ENTERPRISE Transportation Pooled Fund Study TPF-5 (231)

Synthesis of Intelligent Work Zone Practices

FINAL REPORT

Prepared by

Athey Creek Consultants

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The ENTERPRISE Pooled Fund Program initiated a project to document the resources available as well as uses and benefits regarding the following Intelligent Work Zone (IWZ) technologies: queue warning systems, dynamic merge systems, alternate routes and variable speed limits in work zones. A detailed literature search was conducted to summarize work zone materials available related to the four work zone technologies. In addition, intelligent work zone representatives from transportation agencies were contacted to provide details on recent related deployments and provide input to the project.

The purpose of this report is to understand the current status of work on IWZ activities by combining the resources gathered through a literature search with the information collected from the transportation agencies on recent deployments. Also included is a summary of the four IWZ technologies including examples of successes, any guidance possible when technologies are most effective, and the configurations that demonstrated the best results.</td></tr>
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Photos on the cover page of this report are used courtesy of the Minnesota Department of Transportation.

Project Champion

Chris Brookes, Michigan Department of Transportation, was the ENTERPRISE Project Champion for this effort. The Project Champion serves as the overall lead for the project.

Members

The ENTERPRISE Board consists of a representative from each of the following member entities of the program.

- Arizona Department of Transportation
- Federal Highway Administration
- Georgia Department of Transportation
- Idaho Transportation Department
- Illinois Department of Transportation
- Iowa Department of Transportation
- Kansas Department of Transportation
- Maricopa County, Arizona
- Michigan Department of Transportation
- Minnesota Department of Transportation
- Mississippi Department of Transportation
- Oklahoma Department of Transportation
- Ministry of Transportation Ontario
- Dutch Ministry of Transport (Rijkswaterstaat)
- Texas Department of Transportation
- Transport Canada
- Washington (State) Department of Transportation

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1.0 Introduction

Intelligent Work Zone (IWZ) technologies are deployed by some transportation agencies in work zones to provide information to instruct or alert drivers of changing conditions (e.g. stopped traffic ahead). The use and approach of these technologies continues to increase in work zones and the use of these technologies varies among the ENTERPRISE members. Some member states have not deployed any intelligent work zone technologies, while others have considerable experience. While many IWZ technologies and strategies exist, this project *ENTERPRISE Synthesis of Intelligent Work Zone Practices* is focused on the following four (4) technologies:

- **Dynamic merge systems**
  Typically IWZ dynamic merge technologies consist of sensors and Portable Changeable Message Signs (PCMS) placed in advance of a lane closure. As congestion begins to form, the PCMS are activated to provide lane use instructions to drivers (e.g. TAKE YOUR TURN, MERGE HERE, USE BOTH LANES).

- **Queue warning systems**
  Queue warning systems consist of sensors upstream of a work zone. When slow or stopped traffic is detected by the sensors, queue warning systems trigger a warning message on a PCMS further upstream. The message displayed on the PCMS alerts drivers of the condition (e.g. SLOW TRAFFIC AHEAD/PREPARE TO STOP).

- **Alternate route advisories**
  Alternate route advisories in work zones include sensors and PCMS located in and around the work zone. As congestion begins to form, the PCMS are activated by the sensors and display a message to provide drivers with information about an alternate route (e.g. TRAVEL TIME VIA X/ 20 MIN, TRAVEL TIME VIA Y/ 45 MIN).

- **Variable speed limits**
  Variable speed limit technologies in work zones consist of sensors, PCMS and a processing system that calculates the speed limits to be displayed on the PCMS based on measures speed and/or volume data. As congestion begins to form, the PCMS are activated to provide drivers with a safe speed limit through a work zone and to minimize braking as they approach the queue.

The ENTERPRISE members understand that there has been considerable research and documentation on the above IWZ technologies. The intent of this project was not to duplicate or repeat this research. The purpose of the project was to conduct a literature search of existing research and documentation to summarize the resources available, and to understand the current status of work on IWZ activities. Beyond the literature review and synthesis, the project also coordinated with transportation agencies deploying intelligent work zone technologies during recent construction seasons to gather additional real-world experiences.

The objective of this report is to document project findings, summarizing uses and benefits of each of the four (4) technologies and highlighting whenever possible the preferred approaches. The intent is to provide the ENTERPRISE members with information about these IWZ technologies that would be useful for those transportation agencies that are considering deploying IWZ technologies and also enhance the resources available for those agencies that currently deploy IWZ technologies to learn from other similar deployments.

This report includes:

- 2.0 Project Approach – Summarizes the ***four step approach*** used to synthesize the resources gathered through the literature search and through coordination with agencies that recently deployed related IWZ technologies.
- 3.0 Intelligent Work Zone Technologies – Provides ***a listing of resources*** found for each of the four IWZ technologies and highlights ***uses and benefits*** for each of the four technologies.
- 4.0 Summary – Provides an ***overall summary of the uses and benefits*** of dynamic merge systems, queue warning systems, alternate route advisories, and variable speed limits.

2.0 Project Approach

The approach for this *ENTERPRISE Synthesis of Intelligent Work Zone Practices* project included four steps as shown in Figure 1 below. Following the figure are details on how each step was accomplished.

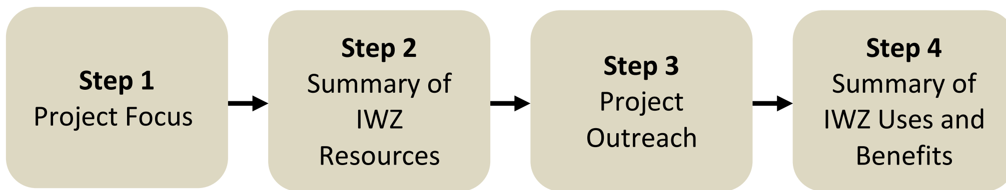


Figure 1: Project Approach

Step 1: Project Focus

There are a variety of intelligent work zone technologies that are used in work zones to increase safety and provide information and instructions to drivers on changing traffic conditions ahead. The approach for this project was to focus on a subset of IWZ technologies and document what IWZ approaches work best in different situations. After considerable discussion and review of work zone technologies, the selected focus for this project was the following four IWZ technologies: dynamic merge systems, queue warning systems, alternate route advisories, and variable speed limits. These technologies were chosen because some member states had experience deploying these technologies and could share lessons learned. In addition, states with little or no IWZ experience had the strongest interest in learning about these technologies as deploying IWZ technologies.

IWZ Project Focus:

Dynamic Merge Systems
Queue Warning Systems
Alternate Route Advisories
Variable Speed Limits

Step 2: Summary of Intelligent Work Zone Resources

Once the focus of the project was identified, the next step was to gather information available (e.g. published reports, transportation agency web pages, news articles) related to the four technologies. Information was gathered through a literature search and information collected from transportation agencies that recently deployed dynamic merge systems, queue warning systems, alternate route advisories, and variable speed limit technologies in work zones.

- ***Literature Search*** -
- Table 1 includes the information sources that were utilized to search for relevant information related to the four IWZ technologies of interest.

- ***Deployment Examples*** - Intelligent work zone representatives from transportation agencies were contacted to provide details on recent projects related to the four intelligent work zone technologies and provide input to the project. Transportation agencies contacted included ENTERPRISE members as well as states where deployment of similar technologies was known. Information gathered from the intelligent work zone contacts assisted in learning the different uses, configurations, and best practices whenever possible about preferred approaches to enhance the literature search.

Table 1: Literature Search Website Sources

Website	Description
Google	Search engine Web Address: www.google.com
Smart Work Zone Deployment Initiative	Through this pooled-fund study, researchers investigate better ways of controlling traffic through work zones. Their goal is to improve the safety and efficiency of traffic operations and highway work. Web Address: http://www.intrans.iastate.edu/smartwz/
USDOT Research and Innovative Technology Administration (RTIS) ITS Knowledge Resources	Provides information on the benefits, costs, deployment levels, and lessons learned regarding ITS deployment and operations. Web Address: http://www.itskrs.its.dot.gov/
Transportation Research Board (TRB) TRID Database	Integrated database that combines the records from TRB's Transportation Research Information Services (TRIS) Database and the Organization for Economic Co-operation and Development (OECD) Joint Transport Research Centre's International Transport Research Documentation (IRTD) Database. Web Address: http://trid.trb.org
The National Work Zone Safety Information Clearinghouse	Provides the transportation construction industry and the general public with comprehensive information to improve motorist, worker and pedestrian safety in roadway work zones. Web Address: http://www.workzonesafety.org/
USDOT FHWA Work Zone Mobility and Safety Program	Serves as a central location for work zone-related resources and is updated with new information and resources on a frequent basis. Web Address: http://www.ops.fhwa.dot.gov/wz/

As resources were noted, categories of information (e.g. project location, technologies used, thresholds, outreach efforts) were collected for each source. The summary of resources gathered from the online literature search and the deployment examples provided by the transportation agencies are included in Section 3.0 Intelligent Work Zone Technologies.

- 3.1.1 Summary of Resources - Dynamic Merge Systems in Work Zones

- 3.2.1 Summary of Resources - Queue Warning Systems in Work Zones
- 3.3.1 Summary of Resources - Alternate Route Advisories in Work Zones
- 3.4.1 Summary of Resources - Variable Speed Limits in Work Zones

Step 3: Project Outreach

In order to gain input on how work zone traffic mobility and safety professionals would use the information delivered in this project, a webinar at the completion of Step 2 was conducted to share the resources found and also provided an opportunity to discuss how to synthesize the information gathered into a summary for each of the four IWZ technologies (Step 4).

ENTEPRISE member states as well as key work zone contacts from around the country were invited to participate in the webinar. Over 30 individuals participated in the webinar including representatives from individual state departments of transportation, the Illinois Tollway, the Ministry of Transport Ontario, and FHWA.

The first half of the webinar provided an overview of the ENTERPRISE Program and overview of the ENTERPRISE IWZ project. The second half of the webinar was presented by Chris Brookes from the Michigan DOT and highlighted two examples of recent deployments of queue warning systems in work zones.

At the conclusion of the webinar one example of how to summarize the information gathered from the literature search and from the information collected from the transportation agencies was shared and the input received helped shape the direction for Step 4.

Step 4: Summary of Intelligent Work Zone Uses and Benefits

Based on the input received from the webinar conducted in Step 3 and the information gathered in Step 2, a summary of uses and benefits for each of the four technologies was prepared. The intent was to provide a brief document highlighting report examples or example deployments, but also including links to detailed information about a deployment or project for those users to quickly review additional project information. The summary of uses and benefits are included in Section 3.0 Intelligent Work Zone Technologies.

- 3.1.2 Summary of Uses and Benefits - Dynamic Merge Systems in Work Zones
- 3.2.2 Summary of Uses and Benefits - Queue Warning Systems in Work Zones
- 3.3.2 Summary of Uses and Benefits - Alternate Route Advisories in Work Zones
- 3.4.2 Summary of Uses and Benefits - Variable Speed Limits in Work Zones

3.0 Intelligent Work Zone Technologies

This section includes the research and documentation gathered related to the four IWZ applications (dynamic merge, queue warning, alternate route advisories, and variable speed limits) focused on for this project. The intent was to provide one location for the ENTERPPRISE members to use and assist them in understanding the current status of work on IWZ activities. It is understood that not every related construction project or evaluation is included in these sections, but it is the hope of ENTERPRISE that as the information gathered in these sections is shared, the listing of information will be enhanced. The online resources gathered in this section were also posted as a resource on ENTERPRISE program website: http://www.enterprise.prog.org/Projects/2010_Present/iwz.html

Based on the summary of resources, uses and benefits for each of the four technologies were prepared and are also included in this section. The intent of the uses and benefits summaries are to provide a high level understanding of each technology enhanced by lessons learned from project deployment examples and evaluations (e.g. guidelines of when to consider a deployment, technologies typically used).

3.1 Dynamic Merge Systems in Work Zones

Typically intelligent work zone dynamic merge applications consist of sensors and PCMS placed in advance of a lane closure. As congestion begins to form, the PCMS are activated to provide lane use instructions to drivers (e.g. TAKE YOUR TURN - MERGE HERE, USE BOTH LANES).

Figure 2 and Figure 3 illustrate two different dynamic merge strategies provided by the America Traffic Safety Services Association (ATSSA) Guidance for the Use of Dynamic Lane Merging Strategies[1] and how they can be used either separately or together to reduce delay and increase safety at work zones that require lane closures. Figure 2 shows the early merging strategy that advises drivers to move out of the closed lane well before the forced merge point and before traffic breaks down. To avoid congestion, the early merging strategy works best when there is a low traffic volume on the road combined with high average speeds.

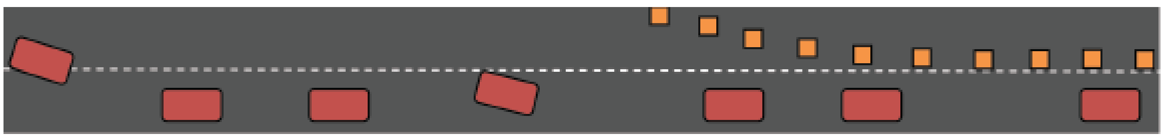


Figure 2: Early Merge Concept Diagram (source: ATSSA Guidance for the Use of Dynamic Lane Merging Strategies[1])

Figure 3 illustrates the late merging strategy that typically works best when the road has a high traffic volume and low average speed due to congestion. Drivers are instructed to remain in their respective lanes until they reach the designated merge point. This strategy ensures that both lanes are being used to their full capacity and minimizes unnecessary lane changes. Once vehicles reach the merge point, late merging encourages an alternating merging style, otherwise called zippered merging, in which vehicles take turns moving in the open lane.

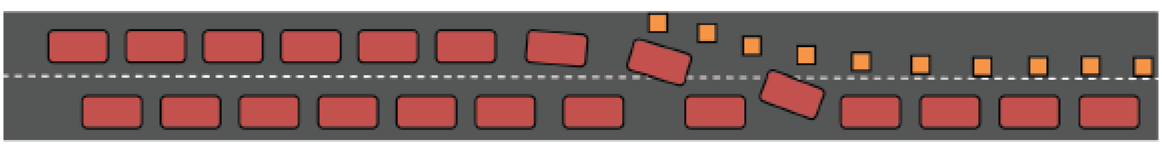


Figure 3: Late Merging Concept Diagram (source: ATSSA Guidance for the Use of Dynamic Lane Merging Strategies[1])

3.1.1 Summary of Resources

The following table includes resources that were reviewed related to dynamic merge systems. Information was gathered from available online resources (e.g. published reports, agency web pages, news articles) or through coordination with transportation agencies that have deployed dynamic merge systems. For those projects that an online hyperlink was not available, a brief summary of the information gathered for the project is provided in Appendix A.

Table 2: Dynamic Merge Systems in Work Zones Related Resources

State/Resource	Document/Intelligent Work Zone Deployment
American Traffic Safety Services Association (ATSSA)	• Online Resource: Guidance for the Use of Dynamic Lane Merging Strategies[1] (2012) - Document introducing innovative merging strategies and when to implement the strategies. • Online Resource: ITS Safety and Mobility Solutions – Improving Travel Through America's Work Zones[2] (2008) - ITS resource manual from ATSSA on multiple parts of improving safety and efficiency of traffic in work zones.
Colorado	• Online Resource: Colorado DOT adds signs asking drivers to merge late[3] (2013) TheDenverChannel.com - News article discussing Colorado DOT's use of late merge signs. • Online Resource: You Tube Video Demonstrating Late Merge[4] (2013) - Colorado DOT YouTube video discussing merge late in construction zones.
Florida	• Online Resource: Evaluating Variable Speed Limits and Dynamic Lane Merging Systems in Work Zones: A Simulation Study[5] (2012) -Study simulating a two-to-one work zone lane closure configuration under different Maintenance of Traffic (MOT) plans and comparing work zone throughputs and travel times across MOTs including early and late Dynamic Lane Merge and VSL combinations. • Online Resource: Dynamic Early Merge and Dynamic Late Merge at Work Zone Lane Closure[6] (2009) - Research suggesting two simplified lane merging schemes to be applied and tested on short term work zones. • Online Resource: Evaluation of Safety and Operational Effectiveness of Dynamic Lane Merge System in Florida[7] (2009) - Study compares the effectiveness of both forms of Simplified Dynamic Lane Merging Systems (SDLMS) to the conventional MOT plan. • Online Resource: Two Simplified Dynamic Lane Merging Systems (SDLMS) for Short Term Work Zones[8] (2009) - Comparison of the effectiveness of SDLMS to the conventional MOT plans during a lane reduction on I-95.
Indiana	• Online Resource: Indiana Lane Merge System – Warrants for Use [9] (2000) - Study proposing a new method of combining crashes and conflicts using an integrated model analysis. • Online Resource: Manual of the Lane Merge Control System[10] (1998) - Manual for persons involved in the utilization of layout and parameter settings of the Lane Merge Control System on rural two-lane freeways.
Iowa	• Online Resource: Effectiveness of Dynamic Messaging on Driver Behavior for Late Merge Lane Road Closures[11] (2009) - Evaluation of Iowa DOT's system of dynamic message signs for construction on I-80 and recommendations for future use of the system based on results. • Online Resource: Traffic Management Strategies for Merge Areas in Rural Interstate Work Zones[12] (1999) - Report seeks to better understand traffic flow behavior at rural interstate highway work zones and to estimate traffic carrying capacity of lane closure.

Kansas	• Online Resource: Construction Area Late Merge (CALM) System[13] (2004) - Study results underscore the importance of considering site characteristics very carefully when selecting sites for deployment of dynamic systems and/or late merge systems.
Maryland	• Online Resource: Use of Intelligent Transportation Systems in Work Zones[14] (2005) – Work Zone Safety toolbox for ITS in work zones.
Michigan	• Deployment Summary: EB I-96 near Mile Marker 9 in Ottawa County (2013) • Online Resource: Late Merging Drives Beware: MDOT Dynamic Merge Lanes Designed to Encourage Safer Driving Around Construction Zones[15] (2013) – mLIVE news article on Michigan DOT's use of dynamic merge lanes. • Online Resource: Evaluation of the Dynamic Late Lane Merge System (DLLMS) at Freeway Construction Work Zones[16] (2007) - Based on the travel time characteristics, queue, merge locations, and throughput the effectiveness of the DLLMS was evaluated by the research group. • Online Resource: Development and Evaluation of an Advanced Dynamic Lane Merge Traffic Control System for 3 to 2 Lane Transition Areas in Work Zones[17] (2004) - Advanced dynamic early lane merge traffic control system for 3 to 2 lane transition in work zones. • Online Resource: ITS in Work Zones – A Case Study – Dynamic Lane Merge System – Reducing Aggressive Driving and Optimizing Throughput At Work Zone Merges in Michigan[18] (2004) - Case Study from Michigan: document from a series of products to provide ITS solutions to meet local and regional transportation needs. • Online Resource: US-131 Kalamazoo, Michigan[19] (2004) - Case Study of a dynamic late merge system used in a work zone in Kalamazoo, MI and findings and tips from the project. • Online Resource: Assessing the Impacts of the Dynamic Early Lane Merge Traffic Control System[20] (2003) - Study, analysis, and results on testing of early merge traffic control system. • Online Resource: Development and Evaluation of the Lane Merge Traffic Control System at Construction Work Zones[21] (2001) - Report on a pilot project to study the effectiveness of a lane merge traffic control system in Michigan.
Minnesota	• Online Resource: Evaluation of 2004 Dynamic Late Merge System[22] (2004) - Evaluation report was created from the deployment of the DLMS on US 10 in Anoka, MN. • Online Resource: Zipper Merge Still Tough Sell for Minnesota Drivers, MnDOT[23] (2013) – StarTribune.com news article discussing the difficulties of zipper merge in Minnesota. • Online Resource: Dynamic Late Merge System Evaluation – Initial Deployment on US-10[24] (2003) - Report on the development, testing, and evaluation of a traffic control system that incorporates the best aspects of both the early and late merge systems.
National Work Zone	• Online Resource: Simulation Trials on an Unconventional Alternative to

Safety Information Clearinghouse	Congestion Mitigation and Traffic Control at Highway Work-Zone Bottlenecks using Advanced Technologies (2008)[25] - Paper presents a method to integrate the DLM with a merge metering via wireless communication area of a work zone, termed as Dynamic Merge Metering Traffic Control System (DMM-Tracs) for highway work-zone bottlenecks.
Nebraska	• Online Resource: Dynamic Late Merge Control Concept for Work Zones on Rural Freeways[26] (2004) - Report discusses when to use different merging strategies on rural freeways.
Street Smart Rental	• Online Resource: Dynamic Late Merge Deployment Criteria Considerations[27] - Short webpage on deployment criteria and anticipated system effects of dynamic late merge.
Texas	• Online Resource: Understanding Road Rage: Evaluation of Promising Mitigation Measures[28] (2001) - Report documents literature review, focus groups, telephone survey, and evaluation of 3 mitigation measures aimed at reducing driver stress that can lead to aggressive driving.
Transportation Research Board	• Online Resource: Traffic Flow Characteristics of the Late Merge Work Zone Control Strategy[29] (2007) - Operational effects of the late merge were evaluated and findings are documented in this study. • Online Resource: Dynamic Late Merge Control at Highway Work Zones: Evaluations, Observations and Suggestions[30] (2007) - Study that evaluates the result of dynamic late merge system for highway work zone operations and focuses on operational efficiency.
USDOT Federal Highway Administration	• Online Resource: Work Zone Intelligent Transportation Systems Implementation Guide[31] (2014) - Document to provide guidance on implementing ITS in work zones to assist public agencies, firms, developers, etc. • Online Resource: Work Zone Public Information and Outreach Strategies[32] (2005) - This guide is designed to help transportation agencies plan and implement effective public information and outreach campaigns to mitigate the negative effects of road construction work zones.
Virginia	• Online Resource: Evaluation of the Late Merge Work Zone Traffic Control Strategy[33] (2004) - Study to determine when, if at all, deployment of the late merge is beneficial.
Wisconsin	• Online Resource: Evaluation of Dynamic Late Merge System in Highway Work Zones[34] (2006) - Study researched speed characteristics with and without DLMS, measured the effectiveness of the DLMS, and determined traffic conditions where the DLMS will be efficient. • Online Resource: I-94 Eastbound – Waukesha County Dynamic Late Merge System[35] - Wisconsin DOT website discussing the I-95 re-pavement project and the use of dynamic late merge system.

3.1.2 Summary of Uses and Benefits

This section includes a high level summary of uses and benefits of dynamic merge system technologies in work zones. Links to documents or projects are provided within the summary to provide a quick reference for additional information regarding the topic of interest.

Dynamic Merge System Benefits

- Reduce Delay
- Increase Safety (reduce aggressive driver behavior)
- Increase instructions on lane usage

Benefits

There are a number of benefits from deployment of dynamic merge systems in work zones. The nature of work zones and lane closures indicate that some delay is inevitable; however, some lane closure and merging techniques are able to improve operations, reduce delay, and increase safety when used appropriately.

ITS Safety and Mobility Solutions[2], a brochure developed by ATSSA, suggests that the early dynamic merge systems can reduce aggressive driving and unsafe merge maneuvers, provide significant advanced warning to allow drivers an adequate distance to merge, and gives drivers positive instructions on lane usage, which helps reduce road rage. A study conducted by the Michigan DOT, Assessing the Impacts of the Dynamic Early Lane Merge Traffic Control System[20], found that with the use of the dynamic early merge it significantly reduced aggressive driver behavior, lane violations and delay, as well as a slight improvement in traffic flow on a two-lane to one-lane suburban freeway work zone.

The late merge system allows the queue to "stack" in multiple lanes, which reduces the overall queue length by approximately half; and reduces the differential in speed between lanes, which provides for safer lane changes. A project conducted by Michigan DOT, ITS in Work Zones – A Case Study – Dynamic Lane Merge System – Reducing Aggressive Driving and Optimizing Throughput at Work Zones in Michigan[18], found that using the dynamic late merge decreased the average number of aggressive driving maneuvers per travel time run from 2.88 to 0.55 during the afternoon peak period.

Typical Use

Dynamic merge systems are typically used in work zones that experience fluctuating traffic demand. The technology typically used for a dynamic merge system can be programmed to change the message and merging strategy based on measurements of real-time traffic conditions such as speed, density, and occupancy. Early and late merging can also use static signage and is most effective when there is a steady flow of traffic because they always display the same message throughout the duration of the lane closure.

Dynamic Merge Systems are typically used in work zones that experience fluctuating traffic demand.

A brochure developed by ATSSA, ITS Safety and Mobility Solutions[2], advises that the dynamic early merge is effective for longer passing zone and lower volumes of traffic; when the work zone requires a two-to-one or three-to-two lane drop; when peak hour traffic demand is between 2,000 and 3,000 vehicles per hour (two-to-one lane closure) and between 3,000 and 3,800 (three-to-two lane closure). Evaluation of Safety and Operational Effectiveness of Dynamic Lane Merge System in Florida[7], a study conducted by the Florida DOT, found that dynamic early merge performs better than late merge with volumes ranging between 0 and 500 veh/hr and 501 and 1000 veh/hr. The same study found that for volumes ranging between 1001 and 1500 veh/hr the dynamic late merge exhibits the highest performance compared to the early merge. In addition, the early merge can be considered for situations when the length of queue is not expected to extend beyond the start of work zone signing; when there is commuter traffic and sufficient project duration to allow adaptation to the system; when travel speed is high; when aggressive, repeat drivers attempt to "jump the queue" by remaining in the dropped lane up to the merge point.

The dynamic late merge is effective for higher volumes of traffic and a definite merge point. In addition, the late merge should be considered in situations when the work zone requires a two-to-one lane drop; when traffic demand exceeds the capacity of the open lane; when traffic demand could create an extensive queue length which may affect other access points or may extend beyond reasonable placement of advance warning signage; and when congestion caused by lane closures varies many times throughout a work day. A study conducted by the Virginia DOT in 2004, Evaluation of the Late Merge Work Zone Traffic Control Strategy[33], concluded that the late merge should be considered for 3-to-1 lane closure configurations but not until a sound methodology for deployment has been developed and tested in the field. For the 2-to-1 and 3-to-2 configurations, the late merge should be implemented only when the percentage of heavy vehicles is a t least 20 percent.

ATSSA, Guidance for the Use of Dynamic Lane Merging Strategies[1], provides a flow chart to determine which merging strategy to use; however, a common thread in the projects researched was a recommendation that the use of engineering judgment and site evaluation be conducted along with the suggestions in this report because of the range of options and combinations for dynamic merge applications.

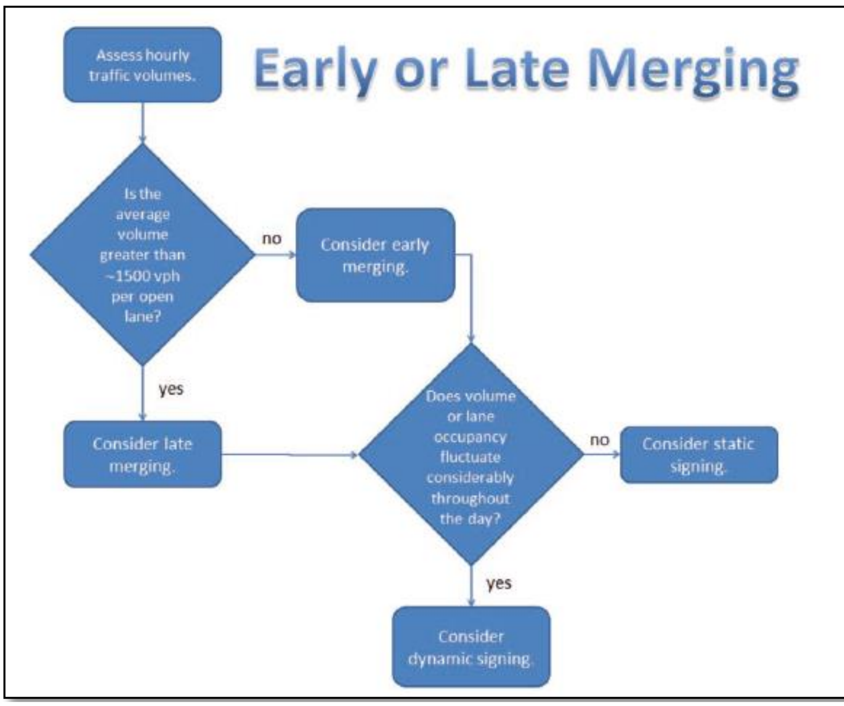


Figure 4: Flow chart diagram indicating guidelines for when to use various merging strategies for either two-to-one lane closures or three-to-two lane closures (ATSSA, Guidance for the Use of Dynamic Lane Merging Strategies[1])

Sign Messages and Thresholds

Messages can either be displayed on static signs or on PCMS systems to alert motorists of required merging and reduced speeds. Typically the messages displayed for early merge say DO NOT PASS with flashing strobes to indicate to motorists to merge right away. A late merge generally shows a sign with

USE BOTH LANES TO MERGE POINT to indicate to wait to merge until the merge point. These messages and thresholds vary depending on the type of dynamic merge used.

Typical System Components

Dynamic merging systems in work zones can alternate which merging technique it displays by using real-time traffic monitoring and conveys instructions to motorists using PCMS. Based on site-specific algorithms, once a dynamic merging system detects a change in traffic conditions, it switches from early to late merge or vice versa to accommodate traffic. Guidance for the Use of Dynamic Lane Merging Strategies[1], developed by ATSSA compiled a list from various practitioners and researchers that have used the following to test, evaluate, and implement dynamic lane merging strategies: microwave signals to identify traffic volume; video analysis to track traffic volume, lane occupancy, and queue; Doppler radar to determine average speed; pneumatic tubes to calculate traffic volume; computer simulations to optimize dynamic merging algorithms.

Public Outreach

There are several strategies to improve public compliance with the dynamic merge techniques. These include public information campaigns to educate the public and law enforcement agencies about the lane closures. An example of this type of public outreach was done by Colorado DOT in 2013 for two projects using dynamic late merge. Colorado DOT utilized news outlets and created a YouTube Video Demonstrating Late Merge[4] to educate drivers about how to understand the signage and use dynamic late merge appropriately.

Figure 5: Screenshot of You Tube Video Demonstrating Late Merge[4]

A project conducted by Michigan DOT in 2004, ITS in Work Zones – A Case Study – Dynamic Lane Merge System – Reducing Aggressive Driving and Optimizing Throughput At Work Zones in Michigan[18], found it beneficial to identify stakeholders early in the planning stage as one of the key steps to a successful implementation. Michigan DOT held several meetings with key stakeholders, including the law enforcement community, to keep them involved and aware of the projects intent.

It is also important to provide motorists with real-time information at appropriate locations because drivers prioritize information and will discard the information that seems irrelevant or unimportant. The time gap between information is critical to a driver in order for him/her to retain the relevant information, and to take appropriate action at the correct time. A study conducted by Michigan DOT, Assessing the Impacts of the Dynamic Early Merge Traffic Control System[20], assessed the effectiveness of dynamic merge system and driver understanding and found certain reasons why motorists can be confused about how or when to take proper action while driving. The study concluded that driver non-compliance or understanding is because of non-optimal system layout and settings, inappropriate spacing

Figure 6: Dynamic Sign and Trailer Used in Michigan[20]

between dynamic signs, the sign messages being new and unfamiliar, and the installation of the system when not warranted that can all lead to non-compliance.

Contracting

There are many different contracting options for IWZ projects. In the US DOT FHWA Work Zone ITS Implementation Guide[31], an overview of procurement approaches (direct or indirect) are provided as well as information to consider to determine the procurement award mechanism, issuing a request for proposals and selecting the preferred vendors, consultant or contractor.

A project conducted on I-94 in Michigan, ITS in Work Zones – A Case Study – Dynamic Lane Merge System – Reducing Aggressive Driving and Optimizing Throughput At Work Zones in Michigan[18], found it beneficial for contracting to add specifications for the dynamic late merge system components as pay items in the prime construction contract after award, as a modification to the contract. The prime construction contractor hired two subcontractors to design, install, and integrate the system components based on the specifications that Michigan DOT provided in the contract modification. Michigan DOT wrote the specifications for temporary use of the system so that they could deploy DLM without having to perform equipment maintenance or store the system after construction was completed. Because these were not permanent installations, Michigan DOT's subcontractor leased all of the system components and Michigan DOT continues to use the lease option to benefit from the latest in rapidly changing technology.

3.2 Queue Warning Systems in Work Zones

Queue warning systems are used in work zones to alert drivers of traffic conditions (e.g. stopped traffic, slowing traffic) ahead in order to reduce the number and severity of rear end crashes and avoid drivers being surprised by stopped or slowing traffic.

Queue warning systems typically consists of sensors upstream of a work zone. When slow or stopped traffic is detected it triggers a warning on a PCMS. The message displayed on the PCMS alert drivers of the condition (e.g. STOPPED TRAFFIC AHEAD) as shown in Figure 7 below.

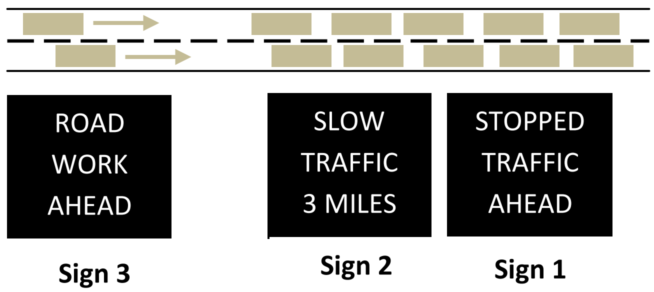


Figure 7: Queue Warning System example PCMS Messages when Slow or Stopped Traffic is detected

3.2.1 Summary of Resources

The following table includes resources that were reviewed related to queue warning systems. Information was gathered from available online resources (e.g. published reports, agency web pages, news articles) or through coordination with transportation agencies that have deployed queue warning systems. For those projects that an online hyperlink was not available, a brief summary of the information gathered for the project is provided in Appendix A.

Table 3: Queue Warning Systems in Work Zones Related Resources

State/Resource	Document/Intelligent Work Zone Deployment
American Traffic Safety Services Association (ATSSA)	• Online Resource: Treating Potential Back-of-Queue Safety Hazards[36] (2009) - Highlights strategies that help reduce work zone congestion that increases back-of-queue crash risk. • Online Resource: ITS Safety and Mobility Solutions – Improving Travel Through America's Work Zones[37] (2008) - ITS resource manual from ATSSA on multiple parts of improving safety and efficiency of traffic in work zones.
California	• Deployment Summary: Caltrans Queue Warning System- San Diego (2013)
Illinois	• Deployment Summary: I-55 (I-70 to IL 140) – Madison County (2012) • Deployment Summary: I-80 Southwest Chicago – Will County (2011) • Deployment Summary: I-57 – Marion (2010)

Ministry of Transport Ontario	• Online Resource: Highway 402 Queue Warning System[38] (2008) - Paper that presents technology solutions as well as lessons learned from the implementation of a Queue Warning System on Hwy 402.
Michigan	• Deployment Summary: Stopped Traffic Advisory (I-94 and Sargent Road) – Jackson (2012)
Minnesota	• Deployment Summary: I-35 Mega Project - Travel Time and Queue Warning - Duluth (2011) • Online Resource: Low-Cost Portable Video-Based Queue Detection for Work-Zone Safety[39] (2011) - Evaluation of a low-cost rapidly deployable and portable queue detection warning system. • Online Resource: Minnesota IWZ Toolbox[40] (2008) - Minnesota strategies for using ITS in work zones and when to appropriately select IWZ systems.
National Transportation Safety Board	• Online Resource: Vehicle and Infrastructure-Based Technology for the Prevention of Rear-end Collisions[41] (2001) - Investigation of nine rear-end collisions in which 20 people died and 181 were injured and common to all accidents was the rear following vehicle driver's degraded perception of traffic conditions ahead.
Oregon	• Online Resource: Dundee Queue Detection System[42] (1999) - Summary of Dundee Queue Detection System that was implemented by the Oregon DOT in 1999.
Pennsylvania	• Deployment Summary: Pennsylvania Turnpike I-476 & I-276 – Montgomery County (2013) • Online Resource: Queue Length Detector Reduces Risk of Rear-End Accidents in Work Zones[43] (1998) - Pennsylvania project using technology to alert motorists on U.S. Route 22 with an infrared intrusion alarm and queue length detector.
Texas	• Deployment Summary: I-35 from Austin to Waco (2013) • Online Resource: TxDOT Set to Deploy End-of-Queue Warning Systems for I-35 Motorists[44] - My Interstate 35 News - News article on Texas DOT's I-35 expansion project using a new alert system for motorists approaching nighttime interstate work zone lane closures. • Online Resource: TxDOT unveils hi-tech warning system on I-35 work zone[45]– HillCountryNews.com (2013) - News article discussing Texas DOT's end-of-queue warning system for I-35 expansion project. • Online Resource: Work Zone Safety Warning System Unveiled [46] - The TXDOT Update (2013) - Update from TxDOT on the new high-tech system to enhance safety and reduce collisions for the I-35 expansion project. • Online Resource: Traffic Control Strategies for Congested Freeways and

	Work Zones[47] (2008) - Study to identify and evaluate effective ways of improving traffic operations and safety on congestions freeways looking at end-of-queue warning, lane closure, and queue spillover at exit ramps. • Online Resource: Advanced Warning of Stopped Traffic on Freeways: Field Studies of Congestion Warning Signs[48] (2005) - Study to that determined current practices for advance warning for stopped traffic, observed field locations with traffic stopped due to various conditions, and determine applicable techniques to Texas. • Online Resource: Advanced Warning of Stopped Traffic on Freeways: Current Practices and Field Studies of Queue Propagation Speeds[49] (2003) - Study that evaluated issues relating to stopped or very slow traffic due to recurrent traffic congestions due to over-capacity conditions during peak periods, congestions due to constructions work zones, and congestions due to incidents such as crashes.
Transportation Research Board (TRB)	• Online Resource: Simulation Based Evaluation of Dynamic Queue Warning System Performance[50] (2013) - Microscopic traffic simulation used to evaluate various design alternatives of a dynamic queue warning system at a freeway work zone with lane closure.
USDOT Federal Highway Administration	• Online Resource: Work Zone Intelligent Transportation Systems Implementation Guide[51] (2014) - Document to provide guidance on implementing ITS in work zones to assist public agencies, firms, developers, etc. • Online Resource: Work Zone Public Information and Outreach Strategies[52] (2005) - This guide is designed to help transportation agencies plan and implement effective public information and outreach campaigns to mitigate the negative effects of road construction work zones. • Online Resource: Innovative Traffic Control Technology and Practice in Europe[53] (1999) - Summary from an International Technology Scanning Program that accessed and evaluated foreign technologies and innovations that could significantly benefit U.S. highway systems.
Virginia	• Online Resource: I-66 ATM Treatment Definitions[54] - Definitions of ITS terms used in Virginia's I-66 ATM Treatment.
Washington State	• Online Resource: Active Traffic Management Concept of Operations[55] (2008) - Public resource manual from Washington State DOT on multiple parts of ITS implementation in work zones.
Work Zone ITS Blog	• Online Resource: Workzoneitsblog[56] - Blog about all things work zone and rural ITS.

3.2.2 Summary of Uses and Benefits

This section includes a high level summary of uses and benefits of queue warning system technologies in work zones. Links to documents or projects are provided within the summary to provide a quick reference for additional information regarding the topic of interest.

Benefits

There are a number of benefits with deployment of queue warning systems in work zones. The most notable benefit is the reduction of rear end crashes. The USDOT FHWA Work Zone ITS Implementation Guide[51] indicates delay, aggressive driving behavior, safety and queue length as being addressed with deployment of a queue warning system. Incidents were reduced by 66% by deploying a Queue Warning System in San Diego, California in 2013 at a location where backups had been an issue in previous years. Based on the effects of deployment in this project it was noted that a similar set up would be recommended for any major long term closure, for construction or maintenance. A Queue Warning System in Madison County, Illinois in 2012 reduced incidents by 13.8%.

Figure 8: Queue Warning System Site in Ontario, Canada

Results from a study by the Ministry of Transport Ontario, Highway 402 Queue Warning System[38], indicated a notable reduction in rear end collisions on the project site. Safety was also improved at this location at a lower cost than modifying the highway geometry and configuration. Figure 8 shows one of the queue warning sites.

In Michigan approximately 50% of total work zone crashes are due to stopped or slowing traffic; the installation of a queue warning systems reduces these types of crashes. Therefore, a high return on investment should be received with deployment of queue warning system because of the number of crashes that can potentially be mitigated.

Typical Use

Queue warning systems are typically used when the goal is to reduce the number and severity of rear end crashes. For example the conclusions listed in the Caltrans Queue Warning System in San Diego, California project recommended the use of queue warning systems for major long term closures. The results from the Stopped Traffic Advisory System in Jackson, Michigan suggested deploying a queue warning system on any project there will be closures during peak time with the exception of a back-up that will extend upstream of the lead-in work zone signing.

In Michigan approximately 50% of total work zone crashes are due to stopped or slowing traffic; the installation of queue warning systems reduced these types of crashes.

Sign Messages and Thresholds

Messages posted on PCMS for queue detection projects typically accommodate three sets of messages for different scenarios as noted in Table 4. For example, in a free flow scenario where traffic is moving at the posted speed limit of 55mph, a PCMS may post CAUTION/ROAD WORK AHEAD. A queue detection system may also not post a message (blank board) during free flow conditions. An otherwise blank board could display dots moving along the board or the four corners flashing to prevent the public from assuming the device is not functioning. The purpose of this type of board is to only post a message when the condition changes to draw more attention to the sign and alert the driver to the situation (e.g. SLOW TRAFFIC AHEAD/PREPARE TO STOP).

Table 4: Example PCMS Messages and Thresholds for Different Scenarios

Scenario	Example Message	Threshold
Free Flow	CAUTION/ROAD WORK AHEAD	55 mph
Slow Traffic	SLOW TRAFFIC AHEAD/PREPARE TO STOP	40-45 mph
Stopped Traffic	TRAFFIC STOPPED AHEAD/PREPARE TO STOP	15-25 mph

There are a number of PCMS messages used to describe a similar queue situation. For example in 2012 at the Stopped Traffic Advisory in Jackson, Michigan, the PCMS message on this queue detection project displayed **CAUTION SLOWED TRAFFIC X MILES AHEAD**. This changed during the project from CAUTION SLOWED TRAFFIC, X MILES AHEAD to CAUTION SLOW TRAFFIC, NEXT X MILES. It is also important to note that the location of the PCMS changed during the project to provide an alternate route after viewing the message. A study by the Ministry of Transport Ontario, Highway 402 Queue Warning System[38], displayed **WATCH FOR SLOW TRAFFIC, NEXT X KM** while operating a queue.

A common conclusion in the projects researched was a recommendation to develop a list of suggested messages for different scenarios (e.g. Stopped traffic, Slowed traffic and free flow) for consistency.

Thresholds tend to vary from project to project and should be adjusted accordingly to fit the needs of each project. However a slow traffic scenario typically was triggered when traffic was between 40 to 45 mph. On I-55 in Madison County in Illinois when traffic slowed below 40 mph the system triggered the slow traffic messages. On the Stopped Traffic Advisory in Jackson, Michigan project the slow traffic message and the stopped traffic message was triggered when traffic slowed below 45 mph and 15 mph respectively. The threshold was changed from 10 mph to 15 mph because when traffic flow was effectively stopped, movement was still above or close to 10 mph in the stop and go condition.

Thresholds tend to vary from project to project and should be adjusted accordingly to fit the needs of each project.

Typical System Components

There are different components to consider when designing an appropriate queue warning system. However, equipment typically includes PCMSs, sensors and a server. When more sensors are deployed the system will provide faster notification of changes to conditions and increase the accuracy of the data. Typically in urban areas sensors are spaced every half mile to a mile in rural areas the spacing might be increased.

In order to monitor the queue warning system remotely a server to store and process the traffic data collected onsite is needed. Cameras also enhance the monitoring abilities of the system and Michigan DOT noted the benefit of adding additional cameras to a queue warning system in the project on the Stopped Traffic Advisory in Jackson, Michigan project on I-94 to make sure that the back-up location could be viewed.

Public Outreach

Deploying a queue warning system may be a new approach that some transportation agencies are using on a construction project. It is important that with a new technology the public is informed on how the system works in order to minimize confusion, reduce frustration, and increase driver awareness.

FHWA developed a guide, Work Zone Public Information Outreach Strategies[52], to help transportation agencies plan and implement effective public information and outreach campaigns to mitigate the negative effects of road construction work zones.

For example, Michigan DOT noted that it would have been beneficial if a video could have been developed to help educate travelers that the queue warning system on I-94 for the Stopped Traffic Advisory in Jackson, Michigan project was providing near real time information.

Contracting

There are many different contracting options for IWZ projects. Some projects may include the IWZ component as a bid item in an overall construction project and some projects may retain an IWZ vendor with a standalone contract.

In the USDOT FHWA Work Zone ITS Implementation Guide[51], an overview of procurement approaches (direct or indirect) are provided as well as information to consider to determine the procurement award mechanism, issuing a request for proposals, and selecting the preferred vendors, consultant or contractor.

Michigan DOT noted the importance of call out of specific pay items (e.g. PCMS boards, sensors, cameras) when developing a contract so that modifications can be made to the system throughout the project.

On the I-35 Mega Project Travel Time and Queue Warning System in Duluth, Minnesota the prime contractor was not allowed to start construction until the Intelligent Work Zone system was installed, tested, and operational. This ensured that the IWZ system worked properly before information was provided to the public.

Other Optional Components

In some work zones, where queue lengths are known or predictable, static signs with flashing beacons may also be used in addition to PCMS to alert the drivers of the conditions as shown in Figure 9. In

2013, Texas DOT placed temporary rumble strips, Work Zone Safety Warning System Unveiled[46], spaced between sensors of a queue warning system to provide an additional alert by sending mild vibrations through oncoming vehicles to alert distracted or drowsy drivers (See Figure 10).

Figure 9: Static Queue Warning Sign with Flashing Beacons in Asheville, North Carolina

Figure 10: Queue Warning System in Texas Incorporates Temporary Rumble Strips[46]

3.3 Alternate Route Advisories in Work Zones

Alternate route advisories in work zones consist of sensors and PCMS located in and around the work zone. As congestion begins to form, the PCMS are activated by the sensors and display a message to provide drivers with an alternate route (e.g. TRAVEL TIME VIA X/ 20 MIN, TRAVEL TIME VIA Y/ 45 MIN).

3.3.1 Summary of Resources

The following table includes resources that were reviewed related to alternate route advisory systems. Information was gathered from available online resources (e.g. published reports, agency web pages, news articles) or through coordination with transportation agencies that have deployed alternate route systems. For those projects that an online hyperlink was not available, a brief summary of the information gathered for the project is provided in Appendix A.

Table 5: Alternate Route Advisories in Work Zones Related Resources

State/Resource	Link
American Traffic Safety Services Association (ATSSA)	• Online Resource: ITS Safety and Mobility Solutions – Improving Travel Through America's Work Zones[57] (2008) - ITS resource manual from ATSSA on multiple areas related to improving safety and efficiency of traffic in work zones.
Illinois	• Deployment Summary: I-70 & I-57 – Effingham (2016) • Deployment Summary: I-57 – Marion (2010)
Federal Highway Administration (FHWA)	• Online Resource: Full Road Closure For Work Zone Operations: A Cross-Cutting Study[58] (2003) - Variety of U.S. case studies on road closures and alternate routes.
Maryland	• Online Resource: Work Zone Lengths for a Four-Lane Road with an Alternate Route[59] (2003) - Evaluation of several alternatives defined by number of closed lanes, fractions of traffic diverted to alternative routes and crossover of diverted traffic to opposite lanes.
Minnesota	• Online Resource: Evaluation of Rural Travel Times During Construction[60] (2013) - Project report focuses on evaluation methods and overall procurement process of the project vs. functionality of Real-time Travel Time Display System.
Nebraska	• Online Resource: Evaluation of Work Zone Speed Advisory System (WZSAS)[61] (2001) - Evaluation study to assess the effectiveness of WZSAS in encouraging traffic diversion when there is congestion in the work zone and its applicability as a traffic management tool.
New Jersey	• Online Resource: Optimization of Work Zone Schedule Considering Time-Varying Traffic Diversion[62] (2009) - Study on using a work zone schedule optimization model and alternate routes.
North Carolina	• Online Resource: Response of North Carolina Motorists to a Smart Work

	Zone System[63] (2003) - Survey conducted of local residents to determine their perceptions and acceptability of the Smart Work Zone.
Street Smart Rental	• Online Resource: Alternative Routes Deployment Criteria Considerations[64] - Short webpage on deployment criteria and anticipated system effects of alternate routes in work zones.
Texas	• Online Resource: I-35 Hillsboro, Texas[65] (2006) - Case study about alternate route conditions and lessons learned.
USDOT Federal Highway Administration	• Online Resource: Work Zone Intelligent Transportation Systems Implementation Guide[66] (2014) - Document to provide guidance on implementing ITS in work zones to assist public agencies, firms, developers, etc.

3.3.2 Summary of Uses and Benefits

This section includes a high level summary of uses and benefits of alternate route technologies in work zones. Links to documents or projects are provided within the summary to provide a quick reference for additional information regarding the topic of interest.

Benefits

There are a number of benefits from deployment of alternate route systems in work zones. Messages that include the location of the expected delay, anticipated delay time, and or possible alternate routes benefits drivers because it provides real-time information so road users can make informed decisions to alter their routes and travel times. Alternate routes in work zones also advise drivers to seek other routes in order to reduce work zone traffic congestion, which decreases fuel consumption and emissions. It also reroutes traffic to reduce traffic demands on roadway sections and allows for more efficient material delivery, which expedites work progress. In addition a resource manual developed by ATSSA, ITS Safety and Mobility Solutions – Improving Travel Through America's Work Zones[57] found that alternate routes can reduce the potential for work zone crashes and helps relieve driver anxiety by providing increased knowledge of the work zone situation and conditions.

When to Use Alternate Routes

Alternate route advisory systems are used for a variety of reasons such as for full road closures or partial closures that result in major traffic delays. A resource manual developed by ATSSA, ATIS Safety and Mobility Solutions – Improving Travel Through America's Work Zones[57], suggests considering alternate routes when another roadway option is available and can accommodate long-distance, regional travelers. This is because most travelers would prefer an alternate route that provides the lowest travel time to the next major populated area or major roadway interchange. Also, when a viable alternate route exists it can help absorb travel demand through the work zone. However, it is important to note that even if an alternate route is an option, if that route is at capacity the alternate route should not be considered.

Alternate routes are often used in conjunction with other ITS technologies, such as advanced messaging signs conveying delay times through the work zone. If the delay becomes excessive (more than the alternate route) then the signs suggest that motorists take the alternate route to increase mobility and reduce overall area wide delays.

Sign Messages and Thresholds

Alternate route advisory information typically is displayed on a changeable message sign by providing the delay time and an alternate route (e.g. 20 MINUTE DELAY, USE XX AS AN ALTERNATE ROUTE) or by providing a comparison of the travel time through the work zone and the alternate route. The sign may also include static portions with changeable panels to indicate delay or travel time (e.g. TRAVEL TIME TO Duluth VIA I-35 62 MIN, VIA 23 73 MIN) as shown in Figure 11.

Figure 11: Minnesota Alternate Route Sign

In addition, PCMS may be strategically placed in advance of an exit and provide only delay time. This information may encourage drivers to consider exiting and finding an alternate route. For example, an evaluation study from Nebraska, Evaluation of Work Zone Speed Advisory System[61], placed PCMS in advance of the work zone at key exits to provide alternate route options to drivers. The system encouraged traffic diversion when there was congestion in the work zone without instructing the drivers to the alternate route.

Transportation agencies may set their own threshold of delayed travel time before considering using an alternate route, but typically a system should be considered if a 10 to 15 minute delay is expected through the work zone.

One example of alternate route sign messages and thresholds used on a project is on I-35 Hillsboro in Texas[65]. Texas used route guidance and PCMS advisory signs that displayed messages based on pre-determined speed and occupancy thresholds, as shown in Table 6 to provide motorists with real-time information on downstream traffic conditions.

Table 6: Example Queue Thresholds on I-35 Hillsboro in Texas

Traffic Flow/Threshold	PCMS Sign 1 (furthest from work zone)	PCMS Sign 2
Normal Traffic, Flow through Work Zone > 55MPH	WORKZONE AHEAD 2 MILES	NO DELAYS -x:xxPM-
Speed Average 40<x>55MPH @ 5 min Lane Occ>20%	WORKZONE AHEAD 2 MILES	MODERATE DELAYS -x:xxPM-
Speed Average 25<x>40MPH @5min Lane Occ>30%	WORKZONE AHEAD 2 MILES	EXPECT DELAYS -x:xxPM-

Speed Average 10<x>25MPH @5min Lane Occ>40%	WORKZONE AHEAD 2 MILES	LONG DELAYS -x:xxPM-
Speed Below 10MPH @5min Lane Occ>50%	WORKZONE TRAFFIC STOPPED	USE ALT ROUTE

Public Outreach

Good communication through internet websites, 511 traveler information systems, public media announcements, highway advisory radio, and permanent ITS systems about work zone conditions can help drivers make informed decisions about their travel plans.

The Minnesota DOT surveyed the public after implementing an alternate route and real-time travel time display system on a rural highway work zone project on I-35 in 2013, Evaluation of Rural Travel Times During Construction[60], and generally received positive feedback. Responses indicated an appreciation of the work zone congestion information to allow for route planning, expectation setting, and less overall stress.

An on-line survey conducted by Nebraska in 2001 Evaluation of Work Zone Speed Advisory System[61], found that 71% of respondents indicated that they would get off of the freeway and take an alternate route if they encountered major congestion on the freeway and 83% of respondents indicated that they would take another route if they found out about major traffic congestions on their normal route before leaving.

Contracting

In the US DOT FHWA Work Zone ITS Implementation Guide[6651], an overview of procurement approaches (direct or indirect) are provided as well as information to consider when determining the procurement award mechanism, issuing a request for proposals and selecting the preferred vendors, consultant or contractor.

Minnesota's I-35 project, Evaluation of Rural Travel Times During Construction[60], on a 70-mile stretch of rural freeway is a successful example of contracting for alternate routes and real-time travel time display system. MnDOT procured a stand-alone contract using Design-Bid-Build and Best Value Procurement. The stand-alone contract was considered effective by both the Minnesota DOT and the Contractor in procuring a qualified Contractor. For this project, MnDOT required the Contractor to propose a system in which the means and methods were previously successful in order to ensure the Contractor had experience with the proposed system.

3.4 Variable Speed Limits in Work Zones

Variable speed limit technology in work zones typically consists of sensors, PCMS, and a processing system that calculates the speed limits to be displayed on the PCMS based on measured speed and/or volume data. As congestion begins to form, the PCMS are activated to provide drivers with a safe speed limit through a work zone and to minimize braking as they approach the queue.

3.4.1 Summary of Resources

The following table includes resources that were reviewed related to variable speed limit systems. Information was gathered from available online resources (e.g. published reports, agency web pages, news articles) or through coordination with transportation agencies that have deployed variable speed limit systems. For those projects that an online hyperlink was not available, a brief summary of the information gathered for the project is provided in Appendix A.

Table 7: Variable Speed Limits in Work Zones: Related Resources

State/Resource	Report/Deployment Project Summary
Florida	• Online Resource: Evaluating Variable Speed Limits and Dynamic Lane Merging Systems in Work Zones: A Simulation Study[67] (2012) -Study simulating a two-to-one work zone lane closure configuration under different Maintenance of Traffic (MOT) plans and comparing work zone throughputs and travel times across MOTs including early and late Dynamic Lane Merge and VSL combinations. • Online Resource: Implementing Variable Speed Limits in Florida[68] (2007) - Study on plans for Florida that called for the implementation of variable speed limits.
Kansas	• Deployment Summary: I-35/Homestead (2013)
Michigan	• Online Resource: Field Test of Variable Speed Limits in Work Zones[69] (2003) - Report objective was to design and deploy a viable VSL system in a work zone and evaluate the extent to which: speed limit compliance is affected; and how safety as well as traffic flow is improved.
Minnesota	• Online Resource: Field Evaluation of Variable Advisory Speed Limit System for Reducing Traffic Conflicts at Work Zones [70] (2006) - Evaluated effectiveness in reducing traffic conflicts and improving operational efficiency at a work zone on I-494. • Online Resource: Minnesota IWZ Toolbox[71] (2008) - Minnesota strategies for using ITS in work zones and when to appropriately select IWZ systems.
Nebraska	• Report Summary: Evaluation of Work Zone Speed Advisory System (WZSAS) [72] (2001) - Evaluation study to assess the effectiveness of WZSAS in encouraging traffic diversion when there is congestion in the work zone and its applicability as a traffic management tool.
New Jersey	• Deployment Summary: Turnpike 6-9 Widening Project (2013)

Smart Work Zone Deployment Initiative (SWZDI)	• Online Resource: Evaluation of Variable Speed Limits in Work Zones[73] (2013) - Study and evaluation of VSL and Variable Advisory Speed Limit systems and recommendations based on the case studies investigated.
Street Smart Rental	• Online Resource: VSL Deployment Criteria Considerations[74] - Short webpage on deployment criteria and anticipated system effects of variable speed limits.
Texas	• Online Resource: Summary of Treatments to Improve Work Zone Speed Limit Compliance[75] (2005) - Project to determine effective measures to motivate and encourage drivers to observe posted speed limits in work zones.
USDOT Federal Highway Administration	• Online Resource: Work Zone Intelligent Transportation Systems Implementation Guide[76] (2014) - Document to provide guidance on implementing ITS in work zones to assist public agencies, firms, developers, etc. • Online Resource: Work Zone Public Information and Outreach Strategies[77] (2005) - This guide is designed to help transportation agencies plan and implement effective public information and outreach campaigns to mitigate the negative effects of road construction work zones. • Online Resource: Examples of Variable Speed Limit Applications[78] (2000) – Transportation Research Board (TRB) Speed Management Workshop that discusses domestic and foreign examples of VSL applications.
Utah	• Report Summary: Evaluation of the Effectiveness of Variable Advisory Speed System (VASS) on Queue Mitigation in Work Zones[80] (2012) - Study objective was to perform a statistical analysis on performance data to evaluate VASS effectiveness on queue mitigation. • Report Summary: VSL Signs Effects on Speed and Speed Variation in Work Zones[81] (2008) - Research tested the compliance and derived potential advantages from the use of variable speed limit equipment.
Virginia	• Online Resource: Work Zone Variable Speed Limit Systems: Effectiveness and System Design Issues[82] (2010) - Study recommends that Virginia DOT pursue VSL technology, but carefully scrutinize algorithm design and VSL sign placement, and a cost/benefit analysis indicates that VSLs may be most appropriate for long-term applications.

3.4.2 Summary of Uses and Benefits

VSL Benefits:

- Reduce Crashes
- Reduce Congestion
- Increase uniformity in traffic speeds

This section includes a high level summary of uses and benefits of variable speed limit technologies in work zones. Links to documents or projects are provided within the summary to provide a quick reference for additional information regarding the topic of interest.

Benefits

There are a number of benefits from the deployment of variable speed limit technology in work zones. If the VSL is deployed far enough ahead of the work zone, it can reduce crashes that could occur as drivers approach the back of the queue. Another benefit of VSL systems is to reduce congestion and ease traffic through a work zone depending on current conditions.

If properly designed, VSL systems have shown to also reduce system travel time through increased uniformity in traffic speeds. A field evaluation conducted by the Minnesota DOT on a VSL System, Field Evaluation of Variable Speed Limit System for Reducing Traffic Conflicts at Work Zones a VSL system[70], in a work zone found that the reduction in speed difference resulted in approximately a 7% increase of the total throughput volume measured.

As another example, according to a study conducted by Utah DOT, VSL Signs Effects on Speed and Speed Variation in Work Zones[81], both the average speed and variation in speeds were reduced by providing drivers real time speed limit information which reacted to the construction conditions in the field.

Typical Use

According to the USDOT FHWA Work Zone ITS Implementation Guide[76] variable speed limit displays should be considered for deployment when any of the following conditions are anticipated:

- Frequent planned lane closures are expected, which will create queues that cause high speed differentials between queued and approaching traffic
- Work activities that will frequently occur for which lower speed limits would be beneficial to have on a temporary basis
- Traffic speeds through the project vary widely due to overstautrated conditions during the peak period, and the timing and extent of congested travel will vary significantly day to day

For example, the Minnesota IWZ Toolbox[71] suggests considering deploying speed information when the work zone will cause additional travel time and the work zone queue is estimated to slow traffic at least 20 mph below the posted speed limit.

A Field Test of VSL in Work Zones In Michigan[69] concluded that a VSL system may have more utility in longer and "simpler" work zones (e.g. long zones with relatively short active work areas).

Typical System Components

Variable speed limit technology in work zones typically consist of sensors and PCMS and are used in conjunction with other ITS technologies. In addition, weather information and road surface condition technology may also be utilized to calculate the appropriate speeds that a driver should be traveling in work zones. The VSL system identifies the average speed of downstream traffic through the sensors and then provides the upstream traffic with an optimum speed to approach the queue.

Sign Messages

There are a variety of messages and signs that may be used to display a safe speed limit to drivers. One example is a static sign used in a Minnesota field evaluation, Field Evaluation of Variable Advisory Speed Limit System for Reducing Traffic Conflicts at Work Zones[70], which states, WATCH FOR SLOW TRAFFIC AHEAD, with a variable changeable message sign to display the speed limit as shown in Figure 12. Figure 13 provides a sign alerting drivers to the beginning of a VSL Zone in Virginia and Figure 14 includes a VSL sign posted in a work zone in Virginia, Work zone VSL Systems: Effectiveness and System Design Issues[82].

Figure 12: VSL Sign installed near Hwy 61 in Minnesota

Figure 14: VSL Alerting Drivers to Beginning of VSL Zone in Virginia

Figure 13: VSL Sign Posted in a Work Zone in Virginia

Compliance

One of the difficulties of implementing VSL is motivating drivers to comply with the traffic regulations within a work zone. Providing more accurate and real time speed restrictions based on the level of construction activity can offer more information to motorists and can encourage drivers to comply with the posted speed while improving safety in the work zone.

The USDOT's Guidelines on Managing Speeds in Work Zones[79] states that "drivers reduce their speeds through the work zone only when they perceive a need to do so, based on conditions in the work zone or the perception of enforcement activities." The potential voluntary speed reduction in a work zone with a reduced speed limit sign is 0 to 3 mph where operating speeds upstream of the work zones ranged from 60 mph to 77 mph. When normal operating speeds on the roadway are high, these voluntary speed reductions alone may not reduce driver's speeds through a work zone. Drivers reduce their speeds through the work zone only when they perceive a need to do so, which is based on the conditions in the work zone or the perception of enforcement activities.

While there are a wide variety of available improvement methods for work zone speed limit compliance, implementing these treatments appropriately, along with consistent presentation of realistic work zone speed limits, can help motivate drivers to comply, which can reduce speeds and improve safety conditions for workers and drivers. The USDOT's Guidelines on Managing Speeds in Work Zones[79] also recommends that other speed management technologies can be used to encourage compliance if law enforcement is not available, such as speed display trailers; PCMS with radar; citizen band radio information systems; transverse rumble strips; drone radar; narrowing lanes with channelizing devices; and transverse pavement markings.

According to the Texas Department of Public Safety documented in a study from the Texas Transportation Institute, Summary of Treatments to Improve Work Zone Speed Limit Compliance[75], more than 9,500 crashes occurred in work zones on the state highway system in 2000 and speed was cited as a contributing factor in approximately 42 percent of these crashes. State's procedures for improving compliance vary widely but enforcement, flagging, speed display trailers, and changeable message signs consistently have shown measureable positive results. The study also found that to avoid work zone speed limits that are ignored or disobeyed, limits should be posted at realistic values and should be confined as much as possible to the specific area where the work is taking place.

Public Outreach

FHWA developed a guide, Work Zone Public Information Outreach Strategies[77], to help transportation agencies plan and implement effective public information and outreach campaigns to mitigate the negative effects of work zones. It may benefit the project and lead to improved compliance rate if the public is educated on the benefits of VSL through a work zone construction project prior to the start of the construction.

Contracting

There are many different contracting options for IWZ projects. Some projects may include the IWZ component as a bid item in an overall construction project and some projects may retain an IWZ vendor with a standalone contract.

In the USDOT FHWA Work Zone ITS Implementation Guide[76], an overview of procurement approaches (direct or indirect) are provided as well as information to consider to determine the procurement award mechanism, issuing a request for proposals, and selecting the preferred vendors, consultant or contractor.

4.0 Summary

This section provides an overall summary of the information collected through the literature search and deployment examples collected through coordination with transportation agencies deploying intelligent work zone technologies during recent construction seasons. Also included is high level summary of the overall uses and benefits noted for dynamic merge, queue warning, alternate route advisories, and variable speed limit IWZ applications.

Summary of Resources

A detailed online literature search was conducted to gathered information resources related to the four IWZ technologies of interest. Resources included reports, studies, evaluations, news articles, blogs, YouTube videos, and recent deployments from transportation agencies. Dynamic merge produced the largest number of resources (35) gathered for the project as shown in Table 8.

Table 8: Number of Resources Reviewed for each IWZ Technology

IWZ Technology	Number of Resources Reviewed
Dynamic Merge System	36
Queue Warning	29
Alternate Route Advisories	12
Variable Speed Limits	17
TOTAL	**94**

Summary of Uses and Benefits

A summary of uses and benefits were prepared for each of the four IWZ technologies based on the review of the resources gathered. Table 9 provides a brief description of each technology, benefits for deploying the technology and when to consider using the technology. For example dynamic merge systems are typically used in a work zone with fluctuating traffic demand and the benefits of deploying a dynamic merge system includes a reduction in delay, increased safety and increased lane usage.

Table 9: IWZ Technology Description, Benefits and Typical Use

IWZ Technology	Description	Benefits	Typical Use
Dynamic Merge System	As congestion begins to form, drivers are provided with lane use instructions (e.g. TAKE YOUR TURN, MERGE HERE, USE BOTH LANES).	• Reduce Delay • Increase Safety (reduce aggressive driver behavior) • Increase lane usage	Work zones with fluctuating traffic demand
Queue Warning	When slow or stopped traffic is detected, drivers are altered of the condition (e.g. STOPPED TRAFFIC AHEAD).	• Increase Safety (Reduce rear end crashes)	Work zones with the goal of reducing the number and severity of rear end crashes

Alternate Route Advisories	As congestion forms, drivers are provided with an alternate route (e.g. TRAVEL TIME VIA X/ 20 MIN, TRAVEL TIME VIA Y/ 45 MIN).	• Reduce work zone traffic congestion	Full or partial road closures that result in major traffic delays
Variable Speed Limits	As congestion forms, drivers are provided with a safe speed limit through a work zone to minimize braking as they approach the queue.	• Safety (reduce crashes) • Reduce work zone congestion	Work zone will create queues with high speed differentials between queued and approaching traffic

Typical System Components

For all four of the IWZ practices summarized in this report, there are different components to consider when designing an appropriate IWZ system; however, typically equipment includes PCMSs, sensors, and a server. The technologies might require additional resources such as cameras to monitor, microwave signals to identify traffic volume; video analysis to track traffic volume, lane occupancy, and queue; Doppler radar to measure average speed; pneumatic tubes to calculate traffic volume; and computer simulations to optimize dynamic merging algorithms. In addition to these technologies, the IWZ practices are often used in conjunction with each other, for example alternate routes use advanced messaging signs conveying delay times and or variable speeds through the work zone.

Public Outreach

Public outreach prior and during the intelligent work zone project was found to be beneficial in deploying these IWZ practices. Deploying any of these systems may be a new approach that some transportation agencies are using on a construction project. It is important that with a new technology the public is informed on how the system works in order to minimize confusion, reduce frustration, and increase driver awareness. FHWA developed a guide, Work Zone Public Information and Outreach Strategies[32], to help transportation agencies plan and implement effective public information and outreach campaigns to mitigate the negative effects of road construction work zones. Good communication through internet websites, 511 traveler information systems, public media announcements, online videos, highway advisory radio, and permanent ITS systems about work zone conditions can help drivers make informed decisions about their travel plans and increase overall safety.

Contracting

There are many different contracting options for IWZ projects. Some projects may include the IWZ component as a bid item in an overall construction project and some projects may retain an IWZ vendor with a standalone contract.

In the US DOT FHWA Work Zone ITS Implementation Guide[31], an overview of procurement approaches (direct or indirect) are provided as well as information to consider when determining the procurement award mechanism, issuing a request for proposals, and selecting the preferred vendors, consultant or contractor.

In summary, there are many different variables with each intelligent work zone technology. What works for one project may not for another, but with each deployment lessons learned will assist in identifying what will work best in each situation for your transportation agency.

Appendix A: Deployment Examples

Dynamic Merge Deployment Summary: EB I-96 near MM – Ottawa County, Michigan

During 2013 EB I-96 underwent the removal of two bridges and replacement with two, pre-stressed concrete box beam bridges, hot mix asphalt road reconstruction, cold milling and resurfacing, new interchange construction, bridge rehabilitation on two bridges, deep overlay on one bridge, water main relocation, guardrail and drainage improvements, signing, pavement markings, and restoration on I-96 from west of GTW Railroad (Abandoned) east to east of 112th Avenue, Ottawa County. This project includes two 5 year materials and workmanship pavement warranties and a 2 year bridge painting warranty. 4 traffic sensors, communication devices, 5 sets-flashers, signs, 5 trailers, 5 sets- solar power equipment and batteries, and PCMS were utilized. The message board with the merge and arrow symbol was removed because traffic was merging prior to them needing to merge. The project indicated very good success with the dynamic merge. A lot of positive feedback from motorists and police enforcing agencies. Traffic is merging properly and not having many motorists “cheat” and pass everyone and merge at the arrow board. As long as you enforce the system with police the motorists are obeying the signs. The key to success is having enough enforcement.

Queue Warning Deployment Summary: Caltrans Queue Warning System – San Diego, California

In San Diego, California holiday mall traffic backs up onto the 805 and the 163 Highway has been an issue in previous years. Steep hills and blind corners exacerbate the issue. From November 2012 to January 2013 a queue warning system was deployed to address these issues. 5 PCMS and 5 Traffic Sensors were deployed at the project location. Incidents were reduced 66% over 2011 and no fatalities during the peak holiday traffic within the project. A similar set up would be recommended for any major long term closure, for construction or maintenance. Future project designs will consider providing detour using local city streets or county roads in addition to the smart PCMS in order to move public motorists from point A to point B as quickly and safely as possible.

Queue Warning Deployment Summary: I-55 (I-70 to IL 140) – Madison County, Illinois

During November 2010 – June 2012 the Illinois DOT deployed one umbrella “Real Time Monitoring System” to cover three construction projects. The construction project was located in Southern Illinois on 30 miles of a bi-directional mainline interstate roadway on I-55 from I-70 to IL 140. The goal of the project was to reduce the number of queuing type (rear-end) accidents with a secondary function to alert traffic to delay times and suggest alternate routes when delay times warranted such.

Equipment used on the project was stationed 6 miles in advance and included 73 PCMS and 56 Doppler sensors. Queue detection PCMS’s were spaced one mile apart along the route to warn motorists about “STOPPED TRAFFIC” and travel times, delay times, and to provide a dynamic detour. When queues were detected the system alerted motorists 1-2 miles in advance of the condition. When speed sensors detected traffic slowed (below 40 mph) the software would trigger STOPPED TRAFFIC AHEAD, BE PREAPRED TO STOP messages for the two boards approaching where the slowed traffic was detected.

An analysis of rear end queuing type accidents for this project was conducted and compared with a similar project on I-55 during the 2010 season without ITS WZ system (See map below) and found a 13.8 % reduction in these type accidents during the 2011 season (with ITS WZ in place) even with 25.4% more traffic exposure. This was with a similar number of miles under construction during the two seasons. The comparison is shown in the chart below.

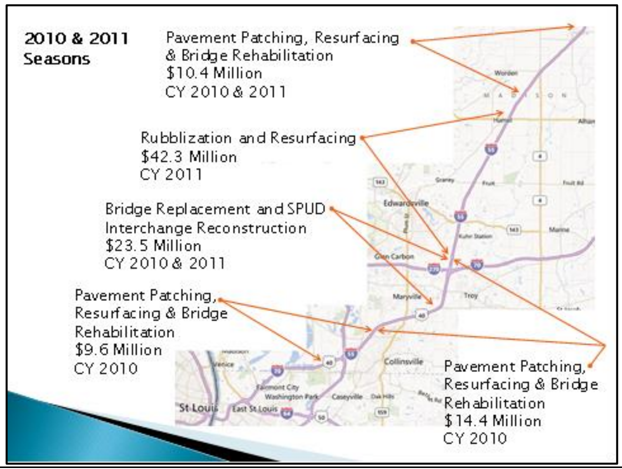
The delay times were fairly accurate although technology in this area is always improving and what was used could probably be improved upon with Bluetooth technology as well as other now available technology.

The entire contract cost for the Roadway project was $42.3 million and the ITS WZ portion was $1.15 million as bid. IDOT did win a 2012 America's Transportation Award for "Best Use of Innovation for Medium Project" for this Work Zone ITS system.

2011 Construction Compared to 2010 (Statistics)

	2010	2011	Difference	% Change
Total Miles I-55 Construction	19.5	20.2	+0.7	+3.6%
Total Lane Closure Days	355	540	+185	+52%
*Total Vehicle Exposure (ADT x Lane Closure Days)	13,031,750	16,346,800	+3,315,050	+25.4%
Property Damage Accidents	75	64	-11	-14.6%
Injury Accidents	18	16	-2	-11%
Fatalities	1	1	0	0%
Total Queuing Accidents	94	81	-13	-13.8%

*Does not account for ADT using Detours



Queue Warning Deployment Summary: I-80 Southwest Chicago, Will County, Illinois

From May to November 2011 a queue warning system was deployed to provide advance warning a key decision points upstream of problem areas on I-80 just southwest of Chicago, Illinois. I-80 was reduced to one lane while accommodating very high heavy truck traffic (8 mile segment). Equipment used included 19 PCMS, 24 traffic sensors and 6 camera trailers. Message displayed on the PCMS included STOPPED TRAFFIC AHEAD and TO I-355, 12 MILES, 38 MINUTES. The DOT Traffic Management Center used the real-time data and video to assist in timely incident management

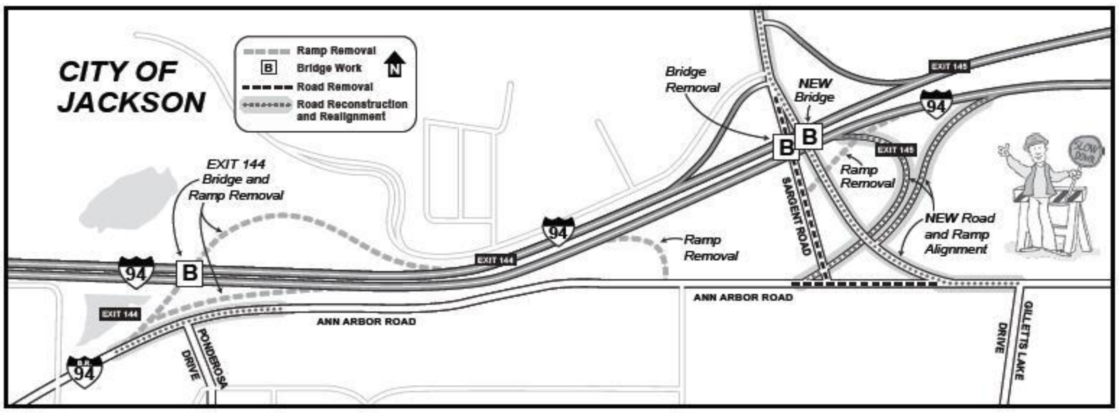
Queue Warning Deployment Summary: I-57 Marion, Illinois

In the summer of 2010 on I-57 in Marion Illinois a dynamic queue detection and warning system was deployed that also included temporary route travel time for I-57 near Marion. The system did very well notifying the traveling public of stopped or slowed traffic ahead with accurate distances. We worked with the manufacturer to expand its use and develop algorithms to provide "real time" delays and promote the use of detour routes. Various systems have been utilized on a number of interstate projects since then and our PD staff continues to modify the special provision to reflect the most current technologies and promote competitive bidding by the various manufacturers.

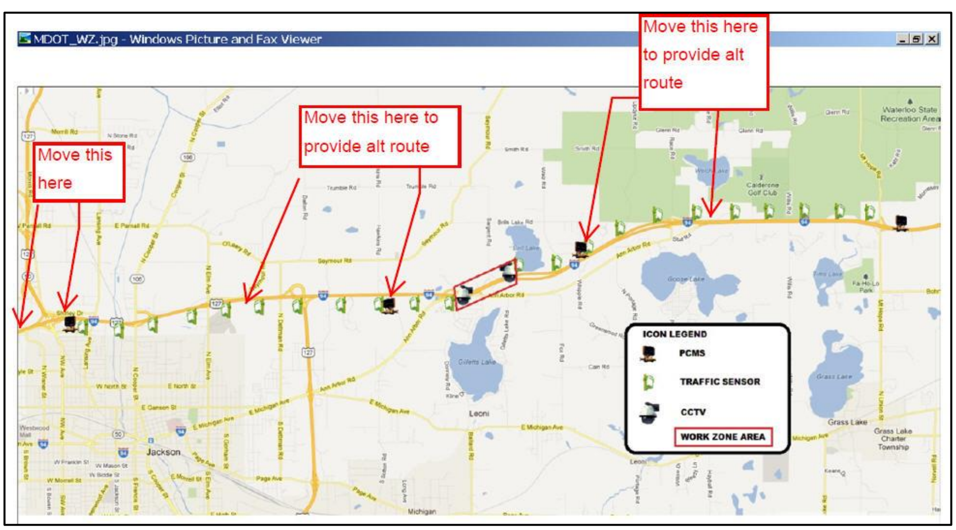
Queue Warning Deployment Summary: Stopped Traffic Advisory (I-94 and Sargent Road) – Jackson, Michigan

Between July 6, 2011 and November 22, 2012 Michigan DOT reduced traffic to one lane in each direction (eastbound and westbound) for two weeks for an interchange realignment, bridge removal and construction on I-94. See map below.

The goal of the project was to reduce slow/stopping traffic crashes. Equipment used for the IWZ included: Portable Changeable Message Signs (PCMS), Portable non-intrusive traffic sensors, portable trailer mounted Closed Circuit Television (CCTV), central computer at the vendor's location and a system web page for the project. The PCMS furthest from the taper activated when traffic was moving slower than 45 mph. The PCMS closest to the taper activated when traffic was slower than 15 mph. CAUTION SLOWED TRAFFIC X MILES AHEAD was posted when the sign was activated. Travel times were placed on the PCMS at free flow speeds.



The message displayed on the PCMS furthest from the taper was changed during the project based on observed conditions from "CAUTION SLOW TRAFFIC, NEXT X MILES" to "CAUTION SLOWED TRAFFIC, X MILES AHEAD". The threshold to activate PCMS 2 was changed from 10 mph to 15 mph. This change was made because when traffic was stopped flow was still above or close to 10 mph when in the stop and go condition. The location of the PCMS signs were moved during the project to provide travelers with an alternate route after viewing the PCMS as show in the figure below.



As of October 2012, all the crash data had not been processed. It is anticipated that there was reduction in rear-ends as compared to previous lane closures on I-94. A determination will be made when crash data is available.

Recommendations and lessons learned from the project include:

- Have a greater saturation of PCMS (both sides of the roadway)
- Provide a list of suggested messages for different scenarios (Stopped Traffic, Slowed Traffic, and Free Flow Traffic)
- Add additional cameras to make sure that the back-up location can be viewed.
- Clearly define the duration of use (Only in use for two weeks on I-94)
- Require E-mail alerts to be sent out based on traffic speeds
- Temporary rumble strips to alert the drivers at the PCMS locations
- Call out specific pay items so that modifications can be made (PCMS boards, Sensors, Cameras, Sensor Adjustment (Stage changes)
- It would have been nice to have a youtube video or something talking about the system to make the public aware that the information provided was near real time. There was not a lot of outreach on the IWZ system itself, but more focus on the bridge reconstruction and the short time frame of the single lane closures.
- It was suggested that this system be used on any project which includes closures during peak time and back-ups that will be outside of the lead in work zone signing. In Michigan about 50% of total work zone crashes are due to stopped or slowing traffic and this system directly reduces those types of crashes. A high return on investment should be received because of the number of crashes that can be potentially mitigated.

Queue Warning Deployment Summary: I-35 Mega Project Travel Time and Queue Warning – Duluth, Minnesota

I-35 in Duluth, Minnesota included many old bridges that were in desperate need of major reconstruction. This vital link between Minneapolis and Duluth and tourist destinations to the north had to be kept open to traffic during the reconstruction. Traffic was restricted to an 11 foot lane in each direction and significant delays were anticipated during April 2010 and October 2011. The goal of the ITS project was to provide an automated system that would convey travel times as far as 30-90 miles in advance to allow drivers to pick alternative routes. In addition the area south of the work zone, where traffic backed up was often prone to fog and bad visibility due to high speeds and limited vertical sight distance. Equipment used on the project included 3 PCMS/3 Travel Time Signs, 4 Prepare to Stop Flashers, 16 Traffic Sensors and 1 Camera Trailer. It is important to note that the prime contractor was not allowed to start construction until the IWZ system was up and operational.

Queue Warning Deployment Summary: Pennsylvania Turnpike I-476 – Montgomery County, Pennsylvania

A condition responsive queue warning and travel time system was deployed on a 3-year construction project on the Pennsylvania Turnpike I-476. The system was deployed February 2011 and is intended to be in operation for 33 months. The goal of the ITS project is to warn motorists of delays and stopped traffic via both the Turnpike's existing 6 older overhead Dynamic Message Signs (DMS) and 15 additional PCMSs. Additional equipment used included 18 traffic sensors and 16 3rd party sensors. All of the portable sensors and signs are monitored at the Turnpike Commission's TOC, but operate automatically based on actual real-time traffic conditions.

Queue Warning Deployment Summary: I-35 from Austin to Waco, Texas

The Texas Transportation Institute developed an integrated system that provides the Texas DOT with work zone monitoring and traveler information dissemination capabilities. The system collects and integrates planned lane closure schedules from the multiple contractors working on the I-35 corridor, from Austin to Waco, automatically assesses the traffic queuing and delay potential associated with those planned closures, and disseminates advance notification of the closures and potential impacts to potential users of the corridor through multiple outreach mechanisms, including social media. The system was designed to assist the Texas DOT and contractors with deployment decisions of portable end-of-queue warning systems, and integrate inputs from those systems with various other traffic monitoring technologies in the corridor to develop accurate delay forecasts. The TTI system works in conjunction with the Texas DOT Lonestar system for posting messages to corridor signage and will eventually transition all operations to Lonestar. Much of the deployed equipment (CCTV, Wavetronix, Bluetooth) concurrently reports data to TTI as well as the Texas DOT. Prior to any deployment, a complete Concept of Operations, a system architecture, and identified user needs through stakeholder meetings, public surveys and a comprehensive systems engineering process were conducted. Beyond the current operational systems, utilizing the depth of infrastructure already developed and operational, the I-35 corridor is also uniquely positioned to be a test-bed in the development of in-vehicle dissemination of work zone queue and delay information to commercial vehicles and others.

Alternate Route Deployment Summary: I-70 and I-57 – Effingham, Illinois

Effingham, IL is located at the crossroads of two major freeways (I-70 & I-57) which accommodate very high heavy truck volumes (over 50%). The Illinois Governor directed DOT staff to utilize smart work zones and specifically queue warning systems after the state experienced two major fatalities on heavy truck routes in work zones the previous year. This project's primary goal was to greatly increase safety and eliminate serious and fatal crashes related to vehicles crashing into the rear end of a queue of vehicles that often forms just before a lane reduction work zone taper. 25 Portable Changeable Message Signs, 35 Traffic Sensors, and 20 Camera Trailers were utilized. Advanced signs conveyed delay times through the work zone and if delays became excessive (more than the alternate route) then they suggested that motorist take the adjacent alternate routes to increase overall area mobility and reduce overall area wide delays. The sign Messages when the thresholds triggered were:

- Free Flow: NO DELAY NEXT XX MILES
- Moderate Delay: XX MIN DELAY NEXT XX MILES
- High Delay: CONSIDER ALT RTE EXIT XXX
- Max Delay: EXPECT MAJOR DELAYS FOLLOW DETOUR EXIT XXX

Alternate Route Deployment Summary: I-57 – Marion, Illinois

A project on I-80 just southwest of Chicago, Illinois in the Summer of 2010 was conducted. The system did very well notifying the traveling public of stopped or slowed traffic ahead with accurate distances. We worked with the manufacturer to expand its use and develop algorithms to provide "real time" delays and promote the use of detour routes. Various systems have been utilized on a number of interstate projects since then and our PD staff continues to modify the special provision to reflect the most current technologies and promote competitive bidding by the various manufacturers.

Variable Speed Limit Deployment Summary: I-35 Smart Work Zone – Kansas City, Kansas

The project on I-35 required the construction of a new interchange. The goals of the project were to retain equipment at the conclusion of the project and improve safety and reduce congestion. Technologies used included 18 PCMS, 6 portable cameras, 21 portable traffic sensors and 8 portable VSL signs. A low bid contract was utilized and a low bid vendor was tied to the construction project.

Variable Speed Limit Deployment Summary: Turnpike 6-9 Widening Project – New Jersey

During 2010 to 2013 a 25 mile segment of the Pennsylvania Turnpike was widened from 6 lanes to 12 lanes under 14 separate contracts. The goal of the project was to provide a turn-key temporary ITS replacement systems from the New Jersey Turnpike's old legacy system of Variable Message Signs and Variable Speed Limit Signs. Technologies used included 27 portable VSL signs, 31 PCMS and 25 traffic sensors. All temporary devices were managed from the NJTPAN/NJDOT TMC headquarters, but operated automatically based on prevailing downstream traffic conditions.

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