COLORADO
Department of Transportation

COLORADO DEPARTMENT OF TRANSPORTATION

Intersection Conflict Warning System Guidelines

2024 Edition

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MULLER
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Introduction

Mission

It is the mission of the Colorado Department of Transportation (CDOT) to provide the best multi modal transportation system for Colorado that most effectively moves people, goods, and information. CDOT policy, state statute, and federal surface transportation law, place a strong emphasis on creating a system for use by persons of all ages and abilities for safe and convenient access to jobs, services, schools, and recreation. The Chief Engineer Design Guidance express support for taking a flexible approach when designing and planning our state transportation system, and to identify resources which can be used to provide context sensitive solutions particularly related to safety improvements.

Purpose

CDOT has developed guidelines and best practices for the application of Intersection Conflict Warning Systems (ICWS). ICWS warn drivers of potential conflicts with other vehicles approaching an intersection. The systems consist of detection and dynamic activated warnings placed on minor road approaches, major road approaches, or both.

Background

The Federal Highway Administration (FHWA) and several other state DOTs have developed guidance on ICWS. CDOT has also implemented ICWS at a few locations in the state. The CDOT ICWS Guidelines were developed to identify best practice for ICWS and to document CDOT's experiences and lessons learned.

General Information

Abbreviations

ADT	Average Daily Traffic
CMF	Crash Modification Factor
ICWS	Intersection Conflict Warning System
ITS	Intelligent Transportation System
MUTCD	Manual on Traffic Control Devices
PTZ	Pan-Tilt-Zoom (Camera)
RRFB	Rectangular Rapid Flashing Beacon
SPF	Safety Performance Function
TOC	Traffic Operations Center
VPD	Vehicles Per Day

Definitions

An **Activated Warning Sign** is a device that includes a dynamic element, which changes state to warn road users of a hazard.

The **Average Daily Traffic (ADT)** is the amount of vehicular traffic that crosses an imaginary line across a roadway in a 24-hour period. On a two-way street, ADT typically includes both directions of travel.

A **Crash Modification Factors (CMF)** is used to compute the expected number of crashes after implementing a countermeasure on a road or intersection. It is defined as the ratio of expected crash frequency with an improvement over that without the improvement.

Detectors are used to determine the presence or passage of vehicles or other road users.

Intersection Conflict Warning Systems (ICWS) are used to provide activated warnings to drivers at intersections where poor sight distance or gap acceptance have contributed to higher crash rates. They are typically comprised of static signing, a dynamic element, and detection.

A **Major Road** is the roadway at an intersection carrying a higher volume of traffic.

The **Manual on Uniform Traffic Control Devices (MUTCD)** defines the standards used by Traffic Engineers nationwide to install and maintain traffic control devices on all public streets, highways, bikeways, and private roads open to the public.

A **Median** is a strip of road, not normally intended for use by traffic, which separates traffic in opposing directions of a divided highway

A **Minor Road** is the roadway at an intersection that carries a lower volume of traffic.

Pan-Tilt-Zoom (PTZ) cameras are built with mechanical parts allowing them to swivel left or right, tilt up or down, and zoom in and out of their view.

Vehicles per day (VPD) is the amount of vehicular traffic that crosses an imaginary line across a roadway in a 24-hour period.

A **Warning Sign** indicates actual or potential hazards to road users.

Additional Resources

In addition to these guidelines, CDOT encourages the use of the following resources when planning or designing ICWS on Colorado's transportation network.

AASHTO 2018, *A Policy on Geometric Design of Highways and Streets*, 7th Edition.

CDOT 2019, *Flashing Beacon and Sign Installations*, Standard Plan No. S-614-14, https://www.codot.gov/safety/traffic-safety/assets/s-standard-plans/2019/s-614-14/S-614-14%20%283-page%20set%29.pdf.

CDOT 2023, "Safety Analysis & Information, Colorado Safety Performance Functions (SPF)" www.codot.gov/safety/traffic-safety/data-analysis/analysis.

ENTERPRISE Transportation Pooled Fund Study 2011, *Design and Evaluation Guidance for Intersection Conflict Warning Systems (ICWS)*, Athey Creek Consultants, http://enterprise.prog.org/Projects/2010_Present/developingconsistencyIWS/Design_and_Eval_Guidance/Guidance%2520for%2520ICWS%2520Version%25201-122011.pdf.

ENTERPRISE Transportation Pooled Fund Study 2013, *System Requirements for Intersection Conflict Warning Systems (ICWS) Final Report*, Athey Creek Consultants, https://enterprise.prog.org/Projects/2010_Present/icwssyseng/ICWS%20System%20Requirements%20FINAL%20051713.pdf.

ENTERPRISE Transportation Pooled Fund Study 2015, "Planning Guidance for the Installation and Use of Technology Devices for Transportation Operations and Maintenance, Intersection Conflict Warning Systems (ICWS)", https://enterprise.prog.org/archive/itswarrants/icws.html.

FHWA 2016, *Intersection Conflict Warning System Human Factors: Final Report*, Publication No. FHWA-HRT-16-061, www.fhwa.dot.gov/publications/research/safety/16061/16061.pdf.

FHWA 2023, Manual on Uniform Traffic Control Devices, 11th Edition, https://mutcd.fhwa.dot.gov/kno_11th_Edition.htm.

Himes, S., Gross, F., Eccles, K., & Persaud, B. 2016, *Safety Evaluation of Intersection Conflict Warning Systems.*

MNDOT 2016, *Intersection Safety Technologies Guidebook*, Report No. MN/RC - 2016RIC10, https://mdl.mndot.gov/items/2016RIC10.

MNDOT 2019*, A Study of the Rural Intersection Conflict Warning System (RICWS)*, Minnesota Department of Transportation, Office of Traffic Engineering, St Paul, MN.

MNDOT 2021, *An Addendum to "A Study of the Rural Intersection Conflict Warning System (RICWS)"*,), Minnesota Department of Transportation, Office of Traffic Engineering, St Paul, MN.

MNDOT 2023, “Rural Intersection Conflict Warning System (RICWS)”, Project Description, Minnesota Department of Transportation, Office of Traffic Engineering, St Paul, MN, viewed August 23, 2024, https://www.dot.state.mn.us/trafficeng/signals/conflictwarning.html.

Tian, D, Morris, NL, & Libby D 2018, *Rural Intersection Conflict Warning System Evaluation and Design Investigation,* Report CTS 18-10, viewed August 23, 2024, www.cts.umn.edu/publications/report/rural-intersection-conflict-warning-system-evaluation-and-design-investigation.

UDOT 2018, *Rural Intersection Conflict Warning System Guidelines*, Final Report, viewed August 23, 2024, https://nwpassage.info/wp-content/uploads/2024/04/13-2-ricws-guidelines-study.pdf.

US DOT 2023, “National ITS Reference Architecture Service Package VS06: Stop Sign Gap Assist”, viewed August 23, 2024, https://www.arc-it.net/html/servicepackages/sp70.html#tab-3.

WSDOT 2022, Roadside Electrical Standard P2 Advance Warning Systems, viewed August 23, 2024, https://wsdot.wa.gov/sites/default/files/2022-09/WSDOT-Traffic-Electrical-REES-P2-AdvanceWarningSystems.pdf

ICWS Types

There are generally four types of ICWS that depend on the intersection layout and which approaches are provided with activated warning signs. These are identified in **Table 1** and illustrated in **Figure 1** through **Figure 4.** The examples show four-legged intersections, but the ICWS type would be similar on T-intersections with a single approach on the minor road. Further details of the warning signs and detection applied are provided in subsequent sections of the guidelines.

Table 1: Types of ICWS and Their Purpose

Type of ICWS	Purpose
1. Minor road only warning	Vehicles on the major road are detected and activate signs visible to drivers on the minor road (refer to **Figure 1**).
2. Minor road warning for median separated intersection	Similar to the minor road only warning (Scenario 1) but includes a median separated major road. Vehicles on the major road are detected and activate signs visible to drivers on the minor road. Typically include separate warning signs on minor road for the near side lanes and far side lanes (refer to **Figure 2**)
3. Major road only warning	Vehicles on minor road are detected and activate signs visible to drivers on the major road (refer to **Figure 3**).
4. Major and minor road warning	Both major and minor road vehicles are detected, and warnings are provided to opposing cross traffic (refer to **Figure 4**).

Note: Based on CDOT practices and those in other states (ENTERPRISE 2011, FHWA 2016, MnDOT 2016, and UDOT 2018)

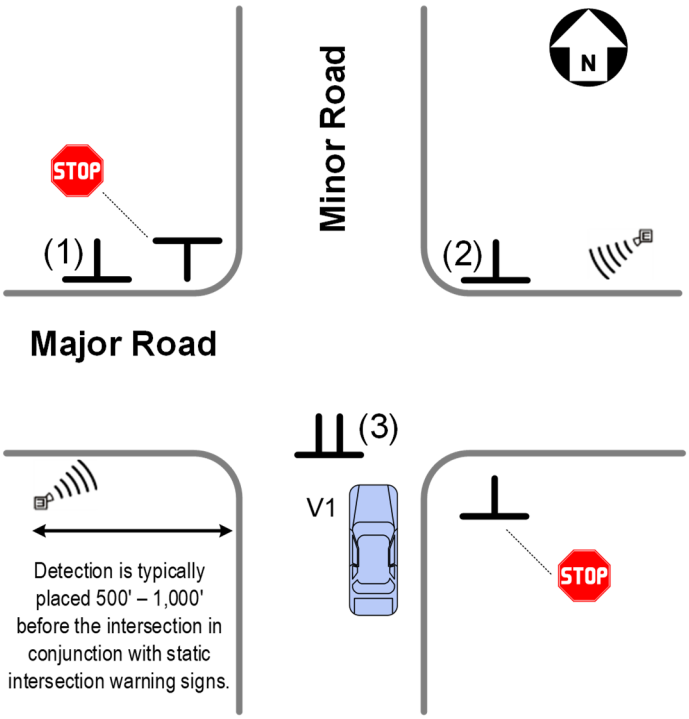
Minor Road Only Warning

Under a Minor Road Only Warning, a driver on the minor road (represented by V1) is provided with a warning when a vehicle is detected on the major road (**Figure 1**).

The minor road approaches are stop controlled with warning signs placed either on the far side opposite corner (1), the far side near corner (2), or an overhead warning sign on the minor road approach (3).

Detection is placed on the major road approaches to activate the warning signs and alert minor road vehicles of oncoming traffic. Detection is typically placed on the major road 500 feet to 1,000 feet in advance of the intersection in conjunction with static intersection warning signs.

Figure 1: Minor Road Only Warning



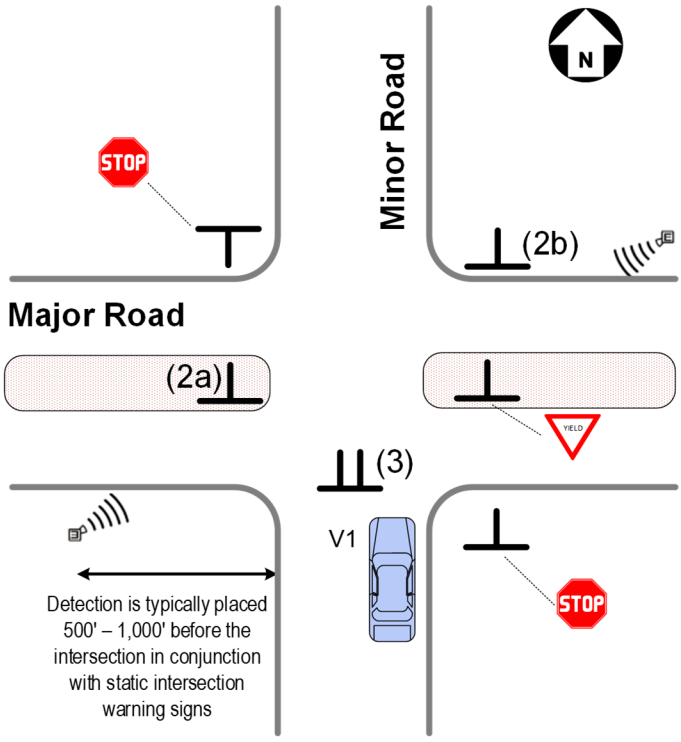
Minor Road Only Warning (Divided)

This type of warning provides a minor road alert at an intersection with a divided major road (**Figure 2**). The minor road approaches are stop controlled. A minor road driver (V1) is provided with two sets of warnings including:

- A near-side warning with signs either placed in the median on the corner opposite the minor road vehicle (2a), or an overhead warning sign on the minor road approach (3).
- A yield sign is placed in the median to warn drivers having crossed the near-side lanes in conjunction with a warning sign placed on the far side (northeast) corner (1b, 2b)

Detection is placed on the major road approaches typically 500’ to 1,000’ in advance of the intersection in conjunction with static intersection warning signs.

Figure 2: Minor Road Warning (Divided)



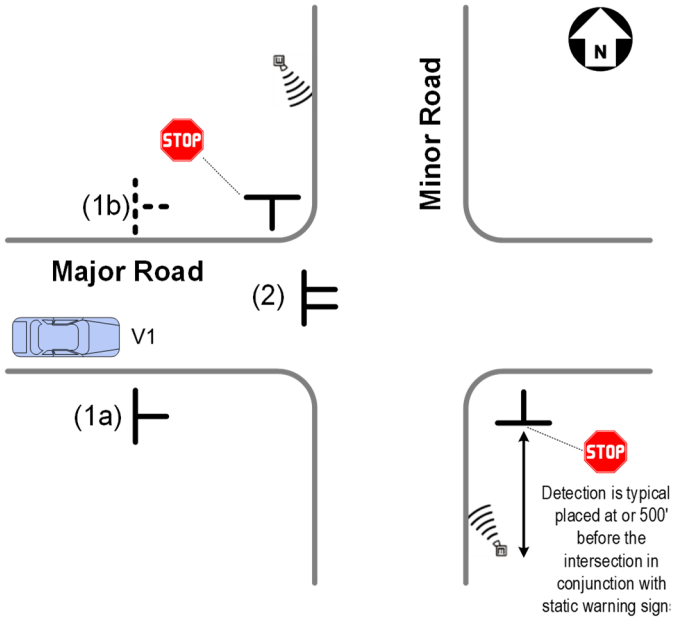
Major Road Only Warning

With a major road only warning, warning signs are placed on the major road to alert drivers to vehicles approaching on the minor road (**Figure 3**).

Warning signs are placed on the major road including Sign 1a. For major roads with multiple lanes in one direction, an additional warning sign (1b) is provided. An overhead sign (2) may also be provided. However, several studies have found an overhead sign along the major road to be ineffective (FHWA 2016, ENTERPRISE 2011).

Detection is typically placed on the minor road at or up to 500 feet before the intersection in conjunction with static warning signs to detect approaching and stopped vehicles.

Figure 3: Major Road Only Warning



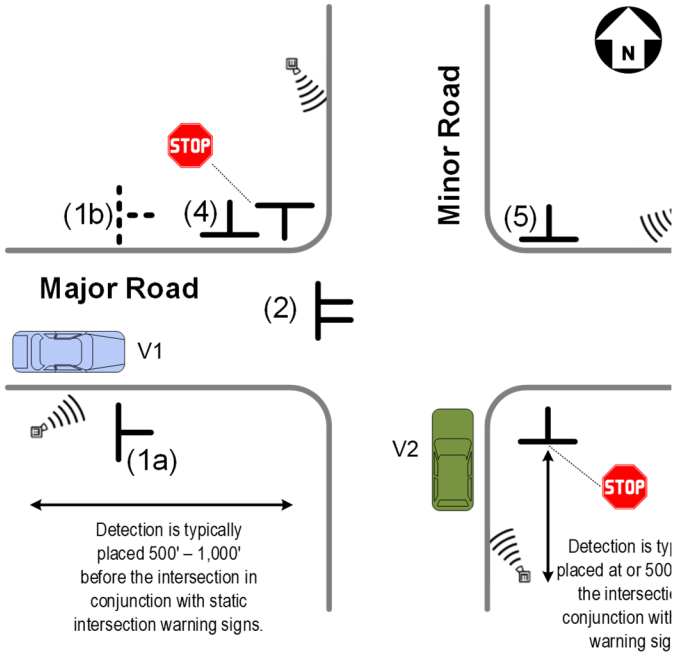
Major and Minor Road Warning

With this scenario, activated warnings and detection are provided on both the major and minor roads (**Figure 4**).

Sign placements are similar to Scenarios 1, 2 and 3 as shown for the major approach (signs 1a, 1b, and 2) and for the minor approach (signs 3, 4 and 5).

Detection is provided on both the major road and minor road approaches.

Figure 4: Major and Minor Road Warning



ICWS Installation Criteria

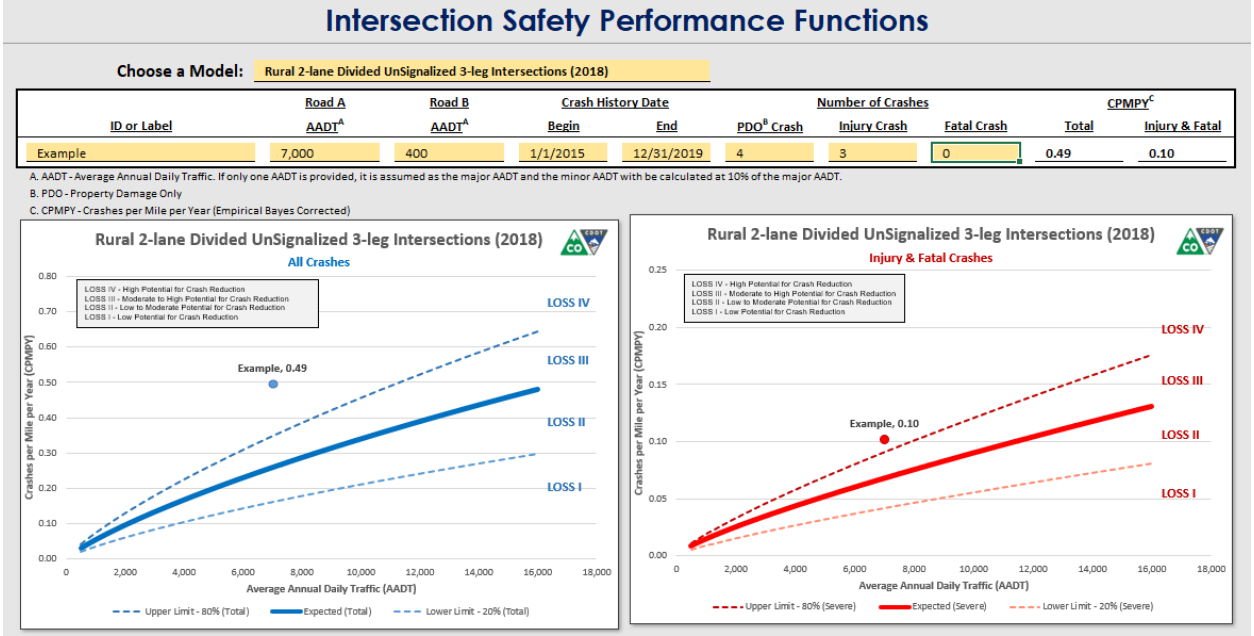
The following criteria identify conditions where ICWS may be considered as part of efforts to improve the safety at side-street stop-controlled intersections. These criteria are identified as planning guidance for considering ICWS among other treatments to improve safety at intersections. While the criteria may indicate where ICWS may be considered, they should be evaluated against other intersection improvements or may be considered as a complimentary improvement to other countermeasures.

Crash Considerations

ICWS are typically installed on higher speed approaches (45 miles per hour or faster) where there is a higher than expected rate of crashes and broadside (right-angle) crashes are the predominant type. On Colorado highways, CDOT has developed Intersection Safety Performance Function (SPF) models that can be used to determine the Level of Safety Service (LOSS) for an intersection. Intersections performing at LOSS III or LOSS IV are locations where crash rates are higher than expected. LOSS can be determined using Vision Zero suite software or via the SPF models and normative baselines available on the CDOT website (CDOT 2023).

Figure 5 shows an example of an intersection SPF analysis for a rural 2-lane unsignalized 3 leg intersection where there is a high potential for crash reduction with a LOSS IV for All Crashes and Injury and Fatal Crashes.

Figure 5: Intersection SPF Analysis Example



Source: Based on CDOT (2023) Colorado Safety Performance Functions (SPF), www.codot.gov/safety/traffic-safety/data-analysis/analysis.

Traffic Volume Criteria

Based on experiences in other states, traffic volume ranges have been identified where ICWS are more effective. The criteria were developed to minimize deploying ICWS at locations where higher traffic volumes are likely to cause too frequent or near constant activations, thereby diminishing the effectiveness of the ICWS dynamic warnings (**Table 2**). The traffic volumes applied to the criteria will typically include both directions of the major road. However, where a dynamic warning is only applied to one direction of travel, the volume for that single direction may be considered.

Table 2: ICWS Volume-based Criteria

Criterion (ADT)	Recommended Treatment
Major road volumes ≤ 3,000	Alerts on minor road approaches
Major road volume > 3,000 and ≤ 10,000	Alerts on major road approaches
Major road volumes > 10,000 and ≤ 12,000	Alerts on major and minor approaches
Major road volumes > 12,000	Consider alternative treatments as ICWS typically would cause frequent or near constant warnings

Source: Based on UDOT (2018) and ENTERPRISE (2015).

Other Criteria and Considerations

Previous research and practices (ENTERPRISE 2015, UDOT 2018) have identified additional intersection characteristics that may indicate a higher risk of broadside crashes including:

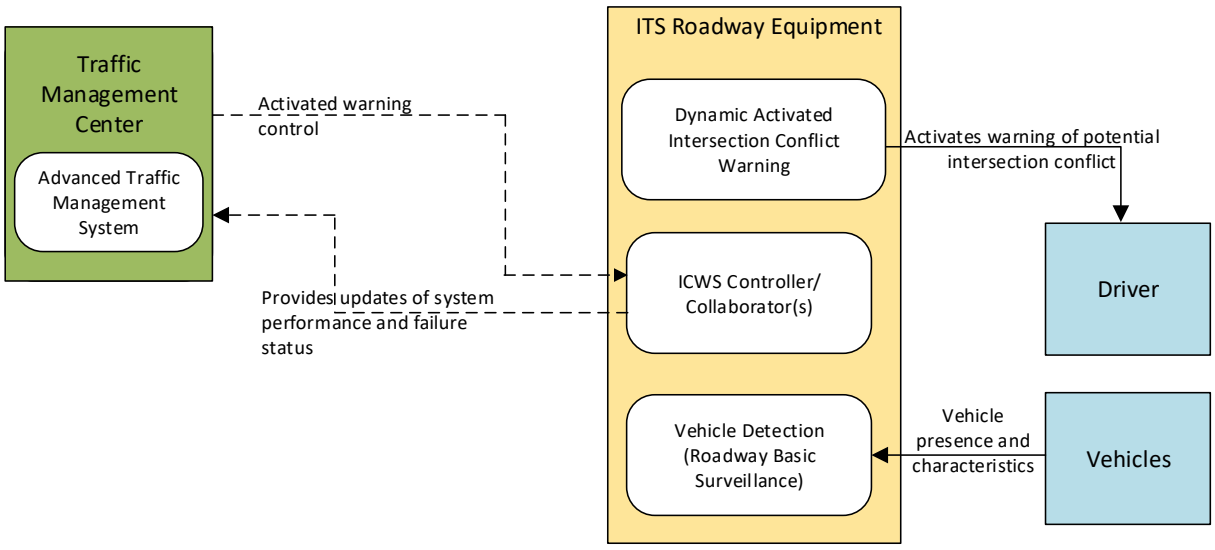
- A minor leg approach that does not have a stop sign within five miles of the intersection
- Limited sight distance and/or poor gap acceptance
- Intersection skew angle greater than 15 degrees
- Presence of a horizontal and/or vertical curve at the intersection
- Railroad crossing at one of the minor intersection legs
- Commercial development present in one or more of the intersection quadrants

Other factors identified include excessive speed, substandard intersection geometry, sign obstructions, and areas with unfamiliar road users (e.g., tourism-related traffic).

ICWS System and Components

An ICWS is comprised of a series of roadway Intelligent Transportation System (ITS) devices that provide a dynamically activated warning triggered by vehicle detection. An example of a system diagram for an ICWS is shown in **Figure 6**. The ICWS may act as an isolated system or may be linked with a traffic management center. The dashed lines on the diagram would only apply if communication with a traffic management center was provided. This diagram is a simplified version of the ITS National Architecture Service Package VS06 Stop Sign Gap Assist (US DOT 2023).

Figure 6: ICWS High-Level System Diagram



Dynamic Activated Warning

ICWS include dynamic warning elements that consist of a static warning sign supplemented with flashing beacons, or dynamic message signs. Examples of dynamic activated ICWS warning signs are shown in

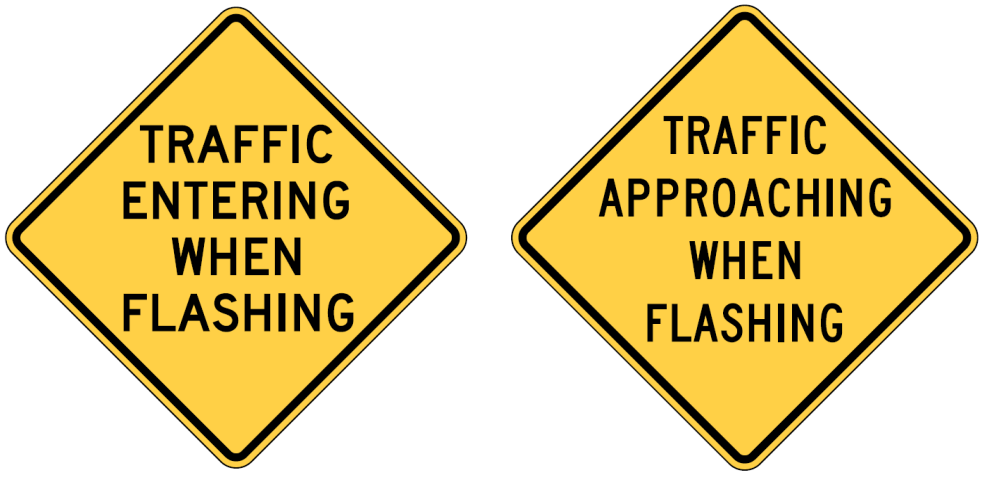
Figure 7. The ICWS on the left uses a flashing beacon. The ICWS on the right uses static warning signs with an LED border and rectangular rapid flashing beacons as dynamic warning elements.

Figure 7: Examples of ICWS Warning Devices

Warning Signs

The *Manual on Uniform Traffic Control Devices* (MUTCD) provides guidance on ICWS warning signs and dynamic elements (FHWA 2023). Section 2C.42 of the MUTCD (Actuated Advance Intersection Signs) identifies warning signing for ICWS (**Figure 8**).

Figure 8: Actuated Advance Intersection Signs



The MUTCD identifies that:

- The TRAFFIC ENTERING WHEN FLASHING (W2-10) warning sign may be used for a Major Road warning.
- The TRAFFIC APPROACHING WHEN FLASHING (W2-11) warning sign may be used for a Minor Road warning.

Both signs should have a minimum size of 36 inches by 36 inches for conventional road single lane or multi-lane approaches (Table 2C-1 of the MUTCD). The minimum size increases to 48 inches by 48 inches for expressways. The MUTCD identifies that the W2-10 or W2-11 signs shall be supplemented with a warning beacon that activates when a vehicle on a conflicting approach is detected.

Prior to the 2023 MUTCD publication, the previous version of the MUTCD did not identify specific warning signs and CDOT practice was to develop special warning signs (e.g., TRAFFIC APPROACHING, CROSS TRAFFIC AHEAD) along with a supplemental WHEN FLASHING (W16-13P) warning plaque.

Warning Beacons

Section 4S.03 of the MUTCD identifies that a warning beacon shall consist of a standard traffic signal face with a flashing CIRCULAR YELLOW signal indication. The 2023 MUTCD notes that LED legend or borders of signs in conjunction with the phrase WHEN FLASHING shall not be used (MUTCD Section 2A.12). CDOT (2019) Standard Plan Number S-614-14 provides design details for flashing beacon and sign installations. CDOT is currently reviewing ICWS installed prior to the 2023 MUTCD publication to update as necessary with these requirements.

Warning Sign Placement

Guidance on the longitudinal placement of intersection warning signs is provided in the MUTCD Table 2C-3 (**Table 3**). As noted in the MUTCD, the advance placement distance is based on providing adequate perception warning time and distances can be adjusted to account for roadway features, other signing, or to improve visibility.

Table 3: Guidelines for Advance Placement of Intersection Warning Signs

Posted or 85th Percentile Speed (mph)	Advance Placement Distance[1] (ft)	Posted or 85th Percentile Speed (mph)	Advance Placement Distance[1] (ft)
20	115	55	495
25	155	60	570
30	200	65	645
35	250	70	730
40	305	75	820
45	360	80	910
50	425	85	1,010

[1]Typical condition is warning of a potential stop situation for intersection warning signs. The distances are based on AASHTO (2018) Policy, Table 3-1, Stopping Sight Distance, providing a perception-reaction time of 2.5 seconds and a deceleration rate of 11.2 feet/second^2.
Source: Condition B for warning of a potential stop situation, from MUTCD Table 2C-3 (FHWA 2023).

Vehicle Detection

ICWS use vehicle detection to determine the presence and speed (in some ICWS) of vehicles on the minor or major street approaches depending on the type of ICWS being developed. Recent CDOT ICWS applications have typically used radar detection, but loop detectors and other forms of detection may also be considered.

Detector placement will depend on the type of ICWS being developed. For ICWS with a minor road warning, detection needs to be placed on the major road, and conversely, a major road warning will require detection placed on the minor road. Alerts required on major and minor approaches will require detection on both the major and minor approaches.

Minor Road Warning with Detection on the Major Road

For a minor road warning, detection is needed to detect traffic that is closer than the stopping sight distance from the crossing roadway. If static warning signs are also being placed on the major road approach, detection can be placed at the location of the static warning sign.

Using the stopping sight distance concept, the following equation, developed by WSDOT (2022), may be used to help determine the detector location in advance of the intersection.

$$D_D = 1.47V_{85}t + \frac{V_{85}^2}{30\left(\frac{a}{32.2}\right) + \left(\frac{G}{100}\right)}$$

Where:

- D_D = Detection distance measured between the start of the detection zone and the edge line of the minor roadway.
- 1.47 = Conversion factor from mph to feet/second
- V_{85} = 85th percentile speed (mph)
- t = Perception-reaction time, in seconds, 2.5 seconds recommended
- a = Deceleration rate (feet/second^2), use 8 feet/second^2 unless trucks are prohibited, 10 feet/second^2 (no trucks present)
- G = Grade (%), uphill approach is positive (+), downhill approach is negative (-)

Major Road Warning with Detection on the Minor Road

The location of detection placed on the minor road approach for a major road warning will be required to detect vehicles stopped on the minor road approach. The detection zone may also capture vehicles approaching the intersection on the minor road.

Controller

The ICWS requires a controller that allows for programming and controlling the warning sign system. The controller will typically contain logic to determine when a detected vehicle should trigger the activated element of the warning sign (flashing beacons, sign borders, etc.).

Individual signs also require controller units (or also referred to as collaborators) that will control the signs and communicate with the overall ICWS controller. Controllers need to be placed in a weather hardened cabinet or enclosure. Previous CDOT projects have used traffic signal cabinets or smaller pole mounted enclosures.

Communication

Communication transmits data between the detection and warning components of the system and the ICWS controller. The ICWS may operate as an isolated system or communication may be established between the ICWS and a traffic operations center (TOC). Communication to a TOC will aid system monitoring and managing system data and operation. Communication between the ICWS and the TOC would require the ICWS to include fiber, radio or other forms of communication back to the TOC.

Power

ICWS require power for the detection, warning, and communication components. A reliable source of power is important to minimize disruption to system operation and to maintain system user confidence. Grid-based power provided by a traditional third-party utility company is the preferred option if it is available in close proximity to the intersection. However, this may not be the case at many rural intersections. Solar power with battery backup provides an alternative option. However, solar power supply may introduce unreliability in the system. Data backup needs to be considered in the design. This may increase system monitoring needs.

System Monitoring and Management

Monitoring will be required to evaluate system performance or system faults and alert operators or maintenance staff to operational issues. The complexity of system monitoring is scalable to operations and maintenance needs. System monitoring may need to support providing system diagnostics to identify failures and malfunctions in a timely manner. Monitored information may include a log of when the system detected vehicles and activated warnings, a system history of equipment faults or status. Where battery power is provided, charging and power status information may also be required.

ICWS Activated Warning Timing

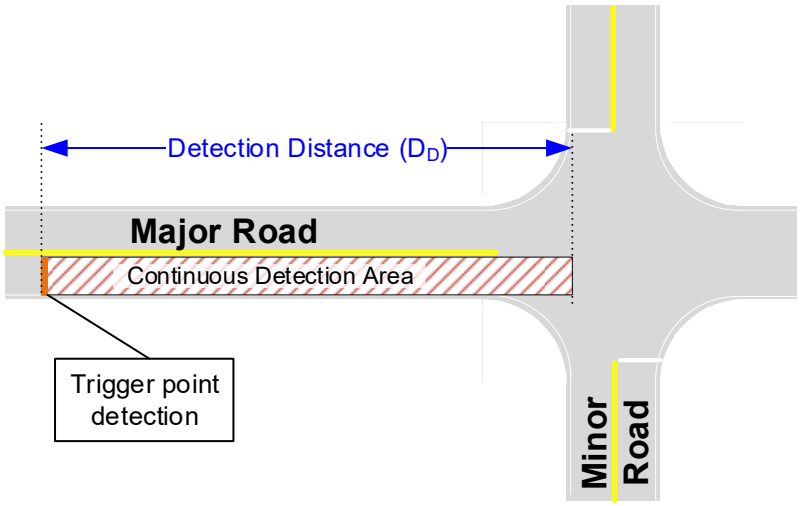
The timing of the activated warning flashers on an ICWS will be dependent on whether warnings are provided on the minor or major approaches. The general approach consists of activating the activated warning flashers when a conflicting vehicle is detected. Once a vehicle is no longer detected, the flashers will then need to be held active for a certain time period as detailed below for warnings on minor or major approaches. These guidelines provide a general method for developing activated warning timings. However, the timings identified in the guidelines will need to be field verified to ensure that they align with the specific conditions at each site.

Warning on Minor Roadway Approaches

For warnings placed on a minor roadway approach, different types of detection may be used. Detection may consist of a single detection component placed a determined distance in advance of an intersection (trigger point detection). Under this configuration, a warning flasher would be timed to keep the flashing beacons activated until the vehicle traveling on the major road had entered the intersection with the minor road based on the approach speed applied.

Another option would be to install speed and distance detection using a continuous detection zone placed on a major approach. Detection such as radar or infrared detection may provide this. Depending on the setup, this type of detection may extend from an upstream location to partway or the entire distance to the minor road approach. The trigger point and continuous detection area types of detection are shown in **Figure 9**.

Figure 9: Timing for Warning on Minor Roadway Approaches



The timing for a warning on a minor approach will need to determine the amount of time for a vehicle to travel between the trigger point or beginning of a continuous detection zone and the edge of the minor roadway approach. This timing, referred to as the conflict warning time, may be determined using the following equation developed by WSDOT (2022).

$$CWT = {}^{D_D}/_{1.47V}$$

Where:

CWT	=	Conflict warning time (seconds)
D_D	=	Distance between the trigger point or start of the continuous detection area and the edge line of the minor roadway
V	=	Approach speed (mph)
1.47	=	Conversion factor from miles per hour to feet per second

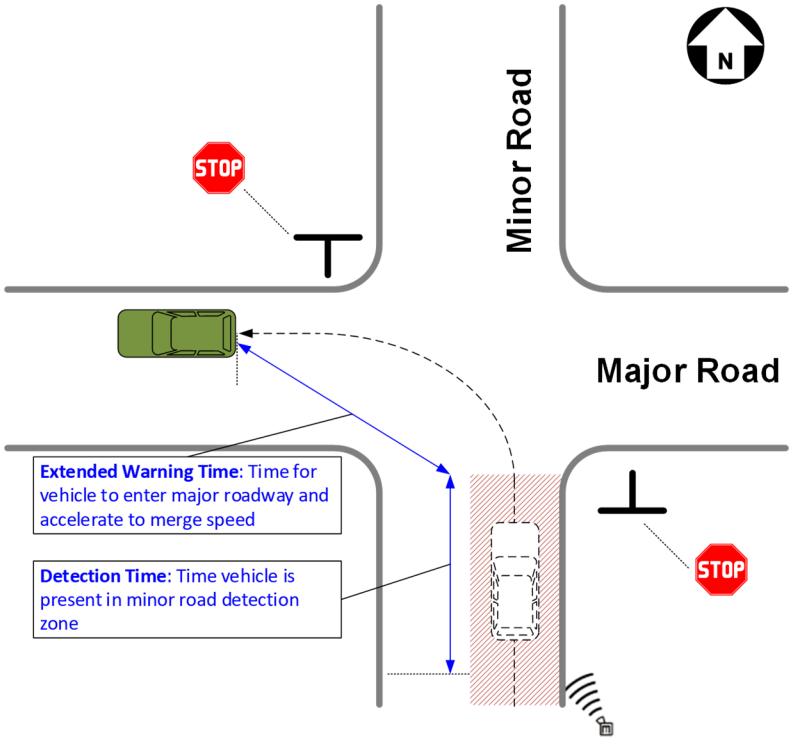
The approach speed will differ depending on the type of detection provided. For single detection component detection, practitioners will need to determine the approach speed. It is desirable to base the approach speed on traffic data. Slower vehicles will take longer to travel between the trigger point and the edge of the minor roadway. Practitioners may consider using the 15th percentile speed or average speed if speed data is available. If the posted speed limit is used as the approach speed, a shorter conflict warning time will be calculated.

A continuous detection area may be able to calculate approach speeds in real time for approaching vehicles and determine the CWT for each individual vehicle.

Warning on Major Roadway Approaches

For ICWS signs on a major roadway approach, the sign should flash any time a crossing, turning, or stopped vehicle is present within the minor street detection zone. Additionally, an extended warning time should be provided for after a vehicle exits the minor street detection zone, enters the major roadway, and accelerates to merge onto the major roadway (**see Figure 10**). The total time provided for the warning flashers will be equal to the detection time plus the extended warning time.

Figure 10: Major Roadway Activated Warning Time



The detection time will vary depending on how long it takes a vehicle to enter the intersection. For the extended warning time, the following equation is recommended (WSDOT 2022). Application of this equation

based on typical posted and merge speeds is shown in **Table 4** (for level conditions with gradients less than a 3% upgrade on the minor approach). For upgrades of 3% or more, the acceleration rate needs to be adjusted using the equation. Where the controlling vehicle type is trucks, the extended warning times will need to be increased.

$$EWT = 1.47V_m/a$$

Where:

EWT = Extended Warning Time (seconds)
V_m = Merge Speed (mph), based on AASHTO (2018) Green Book, Table 10-4
a = Acceleration rate, in feet/sec.^{2}, a rate of 1.6 feet/sec.^{2} where trucks are permitted Where upgrades are present, the acceleration rate can be further reduced to 1.5 (upgrades 3% - 4%) or 1.3 (upgrades 5% or more). Where trucks are prohibited, 4.4 feet/sec.^{2}.
1.47 = Conversion factor from miles per hour to feet per second

Table 4: Extended Warning Times for Accelerating Traffic

Major Road Posted Speed (Mph)	Major Road Merge Speed (Mph)	Extended Warning Time (Seconds)	
		Trucks Allowed	Trucks Prohibited
35	27	25	10
40	31	29	11
45	35	33	12
50	39	36	14
55	43	40	15
60	47	44	16
65	50	46	17

Note: For upgrades of 3% or more, calculate based on the acceleration rate modifications using the EWT equation.
Source: Adapted from WSDOT (2022).

ICWS Applications

CDOT has implemented ICWS at several locations in the state including applications with activated warning signs placed on the major roads and others with the warning signs placed on the minor roads. Design plans from several of these installations are provided in **Appendix A**. It should be noted that all of these applications were installed prior to the publication of the 2023 MUTCD. CDOT is currently reviewing previously installed ICWS to update as necessary to comply with the latest edition.

US 6 and Saint John Road/Decatur Hill Road, Keystone

CDOT Region 3 implemented an ICWS at the intersection of US 6 and Saint Johns Road/Decatur Hill Road in Keystone, Colorado. Details of the system are shown in **Table 5**. The system was installed in late 2021 and to date the system has not been formally evaluated.

Table 5: US 6 Keystone ICWS Details

ICWS Type	Major Road Only Warning
Warning Devices	CROSS TRAFFIC AHEAD warning sign with LED border and WHEN FLASHING supplemental plaque. Located on US 6 550 feet in advance of intersection in each direction.
Detection	Radar detection located on the Saint John Road and Decatur Hill Road approaches on steel sign supports.
Average Daily Traffic	8,600 vehicles per day on US 6 (both directions)
Posted Speed	45 mph on US 6 in both directions.
Power	Solar and battery
Operation	The system triggers the flashing/pulsing warning signs when motion is detected on the side streets exceeding 2 mph. The LEDs flash for a minimum of 60 seconds to accommodate the heaviest traffic flows and cross traffic wait time periods (worst case scenario) before timing out.

An activated warning signs on the US 6 approach and the pole mounted equipment placed on the minor street including the solar panel controller and radar unit is shown in **Figure 11**. As shown in the design plans, the final operations for the system differed than the originally proposed system. The ICWS was originally devised as providing major and minor road warnings. However, there were issues with getting the radar units to function as originally intended, which led to the removal of the minor road alert.

Figure 11: ICWS at US 6 and Saint John Road/Decatur Hill Road, Keystone

Activated Warning Sign on Westbound US 6 Approach

System Controller, Solar Panel and Radar Detection Unit on Minor Street Approach

US 50 AND CO 231, PUEBLO

CDOT Region 2 installed an ICWS at the intersection of US 50 and CO 231 in Pueblo, Colorado. The intersection was identified as part of an intersection improvement project and provides warnings to motorists on eastbound US 50 and northbound CO 231 of conflict with other vehicles at the intersection. The ICWS was proposed to assist with correcting deficiencies in sight distance and gap determination while increasing driver awareness of potential conflicts approaching the intersection.

The location is a T-intersection with CO 231 being the minor road approach. US 50 has a wide median separating the eastbound and westbound traffic. The ICWS was only installed for the intersection of eastbound US 50 and CO 231. In addition to the ICWS, other treatments were installed including:

- Installing a raised median between the eastbound through lane and the eastbound right turn deceleration lane.
- Moving the stop line of CO 231 towards the eastbound through lane so the eastbound right turn lane does not impact motorists view while trying to cross the intersection. This also reduced the crossing distance for northbound left turning vehicles.

Figure 12 shows the intersection and installed treatments. **Figure 13** shows the warning signs. The activated warning uses an LED sign border and rectangular rapid-flashing beacons.

Figure 12: US 50 Eastbound and CO 231 Intersection and Improvements.

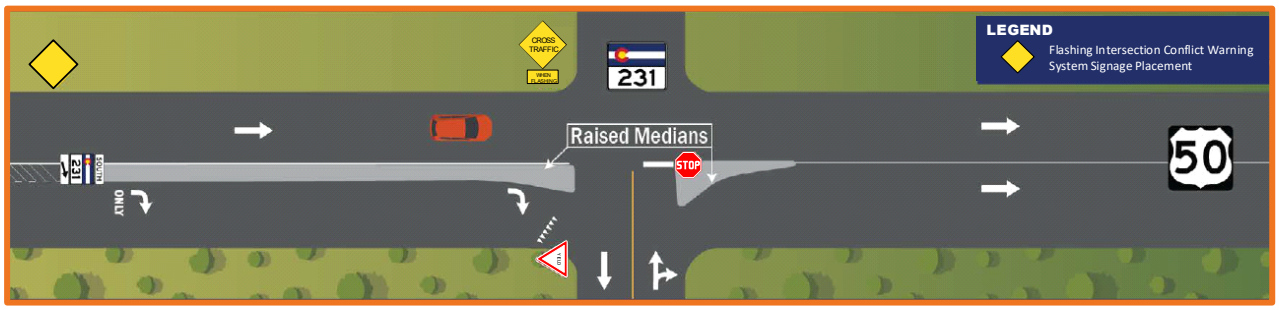


Figure 13: US 50 and CO 231 ICWS

Warning on Eastbound US 50 Approach

Northbound CO 231 Approach Warning Sign

Further details of the intersection and ICWS are provided in **Table 6**. The ICWS provides warnings to the southern half of the intersection between eastbound US 50 and CO 231 (**Figure 12**). CO 231 traffic make a two-stage left turn to join westbound US 50.

Table 6: US 50 Pueblo ICWS Details

ICWS Type	Major and Minor Road Warning (Divided Highway)
Warning Devices	TRAFFIC APPROACHING warning sign and WHEN FLASHING supplemental plaque with an LED sign border located on eastbound US 50 approach to intersection. CROSS TRAFFIC warning sign and WHEN FLASHING supplemental plaque with an LED sign border located on northbound CO 231 approach to intersection. The signs include rectangular rapid-flashing beacons. No ICWS warning signs are provided on the westbound US 50 approach to the intersection.
Detection	Radar detection installed on eastbound US 50 approach to the intersection. Radar detection also installed on the northbound CO 231 approach to detect vehicles approaching the intersection and at the stop line.
Average Daily Traffic	7,000 vehicles per day on US 50 in eastbound direction (provided with dynamic warning) 1,000 vehicles per day on CO 231 in northbound direction
Posted Speed	65 mph on both approaches on US 50 to the intersection. 35 mph on northbound CO 231 approach to intersection
Power	Solar and battery

CO 79 AND 88TH AVENUE, BENNETT

CDOT Region 1 implemented an ICWS at the intersection of CO 79 (Kiowa-Bennett Road) and 88th Avenue seven miles north of Bennett, Colorado. The details of the system are shown in **Table 7**. The system is operated by an Intelight traffic signal controller with cellular communication provided between the ICWS controller and Region 1 Traffic. The ICWS controller was placed on Region 1's TransSuite traffic signal system. TransSuite is primarily used to monitor the site and provide alarms for power, communications and other faults. A CCTV camera was also installed at the intersection and images can be communicated back to Region 1 Traffic. The minor approach on 88th Avenue does not have another stop sign for five miles east of the intersection and nine miles west of the intersection. Region 1 also installed LED borders on the stop signs on the 88th Avenue approaches. The stop sign borders continuously flash and are not part of the ICWS.

Figure 14 and **Figure 15** shows the system components and the project site.

Table 7: CO 79 Bennett ICWS Details

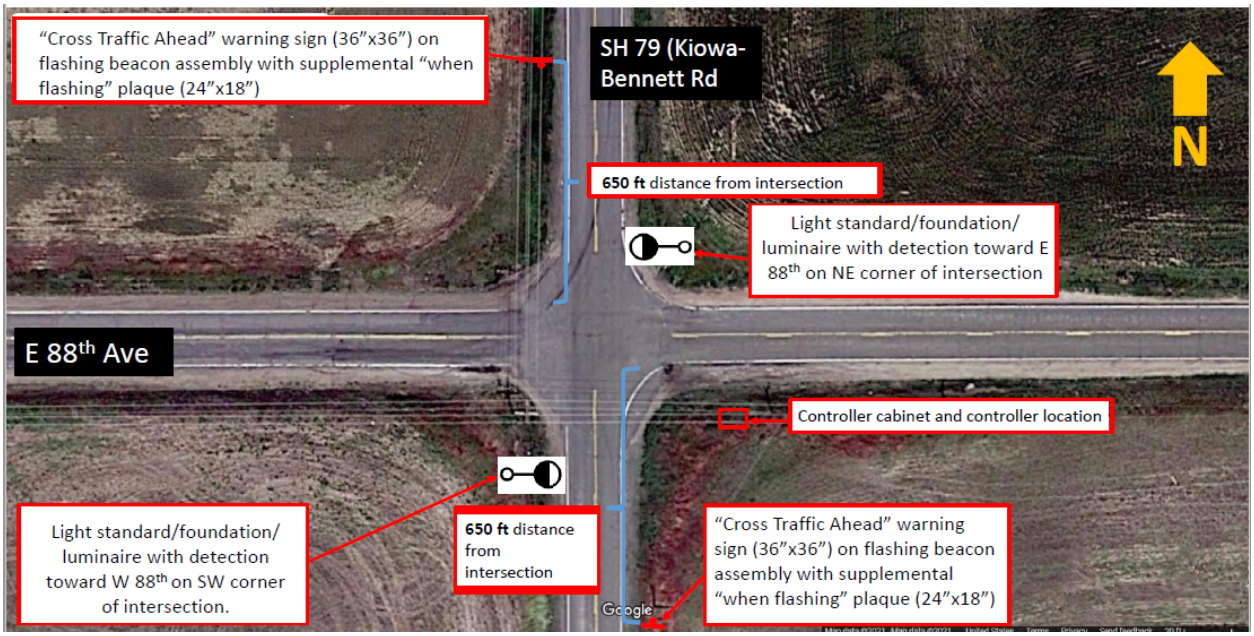
ICWS Type	Major Road Only Alert
Warning Devices	CROSS TRAFFIC AHEAD warning sign and WHEN FLASHING supplemental plaque with flashing beacon. Warning signs are located approximately 650 feet in advance of the intersection. See **Figure 14**.
Detection	Radar detection located on the 88th Avenue approaches. The original design was proposed to use a 360 degree video camera to provide detection on all approaches, detection flexibility, and pan-tilt-zoom (PTZ) camera capabilities. However, challenges with detection led to a change to radar detection and a dedicated PTZ camera.
Average Daily Traffic	4,100 vehicles per day on CO 79 (both directions)
Posted Speed	65 mph on both approaches on CO 79 to the intersection. 55 mph on both approaches on 88th Avenue

Figure 14: Photos of Bennett ICWS

Southbound Warning Sign and Flashing Beacon

Luminaire with PTZ Camera and Detection

Figure 15: SH 79 and 88th Avenue ICWS



CO 133 and Samuel Wade Road, Paonia

CDOT Region 3 implemented an ICWS at the intersection of CO 133 and Samuel Wade Road in Paonia, Colorado. This system provided drivers on minor approaches a warning of traffic approaching on CO 133. Details of the system are shown in **Table 8** and design plans for the ICWS are shown in **Appendix A**. As identified in the design plans, the ICWS was originally intended to have radar detectors on the minor road approaches to provide dynamic warnings on the major road.

Table 8: CO 133 Paonia ICWS Details

ICWS Type	Minor Road Only Alert
Warning Devices	TRAFFIC APPROACHING warning sign and WHEN FLASHING supplemental plaque with an LED sign border. The warning signs are located on the far-side of CO 133 opposite the stop sign on the minor road approach.
Detection	Radar detection is installed on the northbound and southbound CO 133 approaches to the intersection on the same post as intersection warning signs. The radar detection unit is placed approximately 370 feet in advance of the intersection in southbound direction and 450 feet in the northbound direction.
Average Daily Traffic	4,100 vehicles per day on CO 133 (both directions)
Posted Speed	45 mph on both approaches on CO 133 to the intersection.
Power	Solar and battery
Operation	When either the north or south radar detects traffic movement exceeding 10 mph, the LED sign borders are activated for the eastbound and westbound directions. The LEDs will continue to pulse and flash for 15 seconds after the last movement exceeding 15 seconds is detected.

EFFECTIVENESS OF ICWS

FHWA LOW-COST IMPROVEMENT POOLED STUDY

Studies have been conducted to determine the safety effectiveness of ICWS. Himes et. al. (2016) conducted a study to analyze the safety effectiveness of ICWS as part of the Federal Highway Administration (FHWA) Low-Cost Improvement Pooled Study. The study examined the safety impacts of ICWS at rural four-leg intersections in Minnesota, Missouri, and North Carolina and analyzed intersections with two lanes or four lanes on the major road approaches. The study also controlled for changes in traffic volume over time and time-based trends in crash data unrelated to ICWS.

The combined results of the study indicated crash reductions for all crash types analyzed including total, fatal and injury, right-angle, rear-end, and nighttime crashes. Crash modification factors (CMFs) developed by the study are shown in **Table 9,** with results found to be statistically significant (to a 95% confidence level) shown in bold. The study recommended applying the CMFs in bold for the crash types shown.

Table 9: Recommended ICWS CMFs Developed By Study

	Total	Fatal and Injury	Right Angle	Rear-End	Nighttime
Two-Lane at Two-Lane					
CMF	**0.73**	**0.70**	**0.80**	**0.43**	0.90
Standard Error	0.04	0.05	0.05	0.07	0.10
Four-Lane at Two-Lane					
CMF	**0.83**	**0.80**	**0.85**	0.97	**0.61**
Standard Error	0.06	0.07	0.08	0.22	0.11

Source: Himes et. al. (2016).

The study also estimated benefit-cost (B/C) ratios based on the results with cost and service life assumptions (for 2016) and identified a B/C ratio of 27:1 for all 2 x 2 lane intersections and 10:1 for 4 x 2 lane intersections.

The average installation cost for all two-lane at two-lane intersections was $41,590 (2016 values). The average installation cost was $106,150 for four-lane at two-lane intersections. In addition, an annual maintenance and operations cost of $1,075 was assumed for two-lane at two-lane intersections. A value of

$1,200 for maintenance and utility costs was assumed for four-lane at two-lane. A value of $3,400 was used for four-lane at two-lane sites with wireless communication. Note that these costs were from 2016 and current costs are expected to be substantially greater.

The analysis assumed that the useful service life for safety benefits for an ICWS was 10 years. The study noted that loop detectors might need to be replaced every 5 years, and this cost was considered in the annual maintenance cost.

Minnesota Study of Rural ICWS

A more recent study by the Minnesota Department of Transportation (MNDOT 2019) also examined the impact of ICWS on safety based on the analysis of 66 sites where ICWS had been installed starting in 2013. The analysis found that there was no statistically significant increase or decrease in crash rates due to the implementation of the ICWS systems with the before and after study identifying no significant changes and no differences in crash rates were identified between ICWS and control sites.

The authors reviewed maintenance logs to determine if maintenance was a factor at ICWS sites but were only able to identify one crash occurring when an ICWS was not functioning. They also examined crash narratives of fatal and serious injury crashes but were not able to find information indicating that an ICWS was malfunctioning when the crash occurred.

Based on the outcomes of the study, MNDOT did not see a need to remove existing ICWS due to the outcomes of the study, but planned to continue to monitor the performance of the ICWS in service. A second follow-up study (MNDOT 2021) was conducted but found little to no change from the results of the previous report. Based on these findings and the ongoing costs and maintenance of ICWS, MNDOT has been removing ICWS as they reach the end of their lifecycle and does not plan to install additional ICWS at this time (MNDOT 2023).

CDOT Considerations

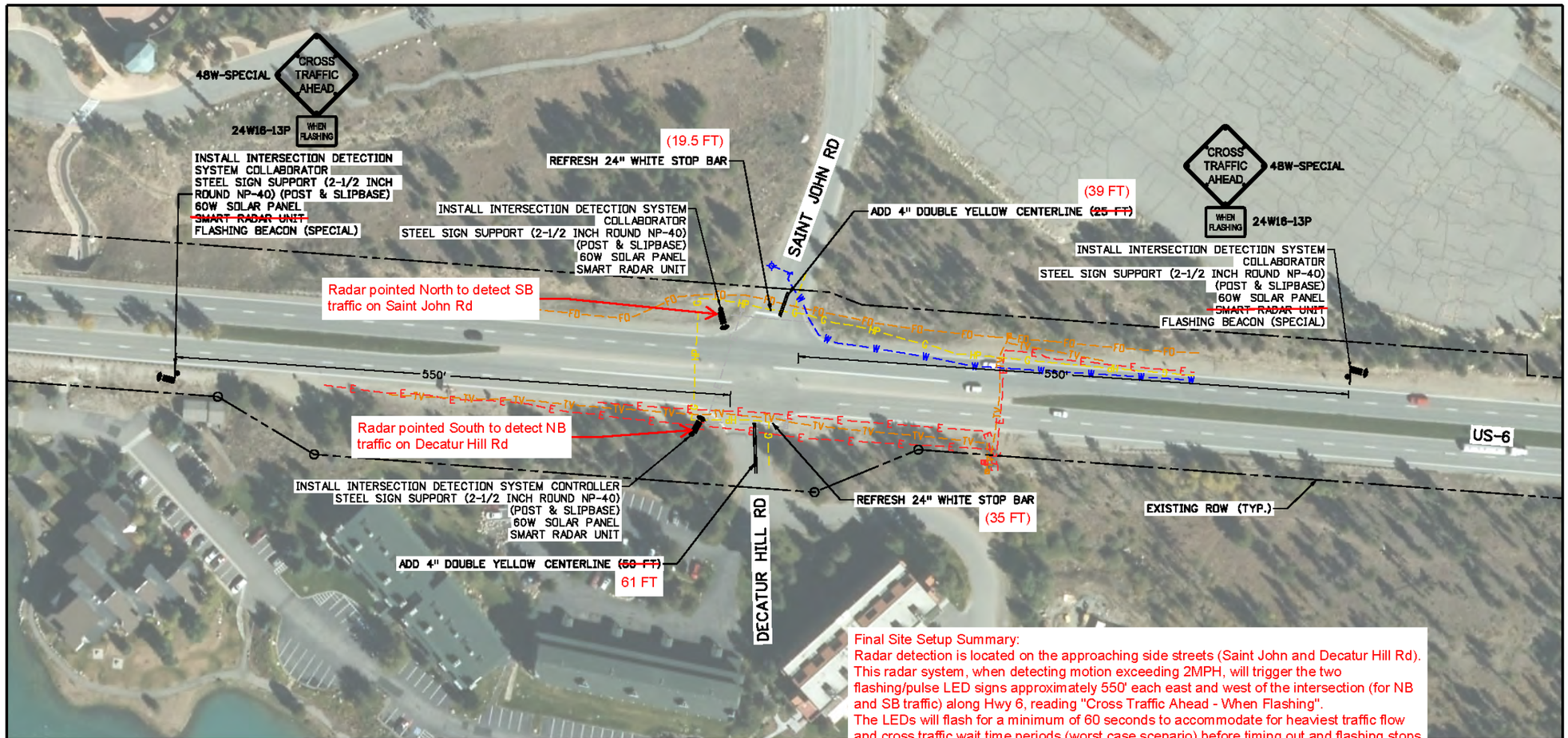
The evaluations of ICWS effectiveness in other states have found ICWS can be an effective treatment to reduce crashes at intersections. However, at some locations ICWS have been found to be less effective.

CDOT will continue to monitor the ICWS applications that have been implemented on Colorado highways. These guidelines have been prepared to assist practitioners in identifying intersection conditions where different types of ICWS may be considered to help improve safety at intersections and to compare against other types of intersection treatments.

APPENDIX A. ICWS EXAMPLE DESIGN PLANS

- US 6 and Saint John Road/Decatur Hill Road As Built Plans
- US 50 and CO 231 Award Set Plans
- CO 133 and Samuel Wade Road As Built Plans

US 6 and Saint John Road/Decatur Hill Road, Keystone As Built Plans



Final Site Setup Summary:
Radar detection is located on the approaching side streets (Saint John and Decatur Hill Rd). This radar system, when detecting motion exceeding 2MPH, will trigger the two flashing/pulse LED signs approximately 550' each east and west of the intersection (for NB and SB traffic) along Hwy 6, reading "Cross Traffic Ahead - When Flashing".
The LEDs will flash for a minimum of 60 seconds to accommodate for heaviest traffic flow and cross traffic wait time periods (worst case scenario) before timing out and flashing stops until triggered again.

Differences from plans:
Only two radar detectors are in use instead of the four shown in the plans (side streets only, not main line) due to TraffiCalm devices not able to function the way originally intended. Instead of the radar being pointed across the intersection at the opposing stop bar (as seen on plans), detectors have been turned towards the stop bars on the same side as installed - this eliminated frequent false detections cause by passing traffic of Hwy 6 (main line).

NOTES:
1. LOCATION OF ALL SIGNS SHALL BE CONFIRMED WITH ENGINEER PRIOR TO CONSTRUCTION. FIELD ADJUSTMENT MAY BE REQUIRED.

811 Know what's below. Call before you dig.

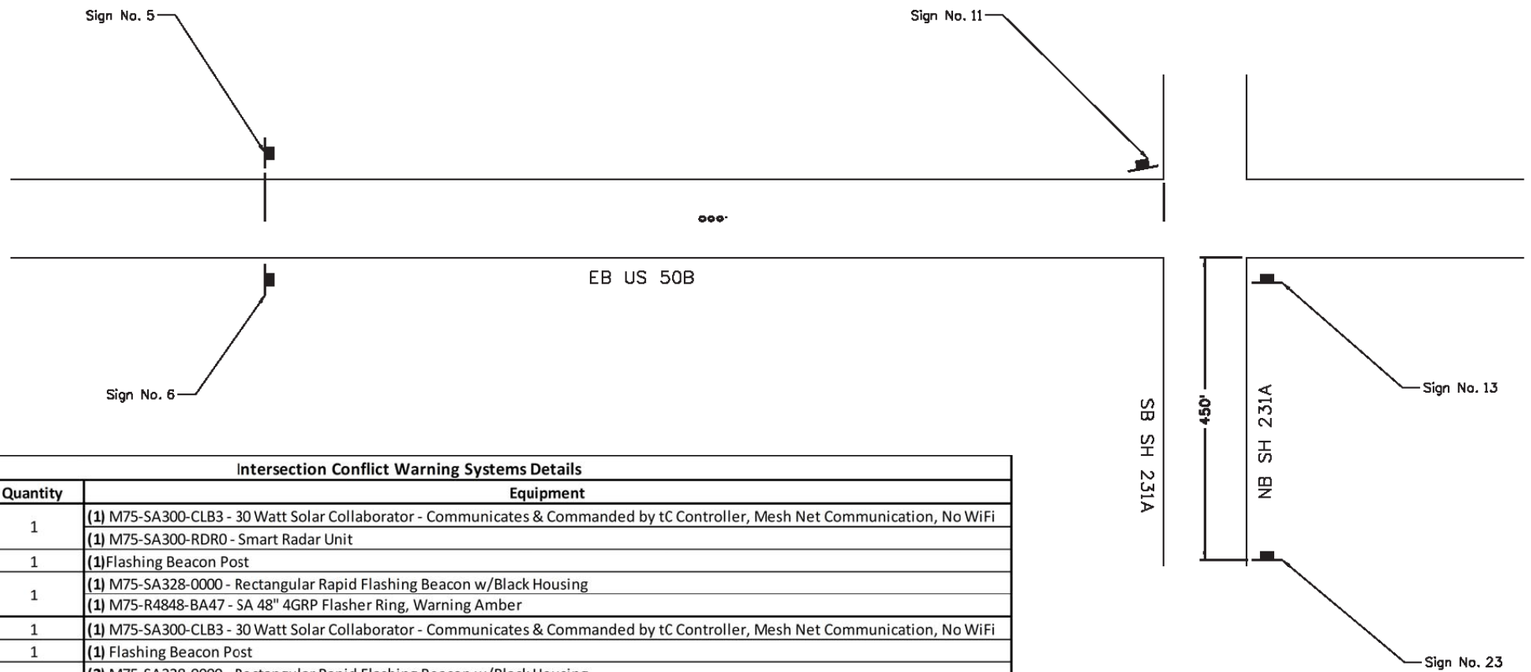
N

0' 50' 100' 200'

Print Date: 5/3/2021 File Name: 180332_RDWY_Plans - US-6 & Saint John.dgn Horiz. Scale: 1:100 Vert. Scale: apexdesign 1675 LARIMER ST, STE 400 DENVER, COLORADO 80202 PH: 303-339-0440 FAX: 303-325-7743	Sheet Revisions Date: / Comments / Init.	Colorado Department of Transportation 222 South 6th Street, Room 100 Grand Junction, CO, 81501 Phone: 970-683-6271 FAX: 970-683-7579 Region 03 MB	As Constructed No Revisions: Revised: JR 07/15/22 Void:	REGION 3 ICWS DESIGN KEYSTONE SITE US-6 & SAINT JOHN RD Designer: S. BINDER Detailer: E. HECKLER Subset: ICWS Structure Numbers Subset Sheets: 1 of 3	Project No./Code SHE-R300-261 23426 Sheet Number 9

Source: CDOT Region 3 2021, Region 3 ICWS Design Keystone Site US 6 & Saint John Rd, As-Built Plans, Construction Project Code No. 23426.

US 50 AND CO 231, PUEBLO AWARD SET PLANS



Intersection Conflict Warning Systems Details			
Sign No.	**Pay Item**	**Quantity**	**Equipment**
5	614-10110	1	**(1)** M75-SA300-CLB3 - 30 Watt Solar Collaborator - Communicates & Commanded by tC Controller, Mesh Net Communication, No WiFi
			(1) M75-SA300-RDR0 - Smart Radar Unit
	614-80000	1	**(1)**Flashing Beacon Post
	614-80004	1	**(1)** M75-SA328-0000 - Rectangular Rapid Flashing Beacon w/Black Housing
			(1) M75-R4848-BA47 - SA 48" 4GRP Flasher Ring, Warning Amber
6	614-10110	1	**(1)** M75-SA300-CLB3 - 30 Watt Solar Collaborator - Communicates & Commanded by tC Controller, Mesh Net Communication, No WiFi
	614-80000	1	**(1)** Flashing Beacon Post
	614-80004	1	**(2)** M75-SA328-0000 - Rectangular Rapid Flashing Beacon w/Black Housing
			(1) M75-R4848-BA47 - SA 48" 4GRP Flasher Ring, Warning Amber
11	614-10110	1	**(1)** M75-SA300-CLB3 - 30 Watt Solar Collaborator - Communicates & Commanded by tC Controller, Mesh Net Communication, No WiFi
	614-80000	1	**(1)** Flashing Beacon Post
	614-80004	1	**(2)** M75-SA328-0000 - Rectangular Rapid Flashing Beacon w/Black Housing
			(1) M75-R4848-BA47 - SA 48" 4GRP Flasher Ring, Warning Amber
13	614-72886	1	**(1)** M75-SA300-CLB3 - 30 Watt Solar Collaborator - Communicates & Commanded by tC Controller, Mesh Net Communication, No WiFi
			(1) M75-RADAR-HP00 - Presence Detection Radar
	614-80000	1	**(1)** Flashing Beacon Post
	614-80004	1	**(2)** M75-SA328-0000 - Rectangular Rapid Flashing Beacon w/Black Housing
			(1) M75-R4848-BA47 - SA 36" 4GRP Flasher Ring, Warning Amber
14	614-10110	1	**(1)** M75-SA300-CLB3 - 30 Watt Solar Collaborator - Communicates & Commanded by tC Controller, Mesh Net Communication, No WiFi
			(1) M75-SA300-RDR0 - Smart Radar Unit
	614-80000	1	**(1)** Flashing Beacon Post

***Sign Numbers correspond with the Tabulation of Signs**

All seals for this set of drawings are applied to the cover page(s)

Print Date: 5/31/2023
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Horiz. Scale: 1"=XX' Vert. Scale: As Noted
Unit Information MJ

Sheet Revisions		
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Colorado Department of Transportation
5615 Wills Blvd, Suite A
Pueblo, CO 81008
Phone: 719-546-5751
Fax: 718-546-5414
Region 2 MJ

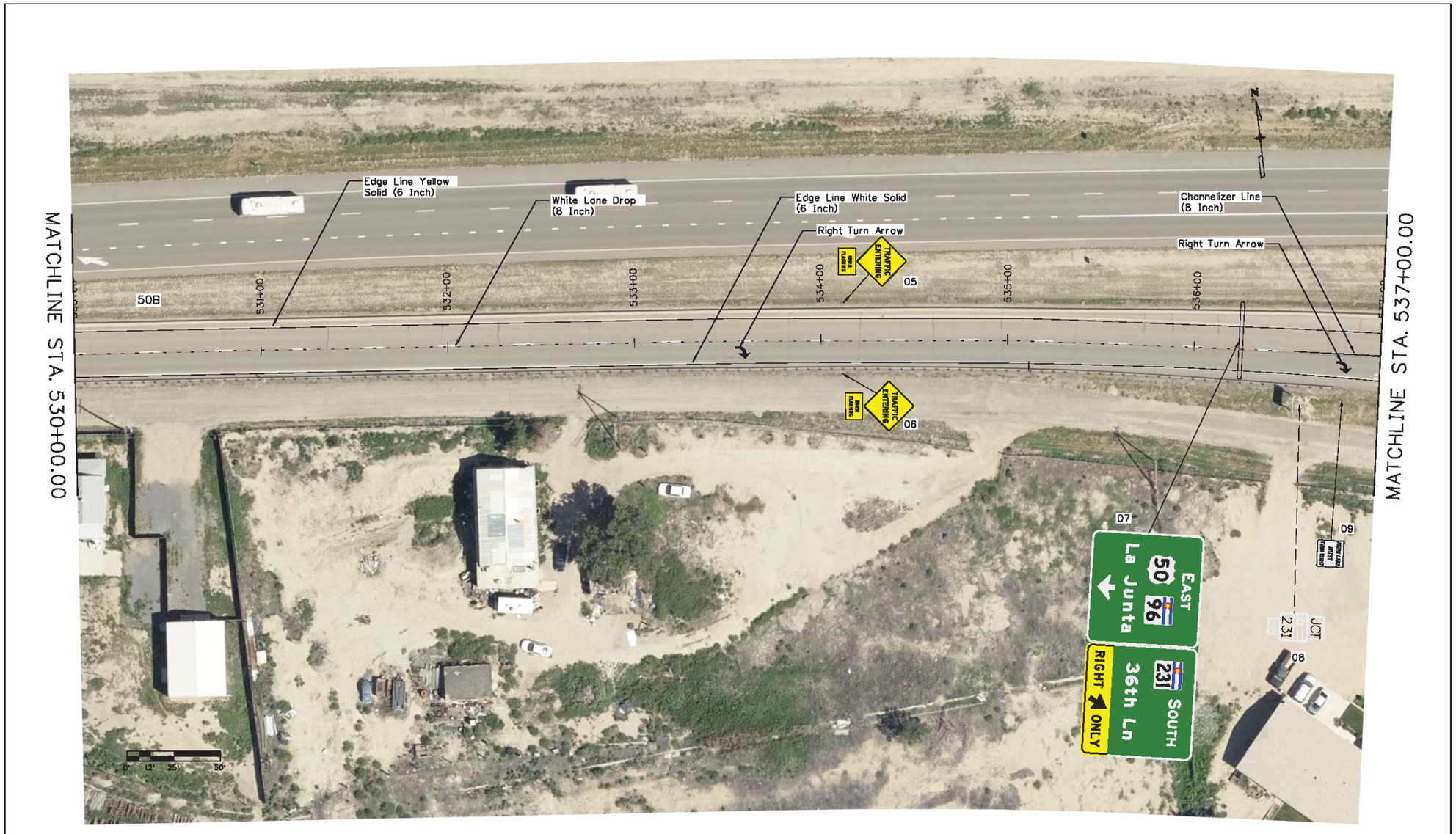
As Constructed
No Revisions:
Revised:
Void:

50B INTERSECTION CONFLICT WARNING SYSTEM

Designer: BTK
Detailer: BTK
Sheet Subset: ICWS
Structure Numbers: X-XX-XX
X-XX-XX
Subset Sheets: A001 of 001

Project No./Code
FSA C020-051
25317
Sheet Number 023

Source: CDOT Region 2 2023, 50B Intersection Conflict Warning System, Award Set Plans, Construction Project Code No. 25317.



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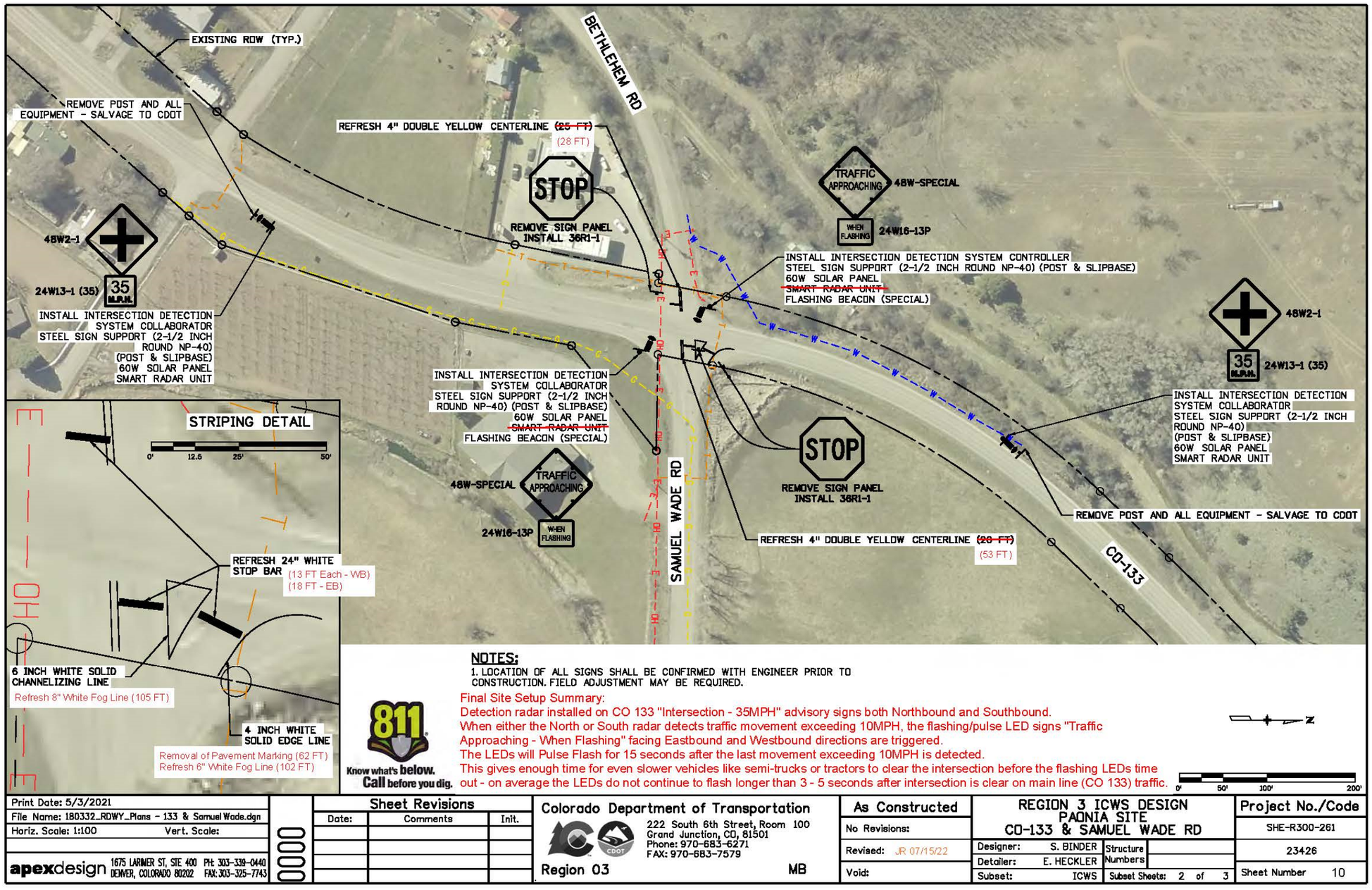
Source: CDOT Region 2 2023, US 50B / CO 231A Signing & Striping Plan, Award Set Plans, Construction Project Code No. 25317.

All seals for this set of drawings are applied to the cover page(s)	Print Date: 5/31/2023 File Name: 25317_DES_PVMT_MRKG_MODEL.dgn Horiz. Scale: 1"=50' Vert. Scale: As Noted Unit Information MJ	Sheet Revisions Date: Comments: Init.	Colorado Department of Transportation 5615 Wills Blvd, Suite A Pueblo, CO 81008 Phone: 719-546-5751 Fax: 718-546-5414 Region 2 MJ	As Constructed No Revisions: Revised: Void:	US 50B / CO 231A SIGNING & STRIPING PLAN Designer: BTK Detailer: BTK Sheet Subset: Striping Structure Numbers Subset Sheets: A005 of 006	Project No./Code FSA C020-051 25317 Sheet Number 029

Source: CDOT Region 2 2023, US 50B / CO 231A Signing & Striping Plan, Award Set Plans, Construction Project Code No. 25317.

CO 133 and Samuel Wade Road, Paonia As Built Plans



Source: CDOT Region 3 2021, *Region 3 ICWS Design Paonia Site CO 133 & Samuel Wade Rd*, Construction Project Code No. 23426.

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Department of Transportation