ENTERPRISE Transportation Pooled Fund Study TPF-5 (231)

ENTERPRISE

System Requirements for Intersection Conflict Warning Systems (ICWS)

FINAL REPORT

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16. Abstract In a previous ICWS ENTERPRISE effort, preliminary design guidance and an evaluation framework for intersection conflict warning system (ICWS) deployments were developed. The project engaged several national standards groups and industry associations including the National Committee on Uniform Traffic Control Devices, AASHTO Subcommittee on Traffic Engineering, and the Traffic Control Devices and Evaluation of Low Cost Safety Improvements pooled funds. This project further supported the standardization of ICWS by developing a model concept of operations and model system requirements for ICWS.		
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Project Champion

Jon Jackels, Minnesota Department of Transportation, was the ENTERPRISE project champion for this effort.

Together with members of the ENTERPRISE program (*), the following individuals provided the content for and review of this document. ENTERPRISE has also engaged several organizations in the preparation of this material, including the American Traffic Safety Services Association, AASHTO Subcommittee on Traffic Engineering, National Committee on Uniform Traffic Control Devices, Traffic Control Devices Transportation Pooled Fund TPF-5(065), and Evaluation of Low Cost Safety Improvements Transportation Pooled Fund TPF-5(099). ENTERPRISE appreciates the time, collaboration and professional input that these organizations and individuals have contributed to this effort.

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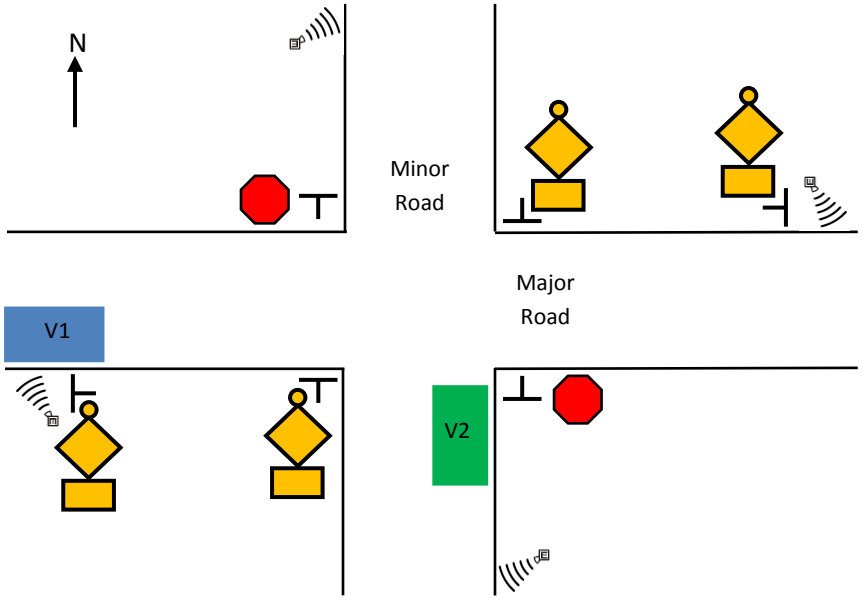
Introduction

Intersection conflict warning systems (ICWS) are typically installed to address crash factors associated with driver inattention and gap selection at stop-controlled intersections. ICWS offer a substantial warning to drivers as they provide real-time, dynamic information about intersection conditions to support driver decision. These systems address crashes at stop-controlled intersections by providing drivers – on major, minor or both roads – with a dynamic warning of other vehicles approaching the intersection. ICWS typically consist of static signing, detection and dynamic elements as illustrated in Figure 1.

Figure 1 Intersection Conflict Warning System Concept



As national groups like the National Committee on Uniform Traffic Control Devices further consider the need for and content of formal ICWS standards, the ENTERPRISE Transportation Pooled Fund TPF-5(231) has engaged transportation agencies, industry and standards groups to discuss and encourage greater consistency among ICWS deployments. ENTERPRISE has compiled information about existing deployments and, with stakeholder input, they have developed Design and Evaluation Guidance for Intersection Conflict Warning Systems. In further support of consistency, ENTERPISE has also developed a model concept of operations to articulate the fundamental needs and operational concept of ICWS. Building on those needs, the model system requirements within this document will describe what ICWS must do and set the basis for system design, procurement, installation and operation.

Both the system requirements and concept of operations are intended to illustrate the basic needs and requirements surrounding ICWS and serve as model documents that may be adapted to meet individual deployments. The materials do not mandate the deployment of such systems, nor do they limit the engineering judgment or policy discretion of the transportation agencies who may consider deploying ICWS. The materials reflect stakeholder needs and requirements based on current standards and known practice nationally and they should be adapted as necessary to reflect any unique or additional needs

and requirements driven by individual deployments. The remainder of **this document presents model system requirements for ICWS as they are driven by the previously developed concept of operations.**

System Requirements

System requirements are verifiable details that define what an intersection conflict warning system will do, how well it will perform or what conditions it must perform under. An important starting point for developing system requirements is to understand where the systems fit within the ITS architecture. This section explains how ICWS fit within the National ITS Architecture 7.0 and then presents a series of high-level and detailed system requirements associated with detection, alerts, placement, operations and maintenance.

ITS Architecture

ICWS are considered part of the Intersection Collision Avoidance User Service in the National ITS Architecture. Systems within this user service provide vehicle operators with assistance in avoiding collisions at intersections. The situations addressed include those that arise when vehicles improperly violate the right-of-way of another vehicle, or when the right-of-way is not clear. The service will provide warnings of imminent collisions with crossing traffic, as well as warnings of stop control – either a stop sign or a traffic signal – in the intersection ahead (USDOT, 2012).

Within the physical architecture of the National ITS Architecture, ICWS are primarily addressed under the Roadway Subsystem; Roadway Intersection Safety Warning Equipment Package and the Roadway Equipment Coordination Equipment Package; AVSS05-Intersection Safety Warning Service Package and the AVSS10-Intersection Collision Avoidance Service Package. Table 1 presents a series of high-level functional requirements as they are presented within the Roadway Intersection Safety Warning Equipment Package and the Roadway Equipment Coordination Equipment Package of the National ITS Architecture. The currently applicable requirements have been incorporated into this document.

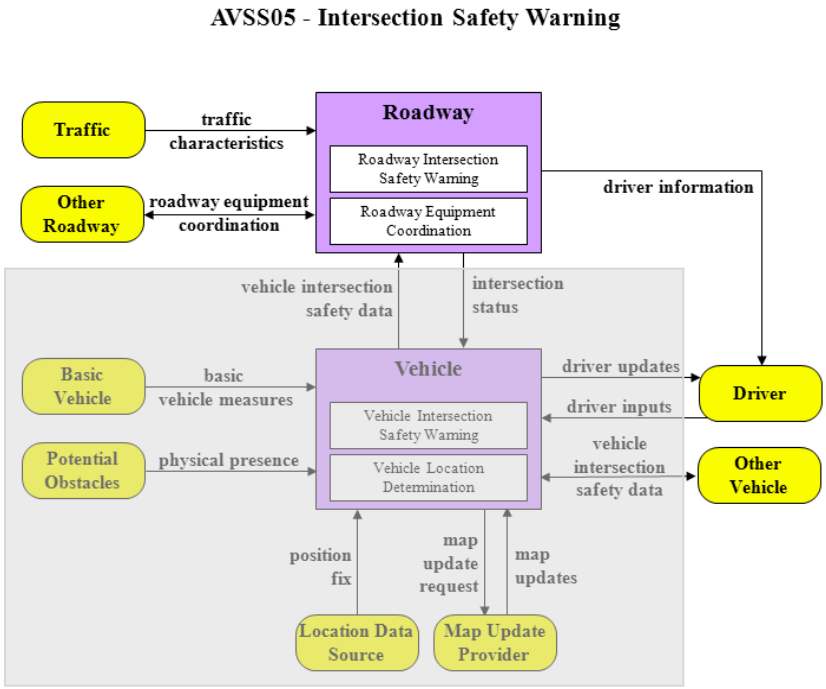
Table 1 ICWS Functional Requirements from National ITS Architecture

	Functional Requirements
Roadway Intersection Safety Warning Equipment Package	1. The field element shall utilize traffic sensors to monitor vehicles approaching and occupying an intersection.
	2. The field element shall monitor the operational state, signal timing, and current phase of the traffic signal (or ICWS).
	3. The field element shall monitor road conditions on approaches to, and within, the intersection.
	4. The field element shall communicate with approaching vehicles to determine vehicle position, velocity, acceleration, direction, and intended turning movement.
	5. The field element shall detect potentially hazardous conditions including impending red-light or stop sign violations and potential conflicts between approaching vehicles.
	6. The field element shall provide intersection status and warnings to approaching vehicles using field-vehicle communications.
	7. The field element shall update signs or signals to warn the driver of potentially hazardous situations.

Roadway Equipment Coordination Equipment Package	Functional Requirements
	1. The field element shall include sensors that provide data and status information to other field element devices, without center control.
	2. The field element shall include sensors that receive configuration data from other field element devices, without center control.
	3. The field element shall include devices that provide data and status information to other field element devices, without center control.
	4. The field element shall include devices that receive configuration data from other field element devices, without center control.

Further illustrating how ICWS fit within the National ITS Architecture, Figure 2 shows the potential system components and interconnects within the AVSS05-Intersection Safety Warning Service Package. Based on the deployments to-date, ICWS have not significantly addressed the Vehicle Subsystem characteristics shaded in Figure 2 or the vehicle-oriented functional requirements shaded in Table 1. However, as USDOT's Connected Vehicle Research evolves, ICWS requirements and designs will also need to evolve and directly address these issues. The requirements identified in this document are focused on the more prominent roadside infrastructure details in the Roadway Subsystem.

Figure 2 AVSS05-Intersection Safety Warning Service Package Graphic



The information presented in this section should be reviewed, confirmed or modified within the context of any state or regional ITS architecture that may impact individual ICWS deployments.

High-Level and Detailed System Requirements

ICWS are traffic control devices and as such it is important to note that these model requirements are based on the principles of traffic control devices outlined in the Manual on Uniform Traffic Control

Devices (MUTCD), Part 1. General, Section 1A.02. The manual states that, "To be effective, a traffic control device should meet five basic requirements: A. Fulfill a need; B. Command attention; C. Convey a clear, simple meaning; D. Command respect from road users; and E. Give adequate time for proper response." The model ICWS requirements presented in this document have been developed with careful consideration of design, placement, operation, maintenance and uniformity to maximize the ability of ICWS to meet these basic requirements as a traffic control device. Vehicle speeds have also been considered as a significant element affecting the operation of ICWS. For those requirements that are particularly dependent upon speed, recommended values have been based on the 85th percentile – the speed at or below which 85 percent of the vehicles travel. The requirements also assume that posted speeds are accurate based on current speed studies. Finally, these model requirements were developed with the intent to provide the reasonable and prudent road user with information necessary to efficiently and lawfully navigate intersections equipped with ICWS.

Many of the requirements are also described in relation to the detection and alert components of an ICWS. It is important to note that the requirements associated with the alert component are described to include both the dynamic alert (e.g. flashing beacon) and static sign elements. Although most ICWS deployments use these physical elements, still others use a fully dynamic message sign to convey both the sign message and an alert. As such, "alert" is used throughout the requirements to encompass both elements when they exist separately or as one component in an ICWS deployment.

These system requirements are defined in direct relation to the needs identified in the concept of operations. They address operational aspects of the system and are noted as such in Table 2. Each of the high level requirements below was originally translated from stakeholder needs identified in the model concept of operations. The number references allow for traceability back to those needs and forward to the detailed system requirements. The first identification number refers to the stakeholder needs as they were presented in the model concept of operations. The second number is used to track high level requirements and the third reference number relates to detailed system requirements, where applicable.

For many of the requirements, special considerations are noted to explain what details were considered as the requirement was developed or what additional details may need to be considered as the requirement is further refined for individual deployments. In some cases, the considerations may also note if a requirement is relevant to a specific type of ICWS deployment – on a median-separated roadway, for example. These considerations are intended to offer context for many of details noted in the requirements and to support further review and tailoring to individual deployments as needed. For any final requirements that result in an exception to current parameters in the MUTCD, requests to experiment may need to be considered.

Table 2 ICWS System Requirements

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
1	**Major road drivers** approaching an intersection equipped with ICWS **need an alert** to indicate when vehicles are approaching, at stop signs or at yield signs on the minor road.	1.1	ICWS **shall detect** all vehicles approaching and waiting at the stop or yield signs on the minor road.	1.1.1	ICWS **shall detect vehicles from both directions on the minor road** as they are a. approaching the intersection less than time *t*, and b. as they are waiting at the stop sign or yield sign on the minor road.
Considerations: Time *t* is a single constant for the intersection and is the largest time computed based on the major road vehicle lag time from 2.5 seconds in advance of the major road warning sign to the intersection at the posted speed limit. Distances are based on the typical condition for deceleration to the listed advisory speed for the warning of a potential stop situation as defined in MUTCD Table 2C-4. The distances are based on the 2005 AASHTO Policy, Exhibit 3-1, Stopping Sight Distance, providing a PRT (Perception-Response Time) of 2.5 seconds, a deceleration rate of 11.2 feet/second, minus the sign legibility distance of 180 feet. The distances shown in Table 2C-4 are provided as an aid for determining sign location and can be adjusted for roadway features, other signing or alert conditions and to improve visibility. Time *t* is applied to the minor road as a range for detecting vehicles that will activate the major road alert. An illustration of how time *t* may be applied is provided in Appendix A for ICWS 3 and ICWS 4. Yield sign location is included in this requirement to accommodate deployments on median-divided roadways.					
				1.1.2	ICWS **shall respond with at least XX% accuracy** when vehicles are on the minor road.
Considerations: This requirement encompasses all ICWS components and presumes they will all function to allow successful activation of the alert for approaching vehicles with an accuracy threshold defined by the transportation agency. When selecting the specific accuracy threshold, it is important to consider both safety and credibility factors. From a safety perspective, the ICWS should have a degree of accuracy that does not create a hazard. Similarly, the accuracy of the system should be such that drivers view the alert as credible. This value should be established using engineering judgment and consideration of how the value translates into vehicles that could be missed by the system. As a reference point, a minor road with an ADT of 2,000 and an ICWS accuracy of 99.95% results in one error per day for the major road alert. A 95% accuracy threshold could result in as many as 100 errors per day for the major road alert.					
		1.2	ICWS **shall display alerts** to major road drivers whenever a vehicle is approaching or waiting at a stop or	1.2.1	ICWS **alert shall be active on the major road whenever any vehicle** on the minor road is a. approaching less than time *t*

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
			yield sign on the minor road.		away from the stop sign, or b. waiting at the stop sign, or c. within the intersection, or d. waiting at the median yield sign.
Considerations: Intersection is defined as follows in the MUTCD, Part 1. General, Section 1A.13 Definitions of Headings, Words, and Phrases in this Manual: a) The area embraced within the prolongation or connection of the lateral curb lines, or if none, the lateral boundary lines of the roadways of two highways that join one another at, or approximately at, right angles or the area within which vehicles traveling on different highways that join at any other angle might come into conflict. b) The junction of an alley or driveway with a roadway or highway shall not constitute an intersection, unless the roadway or highway at said junction is controlled by a traffic control device. c) If a highway includes two roadways that are 30 feet or more apart (see definition of median), then every crossing of each roadway of such divided highway by an intersecting highway shall be a separate intersection. d) If both intersecting highways include two roadways that are 30 feet or more apart, then every crossing of any two roadways of such highways shall be a separate intersection. The yield sign location is included in this requirement to accommodate deployments on median-divided roadways. Also note that the emphasis on "any vehicle" within the stated parameters should cause the ICWS alert to be active.					
				1.2.2	ICWS **alert shall be inactive on the major road whenever there are no vehicles** on the minor road a. approaching less than time *t* away from the stop sign, or b. waiting at the stop sign, or c. within the intersection, or d. waiting at the median yield sign.
Considerations: Yield sign location is included in this requirement to accommodate deployments on median-divided roadways. Also note that the emphasis on "no vehicles" within the stated parameters should cause the ICWS alert to be inactive.					
				1.2.3	ICWS **alert activation and deactivation on the major road** shall be within **±0.5 seconds** of time *t*.

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
Considerations: This requirement describes the degree of accuracy that is tolerated for alert activation on the major road at the beginning of time *t* and deactivation at the end of time *t* as vehicles approach the stop sign on the minor road.					
		1.3	ICWS **may display an alert** for major road drivers **even if no major road vehicles are present**.		No further detail required.
No additional considerations provided.					
2	**Major road drivers** need ICWS **alerts to be visible at a distance** sufficient to allow drivers to take corrective action as needed.	2.1	ICWS **alerts shall be visible to major road drivers at a distance** that allows adequate Perception-Response Time.	2.1.1	ICWS **alerts shall be placed on the major road according to MUTCD** Part 2C. Warning Signs and Object Markers, Section 2C.05 Placement of Warning Signs, and using Table 2C-4. Guidelines for Advance Placement of Warning Signs.
Considerations: Existing MUTCD guidelines for the placement of warning signs are applicable to the placement of ICWS alerts on the major road. The distances shown in Table 2C-4 account for driver PRT and are provided as an aid for determining sign location. Distances can be adjusted for roadway features, other signing or alert conditions and to improve visibility.					
				2.1.2	ICWS **alerts shall be visible** from all approach lanes on the major road.
No additional considerations provided.					
3	**Minor road drivers** approaching, waiting at stop signs or waiting at yield signs of an intersection equipped with ICWS **need an alert** to indicate when vehicles are approaching the intersection on the major road.	3.1	ICWS **shall detect** all vehicles approaching the intersection on the major road.	3.1.1	ICWS **shall detect every vehicle on the major road, in all lanes**, as they are approaching the intersection within a user-configurable lag time.
Considerations: User-configurable lag time is defined as a parameter that allows engineering judgment of how best to establish detection and alert activation parameters based on traffic characteristics (e.g. gap selection, sight distance, speed) at a given intersection. An illustration of how the user-configurable lag time may be applied is provided in Appendix A for ICWS 1 and ICWS 2. The emphasis on “all lanes” in this requirement					

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
may be refined to specify a number of through lanes or turning lanes for multi-lane roadways.					
				3.1.2	ICWS **shall detect vehicles on the major road from both directions** as they are approaching the intersection within a user-configurable lag time.
No additional considerations provided.					
				3.1.3	ICWS **shall respond with at least XX% accuracy** when vehicles are on the major road.
Considerations: This requirement encompasses all ICWS components and presumes they will all function to allow successful activation of the alert for approaching vehicles with an accuracy threshold defined by the transportation agency. When selecting the specific accuracy threshold, it is important to consider both safety and credibility factors. From a safety perspective, the ICWS should have a degree of accuracy that does not create a hazard. This is potentially more important for the minor road alert as drivers may be relying on the ICWS in conjunction with stop sign. Similarly, the accuracy of the system should be such that drivers view the alert as credible. This value should be established using engineering judgment and consideration of how the value translates into vehicles that could be missed by the system. As a reference point, a major roadway with an ADT of 6,000 and an ICWS accuracy of 99.95% results in three errors per day for the minor road alert. A 95% accuracy threshold could result in as many as 300 errors per day for the minor road alert.					
		3.2	ICWS **shall display alerts** to minor road drivers whenever vehicles approach the intersection on the major road.	3.2.1	ICWS **alert shall be active on the minor road whenever any vehicle** on the major road a. is approaching less than a user-configurable lag time away from the intersection, or b. is within the intersection.
Considerations: Note that the emphasis on “any vehicle” within the stated parameters should cause the ICWS alert to be active.					
				3.2.2	ICWS **alert shall be inactive on the minor road whenever there are no vehicles** approaching less than a user-configurable lag time away from the intersection on

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
					the major road.
Considerations: Note that the emphasis on "no vehicles" within the stated parameters should cause the ICWS alert to be inactive.					
				3.2.3	ICWS **alert shall allow a user-configurable lag time** for vehicles approaching the intersection on the major road.
Considerations: The range for the user-configurable lag time may be established based on ICWS deployments in Minnesota. The Minnesota Department of Transportation (MnDOT) established a 4-9 second range by starting with a 6.5 second gap rejection threshold that was based on research cited in, "Alert and Warning Timing for CICAS-SSA – An Approach Using Macroscopic and Microscopic Data: Cooperative Intersection Collision Avoidance System-Stop Sign Assist Report #1." The research showed that 6.5 seconds represents the average weighted 80% gap rejection threshold in Minnesota and Wisconsin. MnDOT added a ±2.5 second buffer, considered a 55 MPH posted speed limit and allowed for vehicles traveling ±10 MPH within the limit. The detailed calculations are included in Appendix A for ICWS 1. The range for the user-configurable lag time may be adjusted as needed for individual deployments, but establishing a range is strongly encouraged to constrain design costs.					
				3.2.4	ICWS **alert shall allow for user configuration of lag time** on the major road without changes to hardware or software.
Considerations: Intersection traffic dynamics may change over time with volumes and speeds increasing or decreasing. This requirement allows ICWS alert parameters to be adjusted by the user without changes to hardware or software.					
				3.2.5	ICWS **shall meet requirements for user-configurable lag times whenever vehicle speeds are within ±10 MPH of the posted speed** on the major road; excluding vehicles that may be decelerating to execute a turn at the intersection.
Considerations: In the introduction to this section, it is noted that ICWS are intended to operate based on 85th percentile speeds, accurate posted speed limits, and reasonable and prudent road users. This requirement further defines a reasonable speed parameter within which the user-					

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
configurable lag time is used to activate the ICWS alert.					
				3.2.6	ICWS **alert activation and deactivation shall be within ±0.5 seconds** of the lag time that has been configured by the user.
Considerations: This requirement describes the degree of accuracy that is tolerated for alert activation on the minor road based on the user-configurable lag time (e.g. MnDOT range from 4-9 seconds) for vehicles approaching the intersection on the major road.					
		3.3	ICWS **may display an alert** for minor road drivers **even if no minor road vehicles are present**.		No further detail required.
No additional considerations provided.					
4	**Minor road drivers** need ICWS **alerts to be visible** while they are waiting at the stop sign or at the yield sign to support their decision to enter or cross the major road.	4.1	ICWS **shall display alerts at a location visible** to minor road drivers waiting at the stop sign or at the yield sign.	4.1.1	ICWS **alert shall be placed** on far right corner of intersection, across from the stop sign or yield sign, where intersection geometry permits. For those intersections with restricted geometry, a supplemental ICWS alert may also be placed on far left corner of intersection, across from the stop sign or yield sign.
Considerations: To the extent possible, ICWS alerts shall be placed on the minor road according to MUTCD Part 2C. Warning Signs and Object Markers, Section 2C.05 Placement of Warning Signs. However, specific placement needs for a dynamic alert of this nature is not directly addressed in the current MUTCD. As such, some agencies have used additional placements to maximize visibility and support driver decision, particularly for the minor road alert. For example, both Missouri and Iowa Departments of Transportation have placed their minor road alert on the left of the stop sign on the minor road, as illustrated in Appendix A under ICWS 2. If a placement is used beyond those described in the current MUTCD, a request to experiment may be necessary.					
5	**Drivers, transportation agencies and law enforcement** need **alerts to be dynamic and not become**	5.1	ICWS shall be placed at intersections where traffic volumes do not create a nearly continuous activation of the	5.1.1	No further detail available.

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	nearly continuous so as to lose impact.		alert.		
Considerations: A range of entering traffic volumes for effective operation of ICWS is not yet known. Understanding that a nearly continuous alert activation will diminish the dynamic nature of the alert, engineering judgment is needed to determine when volumes may be too high for effective deployments. For example, if ICWS is installed to address an off-peak crash problem that does not result in a nearly continuous alert, it may be acceptable for a nearly continuous alert during the peak period. Additional safety effectiveness studies are being conducted by the Evaluation of Low Cost Safety Improvements Transportation Pooled Fund TPF-5(099) and this will offer further insight on optimal volume conditions for ICWS deployment.					
6	**Drivers, transportation agencies and law enforcement** need ICWS **alerts to be easily understood**.	6.1	To the extent possible, ICWS **shall follow recommended design practices** described in "Design and Evaluation Guidance for Intersection Conflict Warning Systems" authored by the ENTERPRISE Transportation Pooled Fund program.	6.1.1	ICWS **should be designed using the placement, sign combinations and message sets described for ICWS 1-4** in "Design and Evaluation Guidance for Intersection Conflict Warning Systems."
Considerations: Ideal placement, sign combinations and message sets are not yet known for ICWS. The Traffic Control Devices Transportation Pooled Fund TPF-5(065) will be studying this issue based on the deployments captured in "Design and Evaluation Guidance for Intersection Conflict Warning Systems" as it has been developed by ENTERPRISE and endorsed by the AASHTO Subcommittee on Traffic Engineering (SCOTE). This requirement references the guidance document to, at a minimum, prevent future deployments from using additional new placements, sign combinations or message sets.					
7	**Drivers, transportation agencies, law enforcement and industry** need ICWS **alerts and signage to be uniform** throughout the United States, to the extent possible.	7.1	ICWS **shall have similar sign combinations and message sets** across jurisdictions.	7.1.1	ICWS **shall be designed in accordance with MUTCD** Part 2C. Warning Signs and Object Markers, Section 2C.03 Design of Warning Signs and Section 2C.04 Size of Warning Signs.
Considerations: As noted in the considerations for 6.1, the additional research being conducted by the Traffic Control Devices Transportation Pooled Fund TPF-5(065) will further clarify which sign combinations and message sets are most effective. The National Committee on Uniform Traffic Control Devices will then consider if the research results merit modifications to the MUTCD.					
8	**Drivers** who are distracted need	8.1	ICWS **alerts shall be conspicuous**.	8.1.1	ICWS **alert shall conform to MUTCD** Part

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
	ICWS **alerts to be of a nature that will capture their attention**.				2A. General, Section 2A.07 Retroreflectivity and Illumination for sign sheeting materials and LED brightness.
Considerations: This requirement applies to ICWS that may consist of a flashing beacon and static sign combination, as well as those ICWS that may of a dynamic message sign to convey alerts and sign messaging.					
9	**Transportation agencies and law enforcement** need ICWS **alerts to provide supplemental warning** that does not contradict or override the regulatory signs at the intersection.	9.1	ICWS **shall function as a warning sign as defined in MUTCD** Part 2C. Warning Signs and Object Markers, Section 2C.01 Function of Warning Signs and Section 2C.02 Application of Warning Signs.		No further detail required.
No additional considerations provided.					
10	**Drivers, transportation agencies and law enforcement** need ICWS to be **operational whenever vehicles approach the intersection**.	10.1	ICWS **shall operate continuously 24x7, 365 days per year**, with minimal service interruption.	10.1.1	ICWS **shall operate in a continuous mode under normal conditions with service interruption occurring** no more frequently than **once every six months on average**, excluding utility power service failure.
Considerations: The emphasis on "once every six months" is a suggested performance parameter based on deployment experience in Minnesota and it is intended to give manufacturers an indication of expected system robustness. This parameter should be adjusted as needed to match similar performance parameters within an agency. This is a performance oriented requirement.					
				10.1.2	ICWS **shall operate in a continuous mode under normal conditions with service interruptions lasting no longer than the time prescribed by agency maintenance procedures**, excluding utility power service failure.
Considerations: Each agency should establish maintenance priorities for ICWS that specify a maximum duration for service interruptions. It is					

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
suggested that an agency's allowable service interruptions for traffic signals be referenced as a baseline. According to the 2012 National Traffic Signal Report Card and the noteworthy findings on traffic signal maintenance, the results showed that 80 percent of agencies have policies and processes to provide a technician at an intersection where a critical (traffic signal) malfunction is reported within four hours during business hours and within eight hours outside of regular business hours. This is a performance oriented requirement.					
				10.1.3	ICWS **components shall conform to NEMA TS 2-2003** environmental requirements.
No additional considerations provided.					
				10.1.4	ICWS **alert shall conform to applicable NEMA TS 4-2005** standards for the hardware and functional characteristics of electronically controlled dynamic message signs.
Considerations: This requirement is only applicable if a dynamic message sign is used in place of static signing and other dynamic alert elements. Some elements of NEMA TS 4-2005 may not be applicable for ICWS. For example, some of the requirements associated with larger overhead dynamic message signs (e.g. walk-in access) will not be relevant to ICWS as a smaller roadside dynamic message sign.					
				10.1.5	ICWS **shall be connected to reliable electrical service.**
Considerations: This requirement specifies "reliable electrical service" because of the performance expectations in 10.1.1 and 10.1.2. This requirement may be modified to specify utility power service or to allow battery or solar power options but the parameters in 10.1.1 and 10.1.2 may then also need to be modified to reflect comparable performance expectations. The selection of utility power service or battery/solar power should be made based on site characteristics and performance expectations.					
				10.1.6	ICWS **system communication components shall comply** with Federal Communications Commission (FCC) emission requirements. The system shall be able to meet needed FCC approvals when design is complete.

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
Considerations: This requirement is only applicable if connections between ICWS components are wireless.					
				10.1.7	ICWS **shall meet the requirements of UL 508 "Standard for Industrial Control Equipment" and UL 48 "Standard for Electric Signs"** , January 28th 1999 Edition, and the **requirements of the current edition of the National Electrical Code** by being listed by a Nationally Recognized Testing Laboratory (NRTL) as safe for its intended purpose.
Considerations: There may be additional or other state-level design requirements for electrical components of ICWS.					
				10.1.8	ICWS **shall restart automatically upon restoration of power** following an event that causes loss of power to the system.
No additional considerations provided.					
		10.2	ICWS **shall not depend on communication with external systems to operate.**		No further detail required.
Considerations: If field to center communication is desirable for ICWS operation, this high level requirement should be modified and requirements added to reflect applicable National Transportation Communications for ITS Protocol (NTCIP) standards for such field to center communication.					
11	**Drivers, transportation agencies, law enforcement and industry** need an ICWS **malfunction to be readily and easily differentiated** from an ICWS that is inactive due to lack of conflicting traffic.	11.1	ICWS **shall display a visible indication of malfunction**.	11.1.1	ICWS **shall detect any system component malfunction** and initiate a failure mode.
No additional considerations provided.					

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
				11.1.2	ICWS **shall display indication of malfunction within one minute of system recognition**.
Considerations: This requirement may be more critical for minor road alerts illustrated in ICWS 1 and 2 where drivers could more closely associate ICWS alerts with their response to the regulatory STOP sign.					
				11.1.3	ICWS **shall display an indication of malfunction in a failsafe manner**.
Considerations: Depending on complexity of the ICWS design, the failsafe indication may be visibly different than any other indication from the system or it may indicate a false positive condition.					
				11.1.4	ICWS **indication of malfunction shall be maintained by the system** until the system is reset, excluding power failure.
Considerations: Assuming the malfunction is not caused by power failure and power is sustained to the ICWS, this requirement forces the system to maintain the indication of malfunction until it is addressed and the system is physically reset.					
				11.1.5	ICWS **indication of malfunction shall be maintained by system** through loss of power for up to the time prescribed by agency maintenance procedures.
Considerations: Depending on the alert used for individual deployments, this requirement could necessitate a battery backup to maintain the indication of malfunction for an agency specified duration. For example, if a flashing beacon is used as the alert, a malfunction could trigger continuous activation of the beacon. If power loss is the cause of the malfunction, a backup battery would be necessary to maintain the indication as required.					
12	**Drivers, transportation agencies and law enforcement** need ICWS **not to obstruct view** of intersection, other vehicles or regulatory signs.	12.1	ICWS **shall not obstruct any drivers' view** of the roadway, other vehicles or regulatory signs at the intersection.		No further detail required.
No additional considerations provided.					

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
13	**Drivers, transportation agencies, law enforcement and industry** need ICWS **components to be crashworthy** in the event they are impacted by errant vehicles.	13.1	ICWS **shall meet MUTCD Part 2A. General, Section 2A.21 Posts and Mountings standard and AASHTO Specification for Structural Supports for Highway Signs, Luminaires and Traffic Signals** for crashworthiness.		No further detail required.
No additional considerations provided.					
14	**Transportation agencies** need a **maintenance process** that can be followed to repair or replace ICWS components in context with priorities for repairing all other traffic control devices.	14.1	ICWS **shall consist of materials** as specified in Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, Section 718 Traffic Signing and Marking Material.		No further detail required.
Considerations: Additional information from state or local transportation agency construction specifications may need to be cited here.					
		14.2	ICWS **shall be installed** as specified in Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, Section 633 Permanent Traffic Control and Section 636 Signal, Lighting and Electrical Systems.		No further detail required.
Considerations: Additional information from state or local transportation agency construction specifications may need to be cited here.					
15	**Transportation agencies** need ICWS to **provide information regarding system performance**.	15.1	ICWS **shall collect and retain data about system performance** that indicates when and what components have failed or may be operating in less than optimal states.	15.1.1	ICWS **shall maintain an internal record of detection and power failures** and a corresponding time/date stamp for when the failure began and ended.
No additional considerations provided.					

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
				15.1.2	ICWS **shall maintain an internal record of individual system activations** with a time/date stamp during a 96 hour period.
Considerations: The 96-hour timeframe is suggested for this requirement to allow time for reviewing performance data over several days, particularly a holiday weekend, or for law enforcement to access data that may be applicable to a traffic incident. This timeframe should be considered within the context of each agency's needs and adjusted as necessary.					
				15.1.3	ICWS **shall maintain an internal record of individual vehicle detections** with a time/date stamp during a 96 hour period.
Considerations: The 96-hour timeframe is suggested for this requirement to allow time for reviewing performance data over several days, particularly a holiday weekend, or for law enforcement to access data that may be applicable to a traffic incident. This timeframe should be considered within the context of each agency's needs and adjusted as necessary.					
16	**Transportation agencies and industry** need installation, operational and maintenance **documentation for ICWS.**	16.1	ICWS **shall be manufactured** with installation, operational and maintenance documentation.		No further detail required.
No additional considerations provided.					
17	**Transportation agencies** need to be able to **maintain ICWS with minimal impact on traffic**.	17.1	ICWS components **shall be physically accessible for maintenance** with one transportation agency vehicle and a 1-2 person crew within the right of way.		No further detail required.
No additional considerations provided.					
18	**Transportation agencies and law enforcement** need to be able to **manually activate the malfunction mode** during maintenance or repair situations.	18.1	ICWS **shall allow manual activation of the malfunction mode** accessible by police panel key.		No further detail required.
No additional considerations provided.					

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
19	**Transportation agencies** need ICWS to be **cost effective**.	19.1	ICWS **shall be scalable and reconfigurable** to allow major road only, minor road only or major/minor road alerts.	19.1.1	ICWS **shall allow a minor road only system to be added to a major road system** and provide combined alert to both major and minor road drivers.
No additional considerations provided.					
				19.1.2	ICWS **shall allow a major road only system to be added to a minor road system** and provide combined alerts to both major and minor road drivers.
No additional considerations provided.					
				19.1.3	ICWS **shall allow the minor or major road alert to be removed from a combined major and minor road alert** and provide alerts to only the major or minor road drivers.
No additional considerations provided.					
20	**Transportation agencies** need to **understand ICWS safety impacts** on total crash reduction, target (right angle) crash reduction and reduction in crash severity.	20.1	ICWS **shall have documentation referencing its safety effectiveness** under specific deployment conditions.		No further detail required.
No additional considerations provided.					

Appendix A: ICWS 1-4, Layouts for Active/Inactive Alert States

ICWS 1: Minor Road Alert for 2-Lane/2-Lane (or Multi-Lane) Intersection

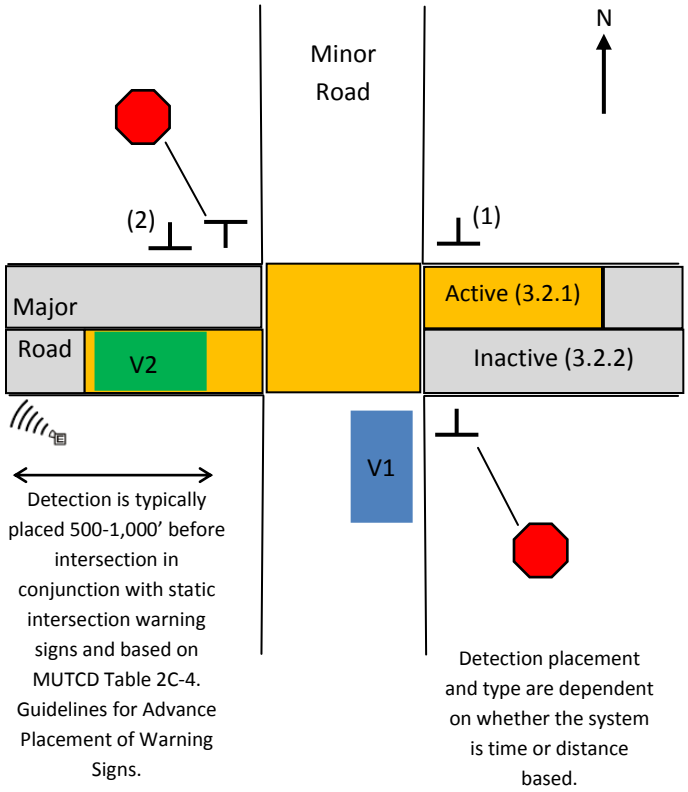


Illustration is not drawn to scale and is shown from the minor road, northbound vehicle (V1) perspective. Warning signs may be placed on the far-side corner (1) from STOP or far-side opposite corner (2) from STOP as a supplement to (1). Signing has also been suspended above the minor road in the intersection but the placement has since been found less effective through a safety effectiveness evaluation conducted by the North Carolina Department of Transportation.

Posted Speed Limit, -10 MPH	Posted Speed Limit	Posted Speed Limit, +10 MPH	Active Alert Timing and Distance (User-Configurable Lag Time)		
			4 Seconds	6.5 Seconds	9 Seconds
45 MPH			264'	429'	594'
	55 MPH		323'	524'	726'
		65 MPH	381'	620'	858'

This table illustrates sample calculations initially used by the Minnesota Department of Transportation (MnDOT) to define a user-configurable lag time range for the timing and distance necessary to activate an alert on the minor road. (3.2.3) The range for the user-configurable lag time is based on deployment experience in Minnesota. MnDOT established the range by starting with a 6.5 second gap rejection threshold. This threshold is based on research cited in, "Alert and Warning Timing for CICAS-SSA – An Approach Using Macroscopic and Microscopic Data: Cooperative Intersection Collision Avoidance System-Stop Sign Assist Report #1." The research showed that 6.5 seconds represents the average weighted 80% gap rejection threshold in Minnesota and Wisconsin. MnDOT added a ±2.5 second buffer to the gap rejection threshold, considered a 55 MPH posted speed limit, and allowed for vehicles traveling ±10 MPH within the limit. Calculation details are included in the table. The range for the user-configurable lag time may be adjusted as needed for individual deployments, but establishing a range is strongly encouraged to constrain design costs.

ICWS 2: Minor Road Alert for 2-Lane/Multi-Lane Median Separated Intersection

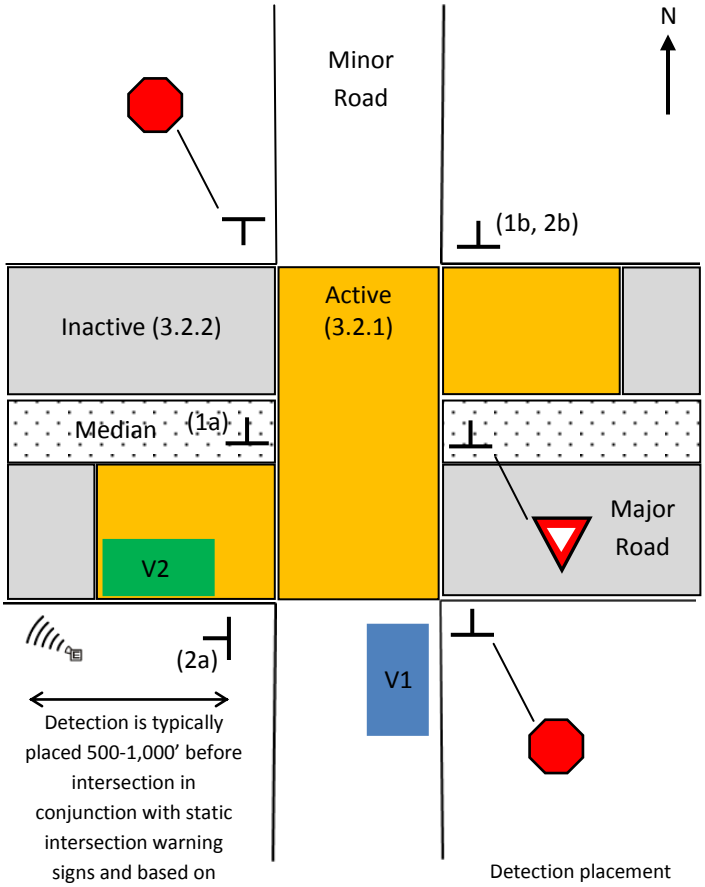
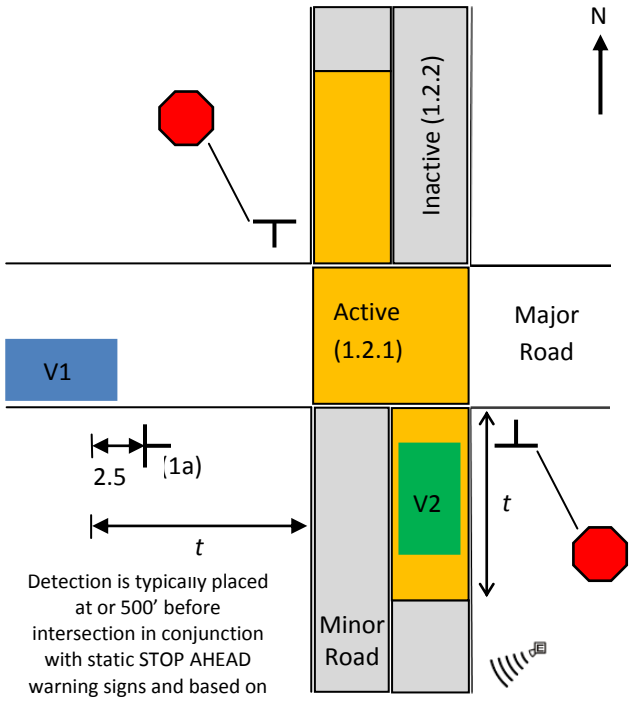


Illustration is not drawn to scale and is shown from the minor road, northbound vehicle (V1) perspective. There is a set of two warning signs for this layout. The first sign may be placed on the far-side opposite corner from STOP (1a) and the second sign may be placed on the far side corner from YIELD (1b). Signing has also been placed left from STOP (2a) and on the far side corner from YIELD (2b) but this placement may require a request to experiment. Other placements have involved signing suspended above the minor road at the intersection but this placement has since been found less effective through a safety effectiveness evaluation conducted by the North Carolina Department of Transportation.

Refer to ICWS 1 for details on the sample calculations for the active alert timing and distance (user-configurable lag time). (3.2.3)

ICWS 3: Major Road Alert for 2-Lane/2-Lane (or Multi-Lane) Intersection

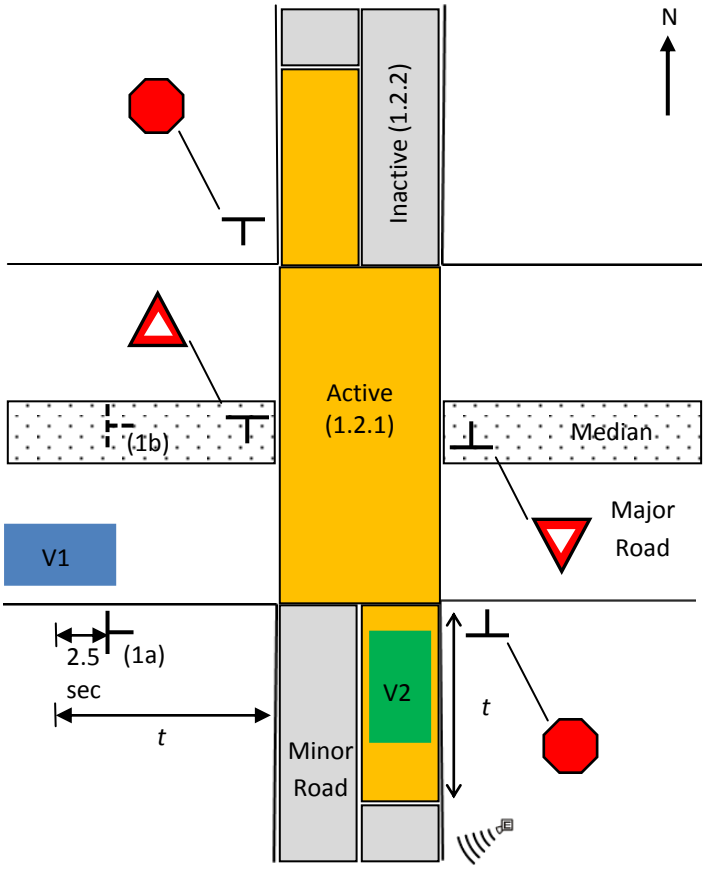


Detection is typically placed at or 500' before intersection in conjunction with static STOP AHEAD warning signs and based on MUTCD Table 2C-4. Guidelines for Advance Placement of Warning Signs

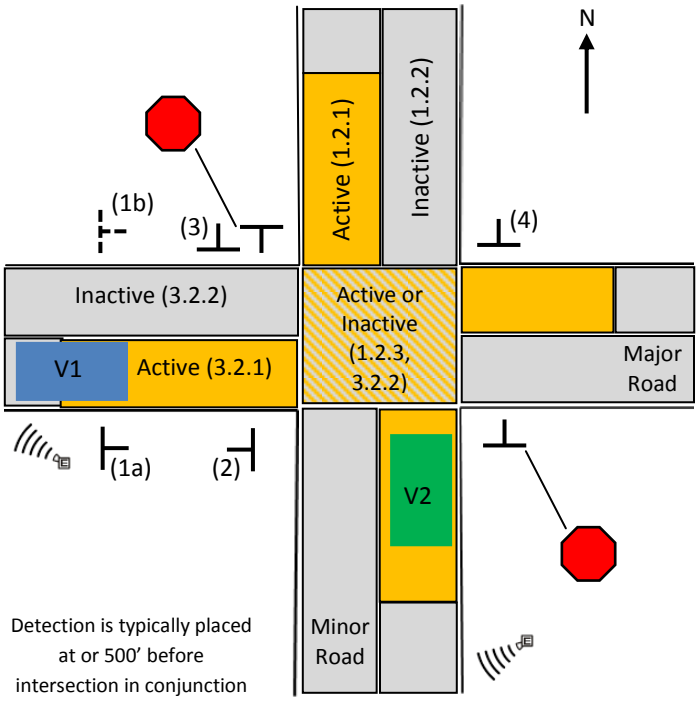
Detection placement and type are dependent on whether the system is time or distance based.

Illustrations are not drawn to scale and are shown from the major road, eastbound vehicle (V1) perspective. For a 2-lane major road, one sign may be placed on the right side (1a). For a multi-lane major road, an additional sign may be placed on the left side (1b) as shown in the multi-lane median separated illustration. Signing has also been suspended above the major road in the intersection but the placement has since been found ineffective through a safety effectiveness evaluation conducted by the North Carolina Department of Transportation.

Time *t* is a single constant for the intersection and is the largest time computed based on the major road vehicle lag time from 2.5 seconds in advance of the major road warning sign to the intersection at the posted speed limit. Distances are based on the typical condition for deceleration to the listed advisory speed for the warning of a potential stop situation as defined in MUTCD Table 2C-4. The distances are based on the 2005 AASHTO Policy, Exhibit 3-1, Stopping Sight Distance, providing a PRT (Perception-Response Time) of 2.5 seconds, a deceleration rate of 11.2 feet/second, minus the sign legibility distance of 180 feet. The distances shown in Table 2C-4 are provided as an aid for determining sign location and can be adjusted for roadway features, other signing or alert conditions and to improve visibility. Time *t* is applied to the minor road as a range for detecting vehicles that will activate the major road alert. (1.2.1)



ICWS 4: Major and Minor Road Alert for 2-Lane/2-Lane (or Multi-Lane) Intersection



Detection is typically placed at or 500' before intersection in conjunction with static STOP AHEAD warning signs and based on MUTCD Table 2C-4. Guidelines for Advance Placement of Warning Signs

Detection placement and type are dependent on whether the system is time or distance based.

Illustration is not drawn to scale and is shown from the major road, eastbound vehicle (V1) perspective. For a 2-lane *major* road, one sign may be placed on the right side (1a). For a multi-lane major road, an additional sign may be placed on the left side (1b). Warning signs for the *minor* road may be placed left from STOP (2), on the far-side opposite corner (3) from STOP, OR on the far-side corner (4) from STOP. Signing has also been suspended above the intersection but the placement has since been found less effective through a safety effectiveness evaluation conducted by the North Carolina Department of Transportation.

Refer to ICWS 1 and ICWS 3 for details on the calculations of the active alert timing and distance (user-configurable lag time and time *t*) associated with both the major and minor road alerts. (1.2.1) (3.2.3)