Stop-Controlled Intersection Safety: Through Route Activated Warning Systems

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Foreword

Over 7,000 people lost their lives at intersections in 2009. The Fatality Analysis Reporting System (FARS) database indicates more people die at stop-controlled intersections compared to those that died at intersections controlled by traffic signals. A set of low-cost, infrastructure-based, intelligent transportation system (ITS) countermeasures has the potential to be used in an innovative way to provide substantial safety benefits to motorists at stop-controlled intersections with crash histories or the potential for severe crashes. Missouri and North Carolina have successfully deployed such technologies, called through route activated warning systems, at several stop-controlled intersections. The following document summarizes information on the technology, knowledge gained from the installations in North Carolina and Missouri, and guidance for applying the countermeasure at other stop-controlled intersections. This report will be of interest to safety engineers, traffic engineers, and State and local authorities with responsibility for public safety.

This document does not supersede any previous document.

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16. Abstract

This report provides information on low cost infrastructure based ITS technologies that may be applied to stop-controlled intersections to improve safety. Crashes at stop-controlled intersections are substantially lower than crashes at signalized intersections; however, overall, more fatalities occur at stop-controlled intersections than occur at signalized intersections. The major type of crash that occurs at stop-controlled intersections is a two-vehicle angle crash between a vehicle on the stop approach and a vehicle on the through approach. The through route activated warning system have been used in an innovative way to provide enhanced intersection safety information to entering traffic compared to traditional sign and marking enhancements. This system is highlighted in this report. North Carolina and Missouri have deployed the technology at several stop-controlled intersections. Noteworthy practices on sign message, site selection, design, and operation of the system are provided. The through traffic advanced warning system is a tried technology. While preliminary crash data analysis indicates the potential for a substantial reduction in crashes, there is insufficient data at this time to prove or validate its effectiveness.

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1. Introduction

Crashes at stop-controlled intersections are substantially lower than crashes at signalized intersections; however, recent FARS (Fatality Analysis Reporting System) data indicate that, overall, more fatalities occur at stop-controlled intersections than occur at signalized intersections. The major type of crash that occurs at stop-controlled intersections is a two-vehicle angle crash where a driver of the vehicle on the stop approach pulls out without a safe gap, resulting in a collision with a vehicle on the through approach.

The FARS data system indicates that approximately two-thirds of all fatal crashes at stop-controlled intersections involve right-angle crashes. Several traditional infrastructure-based countermeasures with varying degrees of effectiveness are available to help reduce the potential for this type of crash. Recently, some infrastructure-based Intelligent Transportation System (ITS) technologies have been used in an innovative way to provide better-quality intersection safety information to entering traffic compared to traditional sign and marking enhancements. One of these technologies, a through route activated warning system, has been successfully deployed at several intersections in North Carolina and Missouri at a relatively low cost per intersection and has generally resulted in substantial intersection crash reductions. The through traffic advanced warning system is a "tried technology."[1] While preliminary crash data analysis indicates the potential for a substantial reduction in crashes, there is insufficient data at this time to prove or validate its effectiveness.

The purpose of this document is to provide information on this technology so it can be considered by other State and local government traffic and safety engineers to lower the crash potential at select stop-controlled intersections.

1 Tried Technology: Those strategies that have been implemented in a number of locations and may even be accepted as standards or standard approaches, but for which there have not been found valid evaluations.

2. The Crash Problem

Nationally, according to the FARS database, in 2009, 7,043 people lost their lives at intersections. Of these, 2,436 people lost their lives at stop-controlled intersections and 2,348 people lost their lives at some form of signalized intersections. The FARS database has only partial data in terms of the type of traffic control governing an intersection, with approximately one-third being designated either "no control" or some other traffic-control device.

Many State databases can provide deeper insight into the characteristics of the intersection crash problem. For example, Table 1 shows the distribution of state highway intersection crashes, and fatalities by urban or rural and signal or stop-controlled intersections for a typical state that has in excess of 100 annual statewide intersection fatalities on the state highway system.

Traffic Control Type	Location	Number of 5-Year Crashes	Number of 5-Year Fatalities	Fatalities per 100 Crashes
Stop	Rural	28,103	514	1.83
Stop	Urban	19,310	24	0.12
Stop-Total		47,413	538	1.13
Signal	Rural	24,210	105	0.43
Signal	Urban	108,285	158	0.15
Signal-Total		132,495	263	0.20

Table 1: Distribution of 5-Year Intersection Crashes, Fatalities, and Fatality Rates for a Typical State with 100 or More Annual State Highway Intersection Fatalities

In the example above, even though approximately 25 percent of the total crashes occur at stop-controlled intersections, over 60 percent of the fatalities occur at stop-controlled intersections. In addition, the probability of a fatality per 100 crashes is more than 12 times greater at rural stop-controlled intersections compared to urban signalized intersections.

In addition, the distribution of crashes per intersection for rural stop-controlled intersections indicates that there are a considerable number of intersections with multiple crashes. An example distribution of crashes at rural stop-controlled intersections from a state with over 100 total annual intersection fatalities on the state highway system is provided in Table 2.

Number Of Five-Year Crashes Per Intersection	Number of Intersections	Cumulative Number of Intersections	Cumulative Percent of Intersections	Cumulative Number of 5-Year Crashes	Cumulative Percent of Crashes
50 and greater	6	6	0.09%	363	1.29%
30 - 49	25	31	0.47%	1,221	4.34%
20 - 29	95	126	1.91%	3,435	12.22%
10 - 19	549	675	10.24%	10,637	37.85%
5 - 9	1,256	1,931	29.28%	18,732	66.65%
4	529	2,460	37.30%	20,848	74.18%
3	870	3,330	50.49%	23,458	83.47%
2	1,380	4,710	71.42%	26,218	93.29%
1	1,885	6,595	100.00%	28,103	100.00%
Total	**6,595**	**6,595**	**100.00%**	**28,103**	**100.00%**

Table 2: Distribution of Crashes at Rural, Stop-Controlled Intersections in a Typical State with over 100 Annual Fatalities on the State Highway System

There are almost 6,600 rural stop-controlled intersections that had at least 1 crash in the past 5 years. Of these, 126, or less than 2 percent of all stop-controlled intersections had 20 or more crashes in the past 5 years and accounted for over 12 percent of all crashes that occurred statewide at rural stop-controlled intersections.

Stop-controlled intersections with high frequencies of crashes are potential candidates for ITS warning systems, particularly those in rural areas where the crash severity is greater.

3. Traditional Low-Cost Infrastructure Countermeasures

Passive Sign and Marking Enhancements

Three levels of low-cost passive sign and marking enhancements to improve safety and reduce the potential for future crashes at stop-controlled intersections may be considered to reduce future crash potential:

1. At the base level, a standard advance intersection warning sign (such as the W 2-1 or W2-2 sign) may be placed on the through approach. States have varying criteria for using this sign:
    - Some States do not use the sign unless there has been a crash problem, complaints, or sight distance or other safety issues associated with the intersection.
    - Some States install the sign routinely at every State – State road intersection.
    - Some States apply the sign at many State – local road and State – State road intersections.
2. At the enhanced level, at those intersections with moderate crash levels (average one or more reportable crashes annually for each of several years) or those having other safety concerns, the passive signing on both the through and stop approaches can be increased in size and number at minimal cost to increase drivers' attention to the intersection. Figure 1 provides information on low-cost sign and marking enhancements to three-legged stop-controlled intersections that can be considered for any stop-controlled intersection with recurring crash histories or safety problems.
3. If the crash history is significant or if crash problems persist after the enhanced signs and markings are in place, flashing warning beacons can be added to the advance intersection warning signs and the "Stop Ahead" signs in Figure 1 to provide added emphasis on the presence of an intersection to the approaching drivers. A stop beacon can also be added for the stop approach if running the stop sign is part of the crash problem.

The safety effectiveness of enhanced signing and marking with continuously operating flashing beacons on the advance warning signs may gradually erode over the long term. While most drivers will probably have higher attention levels and exercise greater caution as they proceed through the intersection immediately after the enhancements are installed, drivers who frequently use the intersection may become less cautious and more inattentive over time, particularly if they are accustomed to seeing no vehicles or little activity on the stop approaches.

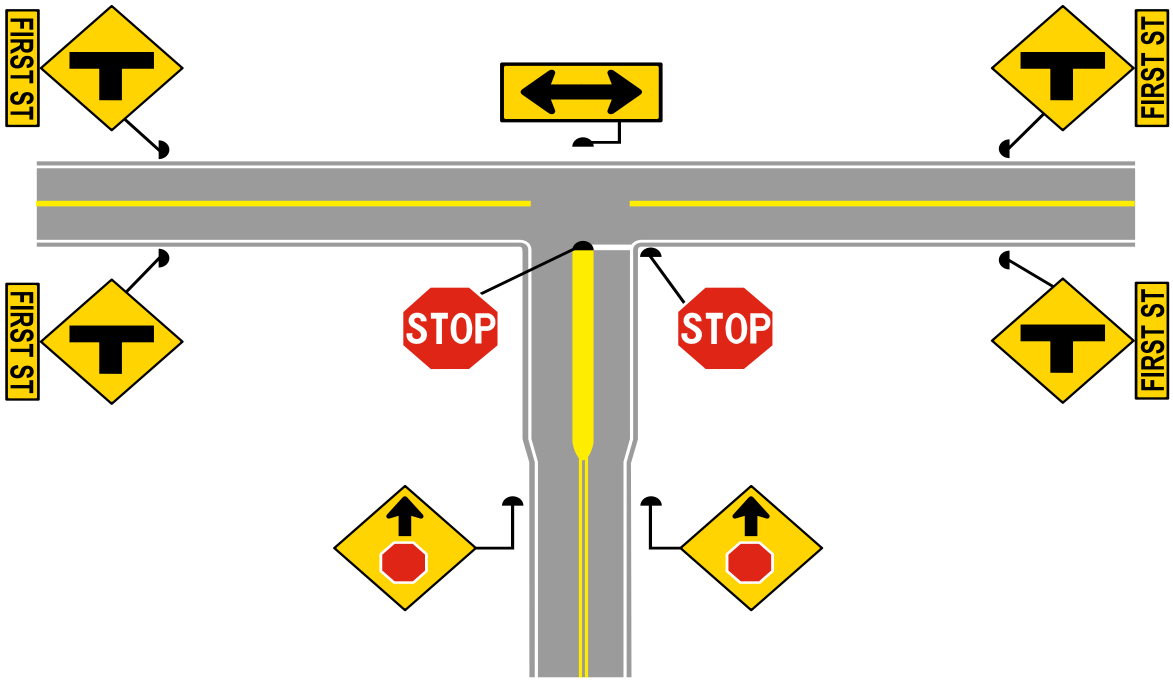


Figure 1: Traditional Sign Enhancements for Stop-Controlled Intersections

Summary

Most States have a small but finite number of rural stop-controlled intersections with a history of multiple crashes or safety concerns such as sight distance restrictions that cannot be easily mitigated. The predominant type of crash that occurs at these intersections is an angle crash, where the driver on the stop approach has misjudged the distance and/or closing speed of a vehicle on the through approach. These crashes are often severe because of the high speeds involved and the destructive nature of side impacts. Low-cost enhanced passive sign and marking improvements should improve drivers' attention level and possibly make them more cautious as they proceed through the intersection, reducing the potential for a crash. Passive warning signs with flashers that only activate and warn through drivers only when a vehicle is on the stop approach may maintain increased attention level to the intersection over time.

4. Infrastructure-Based ITS Intersections

Infrastructure-based ITS technologies are being used in an innovative way with the potential to significantly improve the safety at multi-crash stop-controlled intersections. These systems provide enhanced safety warning information for approaching drivers compared to passive warning systems. These technologies include:

- Enhanced warning to the through driver of a vehicle on a cross road stop approach that may enter the intersection.
- Enhanced warning to drivers approaching a stop approach that their trajectory speed is high and that they may run the Stop sign.
- Enhanced warning to through drivers that they are traveling at too-high an intersection entry speed and advising them to slow down.
- Enhanced warning to drivers on the stop approach of entering vehicles on the through approach, inferring potential unsafe gaps.

A brief discussion of these technologies follows.

Warning the through driver of a vehicle on a cross road stop approach.
These systems usually use a double set of detectors on the stop approach to identify approaching and stopped vehicles and warn traffic on the through approach of their presence using activated flashing beacons on passive intersection warning signs to indicate that a vehicle from the cross street may enter the intersection. They are often deployed at rural stop-controlled intersections that have either a history of crash experience or limited sight distance. Missouri, Minnesota, North Carolina, Pennsylvania, and Virginia have deployed these systems or variations of them.

Figure 2: Through Vehicle Activated Warning Sign System in North Carolina
Photo courtesy of NCDOT

Warning drivers on a stop approach that their speed and trajectory indicate that they may run the stop sign.

These systems use a speed detection system to identify vehicles approaching a stop at too-high of an approach speed at a given point on the roadway. Drivers exceeding a specified speed either activate a flashing beacon on an advance "Stop Ahead" warning sign or cue lights on the perimeter of a stop sign to begin flashing. These devices are most likely applicable where there is a known problem with stop sign running (not drifting through) and where other passive measures to alert drivers of the stopped condition have failed, but more aggressive measures such as transverse rumble strips cannot be installed because of noise issues. Stop sign running may be associated with a) horizontal and/or vertical alignment geometry that makes the intersection visible only when vehicles are close to it, or b) long sections of moderate volume highways that abruptly stop at a major cross road.

Figure 3: Stop Approach Activated LED Red Flashers on Perimeter of Stop Sign
Photo courtesy of SAIC

Warning the driver on a through approach of too-high an intersection entry speed and directing the driver to slow down.

These systems measure the speed of approaching through vehicles and provide feedback to drivers. The feedback may be provided to all approaching vehicles (actual speed of vehicle) or only the speed of those vehicles traveling faster than a pre-determined safe speed. Systems such as that shown in Figure 4, which use radar to measure speed and activate a sign to display the measured speed, have been deployed by many States. These systems provide feedback to all drivers approaching the device. Missouri has deployed one system on the through approach to a stop-controlled intersection. The device is activated only if the speed measured is above a specified threshold speed (Figure 5). The system that provides speed feedback to all drivers has been evaluated in the Federal Highway Administration (FHWA) publication *Traffic Calming on Main Roads Through Rural Communities*[2] and was found to produce a 7 mph reduction of 85th percentile approach speeds. This system may be appropriate to consider on those through approaches to stop-controlled intersections that experience multiple crashes where excessive speeds on through approaches were a factor in the crash occurrence or crash severity. However, its impact on reducing crashes when used on intersection approaches has not been evaluated.

Figure 4: Actual Speed Feedback Sign
Photo courtesy of FHWA

Figure 5: Missouri Through Approach Speed Sign
Photo courtesy of MoDOT

2 Federal Highway Administration, *Traffic Calming on Main Roads Through Rural Communities*, FHWA-HRT-08-067 (Washington, DC: February 2009). Available at: http://www.fhwa.dot.gov/publications/research/safety/08067/index.cfm

Warning drivers on the stop approach to look for oncoming traffic when vehicles on the through approach are detected.
These systems are designed to provide active, real-time supplemental warning to drivers on the stop approach of an intersection and alert them to look for approaching traffic on the through approach. These systems detect the presence of approaching vehicles on the through approaches and activate a dynamic warning for the drivers stopped at the intersection. Two such systems have been identified.

The first system, deployed in Minnesota on rural single through lane intersections, uses advanced Doppler radar to detect oncoming through vehicles. Using measurements of speed and distance to the intersection, it activates "Look for Traffic" LED signs, depicted in Figure 6, to stopped drivers on the stop approach. The LED lights in both arrows flash when a vehicle is detected on the through approach. They continue to flash for a preset time or until the vehicle is estimated to clear the intersection.

Figure 6: Minnesota's "Look for Traffic" Sign – Both Arrows Flash when Traffic is Approaching

While this system offers promise in terms of potential crash reduction, there are some technical issues that should be addressed before wider deployment. First, the use of Doppler radar to measure distance and speed of approaching vehicles cannot track a vehicle completely through an intersection. In rare instances, a vehicles trajectory may slow significantly after detection terminates and the through vehicle may enter the intersection after the flashing light times out. Emerging advances in detection systems may have the capability to track vehicles through the intersection and resolve this concern. Second, in rare instances when the system fails and the flashing lights are not activated when through vehicles are detected, stopped drivers who are familiar with the intersection may infer that there are no oncoming vehicles approaching and enter the intersection without adequately scanning the approaches. This concern can be addressed by using blank out signs that provide default messages if the system fails and displays messages for stopped drivers when vehicles on the through approach are not detected.

The second system also advises drivers on the stop approach they should watch for approaching vehicles on the through approach, but on multi-lane divided highways. This system is a major component of the infrastructure-based ITS technology being developed under the Cooperative Intersection Collision Avoidance System (CICAS). It is based on the observation that crashes at rural stop-controlled intersections arise primarily from a driver attempting to cross or enter the mainline traffic stream after failing to recognize an unsafe gap condition. Because the primary cause of these crashes is not failure to stop, but failure to recognize an unsafe condition, FHWA, Minnesota DOT, and the University of Minnesota ITS Institute undertook the Cooperative Intersection Collision Avoidance System – Stop Sign Assist (CICAS-SSA) program.[3] CICAS-SSA uses roadside radar sensors, a computer processor and algorithms to determine unsafe conditions, and an active LED icon-based sign to provide timely alerts and warnings which are designed to reduce the frequency of crashes at rural expressway intersections. Systems similar to CICAS have also been deployed in Maine, Pennsylvania, Virginia, and Wisconsin.

Three tenets that are particularly germane to the determination of alert and warning timing for the CICAS-SSA system are:

1. **The system does not help a driver choose a safe gap; it assists a driver with unsafe gap rejection.**
2. **It indicates when it is unsafe to proceed, not when it is safe to proceed.**
3. **It must complement good decision making and address those instances where poor decision making could lead to a crash.**

3 CICAS-SSA is a cooperative system; a driver vehicle interface (DVI) for inside the vehicle is being developed and secure radio communication to the vehicle is being implemented using dedicated short range communication (DSRC) with an "IntelliDrive" project.

5. Key Attributes of an ITS Technology Ready for Implementation

An oversight group comprising representative State Department of Transportation (DOT) traffic, research, and safety personnel that have implemented infrastructure-based ITS safety technologies at stop-controlled intersections included: a county traffic engineer; representatives from the International Association of Chiefs of Police (IACP), American Association of State Highway and Transportation Officials (AASHTO), and American Traffic Safety Services Association (ATSSA); and representatives from various Federal agencies was formed and interviewed to identify the major attributes that a successful infrastructure-based ITS technology should possess for widespread, effective implementation. The participating State DOT personnel had implemented or were in the process of implementing one or more of the ITS infrastructure-based technologies at stop-controlled intersections. The personnel represented the State DOTs for Minnesota, Missouri, North Carolina, Pennsylvania, Wisconsin, and Virginia.

Key issues that the group collectively identified as being important for successful deployments are as follows:

State Input

- All of the States interviewed were appreciative of the FHWA Office of Safety taking a leadership role in advancing this set of safety technologies.
- It was generally concluded that the Cooperative Intersection Collision Avoidance Systems (CICAS) installed in Minnesota (in excess of $250,000); and similar systems deployed in Wisconsin ($350,000) and Pennsylvania (in excess of $200,000) were too expensive to consider, develop, and pursue for widespread deployment. However, Minnesota indicated that there are a few isolated intersections (high-speed, high-volume, at-grade expressway intersections) where the technology is probably justified, and eventually the costs may be slightly lowered by replacing full matrix LED signs with blank out signs.
- It was generally concluded that the ITS technology to warn drivers that they may run through a stop approach because of an excessive approach speed should be a low priority and probably not emphasized. The logic for this position is that there are few crashes where a driver actually "blows through" a stop sign, and that passive systems (e.g., transverse rumble strips, dual "Stop Ahead" signs, and oversized stop signs) may be just as effective.
- It was generally concluded that issues related to reliability, maintenance, and vandalism were important and needed to be addressed. The systems have to be designed with a much higher level of reliability and require less maintenance for a widespread deployment scenario. For example, Minnesota indicated that if they have 10 or less of these installations, an emergency call once a year for each system is probably acceptable; however, if they have 200 systems statewide, 200 emergency calls a year is too much.
- The warning messages used in the systems varied by State. It was agreed that more uniform messages should be established before a wider national deployment is considered.
- The technologies should be tested in "silent mode" to insure that everything is functioning correctly before activating the installations for actual use.
- The liability issue must be adequately addressed before States will implement the technology. Redundant passive warning systems and dynamic warning systems that do not "create" the potential for a crash should they malfunction need to be incorporated into the design, along with other design measures that reduce the potential for system malfunctions.
- The National Electrical Manufacturers Association (NEMA) based standards should be pursued to the extent feasible.
- States that have installed these systems indicate a benefit in gaining public acceptance of the technology BEFORE the technology is placed at an intersection. It is important to provide information about the technology to people and local government officials in the near vicinity of the intersection that use it frequently. Some packaged information explaining the technology and its benefits would be helpful.
- An automated malfunction notification system may eventually need to be built into the system to reduce the need for routine on-site inspections and enable a quick response to a malfunction indication.

Local County Engineer Input

- A number of county road intersections exist where the technology may be beneficial to deploy. If offered the opportunity, a number of local governments would look favorably upon participating in implementing the technology. The best way to reach out to local governments on this effort is through the National Association of County Engineers (NACE), American Public Works Association (APWA), and the Institute of Transportation Engineers (ITE).
- Public acceptance of the technology is important. Any information that could be developed and given to the public that would explain how the system operates and how it can benefit the driver would be very beneficial. Providing a warning to the through driver of a stopped vehicle on the stop approach would be a high priority technology to pursue.
- Vendors and contractors need to have information on how to install the systems. This is important not only to insure a quality product, but also to increase competitiveness and lower costs.
- One substantial concern is that if the system is too popular, everyone will want it. Guidelines should be established to help agencies and local governments identify the intersections where these systems are most beneficial to deploy.

ATSSA and AASHTO Input

- Consider performance-based contracting to increase the potential for improved reliability.
- Mounting solar panels on poles and placing polycarbonate sheeting on LED signs may reduce the potential for vandalism and theft.
- ATSSA and AASHTO were very supportive of undertaking the initiative and did not believe it conflicted with other ITS initiatives.

IACP Input

- The IACP is supportive of the initiative.
- Messages should be simple and easily understood.
- There are no enforcement issues from a police perspective with these systems since they are warning, not regulatory signs.

Federal Agency Input

- Agencies interviewed support the initiative to pursue a wider deployment of successful ITS infrastructure-based safety technologies.
- The system should provide the right solution for the right problem. The system must effectively address a justified need.
- There is a need to reduce liability potential through redundancy. A legal opinion of the liability potential and means to reduce it must be sought before deployment.
- Community acceptance of the systems must be obtained before the systems are deployed. In many cases this may mean information on why the technology is preferred in comparison to a traffic signal, four-way stop sign or a roundabout.

Conclusion

Based upon the interview results, it was concluded that the through route activated warning system had the greatest potential to be implemented by State and local governments at stop-controlled intersections with histories of crashes, particularly those in rural areas with higher crash severities, with the possible result being a substantial reduction in future crashes at these locations.

6. Summary of ITS Infrastructure-Based Concerns

Of the four infrastructure-based ITS technologies identified for stop-controlled intersections, at the current stage of development and at this time, only one of them has the potential to be successfully implemented at a considerable number of intersections and substantially reduce crashes at those intersections: systems that warn drivers on the through approach of a stopped vehicle on the stopped approach that may enter the intersection.

A description of the near term implementation concerns with the other systems follows:

- **Warning drivers on the stop approach that their trajectory indicates that they may run the stop sign.** This system is relatively inexpensive and straightforward to implement using detectors to measure approach speed on the stop approach and activating flashers on the stop sign when too-high an entry speed has been detected. It has been successfully deployed in Virginia[4] and is beneficial to consider on high-speed stop approaches where the intersection cannot be readily seen and where other traditional countermeasures such as advance "Stop Ahead" warning signs, doubling up on stop signs, and transverse rumble strips have not reduced running (not drifting) Stop sign violations. While the technology is ready, it is believed that there are few stop-controlled intersections where frequent stop sign running events and crashes due to the driver's failure to observe the traffic control device are experienced and where enhanced passive systems have not addressed this problem already.
- **Warning the through driver of too-high an intersection entry speed and directing the driver to slow down.** The speed feedback systems shown in Figure 4 have been extensively deployed on approaches to various situations or elements such as construction areas, school zones, curves, boundaries to communities and intersections. Their impact in terms of speed reduction has been evaluated with positive results.[5] However, their impact in terms of reducing crashes when used on intersection approaches has not been evaluated.

  The Missouri speed system is similar to the speed feedback system except it uses a larger permanent display sign. The threshold speed is not adjusted if a vehicle is recognized on the stop approach. There is limited knowledge relative to potential impact in reducing crashes. This system needs to be compared with the through approach activated warning system in terms of both speed and crash reduction.
- **Warning drivers on the stop approach to look for oncoming traffic on the through approaches when approaching vehicles on the through approach are detected.** These systems are designed to provide active, real-time supplemental warning to drivers on the stop approach of an intersection and alert them to look for approaching traffic on the through approach. Two types of systems were discussed. The first system deployed in Minnesota on a few rural single lane approaches to stop-controlled intersections uses Doppler radar and flashing LED signs to advise stopped drivers to watch for oncoming vehicles when they are detected. It is relatively inexpensive at approximately $55,000 per intersection. This technology is very promising in terms of potential significant reductions in angle crashes at rural single lane intersections. Further advances in radar detection technology to track a vehicle completely through the intersection and replacing flashing LED signs with blank out signs to avoid false inferences by stopped drivers when the system is down may be beneficial before wider deployment.

  The second system is an infrastructure-based ITS technology being developed under CICAS. This uses extensive detection systems on the through approach of stop-controlled intersections to track through vehicles as they are detected and proceed completely through the intersection. Technical, human factors and financial issues involved in this technology need to be addressed before the technology is ready for wider deployment. Currently these systems cost approximately $250,000 per intersection. Unless costs can be dramatically lowered, this technology may be limited to consideration at a limited number of intersections with very significant crash problems.

4 E.D. Arnold & K.E. Lantz, *Evaluation of Best Practices in Traffic Operations and Safety: Phase 1: Flashing LED Stop Sign and Optical Speed Bars*, .VTRC07-R34: June 2007. Available at: http://www.virginiadot.org/vtrc/main/online_reports/pdf/07-r34.pdf

5 Federal Highway Administration, *Traffic Calming on Main Roads Through Rural Communities*, FHWA-HRT-08-067 (Washington, DC: February 2009). Available at: http://www.fhwa.dot.gov/publications/research/safety/08067/index.cfm

7. State Experience with Through Route Activated Warning Systems

Missouri and North Carolina have the most experience, with each State having installed approximately 10 or more Through Route Activated Warning Systems.

Missouri and North Carolina personnel were further interviewed to gain additional information about their installations. Key findings from these interviews are as follows:

- Both States are satisfied with the operation and safety performance of the installed systems and continue to implement more of these systems as funds allow.
- The systems are relatively low cost, being in the $15,000 to $35,000 per intersection range.
- Neither State has experienced any known tort suits associated with the systems.
- The reliability, performance, and maintenance of the systems have been extremely good, probably because of the simplicity of the system and design parameters used. Both States indicate minimal maintenance with rare call outs. Most probable failures are associated with the loop detector. Both States rely on the public or maintenance personnel to identify that a system is down. Neither State is considering automatic notification systems at this time since the existing systems are highly reliable with minimal call outs.
- Both States predominantly use loop detectors to detect vehicles on the stop approach. Both States use a dual set of loop detectors on the stop approaches to identify vehicles as they approach or are stopped at the intersection. (See Appendix A.)
- Both States use underground conduits to connect the loop detector to the sign and external power sources rather than wireless connections and combinations of solar panels and back up batteries. Both States made this decision to reduce maintenance requirements and potentially to increase reliability of the system.
- Both States now use 12 inch LED flashers and external power sources to operate the system, which may decrease maintenance. (Missouri averages about $250 per year per intersection in energizing costs.)
- Both States retain the flashers in an "On" mode for several seconds, usually between three and seven seconds, after the stopped vehicle leaves the detection area. The time is dependent upon the detector location, width of the intersection, through route speeds, and the distance between the location of the warning sign and the intersection. Flashers are activated every time there is an approaching or stopped vehicle detected on any of the stop approaches.
- Neither State has experienced a vandalism problem with the system.
- Neither State has conducted a survey of public acceptance of the system. However, the unsolicited feedback received from the public and local governments has been overwhelmingly positive. The only negative feedback noted was from a local government at one of the intersections that wanted a traffic signal rather than the ITS warning system. Missouri has also reported that personnel in the Districts where the system has been implemented are pleased with the system's performance.
- While no rigorous crash reduction evaluations have been completed in either State, simple "before and after" crash comparisons in Missouri indicate the following:
  - » Overall average crash reductions – 51 percent.
  - » Reduction in all severe crashes – 59 percent.
  - » Reduction in angle crashes – 58 percent.
  - » Reduction in severe angle crashes – 77 percent.

North Carolina is in the process of acquiring sufficient crash data to perform a more thorough crash analysis. It is anticipated that this analysis will be completed in late 2011.

8. Warning Sign Message Information

The states that have implemented through traffic activated warning systems at stop-controlled intersections have used a number of variations in message content and sign size, shape, and number. In addition to the sign, there have also been variations in the number and location of flashers mounted on the signs.

Four factors needed to be addressed to gain consensus on preferred characteristics:

1. Sign message.
2. Sign size and shape.
3. Number and location of flashers.
4. Number of signs per approach (single or multi-lane approach).

A webinar was held in October 2010 with FHWA safety personnel and stakeholder states to gain consensus on achieving better uniformity among states in each of these factors. The topics and questions discussed are provided in Appendix B. Results of the webinar are as follows.

1. Sign Legend

Participants preferred word legend rather than symbol signs. Issues associated with symbol signs included potential legibility difficulties at long viewing distances and legibility concerns if some of the LED lenses are not lit. Symbol signs also require experimental Manual on Uniform Traffic Control Devices (MUTCD) approval for use while word legends do not. The preferred messages are as follows:

- "Vehicles Entering when Flashing."
- "Watch for Entering Traffic."
- "Watch for Entering Traffic when Flashing."

2. Sign Size and Shape

Both diamond and rectangular shapes are acceptable. Oversize diamond shaped signs on single lane approaches should be either 36 x 36 inches or 48 x 48 inches. On multilane approaches the diamond shaped sign size should be either 48 x 48 inches or 60 x 60 inches. Rectangular shaped signs should use 8 inch lettering for single lane approaches and either 8 or 10 inch (preferable) lettering for multi-lane approaches. The "Watch for Entering Traffic when Flashing" message was preferred compared to the "Watch for Entering Traffic" if there is sufficient lateral width to include the sign. The message should only be displayed on rectangular shaped signs. Figure 7 provides suggested sizes for rectangular "Watch for Entering Traffic When Flashing" signs using 8 and 10 inch letter heights.

3. Number and Location of Beacons

Dual flashing beacons (top and bottom) should be used on diamond shaped signs. Dual flashing beacons (both on top) should be used on rectangular signs.

4. Number of Signs per Approach (Single and Multi-lane Approaches)

For Single Lane Through Approaches, install at least one sign with flashing beacons on the right side. However, it is optional to install dual signs with flashing beacons on both the right and left sides.

For Divided Multilane Through Approaches it is preferred to install dual signs with flashing beacons, one on the right side and one on the left median side.

Typical layouts which illustrate these preferences are provided in Figures 8 and 9.

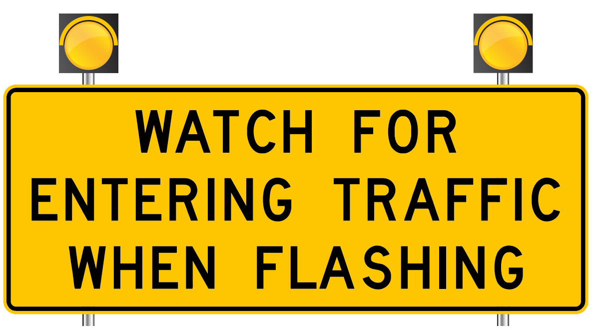
Sign	Letter Height	Overall Size	Speed Limit or 85th percentile speeds
	8″	114″x 48″	< 45 mph
	10″	138″ x 54″	≥ 45 mph

Figure 7: Rectangular Warning Message Sign Dimensions

9. Noteworthy Practices for the Site Selection, Design, and Operation of Successful Through Route Activated Warning Systems

Missouri and North Carolina have achieved successful outcomes in implementing through route activated warning systems at select stop-controlled intersections. This has been accomplished through careful planning and design development throughout the process.

Expansion in the use of this system in other States should be beneficial due to the following:

- Every State has stop-controlled intersections that may be candidates and benefit from this type of improvement in terms of reduced future crash potential.
- The installation cost of the system is low cost, usually in the $15,000 to $35,000 range per intersection.
- Preliminary crash data analyses indicate substantial reduction in crashes, particularly angle crashes, after the system is installed.
- The risk of increased tort exposure and vandalism appears to be very low. Neither Missouri nor North Carolina has experienced any tort suits or vandalism associated with the system.
- Maintenance requirements and energizing costs can be relatively minimal dependent on system design requirements.
- While no formal public evaluation of the system has been undertaken, unsolicited feedback from the public regarding the system has been very positive.

There are, however, commitments and risks associated with implementing the system including the following:

- A modest engineering resource commitment is needed to gain the knowledge and expertise to design and deploy this "new" set of combined technologies successfully.
- A commitment to maintain the system in a functional mode is needed and to keep the time that the system is down to a minimum. Either an automatic notification system or agreements with local governments or maintenance personnel in the immediate vicinity of the system to promptly notify appropriate personnel of a malfunction is needed so that repair can be promptly initiated and completed. The experience in North Carolina and Missouri found that the system will require very little maintenance with few emergency call outs if the components of the system are designed to take maintenance into consideration. The key features that both States designed into the system to reduce future maintenance and call outs included loop detectors placed into stable pavement structures; external power sources to energize the system; and hardwire connections between the detectors, power sources, and LED flashers on warning signs.
- The system may not achieve the crash reduction levels identified in the basic "before and after" analyses once sufficient data is gathered to perform a more rigorous analysis.
- Although North Carolina and Missouri have not experienced any tort suits associated with the system, tort risk exposure could increase if the system is knowingly not operating properly for long periods of time.

Best noteworthy practices have been categorized into the following categories: candidate intersection screening selection; design and construction processes; design provisions; and, maintenance provisions.

Candidate Intersection Screening Selection

Candidate stop-controlled intersections for through route activated warning systems should be initially screened to determine potential success. Two limiting criteria are recommended as follows:

1. Only those stop-controlled intersections that are substantially below the MUTCD warrants for traffic control signals or are not appropriate for roundabout application should be considered. Intersections that are at or near one or more of the warrants may consider traffic signals as a potential solution to known safety concerns.
2. The through route activated warning systems have been predominantly successfully deployed in rural areas or in areas where the through route speed limit is 45 mph or greater. Until additional information is available regarding performance in urban areas, the system should be primarily deployed in rural areas or at intersections where the through route speed limit is at or above 45 mph.

There are three types of stop-controlled intersections which meet this criteria that may be considered for installation of through route activated warning systems as follows:

1. Stop-controlled intersections with a history of total or angle crashes. In analyzing crash data for rural stop-controlled intersections from several states, minimum levels of 10 crashes of all types in 5 years or 5 angle crashes in 5 years may be an appropriate minimum level of crashes to consider applying the technology.
2. Isolated high-speed stop-controlled intersections with substantial sight distance limitations which either cannot be readily mitigated or are too costly to correct. Intersections that meet this criterion and have some history of crashes and near misses should be considered.
3. Isolated stop-controlled intersections on high-speed at-grade arterials that have the potential and or a history for severe angle crashes where J-Turn (or Restricted-Crossing U-turn) treatments that only allow right turn in-right turn out movements are not appropriate safety solutions. In this situation, the through route activated warning system may be considered.

Design and Construction Processes

The established design and construction procedures within a State should be followed. The steps listed below should be considered for addition if they are not already included in the existing processes.

- Schedule and hold a public meeting with local officials, police, and nearby intersection residents to provide information on the through route activated warning system, discuss problems at the intersection, and obtain input regarding installation of the system at the intersection.
- Schedule and hold a pre-bid conference for interested construction contractors to provide information on the through route activated warning system and answer any questions regarding the installation requirements of the system.
- Establish a procedure to test the system in "silent" mode before going "live," including testing the length of time the flashers should remain in a flashing mode once vehicles leave the detection area.
- If an automatic notification system of system malfunction is not built into the design of the system, develop and implement a process where maintenance forces, police, local government may notify the appropriate maintenance personnel of a problem.

Design Provisions

The through route activated warning system may be broken into four separate components as follows:

- Signs and Flashers –Passive warning sign with flashers on the through route that activate when vehicles are detected on any of the side approaches.
- Detectors – Detection of a vehicle approaching or at the intersection on any of the stop approaches.
- Data transmission – Transmission of the detection notification to the through flashers on the sign.
- Energizing the system.

A typical North Carolina DOT layout and plan sheet along with the detailed electrical layout which depicts these components are provided in Appendix A.

Signs and Flashers

Typical sign layouts for single and multilane approaches are provided in Figures 8 and 9. Placement of advance warning signs may use speed limit or 85th percentile speeds on the through approach and Table 2C-4 from the MUTCD, as provided in Table 3 below.

A – Single-lane approach

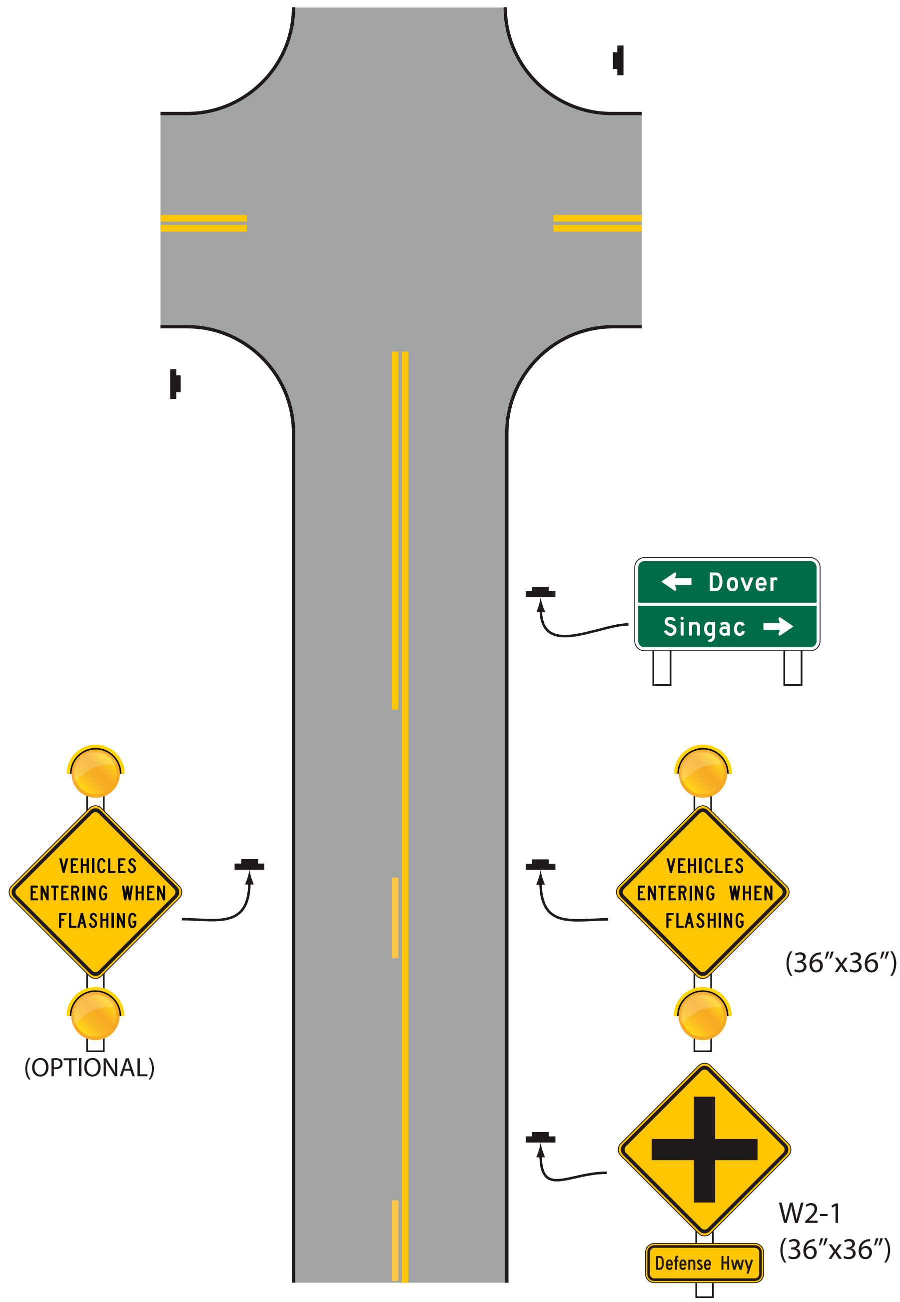


Figure 8: Proposed ITS Warning Sign Location-Single Lane Approach
Figure modified from the MUTCD

Placement of advance warning signs may use speed limit or 85th percentile speeds on the through approach and Table 2C-4 from the MUTCD, below.

Table 2C-4. Guidelines for Advance Placement of Warning Signs

Posted or 85th-Percentile Speed	Advance Placement Distance[1]								
	Condition A: Speed reduction and lane changing in heavy traffic[2]	Condition B: Deceleration to the listed advisory speed (mph) for the condition							
		0[3]	10[4]	20[4]	30[4]	40[4]	50[4]	60[4]	70[4]
20 mph	225 ft	100 ft[6]	N/A[5]	—	—	—	—	—	—
25 mph	325 ft	100 ft[6]	N/A[5]	N/A[5]	—	—	—	—	—
30 mph	460 ft	100 ft[6]	N/A[5]	N/A[5]	—	—	—	—	—
35 mph	565 ft	100 ft[6]	N/A[5]	N/A[5]	N/A[5]	—	—	—	—
40 mph	670 ft	125 ft	100 ft[6]	100 ft[6]	N/A[5]	—	—	—	—
45 mph	775 ft	175 ft	125 ft	100 ft[6]	100 ft[6]	N/A[5]	—	—	—
50 mph	885 ft	250 ft	200 ft	175 ft	125 ft	100 ft[6]	—	—	—
55 mph	990 ft	325 ft	275 ft	225 ft	200 ft	125 ft	N/A[5]	—	—
60 mph	1,100 ft	400 ft	350 ft	325 ft	275 ft	200 ft	100 ft[6]	—	—
65 mph	1,200 ft	475 ft	450 ft	400 ft	350 ft	275 ft	200 ft	100 ft[6]	—
70 mph	1,250 ft	550 ft	525 ft	500 ft	450 ft	375 ft	275 ft	150 ft	—
75 mph	1,350 ft	650 ft	625 ft	600 ft	550 ft	475 ft	375 ft	250 ft	100 ft[6]

[1] The distances are adjusted for a sign legibility distance of 180 feet for Condition A. The distances for Condition B have been adjusted for sign legibiltiy distance of 250 feet, which is appropriate for an alignment warning symbol sign. For Conditions A and B, warning signs with less than 6-inch legend or more than four words, a minimum of 100 feet should be added to the advance placement distance to provide adequate legibility of the warning sign.

[2] Typical conditions are locations where the road user must use extra time to adjust speed and change lanes in heavy traffic because of a complex driving situation. Typical signs are Merge and Right Lane Ends. The distances are determined by providing the driver a PRT of 14.0 to 14.5 seconds for vehicle maneuvers (2005 AASHTO Policy, Exhibit 3-3, Decision Sight Distance, Avoidance Maneuver E) minus the legibility distance of 180 feet the appropriate sign.

[3] Typical condition is the warning of a potential stop situation. Typical signs are Stop Ahead, Yield Ahead, Signal Ahead, and Intersection Warning signs. The distances are based on the 2005 AASHTO Policy, Exhibit 3-1, Stopping Sight Distance, providing a PRT of 2.5 seconds, a deceleration rate of 11.2 feet/second ^{2}, minus the sign legibility distance of 180 feet.

[4] Typical conditions are locations where the road user must decrease speed to maneuver through the warned condition. Typical signs are Turn, Curve, Reverse Turn, or Reverse Curve. The distance is determined by providing a 2.5 second PRT, a vehicle deceleration rate of 10 feet/second^2, minus the sign legibility distance of 250 feet.

[5] No suggested distances are provided for these speeds, as the placement location is dependent on site conditions and other signing. An alignment warning sign may be placed anywhere from the point of curvature up to 100 feet in advance of the curve. However, the alignment warning sign should be installed in advance of the curve and at least 100 feet from any other signs.

[6] The minimum advance placement distance is listed as 100 feet to provide adequate spacing between signs.

Table 3: Table 2C-4 from the 2009 MUTCD

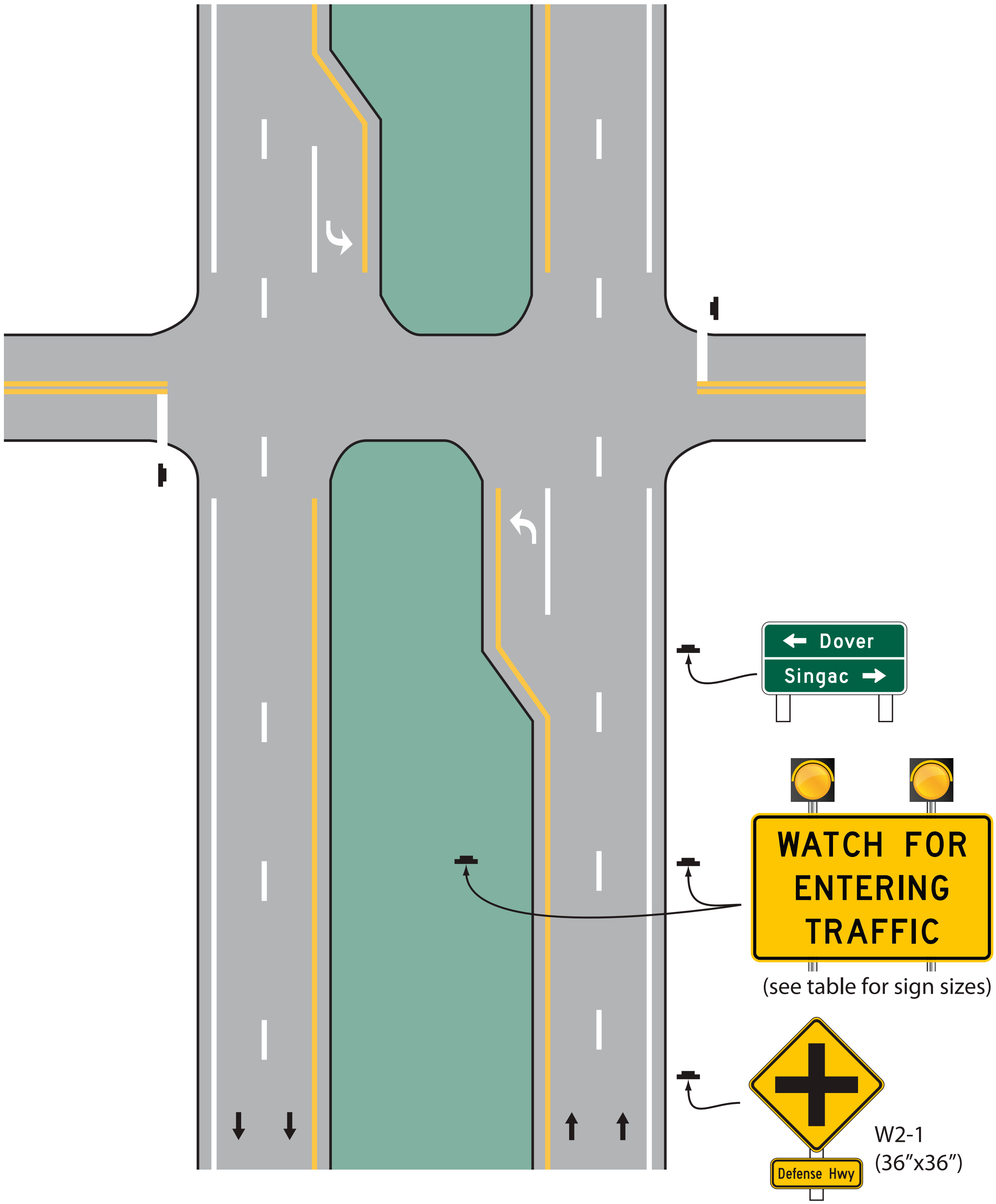


Figure 9: Proposed ITS Warning Sign Location-Multi Lane Approach
Figure modified from the MUTCD

The summary webinar consensus recommendations in the Warning Sign Message Information section of this document for sign message, size and shape, number of flashers, and signs per approach as illustrated in Figure 7 may be used as a guide depending on the intersection configuration for new installations.

While either incandescent or LED flashers may be used, both North Carolina and Missouri have selected LED flashers for these installations to reduce energizing costs and increase longevity of the flasher.

Detectors

All stop approaches should have two detectors per approach; a motion detector to identify vehicles as they approach the stop approach, and a presence detector at the stop to identify vehicles stopped at the intersections awaiting a safe gap to enter. The location of the motion detector (distance back from the intersection) is dependent on the location of the mainline warning sign, through route, and stop route approach speeds.

While a number of detector types can be used, both North Carolina and Missouri have used loop detectors for these installations based primarily on costs and reliability experience.

Data Transmission

Recognition of a vehicle on the stop approach must be transmitted from a detector to a flasher to activate the flashers on the through route warning signs. This may be accomplished by hard wire or wireless. Both North Carolina and Missouri elected to use hard wire and underground conduit to achieve the connection.

Energizing the System

Electrical energy is needed for the data transmission and activation of the flashers. Two options are available: solar energy coupled with back up batteries or external power sources. Both North Carolina and Missouri elected to use external power sources to energize the system. Energy costs are relatively low due to the use of LED flashers at approximately $250 annually.

Maintenance Provisions

Both North Carolina and Missouri designed their systems such that maintenance requirements would be minimal (e.g., use of LED flashers, underground conduit, loops in a stable pavement structure, external power sources). Even with these provisions, maintenance and repair are occasionally needed. Neither State uses an automatic system to notify of a probable system malfunction. They rely on feedback from local maintenance forces, law enforcement, and residents to report problems.

Two maintenance provisions should be in place for through route activated warning systems:

- Either an automatic notification system or coordination with local maintenance forces, police, or residents to notify the appropriate officials of a possible malfunction of the system.
- Capability to promptly respond and address any problems with the system in a timely manner.

Missouri and North Carolina have developed the above noteworthy practices that have led to continued successful application of through route activated warning systems in these States.

10. Summary

Fatalities and severe injuries at stop-controlled intersections are a major safety concern. A small number of these intersections have a substantial number of crashes. Several traditional infrastructure-based countermeasures with varying degrees of effectiveness are available to help reduce the potential for these crashes.

Recently, some infrastructure-based Intelligent Transportation System (ITS) technologies have been used in an innovative way to provide enhanced intersection safety information to entering traffic at stop-controlled intersections compared to traditional sign and marking enhancements. This report discussed available ITS technologies with a focus on those that have lower implementation costs.

Missouri and North Carolina have successfully deployed a through route activated warning system at several stop-controlled intersections. This technology has shown promise in improving safety and is therefore ready for expanded use beyond these States. Knowledge gained as presented in this document from the installations in North Carolina and Missouri for applying the countermeasure at other stop-controlled intersections will be of interest to safety engineers, traffic engineers, and State and local authorities with responsibility for public safety as they build a toolbox of intersection safety strategies and implement them.

Contacts

Additional information on the through route activated warning system may be obtained by contacting:

Rosemarie Anderson
Transportation Specialist
FHWA Office of Safety
202.366.5007

Further information concerning the installations in Missouri, North Carolina, and Minnesota may be obtained by contacting:

Julie Stotlemeyer
Traffic Liaison Engineer
Missouri DOT
573.751.0982

Shawn Troy
Safety Evaluation Engineer
North Carolina DOT
919.773.2897

Jon Jackels
ITS Program Engineer
Minnesota DOT
651.234.7377

Appendix A – Example Through Route Activated Warning System Plan Sheet

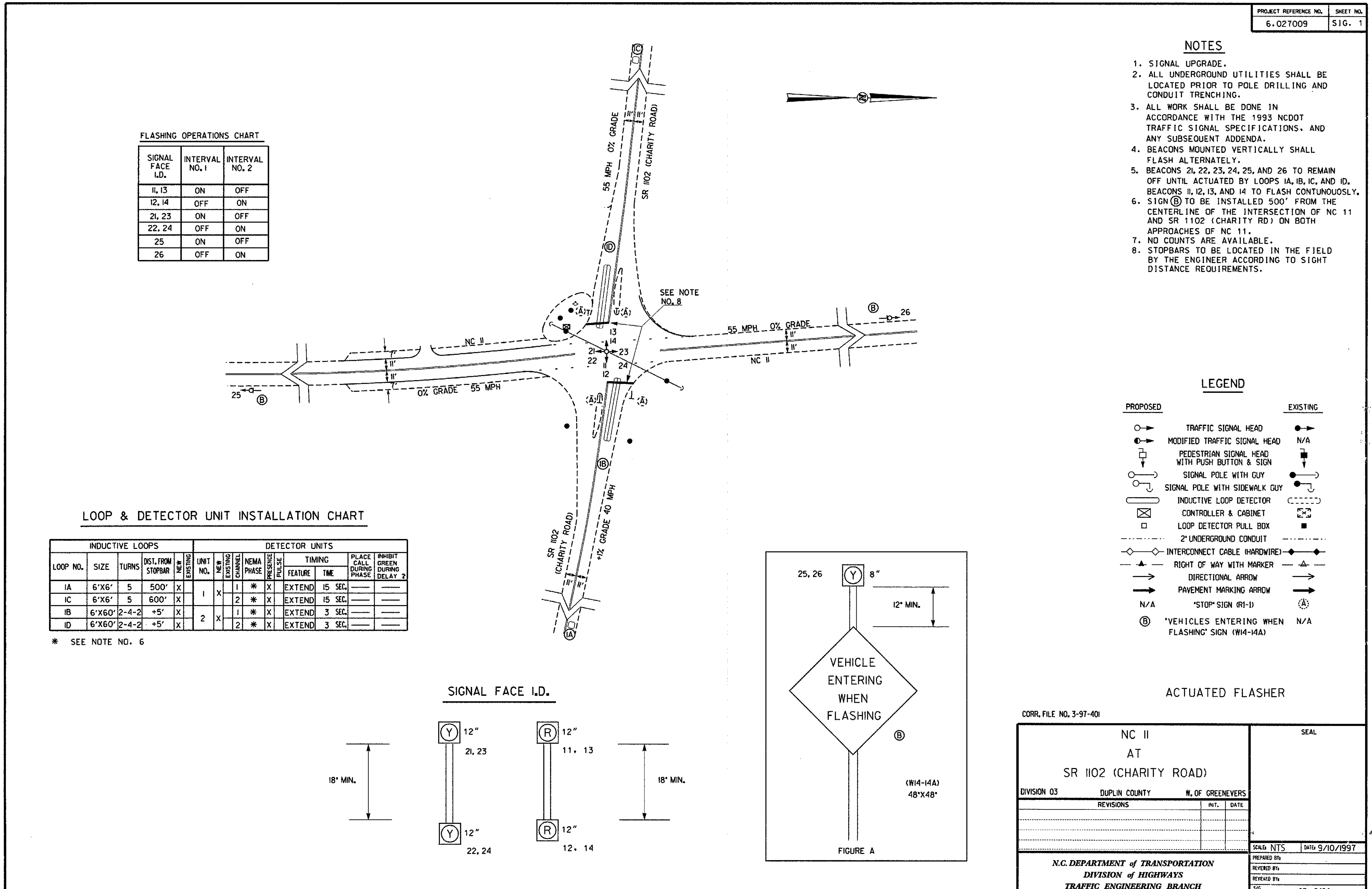


Figure 10: North Carolina Typical Plan Sheet for Through Route Activated Warning System at Stop-Controlled Intersection
Plan courtesy of NCDOT

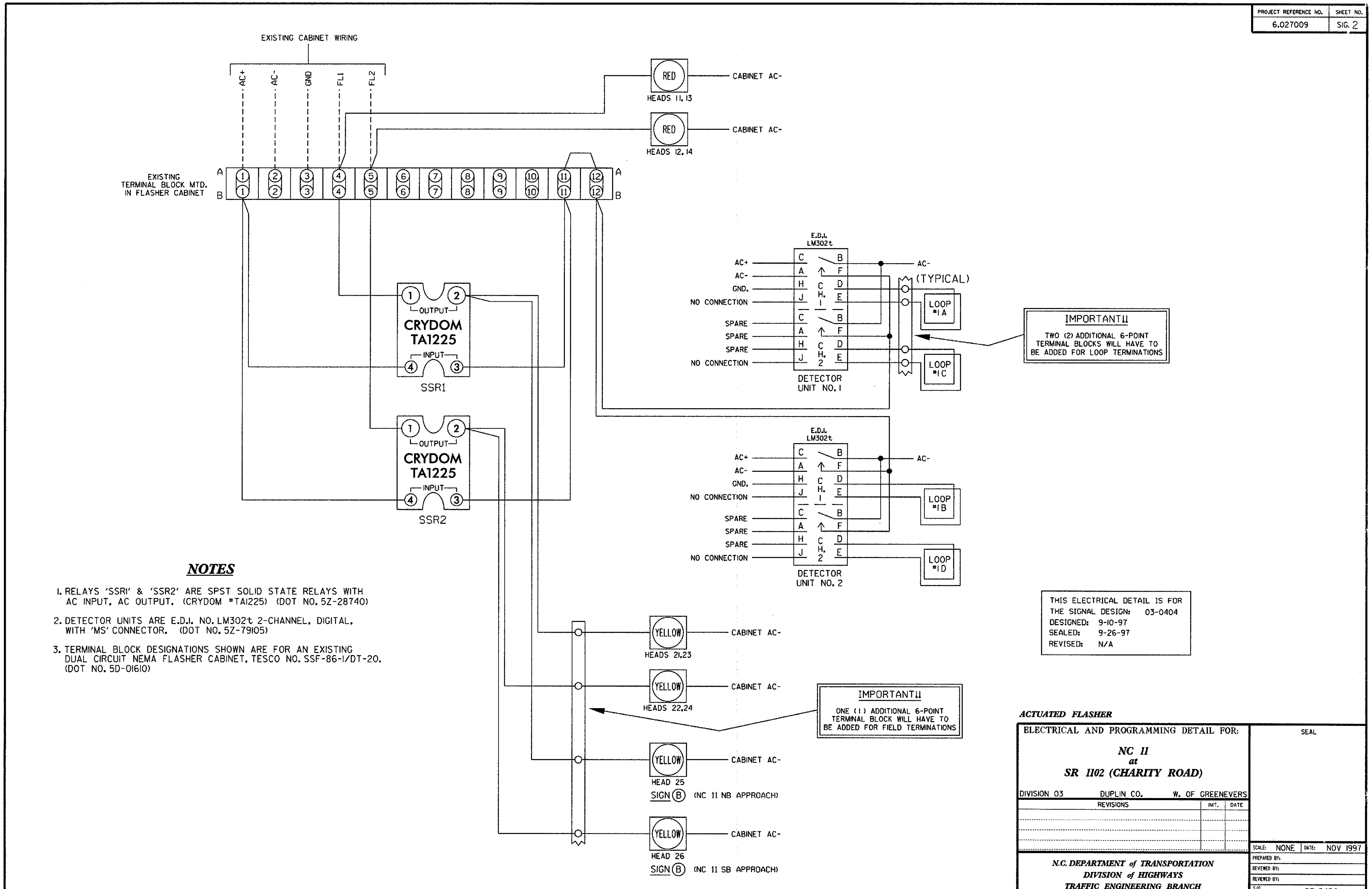


Figure 11: North Carolina Typical Plan Sheet for Through Route Activated Warning System at Stop-Controlled Intersection – Electrical Detail
Plan courtesy of NCDOT

Appendix B – ITS Infrastructure-Based Intersection Warning System Webinar Questions

Signing Options for Through-Approach Activated Warning Systems– Stop-Controlled Intersections

Background: A few states have implemented through traffic activated warning systems at stop-controlled intersections. There have been a number of variations in message content, size, shape, and number of signs used. In addition to the sign, there have also been variations in the number and location of flashers mounted on the signs. The purpose of this discussion is to try and reach consensus on some of these characteristics, such that when other states begin applying the technology, a more consistent message arrangement is provided to approaching drivers.

The intent is to use this system at only stop-controlled intersections that have a significant crash problem (10 or more crashes in five years in rural areas;20 or more crashes in five years in urban areas) or have geometric features (i.e.-reduced site distance) that either cannot or have not been alleviated by standard passive warning systems.

There are five factors to gain consensus on preferred characteristics:

1. **Sign - Legend Message**
2. **Sign - Symbol Message**
3. **Size and Shape of Sign**
4. **Number and Location of Flashers**
5. **Number of Signs per Approach**

1. Sign - Legend Message

States have used various messages on the warning sign- both legend and symbol. The predominant word messages are as follows:

a. Vehicles entering when flashing
b. Vehicles entering
c. Crossing traffic when flashing
d. Standard intersection symbol warning sign with “Entering traffic when flashing”
e. Standard intersection symbol warning sign with “Crossing traffic ahead when flashing”
f. Watch for entering traffic

Questions

Question 1:
For the legend signs, is there a preferred word message or set of messages and if so what is it?

Example Legend Message Signs

North Carolina
Photo courtesy of NCDOT

North Carolina
Photo courtesy of NCDOT

Minnesota
Photo courtesy of Mn/DOT

Virginia
Photo courtesy of VDOT

Missouri
Photo courtesy of MoDOT

2. Sign - Symbol Message

Various symbol signs have been used; examples of these appear on the following page.

Symbol signs that have been used have not received MUTCD approval for widespread use.

Additional legend combinations that can be made that would provide more information to the through driver would be a blank out signs at the bottom of the warning sign that would read 'From Left' and 'From Right'. An example display is as follows: (NOTE: Display the 'entering vehicles when flashing', diamond sign with blank out 'from left' and 'from right' below the sign on the left and right side.

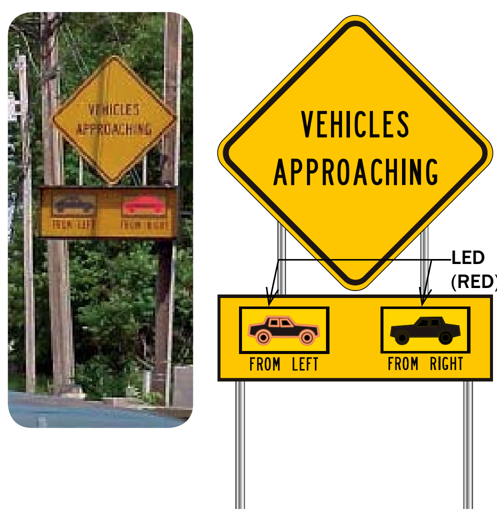
Questions

Question 1:
Is any of the symbol signs considered more effective than a word message in communicating the information to approaching drivers. If so, which one?

Question 2:
Should the symbol LED sign message s be pursued? If so, what message (symbol), if any should be considered using the PA sign as a reference? How should the MUTCD experimental approval requirement be met? (Each state using the symbol, one state representing all states; FHWA; other?)

Example Symbol Message Signs

Pennsylvania
Photo courtesy of PennDOT



Maine
Photo courtesy of MaineDOT

3. Size and Shape of the Sign

States have taken two different directions on the shape of the sign (diamond or rectangular).

The MUTCD standard intersection warning sign (W2-1) size is as follows :

	Single Lane Approach	Multi-lane Approach
W2-1 Size (standard)	30'x30"	36"x36"

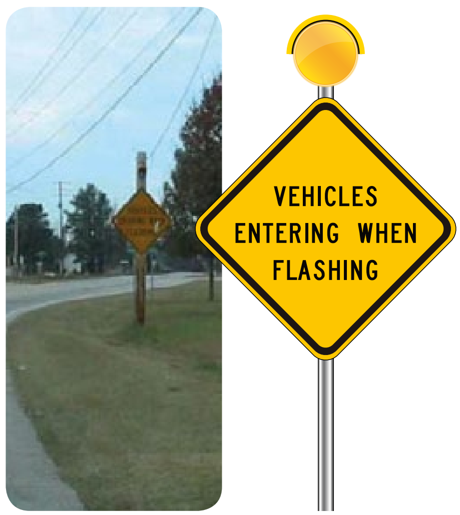
Questions

Question 1:
Is there a difference or preference between using a diamond shape sign or a rectangular shape sign? Are there any concerns with using a rectangular shape for a warning? If so, what is it?

Question 2:
Should the size of the sign be standard or larger?

Question 3:
Should the size of the sign be increased, and if so, one size above the standard size: two sizes above the standard size?

Examples Signs - Various Sizes and Shapes



North Carolina
Photo courtesy of NCDOT

Missouri
Photo courtesy of MoDOT

4. Flashers-Number and Position

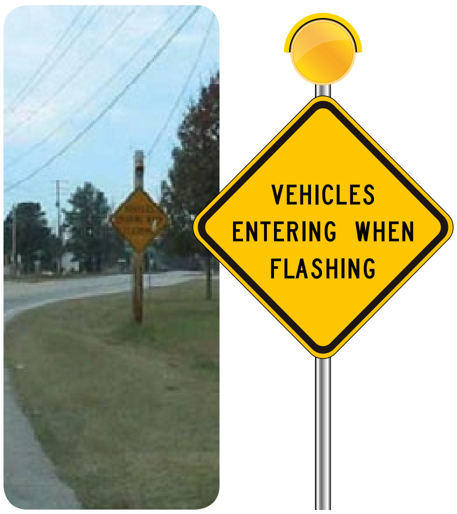
Flashers on diamond signs can be either a single flashers (one above) or dual flashers (one above and one below).

Flashers on rectangular signs probably should be dual flashers (overhead left and right)

Questions

Question 1:
Dual flashers will obviously gain a drivers attention more effectively than the single flasher but they will increase the cost of the system. They will provide some notification to the driver if one flasher malfunctions. Since the intended use of these systems is at stop-controlled intersections with a considerable crash problem or potential, should single or dual flashers be pursued?

Example Signs - Flasher Number and Position



North Carolina
Photo courtesy of NCDOT

North Carolina
Photo courtesy of NCDOT

Missouri
Photo courtesy of MoDOT

5. Number of Signs per Approach

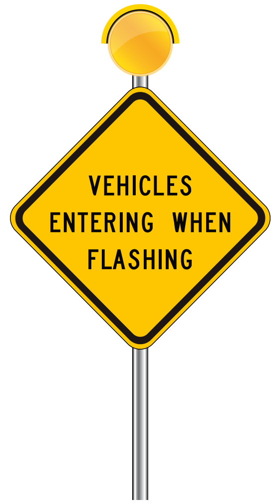
There are four basic options in terms of the number of signs per approach:

Number of Approach Lanes	Number of Warning signs per approach	Number of Warning signs per approach
One	One (right)	Two (one right, one left)
Two	One (right)	Two (one right, one left)

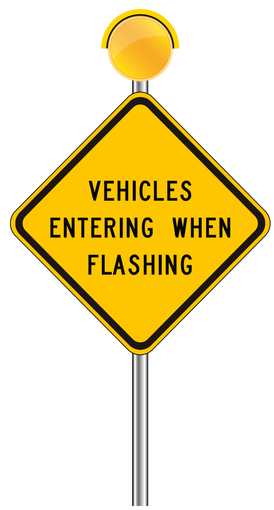
Questions

Question 1:
How many approach warning signs should be used under what conditions?

Example Number of Signs per Approach



North Carolina, single sign
Photo courtesy of NCDOT



North Carolina, double sign
Photo courtesy of NCDOT

For More Information

FHWA Office of Safety
http://safety.fhwa.dot.gov/

U.S. Department of Transportation
Federal Highway Administration