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Queue Warning Systems in Work Zones

Summary of Uses and Benefits

About

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

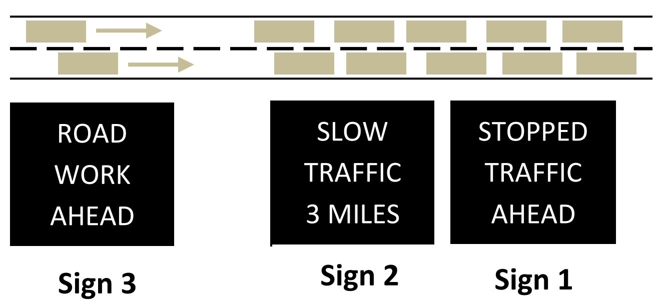
The purpose of the project was to understand the current status of work on IWZ activities by combining the resources gathered through a literature search with the information collected from the transportation agencies on recent deployments. Also included is a summary of queue warning systems in work zones including examples of successes, any guidance possible when technologies are most effective, and the configurations that demonstrated the best results.

While this summary is focused on queue warning systems in work zones, it is important to note that similar summaries were also developed by ENTERPRISE for dynamic merge systems, information describing conditions on alternate routes through work zones; and variable speed limit systems within work zones. These summaries are available on the ENTERPRISE Project Webpage.

Definition

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 Portable Changeable Message Sign (PCMS). The message displayed on the CMS alert drivers of the condition (e.g. STOPPED TRAFFIC AHEAD) as shown below.



Example CMS Messages when Slow or Stopped Traffic is Detected

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 at the end of this document.

Queue Warning Systems Related Resources

State/Resource	Document/Intelligent Work Zone Deployment
American Traffic Safety Services Association (ATSSA)	• Online Resource: Treating Potential Back-of-Queue Safety Hazards[1] (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[2] (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[3] (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: Duluth I-35 Mega Project - Travel Time and Queue Warning (2011) • Online Resource: Low-Cost Portable Video-Based Queue Detection for Work-Zone Safety[4] (2011) - Evaluation of a low-cost rapidly deployable and portable queue detection warning system. • Online Resource: Minnesota IWZ Toolbox[5] (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[6] (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.

State/Resource	Document/Intelligent Work Zone Deployment
Oregon	• Online Resource: Dundee Queue Detection System[7] (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[8] (1998) - Pennsylvania project using technology for alerting motorists on U.S. Route 22 by using 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[9] – 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[10]– 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 [11]– 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[12] (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[13] (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[14] (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[15] (2013) - Microscopic traffic simulation used to evaluate various design alternatives of a dynamic queue warning system at a freeway work zone with lane closure.

State/Resource	Document/Intelligent Work Zone Deployment
USDOT Federal Highway Administration	• Online Resource: Work Zone Intelligent Transportation Systems Implementation Guide[16] (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[17] (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[18] (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 - Definitions of ITS terms used in Virginia's I-66 ATM Treatment.
Washington State	• Online Resource: Active Traffic Management Concept of Operations [19] (2008) - Public resource manual from Washington State DOT on multiple parts of ITS implementation in work zones.
Work Zone ITS Blog	• Online Resource: Workzoneitsblog[20] - Blog about all things work zone and rural ITS.

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[17], 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.

Typical System Components

There are different components to consider when designing an appropriate queue warning system, however typically equipment 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 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 Stopped Traffic Advisory in Jackson, Michigan project to make sure that the back-up location could be viewed.

Benefits

There are a number of benefits of 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[16] indicates delay, aggressive driving behavior, safety and queue length as benign 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%.

Result from the Ministry of Transportation Ontario a Queue Warning System on Highway 402[3] 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. The figure below 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.

Queue Warning System Site in Ontario, Canada

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 Portable CMS to alert the drivers of the conditions as shown below. In 2013, Texas DOT placed temporary rumble strips, Work Zone Safety Warning System Unveiled[10], 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.

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

Queue Warning System in Texas incorporates temporary rumbles strips

When to Use Queue Warning Systems

Queue warning systems are typically used when the goal is to reduce the number and severity of rear end crashes, based on the conclusions listed in the Caltrans Queue Warning System in San Diego, California which 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.

Sign Messages and Thresholds

Messages posted on CMS for queue detection projects typically accommodate three sets of messages for different scenarios as noted in Table 1. For example, in a free flow scenario where traffic is moving at the posted speed limit of 55mph a CMS may post CAUTION/ROAD WORK AHEAD. A queue detection system may also not a 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).

Example CMS 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 CMS messages used to describe a similar queue situation. For example in Jackson, Michigan in 2012 the CMS 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 CMS changed during the project to provide an alternate route after viewing the message. The Ministry of Transport Ontario while operating the queue warning system on Highway 402 Queue Warning System[3] displayed **WATCH FOR SLOW TRAFFIC, NEXT X KM**.

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 in Jackson, Michigan project the slow traffic message was triggered 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.

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[16], 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 system worked properly before information was provided to the public.

Queue Warning System Deployment Examples

Following are queue warning system deployment example project summaries.

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 Portable CMS and 5 Traffic Sensors were deployed at the project location. Noted results from the project included:

- Incidents reduced 66% over 2011
- No fatalities during the peak holiday traffic within the project

Recommendations from deployment of the queue warning system in San Diego included:

- 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.

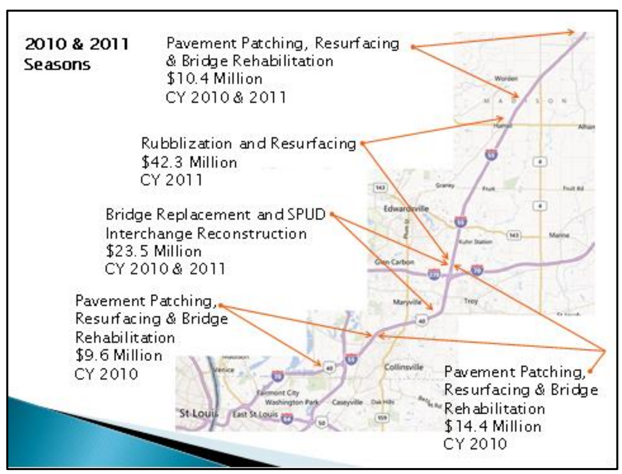
I-55 (I-70 to IL 140) – Madison County, Illinois

Source: Ted Nemsky, Illinois DOT, 618.346.3345, ted.nemsky@illinois.gov

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 on the next page.



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

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.

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.

I-57 Marion, Illinois

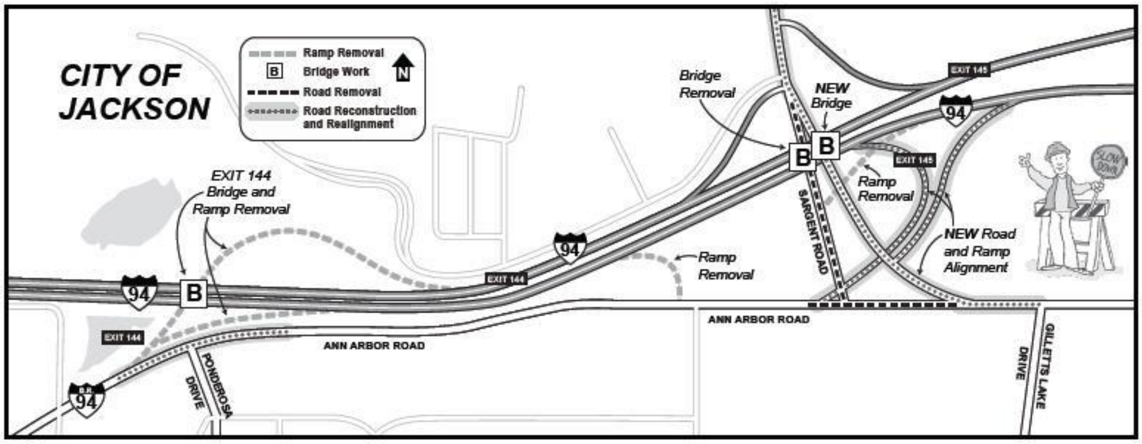
In the summer of 2010 on I-57 in Marion Illinois a dynamic queue detection and warning system was deployed that also included temporary route travel time for I-57 near Marion. The system did very well notifying the traveling public of stopped or slowed traffic ahead with accurate distances. We worked 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.

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

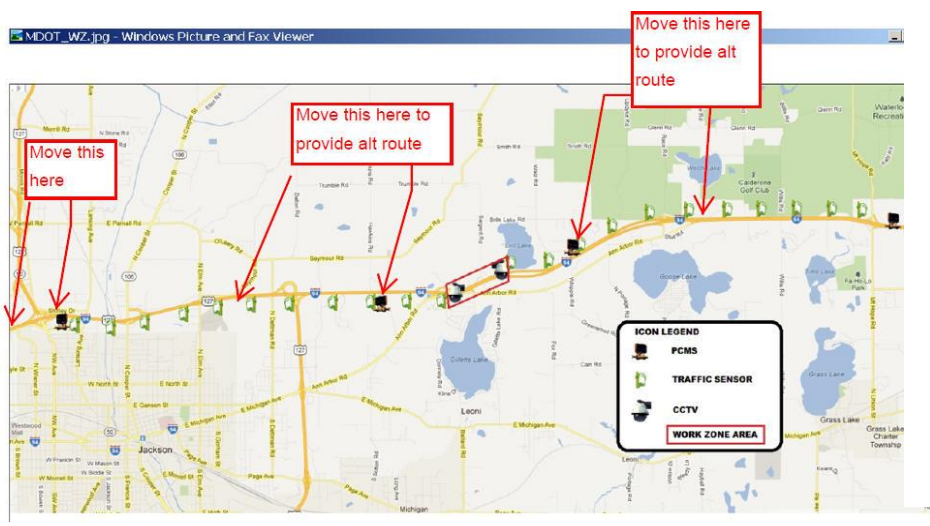


AHEAD". The threshold to activate PCMS 2 was changed from 10 mph to 15 mph. This change was made because when traffic was stopped flow was still above or close to 10 mph when in the stop and go condition. The location of the PCMS signs were moved during the project to provide travelers with an alternate 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.

I-35 Mega Project – 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.

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.

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.

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