Variances in Advance Warning Signs

Requested by
Theresa Drum, Caltrans Division of Maintenance

April 6, 2015

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Table of Contents

Executive Summary

Background

Caltrans' Division of Maintenance is interested in other states' experience using advance warning signs, especially roll-up signs for temporary traffic control ahead of maintenance lane and shoulder work zone closures. Caltrans would like to determine if other states augment the minimum advance warning sign standards set forth in the Manual of Uniform Traffic Control Devices (MUTCD), and if they have data to show a change in motorist behavior or a reduction in work zone speeds or crashes as a result. Minimum standards may be augmented with optional measures such as additional advance warning signs, duplicate signage (signs placed on both sides of the roadway) and portable changeable message signs (PCMS).

To assist Caltrans in identifying variances, CTC & Associates:

- Surveyed state departments of transportation (DOTs) concerning their variances from the MUTCD when placing signage for maintenance lane and shoulder work zone closures.
- Conducted follow-up interviews by telephone with four states concerning their advance warning sign practices.
- Performed a brief review of literature and resources related to variances in advance warning signs.

Summary of Findings

Survey of Current Practice

To gather information about the use of advance warning signs by other state DOTs, CTC surveyed voting members of the AASHTO Subcommittee on Maintenance. Specifically, we asked about their use of 11 measures for augmenting MUTCD advance warning sign requirements:

- Double signage (signs in the center median and right or left shoulder) when it is not otherwise required.
- Flashing beacons on signs during the day.
- Retroreflective signs during the day.
- Sign colors other than "construction orange."
- Supplemental advance warning signs with law enforcement.
- Supplemental advance warning signs with PCMS.
- Extra signs in the array (additional signs beyond the MUTCD requirement, such as two ROAD WORK AHEAD signs instead of one).
- Deviation (with written approval) from spacing standards (for example, using one-quarter mile spacing instead of one-half mile between ROAD WORK AHEAD and RIGHT LANE CLOSED AHEAD signs).
- LED lighting on advance warning signs.
- Larger font sizes on advance warning signs.

- Other signs, sign combinations or devices to augment the signs in lane or shoulder maintenance work zone closures.

Nine states responded to this survey. Most states use each of these measures. Rarely used exceptions include sign colors other than "construction orange" and LED lighting or larger font sizes on advance warning signs. Several states provided links to details and design standards for signs, but only Washington State DOT provided information about the effectiveness of measures (automated speed enforcement — see http://www.wsdot.wa.gov/NR/rdonlyres/626718B3-A2AE-44FF-9197-79A2F7043493/0/TRBSpeedEnforcement.pdf).

Follow-Up with Selected Survey Respondents

CTC conducted follow-up phone interviews with four state DOTs to better determine the extent to which states were going beyond the MUTCD for work zone warning signs and whether they had measured the impacts of these measures or received informal feedback from the field about their effectiveness:

- Connecticut DOT is currently developing performance measures so that it can better evaluate the effectiveness of its work zone warning signs, is transitioning to the eCrash system for managing traffic accident data and is piloting portable work zone systems to collect data. The agency provided documents related to these systems as well as documentation about an effort to measure the effectiveness of portable speed awareness signs. The system was effective in reducing average driver speeds in the work zone by 11 mph. Significant efforts beyond MUTCD requirements include bright fluorescent (Type 8) sheeting for all signs in the last two years and work zone safety audits.
- Michigan DOT has a project to measure speeds in work zones, but does not yet have a report or data it can share. Significant efforts beyond MUTCD requirements include evaluating the possibility of moving to fluorescent orange for drum sheeting and moving toward wet reflective temporary pavement markings.
- Utah DOT has not measured the effectiveness of warning signs in work zones and does not generally go beyond the MUTCD in its work zone warning sign requirements.
- Washington State DOT has not measured the effectiveness of warning signs in work zones and has no plans to gather data. The agency does not generally go beyond the MUTCD in its work zone requirements for warning signs, but it has been implementing behavior-based safety in the last three months.

Related Research and Resources

CTC found two ongoing projects studying the effectiveness of measures for enhancing work zone safety: one in Oregon focusing on "SPEED 50" signs, PCMS on rollers or stationary trailers, and radar speed reader trailers; and another in Indiana reviewing improving driver alertness in work zones (see **Research in Progress**).

Several studies have evaluated the effectiveness of work zone measures in reducing vehicle speeds, including:

- A 2014 paper reported on a study that found graphic-aided PCMS reduced mean vehicle speeds between 13 percent and 17 percent in the upstream of a work zone.
- A 2014 article in *Traffic Injury Prevention* reported on a study that found portable plastic rumble strips and warning lights used together reduced mean speeds by 19.7 percent.

Gaps in Findings

- Only nine states responded to the survey, despite several follow-up emails.
- Respondents did not provide information about the effectiveness of measures to augment minimum MUTCD advance warning sign standards, and follow-up calls seemed to confirm that respondents are doing little to measure the effectiveness of such measures.

Next Steps

Moving forward, Caltrans could consider following up with:

- Connecticut DOT for an update on its progress in establishing performance measures for evaluating the effectiveness of work zone warning signs.
- Michigan DOT at a future date to see if there is an available report or data from its efforts to measure speeds in work zones.
- Oregon and Indiana about two related research projects, which have expected completion dates in 2015 (see **Research in Progress**).

Detailed Findings

Survey of Current Practice

To gather information about the use of advance warning signs by other state DOTs, CTC contacted voting members of the AASHTO Subcommittee on Maintenance and asked them to complete the following online questionnaire:

> For each of the following measures for augmenting MUTCD advance warning sign requirements, please indicate a) whether your agency has implemented, pilot-tested or tried to implement the measure, and b) whether you have found the measure to contribute to a reduction in work zone collisions, queuing or other significant motorist behavior, such as lane changes, earlier merging or reduced speeds. Please also provide any available documentation (via links or attachments) concerning pilot studies or research your agency has conducted concerning these measures as well as policies and guidance for their use.
>
> - Double signage (signs in the center median and right (or left) shoulder) when it is not otherwise required.
> - Flashing beacons on signs during the day.
> - Retroreflective signs during the day.
> - Sign colors other than "construction orange."
> - Supplemental advance warning signs with law enforcement.
> - Supplemental advance warning signs with portable changeable message signs (PCMS).
> - Extra signs in the array (additional signs beyond the MUTCD requirement, such as two ROAD WORK AHEAD signs instead of one).
> - Deviation (with written approval) from spacing standards (for example, using one-quarter mile spacing instead of one-half mile between ROAD WORK AHEAD and RIGHT LANE CLOSED AHEAD signs).
> - LED lighting on advance warning signs.
> - Larger font sizes on advance warning signs.
> - Other signs, sign combinations or devices to augment the signs in lane or shoulder maintenance work zone closures.

CTC received nine responses to the survey. The full text of all responses is given in **Appendix A**; below is a summary of state use of these measures:

1. **Double signage:** Most DOTs in some circumstances (especially on divided highways) except North Carolina and Utah.
2. **Flashing beacons on signs during the day:** Most DOTs in some cases except North Carolina, North Dakota and Washington State. (Virginia did not respond to this question.)
3. **Retroreflective signs during the day:** All DOTs, although Arizona allows nonretroreflective signs if used solely during daylight hours.

4. **Sign colors other than "construction orange":** Only Michigan. Virginia did not respond to this question.
5. **Supplemental advance warning signs with law enforcement:** Most DOTs except Arizona, Connecticut and North Dakota. Virginia did not respond to this question.
6. **Supplemental advance warning signs with PCMS:** Most DOTs except Connecticut and North Dakota.
7. **Extra signs in the array:** Most DOTs except Connecticut, North Carolina and Utah.
8. **Deviation from spacing standards:** All DOTs in some cases (although rarely in North Carolina, for urban settings).
9. **LED lighting on advance warning signs:** Only Connecticut, on post-mounted but not portable signs. Virginia did not respond to this question.
10. **Larger font sizes on advance warning signs:** Only Arizona, Florida and Virginia.
11. **Other:** Connecticut uses arrow boards, crash attenuator trucks with arrows and orange flags on portable signs. North Carolina uses advance changeable message signs.

Several states provided links to details and design standards for signs, but only Washington State provided information about the effectiveness of measures (automated speed enforcement — see http://www.wsdot.wa.gov/NR/rdonlyres/626718B3-A2AE-44FF-9197-79A2F7043493/0/TRBSpeedEnforcement.pdf).

Follow-Up with Selected Survey Respondents

CTC conducted follow-up phone interviews with selected state DOTs to better determine the extent to which states were going beyond the MUTCD in work zone warning signs, and whether they had measured the impacts of these measures or received informal feedback from the field about their effectiveness.

Connecticut Department of Transportation

Contact: Terri Thompson, Transportation Supervising Engineer, Connecticut Department of Transportation, 860-594-2667, terri.thompson@ct.gov.

Connecticut DOT is currently developing performance measures so that it can better evaluate the effectiveness of its work zone warning signs. It is also moving over to the eCrash system for managing data on traffic accidents and piloting portable work zone systems to collect data, including on Interstate 84 (see **Appendix B**, **Appendix C** and **Appendix D**). It is difficult to establish performance measures; the agency counts citations given, but this isn't a good metric.

Connecticut DOT also measured the effectiveness of a portable system to slow down drivers by using an electronic sign to show them their speed as they approached ("speed awareness"); see **Appendix E**, which includes data on the driver speed in a) a nonwork zone area, b) a work zone with typical signage, c) a speed awareness zone and d) a speed awareness zone with blue and red flashing lights when vehicles traveled over 50 mph. The system was effective in reducing average driver speeds in the work zone by 11 mph.

For measures that go beyond the MUTCD, Connecticut DOT started requiring bright fluorescent (Type 8) sheeting for all signs in the last two years, which is much more visible. It also audits work zone safety (for 2010-2012, see http://www.ct.gov/dot/lib/dot/documents/dconstruction/workzone/2010_Work_Zone_Safety_Review_Final_Report.pdf and http://www.ct.gov/dot/lib/dot/documents/dconstruction/workzone/2011__2012_Work_Zone_Safety_Rport-Final.pdf). These audits revealed that contractors were using lightweight materials for signs, leading to bending and a consequent loss of retroreflectivity at night. As a result of this finding, Connecticut DOT now requires signs with aluminum or wood backing. The agency also requires 42-inch cones and drums at night, more than the 28-inch MUTCD requirement; requires double signing on divided highways (optional in the MUTCD); uses extras signs, such as "Fines Doubled"; and uses law enforcement, which the MUTCD does not address. It has not tried larger fonts, which would require new schematics and larger signs, and it has tried LED lighting on equipment but not on warning signs.

Law enforcement is effective when in use, but speeds go back up when not in use. Connecticut DOT also has legally reduced speeds in work zones as well as using pavement markings indicating a reduced speed. These measures did not seem to make a difference.

Michigan Department of Transportation

Contact: Angie Kremer, Traffic Incident Management Engineer, Michigan Department of Transportation, 517-636-0247, kremera@michigan.gov.

Michigan DOT has a project to measure speeds in work zones, but does not yet have a report or data it can share. The agency is also unable to provide feedback from the field about the effectiveness of traffic controls. Work zone fatalities increased during the last year.

For measures that go beyond MUTCD requirements, Michigan DOT is evaluating the possibility of moving to fluorescent orange for drum sheeting and is moving toward wet reflective temporary pavement markings.

Utah Department of Transportation

Contact: Kevin Griffin, Director of Maintenance, Utah Department of Transportation, 801-965-4120, kgriffin@utah.gov.

Utah DOT has not measured the effectiveness of warning signs in work zones. It may do so in the future but has no formal plans. It would like to determine the amount of funding required to meet various performance levels.

Washington State Department of Transportation

Contact: Steve Haapala, Work Zone Training Specialist, Washington State Department of Transportation, 360-705-7241, haapals@wsdot.wa.gov.

Washington DOT has not measured the effectiveness of warning signs in work zones, has no plans to gather data and doesn't have informal feedback from the field about their effectiveness. Haapala believes there is a little more compliance in areas with "Fines Doubled" signs.

The agency has been implementing behavior-based safety in the last three months. Pioneered in the mining industry, this methodology requires everyone in a department — whether in the office or the field — to do a safety analysis of something once a month. Any deficiencies in safety are immediately addressed by a management team. Outside of this measure, Washington DOT does not generally go beyond the MUTCD in its work zone requirements. Liability is a factor; according to Haapala, it's important to maintain consistency and not make extra measures seem like the norm. Consequently, deviations require approval at the regional level by a region traffic engineer.

Washington DOT does use law enforcement quite a bit; there is a huge benefit from having it on projects (both enforcement and the presence of vehicles at sites). And it legally reduces speeds in work zones.

Related Research and Resources

General Guidance

NCHRP Report 746: Traffic Enforcement Strategies for Work Zones, Gerald Ullman, Marcus Brewer, James Bryden, Michael Corkran, C.W. Hubbs, Andre Chandra and Krista Jeannotte, 2013.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_746.pdf
From the abstract: This report presents guidance for the safe and effective deployment of traffic enforcement strategies in work zones on high-speed highways (those with speed limits of 45 mph or greater). The planning, design, and operation of traffic enforcement strategies are discussed, as well as administrative issues that should be addressed. The report will be useful to traffic and construction engineers engaged in these types of projects.

NCHRP Report 500, Volume 17: A Guide for Reducing Work Zone Collisions, Nicholas Antonucci, Kelly Hardy, James Bryden, Timothy Neuman, Ronald Pfefer and Kevin Slack, 2005.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v17.pdf
This guide provides strategies that can be employed to reduce work zone crashes.

"Temporary Traffic Control Zone Devices," Chapter 6F, *Manual on Uniform Traffic Control Devices*, 2009.
http://mutcd.fhwa.dot.gov/htm/2009/part6/part6f.htm
This chapter includes standards for work zone signs.

California Manual on Uniform Traffic Control Devices, Caltrans, 2014.
http://www.dot.ca.gov/hq/traffops/engineering/mutcd/pdf/camutcd2014/CAMUTCD2014.pdf
Section 6F gives guidance on temporary traffic control zone devices.

Research in Progress

Safe and Effective Speed Reductions for Freeway Work Zones Phase 2, Oregon Department of Transportation, ongoing, end date: February 2015.
Citation at http://trid.trb.org/view/2013/P/1308532
From the abstract: The overall goal of the research is to assist the Oregon Department of Transportation (ODOT) with enhancing the safety of motorists and workers in construction work zones on high-speed roadways. The research includes conducting two additional case studies on paving projects similar to those studied in the SPR-751 study. In addition, as recommended

in the SPR-751 final report, the research will include a fewer number of treatments focused on the following specific traffic control measures: “SPEED 50” signs, Portable Changeable Message Signs (PCMS) on a roller(s) or a stationary trailer(s), and radar speed reader trailers. The research is expected to enhance the data already collected on specific treatments and provide guidance to ODOT. The research will take an additional step toward further improvement in safety for highway workers and the driving public with the support of the Federal Highway Administration (FHWA) and the [Associated General Contractors of America]. The specific objectives for this research study are to: (1) Identify potential case study projects and select two projects to study as part of the research. (2) Implement the selected traffic control measures (“SPEED 50” signs, PCMS signs, and radar speed readers) on the case study projects. (3) Compare the performance of the implemented treatments based on their ability to lower speeds a significant amount, ability to minimize speed variability, ease of use, and implementation cost. (4) Develop guidance for ODOT and construction contractors to reference when planning and implementing traffic control measures on highway preservation projects. The research will focus on effective means to reduce actual speeds in work zones. This includes methods to safely reduce legal posted speeds as well as find measures that reduce actual speed without relying on a posted speed reduction. Research products may include advanced traffic control plans and guidelines for [Oregon State Police] activities under these conditions. All of the resources and tools necessary for data collection and analysis are already available from the SPR-751 study. The researchers will be able to utilize their experience and knowledge learned to efficiently and effectively conduct the additional case studies.

Synthesis Study: Best Practices for Maximizing Driver Attention to Work Zone Signs (End of Queue Warning Devices), Indiana Department of Transportation, ongoing, end date: August 2015.
Citation at http://trid.trb.org/view/2014/P/1322206
From the abstract: Methods for attracting driver’s attention either within or in advance of those work zones will be the study focus and the intent will be to provide a database that will comprehensively review solutions that will alert drivers entering work zones from previously conducted studies. The document will potentially assist INDOT in identifying and selecting candidate solutions for improving driver alertness for future implementation and evaluation in construction work zones.

Related Research

“Effectiveness of Graphic-Aided Portable Changeable Message Signs in Reducing Vehicle Speeds in Highway Work Zones,” Yilei Huang and Yong Bai, *Transportation Research Part C: Emerging Technologies*, Vol. 48, pages 311-321, November 2014.
Citation at http://trid.trb.org/view/2014/C/1330606
From the abstract: This paper presents the results of field experiments that were conducted to determine the effectiveness of graphic-aided PCMS in reducing vehicle speeds in the upstream of highway work zones. In field experiment Phase I, a full-matrix PCMS was programmed to display a work zone graphic and a flagger graphic, which were similar to the W21-1 sign and W20-7 sign, respectively, specified by the Manual on Uniform Traffic Control Devices. In field experiment Phase II, the PCMS was programmed to display two alternative work zone graphics along with the original work zone graphic. 1115 and 1600 valid vehicle speed data were collected during field experiments Phase I and Phase II, respectively. The results of data analysis suggested that graphic-aided PCMSs reduced mean vehicle speeds between 13% and 17% in the upstream of a work zone. This study provided valuable knowledge to government agencies and the transportation industry on how to regulate and implement graphic-aided PCMS in highway work zones.

Synthesis of Intelligent Work Zone Practices, Michigan Department of Transportation, June 2014.
http://enterprise.prog.org/Projects/2010_Present/iwz/ENT_SynthesisofIWZPractices_FINALReport_June2014.pdf
This project includes a literature search on the following Intelligent Work Zone technologies: queue warning systems, dynamic merge systems, alternate routes and variable speed limits in work zones. These include links to cases in which states have deployed these methods.

"Investigating Motorists' Behaviors in Response to Supplementary Traffic Control Devices at Land Surveying Work Sites," *Traffic Injury Prevention*, Vol. 15, No. 4, pages 424-430, May 2014.
Citation at http://trid.trb.org/view/2014/C/1298919
From the abstract: This article [investigates] motorist behaviors in response to the use of 2 supplementary TCDs at land surveying work sites: portable plastic rumble strips (PPRS) and warning lights. Extensive field tests were conducted at various land surveying work sites on 2-lane 2-way urban roadways in New Jersey. Scenarios with and without the use of the supplemental TCDs were designed. Motorists' behavior changes were then statistically examined by using surrogate safety measures including mean speed, speed variance, speed limit compliance, and braking action. Statistical analyses showed that the traffic speed variations did not significantly increase when the selected supplemental TCD was used; rather, motorists significantly reduced their driving speed. When warning lights and PPRS were separately deployed at the land surveying work sites the average reduction in mean speed was 6.7 and 15.2 percent, respectively. The mean speed was reduced by 19.7 percent when both of these supplementary TCDs were used. Logistic regression models developed to examine the speeding and braking behavior also showed that motorists were more likely to comply with the speed limit and increase their braking rate when the selected TCDs were used. The use of supplemental TCDs can greatly contribute to the changes in motorists' behaviors at surveying work sites. The changes in motorists' driving behaviors imply that the motorists reacted favorably to the deployed TCDs at the land-surveying work sites.

"Cost-Effectiveness Evaluation of Steady-Burn Warning Lights in Work Zones," LuAnn Theiss, Michael Pratt and Gerald Ullman, *TRB 93rd Annual Meeting*, 2014.
http://docs.trb.org/prp/14-3822.pdf
From the abstract: The 2009 Manual on Uniform Traffic Control Devices (MUTCD) recognizes the potential safety benefit of providing enhanced delineation on temporary traffic control (TTC) devices and allows for warning light enhancements on channelizing devices and temporary barrier walls. The argument for using warning lights in work zones is that they provide an incremental benefit to safety. Ideally, the additional costs of using warning lights should be offset by that safety benefit; in other words, the reduction in crash costs should equal or exceed the costs of the devices. In this study, the researchers collected and analyzed steady-burn warning light cost data, computed the crash cost increases that could be expected to occur in two types of work zones, and computed the crash cost reductions (i.e., safety benefits) that would have to occur by using the steady-burn warning lights in order to justify their use on a benefit-cost basis. Based on the results of this cost-effectiveness evaluation, the researchers recommended that the use of steady-burn warning lights in work zones be discontinued.

"Implementation of Traffic Control Devices on Highway Preservation Projects to Enhance Construction Work Zone Safety," Fan Zhang, John Gambatese and Ali Moghaddam Vahed, *Construction Research Congress 2014: Construction in a Global Network*, pages 1782-1791, May 2014.
Citation at http://trid.trb.org/view/2014/C/1309203
From the abstract: To provide guidance on how to enhance work zone safety effectively and efficiently, a research study was conducted to investigate selected traffic control devices within highway preservation project work zones. The researchers implemented multiple traffic control devices on two case study projects and evaluated their effect on vehicle speed, construction productivity, cost, and motorist and worker safety. Interviews were conducted onsite to collect worker's opinions toward traffic control devices implemented each night. Speed data were gathered to evaluate the effectiveness of traffic control devices. A police officer parked onsite was found to reduce traffic speeds effectively and also was highly recommended by interviewees. The research findings also suggest using a combination of temporary reduced speed limit signs, radar speed monitoring display, and portable changeable message signs (PCMS) on both trailers and rollers.

Investigation of Alternative Work Zone Merging Sign Configurations, Missouri Department of Transportation, 2013.
http://library.modot.mo.gov/RDT/reports/TRyy1318/cmr14-018.pdf
From the abstract: This study investigated the effect of an alternative merge sign configuration within a freeway work zone. In this alternative configuration, the graphical lane closed sign from the Manual on Uniform Traffic Control Devices (MUTCD) was compared with a MERGE/arrow sign on one side and a RIGHT LANE CLOSED sign on the other side. The study measured driver behavior characteristics including speeds and open lane occupancies. The measurements were taken at two identical work zones on Interstate-70 in Missouri, one with the new test sign and the other with the standard MUTCD sign. The study found that the open lane occupancy upstream of the merge sign was higher for the test sign in comparison to the MUTCD sign. Occupancy values at different distances between the merge sign and the taper were similar for both signs. The test sign had 11% more traffic in the open lane upstream of the merge sign. In terms of safety, it is desirable for vehicles to occupy the open lane as far upstream from the taper as possible to avoid conflicts due to the lane drop. Thus, the test sign proved to be a good alternative to the MUTCD sign. The analysis of speed characteristics did not reveal substantial differences between the two sign configurations. The 85th percentile speeds with the MUTCD sign were 1 mph and 2 mph lower than the test sign at the merge sign and taper locations, respectively.

Evaluation of Variable Advisory Speed Limits in Work Zones, Iowa Department of Transportation, Federal Highway Administration, August 2013.
http://publications.iowa.gov/14932/1/IA_DOT_TPF-5-081_InTrans_variable_advisory_speeds.pdf
From the abstract: Variable advisory speed limit (VASL) systems could be effective at both urban and rural work zones, at both uncongested and congested sites. At uncongested urban work zones, the average speeds with VASL were lower than without VASL. But the standard deviation of speeds with VASL was higher. The increase in standard deviation may be due to the advisory nature of VASL. The speed limit compliance with VASL was about eight times greater than without VASL. At the congested sites, the VASL was effective in making drivers slow down gradually as they approached the work zone, reducing any sudden changes in speeds. Mobility-wise the use of VASL resulted in a decrease in average queue length, throughput, number of stops, and an increase in travel time. Several surrogate safety measures also demonstrated the benefits of VASL in congested work zones. VASL deployments in rural

work zones resulted in reductions in mean speed, speed variance, and 85th percentile speeds downstream of the VASL sign. The study makes the following recommendations based on the case studies investigated: 1. The use of VASL is recommended for uncongested work zones to achieve better speed compliance and lower speeds. Greater enforcement of regulatory speed limits could help to decrease the standard deviation in speeds. 2. The use of VASL to complement the static speed limits in rural work zones is beneficial even if the VASL is only used to display the static speed limits. It leads to safer traffic conditions by encouraging traffic to slow down gradually and by reminding traffic of the reduced speed limit. A well-designed VASL algorithm, like the P5 algorithm developed in this study, can significantly improve the mobility and safety conditions in congested work zones. The use of simulation is recommended for optimizing the VASL algorithms before field deployment.

"Hybrid Work Zone Information System with Portable Changeable Message Signs and Dedicated Short-Range Communication," *Transportation Research Record 2380*, pages 29-35, 2013.
Citation at http://trid.trb.org/view/2013/C/1241344
From the abstract: The future deployment of dedicated short-range communication (DSRC) technology requires that applications with their bases in DSRC be integrated with existing traffic management techniques so that vehicles not equipped with DSRC at the early stage of DSRC deployment can also reap the potential benefits of DSRC technology. A hybrid traffic information system was successfully developed; it combines DSRC technology and portable changeable message signs (PCMSs) for use in the work zone environment to improve traffic mobility and thereby driver safety. The developed system uses DSRC-based vehicle-to-infrastructure and vehicle-to-vehicle communication to acquire travel safety parameters, such as travel time (TT) and the starting location of congestion (SLoC), and to disseminate these parameters to DSRC-equipped vehicles and PCMSs, which are strategically placed along the roadside. Through the use of the DSRC-PCMS interface developed and demonstrated in this work, PCMSs can receive these travel safety parameters from nearby DSRC-equipped vehicles on the road through DSRC-based vehicle-to-vehicle communication, and display them for the drivers of vehicles that lack DSRC capability. Such a system can be useful during the early stage of DSRC deployment when DSRC market penetration is low. In addition, a rigorous analysis was conducted to investigate the minimum DSRC market penetration rate needed for successful functionality of the developed system with respect to both acquisition and dissemination of TT and SLoC. Through the use of a realistic traffic flow model, guidelines were developed to estimate a minimum DSRC penetration rate needed to deploy the developed system for a variety of traffic scenarios on a given work zone road.

Portable, Non-Intrusive Advance Warning Devices for Work Zones with or without Flag Operators, John Hourdos, Minnesota Department of Transportation, October 2012.
http://www.cts.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=2292
From the abstract: The main objective of this study was to develop a work zone alert system informing speeding drivers of the upcoming work zone and raising their attention level before they reach the taper line and/or the work zone flag operator. The resulting system, termed Intelligent Drum Line (IDL), is capable of delivering visual and auditory warnings, targeting vehicles that are exceeding the posted or temporary speed limit upstream of the work zone. The IDL system, in its final incarnation, is the best compromise that can be reached between developing a low-cost system that is rugged enough to be deployed on the shoulder of high-speed roadways and comprised of as few individual parts as possible so a single work zone worker can deploy and move the system as the work zone operations are progressing and delivery of a warning targeted only at vehicles that are going faster than the desired speed set by the work zone crew. The IDL system has been tested in the MnROAD facility, targeting

vehicles ranging from regular passenger vehicles to a 3-ton snowplow truck. The auditory warning has been successful in penetrating the vehicle cab and loud enough to attract the attention of the driver. Although, still in a prototype stage, the IDL system has received high marks from MnDOT engineers and work zone workers. Further development is needed to ensure that the final product is crash proof and that it can be produced efficiently.

Evaluation of Methods to Reduce Speeds in Work Zones, Caltrans, June 2012.
http://ahmct.ucdavis.edu/pdf/UCD-ARR-12-06-30-06.pdf
From the abstract: This study [evaluated] the effectiveness of California Highway Patrol (CHP) combination Radar Detection/Changeable Message Sign (CMS) (CHP-CMS) trailers to manage traffic speeds in work zones. The CHP-CMS trailer is a radar-equipped unit outfitted with revolving or flashing lights similar to those used on CHP vehicles. This study investigated whether it provides an effective deterrent to speeding, thereby slowing traffic in the work zones. Three field tests provided preliminary validation and further testing is recommended due to the limited nature of the tests. The research developed a repeatable test methodology based on the use of easily deployable speed sensors distributed throughout the work zone. Additional sensors were also used for validation and collection of other pertinent data. Data was also collected on the combined utilization of the CHP-CMS trailer and a CHP vehicle as in MAZEEP (Maintenance Zone Enhanced Enforcement Program) and its effect on traffic speed reduction at work zones. The use of the CHP-CMS system does result in a deterrent to speeding vehicles near work zones and its use can therefore improve work zone safety.

Work Zone Speed Reduction Utilizing Dynamic Speed Signs, Deborah McAvoy, Ohio University, 2011.
Citation at http://trid.trb.org/view/2011/M/1118479
From the abstract: A simulator study was used in this research to determine speed compliance based upon dynamic speed design and presence. The scenarios designed for this research simulated driving through a highway work zone with a right lane closure. Each participant drove through a control scenario and four experimental scenarios subdivided into five areas for data collection. The four experimental scenarios included dynamic speed signs in place of the regulatory speed limit sign as follows: (1) Steady 'SLOW DOWN 45', (2) Flashing 'SLOW DOWN 45', (3) Steady 'SPEED LIMIT 45' and (4) Steady 'SPEED LIMIT 65'. The five areas included the following: (1) Before the first work zone sign, (2) Between the first work zone sign and the dynamic speed sign, (3) Between the dynamic speed sign and the lane closure, (4) Between the lane closure and the end of the work zone, and (5) After the work zone. Comparisons were made of the measures of effectiveness (speed, lane position, acceleration, deceleration, gap, time to collision, latency of visual detection, average fixation durations and the proportion of target fixations) to assess compliance with the speed limit and changes in driver behavior. When using dynamic message signs stating 'SLOW DOWN 45', participants maintained the speed limit prior to entering the work zone and through the work zone as compared to scenarios using regulatory signs or dynamic message signs displaying the speed limit. The dynamic message signs did not create unsafe driving conditions based upon the analysis of the other measures of effectiveness studied.

"Analyzing Motorists' Responses to Temporary Signage in Highway Work Zones," *Safety Science*, Vol. 48, Issue 2, pages 215-221, 2010.
Citation at http://trid.trb.org/view/2010/C/907155
From the abstract: For decades, the importance of highway work zone safety has increased considerably with the continual increase in the number of highway work zones present on highways for repairs and expansion. Rural work zones on two-lane highways are particularly hazardous and cause a significant safety concern due to the disruption of regular traffic flow. In

this study, researchers determined motorists' responses to warning signs in rural, two-lane highway work zones. The researchers divided vehicles into three classes (passenger car, truck, and semitrailer) and compared the mean change in speed of these classes based on three different sign setups: portable changeable message sign (PCMS) OFF, PCMS ON with the message of Slow Down, Drive Safely, and a temporary traffic sign (W20-1, "Road Work Ahead"). Field experiments were conducted on two two-lane work zones with flagger control. Statistical analyses were performed to determine whether there was a significant interaction between motorists' responses and the sign setups. Data analysis results show that a visible PCMS, either turned on or off, was most effective in reducing truck speeds in rural, two-lane work zones. The temporary traffic sign (W20-1) was more effective in reducing the vehicle speeds of passenger car and semitrailer. Results of this research project will help traffic engineers to better design the two-lane work zone setup and take necessary safety countermeasures to prevent vehicle crashes.

"Evaluation of Work Zone Speed Reduction Measures," Liande Zhong and Dezao Hou, *Proceedings of the 10th International Conference of Chinese Transportation Professionals*, pages 226-233, 2010.
Citation at http://trid.trb.org/view/2010/C/1090353
From the abstract: The relationship between vehicle speed and crash severity is unquestionably based on the laws of physics. That is, the probability of injury, and the severity of injuries that occur in a crash, increase or decrease as a function of vehicular speed. To increase compliance with the reduced work zone speed limit, consideration should be given to speed control techniques other than regulatory or advisory speed limits. This research conducted an evaluation of several speed reduction measures at work zone of highway in China. The speed reduction measures include regulatory speed limit signs, speed bumps, as well as a new type of three-dimensional speed markings. The speed distribution patterns and some statistics of upstream and downstream of the control measures were presented. It was concluded that the effect of the individual speed limit sign was limited, which cannot achieve the desired results. The three-dimensional speed markings took effect to some extent, which can reduce the average speed by 8 km/h. The speed bump showed measurable positive results, which make the average speed decrease by 17 km/h, as well as a large speed variance and also cause the vehicles queuing easily.

"Determining the Effectiveness of Portable Changeable Message Signs in Work Zones," Umar Firman, Yue Li and Yong Bai, *Proceedings of the 2009 Mid-Continent Transportation Research Symposium*, 2009.
Citation at http://trid.trb.org/view/2009/C/899960
From the abstract: Due to the rising needs in highway maintenance and construction, the number of work zones is increasing all across the nation. Highway work zones disrupt normal traffic flow and create safety problems. There were a total of 1,010 fatalities and more than 40,000 injuries in the United States in 2006. Even though there are some countermeasures developed to improve the safety of work zones, there is still a lot of room for improvements. To improve the effectiveness of existing countermeasures and to develop new countermeasures, evaluation of the existing countermeasures is essential. The objective of this research project was to evaluate the effectiveness of a Portable Changeable Message Sign (PCMS) on reducing vehicular speeds in the upstream of rural two-lane highway work zones. This objective was accomplished using field experiments conducted on US 36 located in Seneca, Kansas. During field experiments, the effectiveness of the PCMS was evaluated under two different conditions: (1) PCMS switched on and (2) PCMS switched off. Based on the data analysis results, the PCMS switched on condition reduced the vehicle speeds significantly compared to the PCMS switched off condition. Vehicles with slow speeds approaching a work zone are more likely to

reduce the probability of having crashes. The major contribution of this research project was to quantify the effectiveness of PCMS in rural two-lane work zones which had not been studied in detail.

"Examination of Effectiveness of Early Merge Work-Zone Signing," *TRB 88th Annual Meeting Compendium of Papers DVD*, Paper #09-3766, 2009.
Citation at http://trid.trb.org/view/2009/C/882451
From the abstract: This research examined the safety and operational benefits of having traffic merge early into the open lane prior to a work zone merge area. A 2007 law in Oklahoma adopted the use of additional "STATE LAW MERGE NOW" static signing in the advance warning areas approximately 1/2-mile upstream from freeway merge areas. Work zones that were continuations from the 2006 construction season did not use this signing, while new work zones did. This provided a unique opportunity to compare the impact of early merge signing in actual work zone environments. Measures of effectiveness examined included the number and percentage of traffic that remained in the closed lane and the number of conflicts that occurred at the merge area. It was found that the early merge signs did not appear to reduce the percentage of vehicles that remained in the closed lane. However, at least for right-lane closures, there appeared to be a significant benefit to using the STATE LAW MERGE NOW signing to reduce the number of observed conflicts at the merge area. This was evident when the hourly volumes were more than 550 vph. It seemed likely that although the early merge signs themselves did not improve early merging, the signs seemed to encourage drivers to consider earlier how they would make their merge maneuver, so when they reached the merge area the drivers that must merge were more likely to be able to make the merge without the need to vie for position against other drivers.

Workzone Safety Improvements through Enhanced Warning Signal Devices, PATH Research Report, Caltrans, 2008.
Citation at http://trid.trb.org/view/2008/M/850367
From the abstract: This report describes a project which developed and tested two warning devices for work zones: 1) an improved emergency warning light (EWL) intended specifically for the California Department of Transportation (Caltrans) work zone vehicles; and, 2) an enhanced rear warning light for shadow trucks. Both devices are intended to improve visibility and conspicuity, and to reduce reaction times for drivers approaching the work zone.

Contacts

CTC contacted the organizations below to gather information for this investigation.

State Agencies

Connecticut

Terri Thompson
Transportation Supervising Engineer
Connecticut Department of Transportation
860-594-2667, terri.thompson@ct.gov

Michigan

Angie Kremer
Traffic Incident Management Engineer
Michigan Department of Transportation
517-636-0247, kremera@michigan.gov

Utah

Kevin Griffin
Director of Maintenance
Utah Department of Transportation
801-965-4120, kgriffin@utah.gov

Washington

Steve Haapala
Work Zone Training Specialist
Washington State Department of Transportation
360-705-7241, haapals@wsdot.wa.gov

Appendices

Appendix A: Complete Survey Responses

Arizona

Contact: Richard Moeur, Traffic Standards Engineer, Arizona Department of Transportation, 602-712-6661, rmoeur@azdot.gov.

1. **Double signage:** Double signage is used per MUTCD TAs on divided roadways. Not typically used elsewhere.
2. **Flashing beacons on signs during the day:** Type B warning lights in 24-hour operation have been used on signs on freeways and high-volume highways.
3. **Retroreflective signs during the day:** ADOT PGP 380 requires all work zone signs to be retroreflective, unless used solely during daylight hours.
4. **Sign colors other than "construction orange":** ADOT follows the MUTCD on sign color (no non-standard colors). ADOT stored specification 1007 requires the use of fluorescent orange sheeting for all retroreflective orange signs.
5. **Supplemental advance warning signs with law enforcement:** Law enforcement is used on ADOT construction work zone activities, but not typically assigned to the vicinity of traffic control device(s).
6. **Supplemental advance warning signs with PCMS:** ADOT contractors (and maintenance forces) extensively use PCMS in work zone traffic control.
7. **Extra signs in the array:** ADOT practice is to generally follow the TAs in the MUTCD and the ADOT Traffic Control Design Guidelines (TCDG), unless there is a compelling reason to vary for a specific project (using extra devices in one work zone but not another can have risk management implications).
8. **Deviation from spacing standards:** This can be specified by the design engineer or resident engineer based on site conditions.
9. **LED lighting on advance warning signs:** LEDs within signs in work zones is not typical Arizona practice.
10. **Larger font sizes on advance warning signs:** ADOT follows our own Manual of Approved Signs (MOAS), which uses some FHWA SHS and some Arizona-specific sign designs. Some Arizona-specific signs do use larger letters.
11. **Other:** ADOT typically uses MUTCD-standard devices and treatments in work zones. Above references can be found at http://azdot.gov/business/engineering-and-construction/traffic.

Connecticut

Contact: Terri Thompson, Transportation Supervising Engineer, Connecticut Department of Transportation, 860-594-2667, Terri.Thompson@ct.gov.

1. **Double signage:** Yes, if space permits. CTDOT requires double signing on divided highways. See the traffic plans included in the provided links.
2. **Flashing beacons on signs during the day:** Not on portable signs but do include on post mounted advance warning signs.
3. **Retroreflective signs during the day:** Yes, all construction signs must meet Type 8 fluorescent orange sheeting requirement.

4. **Sign colors other than "construction orange":** Any signs used in a TTC plan must meet MUTCD requirements.
5. **Supplemental advance warning signs with law enforcement:** No.
6. **Supplemental advance warning signs with PCMS:** No.
7. **Extra signs in the array:** Yes, a Fines Doubled sign is required, and may add additional signs depending on location and type of work as long as all meet MUTCD requirements.
8. **Deviation from spacing standards:** Site specific adjustments are permissible and often required and normally approved at the field level as long as at least the minimum standard is met.
9. **LED lighting on advance warning signs:** Not on portable signs only on post mounted.
10. **Larger font sizes on advance warning signs:** Must follow MUTCD standards.
11. **Other:** Other traffic control devices include arrow boards, crash attenuator trucks with arrows and orange flags on portable signs (maintenance operations).

Connecticut DOT provided links to its traffic plans and provisions for contractor operations:

- Traffic Control Plans and Typical Materials, revised February 2013. http://www.ct.gov/dot/lib/dot/0971001A-Traffic_Control_Plans_&_Typical_Material.zip
- Maintenance and Protection of Traffic, revised February 24, 2014. http://www.ct.gov/dot/lib/dot/0971001A-%28Sample%29_Maintenance__Protection_of_Traffic.doc

It also provided a pocket guide developed specific to DOT Maintenance operations (**Appendix F**).

Florida

Contact: Dale Cook, State Maintenance Office, Florida Department of Transportation, 850-410-5638, dale.cook@dot.state.fl.us.

1. **Double signage:** Yes.
2. **Flashing beacons on signs during the day:** Yes.
3. **Retroreflective signs during the day:** Yes.
4. **Sign colors other than "construction orange":** No.
5. **Supplemental advance warning signs with law enforcement:** Yes. Would apply more to long term MOT with construction projects rather than short term maintenance.
6. **Supplemental advance warning signs with PCMS:** Yes.
7. **Extra signs in the array:** Yes.
8. **Deviation from spacing standards:** Yes.
9. **LED lighting on advance warning signs:** No.
10. **Larger font sizes on advance warning signs:** Yes.
11. **Other:** No.

Florida DOT in-house crews and contractors must abide by department-developed Design Standards, 600 index series: http://www.dot.state.fl.us/rddesign/DS/15/STDs.shtm#600. The Design Standards go above what is required in the MUTCD. Florida DOT does allow deviation from these standards but in those cases, it requires plans signed and sealed by a registered professional engineer.

Michigan

Contact: Angie Kremer, Traffic Incident Management Engineer, Michigan Department of Transportation, 517-636-0247, kremera@michigan.gov.

1. **Double signage:** Yes: http://mdotcf.state.mi.us/public/tands/Details_Web/m0200a.pdf
2. **Flashing beacons on signs during the day:** Flashing beacons are included on signs if required per the crash test letter. Implemented case by case basis. http://mdotcf.state.mi.us/public/tands/Details_Web/mdot_wzd-125-e.pdf
3. **Retroreflective signs during the day:** Yes.
4. **Sign colors other than "construction orange":** Yes; regulatory temporary signage posted in work zones are white and traffic incident signs have a red/pink background.
5. **Supplemental advance warning signs with law enforcement:** Yes. Both measures are implemented, separate or together on some projects. Policy: http://www.michigan.gov/documents/mdot/mdot_SOA_2011-06_Uniformed_Law_Enforcement_in_WZ_363149_7.pdf
6. **Supplemental advance warning signs with PCMS:** Yes. Supplemental Advance warning signs (extended lead-in sequence) are often used in conjunction with PCMS.
7. **Extra signs in the array:** Yes – commonly used in Michigan. http://mdotcf.state.mi.us/public/tands/Details_Web/m1020a.pdf
8. **Deviation from spacing standards:** Variations in spacing are allowed for physical characteristics, however arbitrarily reducing the spacing by 50% is not allowed. http://mdotcf.state.mi.us/public/tands/Details_Web/m0020a.pdf.
9. **LED lighting on advance warning signs:** No.
10. **Larger font sizes on advance warning signs:** No.
11. **Other:** Global signs to advise of road work or alternate routes are commonly posted on high traffic routes well in advance of the project. http://mdotcf.state.mi.us/public/tands/Details_Web/m1020a.pdf

North Carolina

Contact: Robert Barrier, Maintenance Programs Engineer, North Carolina Department of Transportation, 919-733-3725, rlbarrier@ncdot.gov.

North Carolina responded to a similar request in October 2014 from Patricia Fyhrie (University of California, Davis). The answers below are those provided to Fyhrie.

1. **Double signage:** No.
2. **Flashing beacons on signs during the day:** We do not require flashing beacons on signs day or night, because we do require a minimum of high intensity type fluorescent orange sign sheeting on all work zone signs, day and night.
3. **Retroreflective signs during the day:** As mentioned in answer #2 we require a minimum of high intensity fluorescent orange sign sheeting on all work zone signs, day and night.
4. **Sign colors other than "construction orange":** We now use fluorescent orange. Our old spec was just orange.
5. **Supplemental advance warning signs with law enforcement:** We use law enforcement if we anticipate speeding problems in the work zone.

6. **Supplemental advance warning signs with PCMS:** Yes but not just to repeat the message on the stationary signs. Changeable message signs should give additional real or near real time information.
7. **Extra signs in the array:** No. Often additional signs does not correct non-compliance. We would probably use "rumble strips" in advance of each work zone sign to get the drivers' attention. Or a changeable message sign 1 mile in advanced of the first warning sign.
8. **Deviation from spacing standards:** The only time I have seen a deviation from the spacing is in highly urbanized work zones where WZ signs may only be a few hundred feet apart.
9. **LED lighting on advance warning signs:** No.
10. **Larger font sizes on advance warning signs:** No.
11. **Other:** As stated above, we have used a changeable message sign in advance of the first stationary WZ sign. We have also used rumble strips a few hundred feet in advance of each WZ warning sign.

North Dakota

Contact: Craig Faul, Transportation Senior Project Manager, North Dakota Department of Transportation, 701-328-2546, cfaul@nd.gov.

1. **Double signage:** The NDDOT signs on the left and right shoulder for operations on the expressways and freeways, according to MUTCD.
2. **Flashing beacons on signs during the day:** No.
3. **Retroreflective signs during the day:** Yes.
4. **Sign colors other than "construction orange":** No.
5. **Supplemental advance warning signs with law enforcement:** No.
6. **Supplemental advance warning signs with PCMS:** No.
7. **Extra signs in the array:** Occasionally in high traffic areas.
8. **Deviation from spacing standards:** No.
9. **LED lighting on advance warning signs:** No.
10. **Larger font sizes on advance warning signs:** No.
11. **Other:** Standard MUTCD practices.

Utah

Contact: Kevin Griffin, Director of Maintenance, Utah Department of Transportation, 801-965-4120, kgriffin@utah.gov.

1. **Double signage:** UDOT follows the Utah MUTCD. Additional signage is not required or used.
2. **Flashing beacons on signs during the day:** We have used these at times but is not the norm for us.
3. **Retroreflective signs during the day:** Most of the signs we use are retro-reflective and are used during the day.
4. **Sign colors other than "construction orange":** The only signs we use that are not "Orange" are "Power Line Overhead" signs.
5. **Supplemental advance warning signs with law enforcement:** We use law enforcement on numerous projects. We have contractual agreements with the Utah Highway Patrol or this service.

6. **Supplemental advance warning signs with PCMS:** The use of VMS is a normal part of or work program. We notify the public a couple of days ahead of the work with VMS if there is going to be impact to traffic on high ADT highways.
7. **Extra signs in the array:** We follow the Utah MUTCD. Additional signage not required.
8. **Deviation from spacing standards:** Modifications can be made with Traffic Engineer approval on constructions projects. Not usually allowed if the changes do not meet the Utah MUTCD.
9. **LED lighting on advance warning signs:** Not usually used.
10. **Larger font sizes on advance warning signs:** No.
11. **Other:** We stick to the Utah MUTCD for required and used signage.

Virginia

Contact: Ray Khoury, State Traffic Engineer, Virginia Department of Transportation, 804-786-2965, raymond.khoury@vdot.virginia.gov.

Virginia DOT did not respond to questions directly, but provided the following information:

> Virginia Department of Transportation maintains the third largest roadway system in the U.S.
>
> Virginia averages for work zone crashes, injuries, and fatalities over the past three years (2011-13) are:
>
> 3309 WZ crashes/year
> 1708 WZ injuries/year
> 15 WZ fatalities/year
>
> VDOT specific work zone safety standards are shown in VDOT's version of Part 6 to the MUTCD, the 2011 Virginia Work Area Protection Manual (Revision 1): http://www.virginiadot.org/VDOT/Business/Const/asset_upload_file171_80343.pdf
>
> Below is some information on VDOT work zone signing practices in response to some of the items.
>
> These are the Areas where VDOT differs on the use of and placement of advanced warning signs from the MUTCD and the reason for the difference are shown in the following table:

VDOT Requirements	MUTCD	Reason for Difference	Results
On divided highways having a median wider than 8', right and left sign assemblies shall be required.	Signs may be placed on both the left-hand and right-hand sides of the roadway.	Allows vehicles from all lanes to see signs, especially where heavy truck traffic is present.	Better compliance to advanced warning messages.
Use of addition signs: ROAD WORK AHEAD, RIGHT LANE CLOSED AHEAD, LANE ENDS MERGE LEFT (on right side of	ROAD WORK XX MILE, RIGHT LANE CLOSED XX MILE, GRAPHIC LANE REDUCTION signs.	Additional signage gives motorist additional information and direction prior to lane closure.	Fewer crashes in the Advanced Warning area (19.8 % of WZ crashes in 2013 occurred in the Advanced Warning

VDOT Requirements	MUTCD	Reason for Difference	Results
roadway) KEEP LEFT (on left side of roadway), GRAPHIC LANE REDUCTION signs.			Area).
Sign spacing should be 1300'-1500' for Limited Access highways. For all other roadways, the spacing should be 500'-800' where the posted speed limit is greater than 45 mph, and 350'-500' where the posted speed limit is 45 mph or less.	**Expressway:** 2460' between 1st & 2nd sign, 1500' between 2nd & 3rd sign, and 1000' between 3rd sign and taper. **Rural:** 500' between all three signs, and 500' between 3rd sign and taper. **Urban**: 350' between all three signs and 350' between 3rd sign and taper.	Range between signs allows for placement adjustments due to field conditions, greater distance from 1st and 2nd sign gives motorists MORE time to react and take appropriate action.	Greater advanced notification of upcoming road conditions, better compliance to signs.
Portable Changeable Message Signs (PCM), although not required for most operations, a list of standardized messages for each typical traffic control layout has been developed for consistency in Appendix D of the 2011 VA Work Area Protection manual.	PCMS may be used.	Operations such as Slow Roll Traffic Control (TTC-66.0) and Total Limited Access Highway Closure (TTC-45.1) require the use of a PCMS for added advanced notification to these unique operations.	
Standard size for all warning signs is 48" by 48".	Allows smaller sizes such as 36" by 36", 30" by 30" and other smaller sizes.	Larger signs allow easier reading of the text.	Better compliance, fewer crashes in our WZs.
All signs are required to be retroreflective day or night.	Only signs used at night are required to be retroreflective	Covers low light conditions (dawn and dusk) often found with daytime only operations.	Better compliance, fewer crashes in our WZs.
All signs required to be fluorescent prismatic lens sheeting, mesh signs not allowed.	Allows fluorescent sheeting signs.	Greater visibility and recognition of the temporary warning signs, especially in urban areas.	Better compliance, fewer crashes in our WZs.

The following question responses are inferred from this table:

1. **Double signage:** Yes.
2. **Flashing beacons on signs during the day:** Unclear.
3. **Retroreflective signs during the day:** Yes.
4. **Sign colors other than "construction orange":** Unclear.
5. **Supplemental advance warning signs with law enforcement:** Unclear.
6. **Supplemental advance warning signs with PCMS:** Yes.
7. **Extra signs in the array:** Yes.
8. **Deviation from spacing standards:** Yes.
9. **LED lighting on advance warning signs:** Unclear.
10. **Larger font sizes on advance warning signs:** Yes.
11. **Other:** Unclear.

Washington

Contact: Steve Haapala, Work Zone Training Specialist, Washington State Department of Transportation, 360-705-7241, haapals@wsdot.wa.gov.

1. **Double signage:** For lane closures or shifts on multi-lane divided highways, WSDOT uses advanced warning signs on the both sides of the roadway. For shoulder closures signs are only used on the closure side. It is felt this effort improves warning to all motorists approaching a work area.
2. **Flashing beacons on signs during the day:** No.
3. **Retroreflective signs during the day:** 48" reflective roll-up signs are used by WSDOT Maintenance for all operations as crews work both day and night.
4. **Sign colors other than "construction orange":** No.
5. **Supplemental advance warning signs with law enforcement:** "Fines Double in Work Zones" signs are being used on our construction projects. When combined with active State Patrol enforcement, traffic speed appear to reduce. We have piloted a program for automated speed enforcement in work zones that did prove to reduce the speeds through a project: http://www.wsdot.wa.gov/Safety/ATSC.htm; http://www.wsdot.wa.gov/NR/rdonlyres/626718B3-A2AE-44FF-9197-79A2F7043493/0/TRBSpeedEnforcement.pdf).
6. **Supplemental advance warning signs with PCMS:** PCMS are used ahead of advance warning signs in most lane closure operations. It is generally felt that these devices get more attention by motorists.
7. **Extra signs in the array:** WAC 296-155-305 (http://app.leg.wa.gov/WAC/default.aspx?cite=296-155-305) requires four advanced warning signs ahead of a flagger station for highways posted at 45 MPH or more. This was implemented as a result of legislation (WRD 27.20: http://www.lni.wa.gov/Safety/Rules/Policies/pdfs/WRD2720.pdf).
8. **Deviation from spacing standards:** WSDOT has modified MUTCD Table 6C-1 for sign spacing WAC 468-95-300 (http://app.leg.wa.gov/WAC/default.aspx?cite=468-95-300). More road type/speed limit breakouts and uniform distances used for each advance sign placement. This was intended to help field placement by having uniform sign spacing and to increase spacing for high speed non-freeway operations.
9. **LED lighting on advance warning signs:** No.
10. **Larger font sizes on advance warning signs:** No.

11. **Other:** RCW 47.36.200 (http://app.leg.wa.gov/rcw/default.aspx?cite=47.36.200) requires an advanced sign stating “motorcycles use extreme caution” along with bump, grooved pavement, abrupt lane edge steel plate or loose gravel signing for work zone conditions.

These measures have been used by WSDOT for many years by department policy along with guideline manuals (http://www.wsdot.wa.gov/Publications/Manuals/M54-44.htm) and training (http://www.wsdot.wa.gov/Safety/WorkZones/training.htm), and also through the direction of our “Work Zone Safety Task Force” (http://www.wsdot.wa.gov/Safety/WorkZones/taskforce.htm) established in 1993.