixed objects.
- Shoulder drop-offs.

CDOT Standard Plans - M & S Standards (CDOT, 2019) contain design and typical installation details for guardrail, end treatments and transitions. The guardrail details in the Standard Plans may not fit all situations. The designer needs to evaluate each location carefully to determine if the standard can be used or if a special detail needs to be created for the locations in question. A new item or design adaptation not covered by CDOT Standard Plans - M & S Standards (CDOT, 2019) is not necessarily precluded from use. Consult the AASHTO *Roadside Design Guide* (AASHTO, 2011) or contact the Standards and Specifications Unit in Project Development for additional information.

Refer to the CDOT Safety Selection Guide, which is on the CDOT web site, and contact the Standards Engineer to determine the acceptability of any alternative design.

Use this link to access more information regarding CDOT's Safety Selection Guide: https://www.codot.gov/business/designsupport/design-docs/selection-guide

15.4.1 Unique Hazards

Special situations may occur where protection is desirable even though not required; for example, where there is a potential obstacle that is not within the clear zone, or where there are objects with historic, environmental or economic significance. The designer needs to carefully consider all alternatives in these situations. Because adding a barrier is a hazard to the motorist, the designer should consider other options before deciding to add a barrier in a special circumstance.

15.4.2 Guardrail

Guardrail should be installed only at specific locations where roadside hazards warrant, and after all other possible mitigation measures have been considered. CDOT uses two primary types of guardrail: strong-post W-Beam (Type 3) and F-shaped concrete barrier (Type 7). Refer to M&S Standards. Modified Thrie-Beam (Type 6), 3- and 4-strand cable guardrail, and other types are also used in special situations. A fully functional guardrail installation will consist of a transition (if changing rail rigidities), a run of computed length of need, and end treatments. Guardrail shall meet MASH standards for all new installations.

In 2021, CDOT issued the Guardrail System Field Guide for Construction Engineers and Inspectors, this guide should be used by the designer to help identify the need to install new guardrail, or to repair or replace existing guardrail. This guide will be essential to the designer to have at the field scoping and field inspection review to evaluate the existing guardrail for replacement with MASH compliant guardrail or repair and replacement with NCHRP 350-approved guardrail.

Use this link to access CDOT's Guardrail Systems Field Guide: https://www.codot.gov/programs/tetp/assets/2018-2019/guardrail-field-guide.pdf

15.4.2.1 Review of Crash History

For 3R projects, guardrail may be warranted in locations where there is a history of frequent run-off-the-road crashes. At least three years (but preferably five years) of the most recent crash data should be analyzed to determine if there is a need for guardrail.

15.4.2.2 Maintaining Continuity

Driver expectation is often a key component in determining guardrail placement. Consider how the placement of guardrail will affect the driver's perception of both the area where the guardrail is placed and the surrounding areas. Maintaining continuity of roadside characteristics is important and can affect the designer's guardrail decisions in many ways. Guardrail choices made for the first section of a corridor will affect the options available for guardrail in the subsequent sections. A decision should be made early in the scoping process on how the corridor will be designed to create a consistent type of roadway.

If a proposed guardrail installation is only marginally warranted, but the rest of the section has guardrail, then installing the guardrail may be appropriate. Placing guardrail, widening shoulders, or straightening horizontal curves may not be advisable for short sections of roadway when it will likely cause a motorist to exceed the safe operating conditions of adjacent segments yet to be improved. Improving safety in a corridor may sometimes be done in short sections, but the overall corridor safety should be maintained during the process. If isolated segments of a corridor are upgraded, a letter outlining the decision should be included in the project file.

15.4.2.3 Determination of Length

The procedure for determining the length of need for guardrail is contained in the AASHTO *Roadside Design Guide* (AASHTO, 2011). Length of need calculations are a critical step in guardrail design development. If the designer is unsure about how to determine length of need, they should reach out to their region traffic program for support.

15.4.2.4 Offset

Standard Plans M-606-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) lists recommended offsets. As a general rule, if the shoulder width is 6 feet or less, the guardrail should be offset an additional 2 feet from the edge of the paved shoulder. If the shoulder width is 8 feet or greater, no additional offset is required. The 2-foot offset is intended to provide additional width for opening the door of a parked or stranded vehicle. If the guardrail is offset from the edge of pavement the design should include a safety edge on the new pavement to prevent vertical drop offs that could catch the wheel of an errant vehicle leaving the paved shoulder.

Use this link to access more information regarding CDOT's Safety Edge for Pavement Detail (D-614-1): *https://www.codot.gov/business/designsupport/2019-and-2012-m-standards/2019-m-standards-plans/2019-project-special-details/d-614-1*

In most cases, new guardrail should not be installed on the z-slope or side slope unless the slope is 10:1 or flatter. Where necessary, installations may be made on slopes as steep as 6:1, but only if they are located so that the errant vehicle is in its normal attitude at the moment of impact.

In general, the placement recommendations shown in the AASHTO *Roadside Design Guide* (AASHTO, 2011), Table 5.5, should be followed.

15.4.2.5 Access Treatments

Short gaps between guardrail sections should always be avoided. Such gaps may allow vehicles to pass behind the rail or strike end treatments, which will cause greater damage than impacting the rail.

Short gaps should be addressed when designing access treatments. Some rules to follow include:

- Move accesses, if possible, to avoid gaps in guardrail.
- Remove obstacles around accesses (flatten slopes, relocate mailboxes, etc.).
- Install Type 3J End Anchorage and 3K Terminal, provided obstacles are cleared behind the rail (refer to details in the CDOT Standard Plans - M & S Standards) (CDOT, 2019).
- Install standard Type 3 guardrail with appropriate end treatments.
- Install Type 3 guardrail with reduced post spacing (refer to detail in CDOT Standard Plans - M & S Standards) (CDOT, 2019).

15.5 Traffic Engineering Plans

Traffic control plans should include a "Schedule of Construction Traffic Control Devices," construction traffic control plans, detour routes, temporary as well as permanent signing, striping, pavement markings, and signal plans.

15.5.1 Source Documents

Many documents and manuals govern how a set of traffic plans is prepared.

While the list below includes the main sources of information for the traffic engineer, it is not exhaustive. Traffic control and operations is an ever-changing field of engineering and the use of the latest state-of-the-art techniques (Smart Work Zones, for example) is encouraged. Refer also to the references provided for this Guide.

- AASHTO *Highway Safety Design and Operations Guide* (AASHTO, 1997).
- AASHTO *Roadside Design Guide* (AASHTO, 2011).
- CDOT Standard Plans ("S" Standards, which are a part of the M & S Standards) (CDOT, 2019).
- Colorado Supplement to the Standard Highways Signs (CDOT, 2012).
- CDOT Procedural Directive 1502.1, Traffic Control for Planned and Unplanned Work.
- CDOT Procedural Directive 1502.2, Temporary Reduction in Speed Limits.
- *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA, [2009] 2022).
- CDOT Recommended Pavement Marking Practices (CDOT, 1998). Copies of this guideline are available from the Safety and Traffic Engineering Section.

- FHWA 2012 Supplement to Standard Highway Signs (FHWA, 2012).
- FHWA Standard Highway Signs (FHWA, 2012).
- CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022).
- AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals (AASHTO, 2020).
- Colorado Supplement to the MUTCD (CDOT, 2009). Sets forth additions, deletions or changes to the MUTCD required by the peculiarities of Colorado State Law.
- ITE *Traffic Control Devices Handbook* (ITE, 2013).
- ITE *Traffic Engineering Handbook* (ITE, 2009).
- ITE *Transportation Planning Handbook* (ITE, 2009)

15.6 Construction Traffic Control

15.6.1 Construction Traffic Control Plan

The Construction Traffic Control Plan (TCP) is a strategy for safely moving traffic through a work zone. The Safety and Traffic Engineering Branch provides standards to be used for developing the TCP.

The components of a typical TCP are:

- Schedule of Construction Traffic Control Devices/Tabulation of Traffic Engineering items.
- Construction Signing Plan.
- Detour Routes.
- Tabulation of Signs.
- Permanent/Existing Signing Plan.
- Cross sections at Class III and overhead sign locations.
- Standard Overhead Sign Bridges/Standard Overhead Sign Cantilever/Standard Overhead Sign Butterfly.
- Tabulation of Pavement Markings.
- Pavement Marking Plan
- Signal Plan.
- List of Standard Special Provisions.
- List of Project Special Provisions.
- Detailed Sign Layouts.

Information contained in a TCP typically includes:

- Placement and maintenance of traffic control devices.
- Methods and devices for delineation and channelization.

- Construction scheduling.
- Application for number and types of traffic control management teams (Traffic Control Supervisors, Technicians, Flaggers, AFADs, TCS Helpers) for different strategies, phases, and situations.
- Application and removal of pavement markings.
- Roadway construction lighting requirements.
- Traffic regulations.
- Uniformed traffic control (surveillance).
- Inspection activities.

The TCP should be developed during the initial planning stages of any scheduled activity and should be considered in all decisions related to the activity. The Region Traffic Engineering Section will work closely with the Project Manager to develop a sound TCP for all construction activities. The TCP is included in the Contract Plan Package along with the specifications for the project.

The MUTCD (FHWA, [2009] 2022) and CDOT Standard Plans – M & S Standards (CDOT, 2019) provide a framework to develop a sound and effective TCP for all construction projects. Refer to Section 20.3 and Section 3.10 "Noise Analysis" of the *CDOT Project Development Manual* (CDOT, 2013, rev. 2022).

15.6.2 Construction Signing and Striping

Construction signing is an essential and integral part of any highway construction project. Part 6 of the MUTCD (FHWA, [2009] 2022) and the "S" Standards of the CDOT Standard Plans – M & S Standards (CDOT, 2019) provide examples of typical construction signing, methods of erection and signing placement to address a variety of typical construction activities. Construction signs are typically placed on the roadway for a short period of time, therefore avoiding the need for standard durable panel material. Section 630 of the CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022) governs the choice of construction sign panel material.

The typical construction signing placement presented in the MUTCD (FHWA, [2009] 2022) and Standard Plan S- 630-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) and typical striping layout presented in Standard Plan S-627-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019), are designed to assist those involved with construction traffic control, but are not intended to replace sound engineering judgment or the experience of a qualified traffic engineer.

15.6.3 Temporary Pavement Markings

Proper temporary striping is a key component of highway projects, particularly for delineation of passing and no-passing zones. Temporary pavement markings are used to supplement drums or traffic cones in a construction work zone or as provisional markings on a roadway. Temporary markings may be categorized as "Full-Compliance," "Interim" or "Control Points." Full Compliance markings are those meeting all the requirements of Part 3 of the MUTCD (FHWA, [2009] 2022).

When appropriate, interim markings, such as paint or removable pressure sensitive tape, are used until full-compliance markings are installed. Control points are placed for the purpose of guiding the installation of interim or full-compliance pavement markings.

In work zones where traffic is redirected for more than one-day, temporary pavement markings are typically placed along tapers and tangents, but may be placed elsewhere in the project if the need arises. Temporary pavement markings may be white or yellow depending on the type of marking (i.e., centerline, edge line, lane line or channelizing line) they replace. When construction is completed, temporary pavement markings should be easy to remove without damaging or scarring the roadway surface. In most cases, temporary pavement markings shall be removed and full compliance markings installed prior to final project acceptance or acceptance of a phase of construction.

Estimates for temporary pavement marking quantities, whether they are paint or removable tape, shall be itemized on the Tabulation of Traffic Engineering Items plan sheet.

15.6.4 Channelizing Devices

Channelizing devices are designed to warn drivers of potential obstacles created by construction or maintenance operations on or near the traveled way, to protect workers in the work zone, and to guide and direct drivers and pedestrians safely past work zone hazards. These devices may be used to provide a smooth and gradual transition in moving traffic from one lane to another, onto a bypass or detour or in reducing the width of a lane. Channelizing devices should always be preceded by a system of warning devices adequate in size, number, and placement for the roadway. Channelizing devices shall be designed in a way that minimizes damage to vehicles that inadvertently strike them.

Taper design is one of the most important elements within the system of construction traffic control devices. A poorly designed taper will almost always produce undesirable traffic operations, congestion, or possibly crashes. Tapers may be necessary in both the upstream and downstream directions of traffic depending on the construction activity. Tapers are classified as merging tapers, shifting tapers, shoulder tapers and two-way traffic tapers. Examples of tapers and formulas for calculating their minimum desirable lengths are found in the Standard Plan S-630-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019).

A variety of channelizing devices have been approved by CDOT for use in construction projects. These channelizing devices include:

- Traffic cones
- Tubular markers
- Vertical panels
- Drums
- Barricades
- Concrete barriers
- Water-filled barriers

Traffic cones are typically reserved for lane closures and other construction activities during daylight hours. Traffic cones with retroreflective bands are also allowed for nighttime use, but only during working hours. The remaining channelizing devices listed above have been approved for both day and nighttime construction activities. Details regarding the placement of channelizing devices can be found in the MUTCD (FHWA, [2009] 2022) and in the CDOT Standard Plans – M & S Standards (CDOT, 2019).

Quantities for all channelizing devices required on a construction project are tabulated in the Schedule of Construction Traffic Control Devices.

15.6.5 Special Devices

Other special traffic control devices may include speed warning signs, variable message signs (VMS) and flashing arrow panels. Requirements for the use of these devices are addressed in Part 6 of the MUTCD (FHWA, [2009] 2022), current CDOT standards and specifications, and under any current CDOT Smart Work Zone guidelines.

15.6.6 Construction Staging/Phasing

Most highway construction projects require the maintenance of traffic throughout the work zone. The Region Traffic Engineering Section will work closely with the design and construction engineers to develop a construction staging concept that can expeditiously complete the project while safely and efficiently conveying traffic through the work zone. Construction signing plans should detail the construction signing schemes for all the planned phases of the project.

Full road closures for construction may help to expedite a project and minimize the duration of traffic impacts. This shall only be considered as a last resort. If a full closure is necessary, this shall be clearly documented and may require public engagement to inform key constituents and stakeholders why the closure is necessary and that all other options have been considered before coming to this conclusion. The design engineer shall inform the resident engineer, traffic engineer, program engineer, and region communications manager of this desired action early on in the project in order to fully consider all options before this decision is finalized.

15.6.7 Construction at or Near Railroad-Highway Grade Crossings

Highway construction at or near railroad-highway grade crossings may require special traffic control measures to preserve highway and traffic safety, protect workers, and provide for the safe passage of trains through the project work zone. Construction traffic control activities involving railroads may occur on:

- Railroad-highway grade crossing safety projects.
- Other projects requiring work on or near railroad tracks or property.
- Railroad-highway grade separation structure projects.

Refer to the MUTCD Section 6G.18 (FHWA, [2009] 2022) for standard guidance for work in the vicinity of grade crossings; and MUTCD Figure 6H-46 (FHWA, [2009] 2022) for typical application of construction traffic control devices at grade crossings. It is necessary to prevent vehicles from stopping on tracks, and to prevent the queuing of stopped vehicles across the tracks.

Highway projects involving work on or near railroad tracks or crossings may, in addition to necessary traffic control measures at grade crossings, also require the use of railroad flaggers. Railroad flaggers are railroad employees who are authorized to stop or direct train traffic on the affected tracks. Whenever the highway work may pose a danger to trains or interfere with normal train movements (construction equipment near tracks, bridge demolition work, etc.), the railroad company will require a railroad flagger to be stationed at the project site. The flagger will monitor site conditions and exert positive control over trains passing through the project.

Railroad flagging requirements, if any, will be set forth in the project special provisions, and flaggers will be paid out of project funds in accordance with the special provisions. Railroad flagging rates (daily or hourly) will be specified by the railroad company.

Highway construction on railroad overpass structures may also require the use of railroad flaggers to guard against hazards to trains such as falling debris, bridge falsework, or construction equipment.

The required contract (refer to Section 20.1.2) among CDOT, the railroad, and involved local agencies will set forth traffic control responsibilities, coordination requirements, and railroad flagging requirements. The designer should request a contract from the Project Development Branch well in advance of planned construction to allow sufficient time for contract development and execution. CDOT field construction personnel should closely coordinate traffic control with railroad and local agency representatives.

15.7 Permanent Signing

15.7.1 Uniform Standard Regulatory and Warning Signs

Additional information on both signing and pavement markings can be found on the CDOT website at the following location.

Use this link to access more information regarding CDOT's Signing and Pavement Markings: https://www.codot.gov/safety/traffic-safety/design/signing-and-markings

CDOT has adopted the MUTCD (FHWA, [2009] 2022) guidelines for the placement of permanent regulatory and warning signs on the State highways. Signing shall be in conformance with the MUTCD Parts 2 and 3 (FHWA, [2009] 2022). Proper installation and consistency of signs provide guidance and information to safely travel a section of roadway. Signs should be clear and positioned for adequate response time, particularly on high-speed roadways. Detailed layouts and standard sizes for these signs can be found in the FHWA Standard Highway Signs (FHWA, 2004). For further details including ground sign placement, consult the MUTCD (FHWA, [2009] 2022) and Standard Plan S-614-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019). All signs must meet the requirements for crashworthiness in MASH (AASHTO, 2016) and NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features (TRB, 1993). Refer to applicable "S" Standards in the CDOT Standard Plans – M & S Standards (CDOT, 2019) and CDOT Specifications for currently accepted sign designs. Refer to the Structure Management Manual (SMM) for low vertical clearance bridge signage.

The Tabulation of Signs sheet provided for permanent signing on the project lists the panel sizes, post lengths, sign locations and color, MUTCD code (FHWA, [2009] 2022), foundation requirements, and quantities required on a construction project.

Signs should be replaced on a project when damaged, faded, or no longer meet retroreflective requirements. For most new construction or reconstruction projects, signs should be updated or replaced. The designer should check with the Region Maintenance or Traffic Engineering Section for the replacement schedule. For overlay projects, the designer should examine the condition of existing signs to determine if replacement is needed. Signs that are more than ten years old will usually require replacement.

Signing is used for a wide range of purposes. The designer will follow the "S" Standards in the CDOT Standard Plans – M & S Standards (CDOT, 2019) and the MUTCD (FHWA, [2009] 2022) when determining the signing requirements for a project.

15.7.2 Special Signs

Special signs are those not designated with a sign code in the MUTCD (FHWA, [2009] 2022). These signs may include construction signs indicating detours or hours of operations or permanent signs such as guide signs, specific information signs, or other special interest signs. The Region Traffic Section will provide detailed sign layouts for all special signs. Legends shall consist of either upper or lowercase characters provided in the 2012 Supplement to Standard Highway Signs (FHWA, 2012), with letter sizes following the guidelines in Part 2 of the MUTCD (FHWA, [2009] 2022)).

Special signs are tabulated on the Schedule of Construction Traffic Control Devices, or the Tabulation of Signs provided in each contract plan package.

Only symbols that have been approved by FHWA may be used on special signs.

15.7.3 Sign Classifications

Permanent sign panels placed on the State highway system are classified as Class I, II or III.

Class I sign panels are single-sheet aluminum with a minimum thickness of 0.080 inches. Class I panels are flush mounted directly to wooden, U-2 steel, or tubular steel posts, as directed in Standard Plan S-614-2 of the CDOT Standard Plans – M & S Standards (CDOT, 2019).

Class II sign panels are also single-sheet aluminum with minimum thicknesses of 0.100 inches mounted on wooden, U-2 steel, or tubular steel posts, however, Class II signs are mounted with one or two aluminum backing zees as outlined in Standard Plan S-614-3 of the CDOT Standard Plans – M & S Standards (CDOT, 2019).

Class III signs are guide or informational signs constructed of 0.125-inch minimum thickness sheet aluminum and mounted with backing zees. Class III signs may be located either on overhead sign structures according to the Standards for Overhead Sign Structures or on the ground using wooden, tubular steel, or W-beam shaped steel posts.

15.7.4 Ground Sign Supports and Foundations (Class III)

Determining the requirements for Class III ground sign supports and foundations is the responsibility of the designer. Standard Plan S-614-6 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) provides data for determining sign supports and concrete footing sizes for all Class III ground sign installations. Class III panels may require either wooden, tubular steel, or W-beam shaped steel supports depending on the panel size and the applied moment due to wind loads. CDOT Standards use a design wind speed of 90 mph for wind loading in most locations. Breakaway sign support requirements are found in Standard Plan S-614-5 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) for both wood and steel sign supports.

Material quantities for sign supports and concrete footings are detailed on the Tabulation of Signs provided in the plans for any permanent signing project done by the Safety and Traffic Engineering Branch.

15.7.5 Overhead Sign Structures

Overhead sign structures used on the State highway system are classified into three categories:

- Sign bridges
- Cantilever sign structures
- Butterfly sign structures

The type of overhead sign structure required for a project is covered in Standard Plan S-614-50 of the CDOT Standard Plans – M & S Standards (CDOT, 2019), and depends on the location and the number of sign panels needed. Once the panel sizes and span lengths are known, the structural and foundational requirements of the structure are determined using the CDOT Standard Plans – M & S Standards (CDOT, 2012) developed by Staff Bridge Branch.

Standard Plan S-614-50 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) should be included in all plans that require overhead sign structures. Plan sheets for overhead sign structures not found in the CDOT Standard Plans – M & S Standards (CDOT, 2019), including cantilevers and butterfly sign structures, can be obtained from the Staff Bridge Branch.

15.7.6 Cross Sections at Class III and Overhead Sign Structure Locations

Cross sections are required for Class III and larger sign installations using appropriate stationing. Cross sections should extend 50 to 100 feet beyond the edge-of-traveled way, depending on the lateral placement of the sign. All features such as curb and gutter, guardrail, ditches, fences, right of way lines, bikeways, and roadways should be indicated. Class III panels should be detailed on the cross sections and placed the appropriate lateral distance from the edge-of- traveled way.

The bottom of the panel shall be located in accordance with Standard Plan S-614- 1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019).

For sign bridge structures, a cross section from the median centerline to 41 feet beyond the edge-of-traveled way should be obtained.

15.8 Specifications

15.8.1 Standard Specifications

All standard specifications for traffic control devices related to construction are found in the most current version of the CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022).

15.8.2 Standard Special Provisions

Traffic Standard Special Provisions are additions and revisions to the CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022) initiated by Safety and Traffic Engineering and approved by the Joint CCA/CDOT Specifications Committee. These provisions are unique to a selected group of projects or are intended for temporary use. Standard Special Provisions to be used on construction projects can be accessed on the Construction Specifications Web Page (CDOT, n.d.).

15.8.3 Traffic Project Special Provisions

Traffic Project Special Provisions are additions and revisions to the CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022) unique to a particular project. They are available for use on a project-by-project basis and are posted on the CDOT Safety and Traffic Engineering Web Page (CDOT, n.d.).

15.9 Signals

15.9.1 Signal Plans

Traffic signals play an important role in the safe and steady flow of traffic at intersections or junctures. The MUTCD Part 4 (FHWA, [2009] 2022) provides the criteria for the design and installation of traffic signals. The traffic signal plan sheets provided by the Region Traffic Section will show the placement of the signal poles, heads, conduit, pull boxes and all other related signal equipment. Standard Plans S-614-40 and S-614- 40A of the CDOT Standard Plans – M & S Standards (CDOT, 2019) provide details of the signal equipment required by CDOT.

When designing sidewalks and channelization islands, consideration of Americans With Disabilities Act (ADA) standards, Public Rights-of-Way Accessibility Guidelines (PROWAG) and the needs of able-bodied pedestrians should be taken into account. Poles, boxes and other related equipment should be placed so that pedestrians have unobstructed walkways.

15.9.2 Warrant Studies

Properly designed traffic signals make intersections safer and more efficient by improving traffic flow. However, signals are not cure-alls for improving traffic flow and reducing crashes at all intersections. Traffic signals should be warranted before they can be installed. Specific criteria are given in Part 4 of the MUTCD (FHWA, [2009] 2022) for the installation of traffic signals. Even if an intersection meets warrant criteria, careful consideration should be given to other traffic control options such as roundabouts before a signal is decided upon.

15.10 Pavement Markings

15.10.1 Permanent

Additional information on both signing and pavement markings can be found on the CDOT website at the following location.

Use this link to access more information regarding CDOT's Signing and Pavement Markings: https://www.codot.gov/safety/traffic-safety/design/signing-and-markings

Adequate pavement markings have been a cost-effective means of enhancing both traffic safety and mobility. CDOT requires centerline, edge line, auxiliary lane, crosswalk and other pavement markings on all roads under its jurisdiction. CDOT requires durable pavement markings on all mainline Interstate projects and on other selected roadways where traffic volumes are high or non-durable markings have not been cost-effective. "Durable" pavement marking materials are those materials capable of providing a longer service life than conventional paint.

General guidelines for the selection of pavement marking materials for roadway projects can be found in the CDOT Pavement Marking Practices Guide on the CDOT website below.

Use this link to access more information regarding CDOT's Pavement Marking Practices Guide: https://www.codot.gov/safety/traffic-safety/assets/documents/pavement-marking-practices

Other considerations in the selection process may include the desire to use materials that are lead- free, materials that contain lower levels of volatile organic compounds (VOC), or materials that do both. The MUTCD (FHWA, [2009] 2022)) and Standard Plan S-627-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) outline the details and requirements for the proper selection and installation of all pavement markings. Refer to Section 627 of the CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022).

Tabulation of Pavement Marking quantities will be included in the plan sheets provided by the designers and reviewed by the Region Traffic Engineering Section for most construction projects.