Intersection Safety Technologies Guidebook

Intersection Conflict Warning Systems & LED STOP Signs

May 2016

2016RIC10

Technical Report Documentation Page

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This Guidebook contains information that should be useful to engineers as they consider alternative solutions to traffic safety concerns at side-street STOP controlled intersections. It is the intent of this guide to provide the engineer information to aid in the consideration, selection and deployment of LED STOP signs and ICWS at these intersections. These safety strategies should be included for consideration along with other safety improvements detailed in the TEM and Traffic Safety Fundamentals Handbook such as improving visibility of the intersection with improved signing, pavement marking, and intersection lighting; improving sight distance by providing clear sight triangles on all approaches; selecting appropriate traffic control such as ALL WAY STOP; and reduce conflict points through geometric design such as turn lanes or bypass lanes.

A shorter, quick reference version of this guidebook was developed as well and can be found at the link listed above.</td></tr>
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Technical Advisory Panel

The following members comprise the project's Technical Advisory Panel (TAP) that contributed to this project:

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EXECUTIVE SUMMARY

Crashes at rural unsignalized intersections are a significant cause of fatal and injury crashes. Minnesota counties and the Minnesota Department of Transportation have implemented and evaluated several safety strategies including the technology-based methods detailed in this report. Safety improvements range from low-cost sight triangle improvements to high cost roadway geometric changes. In addition to these traditional methods, the use of Intersection Conflict Warning Systems (ICWS) and flashing LED STOP signs have proven effective in reducing severe crashes.

ICWS warn drivers of other traffic approaching the intersection. The goal is that increased awareness may improve split-second decision-making that occurs when a traffic conflict is recognized. Because the ICWS are deployed at targeted locations, drivers that see the active alert may drive more defensively. It is not expected that drivers will slow down significantly or drastically change their behavior, but this awareness can make a small change that can translate into a big impact in reducing the severity of crashes from fatal to injury or from injury to property damage only or to no crash at all.

> The Local Road Research Board has developed a companion "Intersection Safety Technologies, Quick Reference Guidebook for Intersection Conflict Warning Systems and LED STOP Signs."
>
> http://www.dot.state.mn.us/research/TS/2016/2016RIC10A.pdf.

Most of these crashes are caused by a failure to yield by a minor road vehicle that is entering the intersection. The driver on the minor road misjudges the gap, enters the intersection, and is struck by a major road driver. ICWS with warnings for the minor road may assist drivers with gap rejection to more safely navigate the intersection.

This report also explains the use and effect of flashing LED STOP signs. In general, these signs have a similar effect to STOP signs with beacons. These signs are effective in reducing how often drivers run the STOP sign. Crashes of this nature are less common than those due to misjudging gaps, but can be just as severe. LED STOP signs are visible to drivers from farther away and some drivers reduce their speed when approaching the intersection.

Like ICWS, LED STOP signs can be dynamically activated by cross traffic or based on speed profiles of the vehicle approaching the intersection. Both of these methods may increase the awareness because drivers become less acclimated to the flashers and see the alert only when it is most needed.

This guidebook explains several options for ICWS deployment and gives expected costs to plan, deploy, and maintain ICWS and LED stop signs. Deployment costs for ICWS range from $50,000 to $125,000 and deployment costs for LED STOP signs start at about $2,000 per sign and increase if additional detection and communication components are added.

Finally, this guidebook has a series of appendices that offer resources that may be useful for Minnesota local agencies that are considering implementing these systems. Of particular note, eight case studies are presented that explain successes and lessons learned from installing these systems. Example plans for three specific ICWS projects are also included as a reference for future design.

INTRODUCTION

PURPOSE

The purpose of this Guidebook is to supplement MnDOT's Traffic Engineering Manual (TEM) and Traffic Safety Fundamentals Handbook with recent improvements to address traffic safety at rural 2-way STOP controlled intersections. These recent improvements are LED STOP signs and Intersection Conflict Warning Systems (ICWS) and examples of these signs are shown in Figure 1. These safety strategies should be included for consideration along with traditional strategies such as improving visibility of the intersection with improved signing, pavement marking, and intersection lighting; improving sight distance by providing clear sight triangles on all approaches; selecting appropriate traffic control such as ALL WAY STOP; and reduce conflict points through geometric design such as turn lanes or bypass lanes.

> As with all safety improvements, it is important to understand the nature of the traffic safety problem before identifying and deploying any safety solution. It is important to analyze the safety objectives and establish appropriate strategies to reduce the frequency and severity of crashes.

SCOPE

This Guidebook contains information that should be useful to the Engineer as they consider alternative solutions to traffic safety concerns at STOP controlled intersections. It is the intent of this guide to provide the engineer information to aid in the consideration, selection and deployment of LED STOP signs and ICWS at these intersections. Other safety improvements are detailed in the TEM and Traffic Safety Fundamentals Handbook.

The systems shown as ICWS systems have varying designs including major road warning, minor road warning, and combined major and minor road warning. Example layouts of these systems are described later in this guidebook.

SAFETY NEED

Crashes at rural, STOP-controlled intersections generally arise when a driver fails to recognize an unsafe gap condition or when they fail to stop at the STOP sign. In both of these situations, the driver enters the intersections and is hit by a vehicle traveling at high speed. Unfortunately, because of the high speeds involved and right-angle crash type, these crashes often produce serious injuries or fatalities.

Figure 1. LED Stop Signs and ICWS Signs

LED STOP Signs

Use at sites with issues with failure to stop.

ICWS Signs

Use at sites with issues with failure to yield.

To address issues related to poor gap selection, the United States Department of Transportation Federal Highway Administration (US DOT FHWA), initiated programs designed to address crashes at stop-controlled intersections. The Minnesota Department of Transportation (MnDOT) and the University of Minnesota have been actively involved in research and deployment associated with these programs.

HISTORY OF SAFETY TECHNOLOGY IN MINNESOTA

Several ICWS and LED STOP sign projects have been conducted in Minnesota and have offered significant lessons learned. The timeline of these Minnesota projects is shown in Figure 3 and more detail about these projects is provided in Appendix B.

Figure 2 shows the distribution of ICWS throughout Minnesota. The system types are shown with different colors to highlight the geographic distribution. Figure 3 shows a timeline of the research, development, and deployment projects that have been conducted over the past almost 20 years and have culminated in the large ICWS deployments MnDOT and Minnesota counties have undertaken.

Figure 2. Map of Minnesota ICWS deployments

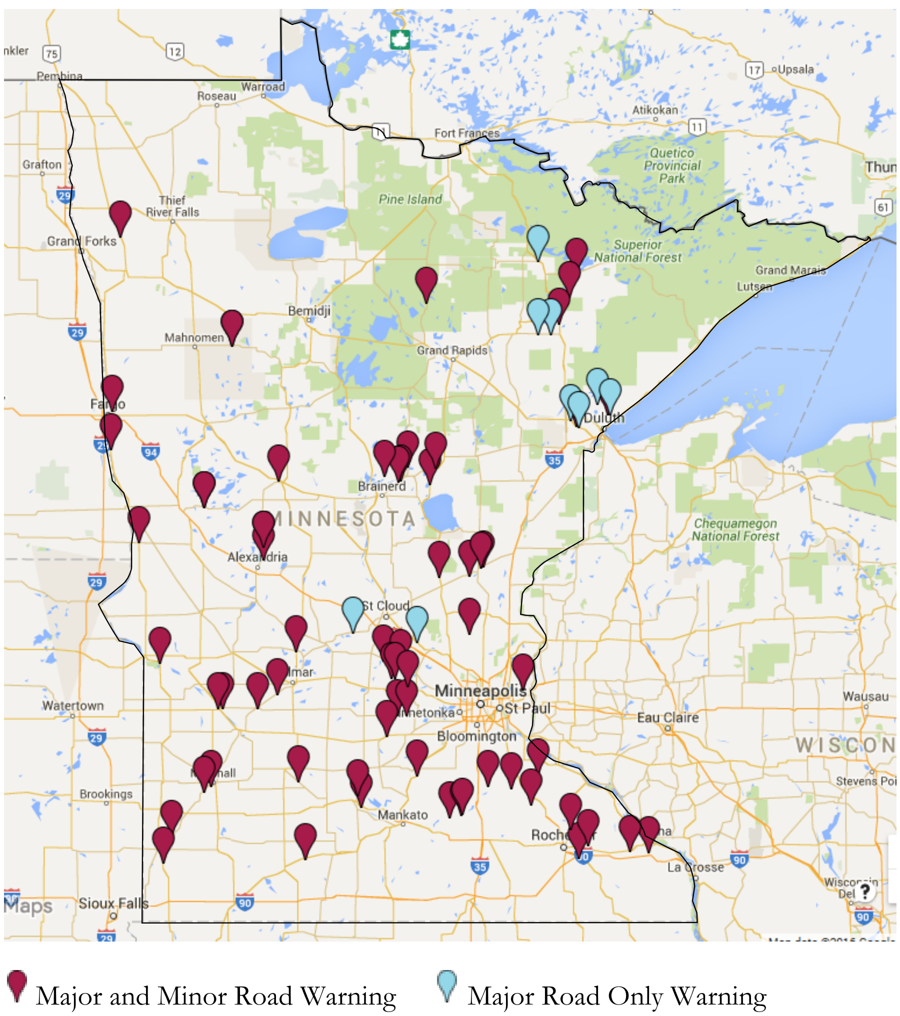
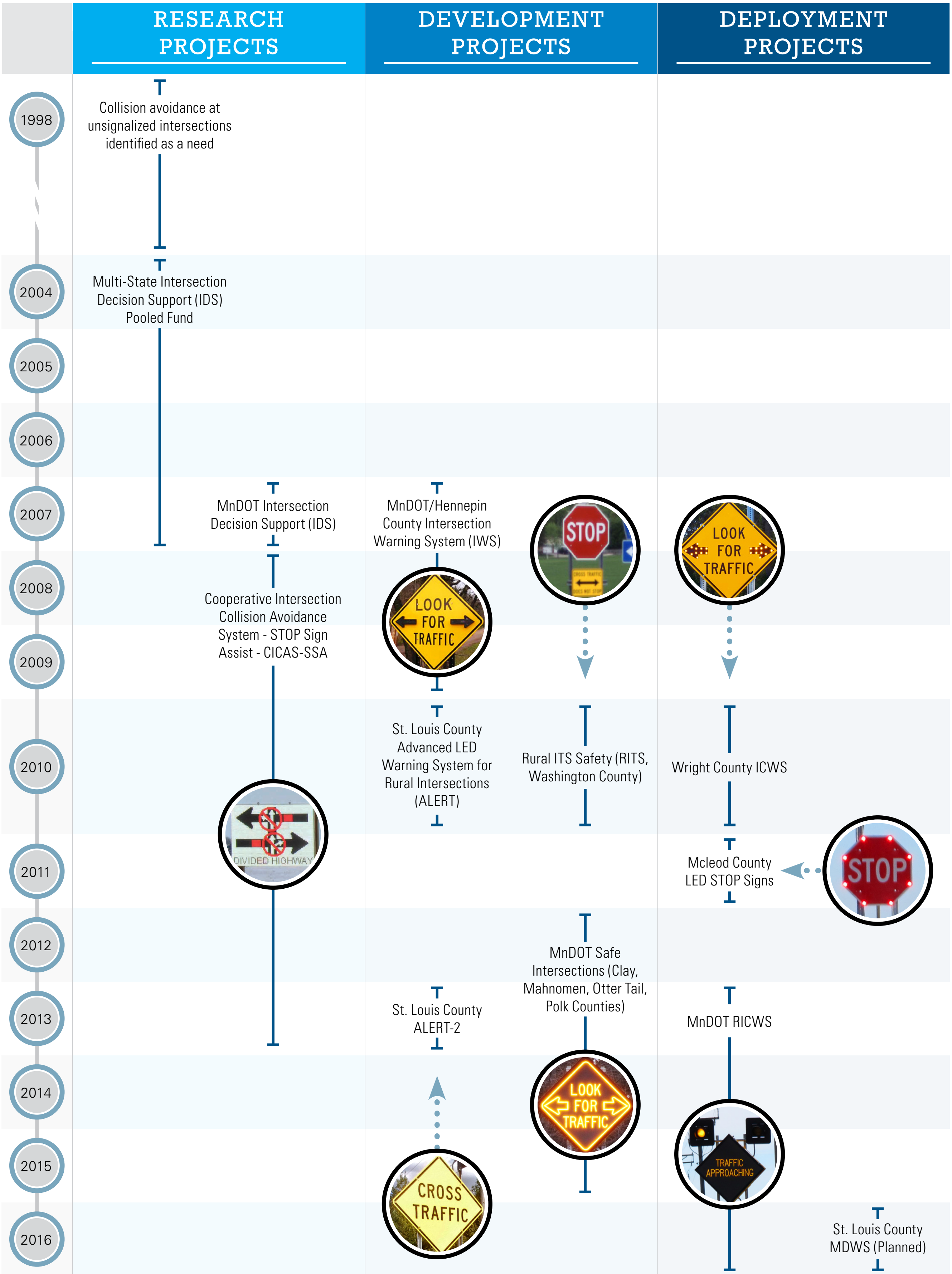


Figure 3. Minnesota History of Efforts to Improve Intersection Safety with LED STOP signs and ICWS



SELECTION OF SAFETY TECHNOLOGY

Intersection-related crashes account for more than 50 percent of all crashes and about one-third of fatal crashes in Minnesota. As a result, MnDOT's Traffic Safety Fundamental Handbook[1] contains many strategies to address crashes at intersections. Some of these strategies are highlighted in Figure 4 – Intersection Safety Strategies.

> It is important to understand the nature of the traffic safety problem before identifying and deploying any safety solution.

As with all safety improvements, it is important to understand the nature of the traffic safety problem before identifying and deploying any safety solution. It is important to analyze the safety objectives and establish appropriate strategies to reduce the frequency and severity of crashes.

As part of FHWA's Highway Safety Improvement Program[2], the Strategic Highway Safety Plan (SHSP)[3] "guides investment decisions towards strategies and countermeasure with the most potential to save lives and prevent injuries." MnDOT's Traffic Safety Fundamentals Handbook provides information about implementing such strategies and suggests safety mitigation strategies including ICWS and LED STOP signs.

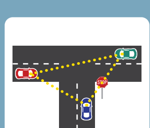
For example, ICWS strategies will not necessarily improve an intersection that has a problem with

Figure 4. Intersection Safety Strategies

The MnDOT Traffic Safety Handbook recommends Intersection Safety Strategies for unsignalized intersections

Improve visibility of intersections by providing enhanced signing. This may include installing larger regulatory, warning, and guide signing and supplementary stop signs.

Improve visibility of intersections by providing enhanced pavement markings, such as adding or widening stop bar on minor-road approaches, supplementary messages (i.e., STOP AHEAD).



Clear sight triangles approaches to intersections; in addition to eliminating objects in the roadside, this may also include eliminating parking that restricts sight distance.

Reduce the frequency and severity of intersection conflicts through geometric design improvements

Choose appropriate intersection traffic control to minimize crash frequency and severity (roundabout or all-way stop).

Improve visibility of intersections by providing lighting (install or enhance) or red flashing beacons mounted on stop signs.

Deploy mainline dynamic flashing beacons to warn drivers of entering traffic

[1] Minnesota Department of Transportation, "Traffic Safety Fundamentals Handbook." http://www.dot.state.mn.us/stateaid/trafficsafety/reference/2015-mndot-safety-handbook-large.pdf

[2] Highway Safety Improvement Program, http://safety.fhwa.dot.gov/hsip/

[3] Strategic Highway Safety Plan, http://safety.fhwa.dot.gov/hsip/shsp/

traffic running through the STOP sign. Conversely, sites with crashes that are due to driver decision error are not necessarily improved by adding flashing STOP signs. Other options include enhanced signing or visibility improvements.

Careful analysis is needed to select the right strategy from available options. A prime example is explained in the safety analysis performed for the intersection of TH 55 and CSAH 3[4]. This site was identified in Wright County's Road Safety Plan and an ICWS system was installed in 2014. However, the safety analysis completed in 2015 showed that the ICWS installed there did not adequately address the main safety problem. Therefore, geometric improvements including the addition of left turn lanes were recommended to mitigate the traffic safety problems.

In summary, consider the following options when addressing a traffic safety problem:

- Assess all safety improvement options.
- If the problem is drivers failing to see the STOP sign, LED STOP signs may be appropriate.
- If the problem is drivers are stopping but then failing to yield to cross traffic, ICWS may be appropriate.

Figure 5. Comments that indicate consideration of safety technologies.

LED STOP signs provide increased visibility and awareness of the upcoming stop condition.

Comments that indicate consideration of LED STOP signs:

- "The driver just blew the STOP sign."
- "I just didn't see the STOP sign."
- "People are always running that STOP sign."

Intersection Conflict Warning System (ICWS) have dynamic flashing signs and detection that provide active warning about traffic on the major road, minor road, or both roads at the intersection.

Comments that indicate consideration of ICWS:

- "He was stopped and just pulled out right in front of me like I wasn't even there."
- "I didn't see the car coming toward me and I pulled out."
- "I didn't think the truck was that close."
- "I thought I could make it across before they got to the intersection."

[4] CH2M HILL. "MnDOT RICWS Safety."
http://www.dot.state.mn.us/its/projects/2011-2015/rural-intersect-conflict-warn-system/documents/d3ricwssafety.pdf

SAFETY TECHNOLOGIES

This section provides definitions, usage information, system configuration, and research findings for LED STOP signs and ICWS.

LED STOP SIGNS

LED STOP signs serve the same function as static STOP signs, but improve the visibility of the signs by incorporating edge lit LEDs that flash and attract driver attention to the stop condition. Another option is to install a flashing beacon that is mounted directly over the STOP sign. Additionally, the STOP Sign may flash continuously or the flash can be dynamically triggered by cross traffic or by high vehicle speeds as the vehicle approaches the STOP sign.

Flashing LED STOP Sign Use Guidance

The MnDOT Traffic Engineering Manual[5] gives guidance for the use of Flashing LED STOP signs that emphasizes which applications flashing STOP signs provide benefits:

> 6-5.07 Flashing LED STOP and YIELD Signs
>
> Flashing LED STOP and YIELD signs should only be considered for installation in situations necessitating enhanced visibility of the sign as determined by engineering study. These signs should be limited to locations with at least two of the following:

- Limited visibility on approach to the intersection, as determined by the sight distance criteria for [Warrant 1 in Section 9-4.02.02](#) of this manual.
- A history of crashes documented to be caused by a failure to stop and deemed preventable by implementation of conspicuity improvements.
- At a rural junction of two or more high speed trunk highways to warn drivers of an unexpected crossing of another highway.
- At a rural junction of a trunk highway and a local road which has no STOP controlled intersection within five miles.

An LED STOP sign is shown in Figure 6. It is common for these signs to be reliably solar powered because the LEDs require little power compared to other flashing beacon systems.

Figure 6. Edge-Lit LED STOP Sign and STOP Sign with Red Beacon

LED STOP Sign Research

Safety findings related to LED STOP signs have been limited and the key findings are generally models and statistical analysis rather than analysis of field data. However, some surrogate safety measures, such as modifications to vehicle speed are presented below.

[5] Minnesota Department of Transportation, "Traffic Engineering Manual." Chapter 6. http://www.dot.state.mn.us/trafficeng/publ/tem/2015/chapter6.pdf

Davis et al.[6] found that LED flashers on stop signs generally indicated a trend toward a reduction in right angle crashes, but could not quantify it with statistical certainty. However, they found about twice as many drivers exhibited clear stops when other traffic was present compared to sites without the LED flashers.[7] It was found that LED STOP Signs reduce crash frequency and severity by 10 to 13 percent.[8]

Fitzpatrick et al. conducted various human factors trials on edge-lit signs (LED STOP signs) and signs with flashing beacons and found that 36-inch STOP Signs with beacons had similar legibility distance to edge-lit signs. They also found that bright LED signs were easier to detect than dim ones during the daytime, but bright LEDs caused glare at night and the dimmer ones were easier to detect. This reinforces the importance of photocell control for the LEDs. Additionally, edge-lit signs took longer for participants to understand.[9]

Arnold and Lantz found that LED STOP signs statistically significantly reduced approaching vehicle speeds by 1 to 3 mph with the greater speed reduction experienced at night.[10]

INTERSECTION CONFLICT WARNING SYSTEMS

Intersection Conflict Warning Systems (ICWS) are an ITS technology strategy that addresses crashes at side-street stop-controlled intersections. ICWS are relatively new--the first Minnesota system was installed in 2007. However, several recent studies have shown that ICWS can have a positive impact on reducing crash frequency and severity.

Types of ICWS

ICWS generally consist of active (dynamically flashing) signs and vehicle detection installed at or near an intersection to provide real-time information about intersection conditions. ICWS are typically installed to address crashes associated with driver inattention, restricted sight distance, and gap selection at side-street stop-controlled intersections.

There are three major configurations of ICWS defined by which approach receives the dynamic warning of approaching or entering vehicles:

- Minor Road Only Warning. Vehicles on the major road are detected and activate signs that are visible to drivers on the minor road.
- Major Road Only Warning—also called Mainline Dynamic Warning Systems (MDWS). Vehicles on the minor road are detected and signs on the major road flash.
- Major and Minor Road Warning. Both major road and minor road vehicles are detected and the cross traffic is warned.

Diagrams of the detection and warning systems are shown in Figures 7-9.

[6] Davis, Gary A. Estimating the crash reduction and vehicle dynamics effects of flashing LED stop signs / prepared by Gary A. Davis, John Hourdos, Hui Xiong. http://www.lrrb.org/media/reports/201402.pdf

[7] Davis, G. et al. "Estimating the Crash Reduction and Vehicle Dynamics Effects of Flashing LED Stop Signs." 2014.

[8] Srinivasan, R. et al., Safety Evaluation of Flashing Beacons at STOP-Controlled Intersections, http://www.fhwa.dot.gov/publications/research/safety/08044/index.cfm

[9] Fitzpatrick, K. et al. "Modern Traffic Control Devices to Improve Safety at Rural Intersections." http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6462-1.pdf

[10] Arnold E D; Lantz K E. "Evaluation of Best Practices in Traffic Operations and Safety: Phase I: Flashing LED Stop Sign and Optical Speed Bars." 2007/6. 41p(3 Apps., 6 Phots., 11 Refs., 7 Tabs.) http://www.virginiadot.org/vtrc/main/online_reports/pdf/07-r34.pdf

Figure 7. Minor Road Only Warning ICWS

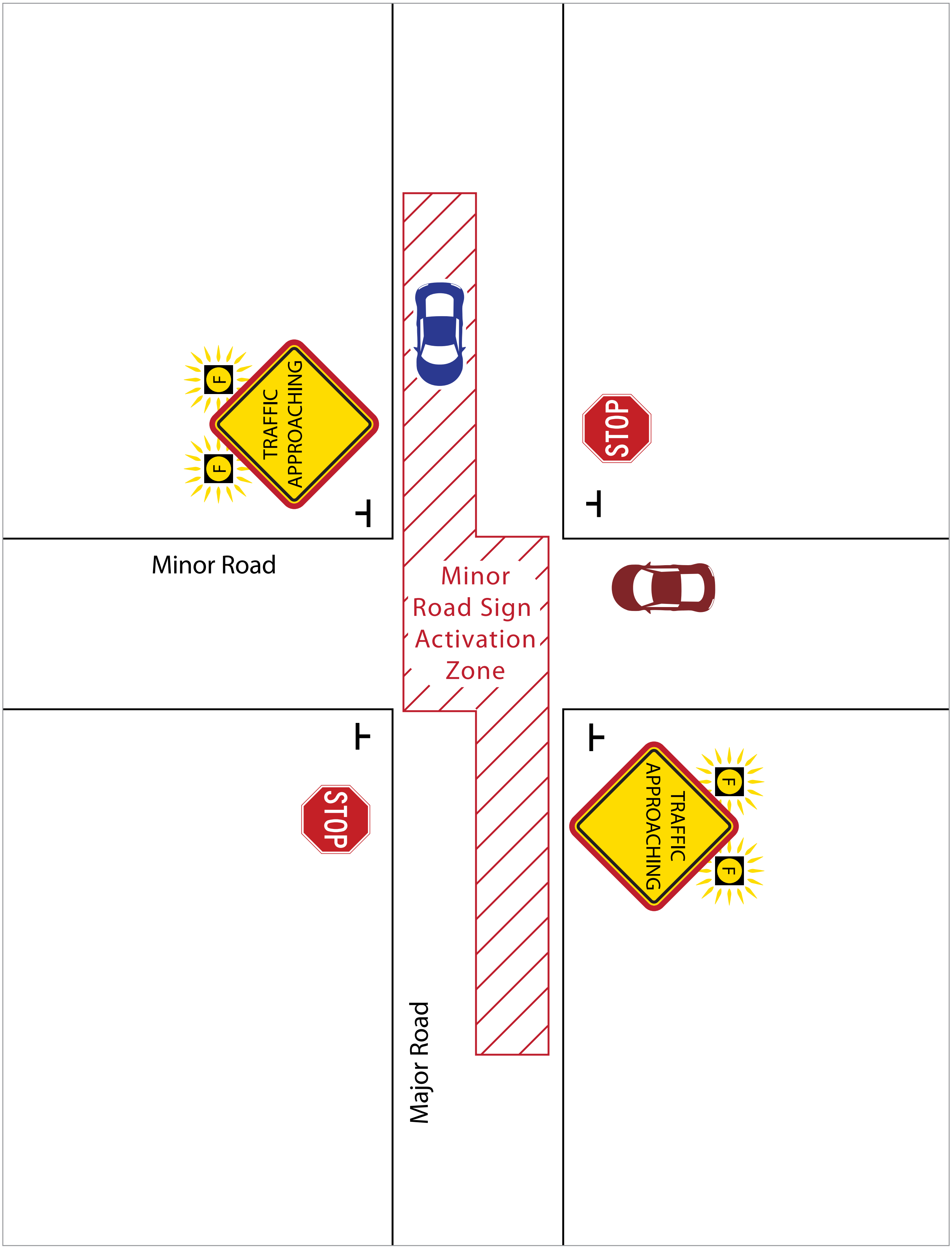


Figure 8. Major Road Only Warning ICWS

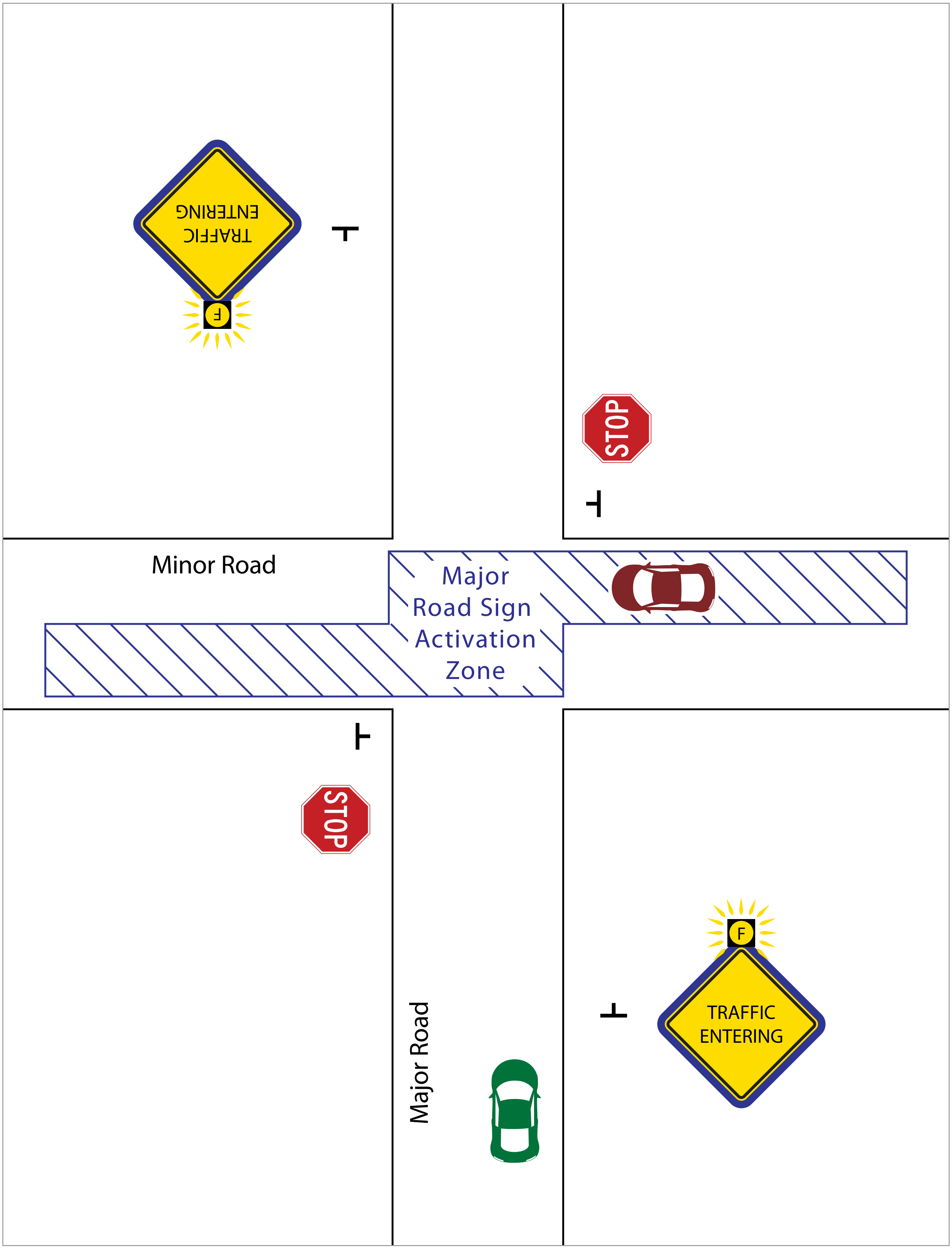
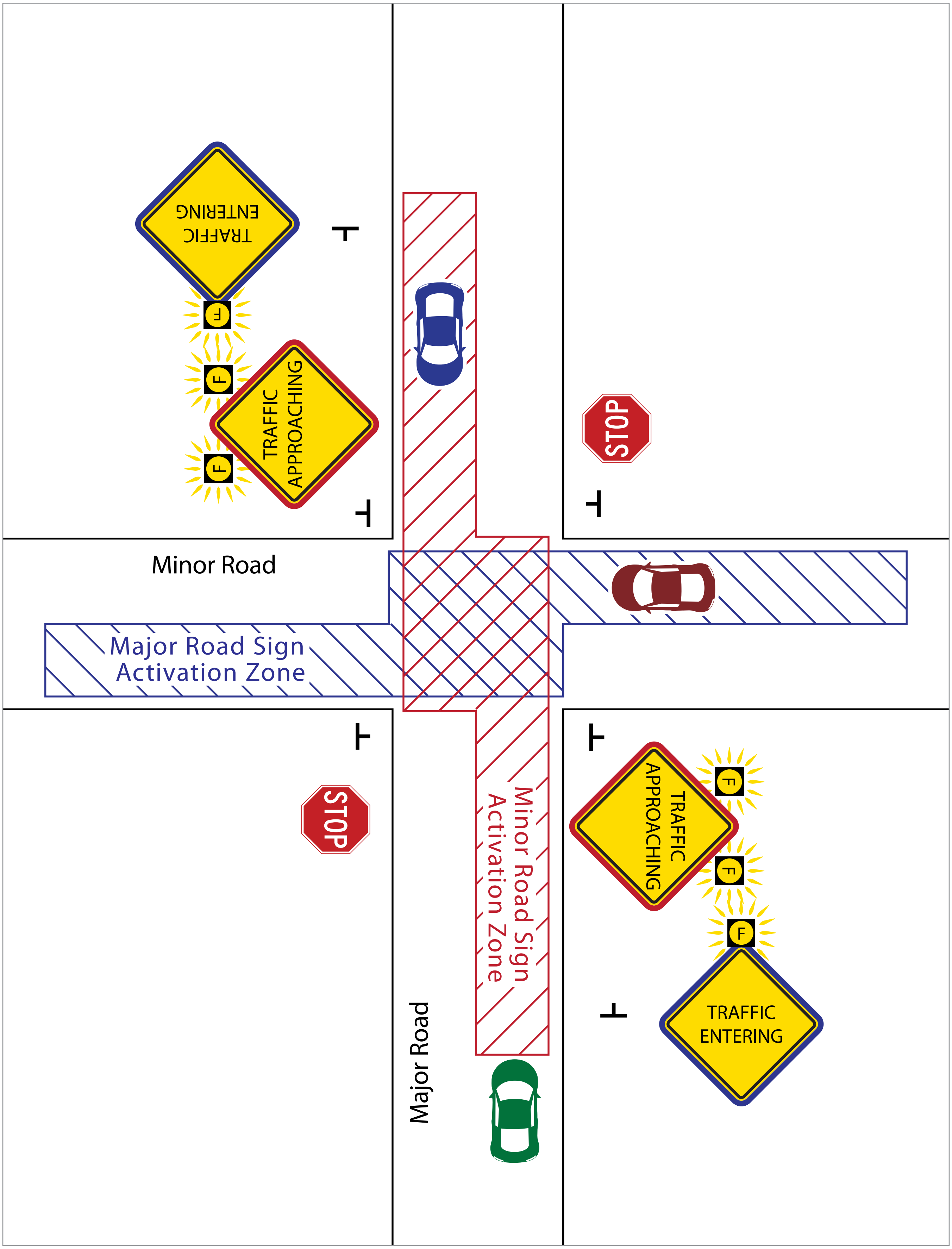


Figure 9. Major and Minor Road Warning ICWS



ICWS Use Guidance

The ENTERPRISE Pooled Fund Study is a forum for collaborative Intelligent Transportation Systems (ITS) research, development, and deployment ventures reflecting the interests of governmental entities and industrial groups. This forum also facilitates the sharing of technological and institutional experiences gained from individual ITS projects conceived and initiated by each participating entity. The program uses the FHWA Transportation Pooled Fund Program as a mechanism to support jointly-sponsored ITS projects of mutual interest to solve transportation problems.

The ENTERPRISE Transportation Pooled Fund[11] has developed planning guidance[12] for ICWS to assist agencies in the decision process of deploying these systems. The AASHTO Subcommittee on Traffic Engineering (SCOTE) has also reviewed and provided comments on the planning guidance. This provides guidance for the use of an ICWS device, regardless of the device configuration. There are two types of guidance provided – ICWS #1 Intersections with High Crash Frequencies or Rates (Reactive Approach) and ICWS #2 Intersection Characteristics (Proactive Approach). They may be used together or as stand-alone approaches for consideration of ICWS.

ICWS Research

Safety research identifies a variety of potential rural intersection safety strategies to reduce right-angle collisions, including the installation of ICWS. The most prominent research study on ICWS is highlighted here. More research findings are presented in Appendix C.

The Federal Highway Administration (FHWA) organized a Pooled Fund Study of 38 States to evaluate low-cost safety strategies including ICWS. To account for potential selection bias and regression-to-the-mean, an Empirical Bayes before-after analysis was conducted, utilizing reference groups of similar four-legged rural side-street stop-controlled intersections without ICWS installation. Data from three states—Minnesota, Missouri, and North Carolina—were used to generate the results. The combined results for all states indicate statistically significant crash reductions for most crash types for two-lane at two-lane intersections and for four-lane at two-lane intersections.[13]

Several safety studies have been conducted that analyze the safety benefits of ICWS. The general finding is that ICWS reduce the occurrence and severity of crashes by 17 to 27 percent. The benefit-cost ratio estimated with conservative cost and service life assumptions is 35:1 for all two-lane at two-lane intersections and 13:1 for four-lane at two-lane intersections with post-mounted warning signs.[14]

The results suggest that the strategy, even with conservative assumptions on cost, service life, and the value of a statistical life, can be cost effective.

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[11] Enterprise Pooled Fund. http://enterprise.prog.org/

[12] ENTERPRISE Pooled Fund, "Planning Guidance for the Installation and Use of Technology Devices for Transportation Operations and Maintenance." http://enterprise.prog.org/itswarrants/icws.html

[13] Himes, S. et al. FHWA Techbrief--Safety Evaluation of Intersection Conflict Warning Systems (ICWS) (HRT-16-035). 2016. http://www.fhwa.dot.gov/publications/research/safety/15076/15076.pdf

[14] Ibid.

STATE OF THE PRACTICE

This section provides information about design considerations and cost for LED STOP signs and ICWS.

DESIGN CONSIDERATIONS

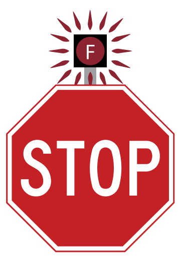
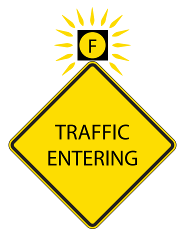
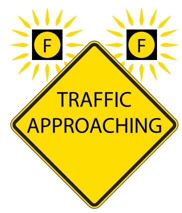
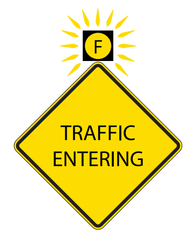
The design considerations shown in Figure 10 give general rules of thumb for systems that incorporated detection and warning systems. Simple LED STOP signs deployments may not require several of these considerations.

Figure 10. Design Considerations for LED STOP Signs and ICWS

Higher Initial Cost – Less Routine Maintenance	Lower Initial Cost – Higher Routine Maintenance
Controller	
Traffic Signal Controller • Can be easily maintained by signal technicians • Staff needs to be trained to operate signal controllers • High Reliability – Low Down Time	**Relay-Based or Simple Detector Control Method** • Data logging capability may be added to facilitate maintenance & troubleshooting • Lower Reliability – Higher Down Time
Detection Options	
Loop Detectors/"Microloops" • Most reliable • Requires wired connection	**Non-Intrusive/Radar** • More options for wireless communication • Low-cost sensors may be unreliable • Routine maintenance required
Communication	
Wired • Most reliable • Requires less routine maintenance	**Wireless** • No underground utility location needed • Routine maintenance required
Power	
Commercial/Grid Power • Most reliable • May not be feasible if power is not accessible nearby	**Solar Power/Battery** • Requires regular battery maintenance & replacement • More susceptible to damage/vandalism • Requires site with adequate sunlight for solar-powered systems
Maintenance	
Contracted Maintenance • Agency able to utilize personnel with more expertise • Agency staff may need less system training	**Agency-Provided Maintenance** • Agency staff can perform maintenance & troubleshooting as needed • Does not rely on third parties

Table 1 summarizes five options detailed in this section.

Table 1. Deployment Options

	Passive LED STOP Sign	Active LED STOP Sign	Major Road Only System	Minor Road Only System	Major & Minor Road Warning
Controller	None	Controlled by Detector	Controlled by Detector	Controlled by Detector	Signal Controller
Signs	 or 	 or 	 on mainline	 on major road	 on mainline  on minor road
Detection	No	Yes	Detect Minor Road Vehicles	Detect Major Road Vehicles	Detect all approaches
Malfunction Detection	No	No	Yes	Yes	Yes
Event Logging	No	No	Yes	Yes	Yes
System Cost	$2,000	$20,000	$50,000	$50,000	$100,000–$125,000

COST

Cost can be a significant factor when considering whether to implement a technology solution. This section provides budgetary costs and information that can be used to explain and plan a technology implementation to funding decision makers. Both upfront and recurring costs and resource needs are included.

A summary of costs related to these systems in shown in Table 2. Further explanation of these costs are contained in the following sections.

Table 2. Cost Summary

System Type	Planning Cost	Design Cost	Equipment and Installation Cost	Annual O&M Cost
Static LED STOP Sign	Minimal	Not Applicable in Most Cases	$2,000 – $3,000 per sign[a]	$100 per sign
Active LED STOP Sign	Depends on system complexity, can range from minimal to cost commensurate with ICWS	$5,000-10,000b	$15,000 to $20,000 per intersection[b]	$100 per intersection[c]
Minor Road Only Warning ICWS	$5,000-$20,000 or adapt existing analysis (one analysis can facilitate multiple projects/ systems)	$5,000-15,000	$50,000 – $80,000 per intersection	$1,000 per intersection
Major Road Only Warning ICWS		$5,000-15,000[d]	$50,000 – $80,000 per intersection[e]	$1,000 per intersection
Major and Minor Road Warning ICWS		$5,000-15,000f	$90,000 – $125,000 per intersection[g]	$1,000 per intersection[h]

[a] Cost for 36" x 36" LED STOP Sign: $1,700, cost to install $500/sign, cost varies with sign size.

[b] McLeod County Active Stop Sign System equipment furnish and install cost was $20,000 per intersection. The furnish and install cost for the Washington County active STOP sign system was $15,000.

[c] McLeod County plans for 1-2 maintenance trips per site per year, but has not needed to perform any maintenance since the system was installed in 2011. Washington County replaced batteries for their active STOP sign system once after five years of operation, but has not otherwise needed to maintain the system.

[d] St. Louis County's Mainline Dynamic Warning System project estimated design cost was $3,000 per intersection with the work performed by County staff.

[e] St. Louis County's Mainline Dynamic Warning System furnish and install cost was about $56,000 per intersection

[f] MnDOT's Rural Intersection Conflict Warning System project design cost was about $5,600 per intersection for the field-level design (no cabinet/controller design) design-bid-build project (seven intersections).

[g] MnDOT's Rural Intersection Conflict Warning System project contractor furnish and install cost per site was about $71,000 per intersection for all equipment except the controller, cabinet, and integration (5 full ICWS, 2 mainline only).

[h] MnDOT's RICWS One Year Warranty Summary Memorandum.

Planning/Systems Engineering Cost

Although the physical appearance of a system may be the most obvious distinguishing factor to differentiate systems, the development of the systems engineering documentation is a better distinguishing factor because it not only guides the system design, but also addresses the important operations, maintenance, and reliability of the system.

All federally-funded Intelligent Transportation Systems (ITS) projects require systems engineering. This process allows stakeholders to conceive and build requirements that will yield functional and operable systems that can be maintained with the resources the operating agency has at its disposal.

Most LED STOP Sign deployments do not have the communications systems that would classify them as ITS and thus do not require systems engineering. However, LED STOP sign deployments have used detection and communication systems and these systems would require systems engineering to use federal funds. Systems engineering for such systems were not found, but they share comparable elements with ICWS and those elements could be incorporated into future systems engineering documents.

While various configurations of ICWS systems have been developed, a few systems engineering efforts have been conducted that are available to be adapted for local needs:

- MnDOT's Rural Intersection Conflict Warning System project[15]
- St. Louis County's Mainline Dynamic Warning System project
- ENTERPRISE model systems engineering[16]

The Highway Safety Improvement Program (HSIP) is a core Federal-aid program.[17] In Minnesota, MnDOT's Office of Traffic Safety and Technology administers the HSIP funds.[18] These funds are eligible for use when installing an ICWS.

When planning an ICWS, it is important to consider data logging and system reliability. Planning for these items adds some upfront cost, but can save significant maintenance costs by easing troubleshooting and being able to determine system status. These considerations are especially important for systems that warn the minor road driver because some drivers rely on the signs to decide when to enter the intersection.

Systems engineering for ICWS costs about $5,000 to $20,000 depending on the scale of the analysis. Existing systems engineering analyses can be adapted to local needs at a lower cost.

Design Cost

LED STOP signs have generally been solar powered and do not require engineering design. However, if the site is blocked from sunlight from the south or otherwise needs commercial power, design may be necessary and may cost from $1,000 to $2,000.

Design costs for ICWS depend on a range of factors including system complexity and the number of systems being designed at the same time because a project may share details and special provisions. A typical site design may be expected to cost about $5,000 per site for a project with multiple sites or about $15,000 for a single site.

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[15] "Rural intersection conflict warning systems." http://www.dot.state.mn.us/trafficeng/signals/conflictwarning.html

[16] ENTERPRISE Program. "Intersection Conflict Warning Systems (ICWS) Coordination and Systems Engineering Phase 2." http://enterprise.prog.org/Projects/2010_Present/icwsphase2.html

[17] Highway Safety Improvement Program. http://safety.fhwa.dot.gov/hsip/

[18] Minnesota Department of Transportation, HSIP Guidebook & Application Form, http://www.dot.state.mn.us/trafficeng/safety/hsip.html

Installation Cost

LED STOP signs cost from about $1,400 to about $1,900 depending on the size of the sign (range from 24" to 48"). Installation cost depends on various factors including mobilization and the number that may be installed in the same trip/project, but the cost should be comparable to other sign installation costs ($500 per sign).

The costs for design and installation of ICWS vary greatly depending system type. Experience has shown that costs range from $50,000 for major road only systems to over $125,000 for the combined major road and minor road warning systems.

Operation and Maintenance Costs

Ongoing operational and maintenance activities ensure the system operates as planned and designed. These costs include power, routine maintenance, malfunction response and repair, and removal/replacement at end of the design life.

LED STOP signs should require minimal maintenance and operation. Most are solar-powered and thus use batteries that must be inspected yearly and replaced on a regular basis, such as after 2-3 years. These signs usually have no underground elements that require utility locating.

MnDOT's Rural Intersection Conflict Warning System (RICWS) project installed 33 sites prior to June 2015. After the initial six-week break-in period these sites experienced a total of 6.8 hours of maintenance per year. Related hardware costs for system maintenance was less than $2,000 per year for all 33 sites or approximately $60 per site per year.

Additional operational costs include power costs, providing underground utility location services, and removal/replacement at the end of the service life and are estimated to be about $1,000 per year including labor and materials.

CONCLUSION

This guidebook explains how and when ICWS and LED STOP signs may be used to improve safety. Additionally, it provides general background about the systems and offers resources that may be used when planning and designing the systems. Because these two strategies address different safety needs, engineers and decision makers need to consider these effects and how they fit in with other safety improvements to reduce intersection crashes. Traffic flow, intersection geometry, and intersection sight characteristics need to be considered uniquely when deciding how to best address safety needs.

As deployments of ICWS and LED STOP signs continue in Minnesota, there will be additional opportunities to gather data and evaluate their effectiveness.

APPENDIX A

APPENDIX A: CASE STUDIES

LED STOP Signs

- Washington County LED STOP Sign
- McLeod County Active LED STOP Signs and "Intersection Ahead" Warning Signs

ICWS

- Polk County "Safe Intersections" ICWS and RICWS
- St. Louis County ALERT ICWS
- St. Louis County Mainline Dynamic Warning System
- Stearns County Rural Intersection Conflict Warning System (RICWS)
- Washington County ICWS
- Wright County Vehicle Detection Advance Warning Systems

Washington County LED STOP Sign

CR 64 (McKusick Rd) at CSAH 15 (Manning Ave N)

Sign-Mounted Detector and LED STOP Sign

System

This system uses an upstream radar detector to detect vehicles exceeding the normal speed/deceleration profile. Upon detection, the edge-lit STOP sign activates. Most drivers see only the normal stop sign and this helps preserve the conspicuity and novelty effect of the LEDs. The system is battery-powered and has a radio link to communicate between the detector and STOP sign. The radar detector was custom, but the other components were commercial off the shelf.

This system was installed as part of MnDOT's "Innovative Ideas" program. This site has a history of run-the-stop crashes as well as good proximity to the maintenance shop.

Public Perception

Because it activates only rarely, the County has never received any direct feedback from the public, positive or negative. However, there was unfortunate media coverage when it was installed with a headline that read "County to pay $15,000 for stop sign."

Lessons Learned

Washington County maintains the system on an as needed basis and has not encountered any problems. It has needed almost zero maintenance.

The County feels that the most important attributes of the system are conspicuity and reliability. The radar component helps preserve the novelty of the system since it does not flash 24/7.

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McLeod County Active LED STOP Signs and "Intersection Ahead" Warning Signs

CSAH 15 and CSAH 3

Active STOP and "Intersection Ahead" Signs

System

McLeod County has three systems that were put into service in 2011. At two sites (CSAH 3 & CSAH 15 and CSAH 3 & CSAH 2), radar sensors activate LED STOP signs. The other site is at CSAH 115 & CSAH 7 on the west edge of Hutchinson and has LED "intersection ahead" signs on CSAH 115 that are activated by radar sensors on the Stop Ahead signs located on CSAH 7.

All three systems are solar powered and were designed and installed by TAPCO.

The CSAH 7/CSAH 115 system was implemented primarily due to traffic control change. There is some crash history on the CSAH 3 systems and they address unique traffic patterns.

Public Perception

The public has not provided much feedback about the systems. However, there was a report from a member of the public asking whether they still have to stop at the STOP sign if the lights are not flashing. This brings up the potential need for education and careful assessment of the system concept from the driver's perspective.

Lessons Learned

A few problems have been encountered. Initially, the contractor had some system setup issues and it took extra time to make the systems function to meet the County's specifications. The County has also had trouble replacing parts that have failed including solar panels and radar units. There was one case of vandalism where a power cable was cut.

In the future, the County would select a more proven system. They felt that these systems required extra effort to work out "bugs."

McLeod County conducts simple maintenance as-needed in house. If there is an issue that cannot be resolved, the County works with TAPCO to fix the problem.

Reliability is the most important aspect of the systems to the County. If the public becomes reliant on these systems they need to function properly or they can become a safety hazard.

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Polk County "Safe Intersections" ICWS and RICWS

TH 75 and CSAH 21

Safe Intersections System Signs

System

TH 75 and CSAH 21 intersection is at a skew. CSAH 21 has nearly three times as much traffic as TH 75. This location also has a railroad crossing on the minor roadway near the intersection. The fatal and injury crashes at this location were higher than expected.

To address the safety concern, the County considered a roundabout, intersection realignment, or the ICWS.

This site was initially part of the 2012 Safe Intersections project and has been replaced by the RICWS design. In both cases it is a major and minor road warning system using grid power. The Safe Intersections system used radar and loop detectors and the RICWS system uses loops and microloop detection. The Safe Intersections and RICWS projects used COTS systems, including the ASC/3 signal controller.

Public Perception

At first the public wondered why the County was installing signs rather than making geometric improvements, but once the system was up and running, they realized that it was effective and liked the cost/land savings.

Lessons Learned

Polk County is satisfied with the system. They thought it could have a battery backup if the grid power failed, although extended downtime has not been a problem.

Both the Safe Intersection and the RICWS system that replaced it have had very few maintenance problems.

The Safe Intersections system was initially maintained by the contractor and later maintained by MnDOT ESS and District forces. The RICWS system is still under on-site warranty by the contractor and will eventually be maintained by MnDOT ESS and District forces.

The County feels that the system has been a low cost reliable solution to a growing safety concern. The other options would have been expensive and may have required costlier annual maintenance.

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St. Louis County ALERT ICWS

Lakewood Rd and Lismore Rd

ALERT System Signs

System

The ALERT System is an ICWS that provides dynamic warning for both the mainline and minor road vehicles. The system uses commercial off the shelf parts including solar power, wireless communication, and non-intrusive vehicle detection. The CROSS TRAFFIC Warning signs flash when there is an approaching vehicle on the minor road.

The main goals of the system are to be low cost, have high reliability, be easy to maintain, and have no underground components.

Public Perception

The system has been favorably received.

The public found the warning system easy to understand (94 percent) and felt the system improved the safety of the intersection (92 percent). About 98 percent felt that the system attracted their attention and 91 percent felt that the system should be expanded to other intersections.

Lessons Learned

A few problems were encountered in the project. In the first phase of research (ALERT System 1), the batteries would drain during the winter because of the limited solar charging periods.

To correct these issues, the following considerations have been made for future systems. These systems will have a higher level of reliability for the batteries, vehicle detectors and wireless communication. Also, the system should be modularized so that devices could be replaced independently. Finally, the system should have a simplified controller that is as easy to use as a Christmas tree light controller.

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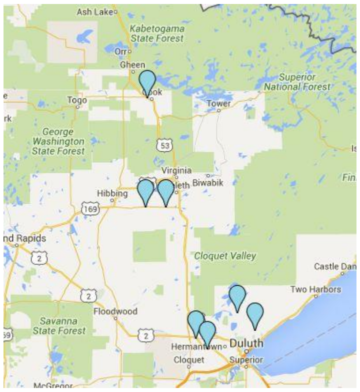
St. Louis County Mainline Dynamic Warning System



Mainline Dynamic Warning System Deployment Location Map

System

After investigating several conceptual approaches, the County elected to pursue development of a system that could provide warnings to drivers that did not have a stop indication or other traffic control as they approached intersections. By providing warnings only to major roadway drivers, the system has low installation and maintenance costs and still provides usable information to drivers. Twelve candidate intersections were identified in the St. Louis County Roadway Safety Plan that could benefit from warning systems. Seven were selected for initial deployments because they were located at two-lane, two-way intersections. The remaining intersections are located at divided expressways. Under the guidance of the Minnesota Department of Transportation, it was thought that the initial deployment should be limited to two-lane, two-way intersections because there is limited experience in Minnesota with intersection warning systems located on divided expressways.

Future deployments will be limited to available funding; however, St. Louis County fully supports the eventual deployment of intersection warning systems at all twelve intersections.

In December 2014, St. Louis County began a systems engineering process to clearly articulate the needs of an automated detection and warning system for rural intersections. County Public Works, Sheriff, and State (MnDOT) stakeholders were engaged in an elicitation process that resulted in a detailed list of needs and high-level requirements. From this discussion, a Concept of Operations was created and a system concept was developed.

Initial deployments are anticipated to be completed in 2016.

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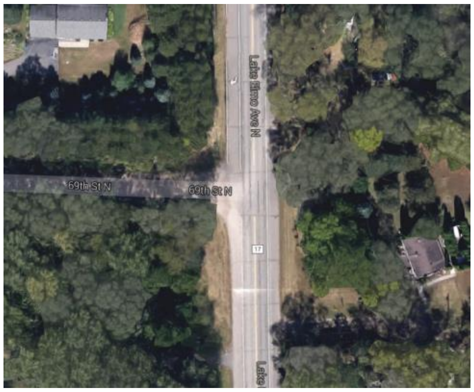
Washington County ICWS



CSAH 17 (Lake Elmo Ave N) at 69th St N

Intersection Conflict Warning System

System

This system is a mainline and minor road ICWS. The power source is hard-wired. The detectors are loops and microloops. Equipment generally followed MnDOT RICWS specification. Unlike many other RICWS systems, the mainline warning was provided in only one direction, because the other direction had no problems with sight distance. Installing the mainline warning in both directions would have increased costs and decreased the novelty of the system.

Washington County was eager to try out an ICWS and this location had a severe sight distance restriction, but the volumes were very low so the cost of the system was a concern.

Public Perception

There have been no comments from the public.

Lessons Learned

Lessons learned included utility conflicts, drainage issues near the new cabinet, and a lack of realization that the micro-loop conduits needed to extend across the entire roadway.

The County maintains the system. It is relatively new so it is not yet on a predictable maintenance schedule.

Washington County feels that reliability is the most significant factor for ICWS.

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Wright County Vehicle Detection Advance Warning Systems


CSAH 6 at CSAH 35

Intersection Warning and LOOK FOR TRAFFIC Signs

System

Wright County installed "Vehicle Detection Advance Warning Systems," at the intersections of CSAH 6 at CSAH 35, CSAH 8 at CSAH 35, and CSAH 9 at CR 107.

These systems provided a warning to a stopped motorist at the intersection that an oncoming vehicle is approaching on the cross street. They also provided a warning to a vehicle on the through roadway that a vehicle is stopped at or approaching from the minor road.

The systems were designed to be modular with wireless communication, radar detection, and have solar power.

The County needed to improve safety at intersections where drivers were stopping at the stop sign, but misjudging the gap and continuing into the intersection and causing right angle crashes.

Public Perception

The system was well received by the public.

Lessons Learned

Several issues were encountered. The mounting hardware was insufficient and not well attached to the square tube. The battery boxes were placed underground and flooded and the solar panels were undersized. Additionally, the detectors and communications were problematic. Overall, the systems were unreliable and difficult to troubleshoot and these were removed.

Future systems will be hardwired rather than solar-powered and use a traffic signal controller and loop detectors rather than radar and other custom components.

Wright County has HSIP funding to install new RICWS systems at the two of the intersections where the systems are no longer in use.

Off the shelf reliability, cost, ease of maintenance are all critical factors for a successful system.

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APPENDIX B

APPENDIX B: HISTORY OF INTERSECTION CRASH MITIGATION TECHNOLOGIES IN MINNESOTA

Cooperative Intersection Collision Avoidance System

The Cooperative Intersection Collision Avoidance System – Stop Sign Assist (CICAS-SSA)[1], 2006-2014 analyzed the driver gap acceptance and rejection data from the Pooled fund study, and implemented the alert and warning timing at actual experimental intersections sites. This project was conducted by MnDOT and the University of Minnesota which focused on warning drivers of unsafe gaps at rural side-street stop-controlled intersections in the CICAS-SSA project. CICAS-SSA was a successor to the Intersection Decision Support project and its cooperative aspect and coordinated with the Vehicle Infrastructure Integration (VII) initiative.

These systems were installed at three intersections in Minnesota. These systems have since been replaced by RICWS systems described below.

Intersection Warning System

This Intersection Warning System[2] project was part of MnDOT's Innovative Projects program and installed a system in 2007 at the intersection of Hennepin County Road 47 and Lawndale Ave. Like CICAS this system provided warning to minor road drivers waiting at the stop sign that a vehicle was approaching the intersection on the major through roadway. The purpose of this project was to develop a lower cost system that could provide a cost effective alternative for local roads. This system is still in operation.

Safe Intersections

The Safe Intersections[3] project deployed five experimental systems in 2012 at selected non-signalized low-volume intersections to investigate the use of Commercial Off-the-Shelf (COTS) traffic components to provide detection, processing, communications and display for five Intersection Conflict Warning (ICW) systems to determine feasibility. These systems provided a dynamic alert to both minor road and major road drivers.

The objective of this project was to recommend low-cost, readily deployable, reliable, low maintenance and cost effective systems that can be used by government agencies to improve safety on rural roads and non-signalized rural intersections.

Locations are shown in Appendix A. All of these systems have since been replaced by Rural Intersection Conflict Warning Systems described below.

ENTERPRISE Transportation Pooled Fund

Established in 1991, the ENTERPRISE Pooled Fund Study[4] is a forum for collaborative Intelligent Transportation Systems (ITS) research, development, and deployment ventures reflecting the

[1] Minnesota Department of Transportation. "Cooperative Intersection Collision Avoidance Systems (CICAS)." http://www.dot.state.mn.us/its/projects/2011-2015/cicas.html

[2] Minnesota Guidestar. "Intersection Warning System." http://www.dot.state.mn.us/guidestar/2006_2010/intersection_warning_system.html

[3] Minnesota Guidestar. "Safe Intersections." http://www.dot.state.mn.us/guidestar/2006_2010/safeintersections.html

[4] ENTERPRISE Pooled Fund Study. http://www.enterprise.prog.org/index.html

interests of governmental entities and industrial groups. This forum also facilitates the sharing of technological and institutional experiences gained from individual ITS projects conceived and initiated by each participating entity. The program uses the FHWA Transportation Pooled Fund Program as a mechanism to support jointly-sponsored ITS projects of mutual interest to solve transportation problems.

In 2011, ENTERPRISE lead an ICWS effort with the project Developing Consistency in ITS Safety Solutions - Intersection Conflict Warning Systems (ICWS) – Phase 1[5] by bringing together organizations that have developed and deployed intersection conflict warning systems, the purpose of this project was to develop a consistent approach for accelerated, uniform deployment and further evaluation of intersection conflict warning systems (ICWS), and to recommend preliminary standards for MUTCD consideration.

This effort was followed in 2012 by the Intersection Conflict Warning Systems (ICWS) Coordination and Systems Engineering – Phase 2[6] that supported the standardization of intersection conflict warning systems by coordinating among the various national standards and association groups, and by developing a model concept of operations and model system requirements for the four types of ICWS.

This effort was successful is gaining the support of AASHTO's Subcommittee on Traffic Engineering which recommended consideration of these systems in the national Manual on Uniform Traffic Control Devices (MUTCD). The National Committee on Uniform Traffic Control Devices (NCUTCD) technical committee on Regulatory and Warning Signs was tasked with developing language to recommend to the Federal Highway Administration (FHWA) for inclusion in the MUTCD. This recommendation was approved by the NCUTCD in June 2014.[7]

ENTERPRISE conducted Intersection Conflict Warning Systems (ICWS) Support and Outreach – Phase 3[8] to coordinate national standards groups, industry associations and other pooled fund programs that have been engaged through the ENTERPRISE ICWS work. Phase 3 provided ICWS deployment support to ENTERPRISE members. There is a series of webinars available on the ENTERPRISE website that cover these topics.

Rural Intersection Conflict Warning System

In 2013 MnDOT issued a request for proposals for a design build project to deploy a minimum of twenty and up to fifty ICWS. The goal of the Rural Intersection Conflict Warning System[9] deployment (RICWS) program is to reduce the fatal and serious injury crashes at rural non-signalized intersections. RICWS provides supplemental warning to drivers of other vehicles approaching the intersection. MnDOT has deployed these warning systems statewide at high crash risk locations.

RICWS consists of a combination of a minor road warning and major road warning or major road warning only. The minor road warning will warn drivers that there are major road vehicles approaching the intersection. The major road warning will warn drivers that there are vehicles on the minor road that are entering the intersection.

[5] ENTERPRISE Pooled Fund Study. "Developing Consistency in ITS Safety Solutions - Intersection Conflict Warning Systems (ICWS) Phase 1." http://www.enterprise.prog.org/Projects/2010_Present/developingconsistency.html

[6] ENTERPRISE Pooled Fund Study. "Intersection Conflict Warning Systems (ICWS) Coordination and Systems Engineering Phase 2." http://www.enterprise.prog.org/Projects/2010_Present/icwsphase2.html

[7] National Committee on Uniform Traffic Control Devices. "National Committee on Uniform Traffic Control Devices RWSTC Recommendation." http://www.enterprise.prog.org/Projects/2010_Present/developingconsistencyIWS/ConflictWarningSignsSection2C%20XXapprovedbyCOUNCIL6-28-14.pdf

[8] ENTERPRISE Pooled Fund Study. "Intersection Conflict Warning Systems (ICWS) Support and Outreach Phase 3." http://www.enterprise.prog.org/Projects/2013/icws_phase3.html

[9] Minnesota Department of Transportation. "Rural Intersection Conflict Warning System (RICWS)." http://www.dot.state.mn.us/its/projects/2011-2015/ricws.html

Other ICWS Systems

There have been other efforts to install ICWS in Minnesota. This includes installation of major and minor road dynamic warning systems in Wright County in 2009. St. Louis County also installed an experimental Advanced LED Warning Systems for Rural Intersections (ALERT) and ALERT 2 systems in 2010 and 2012 that included use of renewable power to provide a major road and minor road alert.

A system with a unique Stop Sign Warning System was installed as part of MnDOT Rural ITS Safety Innovation project in 2010. This system provides active real-time supplemental warning to drivers approaching the stop sign at an intersection, to alert them of the approaching stop ahead and to be more aware. This device equips a stop sign with a visual warning system such as LED flashers. The sign flashes when vehicles fail to decelerate at a safe rate for a safe stop.

Currently St. Louis County is working on the deployment of seven Mainline Dynamic Warning Systems (MDWS) scheduled for a 2016 deployment.

APPENDIX C

APPENDIX C: ADDITIONAL ICWS RESEARCH

ICWS

The following research shows that while ICWS will not improve the safety at all intersections, crash reduction benefits have been shown.

St. Louis County ALERT (Advanced LED Warning System for Rural Intersections)

The Minnesota Local Road Research Board (LRRB) funded this two phase project to test a low-cost, easy to install solar powered advanced warning system.

Phase 1 (ALERT-1) safety findings:[10]

- The average vehicle speed on the main approach decreased during nighttime after installation of the ALWS while no changes were observed during the daytime.
- When a vehicle enters the intersection from the minor approach, the average speed on the main approach decreased after installation of the ALWS.
- The average intersection wait time from the minor approach was significantly increased (5.4 seconds) when the warning signs were flashing.
- Number of intersection roll-throughs decreased to zero when the warning signs on the minor approaches were flashing.
- Number of intersection roll-throughs increased when the warning signs in the minor approach were not flashing.

Phase 2 (ALERT-2) safety findings:[11]

- The ALERT system reduced vehicle speeds on the main approach
- Increased STOP wait time on minor approaches
- The minor road wait time at stop signs was 2.5 seconds for no-conflict cases and 3.91 seconds for conflict cases, resulting in a 56 percent increase in conflict cases. The analysis of average vehicle speeds on the major road showed a decrease of 3.89 mph in the conflict case. This decrease translates to 0.93 seconds of difference in time from the moment the driver passes the blinking sign to entering the intersection, thus increasing the gap time.

North Carolina DOT

A study by the North Carolina DOT discovered that their dynamic warning systems reduced total intersection crashes by 32 percent and severe (fatal and serious injury) crashes by 30 percent.[12]

MnDOT RICWS Safety Report

- The MnDOT RICWS Safety report reviewed before and after crash data (2011-2015) for 27 locations where RICWS systems were install

[10] Kwon, T. "Advanced LED Warning Signs for Rural Intersections Powered by Renewable Energy." http://www.dot.state.mn.us/research/TS/2011/2011-04.pdf

[11] Kwon, T. "Advanced LED Warning System for Rural Intersections: Phase 2 (ALERT-2)." http://www.dot.state.mn.us/research/TS/2014/201410.pdf

[12] Simpson, Carrie. "Evaluation of the Safety Effectiveness of 'Vehicle Entering When Flashing' Signs and Actuated Flashers at 74 Stop-Controlled Intersections in North Carolina." http://enterprise.prog.org/Projects/2010_Present/developingconsistencyIWS/NC%20TRB_VEWF_SimpsonTroy_073112.pdf

and discovered the following trends.[13]

- A 22 percent decrease in overall annualized crash frequency
- A 24 percent decrease in overall crash rate
- A 30 percent decrease in fatal crashes and 62 percent decrease in severe (fatal +serious injury) crashes
- A total of 19 of the 27 sites (69 percent) had reductions in (annualized) crash frequency and in crash rates

Another key trend suggests that traffic volume appears to make a difference. Both sites with a daily traffic volume cross-product (sample equation below) greater than 12 million entering vehicles (MEV) experienced increases in both annualized crash frequency and crash rate.

Cross Product = Major Entering ADT * Minor Entering ADT = 5,950 * 2,100 = 12,495,000

In addition, the 25 sites with a cross-product less than 12 MEV experienced a 73 percent reduction in crash frequency and crash rate. Looking at the nine sites with a cross-product under 6 MEV as a group, they experienced reductions of approximately 80 percent. Another volume trend suggests that minor road entering volume appears to be a larger factor than either major road entering volume or cross-product – 8 of 10 sites with minor entering volumes less than 1000 vpd experienced a decrease and 7 of 10 sites had 100 percent decrease.

NCHRP Report 500[14] is a series of safety reports that classifies safety strategies as "Proven," "Experimental," and "Tried." With the findings of the Low-Cost Safety Improvements Pooled Fund Study, ICWS meets the criteria of Proven:

"Proven (P): Those strategies that have been used in one or more locations and for which properly designed evaluations have been conducted that show it to be effective. These strategies may be employed with a good degree of confidence, but with the understanding that any application can lead to results that vary significantly from those found in previous evaluations. The attributes of the strategies that are provided will help users judge which strategy is the most appropriate for the particular situation."

Traffic Control Devices Pooled Fund

The pooled fund group is working on Intersection Conflict Warning Systems human factors research. They are investigating the wording on signs, the flash rate/pattern and flasher location. This research is currently underway.

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[13] Minnesota Department of Transportation. "MnDOT RICWS Safety." http://www.dot.state.mn.us/its/projects/2011-2015/rural-intersect-conflict-warn-system/documents/d3ricwssafety.pdf

[14] Neuman, T. "NCHRP Report 500 Safety and Human Performance Guidance for Implementation of the AASHTO Strategic Highway Safety Plan Volume 5: A Guide for Addressing Unsignalized Intersection Collisions." 2003. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v5.pdf

APPENDIX D

APPENDIX D: EXAMPLE PLANS

Appendix D content can be found at this link: http://www.lrrb.org/pdf/2016RIC10b.pdf