Work Zone Intelligent Transportation Systems - Technology Supplement

A supplemental document to the 2014 Work Zone Intelligent Transportation Systems (ITS) Implementation Guide

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16. Abstract

This report represents a technology supplement to the 2014 Work Zone Intelligent Transportation Systems (WZITS) Implementation Guide (Report No. FHWA-HOP-14-008). The Guide forms the foundational framework, concepts, and methods for establishing a WZITS program. The Guide further introduces various Intelligent Transportation Systems (ITS) technology solutions, but does not go into details on their functionality or standard specifications. The purpose of this document is to supplement the original Guide with this information, and includes factsheets and specification sheets for nine WZITS technologies. The technologies are Dynamic Lane Merge, Queue Warning, Variable Speed Limit, Automated Enforcement, Entering/Exiting Construction Vehicle Notification, Temporary Ramp Metering, Real-Time Traveler Information, Incident Management System, and Performance Measurement.

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Background

In 2014, the Federal Highway Administration (FWHA) published the Work Zone Intelligent Transportation System (WZITS) Implementation Guide. The purpose of the Guide is to provide information on implementing ITS in work zones to assist public agencies, design and construction firms, and industry, including developers, manufacturers, distributors, packagers, and providers of devices, systems, and programs.

WZITS is one possible operational strategy of many potential solutions that an agency can include in a transportation management plan (TMP). The WZITS Implementation Guide summarizes key steps for successfully implementing ITS in work zones by using a systematic approach to provide a technical solution that accomplishes a specific set of clearly defined objectives. It illustrates how a systems-engineering process should be applied to determine the feasibility and design of WZITS for a given application, regardless of its scale, by walking through the key phases, from project concept to operation. These steps include assessment of needs; concept development and feasibility; detailed system planning and design; procurement; system deployment; and system operation, maintenance, and evaluation.

In 2018, FHWA released the Work Zone ITS Implementation Tool (FHWA-HRT-18-004) to extend the Guide's utility by building additional functionality in three key areas: content management, a decision-support system, and streamlined project workflow. The WZITS Implementation Tool is a software solution that walks an analyst through the steps in the Guide via a user-friendly interface and with several steps and computations automated via the software. FHWA released an update of the WZITS Implementation Tool in 2020. Version 2.0 further enhances user-friendliness through an updated interface, automates additional computations, provides increased ability to customize the tool to agency-specific needs, and updates the PDF report generation utility.

While both the 2014 Guide and WZITS Implementation Tool remain valid and current resources for States and municipal agencies in establishing a WZITS program, neither resource provides in-depth details on technology and specifications for the actual ITS solutions. This technology supplement to the 2014 Guide addresses that gap.

Objective

The objective of this document is to serve as a technology supplement to the 2014 Work Zone ITS Implementation Guide by providing a detailed factsheet and sample specifications for each of nine primary WZITS technologies. The document is intended to be used in conjunction with the original Guide and its implementing tool and does not replace either resource.

Document Overview

This document is organized by technology, with each technology being summarized by (1) a technology factsheet, and (2) example performance specifications. The individual sections are formatted to be used as standalone resources and may be extracted for use and distribution as needed. The nine WZITS technologies covered by the document are as follows:

- Dynamic Lane Merge.
- Queue Warning.
- Variable Speed Limit.
- Automated Enforcement.
- Entering/Exiting Construction Vehicle Notification.
- Temporary Ramp Metering.
- Real-Time Traveler Information.
- Incident Management System.
- Performance Measurement.

Each technology is described with two separate documents:

1. **Technology Factsheet** – a three- to five-page document summarizing the purpose and need for the technology, providing an overview of system components, discussing options for technology deployment as applicable, summarizing the effectiveness of the system, and documenting approximate unit cost and total cost for the system. The technology factsheets are formatted graphically to serve as standalone resources or handouts by agencies.
2. **Example Specifications** – a longer document providing specifications of technology details, system components, and overall functionality of the system. The example specifications are formatted as a plain text document, intended to be used and adapted by agencies to meet their needs. Placeholder numbers, labeled as "XX," should be filled in by the agency based on the project site and needs.

Notes

The technology factsheet is intended to be used "as is" to provide detailed information about each of the nine technologies, while the example specifications are intended to be used as an example and starting point for agencies to develop their own technology-specific bid documents. In developing their bid specifications, the agency may alter text in the example specifications as needed, and should augment the material to address the specific needs of the agency. As needed, the agency should refer to the technology factsheet, the WZITS Implementation Guide, or the Smarter Work Zones website for additional information about the technology. The agency may also contact the FHWA work zone team within FHWA Office of Operations directly for assistances.

This publication describes examples of nonbinding specifications that are not required by Federal statute or regulation—they are only examples. They do not establish legally enforceable regulatory specifications or standards and compliance with them is not mandatory under Federal law. Use of the words "should" and "shall" in specification statements is for illustrative purposes only. Transportation agencies should consult appropriate legal counsel about whether any of the specifications are enforceable under State law or regulation.

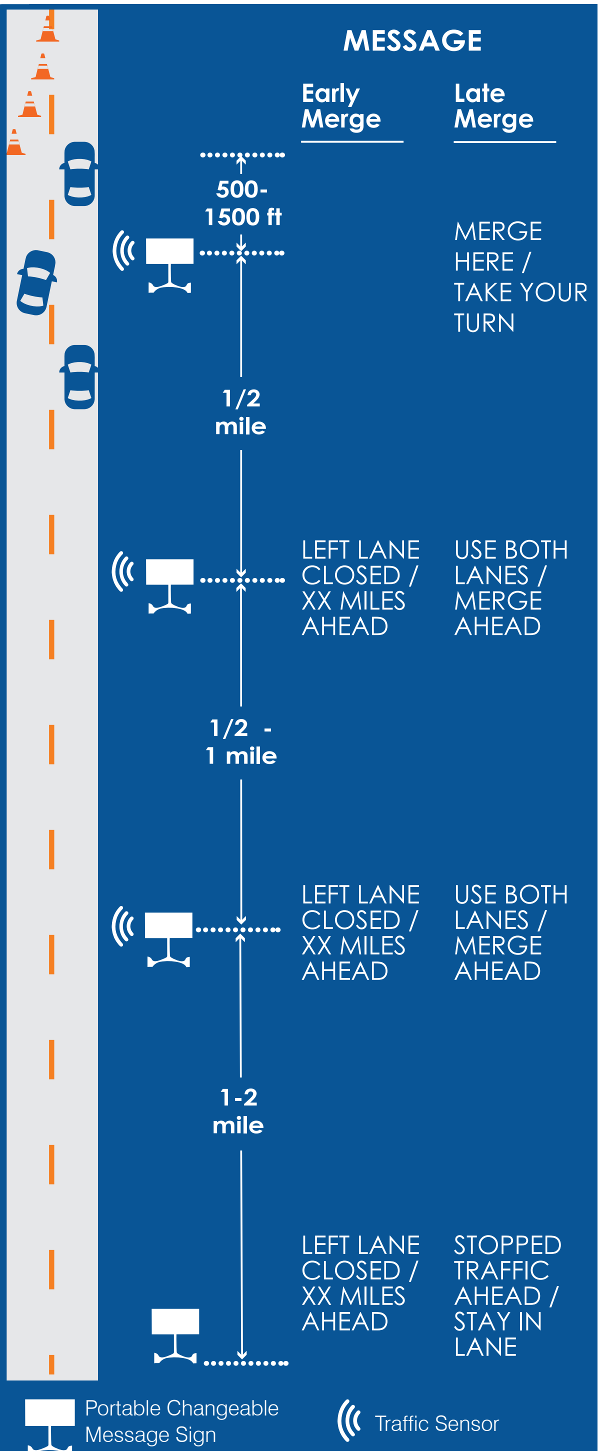
The Manual on Uniform Traffic Control Devices (MUTCD) is adopted by 23 CFR part 630 subpart J as the national standard for all traffic control devices installed on any street, highway, bikeway, or private road open to public travel. It is intended that all traffic control devices addressed in this document comply with the provisions of the MUTCD.[1]

References

1 Federal Highway Administration, Manual on Uniform Traffic Control Devices for Streets and Highways. Last modified March 3, 2022. https://mutcd.fhwa.dot.gov/.

A. Dynamic Lane Merge

U.S. Department of Transportation
Federal Highway Administration



Diagrams represent approximate equipment locations. Review local guidance for required layout.

Figure 1. Diagram. Dynamic Lane Merge Diagram. Source: FHWA.

Description

Drivers respond to highway lane drops differently: some preemptively merge before they must, while others wait to merge until pavement markings require them to do so. This variation can confuse drivers, contribute to queueing, and compromise safety when merging. Dynamic lane merge (DLM) systems aim to resolve these challenges by clarifying when and how drivers should merge.

There are two operating modes of DLM systems that communicate proper behavior to drivers based on traffic conditions: early merge or late merge. Operating modes are a function of traffic volume (vehicle per hour [vph]) and traffic speed. Traffic sensors capture the traffic conditions, while changeable message signs communicate the proper behavior to drivers.

Dynamic early merge notifies drivers of the lane closure and encourages them to merge before the work zone. This DLM type is comparable to static merging. Dynamic early merge is optimal for lower vehicle volumes (under 1,500 vph for a 2-to-1 lane drop) and should be used when traffic speeds are near free-flow speed.[2]

Dynamic late merge encourages drivers to stay in the lane that will drop until the specified merge point. At the merge point, a sign dictates the merge pattern to drivers. This DLM type is optimal for vehicle volumes near capacity (1,500 vph to 2,000 vph for a 2-to-1 lane drop) and should be used when traffic speeds approach congestion speeds.[3]

Several States, including Florida, Michigan, Minnesota, Missouri, and North Carolina, use DLM systems. DLM systems are typically used when two lanes reduce to one, but can be used whenever there is a temporary lane reduction, such as when three lanes are reduced to two.[4] DLM systems have successfully been used to manage queues in both urban and rural areas. Due to the costs of DLM systems, they are typically installed at long-term lane closures.[5]

DLM systems rely on messaging through technologies such as portable changeable message signs, which activate during periods of congestion. Up-to-date and working technology is critical for the dynamic components of DLM to be effective. Distances between the signs are shown in figure 1, but may fluctuate based on vehicle speed, particularly for temporary construction-related installations. Additional signs can be posted to notify drivers of construction activity or a slow-down ahead.

Benefits

Since the dynamic early merge is comparable to static merging, the benefits of DLM are greatest in congested periods when the dynamic late merge is activated. Key benefits of DLM systems include:

- Reduced risk of crashes.
- Reduced queue lengths.
- Easier merging experiences.
- Safer conditions for construction workers.

Reduced risk of merge crashes. DLM systems significantly reduce the speed differential between lanes. This improves safety by reducing sudden stops and flows when merging, and by reducing traffic speeds in both lanes. With a DLM system in use, the merge pattern reduces the number of unsafe merges and keeps both lanes moving at similar speeds.[6]

Reduced queue lengths. DLM systems can reduce queue lengths 40 to 50 percent.[7] When queue lengths are reduced, the distance traveled in congestion also reduces. This results in drivers perceiving shorter travel times and easier driving conditions. Also, drivers use highway lane space more efficiently by increasing their distances traveled in the discontinued lane.

Easier merging experiences. DLM systems eliminate confusion among drivers and help to curb aggressive driving behavior with clear merging instructions. DLM systems effectively influence drivers' merging behaviors, improving conditions for drivers, construction workers, and the highway system.[8]

Safer conditions for construction workers. When DLM systems are in use, merging occurs with a more consistent pattern and drivers have more advanced warning. Improving highway safety and drivers' alertness has the potential to improve the safety of construction workers.

Considerations

The following are the key considerations for DLM systems:

- Potential impact to travel time.
- Public outreach and communication.
- Effectiveness contingent on driver behavior and compliance.

Potential impact to travel time. Evaluations of DLM systems have found that there are either no impacts to vehicle travel time, or a slight increase in travel time compared to a work zone without DLM. Increases in travel time can be attributable to drivers slowing down for construction hazards, limited visibility of the merging pattern or signs, or confusion regarding the DLM system in use.[9] Agencies need to consider when, where, and how the DLM system is set up to minimize potential traffic impacts.

Public outreach and communication. Because drivers do not naturally merge in a late pattern during congested conditions, public outreach and media outlets are critical to making drivers aware of how to use DLM systems. Similarly, signs must communicate the merging pattern with very clear and precise wording or images to be effective.[10]

Effectiveness contingent on driver behavior and compliance. Drivers may need exposure to DLM systems for the systems to operate effectively. Familiar travelers may navigate DLM systems more easily and smoothly than visitors. Additionally, drivers who do not comply with either late merge or early merge systems, or unfamiliar drivers who simply follow other drivers not complying, can significantly disrupt the correct merging pattern and effectiveness of the systems. Police enforcement can deter aggressive merging behavior and encourage compliance.[11, 12]

Additional Resources

Late Versus Early Merges in Kentucky Work Zones https://rosap. ntl. bts. gov/view/dot/35694

Alberta Motor Association's Zipper Merge Demonstration Video https://www. youtube. com/watch?v=cX0I8OdK7Tk

DLM for Rural Freeways https://ops. fhwa. dot. gov/wz/workshops/accessible/McCoy. htm

Missouri DOT Public Facing Zipper Merge Website https://www2. modot. org/workzones/ZipperMerge. htm

FHWA Smart Work Zone Technology Applications DLM Landing Page https://www.workzonesafety.org/swz/swztechnology application/types-of-applications/dynamic-lane-merge/

Cost and Equipment

DLM systems use either portable changeable message signs (PCMSs) or static signs with warning beacons to dynamically switch from early merge to late merge when needed.

A DLM system requires equipment to capture real-time data on vehicle volumes and vehicle speeds. It also requires communication devices between the sensors, PCMSs, and a central computer system. Some agencies also install equipment for remote monitoring of the system and/or traffic conditions.

DLM systems can increase the cost of lane closure by up to $120 per day compared to a standard lane closure.[13] Cost estimates vary between purchased or leased DLM equipment. Leasing equipment allows agencies to implement the most current technologies and eliminate the need to store or maintain equipment. Purchasing equipment may be more cost efficient, depending on the length of time the work zone is in place.

For reference, example costs (adjusted to 2020 dollars) from DLM installations in Michigan and Minnesota are:

- A basic DLM system costs $60,000-$75,000 to purchase or $50,000-$55,000 to rent per year.[14]
- Using a DLM system increased the cost of lane closure by $120 per day, compared to a standard lane closure.[15]
- Over a two-year period, a subcontractor's cost to design, install, calibrate, test, operate, and maintain a DLM system with five PCMS was $173,000.[16]
- The total cost to purchase, install, and operate a DLM system for 11 weeks was $73,275.[17]
- A study by Minnesota DOT found total deployment costs for PCMSs and detection were $233 and $133, respectively, per day, per unit.[18]

Item Costs

Below are example unit costs for typical equipment used in a DLM system, as well as the total cost for the equipment setup shown in figure 1.[19]

Table 1. Dynamic Lane Merge Costs

Item	Unit Price	Quantity	Cost
PCMS	$12,500	4	$50,000
PCMS Communication	$550	4	$2,200
Sensor	$2,500	3	$7,500
Sensor Communication	$550	3	$1,650
Central Computer Station	$5,000	1	$5,000
ITS Field Equipment Cabinet	$6,500	1	$6,500
Cellular Antenna for Remote Monitoring	$2,000	1	$2,000
		TOTAL	**$74,850**

References

2 Vaughan, Christopher, Christopher Cunningham, Shannon Warchol, Daniel Findley, Chris Carnes, Scott Sallade, Geoffrey Oyler, Daniel Coble, Brendan Kearns. *The Effects of Late Lane Merges on Travel Times. North Carolina: North Carolina Department of Transportation*, 2018. https://connect. ncdot. gov/projects/research/Pages/ProjDetails. aspx?ProjectID=2015-08.

3 Vaughan, Cunningham, Warchol, Findley, Carnes, Sallade, Oyler, Coble, Kearns. *The Effects of Late Lane Merges on Travel Times*.

4 Radwan, Essam. "Evaluation of Safety and Operational Effectiveness of Dynamic Lane Merge System in Florida" (2009). Retrieved from: https://www.workzonesafety.org/swz/swztechnology-application/types-of-applications/dynamic-lane-merge/.

5 American Traffic Safety Services Association. "Guidance for the Use of Dynamic Lane Merging Strategies." Washington, D.C.: U.S. Department of Transportation (USDOT), Federal Highway Administration, 2012. https://www.workzonesafety.org/ training-resources/fhwa_wz_grant/atssa_dynamic_lane_merging/.

6 Vaughan, Cunningham, Warchol, Findley, Carnes, Sallade, Oyler, Coble, Kearns. *The Effects of Late Lane Merges on Travel Times.*

7 American Traffic Safety Services Association. "Guidance for the Use of Dynamic Lane Merging Strategies."

8 URS Corporation. *Evaluation of 2004 Dynamic Late Merge System for the Minnesota Department of Transportation.* St. Paul, MN: Minnesota Department of Transportation, 2004. http://www.dot.state.mn.us/trafficeng/workzone/doc/2004DLMS-Evaluation.pdf.

9 American Traffic Safety Services Association. "Guidance for the Use of Dynamic Lane Merging Strategies."

10 Radwan, Essam. Evaluation of Safety and Operational Effectiveness of Dynamic Lane Merge System in Florida.

11 Vaughan, Cunningham, Warchol, Findley, Carnes, Sallade, Oyler, Coble, Kearns. The Effects of Late Lane Merges on Travel Times.

12 URS Corporation. Evaluation of 2004 Dynamic Late Merge System for the Minnesota Department of Transportation.

13 American Traffic Safety Services Association. "Guidance for the Use of Dynamic Lane Merging Strategies."

14 American Traffic Safety Services Association. "Guidance for the Use of Dynamic Lane Merging Strategies."

15 American Traffic Safety Services Association. "Guidance for the Use of Dynamic Lane Merging Strategies."

16 ITS Deployment Evaluation. "Michigan DOT leased a dynamic lane merge system for I-94 reconstruction project at a cost of $120,000." Washington, D.C.: USDOT. Last modified January 9, 2007. https://www.itskrs.its.dot.gov/its/benecost.nsf/ID/dde520872475efcc8525725d0068879b.

17 ITS Deployment Evaluation. "The cost to implement and operate a dynamic merge lane system for 11 weeks was estimated at $57,108." Washington, D.C.: USDOT. Last modified December 17, 2013.

18 ITS Deployment Evaluation. "Minnesota DOT deployed a dynamic late merge system for $900 per day per direction." Washington, D.C.: USDOT. Last modified January 17, 2007. https://www.itskrs.its.dot.gov/its/benecost.nsf/ID/951e7206e8d9fa89852572550016be2c?OpenDocument=&Query=Home.

19 ITS Deployment Evaluation. System Cost Estimate in 2020 dollars. Washington, D.C.: USDOT. Accessed July 28, 2021. https://www.itskrs.its.dot.gov.

A. Dynamic Lane Merge Example Specification*

DESCRIPTION

A Dynamic Lane Merge (DLM) system shall/should* be used for maintenance of traffic as provided in the project plans and as specified in this document. The DLM system shall/should be a fully automated, stand-alone system, capable of making real-time changes to the information displayed to drivers in response to traffic conditions. The system must be able to, in real time, collect traffic data and, under predefined traffic conditions, use Portable Changeable Message Signs (PCMSs) to display merging instructions to drivers in the section of roadway preceding the lane closure. The system must also generate condition and event logs that can be accessed remotely by the Contractor and the sponsoring agency and provide alerts to specified individuals when the system or a component of the system is not functioning properly.

MATERIALS

The DLM system shall/should include PCMSs, traffic sensors, communications devices, a system controller and field cabinet, system operating software, and all miscellaneous equipment and hardware required for a fully operational system. All roadside devices used for the DLM system shall/should conform to the latest Manual for Assessing Safety Hardware (MASH)[1] standards, when available. The DLM system shall/should conform to the following system and operations requirements:

SYSTEM REQUIREMENTS

The DLM system shall/should consist of at least the following components:

- At least XX** PCMSs per lane closure, as defined on the project plans.
- A central system controller to maintain continuous traffic and system status monitoring; provide communication to deliver appropriate messaging to the PCMSs; and provide remote access to the system for operation, malfunction detection, and data collection.
- Sufficient traffic detection devices to achieve the desired dynamic traffic control as described in the System Operation section.
- A reliable communication system to connect devices to the central controller and to allow for remote system access.

SYSTEM OPERATION

The DLM System shall/should detect two distinct traffic conditions: free flow and congested.

(a) **Free Flow:** Free flow may be defined in multiple ways. The DLM system shall/should be capable of detecting free-flow conditions with a speed or volume threshold, which can be adjusted during the day, as necessary. For this project, free flow is initially defined as an average travel speed of XX mph or greater, measured over a 3-minute period, upstream of the merge point. During free-flow operating conditions, the PCMSs shall/should display a general lane closure message (e.g., “LEFT LANE CLOSED / XX MILES AHEAD”), allowing traffic to operate with typical early merge operation.

The DLM system shall/should begin operation each day in free-flow mode (i.e., general lane closure message displayed at time of deployment). The system shall/should revert from congestion mode to free-flow mode at any time if free-flow conditions are detected for 3 consecutive minutes.

* This example specification is for illustrative purposes only and is not enforceable under Federal law. It may be used or adapted by transportation agencies to meet their needs. Use of the words “should” and “shall” is for illustrative purposes only.

** Agency staff can supply the appropriate number.

(b) **Congested**: Congestion may be defined in multiple ways. The DLM system shall/should have the capability of detecting congested conditions with a speed or volume threshold, which can be adjusted during the day, as necessary. For this project, congested flow is initially defined as an average travel speed of less than XX mph, measured over a 3-minute period, upstream of the merge point. When congested conditions are detected for 3 consecutive minutes, the DLM system shall/should become active and display messages such as "STOPPED TRAFFIC AHEAD / STAY IN LANE," "USE BOTH LANES / MERGE AHEAD," and "TAKE YOUR TURN / MERGE HERE" on the PCMSs. The system shall/should remain active until (1) free-flow conditions, as defined above, are detected for 3 consecutive minutes, or (2) the lane closure is removed and normal traffic operations are restored.

When congested conditions are present, the messages identified in the project plans shall/should be displayed on the PCMSs located according to the project plans.

DEPLOYMENT REQUIREMENTS

The Contractor is responsible for furnishing, coordinating, installing, relocating, operating, maintaining, monitoring, and subsequently removing the approved DLM system according to the project plans and these specifications. The Contractor shall/should be able to maintain locally all components, move portable devices as necessary, including adjusting device location and replacing any malfunctioning devices, to ensure the system is operating as designed. The Contractor may adjust the location of signs in response to site-specific conditions, with the Project Engineer's approval. The Contractor shall/should be available 24 hours a day, 7 days a week while the system is deployed. The Contractor shall/should provide the Project Engineer a 24/7 contact phone number. The Contractor shall/should provide weekly reports on system performance and response to emergencies.

SYSTEM DOCUMENTATION

Provide documentation detailing the technical and operational elements of the proposed DLM system for review and approval.

OPERATIONAL TEST

The DLM system shall/should be tested in two stages:

(a) **Off-Site Acceptance Testing:** The Contractor shall/should test the system at an off-site location XX weeks prior to the field deployment to ensure all system components are functioning as designed. To test the PCMSs and the central system controller, the Contractor can virtually mimic a work zone under free-flow and congested conditions. The Contractor shall/should develop a testing plan and submit it for review and approval prior to the start of testing.

(b) **Site Acceptance Testing:** After the DLM system is installed or moved in the field, the DLM system and all sub-systems, such as a remote access systems, shall/should be tested to ensure all components of the system function as designed. For long-term installations, the Contractor shall/should perform weekly site acceptance testing. Testing shall/should be done for each specific deployment location within the project. The Contractor shall/should verify the accuracy of the traffic sensors, the information displayed on each PCMS, and the data being recorded. The traffic sensor detected speeds shall/should not deviate by more than 5 mph from the actual vehicle speeds, and traffic volumes detected shall/should not vary by more than 10 percent from actual volumes. If the system does not meet the accuracy requirement, the equipment shall/should be recalibrated or replaced, if necessary, and re-tested. The Contractor shall/should submit a report no later than one calendar day following the completion of the Site Acceptance Testing. Construction can commence upon testing approval by the Project Engineer.

PERMITTED WORK HOURS

The DLM system can be used for both daytime and nighttime lane closures.

SYSTEM PERFORMANCE

The DLM system shall/should meet the following system performance requirements:

(a) **Continuous operation**: The DLM system shall/should be in place and functioning when lane closures are in place.

(b) **Traffic detectors:** All sensors shall/should be of a type whose accuracy is not degraded by inclement weather or decreased visibility conditions including precipitation, fog, darkness, excessive dust, and road debris.

(c) **Data logging:** The DLM system shall/should capture a continuous event log, including all traffic conditions, all system state changes, and all changes in the messages displayed.

(d) **Remote access:**

(1) **System data log:** Password-protected users shall/should have the capability to view all system log data on a website and create graphs based on available data with time and date stamps. At the request of the Project Engineer, the vendor shall/should provide a digital copy of the logged information.

(2) **System assessment:** The DLM system shall/should be configured to assess any type of malfunction that occurs. This assessment includes communication disruption between any device in the system and any device malfunctions including PCMS malfunctioning. The system shall/should be capable of notifying the specified individuals via phone and email about any system malfunction.

(3) **Remote control:** The DLM system shall/should include the capability to allow a password-protected user to reset the system state via the internet.

(4) **Remote monitoring:** The DLM system shall/should have the capability of real-time remote monitoring and PCMS control.

(e) **Manual control:** The DLM system shall/should be manually controllable onsite. The capability to manually switch between states of free flow and congestion allows for maximum flexibility.

SYSTEM TRAINING

DLM system training shall/should be conducted by the Contractor directly responsible for the system operation and the system supplier. The training shall/should include representatives from the Contractor, Agency, Enforcement, and others responsible for construction, maintenance of traffic, and safety. The training shall/should, at a minimum, cover the following items:

(a) Review of the messages that shall/should be displayed.

(b) In the event of an emergency, instructions on how to override system messages.

(c) In the event of a power failure, instructions detailing how to power cycle the system.

(d) Online system access and remote monitoring.

(e) Basic listing of what to monitor and what causes messages to change.

(f) List of telephone numbers to call to request technical support.

SYSTEM WARRANTY, MAINTENANCE, AND SUPPORT

The DLM system shall/should be maintained, supported, and warranted against material defects by its supplier through the duration of the deployment. The Contractor shall/should respond immediately to any call from the Project Engineer or designated representative concerning any request for correcting any deficiency in the system. Deficiencies include field conditions and remote monitoring capabilities.

MEASUREMENT AND PAYMENT

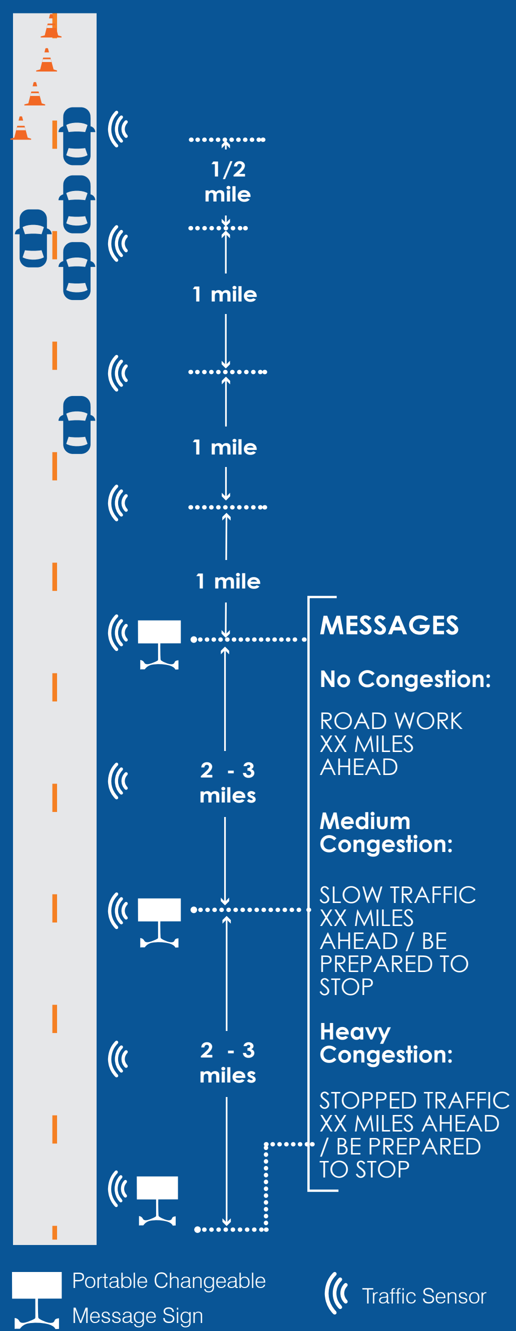
Measurement and payment shall/should be made at the contract unit price per day that the DLM system is deployed, in use, and operational, which shall/should be compensation in full for furnishing, installing, operating, relocating, reporting, maintaining, and removing the system. System testing and training, communications costs, and any relocation or repositioning within the work zone or removal of equipment from the work zone shall/should be incidental to the contract unit price. Performance reports shall/should be provided prior to payment. Payment shall/should not be made until any performance problems or operations are fully tested and operational.

B. Queue Warning

U.S. Department of Transportation
Federal Highway Administration

Description

A queue warning system (QWS), also known as Stopped Traffic Advisory System, informs travelers of the presence of downstream slow-downs and stop-and-go traffic based on real-time traffic detection.



Diagrams represent approximate equipment locations. Review local guidance for required layout

Figure 2. Diagram. Queue Warning Diagram. Source: FHWA.

The system activates warning signs and flashing lights that:

- **Alert drivers to expect emergency braking and to slow down**
- **Reduce erratic behavior**
- **Reduce queuing-related crashes[20]**

Free-flow warnings are displayed upstream of work zones during free-flow traffic. They warn drivers about road work. For example, when traffic is moving at the posted speed limit of 55 mph, a portable changeable message sign (PCMS) may post “ROAD WORK XX MILES AHEAD.” It is also possible that a queue warning does not post anything during free-flow conditions.[21]

Slow-down warnings warn drivers to anticipate slower speeds downstream. They also inform drivers about the approximate location of the slow-down. The system uses sensors to monitor the speed of the vehicles along a stretch of roadway and then warns drivers when a slow-down is detected.[22] For example, at a section with a 55 mph posted speed limit, if the speed drops to between 40-45 mph, the PCMS can show “SLOW TRAFFIC XX MILES AHEAD, BE PREPARED TO STOP.”[23]

Stopped-traffic warnings inform drivers about the queue location when sensors detect stop-and-go traffic downstream. This type of warning is activated when speed drops significantly and queues are likely formed, whereas the slow-down warning is activated when speeds drop, but there is no queue downstream. For example, at a section with a 55 mph posted speed limit, if speed drops to 15-25 mph, the PCMS can show “STOPPED TRAFFIC XX MILES AHEAD, BE PREPARED TO STOP.”[24]

Based on the sophistication of the system and the specific needs of the roadway, QWSs can operate automatically using local real-time traffic detectors as a trigger or be manually controlled by an operator at a traffic management center (TMC).[25]

The critical work zone characteristics where QWSs could be beneficial include:[26]

- Frequent planned lane closures, which will create queues that cause high speed differentials between queued and approaching traffic.

- Emergency shoulder closures through work zones, where frequent stalls and rear-end crashes are expected to occur that cause queues (because they cannot be moved to the shoulder).
- When frequent crashes are expected to occur within the project area.

Work zones benefit the most from queue warning with PCMS units placed upstream of expected queue points. Queue warnings can be used as a supporting strategy in conjunction with other active traffic management and traveler information strategies, such as variable speed limits, dynamic lane assignments, and a traveler information system. These active traffic management systems are often implemented together as part of a larger corridor management strategy.

Benefits

- Reduce Crash Risk.
- Delay the Onset of Congestion.
- Reduce Emissions.
- Inform Driver Expectations.

Reduce crash risk. These systems reduce primary and secondary crashes (primarily rear-end crashes), as well as the severity of crashes, by alerting drivers to congested conditions ahead so they can slow down in time.

Delay the onset of congestion. QWSs delay the onset and shorten the duration of recurring freeway congestion by maintaining uniform speeds and reducing crashes through increased driver awareness of potential congestion. A QWS improves the smooth and efficient flow of traffic, and therefore increases travel time reliability.

Reduce emissions. These systems reduce emissions, noise, and fuel consumption by decreasing stop-and-go traffic.

Inform driver expectations. QWSs relieve drivers' frustration by setting expectations ahead of delays.

Considerations

The following are the key considerations for QWSs:

- Queue Length.
- Queue Spillbacks from Crossroads or Ramps.
- PCMS Visibility.
- Operator Intervention.

Queue length. Queue lengths can vary greatly, day-by-day and hour-by-hour, so a suitable location for the advance-warning signs cannot be predicted. Queue lengths may encroach upstream beyond a drivers' reasonable expectations for stopped traffic, and there is the likelihood that the geometrics (terrain) may cause poor visibility of end-of-traffic queues, causing short reaction times and sudden stops.

Queue spillbacks from crossroads or ramps. Queues launched on crossroads are estimated to cause traffic conflicts and delays on the mainline road, such as back-ups beyond the length of ramps, through or around turns in intersections, or other congested situations.

PCMS visibility. QWSs can be more effective when deployed in conjunction with variable speed limits. Pictograms and warning beacons need to be in compliance with MUTCD requirements and need to be visible to all vehicles. During normal operation, all PCMS are blank, and variable speed limit signs display the posted speed limit. The signs should also be consistent and uniform to clearly indicate congestion ahead.

Operator intervention. An intelligent system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention is optimal. For systems controlled by operators, systems should have adequate connections to the local traffic center and other supporting infrastructure.

Additional Resources

Bid Specifications - TXDOT: https://www. workzonesafety. org/files/documents/SWZ/deployment_plans_Waco_prs.pdf

Bid Specifications - Michigan: https://www. workzonesafety. org/files/documents/SWZ/deployment_plan_Michigan.pdf

Bid Specifications - Pennsylvania: https://www. workzonesafety. org/files/documents/SWZ/deployment_plans_PennDOT.pdf

FHWA. *A Summary of Vehicle Detection and Surveillance Technologies use in Intelligent Transportation Systems.* 2020. Retrieved from: https://www.fhwa.dot.gov/policyinformation/pubs/vdstits2007/vdstits2007.pdf

USDOT. *Sample unit cost entries for Dynamic Message Sign*. 2020. Retrieved from: https://www.itskrs.its.dot.gov/search?search_api_fulltext=dynamic+message+sign

Cost and Equipment

The equipment needs and cost vary depending on the sophistication of the warning system, level of automation, and the types of conditions it is designed to detect.

The cost of a QWS within a work zone varies considerably depending on the existing infrastructure and equipment, as well as the area of the deployment and the level of automation involved. All QWSs require traffic detection, software to identify queues, and communications to a roadway sign to display the warning. When more sensors are deployed, the system will provide faster notification of changes to conditions and increase data accuracy. Typically, in urban areas, sensors are spaced every half mile to mile, and in rural areas, the spacing can be increased to 2 or 3 miles.[27] Cost estimates also vary depending on whether an agency buys or leases QWS equipment. Leasing equipment allows agencies to implement current technologies and eliminate the need to store or maintain equipment, while purchasing equipment may be cost efficient if the QWS is implemented long term.

Example deployments have included costs (adjusted to 2020 dollars) such as:

- Equipment rental cost for QWS was $210 per day, per site.[28]
- The contract cost for deploying QWSs in Arkansas at two sites, including traffic sensors for measuring vehicles' speed and communicating the real-time traffic information to travelers through PCMSs, was $482,000 – $733,500.[29]

Item Costs

The table below estimates the costs of purchasing the components necessary to implement a user-friendly, accessible, and accurate QWS in a work zone, as configured in figure 2. These costs are in 2020 dollars.[30]

Table 2. Queue Warning System Cost Estimate

Item	Unit Price	Quantity	Cost
3-Line PCMS, Solar Powered, with Modem and Roadway Radar, and Management Software	$19,545 (Buy)	4	$78,180
Roadway Data Sensors	$2,500	9	$22,500
Field Laptop	$450 (Buy)	1	$450
Field Hotspot Wi-Fi and Data Plan	$200 (Buy) + $65 (Per Month Subscription)	1	$265
Data Analysis Software	$650 (Per Year Subscription)	1	$650
		TOTAL	**$102,045**

References

20 Street Smart. *Queue Warning Systems*. 2020. Retrieved from: https://www. streetsmartrental. com/smart-work-zones/queue- warning-system/.

21 Enterprise. *Queue Warning Systems in Work Zones – Summary of Uses and Benefits.* 2014. Retrieved from: http:// enterprise.prog.org/Projects/2010_Present/iwz/QueueWarning_Summary_FINAL_June2014.pdf.

22 Stinson Owl-Lite. "Automated Queue Warning (AQW) Systems" 2020. Retrieved from: https://stinson.ca/its-solutions/ portable-queue-end-warning.html.

23 Enterprise. *Queue Warning Systems in Work Zones – Summary of Uses and Benefits.*

24 Stinson Owl-Lite. "Automated Queue Warning (AQW) Systems" 2020. Retrieved from: https://stinson.ca/its-solutions/portable-queue-end-warning.html.

25 MnDOT. "End of Queue Warning Systems – System Requirements." 2018. Retrieved from: https://www.dot.state.mn.us/its/projects/2011-2015/solvingworkzonechallenges/systemreqchallenge2.pdf.

26 TSMO. *Queue Warnings*. 2020. Retrieved from: https://tsmowa.org/category/traveler-information/queue-warnings.

27 Ullman et al. *Work Zone Intelligent Transportation Systems Implementation Guide – Use of Technology and Data for Effective Work Zone Management*. 2014. DTFH61-06-D-0007/BA07-101, U. S. Department of Transportation, Federal Highway Administration.

28 Utah DOT. *Utah DOT rented equipment for a portable variable speed limit system for an average daily cost of between $173 and $329.* 2018. Retrieved from: https://www. itscosts. its. dot. gov/ITS/benecost. nsf/0/09F7452DDE73BF97852582D3004F729E?OpenDocument&Query=Home.

29 Arkansas State Highway and Transportation Department (AHTD). *In Arkansas, the contract bid costs for two different automated work zone information system ranged from $390 to $750 per day*. 2003. Retrieved from: https://www.itscosts.its.dot.gov/ITS/benecost. nsf/0/8CA0144FB5B6EDC085256E4A004ABE9B?OpenDocument&Query=Home.

30 ITS Deployment Evaluation. System Cost Estimate in 2020 dollars. Washington, D.C.: USDOT. Accessed July 28, 2021. https://www.itskrs.its.dot.gov.

B. Queue Warning Example Specification*

DESCRIPTION

A queue warning system (QWS) shall/should* be used for maintenance of traffic as provided in the project plans and as specified in this document. The QWS shall/should be a fully automated, stand-alone system, capable of making real-time changes in the information displayed to drivers in response to traffic conditions. The system must be able to, in real time, collect traffic data and, under predefined traffic conditions, using Portable Changeable Message Signs (PCMSs) display advance queue warnings to drivers in the section of roadway preceding the lane closure. The system must also generate condition and event logs that can be accessed remotely by the Contractor and the sponsoring agency, and automatically send alerts to specified individuals when the system or a component of the system is not functioning properly.

MATERIALS

The QWS shall/should include PCMSs, traffic sensors, communications devices, a system controller and field cabinet, system operating software, and all miscellaneous equipment and hardware required for a fully operational system. All roadside devices used for the QWS shall/should conform to the latest Manual for Assessing Safety Hardware (MASH) standards, when available. The QWS shall/should conform to the following system and operations requirements:

SYSTEM REQUIREMENTS

The QWS shall/should consist of at least the following components:

(a) XX** PCMSs, as defined on the Temporary Traffic Control Plans. Each PCMS shall/should conform to the standards and requirements in the most current edition of the Manual on Uniform Traffic Control Devices (MUTCD).

(b) Sufficient traffic detection device(s) to achieve the desired dynamic advance queue warnings to achieve the desired dynamic advance queue warnings as described in the System Operation section.

(c) A central system controller used to: receive and process traffic detector data; deliver appropriate messaging to the PCMSs; monitor and record the system status; and provide the Operator on-site and remote access to the system for operation control, manual override of the messages being displayed, malfunction detection, and data collection.

(d) A reliable and secure communication system that connects the PCMSs, traffic detection devices, and central system controller, and allows for on-site and remote system access.

(e) A reliable power source(s) to allow for continuous operation during periods when the system is in use. This may include the need for an uninterrupted power supply (UPS) or backup generator.

(f) A deployment plan, submitted by the Contractor, which at a minimum provides: locations of the devices; description of the proposed method of communication between the devices; a list of required equipment details; and proposed corrective method procedure (including response times and weekly reporting details), and notification process in case of a system failure.

* This example specification is for illustrative purposes only and is not enforceable under Federal law. It may be used or adapted by transportation agencies to meet their needs. Use of the words “should” and “shall” is for illustrative purposes only.

** Agency staff can supply the appropriate number.

SYSTEM OPERATION

If the work zone is not active, the PCMSs shall/should be removed or turned off. If the work zone is active, the QWS shall/should detect three distinct traffic conditions: free flow, medium congestion, and heavy congestion.

1. **Free flow:** Free flow may be defined in multiple ways. The QWS shall/should be capable of detecting free-flow conditions with a speed or volume threshold, which can be adjusted during the day, as necessary. For this project, free flow is initially defined as an average travel speed of XX mph or greater, measured over a 3-minute period, upstream of the work zone merge point. The QWS shall/should begin operation each day in free-flow mode. During free-flow operating conditions, the PCMSs shall/should display the free-flow message(s) approved by the Project Engineer. For example: "ROAD WORK XX MILES AHEAD."

2. **Medium congestion:** Medium congestion, resulting in slow traffic ahead, may be defined in multiple ways. The QWS shall/should have the capability of detecting congested conditions with a speed or volume threshold, which can be adjusted during the day, as necessary. For this project, medium congestion is initially defined as an average travel speed of less than XX mph but greater than or equal to YY mph, measured over a 3-minute period, upstream of the work zone merge point. When medium congestion conditions are detected for 3 consecutive minutes, an approved message indicating slowing traffic ahead shall/should be displayed on each PCMS. For example: "SLOW TRAFFIC XX MILES AHEAD / BE PREPARED TO STOP." The message shall/should be displayed until (1) free-flow conditions, as defined above, are detected for 3 consecutive minutes, (2) heavy congestion conditions, as defined below, are detected for 3 consecutive minutes, or (3) the lane closure is removed and normal traffic operations are restored.

3. **Heavy congestion:** Heavy congestion, resulting in stopped traffic ahead, may be defined in multiple ways. The QWS shall/should have the capability of detecting congested conditions with a speed or volume threshold, which can be adjusted during the day, as necessary. For this project, heavy congestion is initially defined as an average travel speed of less than YY mph, measured over a 3-minute period, upstream of the work zone merge point. When heavy congestion conditions are detected for 3 consecutive minutes, an approved message indicating stopped traffic ahead shall/should be displayed on each PCMS. For example: "STOPPED TRAFFIC XX MILES AHEAD / BE PREPARED TO STOP." The system shall/should remain active until (1) free-flow conditions, as defined above, are detected for 3 consecutive minutes, (2) medium congestion condition, as defined above, are detected for 3 consecutive minutes, or (3) the lane closure is removed and normal traffic operations are restored.

DEPLOYMENT REQUIREMENTS

The Contractor is responsible for furnishing, coordinating, installing, relocating, operating, maintaining, monitoring, and subsequently removing the approved QWS according to the project plans and these specifications. The Contractor shall/should be able to maintain locally all components, move portable devices as necessary, including adjusting device location and replacing any malfunctioning devices, to ensure the system is operating as designed. The Contractor may adjust the location of signs in response to site-specific conditions, with the Project Engineer's approval. The Contractor shall/should be available seven days a week, 24 hours a day while the system is deployed. The Contractor shall/should provide the Project Engineer a 24/7 contact phone number. The Contractor shall/should provide weekly reports on system performance and response to emergencies.

SYSTEM DOCUMENTATION

Provide documentation detailing the technical and operational elements of the proposed QWS for review and approval.

OPERATIONAL TEST

The QWS shall/should be tested in two stages:

(a) **Off-site acceptance testing**: The Contractor shall/should test the system at an off-site location XX weeks prior to the field deployment to ensure all system components are functioning as designed. To test the PCMSs and the central system controller, a work zone under free-flow, medium, and heavy conditions can be virtually mimicked. The Contractor shall/should develop a testing plan and submit it for review and approval prior to the start of testing.

(b) **Site acceptance testing:** After the QWS is installed or moved in the field, the QWS, and all sub-systems such as remote access systems, shall/should be tested to ensure all components of the system function as designed. For long-term installations, site acceptance testing shall/should be performed weekly by the Contractor. Testing shall/should be done for each specific deployment location within the project. The Contractor shall/should verify the accuracy of the traffic sensors, the information displayed on each PCMS, and the data being recorded. The traffic-sensor-detected speeds shall/should not deviate by more than 5 mph from the actual vehicle speeds, and traffic volumes detected shall/should not vary by more than 10 percent from actual volumes. If the system does not meet the accuracy requirement, the equipment shall/should be recalibrated or replaced, if necessary, and re-tested. The Contractor shall/should submit a report no later than one calendar day following the completion of the Site Acceptance Testing. Construction can commence upon testing approval by the Project Engineer.

PERMITTED WORK HOURS

The QWS can be used for both daytime and nighttime lane closures.

SYSTEM PERFORMANCE

The QWS System shall/should meet the following system performance requirements:

(a) **Continuous operation:** The QWS shall/should be in place and functioning while lane closures are in place.

(b) **Traffic detectors:** All sensors shall/should be of a type whose accuracy is not degraded by inclement weather or decreased visibility conditions including precipitation, fog, darkness, excessive dust, and road debris.

(c) **Data logging:** The QWS shall/should capture a continuous event log including all traffic conditions, all system state changes, and all changes in the messages displayed.

(d) **Remote access:**

(1) **System data log:** Password-protected users shall/should have the capability to view all system log data on a website and create graphs based on available data with time and date stamps. At the request of the Project Engineer, the vendor shall/should provide a digital copy of the logged information.

(2) **System assessment**: The QWS shall/should be configured to assess any type of malfunction that has occurred. This assessment includes communication disruption between any device in the system and any device malfunctions including PCMS malfunctioning. The system shall/should be capable of notifying the specified individuals via phone and email about any system malfunction.

(3) **Remote control:** The QWS shall/should include the capability to allow a password-protected user to reset the system state and override the message being displayed via the internet.

(4) **Remote monitoring:** The QWS shall/should have the capability of real-time remote monitoring and PCMS control.

(e) **Manual control:** The QWS shall/should be manually controllable onsite. The capability to manually switch between states of free flow and congestion allows for maximum flexibility.

(f) **Display conditions:** The QWS shall/should be capable of displaying current traffic conditions on the upstream PCMS and calculating real-time speed and travel time to the nearest minute. Information shall/should be updated every minute.

SYSTEM TRAINING

QWS training shall/should be conducted by the Contractor directly responsible for the system operation and the system supplier. The training shall/should include representatives from the Contractor, Agency, Enforcement, and others responsible for construction, maintenance of traffic, and safety. The training shall/should, at a minimum, cover the following items:

(a) Review of the messages that shall/should be displayed.

(b) In the event of an emergency, instructions on how to override system messages.

(c) In the event of a power failure, instructions detailing how to power cycle the system.

(d) Online system access, remote monitoring, and remote control.

(e) Basic listing of what to monitor and what causes messages to change.

(f) List of telephone numbers to call to request technical support.

SYSTEM WARRANTY, MAINTENANCE, AND SUPPORT

The QWS shall/should be maintained, supported, and warranted against material defects by its supplier through the duration of the deployment. The Contractor shall/should respond immediately to any call from the Project Engineer or designated representative concerning any request for correcting any deficiency in the system. Deficiencies include field conditions and remote monitoring capabilities.

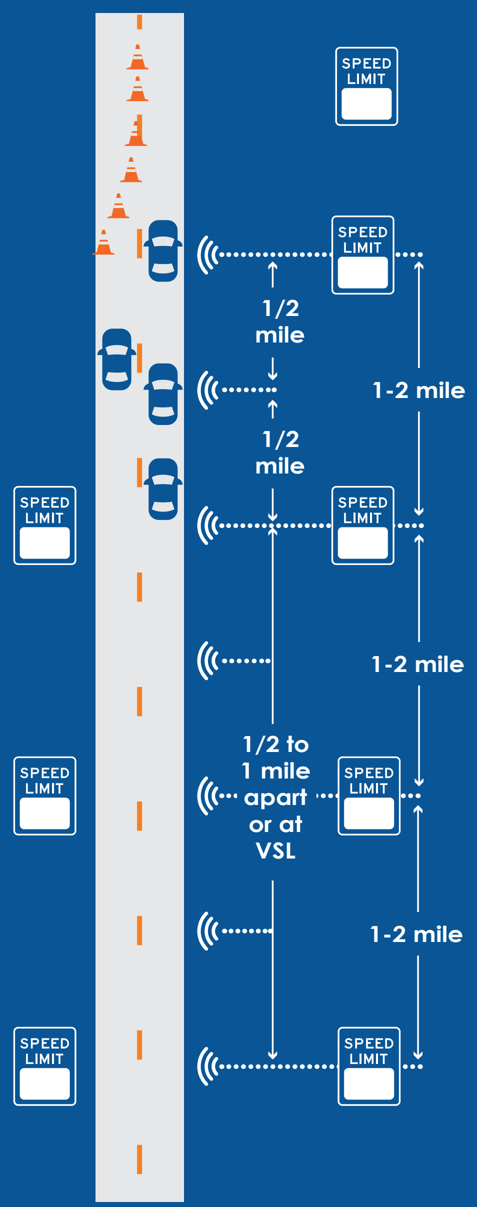
MEASUREMENT AND PAYMENT

Measurement and payment shall/should be made at the contract unit price per day that the QWS is deployed, in use, and operational, which shall/should be compensation in full for furnishing, installing, operating, relocating, reporting, maintaining, and removing the system. System testing and training, communications costs, and any relocation or repositioning within the work zone or removal of equipment from the work zone shall/should be incidental to the contract unit price. Performance reports shall/should be provided prior to payment. Payment shall/should not be made until any performance problems or operations are fully tested and operational.

C. Variable Speed Limit

U.S. Department of Transportation
Federal Highway Administration

Cannot have static signs displaying 1 speed and variable signs displaying different speeds



Diagrams represent approximate equipment locations. Review local guidance for required layout

Figure 3. Diagram. Variable Speed Limit Diagram. Source: FHWA.

Description

Dating back to the 1980s, studies have associated active work zones with higher crash rates, due to both their contribution to traffic congestion (lane closures) and driver noncompliance with static work zone speed limits. Aggressive driving behaviors, in addition to noncompliance with work zone posted speeds, create safety risks to construction workers and drivers alike.[31] Variable speed limit (VSL) systems are one of several technologies that have been developed to manage speed, and therefore safety and traffic, in work zones. VSLs are complemented, and their effects compounded, by queue warning technologies and automated speed enforcement systems. Note that some jurisdictions do not allow VSLs, so the sponsoring government agency should review state and local regulations during the initial planning stage.

Variable speed limit systems adjust posted speed limits upstream of work zones to reduce driver speeds, facilitate merging, reduce crash rates, and ease traffic congestion by reducing "stop and go" traffic.

VSLs function on the principle of "speed harmonization," in which the speed limit is lowered to obtain a consistent and homogenous traffic flow at a speed that is sustainable with traffic volumes.[32] A VSL is an Intelligent Transportation System (ITS) strategy typically used upstream of a queue to reduce the effects of congestion. For work zone applications, VSLs are used upstream of lane closures. By lowering the speeds of the vehicles approaching a queue, a queue has more time to dissipate from the front before it continues to grow from the back. VSLs typically have the greatest benefit under moderately congested conditions and on projects with longer-term lane closures.

The components of a successful VSL vary depending on the construction work to be performed, the roadway conditions (number of lanes, shoulder widths, existing dynamic message signs, etc.), and the complementary technologies available. Most VSLs are composed of sensors (to detect vehicular speeds and volume), changeable speed limit signs, variable message signs, communications equipment, and a central processing unit (to execute control actions) along with operational and analysis software. VSLs have been deployed and studied in active work zones in Texas, Michigan, Virginia, Utah, and Kansas.

Benefits

Within work zones, VSLs can:

- Reduce Crash Severity and Frequency.
- Increase Vehicle Throughput.
- Decrease Speed Variance.
- Improve Travel Time Reliability.
- Reduce Fuel Consumption and Greenhouse Gas Emissions.
- Increase Driver Compliance and Improve Driver Experience.

Reduce crash frequency and severity. VSLs improve worker and driver safety by decreasing the frequency and severity of crashes. VSL deployment is typically combined with a queue warning system to reinforce the need for slower speeds in work zones, resulting in a reduction in rear-end and sideswipe crashes.[33]

Increase vehicle throughput. The algorithms that calculate speed harmonization in a work zone VSL increase vehicle throughput while decreasing delay due to more seamless merging.[34] The lower speeds and ability to merge allow more vehicles to traverse the work zone and can reduce the average delay of upstream segments. VSL algorithms can yield up to a seven percent increase in both work zone throughputs and reduction in total vehicle delays.[35]

Decrease speed variance. Speed variance, or the differences in the speeds that multiple drivers on the same road are traveling, has been associated with higher crash rates.[36] For this reason, when designing VSLs for active work zones, VSL projects in the United States have focused on decreasing speed variance (while increasing speed harmony). Both simulation results and field data have indicated the success of VSL in decreasing speed variance, with results as high as 35-percent reductions reported,[37,38] resulting in increased work zone safety.[39]

Improve travel time reliability. VSLs, by reducing crashes, increasing vehicle throughput, and decreasing speed variance, improve travel time reliability. These effects are especially notable in work zones when compared to static speed scenarios, which are typically the cause of hundreds of hours of delay throughout the course of a project. VSLs, when programmed appropriately for the work zone, can improve travel time reliability by reducing congestion.[40]

Reduce fuel consumption and greenhouse gas emissions. The reduced amount of "stop-and-go" traffic has a positive effect on air quality. Consistent traffic flow results in decreased fuel consumption, and therefore fewer greenhouse gases emitted. A simulation of connected vehicle technologies discovered that with 100 percent market penetration, a VSL could reduce fuel consumption 5 to 16 percent.[41]

Increase driver compliance and improve driver experience. Work zones can create stressful driving conditions, which frustrate drivers if posted work zone speeds are not context appropriate. VSLs, by dynamically providing updated information to drivers, improve driver compliance with posted speeds.[42] Driver compliance with the variable speeds provides many of the network benefits previously discussed, even with compliance rates as low as 20 percent.[43]

Considerations

The following are the key considerations for VSLs:

- Project Type, Context, and Conditions.
- Legal Permissibility and Implications.
- Design Components.
- Recommendations.

Project type, context, and conditions. Researchers recommend avoiding the following project types for work zone VSL implementation: moving operations (striping, sweeping); shoulder work (small impact); those with need for flagger control, pilot cars, or temporary signals; and zones close to access/traffic control devices.[44] Projects where lane closures shift can be difficult, as the sensors and other equipment will require reconfiguration. Work zone VSLs provide the most benefit in longer-term projects with moderately congested conditions.[45,46]

Legal permissibility and implications. As a VSL operates by determining a context-appropriate speed for the work zone, the controlling algorithms are programmed to allow increases or decreases by mile-per-hour increments, with changes occurring every 1 to 15 minutes. Many VSL algorithms analyze real-time speed data and incorporate these changes into their posted speeds. The VSL operational software must reference State codes to ensure that all legally binding restrictions regarding speed maximums, sign spacing minimums, and allowable decreases are incorporated.[47]

Design components. In the various deployments that have been conducted throughout the U.S., design challenges have included:

- **Visibility and sign placement** – Variable speed limit signs may be placed on both sides of the roadway to aid drivers in recognizing the displayed speed.
- **Update frequency** – When programming the controlling algorithm, the period of speed updates must reflect current conditions without needlessly changing.
- **Data collection** – Speed and volume data are crucial for the controller to provide relevant, appropriate speed limits. When designing the work zone, it is important to account for the placement of sensors for each lane, as by-lane volume and speed data are crucial components of the calculation for adjusting speeds in real-time.

Recommendations

- Install sensors by lane.
- Ensure quick connection with local Traffic Management Center (TMC).
- Clearly communicate whether the variable speed limit is regulatory or advisory.

References

31 Ye, Z., & Al-Kaisy, A. (2010). *Explore ITS Technologies for Work Zones and Work Zone Impact Areas*.

32 Kuhn, B. , Balke, K., Robery, B. , Theiss, L. , Tsapakis, I. , Ruback, L. , & Le, M. (2015). Evaluation of TxDOT Variable Speed Limit Pilot Projects: Final Report. *Texas A&M Transportation Institute*. https://static.tti.tamu.edu/tti.tamu.edu/documents/TTI-2015-10.pdf

33 Cunningham, Ryan, "Examining Dynamic Variable Speed Limit Strategies For The Reduction Of Real-time Crash Risk On Freeways" (2007). Electronic Theses and Dissertations, 2004-2019. 3128. https://stars.library.ucf.edu/etd/3128

34 Saito, M., & Wilson, A. B. (2011). *Evaluation of the effectiveness of a variable advisory speed system on queue mitigation in work zones* (No. UT--11. 04). Utah. Dept. of Transportation. Research Division.

35 Kang, K. P., Chang, G. L. , & Zou, N. (2004). Optimal dynamic speed-limit control for highway work zone operations.*Transportation Research Record*, 1877(1), 77-84.

36 Kwon, E., Brannan, D. , Shouman, K. , Isackson, C. , & Arseneau, B. (2007). Development and field evaluation of variable advisory speed limit system for work zones. *Transportation Research Record,* 2015(1), 12-18.

37 Kang, Kyeong-Pyo, Gang-Len Chang, and Nan Zou. "Optimal Dynamic Speed-Limit Control for Highway Work Zone Operations." 77-84.

38 Kwon, Brannan, Shouman, Isackson, & Arseneau. "Development and field evaluation of variable advisory speed limit system for work zones." 12-18

39 Lin, P. W., Kang, K. P., & Chang, G. L. (2004, July). *Exploring the effectiveness of variable speed limit controls on highway work-zone operations. In Intelligent transportation systems* (Vol. 8, No. 3, pp. 155-168). Taylor & Francis Group.

Cost and Equipment

The cost of a VSL within a work zone varies considerably depending on the existing infrastructure, as well as the selection and spacing of overhead gantries, portable changeable message signs, and other related signs. The cost of a deployment depends on the number of signs and sensors installed along the corridor and the extent to which existing infrastructure can be utilized. An agency's cost estimate must consider whether to buy or lease the VSL equipment. Updated for 2020 dollars, previous U.S.-based deployments of work zone VSLs have ranged between $40,000 and $3.3 million.

Examples of VSL deployments and their associated costs (adjusted to 2020 dollars) include:

- Utah DOT rented equipment for a portable VSL for an average daily cost between $173 - $329 in 2018.[52]
- Virginia DOT implemented and operated a VSL for two years on a 7.5-mile section of I-495 for $3.2 million in 2008.[53]
- Michigan DOT leased seven VSL trailers for six months at a cost of $400,900 in 2002.[54]

Item Costs

The table below estimates the costs of purchasing the components necessary to implement a user-friendly, accessible, and accurate VSL in a work zone. These costs are in 2020 dollars.[48] This cost estimate assumes the minimum acceptable number of portable changeable message signs (PCMS), as shown in figure 3.

Table 3. Variable Speed Limit System Cost Estimate

Item	Unit Price	Quantity	Cost
3-Line PCMS, Solar Powered, with Modem and Roadway Radar, and Management Software[49]	$19,545 (Buy)	1	$19,545
VSL PCMS, Solar Powered with Mounting Brackets, Roadway Data Sensor, and Management Software[50]	$4,340 (Buy)	7	$30,380
VSL PCMS Modem and Online Data Storage	$800 (Per Year Per Sign Subscription)	7	$5,600
Field Laptop	$450 (Buy)	1	$450
Field Hotspot Wi-Fi and Data Plan	$200 (Buy) + $65 (Per Month Subscription)	1	$265
CCTV Video Detection and Monitoring System[51]	$750	1	$750
		TOTAL	**$56,990**

References continued

40 Garber, N. J., & Gadiraju, R. (1989). Factors affecting speed variance and its influence on accidents. *Transportation Research Record*, 1213, 64-71.

41 Fudala, N. J., & Fontaine, M. D. (2010). *Work Zone Variable Speed Limit Systems: Effectiveness And System Design Issues* (No. FHWA/VTRC 10-R20). Virginia Transportation Research Council. http://www.virginiadot. org/vtrc/main/online_reports/ pdf/10-r20.pdf.

42 Lin, Kang, & Chang. *Exploring the effectiveness of variable speed limit controls on highway work-zone operations. In Intelligent transportation systems* (Vol. 8, No. 3, pp. 155-168).

43 Fudala & Fontaine. *Work Zone Variable Speed Limit Systems: Effectiveness And System Design Issues* (No. FHWA/VTRC 10-R20)

References continued

44 Van Jura, J., Haines, D., & Gemperline, A. (2018). Use of portable and dynamic variable speed limits in construction zones. Transportation Research Record, 2672(16), 35-45.

45 Kang, Chang, & Zou. Optimal dynamic speed-limit control for highway work zone operations. 77-84.

46 Fudala & Fontaine. *Work Zone Variable Speed Limit Systems: Effectiveness And System Design Issues* (No. FHWA/VTRC 10-R20)

47 Saito Wilson. *Evaluation of the effectiveness of a variable advisory speed system on queue mitigation in work zones* (No. UT--11. 04).n.

48 System Cost Estimate in 2020 dollars. USDOT ITS Deployment Evaluation Landing Page: https://www.itskrs.its.dot.gov/

49 Grossklaus, J. (2002). Cost of Variable Speed Limit System in Michigan. *Correspondence with Construction & Technology Division, Michigan DOT.*

50 Elefteriadou, L., Washburn, S. S. , Yin, Y. , Modi, V. , & Letter, C. (2012). V*ariable Speed Limit (VSL)-Best Management Practice.*(No. FDOT contract BDK77 977-11). University of Florida. Transportation Research Center.

51 Kieninger, D. & Ring, J. (2005). ITS Integration Program Unit Cost Data Collection Sheet: Variable Speed Limit System, US 2 - Wenatchee, WA (FY03 Yr3). https://www.itscosts.its.dot.gov/ITS/benecost.nsf/0/34563A8048B8ED668525772000693FAF?OpenDocument&Query=Home

52 Van Jura, J., Haines, D., & Gemperline, A. Use of portable and dynamic variable speed limits in construction zones.

53 Fudala & Fontaine. *Work Zone Variable Speed Limit Systems: Effectiveness And System Design Issues* (No. FHWA/VTRC 10-R20).

54 Grossklaus, J. (2002). Cost of Variable Speed Limit System in Michigan. *Correspondence with Construction & Technology Division, Michigan DOT*.

C. Variable Speed Limit Example Specification*

DESCRIPTION

A Variable Speed Limit system shall/should* be used for maintenance of traffic as provided in the project plans and as specified in this document. The Variable Speed Limit system shall/should be a fully automated, stand-alone system, capable of making real-time changes in the information displayed to drivers in response to traffic conditions. The system must be able to, in real time, collect traffic data and, under predefined traffic conditions and using Changeable Speed Limit Signs, display the work zone speed limit to drivers in the section of roadway preceding the lane closure. The system must also generate condition and event logs that can be accessed remotely, and automatically send alerts to specified individuals when the system or a component of the system is not functioning properly.

MATERIALS

The Variable Speed Limit system shall/should include Changeable Speed Limit Signs, traffic sensors, communications devices, a system controller and field cabinet, system operating software, and all miscellaneous equipment and hardware required for a fully operational system. All roadside devices used for the Variable Speed Limit system shall/should conform to the latest Manual for Assessing Safety Hardware (MASH) standards, when available. The Variable Speed Limit system shall/should conform to the following system and operations requirements.

SYSTEM REQUIREMENTS

The Variable Speed Limit system shall/should consist of at least the following components:

(a) XX** Changeable Speed Limit Signs, as defined on the Temporary Traffic Control Plans. Each Changeable Speed Limit Sign shall/should conform to the standards and requirements in the most current edition of the Manual on Uniform Traffic Control Devices (MUTCD). Changeable Speed Limit Signs can be portable changeable message signs (PCMSs) or portable speed limit signs.

(b) Sufficient traffic detection device(s) to achieve the desired dynamic speed limits to achieve the desired dynamic speed limits as described in the System Operation section.

(c) A central system controller in a weatherproof cabinet used to: receive and process traffic detector data; deliver appropriate messaging to the Changeable Speed Limit Signs; monitor and record the system status; and provide the Operator on-site and remote access to the system for operation control, manual override of the messages being displayed, malfunction detection, and data collection.

(d) A reliable and secure communication system that connects the Changeable Speed Limit Signs, traffic detection devices, and central system controller, and allows for on-site and remote system access.

(e) A reliable power source(s) to allow for continuous operation during periods when the system is in use. This may include the need for an uninterrupted power supply (UPS) or backup generator.

(f) A deployment plan, submit by the Contractor, which at a minimum provides: locations of the devices; description of the proposed method of communication between the devices; a list of required equipment details; and proposed corrective method procedure (including response times and weekly reporting details), and notification process in case of a system failure.

* This example specification is for illustrative purposes only and is not enforceable under Federal law. It may be used or adapted by transportation agencies to meet their needs. Use of the words “should” and “shall” is for illustrative purposes only.

** Agency staff can supply the appropriate number.

SYSTEM OPERATION

If the work zone is not active, the Changeable Speed Limit Signs shall/should display the relevant speed limit, depending on the sign location. Signs in the work zone warning area, as defined in the MUTCD, shall/should display the work zone speed limit, as approved by the Project Engineer, and signs upstream of the warning area shall/should display the posted roadway speed limit. If the work zone is active, the Variable Speed Limit System shall/should detect two distinct traffic conditions: free flow and reduced speed:

(a) **Free flow:** Under free-flow conditions, the Changeable Speed Limit Signs in the upstream warning area shall/should display the typical work zone speed limit reduction sequence as defined on the Temporary Traffic Control Plans or as approved by the Project Engineer. Changeable Speed Limit Signs upstream of the warning area shall/should display the posted roadway speed limit. For this project, free flow is initially defined as an average travel speed of XX mph or greater, measured over a 3-minute period, upstream of the work zone merge point. The Variable Speed Limit system shall/should begin operation each day in free-flow mode.

(b) **Reduced speed:** As congestion approaching the work zone increases, the system shall/should begin to reduce the Variable Speed Limit speeds at locations upstream of the congestion. For this project, congestion is initially defined as an average travel speed XX mph under the posted speed limit, measured over a 3-minute period. When congestion is detected for 3 consecutive minutes, the Changeable Speed Limit Sign upstream of the congestion shall/should automatically be lowered. The message shall/should be displayed until (1) free-flow conditions, as defined above, are detected for 3 consecutive minutes, or (2) congestion increases over 3 consecutive minutes, lowering the speed displayed. Note that the speed limits displayed can vary by location. Speeds should be lowered in XX mph increments, and speeds should not be lowered by more than XX mph from the speed limit defined in the Free Flow section.

DEPLOYMENT REQUIREMENTS

The Contractor is responsible for furnishing, coordinating, installing, relocating, operating, maintaining, monitoring, and subsequently removing the approved Variable Speed Limit system according to the project plans and these specifications. The Contractor shall/should be able to maintain locally all components, move portable devices as necessary, including adjusting device location and replacing any malfunctioning devices, to ensure the system is operating as designed. The Contractor may adjust the location of signs in response to site-specific conditions, with the Project Engineer's approval. The Contractor shall/should be available seven days a week, 24 hours a day while the system is deployed. The 24/7 contact phone number shall/should be supplied to the Prime Contractor and Project Engineer. The Contractor shall/should provide weekly reports on system performance and response to emergencies.

SYSTEM DOCUMENTATION

Provide documentation detailing the technical and operational elements of the proposed Variable Speed Limit system for review and approval.

OPERATIONAL TEST

The Variable Speed Limit system shall/should be tested in two stages:

(a) **Off-site acceptance testing:** The Contractor shall/should test the system at an off-site location XX weeks prior to the field deployment of the system to ensure all system components are functioning as designed. To test the Changeable Speed Limit Signs and the central system controller, a work zone under free-flow and reduced-speed conditions can be virtually mimicked. The Contractor shall/should develop a testing plan and submit it for review and approval prior to the start of testing.

(b) **Site acceptance testing:** After the Variable Speed Limit system is installed or moved in the field, the Variable Speed Limit system, and all sub-systems such as a remote access systems, shall/should be tested to ensure all components of the system function as designed. For long-term installations, site acceptance testing shall/should be performed weekly by the Contractor. Testing shall/should be done for each specific deployment location within the project. The Contractor shall/should verify the accuracy of the traffic sensors, the information displayed on each Changeable Speed Limit Sign, and the data being recorded. The traffic sensor detected speeds shall/should not deviate by more than 5 mph from the actual vehicle speeds, and traffic volumes detected shall/should not vary by more than 10 percent from actual volumes. If the system does not meet the accuracy requirement, the equipment shall/should be recalibrated or replaced, if necessary, and re-tested. The Contractor shall/should submit a report no later than one calendar day following the completion of the Site Acceptance Testing. Construction can commence upon testing approval by the Project Engineer.

PERMITTED WORK HOURS

The Variable Speed Limit system can be used for both daytime and nighttime lane closures.

SYSTEM PERFORMANCE

(a) **Continuous operation:** The Variable Speed Limit system shall/should be in place and functioning while lane closures are in place.

(b) **Traffic detectors**: All sensors shall/should be of a type whose accuracy is not degraded by inclement weather or decreased visibility conditions including precipitation, fog, darkness, excessive dust, and road debris.

(c) **Data logging:** The Variable Speed Limit system shall/should capture a continuous event log including all traffic conditions, all system state changes, and all changes in the messages displayed.

(d) **Remote access:**

  (1) **System data log:** Password-protected users shall/should have the capability to view all system log data on a website and create graphs based on available data with time and date stamps. At the request of the Project Engineer, the vendor shall/should provide a digital copy of the logged information.

  (2) **System assessment:** The Variable Speed Limit system shall/should be configured to assess any type of malfunction that has occurred. This assessment includes communication disruption between any device in the system and any device malfunctions including Changeable Speed Limit Signs malfunctioning. The system shall/should be capable of notifying the specified individuals via phone and email about any system malfunction.

  (3) **Remote monitoring and control:** The Variable Speed Limit system shall/should have the capability of real-time remote monitoring and control.

(e) **Manual control:** The Variable Speed Limit system shall/should be manually controllable onsite. The capability to manually switch between states of free flow and congestion allows for maximum flexibility.

(f) **Speed detection:** The Variable Speed Limit system shall/should have the capability of calculating real-time travel speed and updating the speed limits on the Changeable Speed Limit Signs every minute.

SYSTEM TRAINING

Variable Speed Limit system training shall/should be conducted by the Contractor directly responsible for the system operation and the system supplier. The training shall/should include representatives from the Contractor, Agency, Enforcement, and others responsible for construction, maintenance of traffic, and safety. The training shall/should, at a minimum, cover the following items:

(a) Review of system operation.

(b) In the event of an emergency, instructions on how to override the system.

(c) In the event of a power failure, instructions detailing how to power cycle the system.

(d) Online system access, remote monitoring, and remote control.

(e) Basic listing of what to monitor and what causes messages to change.

(f) List of telephone numbers to call to request technical support.

SYSTEM WARRANTY, MAINTENANCE, AND SUPPORT

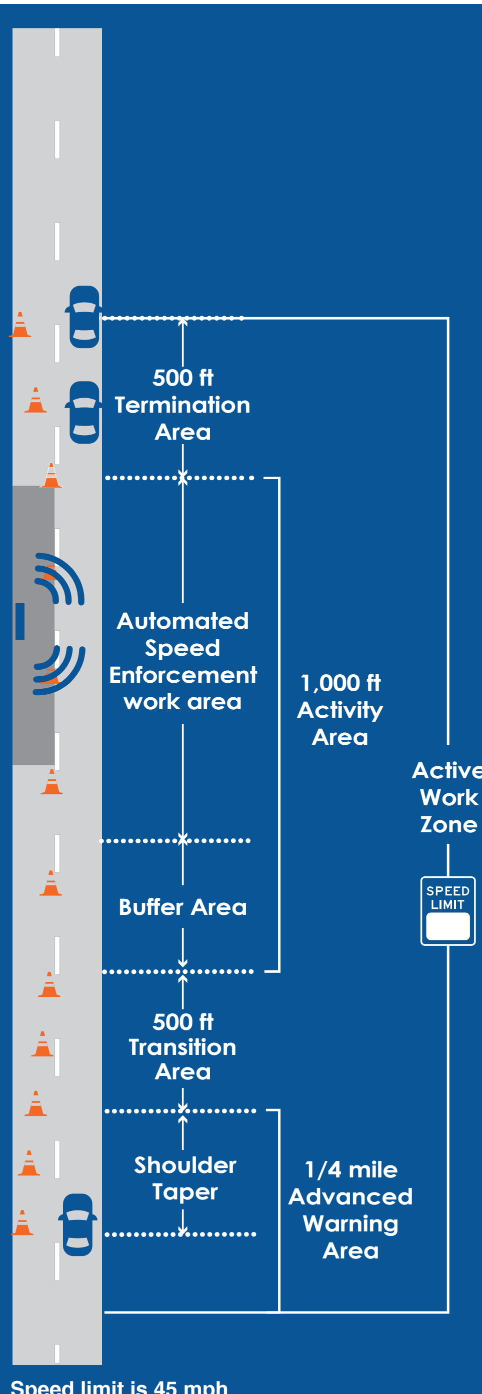
The Variable Speed Limit system shall/should be maintained, supported, and warranted against material defects by its supplier through the duration of the deployment. The Contractor shall/should respond immediately to any call from the Project Engineer or designated representative concerning any request for correcting any deficiency in the system. Deficiencies include field conditions and remote monitoring capabilities.

MEASUREMENT AND PAYMENT

Measurement and payment shall/should be made at the contract unit price per day that the Variable Speed Limit system is deployed, in use, and operational, which shall/should be compensation in full for furnishing, installing, operating, relocating, reporting, maintaining, and removing the system. System testing and training, communications costs, and any relocation or repositioning within the work zone or removal of equipment from the work zone shall/should be incidental to the contract unit price. Performance reports shall/should be provided prior to payment. Payment shall/should not be made until any performance problems or operations are fully tested and operational.

D. Automated Enforcement

U.S. Department of Transportation
Federal Highway Administration



Diagrams represent approximate equipment locations.
Review local guidance for required layout

Figure 4. Diagram. Automated enforcement diagram. Source: FHWA.

Description

Speeding violations in work zones significantly contribute to a majority of work-zone-related crashes involving drivers and work zone workers. Tracking and enforcing the violators is crucial to changing driver behavior and minimizing speed variations, thereby reducing speed-related crashes. Many States deploy automated enforcement systems to monitor, identify, and enforce speeding violations without continuous monitoring/presence of law enforcement agents.

An automated enforcement system uses an electronic camera to enforce traffic laws by assisting with detection of infractions and providing photo documentation of the vehicle or driver violating the traffic law.

ASE systems are the most typical type of automated enforcement systems used in work zones. They use Radar or LiDAR to determine vehicle speed. When a vehicle's speed exceeds (by a pre-determined threshold) the posted speed limit, a computer-controlled camera takes a photograph of the vehicle and license plate. The system also registers the time, date, location, and vehicle speed.

Four types of ASE systems include:

- Fixed Cameras – which continually monitor traffic speeds without an operator.
- Semi-Fixed Cameras – which are rotated between housings, resulting in housings with active cameras and "dummy housings" without cameras.
- Mobile Cameras – most often deployed in vehicles with or without law enforcement agents present.
- Average Speed Enforcement Systems – which measure average speed between two checkpoints on a roadway.

Among the four types, the mobile cameras deployed in vehicles are more suitable to work zones due to the limited duration of work zone activities and reusability of the equipment across multiple corridors. These ASE systems work similar to the permanent ASE installations, but have the extra feature of being able to be repositioned at a moment's notice. The work zone ASE systems are recommended only for roadways with a posted speed limit of 45 mph or higher.

ASE systems typically include signs, placed well before the speed camera installation, clearly indicating that ASE systems are in use and specifying the lowered speed limit. A speed display trailer is usually deployed alongside the speed camera unit to inform drivers of their speed. Many States have specific signing requirements regarding their use.

ASE technology has been utilized in the United States since 1986 and is in use in 142 communities.[55] More than 20 States and the District of Columbia have passed laws that permit the use of speed enforcement cameras. However, legislation specific to ASE systems for work zones has been passed in only a handful of States:

- Colorado (police officer or government employee must be present at time of violation).
- Illinois.
- Louisiana (must be operated by the State).
- Maryland.
- Oregon (no more than 4 hours per day and must be operated by uniformed police officer).
- Pennsylvania.
- Virginia.

ASE systems rely on signs and technology, which activate when construction workers are present in a work zone. Example distances between signs and ASE cameras are shown in figure 4 above. Actual distances in a specific work zone may vary based on the speed limit, violation hotspots, sight distance, and type of technology.

ASE systems for work zones are usually contracted to an approved vendor, and that vendor is responsible for deploying the system; providing on-site operating personnel; capturing speed violations via an image that provides license plate information, as well as general vehicle characteristics; and a record of the date, location, and speed. The vendor typically analyzes the collected data and retrieves vehicle owner information based on State Department of Motor Vehicle records. Once the citation record is reviewed and approved by the State agency, the vendor mails the citation.

Benefits

Within work zones, ASE systems can:

- Reduce Crash Rate.
- Reduce Crash Severity.
- Increase Compliance.
- Provide Uniform Enforcement.
- Increase Safety for Police Enforcement.

Reduce crash rate. ASE systems reduce traffic speeds prior to the work zone, which significantly reduces the speed differential between vehicles. An increase in speed harmonization, similar to the benefits of a variable speed limit system, lessens the likelihood of sudden stops and rear-end crashes, thereby improving traveler safety. All reviewed studies on automated speed enforcement reported statistically significant reductions in crashes following the introduction of automated speed enforcement.[56, 57, 58, 59, 60, 61, 62]

Reduce crash severity. ASE systems can result in reduced speed differential between vehicles involved in a crash, which directly contributes to a reduction in crash severity. As a result, a significant reduction in work zone fatalities and injuries can be achieved.

Increase compliance. Deployment of ASE systems can result in improved compliance by travelers with the posted speed limits. This decreases the likelihood of a driver exceeding the speed limit by more than 10 mph on roads with ASE systems, thereby reducing the number of speeding violations in the work zone corridor.[63,64]

Provide uniform enforcement. Using an ASE system for enforcing speeding violations can lead to improved fairness and consistency by uniformly applying enforcement rules and identifying all the violators across the enforcement time window.

Increase safety for enforcement. ASE systems issuing automated citations for speeding violations can reduce the requirement of human resources needed for speeding enforcement. This also minimizes the need for enforcement vehicles entering moving traffic to issue citations, thereby improving the safety of enforcement officers. With ASE systems in place, highway patrol and other officer resources can be more efficiently used for other work zone or traffic-related monitoring and enforcement activities.

Considerations

The following are key considerations for ASE systems:

- Legislative Permissions and Limitations.
- Public Outreach and Communication.
- Use of Warning Signs and Probationary Warning-Only Period.
- Enforcement.

Legislative permissions and limitations. Many jurisdictions using automated enforcement are in States with laws authorizing its use. Some States permit automated enforcement without a specific State law. A few States prohibit or restrict some forms of automated enforcement. Before planning to use an ASE system, it is important to review the local and State law for permissions, limitations, and applicability of ASE systems within the deployment area. Especially for work zones, the majority of States limit the application of ASE systems to expressways or controlled access highways with a speed limit of 45 mph or greater. Some States also restrict the use of ASE systems in work zones to times when construction workers, law enforcement vehicles, and/or uniformed Police Enforcement are present, as well as stipulate minimum distances between posted signs and ASE systems.

Public outreach and communication. Drivers may need sustained communication and education about the operational mechanism, requirement, and benefits of an ASE system for it to be efficiently operated. Agencies should use various traditional and social media sources to conduct customer outreach and gather feedback. In addition, it is important to inform the public about the measures taken to protect traveler privacy. These measures could include restricting the use of recorded information for strictly speeding enforcement purposes, ASE system information not being subjected to right-to-know laws, etc.

Use of warning signs and probationary warning-only period. In addition to traveler outreach, it is important to install advance warning systems and offer a probationary warning-only period to acclimate travelers to the ASE technology. Warning signs should be placed at least 600 feet in advance of an ASE system to notify travelers about its presence and operational status. Offering a probationary warning-only period gives travelers an initial adaptation period without any penalties.

Enforcement. Agencies implementing ASE systems should consider enforcement-related issues, including points assessed for citations, fine amounts, driver record impacts, time frames for mailing citations to violators, and procedures and standards for data extraction and processing. Without these legislative and enforcement safeguards, a jurisdiction runs the risk of having the ASE system challenged in court.

References

55 Poole, Bryan, Sarah Johnson, and Libby Thomas. *An Overview of Automated Enforcement Systems and Their Potential for Improving Pedestrian and Bicyclist Safety*. Chapel Hill, NC: Pedestrian and Bicycle Information Center, 2007. http://www.pedbikeinfo.org/cms/downloads/WhitePaper_AutomatedSafetyEnforcement_PBIC.pdf.

56 City of Chicago. “Automated Speed Enforcement Cameras Begin Warning Period.” Last modified August 23, 2013. https://www.chicago.gov/city/en/depts/cdot/provdrs/traffic_signals_andstreetlights/news/2013/aug/automated_speed_enforcementcamerasbeginwarningperiod.html.

57 Bates, Jonathon and Shelly Oren. “Enforcing Traffic Laws with Red-Light and Speed Cameras.” National Conference of State Legislatures, July 2020. https://www.ncsl.org/research/transportation/enforcing-traffic-laws-with-red-light-and-speed-cameras.aspx.

58 Federal Highway Administration. Work Zone Automated Speed Enforcement Program. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, *Mobility & Safety*, Fall 2017. https://ops.fhwa.dot.gov/publications/fhwahop17044/fhwahop17044.pdf.

59 Shinkle, Douglas, Annie Kitch, and Kevin Pula. Traffic Safety Trends | State Legislative Actions 2018. National Conference of State Legislatures, June 9, 2020. https://www.ncsl.org/research/transportation/traffic-safety-trends-state-legislative-action-2018.aspx.

Cost and Equipment

The cost of an ASE system within a work zone varies considerably depending on the existing infrastructure. The cost of a deployment depends on the number of signs and sensors installed along the corridor and the extent to which agencies can utilize existing infrastructure. An agency's cost estimate must consider whether to buy, rent, or lease the ASE equipment—but most agencies contract ASE systems with an approved vendor that provides end-to-end services, except the review by law enforcement. Updated for 2020 dollars, previous U.S.-based deployments of a work zone ASE system have ranged from $700 to $1,500 per 8-hour shift deployment. This is a fixed cost regardless of the number of infractions recorded per shift. Variations on the cost depend on the number of deployments contracted, as well as if the agency requires vendor-approved personnel during the deployment.

Item Costs

The table below estimates the costs of purchasing the components necessary to implement a user-friendly, accessible, and accurate ASE system in a work zone, as shown in figure 4. These costs are in 2020 dollars.[65]

Table 4. Automated Enforcement System Cost Estimate

Item	Unit Price	Quantity	Cost
Speed Detection Sensors	$4,500	1 per 6 Lanes	$4,500
Cameras (minimum 6 megapixels resolution)	$3,000	2	$6,000
Non-visible Infrared Flashlight	$100	2	$200
Central Computer System	$5,000 (Buy)	1	$5,000
Field Hotspot Wi-Fi and Data Plan	$200 (Buy) + $65 (Per Month Subscription)	1	$265
Sensor-Camera Communication Device	$550	1	$550
Advance Warning Signs	$550	2	$1,100
		TOTAL	**$17,615**

References continued

60 Governors Highway Safety Association. "State Laws by Issue | Speed and Red Light Cameras." Accessed July 28, 2021. https://www.ghsa.org/state-laws/issues/speed%20and%20red%20light%20cameras.

61 Hamzah, Muhamad K., Choy P. Ng, Faridah H. Khairuddin, Mohammed A. Yusof. The Automated Speed Enforcement System – A Case Study in Putrajaya. *Proceedings of the Eastern Asia Society for Transportation Studies*, Volume 10. https://www.jstage.jst.go.jp/article/easts/10/0/10_2133/_article.

62 Wijers, Peter. "The Benefits of Automated In-Vehicle Traffic Enforcement." Making Traffic Safer, March 2017. https://making-traffic-safer.com/benefits-automated-vehicle-traffic-enforcement/

63 Benekohl, Rahim F., Chitturi, Madhav V., Hajbabie, Ali, Wang, Ming Heng, Medina, Juan C. "Automated speed photo enforcement effects on speeds in work zones." Accessed July 28, 2021. https://experts.illinois.edu/en/publications/automated-speed-photo-enforcement-effects-on-speeds-in-work-zones.

64 Franz, Mark L., Chang, Gang-Len. "Effects of Automated Speed Enforcement in Maryland Work Zones." Accessed July 28, 2021. https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa1304/resources2/13%20-%20Effects%20of%20Automated%20Speed%20Enforcement%20in%20Maryland%20Work%20Zones.pdf.

65 ITS Deployment Evaluation. System Cost Estimate in 2020 dollars. Washington, D.C.: U.S. Department of Transportation. Accessed July 28, 2021. https://www.itskrs.its.dot.gov

D. Automated Enforcement Example Specification*

DESCRIPTION

An Automated Speed Enforcement (ASE) system shall/should* be used for monitoring traffic speeds, as well as identifying and enforcing traffic violations as provided in the project plans and as specified in this document. The ASE system shall/should be a fully automated, mobile system. The system must be able to, in real time, measure traveling speeds of individual vehicles, identify speeding violations, and capture and log violation information including date and time, location, travel speed, and violating vehicle's license plate. The system, which must operate continuously while the work zone is in place, must also generate violation event logs for processing, generation and sending of speeding citations, and payment collection.

MATERIALS

The ASE system shall/should include static signs, speed detection module, camera, communications devices, a system controller, system operating software, and all miscellaneous equipment and hardware required for a fully operational system. All roadside devices used for the ASE system shall/should conform to the latest Manual for Assessing Safety Hardware (MASH) standards, when available. The ASE system shall/should conform to the following system and operations requirements.

SYSTEM REQUIREMENTS

The ASE system shall/should meet the following requirements:

(a) Capable of capturing vehicle speeds and violations in all lanes in both directions of travel.

(b) The speed detection equipment shall/should use proven technology approved by the International Association of Chiefs of Police (IACP) for speed measurement.

(c) Capable of capturing high-resolution images and high-definition videos of speeding vehicles' license plate information with location, date, and time stamps for review at a later time.

(d) Transportable and mobile in nature.

(e) Configurable to trigger at different speeds at different times of the day.

(f) Weatherproof system that can operate in all weather conditions.

(g) A reliable communication system to connect devices to the central controller and to allow for remote access to the system for operation, malfunction detection, and data collection.

(h) Include a vehicle in which the system is installed, which shall/should be placed within the work zone.

(i) Include a module that is capable of back office processes such as generation of traffic violation citations, payment processing, and customer service.

SYSTEM OPERATION

The ASE system shall/should detect the speeds of all vehicles on the road. When the ASE system detects a vehicle that exceeds the speed limit by a specific threshold as defined by the deployment organization, a citation shall/should be issued to the violator.

* This example specification is for illustrative purposes only and is not enforceable under Federal law. It may be used or adapted by transportation agencies to meet their needs. Use of the words "should" and "shall" is for illustrative purposes only.

** Agency staff can supply the appropriate number.

The ASE system shall/should be able to be deployed to a predetermined work zone and be ready to detect speed violations as soon as the system is activated and when there are work zone workers present. When a vehicle exceeds the specified speed limit threshold, an image of the vehicle shall/should be captured, ensuring that only license plate information is captured and the driver is not identified. The collection of license plate information images shall/should then be reviewed for quality, ensuring a clear image of a license plate is collected. The license plate information shall/should be used to identify the vehicle owner and their address, the address the vehicle is registered to, and a general vehicle description which shall/should be used to ensure the information matches the image. The violation information shall/should be sent to the agency for approval or rejection. Once approved, the system shall/should generate a citation, which is then sent to the registered vehicle owner.

DEPLOYMENT REQUIREMENTS

Furnish, coordinate, install, operate, maintain, monitor, and subsequently remove the approved ASE system according to the project plans and these specifications.

SYSTEM DOCUMENTATION

Provide documentation detailing the technical and operational elements of the proposed ASE system for review and approval.

OPERATIONAL TEST

The ASE System shall/should be tested in two stages:

(a) **Off-site acceptance testing:** The Contractor shall/should test the system at an off-site location XX** weeks prior to the field deployment to ensure all system components are functioning as designed. The Contractor shall/should develop a testing plan and submit it for review and approval prior to the start of testing.

(b) **Site acceptance testing:** After the ASE system is installed or moved in the field, the Contractor shall/should test the system prior to the start of the work zone activities. Testing shall/should be done for each specific deployment location within the project. Testing shall/should include a lane closure and a full maintenance of traffic setup. If the system does not meet the accuracy requirement, the equipment shall/should be recalibrated or replaced, if necessary, and re-tested. The Contractor shall/should develop a testing plan and submit it for review and approval prior to the start of testing. Testing shall/should be done for each specific deployment location within the project. The Contractor shall/should submit a report no later than one calendar day following the completion of the site acceptance testing.

PERMITTED WORK HOURS

The ASE system shall/should be used during active work zone hours or when the work zone workers are present.

SYSTEM PERFORMANCE

(a) **Continuous operation:** The ASE system shall/should be in place and functioning when work zone workers are present.

(b) **Enforcement cameras and radars:** All sensors shall/should be of a type whose accuracy is not degraded by inclement weather or decreased visibility conditions including precipitation, fog, darkness, excessive dust, and road debris.

(c) **Data logging:** The ASE system shall/should capture a continuous event log including all traffic speeds of individual vehicles, speeding violations images, and date and time of violations.

(d) **System assessment:** The ASE system shall/should be configured to assess any type of malfunction that has occurred. If a malfunction is detected, the system shall/should be taken out of service and any speed violation detected shall/should be discarded.

(e) **Calibration and testing:** The system shall/should undergo testing and calibration XXX times per week. The system shall/should be calibrated on a yearly basis by a certified third-party laboratory following the State standards.

SYSTEM TRAINING

ASE system training shall/should be conducted by the Contractor directly responsible for the system operation and the system supplier. The training shall/should include representatives from the Contractor, Agency, Enforcement, and others responsible for construction, maintenance of traffic, and safety. The training shall/should, at a minimum, cover:

(a) Review of system operation.

(b) In the event of an emergency, instructions on how to override the system.

(c) In the event of a power failure, instructions detailing how to power cycle the system.

(d) Online system access and remote monitoring.

(e) Information regarding issues that can degrade the performance of the system.

(f) List of telephone numbers to call to request technical support.

SYSTEM WARRANTY, MAINTENANCE, AND SUPPORT

The ASE system shall/should be maintained, supported, and warranted against material defects by its supplier through the duration of the deployment. The Contractor shall/should respond immediately to any call from the Project Engineer or designated representative concerning any request for correcting any deficiency in the system. Deficiencies include field conditions and remote monitoring capabilities.

MEASUREMENT AND PAYMENT

Measurement and payment shall/should be made at the contract unit price per day that the ASE system is deployed, in use, and is fully operational, which shall/should be compensation in full for furnishing, installing, operating, reporting, maintaining, and removing the system. System testing and training, communications costs, and any relocation or repositioning within the work zone or removal of equipment from the work zone shall/should be incidental to the contract unit price.

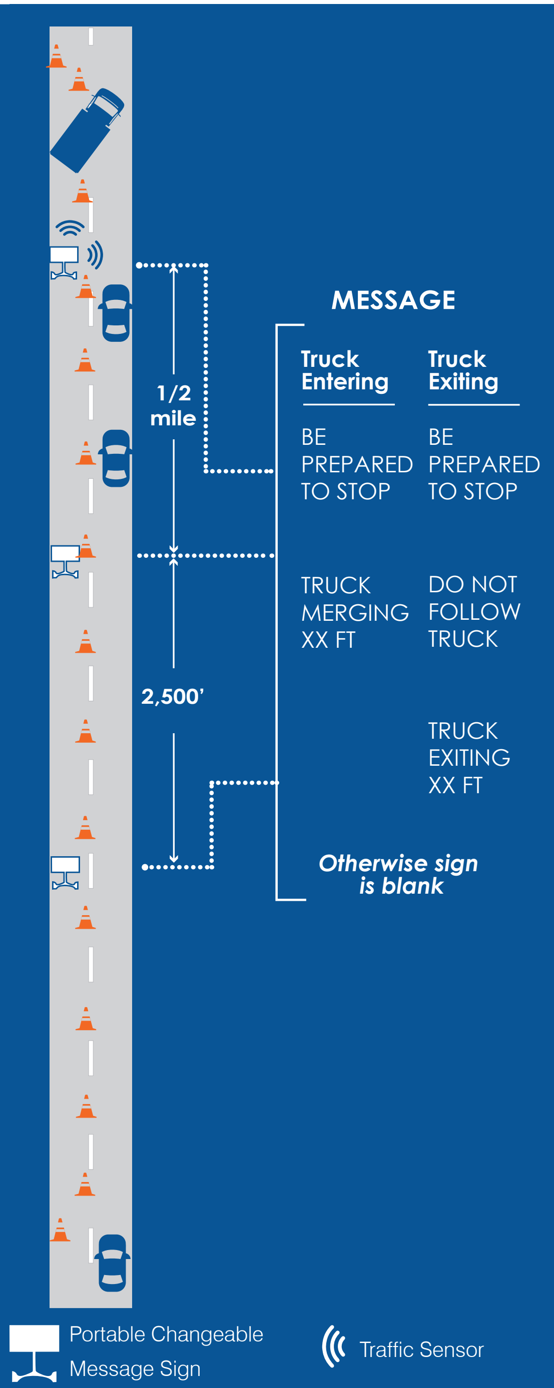
E. Entering/Exiting Construction Vehicle Notification

U.S. Department of Transportation
Federal Highway Administration

Description

Work zones are often areas of constrained access and capacity that have slow-moving construction vehicles entering, exiting, and crossing active travel lanes, which presents potential safety and mobility concerns to roadway users and construction workers.

An Entering/Exiting Construction Vehicle Notification System warns drivers of slow-moving construction vehicles that may be entering the travel lane. The system also warns travelers that a construction vehicle is exiting the travel lane and not to follow it into the work zone area.



Diagrams represent approximate equipment locations. Review local guidance for required layout.

Figure 5. Diagram. Entering/exiting construction vehicle notification diagram. Source: FHWA

An Entering/Exiting Construction Vehicle Notification System is a stand-alone system that requires no communication or link-up with a traffic management center (TMC). This system uses a vehicle detection system, a portable changeable message sign (PCMS) or static warning signs with warning beacons, and a wireless communication link to trigger the sign. The system sends an advanced warning to drivers by broadcasting messages through the PCMS or triggering the warning beacons on the static warning sign (or both) when a construction vehicle is entering or exiting the active travel lanes.

The functionality of the system differs depending on whether the construction vehicle is entering or exiting the active travel lanes. A sensor detects a construction vehicle entering the active travel lanes (e.g., pneumatic tube, radar) near the travel lane entrance point, which in turn sends an activation signal to the PCMS or warning beacons on the static sign. In the case of a construction vehicle exiting the travel lane, there are two types of system activation: manual and automatic. For manual activation, the driver of the construction vehicle activates a switch in the vehicle's cab as the vehicle approaches the travel lane exit point, which broadcasts a signal to the PCMS and/or warning beacons. For an automatic system, a sensor detects the construction vehicle approaching the travel lane exit point and activates the PCMS and/or warning beacons.

To reduce false triggering, the system needs to differentiate between a construction vehicle entering or exiting a travel lane and other vehicles and equipment moving within the work zone. In the case of a construction vehicle entering the travel lane, this can be handled by carefully limiting the detection zone to the construction vehicle entrance points. In the case of a construction vehicle exiting the travel lane, a dedicated activation switch can be provided to the vehicle's driver. Alternatively, vehicle-to-infrastructure (V2I) communication devices can be installed in construction vehicles and work sites to enable automatic activation of the PCMS and/or warning beacons.

Information provided to drivers by the Entering/Exiting Construction Vehicle Notification System includes distance to entrance/exit point, reduced speed limit, and intrusion restrictions. For construction vehicles entering the active travel lanes, the system provides alerts, including "BE PREPARED TO STOP" and "TRUCK MERGING XX FT." For construction vehicles exiting the active travel lanes, alerts provided by the system include "BE PREPARED TO STOP," "TRUCK EXITING XX FT," and "DO NOT FOLLOW TRUCK."

The PCMS and/or warning beacons should be located at a predetermined distance from the entrance/exit point that provides ample time for travelers to change lanes or slow down appropriately, which will allow for safe truck merging into the travel lane. The distance between entrance/exit points and the PCMS and/or warning beacons should be calculated based on the MUTCD. Once the PCMS and/or warning beacons are activated, they should remain active for a configurable amount of time, which will allow the construction vehicle to perform its entry/exit maneuvers. The figure above shows an example deployment of a system on a two-lane highway that incorporates both trucks entering and exiting the active travel lanes. In this example, two PCMSs and one vehicle detection trailer are used. The first PCMS is positioned around 2500 ft upstream from the entrance/exit point of the active travel lanes. The second one is at 1500 ft, and the vehicle detection trailer is located at the entrance/exit point. This configuration provides ample warning for drivers to see the signs and react accordingly. Distances shown in the figure may vary based on the time of operation, sight distance, traffic conditions, and speed limit.

BENEFITS

Early notification of entering and exiting construction vehicles will improve safety and mobility performance of drivers and work zone personnel. Key benefits of the notification system include:

- Increased Speed Harmonization.
- Reduced Crash Risk.
- Reduced Motorist Intrusion into Work Zones.

Increased speed harmonization. Timely communication of construction vehicle maneuvers from work zone areas allows drivers to be prepared for the maneuvers by reducing travel speeds or changing lanes. This reduces the number of sudden stops and resulting slowdowns in the traffic stream near the construction vehicle entrance/exit point.

Reduced crash risk. Reduction in sudden stops can contribute significantly to decreasing the number and severity of rear-end and secondary crashes related to work zones.

Reduced motorist intrusion into work zones. Drivers entering work zone areas through construction vehicle entry points pose a safety concern for the construction workers. This system provides advance alerts to drivers about the intrusion restrictions into the work zones and thereby results in reduced intrusion.

CONSIDERATIONS

For an efficient planning and implementation of an Entering/Exiting Construction Vehicle Notification System, key considerations include:

- Reduced Visibility of Roadway Workers.
- Sufficient Sight Distance.
- Public Outreach.
- Adequate Acceleration and Deceleration Distances for Construction Vehicles.

Reduced visibility of roadway workers. Agencies should place the notification system equipment in a manner that it does not obstruct the drivers' ability to see the presence of work zone workers.

Sufficient sight distance. Agencies implementing this system must ensure that the distances between the construction vehicle maneuvering point and the PCMS and/or warning beacons are adequate for drivers to perform safe and smooth transition of speeds and lane changes.

Public outreach. Because the technology is in emerging stages in most States, early education of technology operation and its benefits will allow drivers to quickly adapt and comply with the technology.

Adequate acceleration and deceleration distances for construction vehicles. Agencies must provide adequate acceleration and deceleration distances for construction vehicles. This will allow construction vehicles to reach the traveling speed of drivers when merging into the travel lane and make safe stops in a work zone area by decelerating at a normal rate when entering from a travel lane.

Cost and Equipment

The cost of an Entering/Exiting Construction Vehicle Notification system varies depending on an agency's decision to buy or lease the equipment. At minimum, this system requires one PCMS or static sign with warning beacons, a cab transmitter and receiver or a detector system to sense the construction vehicle, and other static warning signs, as well as communication equipment between sensors and PCMS and/or warning beacons. Updated for 2020 dollars, previous U.S.-based deployments of work zone entry/exit warning systems have ranged between $44,000 and $400,000. The systems depicted here implemented a limited version of the system, which focused only on construction vehicles entering the travel lane.

- For a 6-month project deployed in Willow River, MN, a system that used 6 doppler radars, 16 advance warning beacons, and cellphone communications was deployed. The system allowed for e-mail reporting. The rental fee of the equipment was $44,000, which included hardware, installation, and removal, as well as 24/7 technical support.[66]
- For a 45-month project deployed in Honolulu, HI, a system that used eight PCMSs, a license plate reader system, 15 Bluetooth sensors, and cellphone communications was deployed. The system allowed for e-mail reporting. The rental fee of the equipment was $400,000, which included hardware, installation, and removal, as well as 24/7 tech support.[67]

Item Costs

The table below estimates the costs of purchasing the components necessary to implement a user-friendly, accessible, and accurate Entering/Exiting Construction Vehicle Notification system in a work zone. These costs are in 2020 dollars.[68] This cost estimate assumes the minimum acceptable number of PCMSs, as shown in figure 5.

Table 5. Entering/Exiting Construction Vehicle Notification System Cost Estimate

Item	Unit Price	Quantity	Cost
Post/Trailer PCMS	$15,000	3	$45,000
PCMS Communication	$550	3	$1,650
Work Zone Exiting Vehicle Detector - Trailer Mounted	$3,000	1	$3,000
Freeway Traffic Speed Detector – Trailer Mounted	$3,000	1	$3,000
Detector Communication	$550	2	$1,100
Cellular Antenna for Remote Monitoring	$1,800	1	$1,800
Static Signs	$400	9	$3,600
		TOTAL	**$53,450**

Additional Resources

Guidance for the Use of Portable Changeable Message Signs in Work Zones (2013). Retrieved from: https://www. workzonesafety.org/training-resources/fhwa_wz_grant/atssa_pcms_wz/

Trucks Entering/Exiting System Street Smart Design. Retrieved from: https://www.streetsmartrental.com/wp-content/uploads/Trucks-Entering-Existing-System-Street-Smart-Design.pdf

Federal Highway Administration. Work Zone Management Program. Best Practice. Retrieved from:

https://ops.fhwa.dot.gov/WZ/practices/best/view_document.asp?ID=349&from=state&State_ID=06

United States Department of Transportation. ITS Deployment Evaluation. Equipment Cost for Roadside Information. Retrieved from: https://www.itskrs.its.dot.gov/costs/unadjusted/rsi

References

66 Texas Department of Transportation (DOT). Smart Work Zone guidelines, *Design Guidelines for Deployment of Work Zone Intelligent Transportation Systems (ITS)*. Austin, TX: Texas Department of Transportation, 2018. https://www.txdot.gov/inside-txdot/division/traffic/smart-work-zones.html.

67 Texas DOT. Smart Work Zone guidelines, *Design Guidelines for Deployment of Work Zone ITS*.

68 ITS Deployment Evaluation. System Cost Estimate in 2020 dollars. Washington, D.C.: U.S. Department of Transportation. Accessed July 28, 2021. https://www.itskrs.its.dot.gov.

E. Entering/Exiting Construction Vehicle Notification Example Specification*

DESCRIPTION

An Entering/Exiting Construction Vehicle Notification System shall/should* be used to monitor construction vehicles entering and exiting the active travel lanes and notify drivers of the construction vehicle maneuver as provided in the project plans and as specified in this document. This system should be a fully automated system. The system must be able to, in real-time, detect construction vehicles entering or exiting the active travel lanes, display traveler information to drivers in the section of roadway preceding a work zone, and capture and log Portable Changeable Message Sign (PCMS) information including date and time, locations, and number and types of messages posted. The system, which must operate continuously while the work zone is in place, must also generate notification event logs that can be accessed remotely by the Contractor and the sponsoring agency for analysis and performance monitoring purposes.

MATERIALS

The Entering/Exiting Construction Vehicle Notification System shall/should include XXXX** PCMS and/or static signs with warning beacons, vehicle detectors, communications devices, system operating software, and all miscellaneous equipment and hardware required for a fully operational system. All roadside devices used for the Entering/Exiting Construction Vehicle Notification System shall/should conform to the latest Manual for Assessing Safety Hardware (MASH) standards, when available.

This system shall/should conform to the following system and operations requirements.

SYSTEM REQUIREMENTS

The Entering/Exiting Construction Vehicle Notification System shall/should meet the following requirements at a minimum:

(a) At least XX** PCMSs, as defined in the project plan.

(b) Sufficient construction vehicle sensor(s) to detect and display the desired dynamic construction vehicle entering and exiting messages as described in the System Operation section.

(c) Traffic sensors capable of distinguishing between a vehicle entering/exiting the travel lane and all other vehicles, as well as counting each construction vehicle passing the sensor, recording the date and time each vehicle passes the sensor, and saving the construction vehicle count data.

(d) A roadside speed detector that activates the system when a construction vehicle's speed is below a pre-set threshold.

(e) A vehicle proximity device on the construction vehicles that enables detection and system activation as the vehicles approach the entrance/exit point.

(f) A dedicated website or other wireless remote system for monitoring smart work zone system functions and remotely managing warning messages.

(g) A reliable wireless communication system that connects all system devices, including the construction vehicles and PCMSs, and allows for on-site and remote system access and control.

(h) Format and frequency requirements for archiving data if desired. An error detection-correction mechanism capable of detecting system errors or malfunctions, logging the detected errors, and correcting the error or malfunction.

(i) Portable and mobile in nature that stands alone without requiring connectivity to a traffic management center.

(j) Availability for easy removal/relocation of the system if/when the construction vehicle access roadway is eliminated or relocated

(k) A proximity device capable of distinguishing between construction vehicles leaving work zone and other construction equipment moving within the work zone.

* This example specification is for illustrative purposes only and is not enforceable under Federal law. It may be used or adapted by transportation agencies to meet their needs. Use of the words "should" and "shall" is for illustrative purposes only.

** Agency staff can supply the appropriate number.

SYSTEM OPERATION

This system shall/should detect designated work zone construction vehicles entering or exiting the roadway and provide alerts to drivers on the travel lanes using PCMS and/or warning beacon notifications. For daytime operation at a minimum, a static sign with flashing lights should be used as a warning device. The Entering/Exiting Construction Vehicle Notification System shall/should be able to detect five distinct events: No Construction Vehicle Present; Construction Vehicle Exiting the Travel Lane; Construction Vehicle Entering the Travel Lane; Work Zone is Inactive; and System Malfunction/Communication Failure.

No construction vehicle present: When a construction vehicle is not present, the PCMSs shall/should be blank.

Construction vehicles entering the travel lane: The system shall/should be able to detect a designated work zone vehicle approaching a designated merge point into the travel lane and provide a warning to drivers through static signs with warning beacons or PCMSs so they can react accordingly. If a PCMS is used, it is recommended to display "BE PREPARED TO STOP" or "TRUCKS MERGING XX FT" messages when construction vehicles are entering the active travel lanes from work zones.

Construction vehicles exiting the travel lane: The system shall/should be able to detect a designated construction vehicle exiting an active travel lane to work zones, either by a proximity sensor or by a speed sensor and provide a warning to drivers through static signs with warning beacons or PCMSs so they can react accordingly. If a PCMS is used, it is recommended to display "BE PREPARED TO STOP," "TRUCK EXITING XX FT," or "DO NOT FOLLOW TRUCK" messages during this event.

Work zone is inactive: The PCMS can be used to display other traffic-related messages when the work zone is inactive.

System malfunction/communication failure: The PCMS shall/should be able to detect a communication failure with the construction vehicle sensor unit. When a malfunction is detected, the PCMS is recommended to display a message that shall/should not alarm the motorist but shall/should indicate a system malfunction to field personnel.

If deployed, use of PCMS with programmed messages is desired during daytime operation. For nighttime operations, a PCMS with programmed messages should be used. For both systems, the location of the warning sign shall/should be far enough upstream of the access point to alert drivers of the warning message and provide ample time to react.

DEPLOYMENT REQUIREMENTS

Furnish, coordinate, install, operate, maintain, monitor, and subsequently remove the approved Entering/Exiting Construction Vehicle Notification System according to the project plans and these specifications.

SYSTEM DOCUMENTATION

Provide documentation detailing the technical and operational elements of the proposed system for review and approval.

OPERATIONAL TEST

The Entering/Exiting Construction Vehicle Notification System shall/should be tested in two stages:

(a) **Off-site acceptance testing:** The Contractor shall/should test the system at an off-site location XX weeks prior to the field deployment to ensure all system components are functioning as designed. To test the components, a work zone with a construction vehicle entering and exiting the travel lane can be virtually mimicked. The Contractor shall/should develop a testing plan and submit it for review and approval prior to the start of testing.

(b) **Site acceptance testing:** After the System is installed or moved in the field, the Entering/Exiting Construction Vehicle Notification System, and all sub-systems such as a remote access systems, shall/should be tested to ensure all components of the system function as designed. For long-term installations, site acceptance testing shall/should be performed weekly by the Contractor. Testing shall/should be done for each specific deployment location within the project. The Contractor shall/should verify the accuracy of the traffic sensors, the information displayed on each PCMS, and the data being recorded. The traffic sensor detected speeds shall/should not deviate by more than 5 mph from the actual vehicle speeds. If the system does not meet the accuracy requirement, the equipment shall/should be recalibrated or replaced, if necessary, and re-tested. The Contractor shall/should submit a report no later than one calendar day following the completion of the Site Acceptance Testing. Construction can commence upon testing approval by the Project Engineer.

PERMITTED WORK HOURS

The system shall/should be used during active work zone hours or when the work zone vehicles are present.

SYSTEM PERFORMANCE

The Entering/Exiting Construction Vehicle Notification System shall/should meet the following system performance requirements:

(a) **Continuous operation:** The system shall/should be in place and functioning when work zone vehicles are present.

(b) **Detection sensor:** All sensors shall/should be of a type whose accuracy is not degraded by inclement weather or decreased visibility conditions including precipitation, fog, darkness, excessive dust, and road debris.

(c) **Data logging:** The system shall/should capture the time, date, and number of vehicles entering and exiting the work zone area.

(d) **Remote access:**

   (1) **System data log:** Password-protected users shall/should have the capability to download all system log data remotely. At the request of the Project Engineer, the vendor shall/should provide a digital copy of the logged information.

   (2) **System assessment:** The system shall/should be configured to assess any type of malfunction that has occurred and enter a failsafe mode—a pre-programed message in the case of using PCMS or flashing lights in case of a static message. This assessment includes communication disruption between any device in the system and any device malfunctions.

   (3) **Remote monitoring:** The system shall/should have the capability of real-time remote monitoring (if applicable).

(e) **Manual control:** The system shall/should be manually controllable onsite. The capability to manually activate a warning sign to the motorist in the event of an emergency is beneficial.

SYSTEM TRAINING

The system training shall/should be conducted by the Contractor directly responsible for the system operation and the system supplier. The training shall/should include representatives from the Contractor, Agency, Enforcement, and others responsible for construction, maintenance of traffic, and safety. The training shall/should, at a minimum, cover the following items:

(a) Review of system operation

(b) In the event of an emergency, instructions on how to override the system

(c) In the event of a power failure, instructions detailing how to power cycle the system

(d) Online system access, remote monitoring, and remote control

(e) Basic listing of what to monitor and what causes messages to change

(f) List of telephone numbers to call to request technical support

SYSTEM WARRANTY, MAINTENANCE, AND SUPPORT

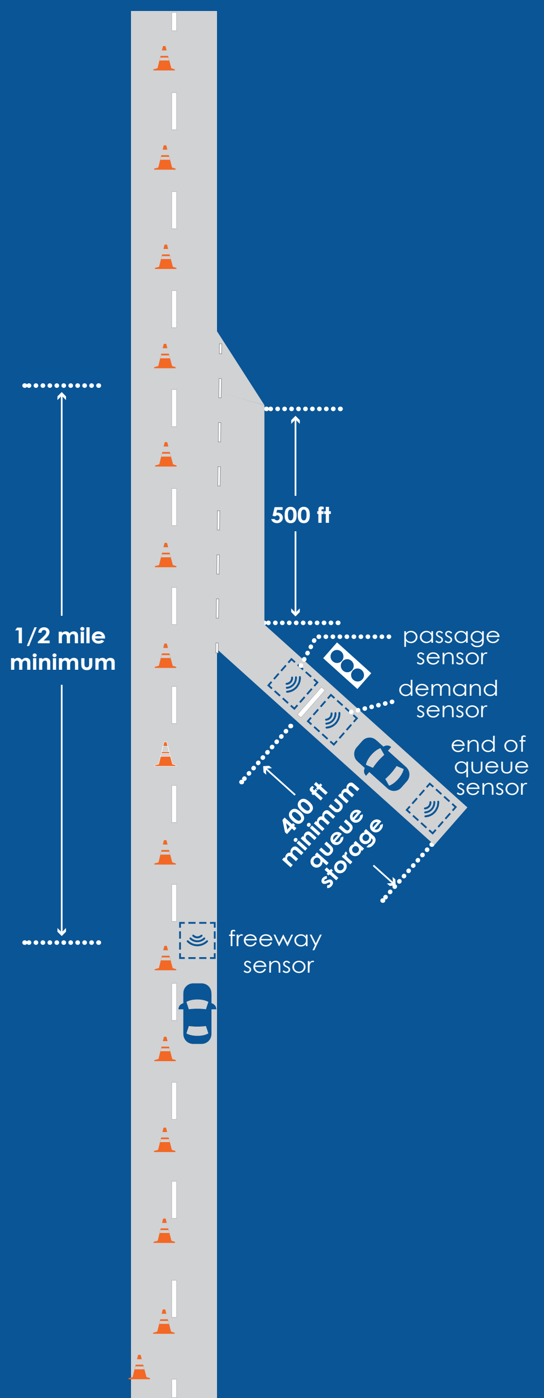
The system shall/should be maintained, supported, and warranted against material defects by its supplier through the duration of the deployment. The Contractor shall/should respond immediately to any call from the Project Engineer or designated representative concerning any request for correcting any deficiency in the system. Deficiencies include field conditions and remote monitoring capabilities.

MEASUREMENT AND PAYMENT

Measurement and payment shall/should be made at the contract unit price per day that the system is deployed, in use, and is fully operational, which shall/should be compensation in full for furnishing, installing, operating, reporting, maintaining, and removing the system. System testing and training, communications costs, and any relocation or repositioning within the work zone or removal of equipment from the work zone shall/should be incidental to the contract unit price.

F. Temporary Ramp Metering

U.S. Department of Transportation
Federal Highway Administration



Diagrams represent approximate equipment locations. Review local guidance for required layout

Figure 6. Diagram. Temporary ramp metering diagram. Source: FHWA.

Description

Freeway Entrance Ramp Control Signals are traffic control signals with circular red and green signal indications (or red, yellow, and green) that control the flow of traffic entering a freeway (for more details, reference MUTCD Chapter 4i). This freeway management technique is commonly referred to as ramp metering. This application controls the frequency with which vehicles from on-ramps enter the flow of traffic on the mainline. Ramp metering has traditionally been implemented during peak hours to reduce the effect of recurring congestion. However, State agencies have begun implementing ramp metering on a temporary basis to mitigate the effect of non-recurring congestion resulting from freeway construction activities.

Ramp metering upstream of work zones can steadily regulate the flow of traffic entering a work zone, resulting in speed harmonization and increased safety for roadway users and workers.

A Temporary Ramp Metering (TRM) system functions and operates similar to the permanent deployment. Ramp-metering systems operate under two approaches including pre-timed / fixed timing and variable timing.

Pre-timed / fixed timing is used at locations with known recurring congestion during a predetermined period of time (e.g., peak hours, events). During this approach, traffic flow onto to the mainline is controlled at a predetermined rate.

Variable timing is used at locations that require dynamic traffic demand responsive metering (e.g., construction activities, incidents). During this approach, traffic on the mainline and on-ramp are dynamically tracked using detectors. When warranted by the speed and volume of the mainline traffic, the TRM system is activated at a rate that is adjusted based on mainline and on-ramp traffic conditions.

Both fixed and variable ramp metering systems are optimal when combined mainline and on-ramp traffic volumes are less than or close to 1,600 vehicles per hour per lane (vphpl) and ramp volumes are not exceeding 400 to 600 vehicles per hour (vph). Optimally planned ramp metering ensures smooth mainline merging of on-ramp vehicles and minimal on-ramp queuing.

Additionally, operational enhancements like adaptive ramp metering and freeway and arterial system integration are proven to improve the efficiency of ramp meters. Functions supported by these enhancements include automatic identification and reaction to bottlenecks and incidents, as well as integration of arterial traffic signals with ramp meter signals.

TRM relies on technology and traffic control devices to effectively manage traffic. Use of the latest technology is critical for the dynamic components of ramp metering to achieve optimal safety and mobility performance. Distances between signs and ramp metering vary based on the acceleration length, percentage of truck traffic, grade of ramp, on-ramp speed, line of sight, or other roadway characteristics.

Benefits

The benefits of TRM are greatest at locations with construction activities during congestion periods where demand exceeds capacity. TRM systems can:

- Increase Traffic Throughput.
- Increase Vehicle Speeds.
- Reduce Travel Time.
- Reduce Crash Risk.

Increase traffic throughput. TRM systems break up on-ramp vehicle platoons merging onto the mainline, which reduces bottlenecking and allows more vehicles to travel through the mainline during any given time period. As a result, during saturated conditions, an increase in the mainline traffic throughput occurs.

Increase vehicle speeds. Through controlled metering of on-ramp vehicles onto the mainline, TRM systems reduce the number of merging maneuvers. This reduces the number of interruptions experienced by the mainline roadway users. As a result, an increase in overall vehicle speeds is observed.

Reduce travel times. As the overall vehicle speed gets closer to the speed limit during saturated conditions, an overall reduction in travel time and delay is experienced by drivers on the mainline.

Reduce crash risk. TRM systems improve the traffic safety by enabling smoother merges and reducing the stop-and-go traffic along the entrances. This reduces the number of work-zone-related crashes and their severity at merge zones.

Considerations

When deciding whether to implement a TRM system during highway construction, agencies should consider:

- Feasibility Study with Benefit/Cost Analysis.
- Mainline Congestion due to Work Zone Activity.
- Geometry Issues.
- Public Outreach.

Feasibility study with benefit/cost analysis. Before implementing a TRM system, agencies should conduct feasibility studies and benefit/cost analyses on proposed ramp metering locations. Feasibility studies help agencies validate the applicability of a TRM system in solving the targeted problems. Typical problems include mainline congestion, safety issues at merge zones, construction impacts, and special event impacts, among others. Benefit/cost analyses monetize the estimated benefits of ramp metering associated with travel time, crash reduction, and safety improvements and compare them against estimated capital and operations and maintenance costs.

Mainline congestion due to work zone activity. Before selection of a TRM system, agencies should thoroughly comprehend the impact of construction activities on mainline traffic conditions, including reduction in travel lanes and capacity, reduction in lane width, and other work zone characteristics. For the work zone ramp meter to be effective, the combined mainline and ramp traffic volumes should be less than or close to 1,600 vphpl and ramp volumes should not exceed 400 to 600 vph.

Geometry issues. When investigating the feasibility of ramp metering, agencies should investigate key geometry issues of the mainline and ramp, including inadequate acceleration length, mainline weaving problems caused by closely spaced ramps, and limited sight distances on a horizontal or crest vertical curve. An acceleration lane and adequate storage to accommodate queues resulting from metered traffic are needed to accommodate the ramp-metering setup.

Public outreach. Public outreach for ramp metering is important to explain the benefits and to educate motorists on how to use the system so the desired benefits are achieved. This is particularly important in areas where permanent ramp metering systems do not exist. Early and clear communication of placements and benefits of ramp metering systems prepares drivers to quickly get used to the system. In order to reach a broader local population, agencies should maintain important information on a website and distribute it via brochure, flyer, or social media.

Additional Resources

Edara et al. *Evaluation of Temporary Ramp Metering for Work Zones* (2012). Smart Work Zone Deployment Initiative TPF-5(081). Federal Highway Administration - InTrans Project 06-277. Retrieved from: https://intrans.iastate.edu/app/uploads/2018/08/Ramp-_Metering_for_Work_Zones.pdf

Model Systems Engineering Document ITS Application: Ramp Metering. Retrieved from: https://www.dot.state.mn.us/its/projects/2016-2020/systemsengineeringforitsandcav/rampmeteringse.pdf

Ramp Metering in Work Zones. Retrieved from: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rr_945RampMeter.pdf

Florida DOT – Ramp Signaling. Retrieved from: https://www.fdot.gov/traffic/Ramp-Signaling

How Ramp Metering Works. Retrieved from: https://mtc.ca.gov/sites/default/files/4.3c4-RampMetering.pdf

Initial findings from a ramp meter evaluation in Kansas City were consistent with findings in other cities that show ramp metering can reduce crashes by 26 to 50 percent. Retrieved from: https://www.itskrs.its.dot.gov/its/benecost.nsf/ID/3b602a4f31fc2ea985257a7e005e9902?OpenDocument&Query=Home

Ramp Metering Design Guide (2013). Retrieved from: https://www.azdot.gov/sites/default/files/2019/06/adotrampmeteringdesignguide_november2013.pdf#:~:text=Ramp%20metering%20is%20not%20typically%20used%20where%20the,considered%20if%20acceptable%20acceleration%20distance%20can%20be%20provided.

Typical application of Temporary Ramp Metering System. Retrieved from: http://www.dot.state.mn.us/trafficeng/workzone/wz-ltta/pdf/ltta80.pdf

Equipment Costs for Roadside Control (RS-C). Retrieved from: https://www.itskrs.its.dot.gov/costs/adjusted/rsc

Various ITS Vendors.

A freeway work zone queue warning system was installed for approximately $1.545 million. Retrieved from: https://www.itskrs.its.dot.gov/its/benecost.nsf/ID/590e8092dfb5a50985257d960052faf7?OpenDocument

Cost and Equipment

TRM systems use the following components and equipment to maintain their functionality:

- Controller cabinet.
- Temporary signal faces, either green/red signal faces or green/yellow/red signal faces to control the flow of traffic from the on-ramp to the mainline.
- Traffic detectors to measure traffic conditions (speed and occupancy) upstream and downstream on the mainline.
- Ramp meter detector at the stop bar.
- Ramp meter queue detector upstream on the on-ramp.
- Signing at the start of the on-ramp to warn vehicles of upcoming conditions and near the signal face to instruct vehicles to exit the on-ramp one at a time on a green signal. (for details on signing, reference MUTCD Chapter 2 – Section 2B.56).

Cost estimates vary according to buying or renting TRM system equipment. Due to the temporary nature of the deployments, renting equipment allows agencies to implement the latest advances in technology that provide efficient traffic management between on-ramps and freeway construction zones. For long-term work zones, some agencies buy and deploy equipment. After completion of work at one work zone, the same equipment can be used for other work zone sites with minimal changes to the system. For example, in a 2018 deployment, the Pennsylvania DOT rented a TRM system for $234,496 (in 2020 dollars). This project included equipment installed at the on-ramp and on the mainline, such as a ramp meter controller system, which includes a cabinet, controller, traffic signal face, remote connection via cellphone connection, and all associated signs (flashing/static). For the on-ramp queue detection, a queue detector loop was installed, along with presence/passage loop detectors and a downstream radar mounted on a trailer. For the mainline, two sets of upstream traffic detectors and one set of downstream traffic detectors were deployed, along with signs. The rental fee included hardware, installation, removal, and technical support.

Item Costs

The table below contains example unit costs for typical equipment used in a TRM system, as presented in figure 6. All costs are in 2020 dollars.[69]

Table 6. Temporary Ramp Metering System Cost Estimate

Item	Unit Price	Quantity	Cost
Traffic Signal Head	$10,000	1	$10,000
Freeway Traffic Detector	$2,500	2	$5,000
Ramp Queue Detector	$2,500	3	$7,500
Detector Communication	$550	4	$2,200
ITS Field Equipment Cabinet	$6,500	1	$6,500
Central Computer System	$5,000	1	$5,000
Ramp Metering Signs	$500	4	$2,000
		TOTAL	**$38,200**

References

69 ITS Deployment Evaluation. System Cost Estimate in 2020 dollars. Washington, D.C.: U.S. Department of Transportation. Accessed July 28, 2021. https://www.itskrs.its.dot.gov.

F. Temporary Ramp Metering Example Specification*

DESCRIPTION

A Temporary Ramp Metering (TRM) system shall/should* be used for managing traffic from on-ramps to congested freeways as provided in the project plans and as specified in this document. The TRM system should be a semi-fixed or mobile system that can be fully automated or remotely operated.

For dynamic TRM systems, the system must be able to, in real-time, measure freeway traffic speeds, identify queuing, feed traffic information to the ramp meter controller, and activate ramp metering to break down the platoons of vehicles entering from the on-ramp, which shall/should minimize bottlenecking and allow more vehicles to travel through the mainline during the active work zone hours. The TRM system consists of mainline traffic detection sensors placed a least XXX** feet upstream of the merge point. The traffic detection sensors must detect the speed, identify queuing on the freeway mainline, and communicate with the ramp meter controller. Traffic detectors such as radars and/or sensors can serve as the traffic detection sensor. The ramp meter controller must activate the ramp meters based on the information received from freeway and on-ramp sensors. Vehicles entering the on-ramp shall/should approach a stop bar. Demand sensors placed before the stop bar identify vehicles stopped behind it and activate the green light. Passage sensors placed after the stop bar detect the vehicle passing the stop bar and activate the red light. The system must also detect queuing of vehicles on the on-ramp and adjust the metering of vehicles onto the mainline to ensure that the on-ramp traffic is not backing up and conflicting with arterial traffic. The system must maintain a log of different ramp metering cycles applied during the activation period.

For fixed TRM systems, the system must be able to activate the ramp metering based on the pre-calculated and configured signal cycles developed based on the recurring traffic conditions. The system must be easily configurable to different cycle settings depending on the time of day and location of deployment.

MATERIALS

The TRM system shall/should include static signs with warning beacons, vehicle detectors, communication devices, traffic signal faces, a system controller and field cabinet, system operating software, and all miscellaneous equipment and hardware required for a fully operational system. All roadside devices used for the TRM System shall/should conform to the latest Manual for Assessing Safety Hardware (MASH) standards, when available.

The TRM system shall/should conform to the following system and operations requirements:

SYSTEM REQUIREMENTS

The TRM system shall/should consist of at least the following components:

(a) Cameras or radar that capture vehicle speeds and queuing in all lanes in the designated direction of travel

(b) Cameras or radar that are transportable and semi-fixed or mobile in nature

(c) Cameras or radar that can be configured to trigger at different speeds and queuing thresholds at different times of the day

(d) Weatherproof cameras or radar that can operate in all weather conditions

(e) Signal face that can be remotely operated

* This example specification is for illustrative purposes only and is not enforceable under Federal law. It may be used or adapted by transportation agencies to meet their needs. Use of the words “should” and “shall” is for illustrative purposes only.

** Agency staff can supply the appropriate number.

The TRM system shall/should comply with the following requirements:

(a) Ability to be configured to different signal activation time cycles

(b) Ramp meter controller shall/should wirelessly connect to ramp meter detectors, signals, and video cameras (if required)

(c) The latency for information communicated between detectors, controller, and ramp metering shall/should not exceed a specified threshold of X milliseconds

(d) A reliable communication system to connect devices to the central controller and to allow for remote access to the system for operation, malfunction detection, and data collection

(e) Ability to incorporate video surveillance on the ramp and mainline

(f) Ability to capture and document activation logs including activation cycle types, time stamps, throughput, etc.

(g) Ability to collect vehicle volume, speed, headway, occupancy, and vehicle classification data at a minimum of 1-minute bin (configurable) from both on-ramp and mainline

(h) Ramp meter detectors and signals shall/should be trailer mounted for easy relocation

(i) Trailers shall/should be battery operated with solar panels and 110-volt charging

SYSTEM OPERATION

The TRM System shall/should be operated under two different settings including (i) variable setting and (ii) fixed or pre-timed setting.

(a) **Variable setting:** Under the variable setting, the TRM system shall/should detect the mainline traffic flow conditions (speed and queuing), identify congestion conditions, and activate ramp metering to break up the vehicle platoons from on-ramps. For this project, the mainline congestion threshold is defined as X vehicles per hour per lane, measured over a Y-minute time period, XX feet upstream of the merge point. The variable setting is more suitable for non-recurring congestion caused by work zones and traffic incidents. The TRM system shall/should detect the queuing on the on-ramp and adjust the ramp-metering cycle to ensure that the on-ramp traffic is not backing up onto the arterials. When the congestion condition is not met, measured over a Y-minute time period, the ramp metering signals shall/should be turned off.

(b) **Fixed or pre-timed setting:** Under this setting, the TRM system shall/should activate ramp metering during pre-determined time windows at pre-defined metering cycles. These fixed metering cycles are calculated based on the recurring traffic congestion data captured from the freeway and on-ramp lanes. Outside of the pre-determined time windows, the signals shall/should be turned off.

During both settings, a sign with a message such as “XX VEHICLE(S) PER GREEN” or “XX VEHICLE(S) PER GREEN EACH LANE” is required to be installed adjacent to the ramp control signal faces to instruct drivers of the ramp metering operation (see MUTCD Section 2B.56). When ramp metering is activated, warning beacons attached to the static signs upstream of the TRM System shall/should be activated as identified in the project plans.

DEPLOYMENT REQUIREMENTS

The Contractor is responsible for furnishing, coordinating, installing, testing and calibrating, relocating, operating, maintaining, monitoring, and subsequently removing the approved TRM System according to the project plans and these specifications. The Contractor shall/should maintain all system components, move portable devices as necessary, including adjusting device location and replacing any malfunctioning devices, to ensure the system is operating as designed. The Contractor may adjust the location of signs in response to site-specific conditions, with the Project Engineer’s approval. The Contractor shall/should be available 24 hours a day, 7 days a week while the system is deployed to respond to system malfunctions and maintenance requirements. The Contractor shall/should provide the Project Engineer a 24/7 contact phone number. The Contractor shall/should provide weekly reports on system performance and response to emergencies.

SYSTEM DOCUMENTATION

Provide documentation detailing the technical and operational elements of the proposed TRM System for review and approval.

OPERATIONAL TEST

The TRM System shall/should be tested in two stages:

(a) **Off-site acceptance testing:** The Contractor shall/should test the system at an off-site location XX days prior to the field deployment to ensure all system components are functioning as designed. To test the signals and the central system controller, a set of congestion conditions can be virtually mimicked. The Contractor shall/should develop a testing plan and submit it for review and approval prior to the start of testing.

(b) **Site acceptance testing:** After the TRM System is installed or moved in the field, the TRM System, and all sub-systems such as a remote access systems, shall/should be tested to ensure all components of the system function as designed. For long-term installations, site acceptance testing shall/should be performed weekly by the Contractor. Testing shall/should be done for each specific deployment location within the project. The Contractor shall/should verify the functionality and accuracy of the traffic sensors, the traffic signal state during congested and non-congested periods, and the data being recorded. The traffic sensor detected speeds shall/should not deviate by more than XX mph from the actual vehicle speeds, traffic volumes detected shall/should not vary by more than XX percent from actual volumes, and vehicle headway shall/should not deviate by more than XX feet from the actual vehicle headway. If the system does not meet the accuracy requirement(s), the equipment shall/should be recalibrated or replaced, if necessary, and re-tested. The Contractor shall/should submit a report no later than one calendar day following the completion of the Site Acceptance Testing. Construction can commence upon testing approval by the Project Engineer.

PERMITTED WORK HOURS

The TRM system shall/should be used when traffic congestion is detected during or after active work zone hours.

SYSTEM PERFORMANCE

The TRM System shall/should meet the following system performance requirements:

(a) **Continuous operation:** The TRM system shall/should be in place and available for activation during and after active work zone hours.

(b) **Enforcement cameras and radar:** All sensors shall/should be of a type whose accuracy is not degraded by inclement weather or decreased visibility conditions including precipitation, fog, darkness, excessive dust, and road debris.

(c) **Data logging:** The TRM system shall/should capture a continuous event log including all traffic conditions, activation types, and date and time of activations.

(d) **Remote access:**

  (1) **System data log:** Password-protected users shall/should have the capability to view all system log data on a website and create graphs based on available data with time and date stamps. At the request of the Project Engineer, the vendor shall/should provide a digital copy of the logged information.

  (2) **System assessment:** The TRM system shall/should be configured to assess any type of malfunction that has occurred. This assessment includes communication disruption between any device in the system and any device malfunctions including detector, controller, or ramp meter malfunctioning. The system shall/should be capable of notifying the specified individuals via phone and email about any system malfunction.

  (3) **Remote control:** The TRM system shall/should include the capability to allow a password-protected user to reset the system state via the internet.

  (4) **Remote monitoring:** The TRM system shall/should have the capability of real-time remote monitoring.

(e) **Manual control:** The TRM system shall/should be manually controllable onsite. The capability to manually switch between states of variable and pre-timed settings allows for maximum flexibility.

SYSTEM TRAINING

The TRM system training shall/should be conducted by the Contractor directly responsible for the system operation and the system supplier. The training shall/should include representatives from the Contractor, Agency, Enforcement, and others responsible for construction, maintenance of traffic, and safety. The training shall/should, at a minimum, cover the following items:

(a) Review of system operation

(b) In the event of an emergency, instructions on how to override the system

(c) In the event of a power failure, instructions detailing how to power cycle the system

(d) Online system access, remote monitoring, and remote control

(e) Basic listing of what to monitor

(f) List of telephone numbers to call to request technical support

SYSTEM WARRANTY, MAINTENANCE, AND SUPPORT

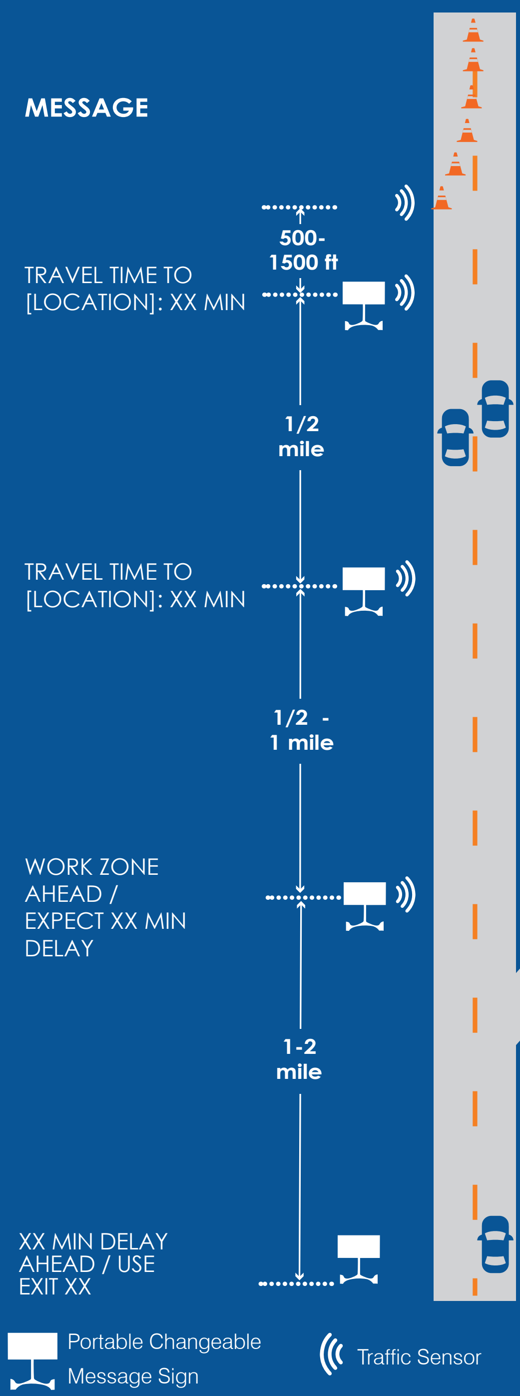
The TRM system shall/should be maintained, supported, and warranted against material defects by its supplier through the duration of the deployment. The Contractor shall/should respond immediately to any call from the Project Engineer or designated representative concerning any request for correcting any deficiency in the system. Deficiencies include field conditions and remote monitoring capabilities.

MEASUREMENT AND PAYMENT

Measurement and payment shall/should be made at the contract unit price per day that the TRM system is deployed, in use, and is fully operational, which shall/should be compensation in full for furnishing, installing, operating, reporting, maintaining, and removing the system. System testing and training, communications costs, and any relocation or repositioning within the work zone or removal of equipment from the work zone shall/should be incidental to the contract unit price.

G. Real-Time Traveler Information

U.S. Department of Transportation
Federal Highway Administration



Diagrams represent approximate equipment locations. Review local guidance for required layout.

Figure 7. Diagram. Real-time traveler information diagram. Source: FHWA.

Description

Real-Time Traveler Information Systems (RTISs) provide crucial roadway information, such as weather, traffic, and work zone conditions, that empower drivers to make better decisions.[70] RTISs can empower decision-making in two ways:

- When provided as part of online trip-planning tools, media platforms, and navigation apps, RTIS data can encourage off-peak travel or alternate route use (thus avoiding the work zone). These driver behavior changes reduce delay, which in turn decreases crash rates and improves network travel time reliability.
- When provided along the corridor through portable changeable message signs (PCMSs), a RTIS provides delay information that identifies the presence of a work zone, verifies the length of the work zone, and aids drivers in complying with work zone speed limits or alternate route instructions.

RTISs provide crucial roadway condition information, such as weather, traffic, and work zone conditions, that empower drivers to make better decisions.

In a survey of department of transportation maintenance leaders, 98 percent of studied agencies provided some form of real-time information to the traveling public to facilitate better decision-making, which in turn improves individual travel time and systemwide performance.[71] This real-time information is especially important in work zones, as 40 percent of drivers indicate that it is the most highly sought-after type of information used in trip decisions—this is particularly relevant for lane closures.[72] Drivers have also indicated that the most favorable methods of receiving real-time information are via apps and on-road signs (in contrast to advisory radio stations and 511 phone systems, which were ranked lowest for user approval).[73] Real-time travel information about work zone conditions, including time in minutes of delay, provides the most benefits to the network when deployed in conjunction with an alternate route that is advertised in advance, so drivers can elect to change their route.

There are two methods of calculating travel time information for RTIS deployments: probe data collection and projections based on historic traffic data, and real-time crowd-sourced, app-enabled data. Probe data are defined as “data that are generated by monitoring the position of individual vehicles (i.e., probes) over space and time rather than measuring characteristics of vehicles or groups of vehicles at a specific place and time.”[74] Using these data points, the central processing unit calculates the average, median, or 85^{th} percentile travel time for a given interval, which is then displayed on PCMSs prior to entering the work zone. This information can also be pushed through smartphone apps, such as Waze or Google Maps.[75] Probe data collection offers the opportunity to obtain very good estimates of travel time performance measures, such as the FHWA Travel Time Index, which is the ratio of the average peak period travel time compared to a free-flow travel time, and the FHWA Planning Time Index, which is a ratio of the total time needed to ensure 95-percent on-time arrival compared to a free-flow travel time.[76] Successful deployments have occurred since 2009, with Indiana, Illinois, and Texas, as well as Ontario, successfully deploying probe-based RTIS in work zones.[77, 78] Figure 8 demonstrates the infrastructure that allows Bluetooth probe data collection to contribute to the fast and easy deployment of RTIS in a work zone

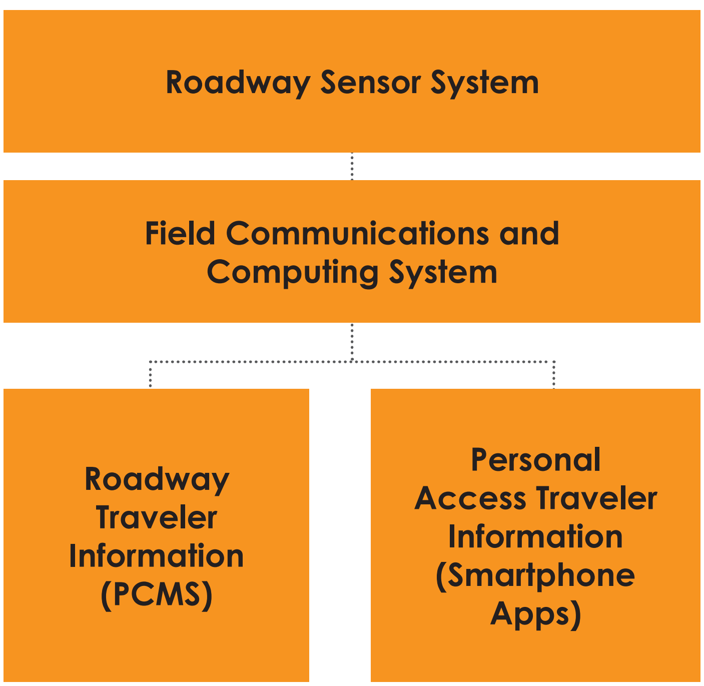


Figure 8. Diagram. Data communication diagram. Source: FWHA.

Additionally, RTIS deployments can use historic speed and volume data, provided by a third-party data vendor to calculate average travel times for the corridor. These archival data are used to model typical travel times, which are compared to existing work zone constraints using traffic analysis software. This method of travel time information has been employed for a number of years and is a reliable source of travel time information.

Agencies can also utilize the massive amounts of cell-phone user data by partnering with mapping providers for real-time, crowdsourced traffic data. For example, Wisconsin DOT (WisDOT) recently formed a partnership with Waze, in what has been dubbed the Connected Citizen Program. This data-sharing agreement provides WisDOT with real-time, anonymous, Waze-generated incident and slow-down information directly from roadway users already using Waze’s navigation instructions. In return, WisDOT provides real-time government-reported construction, crash, and road closure data from its existing 511 system.[79] All of these methods empower drivers by providing RTIS.

Benefits

RTIS programs provide significant benefits to highway systems and agencies, drivers, and first responders. RTIS programs can:

- Improve Travel Time Reliability.
- Increase Safety.

Improve travel time reliability. By providing information on the duration of time necessary to traverse the work zone based on real-time traffic conditions, RTIS can improve travel time reliability along a corridor. This is best accomplished with the inclusion of active alternate routes, with PCMS, as well as navigational apps, instructing drivers toward that route—recent research indicates that pairing delay information with alternate route instructions reduces average travel time up to 30 percent.[80] In a deployment along I-55 in Springfield, Illinois, a highway with an average of 41,000 vehicles per day, no significant queues were reported during the work zone deployment of the RTIS.[81]

Increase safety. RTIS programs improve safety for construction workers in work zones by reducing crash rates upstream and within the active work zone. Real-Time Traveler Information provided to drivers reduces frustration. Increased driver understanding can increase driver compliance with work zone speed limits, which typically facilitates queue mitigation, resulting in a decrease in crash rates upstream of work zones and within them. In an Illinois project, Illinois DOT deployed one additional PCMS in the work zone with the current count of citations issued for disobeying work zone speed limits. The RTIS decreased the number of moving violations and was also associated with a reduction in the number of crashes throughout the construction period.

Considerations

The following are the key considerations for RTIS programs:

- Messaging.
- Data Collection.
- Internet Interoperability.

As with any smart deployment, project engineering should consider the estimated work zone traffic volumes and systemwide effects of congestion at the project location.[82]

Messaging. RTISs are as beneficial as the messages that they convey to the traveling public. Drivers report a preference for descriptive information, which includes terms such as "moderately congested" or "heavily congested," as well as the numerical time to traverse the work zone (i.e., "XX MIN OF DELAY").[83] Depending on the work zone, additional messages that inform the traveling public include those that describe the situation ("ROAD WORK AHEAD"), the location of the work zone ("XX MILES AHEAD"), the effect on travel ("XX MIN OF DELAY"), and if possible, a recommended action ("USE ALT ROUTE X").[84, 85] For RTISs that are communicating with online data portals or smart phone apps, users also report a preference for a time stamp of when the information was last updated.[86] For more information on messaging, the Manual on Uniform Traffic Control Devices (MUTCD) contains policies, standards, and guidance regarding PCMSs in Section 1A.15 and 2L.

Data collection. As work zones are temporary by nature, it is recommended to implement a portable data collection system—typically these are battery-powered and can contain solar-panels for charging. With this consideration in mind, the local weather and climate are determining factors for the feasibility of solar-powered charging. Other detection unit considerations include the system's communication abilities—for the RTIS application, the detection units must be equipped with a modem and cellular data to communicate with a dedicated server for the computation and dissemination of the travel time information. The telecommunications capabilities of the detection units are also important for the continual monitoring of the work zone RTIS, as their placement in the vicinity of the work zone may render them difficult to access. Remote monitoring allows for early detection of malfunctioning units and other inconsistencies. Remote configuration can range from configuring the sampling rate and/or sleeping sensors when not required, which becomes critical for battery-powered units. The implication of remote monitoring and configuration is that wireless access via Wi-Fi or cellular is available to the probes.[87]

Internet interoperability. As telecommunications infrastructure, and its various applications and/or specifications evolve, the interoperability of existing roadside equipment will be critical to the success of work zone RTIS deployments. Collaborating with vendors to test system function prior to deployment is a key aspect of the construction design process.

References

70 ITS Deployment Evaluation. "Benefits." Accessed July 28, 2021. www.itsbenefits.its.dot.gov.

71 Robinson, Emanuel, Thomas Jacobs, Kathleen Frankle, Nayel Serulle, and Michael Pack. *Project 08-82: Deployment, Use, and Effect of Real-Time Traveler Information Systems.* Washington, D.C.: Transportation Research Board, National Cooperative Highway Research Program (NCHRP), 2012.

72 Robinson, Thomas, Frankle, Serulle, and Pack. P*roject 08-82: Deployment, Use, and Effect of Real-Time Traveler Information Systems*.

73 Robinson, Thomas, Frankle, Serulle, and Pack. P*roject 08-82: Deployment, Use, and Effect of Real-Time Traveler Information Systems*

74 Work Zone Mobility and Safety Program. "Work Zone Performance Measurement Using Probe Data." Washington, D.C.: Federal Highway Administration. Accessed July 28, 2021. https://ops.fhwa.dot.gov/wz/resources/publications/fhwahop13043/ch2.htm.

75 Zhang, Xu, Chris Van Dyke, Greg Erhardt, and Mei Chen. NHCRP Synthesis 541: Practices on Acquiring Proprietary Data for Transportation Applications. Washington, D.C.: Transportation Research Board, 2019.

Cost and Equipment

The cost of a RTIS within a work zone varies considerably depending on the existing infrastructure and equipment, as well as the area of the deployment. Cost estimates also vary depending on whether an agency buys or leases RTIS equipment. Leasing equipment allows agencies to implement current technologies and eliminate the need to store or maintain equipment, while purchasing equipment may be cost efficient if the RTIS is implemented long-term.

Item Costs

The table below estimates the costs of purchasing the components necessary to implement a user-friendly, accessible, and accurate RTIS system in a work zone, as shown in figure 7. These costs are in 2020 dollars.[88]

Table 7. Real-Time Traveler Information System Cost Estimate

Item	Unit Price	Quantity	Cost
3-Line PCMS, Solar Powered, with Modem and Roadway Radar, and Management Software	$19,545 (Buy)	4	$78,180
Roadway Data Sensors (Depending on Project Length)	$	By Project	-
Field Laptop	$450 (Buy)	1	$450
Field Hotspot Wi-Fi and Data Plan	$200 (Buy) + $65 (Per Month Subscription)	1	$265
Data Analysis Software	$650 (Per Year Subscription)	1	$650
		TOTAL	**$79,545**

References continued

76 Kim, David, David Porter, Mario Magaña, SeJoon Park, and Amirali Saeedi. *Wireless data collection system for travel time estimation and traffic performance evaluation*. Salem, OR: Oregon Department of Transportation, 2012.

77 Friesen, Marcia R. and R.D. McLeod. (2015). “Bluetooth in intelligent transportation systems: a survey.” International Journal of Intelligent Transportation Systems Research, 13, No. 3 (January 2014): 143-153.

78 Zinner, Stephanie. “A methodology for using bluetooth to measure real-time work zone travel time.” PhD diss., Georgia Institute of Technology, 2012. https://smartech.gatech.edu/bitstream/handle/1853/45936/zinner_stephanie_l_201212_mast.pdf.

79 Wisconsin Department of Transportation. “Wisconsin DOT Joins Waze Connected Citizens Program.” National Work Zone Safety Information Clearinghouse, January 2017. https://www.workzonesafety.org/publication/wisconsin-dot-joins-waze-connected-citizens-program/.

80 Wisconsin Department of Transportation. “Wisconsin DOT Joins Waze Connected Citizens Program.”

References continued

81 Federal Highway Administration. *Intelligent Transportation Systems in Work Zones: A Case Study: Real-Time Work Zone Traffic Control System: Using an Automated Traffic Information System to Reduce Congestion and Improve Safety during Reconstruction of the I-55 Lake Springfield Bridge in Illinois.* Washington, D.C.: Federal Highway Administration, 2004.

82 Minnesota Department of Transportation. "Application Guidelines, Operational Strategy, and Intelligent Work Zone Travel Time System Specifications." St. Paul, MN: Minnesota Department of Transportation, 2005.

83 Robinson, Thomas, Frankle, Serulle, and Pack. Project 08-82: *Deployment, Use, and Effect of Real-Time Traveler Information Systems*.

84 Haseman, Ross J., Jason S. Wasson, and Darcy M. Bullock. "Real-time measurement of travel time delay in work zones and evaluation metrics using bluetooth probe tracking." *Transportation Research Record*, 2169, No. 1 (January 2010): 40-5.

85 *Federal Highway Administration. Intelligent Transportation Systems in Work Zones: A Case Study: Real- Time Work Zone Traffic Control System: Using an Automated Traffic Information System to Reduce Congestion and Improve Safety during Reconstruction of the I-55 Lake Springfield Bridge in Illinois.*

86 Robinson, Thomas, Frankle, Serulle, and Pack. P*roject 08-82: Deployment, Use, and Effect of Real-Time Traveler Information Systems.*

87 Zinner, Stephanie. "A methodology for using bluetooth to measure real-time work zone travel time.".

88 ITS Deployment Evaluation. System Cost Estimate in 2020 dollars. Washington, D.C.: U.S. Department of Transportation. Accessed July 28, 2021. https://www.itskrs.its.dot.gov/.

G. Real-Time Traveler Information Example Specification*

DESCRIPTION

A Real-Time Traveler Information System (RTIS) shall/should* be used for maintenance of traffic as provided in the project plans and as specified in this document. The RTIS should be a fully automated, stand-alone system, capable of making real-time changes in the information displayed to drivers in response to traffic conditions. The system must be able to, in real time, collect traffic data and, under predefined traffic conditions, display traveler information to drivers in the section of roadway preceding a work zone. using Portable Changeable Message Signs (PCMSs) and provide traveler information via the agency's website or other Internet site. The system, which must operate continuously while the work zone is in place, must also generate condition and event logs that can be accessed remotely by the Contractor and the sponsoring agency, notify specified individuals of traffic conditions, and provide alerts to specified individuals when the system or a component of the system is not functioning properly.

MATERIALS

The RTIS shall/should include PCMSs, traffic sensors, communications devices, a system controller and field cabinet, system operating software, and all miscellaneous equipment and hardware required for a fully operational system. All roadside devices used for the RTIS shall/should conform to the latest Manual for Assessing Safety Hardware (MASH) standards, when available.

The RTIS shall/should conform to the following system and operations requirements:

SYSTEM REQUIREMENTS

The RTIS shall/should consist of at least the following components:

(a) At least XX** PCMSs, as defined on the project plans.

(b) A central system controller to maintain continuous traffic and system status monitoring; provide communication to deliver appropriate messaging via the PCMSs and the Internet; and provide remote access to the system for operation, malfunction detection and data collection.

(c) Sufficient traffic detection device(s) to display the desired dynamic traveler information messages as described in the System Operation section.

(d) A reliable wireless communication system to connect devices to the central controller and to allow for remote system access.

SYSTEM OPERATION

The RTIS shall/should display traveler information on the PCMSs based on the travel time delays in advance of the work zone. The RTIS system should also be capable of displaying critical traveler information such as pending severe weather and unexpected roadway conditions like flooding or icy roads. The RTIS shall/should be able to detect two distinct traffic conditions: little to moderate congestion, and heavy congestion. The traffic conditions should be based on a metric like the vehicle travel time delay through the work zone or the level of congestion with a speed or volume threshold which can be adjusted throughout the day, as necessary. The messages displayed should vary based on the detected traffic conditions.

(a) **Little to moderate congestion:** Under little to moderate congestion conditions, the PCMSs should display general work zone and travel information such as the work zone location and travel time through the work zone. Messages displayed can include "WORK ZONE AHEAD," "TRAVEL TIME TO [LOCATION];XX MIN," and "XX MIN DELAY. AHEAD" For this project, moderate congestion is initially defined as travel time delays of XX minutes or less.

* This example specification is for illustrative purposes only and is not enforceable under Federal law. It may be used or adapted by transportation agencies to meet their needs. Use of the words "should" and "shall" is for illustrative purposes only.

** Agency staff can supply the appropriate number.

(b) **Heavy congestion:** Under heavy congestion conditions, the PCMSs should display the work zone information and travel information such as the work zone location, travel time through the work zone, and potential detours if available. Messages displayed can include "WORK ZONE AHEAD," "TRAVEL TIME TO [LOCATION];XX MIN," "XX MIN DELAY," and "USE EXIT XX." Messages displayed on the PCMSs can vary by location. For this project, heavy congestion is initially defined as travel time delays of XX minutes or greater. The system shall/should remain in heavy congestion mode conditions with little to moderate congestion, as defined above, are detected for 3 consecutive minutes.

DEPLOYMENT REQUIREMENTS

The Contractor is responsible for furnishing, coordinating, installing, testing and calibrating, relocating, operating, maintaining, monitoring, and subsequently removing the approved RTIS according to the project plans and these specifications. The Contractor shall/should maintain all system components, move portable devices as necessary, including adjusting device location and replacing any malfunctioning devices, to ensure the system is operating as designed. The Contractor may adjust the location of signs in response to site-specific conditions, with the Project Engineer's approval. The Contractor shall/should be available seven days a week, 24 hours a day while the system is deployed to respond to system malfunctions and maintenance requirements. The Contractor shall/should provide the Project Engineer a 24/7 contact phone number. The Contractor shall/should provide weekly reports on system performance and response to emergencies.

SYSTEM DOCUMENTATION

The Contractor shall/should provide documentation detailing the technical and operational elements of the proposed RTIS for review and approval.

OPERATIONAL TEST

The RTIS shall/should be tested in two stages:

(a) **Off-site acceptance testing:** The Contractor shall/should test the system at an off-site location XX weeks prior to the field deployment to ensure all system components are functioning as designed. To test the PCMSs and the central system controller, a work zone under little to moderate and heavy congestion can be virtually mimicked. The Contractor shall/should develop a testing plan and submit it for review and approval prior to the start of testing.

(b) **Site acceptance testing:** After the RTIS is installed or moved in the field, the RTIS, and all sub-systems such as a remote access systems, shall/should be tested to ensure all components of the system function as designed. For long-term installations, site acceptance testing shall/should be performed weekly by the Contractor. Testing shall/should be done for each specific deployment location within the project. The Contractor shall/should verify the functionality and accuracy of the traffic sensors, the information displayed on each PCMS, and the data being recorded. The traffic sensor detected speeds and travel delays shall/should not deviate by more than XX mph from the actual vehicle speeds, XX minutes from the actual vehicle travel time, and traffic volumes detected shall/should not vary by more than XX percent from actual volumes. If the system does not meet the accuracy requirement, the equipment shall/should be recalibrated or replaced, if necessary, and re-tested. The Contractor shall/should submit a report no later than one calendar day following the completion of the Site Acceptance Testing. Construction can commence upon testing approval by the Project Engineer.

PERMITTED WORK HOURS

The RTIS can be used for both daytime and nighttime lane closures.

SYSTEM PERFORMANCE

The RTIS shall/should meet the following system performance requirements:

(a) **Continuous operation:** The RTIS shall/should be in place and functioning while the work zone is in place.

(b) **Traffic detectors:** All sensors shall/should be of a type whose accuracy is not degraded by inclement weather or decreased visibility conditions including precipitation, fog, darkness, excessive dust, and road debris.

(c) **Traffic detection:** The RTIS shall/should be capable of calculating the real-time travel speed and travel time every minute and immediately updating the message being displayed on the PCMSs when the congestion thresholds are surpassed.

(d) **Data logging:** The RTIS shall/should capture a continuous event log including all traffic conditions, all system state changes, and all changes in the messages displayed.

(e) **Remote access:**

(1) **Remote monitoring and control:** The RTIS shall/should have the capability of real-time remote monitoring and control.

(2) **System data log:** Password-protected users shall/should have the capability to view all system log data on a website and create graphs based on available data with time and date stamps. At the request of the Project Engineer, the vendor shall/should provide a digital copy of the logged information.

(3) **System assessment:** The RTIS shall/should be configured to assess any type of malfunction that has occurred. This assessment includes communication disruption between any device in the system and any device malfunction including PCMSs. The system shall/should be capable of notifying the specified individuals via phone and email about any system malfunction.

(f) **Manual control:** The RTIS shall/should be manually controllable onsite. The capability to manually switch between states of moderate and heavy congestion allows for maximum flexibility.

SYSTEM TRAINING

RTIS training shall/should be conducted by the Contractor directly responsible for the system operation and the system supplier. The training shall/should include representatives from the Contractor, Agency, Enforcement, and others responsible for construction, maintenance of traffic, and safety. The training shall/should, at a minimum, cover the following items:

(a) Review of system operation.

(b) In the event of an emergency, instructions on how to override the system.

(c) In the event of a power failure, instructions detailing how to power cycle the system.

(d) Online system access, remote monitoring, and remote control.

(e) Basic listing of what to monitor and what causes messages to change.

(f) List of telephone numbers to call to request technical support.

SYSTEM WARRANTY, MAINTENANCE, AND SUPPORT

The RTIS shall/should be maintained, supported, and warranted against material defects by its supplier through the duration of the deployment. The Contractor shall/should respond within XX hours to any call from the Project Engineer or designated representative concerning any request for correcting any deficiency in the system.

MEASUREMENT AND PAYMENT

Measurement and payment shall/should be made at the contract unit price per day that the RTIS is deployed, in use, and is fully operational, which shall/should be compensation in full for furnishing, installing, operating, reporting, maintaining, and removing the system. System testing and training, communications costs, and any relocation or repositioning within the work zone or removal of equipment from the work zone shall/should be incidental to the contract unit price.

H. Incident Management System

U.S. Department of Transportation
Federal Highway Administration

Incident management programs facilitate smoother traffic flow and provide drivers involved in incidents with appropriate, timely resources.

Description

Incident Management System (IM) programs aim to respond to and clear incidents in a timely, efficient, and appropriate manner. As defined by the Federal Highway Administration Manual on Uniform Traffic Control Devices (MUTCD), an incident is an "emergency road user occurrence, a natural disaster, or other unplanned event that affects or impedes the flow of traffic."[89]

Successful IM programs improve safety for drivers, workers, and emergency responders while maintaining traffic flow through the incident area. Elements of successful IM programs include human, infrastructural, and technology components that work together seamlessly to maximize the potential benefits of IM. Many IM programs are built from other Intelligent Transportation System (ITS) work zone technologies, such as queue warning systems and RTISs.

IM programs are especially important in work zones, as traffic congestion and road worker safety risks can be compounded when an incident occurs upstream or within a work zone.[90] IM systems function by:

Incident detection

- Traffic detectors register an incident, whether through unusually slow speeds for the given time period, or a queue warning system.
- Agency staff at the local traffic management center (TMC) use closed-circuit television (CCTV) images and footage of live traffic conditions to verify and assess the incident.

Incident response

- The incident is categorized by the TMC staff.
- TMC staff transmit details regarding the incident to the appropriate responding agencies, such as fire and police departments, or towing companies.
- Emergency response teams are dispatched.

Incident information

- TMC staff communicate a change in traffic conditions using portable changeable message signs (PCMSs), radio alert systems, and online information services, such as smartphone apps.

In addition to staff resources, IM programs typically include equipment such as roadway sensors, PCMSs, and CCTV; communications media such as an agency website; and a vehicle patrol fleet. Sensors, cameras, and PCMSs should be strategically placed upstream of expected queues in a work zone to prevent rear-end crashes.[91] Incident response teams (IRTs), which use fleet vehicles to directly serve drivers involved in incidents, are a critical component of incident management programs, as are partnerships with towing companies. As mapping providers like Google and Waze increase in their ubiquity, establishing processes for direct communication between TMC staff and mapping providers will be crucial to providing a seamless flow of incident information for roadway users.

Benefits

IM programs provide significant benefits to highway systems, agencies, drivers, and first responders. Key benefits of IM programs include:

- Improve Safety.
- Increase Coordination.
- Faster Response Times.
- Reduce Delay.

Improve safety. IM programs improve safety for all road users on highways. Due to timely and appropriate incident response, IM programs have been found to reduce the occurrence of secondary incidents by up to 40 percent.[92] CCTV used in IM programs also allows agencies to identify where in the work zone to target for improvements, based on driver behavior observations.[93] Notably, working conditions for emergency responders improves by more clearly directing roadway users around incidents and establishing clear policies and practices.[94]

Increase coordination. IM programs facilitate the coordination among highway agencies, emergency response providers, and neighboring jurisdictions. IM task forces define who is responsible for detection and response, and communications and technology components of IM programs streamline coordinated responses to incidents. IM programs also provide an opportunity to pursue public-private partnerships, further minimizing agency costs.[95]

Faster response times. In remotely assessing incidents and determining the appropriate response, IM programs have reduced response times by 20 to 66 percent.[96] During a major reconstruction project in New Mexico, the average response time was less than seven minutes to incidents in work zones.[97] Faster response times increase survival rates of crash victims and help to clear incidents more promptly and keep vehicle traffic moving. In addition to better serving drivers involved in incidents, the information given to emergency responders by the IM program aids in the decision-making process for providing the most appropriate emergency response, which translates into cost savings for emergency response providers.

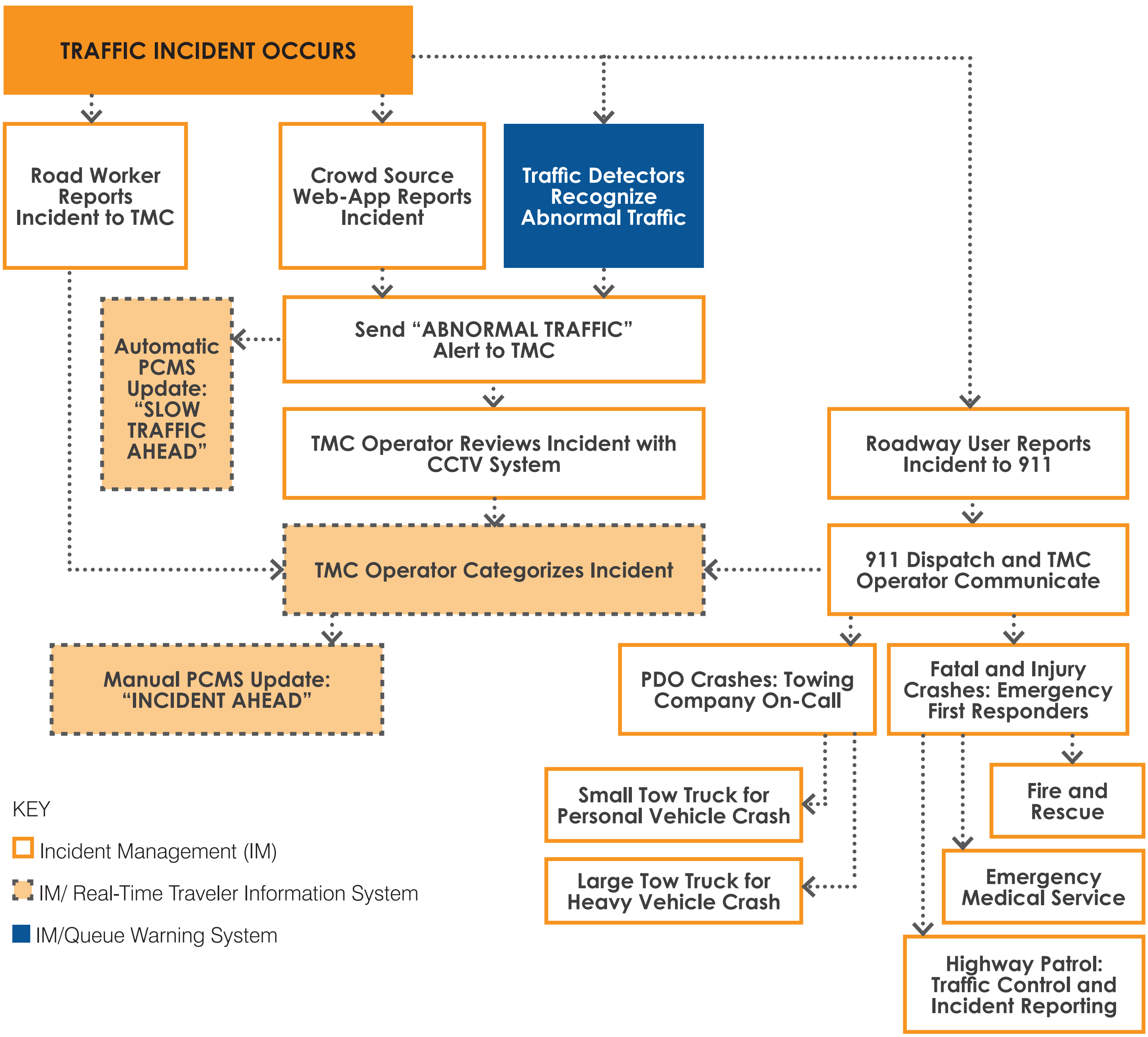


Figure 9. Diagram. Incident management diagram. Source: FHWA.

Reduce delay. By improving incident clearance time, the delay that other roadway users experience is reduced. IM programs have reduced delay in work zones by up to 55 percent, resulting in decreases in overall non-recurrent congestion delay.[98] Reducing delay alleviates driver frustration by improving traffic flow and has environmental benefits, resulting in less fuel consumption and emissions generated.[99]

Considerations

The following are the key considerations for IM systems:

- Accuracy and Reliability.
- Start-Up Time and Troubleshooting.
- Interagency Consistency.
- Continuous Training.
- Traffic Management Plan – Coordination.

Accuracy and reliability. Accurate communications technology is required for IM programs to be effective in providing timely, appropriate responses to incidents in work zones.[100] Notably, PCMSs must provide accurate messages to the public to gain and maintain public trust and compliance with signs. In order to ensure that both equipment and practices are reliable and accurate, it is necessary to evaluate IM programs and collect any needed data, such as speed data, crash data, and incident clearance and closure time data.[101]

Start-up time and troubleshooting. Before IM programs can be fully used, agencies need to develop a traffic control plan, work out technology issues, inform the public of the program or work zone, and coordinate with any necessary parties. If technology issues arise, this can increase maintenance costs, depending on if equipment is purchased or leased and if a Contractor is employed to manage the equipment. Public communications may be coordinated with other safety campaigns or with local officials.[102, 103]

Interagency consistency. While the benefits of improved coordination are significant, consistent policies and practices across highway agencies and emergency responders can be challenging to establish. IM programs require that other departments and agencies are involved as early as possible and that useful information and data are shared with involved departments and agencies.[104] It may be necessary to obtain technical and advisory support from regional, State, or Federal agencies such as FHWA, or to come to regional agreements on emergency response to incidents in work zones.[105]

Continuous training. Agency staff and incident response teams require continued training in order to enact best practices.[106] Staff turnover can add a layer of complexity to this necessity if agencies rely on training from State or Federal government agencies, as new staff may need to wait to attend such trainings. Resource guides are a useful tool to formalize incident response strategies, policies, and practices and train staff.[107] However, resource guides should be developed in close coordination with other agencies to ensure that practices are uniform throughout the area and are the most appropriate to local contexts.

Traffic management plan – coordination. A fundamental aspect of a IM program is agency coordination, which occurs through formal agreements between departments of transportation, public works, and first responders, such as emergency medical teams and firefighters. Collaborating on a traffic management plan, with scenario planning, clear roles and responsibilities, and funding agreements, will allow agencies to form cross-jurisdictional teams that provide the correct services in a timely manner.

References

89 ITS Deployment Evaluation. “Benefits.” Washington, D.C.: U.S. Department of Transportation. Accessed July 28, 2021. www.itsbenefits.its.dot.gov.

90 Robinson, Emanuel, Thomas Jacobs, Kathleen Frankle, Nayel Serulle, and Michael Pack. *Project 08-82: Deployment, Use, and Effect of Real-Time Traveler Information Systems. Washington*, D.C.: Transportation Research Board, National Cooperative Highway Research Program (NCHRP), 2012.

91 Friesen, Marcia R. and R.D. McLeod. (2015). “Bluetooth in intelligent transportation systems: a survey.” International Journal of Intelligent Transportation Systems Research, 13, No. 3 (January 2014): 143-153.

Cost and Equipment

The cost of an IM system within a work zone varies considerably depending on the existing infrastructure and equipment, as well as the area of the deployment. Cost estimates also vary whether an agency purchases or leases IM equipment. Leasing equipment allows agencies to implement current technologies and eliminate the need to store or maintain equipment, while purchasing equipment may be cost efficient if the IM system is implemented long term. Below are some example costs, adjusted to 2020 dollars:

- An advanced IM system, including fiber optic cable, 20 CCTV cameras, 13 PCMS sign The TMC operator shall also be able to manually update the traffic condition information displayed on the PCMSs after viewing the CCTV system. The messages displayed should vary based on the detected traffic conditions, two wrong way driving systems, cost $34 million to install along 85 miles of a toll road in Indiana.[109]
- Installing automatic vehicle location (AVL) devices on 230 emergency response vehicles in Georgia cost $602,860.[110]
- The operation of the Minnesota Highway Helper Program cost about $902,790 to operate.[111]

Item Costs

The table below estimates the costs of purchasing the components necessary to implement a user-friendly, accessible, and accurate IM system in a work zone, as shown in figure 9. An additional cost not reflected in this table is the full time equivalent of a field technician, monitoring the CCTV network for incidents during working hours in the work zone. These costs are in 2020 dollars.[108]

Table 8. Incident Management System Cost Estimate

Item	Unit Price	Quantity	Cost
CCTV Video Detection and Monitoring System	$6,500 (Buy)	1	$6,500
3-Line PCMS, Solar Powered, with Modem and Roadway Radar, and Management Software	$19,545 (Buy)	1	$19,545
Additional Roadway Data Sensors (Depending on Roadway Width and Project Length)	$	Per Lane, By Project	-
Field Laptop	$450 (Buy)	1	$450
Field Hotspot Wi-Fi and Data Plan	$200 (Buy) + $65 (Per Month Subscription)	1	$265
		TOTAL	**$26,760**

References continued

92 Work Zone Mobility and Safety Program. "Work Zone Performance Measurement Using Probe Data." Washington, D.C.: Federal Highway Administration. Accessed July 28, 2021. https://ops.fhwa.dot.gov/wz/resources/publications/fhwahop13043/ch2.htm.

93 Robinson, Jacobs, Frankle, Serulle, and Pack. *Project 08-82: Deployment, Use, and Effect of Real-Time Traveler Information Systems.*

94 Zhang, Xu, Chris Van Dyke, Greg Erhardt, and Mei Chen. *NHCRP Synthesis 541: Practices on Acquiring Proprietary Data for Transportation Applications*. Washington, D.C.: Transportation Research Board, 2019.

95 Work Zone Mobility and Safety Program. "Work Zone Performance Measurement Using Probe Data."

96 Work Zone Mobility and Safety Program. "Work Zone Performance Measurement Using Probe Data."

97 Robinson, Emanuel, Thomas Jacobs, Kathleen Frankle, Nayel Serulle, and Michael Pack. *Project 08-82: Deployment, Use, and Effect of Real-Time Traveler Information Systems.* Washington, D.C.: Transportation Research Board, National Cooperative Highway Research Program (NCHRP), 2012.

References continued

98 Zhang, Van Dyke, Erhardt, and Chen. *NHCRP Synthesis 541: Practices on Acquiring Proprietary Data for Transportation Applications.*

99 Zhang, Van Dyke, Erhardt, and Chen. *NHCRP Synthesis 541: Practices on Acquiring Proprietary Data for Transportation Applications.*

100 Friesen, Marcia R. and R.D. McLeod. (2015). "Bluetooth in intelligent transportation systems: a survey." 143-153.

101 Zhang, Van Dyke, Erhardt, and Chen. *NHCRP Synthesis 541: Practices on Acquiring Proprietary Data for Transportation Applications.*

102 Robinson, Emanuel, Thomas Jacobs, Kathleen Frankle, Nayel Serulle, and Michael Pack. *Project 08-82: Deployment, Use, and Effect of Real-Time Traveler Information Systems*.

103 Friesen, Marcia R. and R.D. McLeod. (2015). "Bluetooth in intelligent transportation systems: a survey." *International Journal of Intelligent Transportation Systems Research,* 13, No. 3 (January 2014): 143-153.

104 ITS Deployment Evaluation. "Benefits."

105 Zhang, Van Dyke, Erhardt, and Chen. *NHCRP Synthesis 541: Practices on Acquiring Proprietary Data for Transportation Applications.*

106 Zhang, Van Dyke, Erhardt, and Chen. *NHCRP Synthesis 541: Practices on Acquiring Proprietary Data for Transportation Applications.*

107 Friesen, Marcia R. and R.D. McLeod. (2015). "Bluetooth in intelligent transportation systems: a survey." 143-153.

108 ITS Deployment Evaluation. System Cost Estimate in 2020 dollars. Washington, D.C.: U.S. Department of Transportation. Accessed July 28, 2021. https://www.itskrs.its.dot.gov.

109 Zinner, Stephanie. "A methodology for using bluetooth to measure real-time work zone travel time." PhD diss., Georgia Institute of Technology, 2012. https://smartech.gatech.edu/bitstream/handle/1853/45936/zinner_stephanie_l_201212_mast.pdf.

110 Kim, David, David Porter, Mario Magaña, SeJoon Park, and Amirali Saeedi. *Wireless data collection system for travel time estimation and traffic performance evaluation*. Salem, OR: Oregon Department of Transportation, 2012.

111 Zhang, Van Dyke, Erhardt, and Chen. *NHCRP Synthesis 541: Practices on Acquiring Proprietary Data for Transportation Applications.*

H. Incident Management System Example Specification*

DESCRIPTION

The Incident Management (IM) System shall/should* be used for maintenance of traffic as provided in the project plans and as specified in this document. The IM System should be a semi-automated, stand-alone system, capable of detecting crashes, making real-time changes in the information displayed to drivers in response to traffic conditions, and alerting a traffic management center (TMC) of the crashes. Once the TMC receives notification of a potential crash, the IM System shall/should allow an operator to use a closed-circuit television (CCTV) system to view the potential crash location, assess the situation, and then contact and send the appropriate emergency responders and tow trucks to the crash site. When a crash is detected, critical traveler information shall/should be disseminated to the public by updating the messages displayed on Portable Changeable Message Signs (PCMSs). The system must also generate condition and event logs that can be accessed remotely by the Contractor and the sponsoring agency and provide alerts to specified individuals when the system or a component of the system is not functioning properly.

MATERIALS

The IM System shall/should include PCMSs, traffic sensors, communications devices, a CCTV system, a system controller and field cabinet, system operating software, and all miscellaneous equipment and hardware required for a fully operational system. All roadside devices used for the IM System shall/should conform to the latest Manual for Assessing Safety Hardware (MASH) standards, when available.

The IM System shall/should conform to the following system and operations requirements:

SYSTEM REQUIREMENTS

The IM System shall/should consist of at least the following components:

(a) At least XX** PCMSs, as defined on the project plans.

(b) A central system controller in a weatherproof cabinet to maintain continuous traffic and system status monitoring; provide communication to deliver appropriate messaging via the PCMSs and the Internet; provide remote access to the system for operation, malfunction detection and data collection; and provide remote access to an on-site CCTV system.

(c) Sufficient traffic detection device(s) to detect a crash and display the desired dynamic traveler information messages as described in the System Operation section.

(d) A reliable wireless communication system to connect devices to the central controller and to allow for remote system access.

(e) The ability to record and archive video footage with date and time stamps for review at a later time.

SYSTEM OPERATION

The IM System shall/should be capable of detecting a crash. A potential crash can be detected using sensors that measure abnormally slow speeds or long queues over a given time period. If a potential crash is detected, the IM System shall/should notify the TMC. Crashes can also be reported to the TMC by roadway workers or through the 911 system. When the TMC receives notification of a potential crash, the systems and process detailed below can be followed:

(a) **Video monitoring:** The TMC operator shall/should be capable of remotely accessing a CCTV system monitoring the work zone and the approaches to the work zone. Using the CCTV system, the TMC operator can verify a crash occurred, assess and categorize the incident, and transmit details regarding the incident to the appropriate responding agencies (such as fire and police departments, or towing companies) who can dispatch an appropriate response team.

* This example specification is for illustrative purposes only and is not enforceable under Federal law. It may be used or adapted by transportation agencies to meet their needs. Use of the words "should" and "shall" is for illustrative purposes only.

** Agency staff can supply the appropriate number.

(b) **Incident information**: The IM system shall/should be capable of displaying critical traveler information to drivers using PCMSs. The IM System shall/should be able to detect two distinct traffic conditions: no-crash and crash. The two traffic conditions should be based on metrics like unexpected delay, queues, and travel times through the work zone which should be adjusted throughout the day as necessary. The TMC operator shall/should also be able to manually update the traffic condition information displayed on the PCMSs after viewing the CCTV system. The messages displayed should vary based on the detected traffic conditions.

(1) **No-crash:** When there is no-crash detected, the PCMSs should display general work zone and traveler information such as the work zone location and travel time through the work zone. Messages displayed can include "WORK ZONE AHEAD," "WORK ZONE XX MILES AHEAD," and "XX MIN DELAY AHEAD." The no-crash condition should be based on the comparison of detected traffic conditions (i.e., travel time, queueing, speed) with typical conditions observed within the work zone throughout the day.

(2) **Crash:** When a crash is detected, the TMC shall/should remotely display crash-related information on the PCMSs. Messages displayed can include "CRASH AHEAD," "RIGHT/ LEFT LANE CLOSED AHEAD," "XX MIN DELAY AHEAD," and "USE EXIT XX." Messages displayed on the PCMSs can vary by location. For this project, a crash is initially defined as XX minutes of travel time delays or greater over the typical travel time delay for a given time of the day. The system shall/should remain in crash mode until the crash is cleared.

DEPLOYMENT REQUIREMENTS

The Contractor is responsible for furnishing, coordinating, installing, relocating, operating, maintaining, monitoring, and subsequently removing the approved IM System according to the project plans and these specifications.

The Contractor shall/should be able to maintain locally all components, move portable devices as necessary, including adjusting device location and replacing any malfunctioning devices, to ensure the system is operating as designed. The Contractor may adjust the location of signs in response to site-specific conditions, with the Project Engineer's approval. The Contractor shall/should be available 24 hours per day, 7 days per week while the system is deployed. The Contractor shall/should provide the Project Engineer a 24/7 contact phone number. The Contractor shall/should provide weekly reports on system performance and response to emergencies. The Contractor shall/should participate in the development of a Traffic Incident Management Plan for the work zone.

SYSTEM DOCUMENTATION

The Contractor shall/should provide documentation detailing the technical and operational elements of the proposed IM System for review and approval.

OPERATIONAL TEST

The IM System shall/should be tested in two stages:

(a) **Off-site acceptance testing:** The Contractor shall/should test the system at an off-site location XX weeks prior to the field deployment to ensure all system components are functioning as designed. To test the PCMSs and the central system controller, a work zone under no-crash and crash can be virtually mimicked. The Contractor shall/should develop a testing plan and submit it for review and approval prior to the start of testing.

(b) **Site acceptance testing:** After the IM System is installed or moved in the field, the IM System, and all sub-systems such as a remote access systems, shall/should be tested to ensure all components of the system function as designed. For long-term installations, site acceptance testing shall/should be performed weekly by the Contractor and TMC operator. Testing shall/should be done for each specific deployment location within the project. The Contractor shall/should verify the functionality and accuracy of the CCTV system, the traffic sensors, and the information displayed on each PCMS. The traffic sensor detected speeds and travel delays shall/should not deviate by more than XX mph from the actual vehicle speeds, XX minutes from the actual vehicle travel time, and traffic volumes detected shall/should not vary by more than XX percent from actual volumes. If the system does not meet the accuracy requirement, the equipment shall/should be recalibrated or replaced, if necessary, and re-tested. The Contractor shall/should submit a report no later than one calendar day following the completion of the Site Acceptance Testing. Construction can commence upon testing approval by the Project Engineer.

PERMITTED WORK HOURS

The IM System can be used for both daytime and nighttime lane closures.

SYSTEM PERFORMANCE

The IM System shall/should meet the following system performance requirements:

(a) **Continuous operation:** The IM System shall/should be in place and continuously functioning while the work zone is in place.

(b) **Traffic detectors:** All sensors shall/should be of a type whose accuracy is not degraded by inclement weather or decreased visibility conditions including precipitation, fog, darkness, excessive dust, and road debris.

(c) **Traffic detection:** The IM System shall/should be capable of calculating the real-time travel speed and travel time every minute.

(d) **PCMS:** The IM System shall/should be capable of automatically updating the message being displayed on the PCMSs when a crash is detected. The TMC operator should also be able to remotely update the PCMSs in the event of an emergency or system malfunction.

(e) **Video monitoring:** All video equipment shall/should be weatherproof. The video resolution and communication equipment shall/should allow an operator at the TMC to view and accurately categorize a crash. The video quality should not be reasonably degraded by inclement weather or decreased visibility conditions including precipitation, darkness, and road debris.

(f) **Data logging:** The IM System shall/should capture a continuous event log including all traffic conditions, all system state changes, and all changes in the messages displayed.

(g) **Remote access:**

  (1) **Remote monitoring and control:** The IM System shall/should have the capability of real-time remote monitoring and control.

  (2) **System data log:** Password-protected users shall/should have the capability to view all system log data on a website and create graphs based on available data with time and date stamps. At the request of the Project Engineer, the vendor shall/should provide the logged information in electronic format.

  (3) **System assessment:** The IM System shall/should be configured to assess any type of malfunction that has occurred. This assessment includes communication disruption between any device in the system and any device malfunction including the CCTV system and the PCMSs. The system shall/should be capable of notifying the specified individuals via phone and email about any system malfunction.

(h) **Manual control:** The IM System shall/should be manually controllable onsite. The capability to manually switch between states of no-crash and crash allows for maximum flexibility.

SYSTEM TRAINING

IM System training shall/should be conducted by the Contractor directly responsible for the system operation and the system supplier. The training shall/should include representatives from the Contractor, Agency, Enforcement, and others responsible for construction, maintenance of traffic, and safety. The training shall/should, at a minimum, cover the following items:

(a) Review of system operation.

(b) In the event of an emergency, who to contact and instructions on how to override the system.

(c) In the event of a power failure, instructions detailing how to power cycle the system.

(d) Online system access, remote monitoring, and remote control.

(e) Basic listing of what to monitor and what causes messages to change.

(f) List of telephone numbers to call to request technical support.

SYSTEM WARRANTY, MAINTENANCE, AND SUPPORT

The IM System shall/should be maintained, supported, and warranted against material defects by its supplier through the duration of the deployment. The Contractor shall/should respond immediately to any call from the Project Engineer or designated representative concerning any request for correcting any deficiency in the system. Deficiencies include field conditions and remote monitoring capabilities.

MEASUREMENT AND PAYMENT

Measurement and payment shall/should be made at the contract unit price per day that the IM System is deployed, in use, and is fully operational, which shall/should be compensation in full for furnishing, installing, operating, reporting, maintaining, and removing the system. System testing and training, communications costs, and any relocation or repositioning within the work zone or removal of equipment from the work zone shall/should be incidental to the contract unit price.

I. Performance Measurement

U.S. Department of Transportation
Federal Highway Administration

PROCESS

The establishment of a performance measurement program for work zones is recommended to follow the seven-step process detailed in the Federal Highway Administration's "Tutorial on Establishing Work Zone Performance Measures," and is summarized in figure 10:

Figure 10. Diagram. Performance measurement diagram. Source: FHWA.

Description

Performance measures are sets of defined, outcome-based conditions or response times used to evaluate success—they quantify, with objective and subjective evidence, the degree to which an intended outcome is occurring over time.[112] The data-driven evaluation of progress towards specific, agency-defined objectives is especially important in work zones, as performance measures are typically related to agency goals in the realms of safety, mobility, project quality, and customer satisfaction.[113] Specifically, work zone performance measures quantify how roadway construction impacts workers, travelers, residents, and businesses at both the project level and agency program level. Project-level metrics describe specific work zones, while agency program metrics correspond with the system-wide impacts of construction.[114]

Performance measures are a critical component of a data-driven approach toward achieving agency-defined objectives in work zone safety and mobility.

A successful performance measurement program is based on data collection and monitoring, which are enabled by intelligent transportation system (ITS) deployments. For work zones, these data can be categorized as:

- **Performance data**: Mobility metrics such as volumes, queue lengths, and speeds, or safety metrics such as crashes, worker incidents, or user complaints.
- **Exposure data**: Information that describes the duration of potential conflicts, such as the number of workers in the zone, the length of the work zone, and the activities being performed.
- **Indicator data:** Descriptive information such as the design characteristics of the roadway and work zone, the times and locations of activities, and the time and characteristics of incidents.

These data types are integrated and analyzed in order to measure the mobility, safety, and quality of the work zone, which is useful for quantifying the impacts of the work zone, empowering deeper analysis of trends, assisting in communication efforts, and guiding investment decisions.[115]

The most effective performance measures shall:

- Relate to the established agency safety and mobility goals and objectives.
- Correspond with measures used in traffic impact assessments for planning and design.[116]
- Utilize and integrate existing data sources and ITS deployments.[117]

Performance measurement begins with work zone planning and functions best when incorporated throughout the design of the work zone. A continuous focus on performance measurement throughout the project lifecycle can work to mitigate impacts, as well as to improve efficiency in work phasing and sequencing operations.[118]

Benefits

Performance measurement programs provide significant benefits to highway systems and agencies, roadway users, and road workers. Key benefits of performance measurement programs include:

- Quantify Work Zone Impacts.
- Empower Trend Analysis.
- Assist in Communication.
- Direct Investment Decisions.

Quantify work zone impacts. Work zones have traditionally decreased safety for roadway users and workers while negatively impacting mobility on a system level. The inclusion of performance measures in work zone planning and design allows agencies to understand weaknesses and adapt work zones to mitigate unsafe conditions and heavy congestion. Multiple work zone ITS deployments, such as queue warning systems, dynamic lane merge systems, and variable speed limit systems can serve as the basis for a robust performance measurement program. The impacts of these deployments can be tested in the planning- and operational-level freeway capacity software FREEVAL, which includes work zone impact assessments based on Highway Capacity Manual 6th Edition. Utilizing baseline data and data collected via ITS deployments, FREEVAL can be used to measure performance for important metrics, such as level of service, average travel time, vehicle delay per interval, average speed, maximum cost delay, and user cost of delay.

The Ohio Department of Transportation (ODOT) operates under a policy framework that incorporates ITS-empowered performance measurement into the management of its work zones. Through what is known as a permitted lane closure system (PLCS), ODOT has set volume thresholds for allowable lane closures by time of day. If the threshold is exceeded, which is measured through roadway sensors and computed at the roadway's traffic management center (TMC), then a queuing analysis is performed, using a tool that incorporates site and project inputs, free-flow speed, and work activities. ODOT's framework allows for a work zone queue that is 0.75 mile in length and for work zone speeds to be no lower than 35 mph, which is measured by a queue warning system and a variable speed limit system powered by INRIX data. Once this threshold is exceeded, mitigation strategies, such as dynamic lane merge or the halting of work activities, are implemented. The PLCS is informed by count data that are updated annually as a part of ODOT's Transportation Systems Management and Operations program, a performance measurement-based system. Through ITS deployments in their work zones, ODOT is able to quantify the impacts that work zones produce.[119]

Empower trend analysis. The continuous and targeted collection of data for performance measurement can empower agencies to analyze both short- and long-term trends. These patterns can then inform work zone planning and design to increase both safety and mobility, as well as efficiency. The California Department of Transportation (Caltrans) has implemented a Performance Measurement System (PeMS) that is a comprehensive performance monitoring system, consisting of roadway sensors for data collection, a web-based data warehouse, and a data analytics suite.[7] In doing so, Caltrans has created powerful real-time web-based visualization and query tools, including:

- Interactive map and dashboard of road closure activities by work status, lane closure delay, and detour route performance.
- Dynamic report generation of road closure status through both webpage and 511 Traveler Information System.

These tools have been implemented in the planning, construction, and maintenance of roadways, for the purposes of estimating, monitoring, documenting, analyzing, and communicating work zone impacts. This information also serves for work zone management, when applied with a lane requirement chart, similar to the aforementioned ODOT policy.

Assist in communication. Real-time traveler information systems (RTISs) provide crucial roadway condition information, such as weather, traffic, and work zone conditions, that enable drivers to make better decisions. This real-time information is especially important in work zones, as 40 percent of drivers indicate that it is the most highly sought-after type of information used in trip decisions—this is particularly relevant for lane closures. Drivers have also indicated that the most favorable methods of receiving real-time information are via apps and on-road signs (in contrast to advisory radio stations and 511 phone systems, which were ranked lowest for user approval).[120] Real-Time Traveler Information about work zone conditions, including time in minutes of delay, provides the most benefits to the network when deployed in conjunction with an alternate route that is advertised in advance, so drivers can elect to change their route. Performance measurement programs can envelop the data accrued through RTIS deployments in work zones as crucial metrics in a robust Transportation Systems Management and Operations (TSMO) strategy, as well as a communication and education capacity for the traveling public.[121]

Direct investment decisions. Since 2007, 23 CFR 630 Subpart J has required all State and local agencies that receive Federal-aid highway funding to abide by the 2004 Work Zone Safety and Mobility Rule, which addresses current issues impeding safety and mobility in work zones. More recently, the Moving Ahead for Progress in the 21st Century (MAP-21) Act emphasizes performance measurement when awarding Federal funding, highly favoring projects that include a well-thought strategy for performance-based planning and monitoring. MAP-21 focuses on several areas relevant to work zones, including safety, congestion reduction, and reduced project delivery delays.[122]

References continued

112 Hallmark, Shauna, Jordan Turner, and Chris Albrecht. *Synthesis of Work-Zone Performance Measures.* Washington, D.C.: Federal Highway Administration (FHWA), 2013.

113 Scriba, Tracy and Gerald L. Ullman. *A Tutorial on Establishing Effective Work Zone Performance Measures*. Washington, D.C.: FHWA, 2011.

114 Ullman, Gerald L., Timothy J. Lomax, and Tracy Scriba. *A Primer on Work Zone Safety and Mobility Performance Measurement.* Washington, D.C.: FHWA, 2011.

Considerations

The following are key considerations for performance measurement programs:

- Baseline Data Collection.
- Tiered Approach.
- Possibilities of V2X Communication.

Baseline data collection. A successful performance measurement program for work zones is built upon the foundation of consistent data collection of traffic volumes, speeds, queues, and crashes along roadways prior to the creation of a work zone.[123] Baseline data collection efforts can include traditional methods for counts such as pneumatic tubes, microwave radar, and magnetic sensors, as well as technologies like automatic license plate recognition and CCTV. Probe data collection methods include cellular, GPS, and Bluetooth.[124] Additionally, multiple data sources can be standardized, automated, and aggregated into analysis software using an application programming interface (API) into a data warehouse for initial analysis.

Tiered approach. A performance measurement program must dovetail with the goals, objectives, needs, and resources of the agency implementing it, as there is no one-size-fits-all approach to measuring success. For this reason, a tiered approach has been developed by the Institute for Transportation Research and Education that consists of 5 Data Levels shown in figure 11, each of which correspond to an increased degree, as displayed to the right. Following the baseline data collection (either routine or performed prior to the creation of the work zone), initial data collected on queue lengths and travel time delay caused by temporary lane closures are analyzed to determine congestion and delay resulting from the work zone, as these are the simplest to isolate and attribute to the work activities.[125]

Depending on the type of work performed, the expected duration of the project, and the projected closures, further monitoring, measurement, and mitigation strategies can be incorporated. Work zone performance measurement can begin simply, with agencies carefully selecting appropriate measures based on the project characteristics, communicating to all stakeholders and staff, and tracking these metrics clearly, seriously, and consistently.[126] As the work zone performance measurement program progresses, incorporation into a Statewide TSMO reporting system will enable easier tracking and coordination of work zone activities.[127]

Data Level 1: Simple Impact Assessment	• Speed and travel times from probes • Queue lengths estimated from probes
Data Level 2: Corridor Performance	• Mainline volume point sensors
Data Level 3: Real-Time Corridor Performance	• Streaming video along work zone corridor
Data Level 4: Route Diversion Estimates	• Volume point sensors on work zone and alternate route • Stream video in work zone and on alternate route • Bluetooth readers on work zone and alternate route for diversion estimate
Data Level 5: Network Assessment	• Volume point sensors at all key network points • Video streaming at all key network points • Bluetooth readers at all key network points for origin-destination estimation

Figure 11. Diagram. Five data levels. Source: ITRE.

Possibilities of V2X communication. In the coming years, national and regional partnerships with private companies developing connected vehicle technologies will serve as a new source of data for measuring work zone performance. The combination of variable speed limit, dynamic lane merge, automated enforcement, queue warning, and real-time traveler information systems will culminate, alongside vehicle location, fleet management, and advanced signal systems, into an efficient and effective data model, capable of seamlessly mitigating the impacts to mobility and safety in work zones.

Cost and Equipment

The cost of an ITS deployment that enables performance measurement within a work zone varies considerably depending on the existing infrastructure and equipment, as well as the area of the deployment. The hardware costs associated with establishing a performance measurement program are often encompassed by the costs associated with the work zone ITS deployment, as the equipment necessary—roadway sensors, PCMSs, CCTV, telecommunications, and analysis software—are the foundation of the deployment itself. Therefore, a performance measurement program would not necessarily have standalone equipment costs.

References continued

115 Scriba, Tracy and Gerald L. Ullman. *A Tutorial on Establishing Effective Work Zone Performance Measures.* Washington, D.C.: FHWA, 2011.

116 Ullman, Gerald L., Timothy J. Lomax, and Tracy Scriba. *A Primer on Work Zone Safety and Mobility Performance Measurement*.

117 FHWA. *Comprehensive Work Zone Mobility Performance Management Across Project Stages: Caltrans.* Washington, D.C.: FHWA, 2019.

118 Ullman, Gerald L., Richard J. Porter, and Ganesh J. Karkee. *Monitoring Work Zone Safety and Mobility Impacts in Texas. College Station, TX*: Texas A&M University, Texas Transportation Institute, 2009.

119 FHWA. *Comprehensive Work Zone Mobility Performance Management Across Project Stages: Ohio DOT*. Washington, D.C.: FHWA, 2019.

120 Robinson, Emanuel, Thomas Jacobs, Kathleen Frankle, Nayel Serulle, and Michael Pack. *Project 08-82: Deployment, Use, and Effect of Real-Time Traveler Information Systems*. Washington, D.C.: Transportation Research Board, National Cooperative Highway Research Program (NCHRP), 2012.

121 Work Zone Management Program. "Performance Measurement." Washington, D.C.: FHWA. Accessed July 28, 2021. https://ops.fhwa.dot.gov/wz/decision_support/perf_measurement.htm.

122 FHWA. "MAP-21 Performance Management." Washington, D.C.: FHWA. Accessed July 28, 2021. www.fhwa.dot.gov/map21/pm.cfm.

123 Ullman, Porter, and Karkee. *Monitoring Work Zone Safety and Mobility Impacts in Texas*. College.

124 Hallmark, Shauna, Jordan Turner, and Chris Albrecht. *Synthesis of Work-Zone Performance Measures*. Washington, D.

125 Ullman, Porter, and Karkee. *Monitoring Work Zone Safety and Mobility Impacts in Texas*. College.

126 Ullman, Lomax, and Scriba. *A Primer on Work Zone Safety and Mobility Performance Measurement*.

127 Federal Highway Administration (FHWA). *Comprehensive Work Zone Mobility Performance Management Across Project Stages: Caltrans.*

I. Performance Measures Example Specification*

DESCRIPTION

The Performance Measurement System shall/should* be used for maintenance of traffic as provided in the project plans and as specified in this document. The Performance Measurement System deploys a series of traffic detectors to collect real-time traffic information such as traffic volume, queue lengths, and speeds to quantify the short-term and long-term traffic impacts of a work zone, including the effectiveness of a work zone Intelligent Transportation System (ITS) deployment. The Performance Measurement System should relay the traffic information back to a traffic management center (TMC) where the data can be stored, aggregated, and analyzed. The system must also generate condition and event logs that can be accessed remotely by the Contractor and the sponsoring agency and provide alerts to specified individuals when the system or a component of the system is not functioning properly.

MATERIALS

The Performance Measurement System shall/should include, traffic sensors, communications devices, system controller and field cabinet, system operating software, and all miscellaneous equipment and hardware required for a fully operational system. All roadside devices used for the Performance Measurement System shall/should conform to the latest Manual for Assessing Safety Hardware (MASH) standards, when available.

The Performance Measurement System shall/should conform to the following system and operations requirements:

SYSTEM REQUIREMENTS

The Performance Measurement System shall/should consist of at least the following components:

(a) A central system controller in a weatherproof cabinet to maintain continuous traffic and system status monitoring; provide communication to relay traffic information back to the TMC; and provide remote access to the system for operation, malfunction detection, and data collection.

(b) Sufficient traffic detection device(s) to collect traffic information at strategically chosen locations as described in the System Operation section.

(c) A reliable wireless communication system to connect devices to the central controller and to allow for remote system access.

SYSTEM OPERATION

The Performance Measurement System shall/should be capable of using traffic sensors to detect real-time traffic information such as the detector location, traffic volume, queue lengths, and vehicle speeds at strategic locations. The real-time traffic information shall/should be collected every XX** second(s) and sent to the TMC every XX minutes. At the TMC, the Performance Measurement System shall/should establish standard procedures or tools to aggregate and analyze the traffic data to evaluate the short-term and long-term traffic impacts of a work zone and any supporting ITS deployment. At the TMC, additional roadway information such as Safety Data (e.g., crashes, worker incidents, or user complaints) Exposure Data (e.g., number of workers in the work zone, the distance to the work zone, and the activities being performed) and Indicator Data (e.g., design characteristics of the roadway and work zone, the times and locations of activities, and the time and characteristics of incident) can be overlaid with the real-time traffic information to enhance the analysis. At the TMC, the traffic data shall/should be automatically backed up every XX hours.

* This example specification is for illustrative purposes only and is not enforceable under Federal law. It may be used or adapted by transportation agencies to meet their needs. Use of the words “should” and “shall” is for illustrative purposes only.

** Agency staff can supply the appropriate number.

DEPLOYMENT REQUIREMENTS

The Contractor is responsible for furnishing, coordinating, installing, relocating, operating, maintaining, monitoring, and subsequently removing the approved Performance Measurement System according to the project plans and these specifications. The Contractor shall/should be able to maintain locally all components, move portable devices as necessary, including adjusting device location and replacing any malfunctioning devices, to ensure the system is operating as designed. The Contractor shall/should be available 24 hours per day, 7 days a week while the system is deployed. The Contractor shall/should provide the Project Engineer a 24/7 contact phone number. The Contractor shall/should provide weekly reports on system performance and response to emergencies.

SYSTEM DOCUMENTATION

Provide documentation detailing the technical and operational elements of the proposed Performance Measurement System for review and approval.

OPERATIONAL TEST

The Performance Measurement System shall/should be tested in two stages:

(a) **Off-site acceptance testing:** The Contractor shall/should test the system at an off-site location XX weeks prior to the field deployment of the Performance Measurement System to ensure all system components are functioning as designed. To test the central system controller and traffic detectors a work zone with varying levels of congestion can be virtually mimicked. The Contractor shall/should develop a testing plan and submit it for review and approval prior to the start of testing.

(b) **Site acceptance testing:** After the Performance Measurement System is installed or moved in the field, the Performance Measurement System, and all sub-systems such as a remote access systems, shall/should be tested to ensure all components of the system function as designed. For long-term installations, site acceptance testing shall/should be performed weekly by the Contractor. Testing shall/should be done for each specific deployment location within the project. The Contractor shall/should verify the functionality and accuracy of the traffic sensors. The traffic sensor detected speeds and travel delays shall/should not deviate by more than XX mph from the actual vehicle speeds, XX minutes from the actual vehicle travel time, and traffic volumes detected shall/should not vary by more than XX percent from actual volumes. If the system does not meet the accuracy requirement, the equipment shall/should be recalibrated or replaced, if necessary, and re-tested. The Contractor shall/should submit a report no later than one calendar day following the completion of the Site Acceptance Testing. Construction can commence upon testing approval by the Project Engineer.

PERMITTED WORK HOURS

The Performance Measurement System can be used for both daytime and nighttime lane closures.

SYSTEM PERFORMANCE

The Performance Measurement System shall/should meet the following system performance requirements:

(a) Continuous Operation: The Performance Measurement System shall/should be in place and continuously functioning while the work zone is in place.

(b) Traffic Detectors: All sensors shall/should be of a type whose accuracy is not degraded by inclement weather or decreased visibility conditions including precipitation, fog, darkness, excessive dust, and road debris.

(c) Traffic Detection: The Performance Measurement System shall/should be capable of capturing the real-time travel speed and travel time.

(d) Data Logging: The Performance Measurement System shall/should capture a continuous event log including all traffic conditions, all system state changes, and all changes in the messages displayed.

REMOTE ACCESS:

(a) Remote Monitoring and Control: The Performance Measurement System shall/should have the capability of real-time remote monitoring and control.

(b) System Data Log: Password-protected users shall/should have the capability to view all system log data on a website and create graphs based on available data with time and date stamps. At the request of the Project Engineer, the vendor shall/should provide a digital copy of the logged information.

(c) System Assessment: The Performance Measurement System shall/should be configured to assess any type of malfunction that has occurred. This assessment includes communication disruption between any device in the system and any device malfunction. The system shall/should be capable of notifying the specified individuals via phone and email about any system malfunction.

SYSTEM TRAINING

Performance Measurement System training shall/should be conducted by the Contractor directly responsible for the system operation and the system supplier. The training shall/should include representatives from the Contractor, Agency, Enforcement, and others responsible for construction, maintenance of traffic, and safety. The training shall/should, at a minimum, cover the following items:

(a) Review of system operation.

(b) In the event of an emergency, who to contact and instructions on how to override the system.

(c) In the event of a power failure, instructions detailing how to power cycle the system.

(d) Online system access, remote monitoring, and remote control.

(e) Basic listing of what to monitor.

(f) List of telephone numbers to call to request technical support.

SYSTEM WARRANTY, MAINTENANCE, AND SUPPORT

The Performance Measurement System shall/should be maintained, supported, and warranted against material defects by its supplier through the duration of the deployment. The Contractor shall/should respond immediately to any call from the Project Engineer or designated representative concerning any request for correcting any deficiency in the system. Deficiencies include field conditions and remote monitoring capabilities.

MEASUREMENT AND PAYMENT

Measurement and payment shall/should be made at the contract unit price per day that the Performance Measurement System is deployed, in use, and is fully operational, which shall/should be compensation in full for furnishing, installing, operating, reporting, maintaining, and removing the system. System testing and training, communications costs, and any relocation or repositioning within the work zone or removal of equipment from the work zone shall/should be incidental to the contract unit price.

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Office of Operations
Work Zone Management Program Website
https://ops.fhwa.dot.gov/wz
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