



U.S. Department of Transportation
Federal Highway Administration

Work Zone Intelligent Transportation Systems Implementation Guide

Use of Technology and Data for Effective
Work Zone Management

January 2014



Notice

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. This report does not constitute a standard, specification, or regulation.

The United States Government does not endorse products or manufacturers. Trade and manufacturers' names appear in this report only because they are considered essential to the object of the document.

Quality Assurance Statement

The Federal Highway Administration (FHWA) provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

Cover photo and chapter heading photos courtesy of Shutterstock, Fotolia, and Veer.

| | | | | | |
|---|--|--|--|--|-----------|
| 1. Report No. FHWA-HOP-14-008 | | 2. Government Accession No. | | 3. Recipient's Catalog No. | |
| 4. Title and Subtitle Use of Technology and Data for Effective Work Zone Management: Work Zone ITS Implementation Guide | | | | 5. Report Date January 2014 | |
| | | | | 6. Performing Organization Code | |
| 7. Author(s) Gerald Ullman (TTI); Jeremy Schroeder, Deepak Gopalakrishna (Battelle) | | | | 8. Performing Organization Report No. | |
| 9. Performing Organization Name and Address Battelle Texas A&M Transportation Institute 505 King Ave. The Texas A&M University System Columbus, OH 43201 College Station, Texas 77843-3135 | | | | 10. Work Unit No. (TRAVIS) | |
| | | | | 11. Contract or Grant No. DTFH61-06-D-0007 / BA07-101 | |
| 12. Sponsoring Agency Name and Address Federal Highway Administration Office of Operations (HOP) 1200 New Jersey Avenue SE Washington, DC 20590 | | | | 13. Type of Report and Period Covered | |
| | | | | 14. Sponsoring Agency Code | |
| 15. Supplementary Notes Project performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration. Tracy Scriba, project lead | | | | | |
| 16. Abstract ITS is the use of a broad range of communications-based information and electronics technologies to enhance transportation. Work zone ITS is the use of ITS to enhance transportation and improve safety and mobility in and around work zones. A work zone ITS deployment can be focused around safety or mobility, but often supports both goals, and can also enhance productivity. The systems are portable and temporary in most cases, although some deployments may use either existing fixed infrastructure or become a permanent system. The purpose of this document is to provide guidance 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. Work zone ITS is one possible operational strategy of many potential solutions that an agency can include in a transportation management plan (TMP). This document summarizes key steps for successfully implementing ITS in work zones, using a systematic approach to provide a technical solution that accomplishes a specific set of clearly defined objectives. The document illustrates how a systems engineering process should be applied to determine the feasibility and design of work zone ITS for a given application, regardless of its scale, by walking through the key phases, from project concept through 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. | | | | | |
| 17. Key Words Work zones, intelligent transportation systems, ITS | | | 18. Distribution Statement No restrictions. This document is available to the public. | | |
| 19. Security Classif.(of this report) Unclassified | | 20. Security Classif. (of this page) Unclassified | | 21. No. of Pages 80 | 22. Price |

| | |
|--|---|
| INTRODUCTION | 1 |
| What is work zone ITS? | 1 |
| Some current technology options and strategies | 2 |
| Benefits that are possible with work zone ITS | 4 |
| Purpose and organization of this document | 4 |

STEP 1 – ASSESSMENT OF NEEDS 7

| | | |
|-----|---|----|
| 1.1 | What are the user needs? | 7 |
| 1.2 | What are the system goals and objectives? | 9 |
| 1.3 | Who are the stakeholders? | 11 |
| 1.4 | Who should be on the project team? | 12 |
| 1.5 | What, if any, existing ITS resources are available? | 12 |

STEP 2 – CONCEPT DEVELOPMENT AND FEASIBILITY 15

| | | |
|-----|--|----|
| 2.1 | What is the overall work zone ITS concept of operations? | 15 |
| 2.2 | What ITS solutions are available? | 18 |
| 2.3 | What are the potential benefits of an ITS deployment? | 21 |
| 2.4 | How much will an ITS deployment cost? | 21 |
| 2.5 | What are potential institutional and jurisdictional challenges? | 22 |
| 2.6 | Addressing legal and policy issues | 23 |
| 2.7 | How can project feasibility be established? | 23 |
| 2.8 | How can buy-in be obtained from stakeholders and other agencies? | 27 |

STEP 3 – DETAILED SYSTEM PLANNING AND DESIGN 29

| | | |
|-----|--|----|
| 3.1 | Determining system requirements and specifications | 29 |
| 3.2 | Developing the system design | 31 |
| 3.3 | Developing a testing strategy | 32 |
| 3.4 | Planning for operations and maintenance | 33 |
| 3.5 | Determining staff training needs for those using and operating the work zone ITS | 33 |
| 3.6 | Planning for public outreach | 34 |
| 3.7 | Investigating system security | 36 |
| 3.8 | Planning for evaluation | 36 |
| 3.9 | Estimating system benefits and costs | 39 |

STEP 4 – PROCUREMENT 41

| | | |
|-----|---|----|
| 4.1 | Overview of procurement approaches | 41 |
| 4.2 | Deciding between direct or indirect procurement | 43 |
| 4.3 | Determining the procurement award mechanism | 46 |
| 4.4 | Issuing a request for proposals or bids | 46 |
| 4.5 | Selecting the preferred vendor, consultant, or contractor | 47 |

STEP 5 – SYSTEM DEPLOYMENT 51

| | | |
|-----|----------------------------------|----|
| 5.1 | Implementing the system plans | 52 |
| 5.2 | Scheduling decisions | 52 |
| 5.3 | System acceptance testing | 53 |
| 5.4 | Handling major deployment issues | 53 |

STEP 6 – SYSTEM OPERATION, MAINTENANCE, AND EVALUATION 55

| | | |
|-----|--|----|
| 6.1 | Dealing with changing work zone conditions | 55 |
| 6.2 | Using and sharing ITS information | 56 |
| 6.3 | Maintaining adequate staffing | 58 |

| | | |
|-------|---|----|
| 6.4 | Leveraging public support | 58 |
| 6.5 | Conducting system monitoring and evaluation | 58 |
| 6.5.1 | System monitoring | 58 |
| 6.5.2 | System modification | 59 |
| 6.5.3 | Final evaluation | 60 |

List of Appendices

| | | |
|-------------|--|----|
| Appendix A. | National ITS Architecture | 61 |
| Appendix B. | Summary of Resources Reported in this Document | 63 |
| Appendix C. | Issues for Consideration | 65 |
| Appendix D. | Acknowledgements | 68 |

List of Figures

| | | |
|------------|---|----|
| Figure 1. | A portable changeable message sign providing downstream traffic speeds from sensor data. | 1 |
| Figure 2. | Temporary, solar-powered vehicle detection and camera systems. | 2 |
| Figure 3. | Sequencing comparative travel time sign at a decision point for two different routes to the town of Lehi that was used for a project in Utah. | 5 |
| Figure 4. | Overview of the implementation process. | 5 |
| Figure 5. | Sub-steps to be explored in Step 1. | 7 |
| Figure 6. | Example of a work zone and area of expected impacts. | 10 |
| Figure 7. | Existing ITS resources can be used to help manage the work zone and reduce costs. | 12 |
| Figure 8. | Sub-steps to be explored in Step 2. | 15 |
| Figure 9. | General outline showing the sections of a formal concept of operations document based on the IEEE 1362-1998 standard. | 16 |
| Figure 10. | High-level sketch for the concept of operations of a work zone ITS deployment in Utah. | 17 |
| Figure 11. | The product of this step should include concept of operations scenarios, such as this graphic for a work zone traffic management system. | 28 |
| Figure 12. | Sub-steps to be explored in Step 3. | 29 |
| Figure 13. | Requirements for a work zone ITS deployment in Minnesota. | 30 |
| Figure 14. | The Las Vegas Freeway and Arterial System for Transportation (FAST) provides regional support for work zone activities. | 31 |
| Figure 15. | Example press release for a work zone in New Hampshire. | 35 |
| Figure 16. | PCMS in several states have been illegally accessed and had messages changed. | 36 |
| Figure 17. | Overall evaluation process for ITS applications in work zones. | 38 |
| Figure 18. | Sub-steps to be explored in Step 4. | 41 |
| Figure 19. | Agencies must select the work zone ITS type first, which could impact the type of procurement method and award mechanism that are used. | 42 |
| Figure 20. | Sub-steps to be explored in Step 5. | 51 |
| Figure 21. | Sub-steps to be explored in Step 6. | 55 |
| Figure 22. | PCMS messages were modified from a generic message (left) as stated in the contract to a more specific message (right). | 59 |

List of Tables

| | |
|--|----|
| Table 1. Sample work zone ITS applications. | 3 |
| Table 2. Examples of site-specific issues and problems. | 8 |
| Table 3. ITS components. | 18 |
| Table 4. Communication options, advantages, and disadvantages. | 20 |
| Table 5. Examples of benefits for various work zone ITS. | 21 |
| Table 6. Example set of scoring criteria to establish feasibility of work zone ITS. | 25 |
| Table 7. Possible work zone ITS applications to consider for various critical project characteristics. | 26 |
| Table 8. Example evaluation criteria. | 39 |
| Table 9. Summary table of procurement methods. | 45 |

Acronyms and Abbreviations

| | |
|---------------|--|
| AASHTO | American Association of State Highway and Transportation Officials |
| ADT | Average Daily Traffic |
| ATIS | Advanced Traveler Information System |
| ATSSA | American Traffic Safety Services Association |
| AVI | Automatic Vehicle Identification |
| AVL | Automatic Vehicle Location |
| CCTV | Closed-Circuit Television |
| CITE | Consortium for ITS Training and Education |
| CMS | Changeable message sign |
| COTS | Commercial Off-The-Shelf |
| DB | Design-Build |
| DOT | Department of Transportation |
| FCC | Federal Communications Commission |
| FHWA | Federal Highway Administration |
| GPS | Global Positioning System (Satellite) |
| HAR | Highway Advisory Radio |
| IP | Internet Protocol |
| ITS | Intelligent Transportation Systems |
| IDAS | ITS Deployment Analysis System |
| JPO | Joint Program Office |
| LED | Light Emitting Diode |
| LTAP | Local Technical Assistance Program |
| MCO | Maintenance & Construction Operations |
| MOE | Measure of Effectiveness |
| MUTCD | Manual of Uniform Traffic Control Devices |
| NCHRP | National Cooperative Highway Research Program |
| NHI | National Highway Institute |
| NTCIP | National Transportation Communications for ITS Protocol |
| PCB | Professional Capacity Building |
| PCMS | Portable Changeable message sign |
| RFID | Radio Frequency Identification |
| RFP | Request for Proposals |
| RITA | Research and Innovative Technology Administration |
| TMC | Transportation Management Center |
| TMP | Transportation Management Plan |
| TRB | Transportation Research Board |
| UNII | Unlicensed National Information Infrastructure |
| VSL | Variable Speed Limit |
| VMT | Vehicle Miles Traveled |
| V2I | Vehicle-to-Infrastructure |
| V2V | Vehicle-to-Vehicle |
| Wi-Fi | Wireless Internet/Network |

INTRODUCTION

Highway work zones present challenges to work zone safety and mobility. Work zones often reduce roadway capacity, causing congestion and traveler delay and creating irregular traffic flow. These factors, as well as the changing lane configurations and other factors in work zones, can lead to safety hazards. There are more than 500 fatalities and 37,000 injuries in work zones every year.¹ However, work zones are a necessary part of maintaining and rehabilitating our transportation infrastructure. These needs are increasing as our transportation system ages, which means more work zones will likely occur. These factors all combine to create challenges to moving traffic smoothly and safely through work zones and which heightens the need for finding new ways to enhance work zone traffic management. Agencies are deploying intelligent transportation systems (ITS) to help manage traffic in and around work zones more efficiently.

What is work zone ITS?

ITS is the use of a broad range of communications-based information and electronics technologies to enhance transportation. These systems generally include:

- Sensors and other components in the field to collect traffic information, such as traffic volumes and speeds and video of traffic flow
- Communications links (wireless and wired) to transmit that data for processing or dissemination
- Software that processes and analyzes the data, converting it to information that can be used by other components and various users of the information
- Electronic equipment to disseminate the processed information to end users of the information, such as motorists and transportation agencies.

Work zone ITS is the use of ITS to enhance transportation and improve safety and mobility in and around work zones. Information provided by work zone ITS may be in the form of real-time traffic conditions, such as travel delays through a work zone or recommended diversion routes, which can be used by motorists to alter their travel behavior and by contractors and transportation agencies to alter traffic control strategies, traveler information, or work schedules. Work zone ITS may also be used to provide immediate warnings, such as to drivers that traffic is stopped ahead

or that a slow truck is entering from a work zone or to workers that a vehicle is intruding into their work area.

A work zone ITS deployment can be focused around safety or mobility, but often supports both goals, and can also enhance productivity. The systems are portable and temporary in most cases, although some deployments may use either existing fixed infrastructure or become a permanent system.

A work zone ITS deployment varies in scale based on the magnitude of the construction project and the specific concerns being addressed in a given location. Not all ITS deployments are complicated and expensive. One of the most common components of a work zone ITS deployment is a portable changeable message signs (PCMS) that can be used to communicate traffic conditions to motorists, as shown in Figure 1, based on real-time traffic data collected from sensors.

ITS deployments can have the same objective, but vary widely in how the objective is achieved. Factors that vary from deployment to deployment include:

- What type of data is collected (e.g., traffic volumes and speeds, queue detection);
- How data is collected (e.g., radar, cameras);
- How data is communicated (e.g., cellular, Bluetooth, fiber optic connection);
- What level of detail of information is disseminated (e.g., “slow traffic ahead”, “speed ahead 35 mph”);
- How that information is shared (e.g., websites, PCMS);
- How “real-time” the information is (e.g., predicted, based on current speeds).



Source: FHWA

Figure 1. A portable changeable message sign providing downstream traffic speeds from sensor data.

¹ As of 2010; for more information, see: http://www.ops.fhwa.dot.gov/wz/resources/facts_stats/injuries_fatalities.htm.

Work zone ITS may be leased or purchased through variety of procurement mechanisms. In some cases, data may be leased/purchased from a third party that is already collecting the data (e.g., through Bluetooth) and the ITS is primarily used to process and disseminate the information.

Users of the information provided by work zone ITS may include departments of transportation (DOTs), the public and road users, nearby businesses and employers, media outlets, contractors, trucking companies, emergency services providers, motorist assistance patrols, and third party traveler information providers.

Some current technology options and strategies

ITS can be used to help address many work zone challenges and can take many forms in work zone applications. For example:

Challenge: Frequent but unpredictable congestion due to long-term or short-term lane closures.

Potential application: Benefits may be achieved from deploying a system that detects the onset of congestion, measures conditions on nearby alternate route(s), and automatically presents current travel times on the alternate and the current roadway to encourage diversion when appropriate. If alternate routes are not available, the work zone may benefit from an automatic queue detection warning system if the speed differential between approaching traffic and the traffic already in the queue is large.

Challenge: Reduced or eliminated emergency shoulders.

Potential application: Benefits may be achieved from an ITS deployment that focuses on incident detection, verification, and response within the work zone.

Challenge: Need for frequent direct access by construction vehicles and equipment to/from the travel lanes may result in conflicts with other road users, such as drivers following work vehicles into the work space or large speed differentials between motorists and construction vehicles entering the travel lanes from the work space.

Potential application: ITS could be used to notify motorists following a work vehicle that it will be entering the work zone and not to follow the construction vehicle, or to determine when the entrance of a construction vehicle is imminent and warn approaching motorists or direct them to change lanes or to stop.

Challenge: Agencies may impose penalties to contractors for creating excessive delays or queues during a project, but may not have the personnel available to monitor work activities continuously to verify compliance.

Potential application: Work zone ITS can be deployed to monitor and archive traffic conditions continuously, and the resulting data can be used when assessing liquidated damages or lane rental fees. Archived data can also be used to evaluate traffic control plan changes or even analyze and estimate impacts in future similar work zones.



Source: FHWA

Figure 2. Temporary, solar-powered vehicle detection and camera systems.

Table 1 provides a listing of common work zone ITS applications. It summarizes the components included in each application and provides a general indication of the safety and mobility issues the application attempts to address. As Table 1 suggests, many of the same ITS components are used in each application. Consequently, there are some overlaps in how systems can be designed and implemented to address specific work zone conditions. The differences between applications lie primarily in how the systems are designed to convey information to the motorist or traveler.

The applications presented in Table 1 may be deployed individually or be grouped together depending on the work zone. Ultimately, all of these applications seek to provide a more active management capability to the agency to achieve desired mobility and/or safety goals. Additional deployment examples have been documented in numerous case studies conducted by FHWA on work zone ITS.² As a part of this project, FHWA sponsored additional case studies to examine deployments of ITS in work zones in Effingham, Illinois; Mount Vernon, Illinois; Salt Lake City, Utah; Orem/Provo, Utah; and Las Vegas, Nevada in 2012.

² Additional information on these case studies can be found at: <http://www.ops.fhwa.dot.gov/wz/its>.

Table 1. Sample work zone ITS applications.

| Work Zone ITS | Brief System Description | ITS Components | Issue(s) being Addressed | Example of Deployment |
|--|---|--|--|--|
| Real-time Traveler Information | Drivers provided information about current travel conditions; can be used to encourage diversion | <ul style="list-style-type: none"> Traffic data Changeable Message Signs (CMS) Communications | <ul style="list-style-type: none"> Congestion/delay Safety Driver awareness | For the I-15 Corridor Expansion (CORE) project, Utah DOT monitored travel times for I-15 and US-89 and posted current, comparative information on changeable message signs to reduce delays, stops, emissions, and the number and severity of traffic incidents. http://www.i15score.utah.gov/ |
| Queue Warning | Signs provide warnings to drivers about stopped or slow traffic ahead | <ul style="list-style-type: none"> Traffic data CMS Communications | <ul style="list-style-type: none"> Safety (crashes) | For a large work zone on I-35, Texas DOT used sensors to detect the formation of queues and warn drivers of slowed or stopped traffic downstream via CMS. http://www.ops.fhwa.dot.gov/wz/resources/news/wznews_detail.asp?id=618 |
| Dynamic Lane Merge (early merge, late merge) | Signs encourage drivers to merge at a specified point based on current conditions | <ul style="list-style-type: none"> Traffic data CMS Communications | <ul style="list-style-type: none"> Delay Aggressive driving behavior Safety Queue length | Dynamic lane merge systems on I-95 and evaluated by Florida DOT have shown potential to enhance safety and operations. http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_CN/FDOT_BD548-24_rpt.pdf |
| Incident Management | Enables faster detection of incidents for quicker response and clearance time | <ul style="list-style-type: none"> Cameras Traffic data Communications CMS | <ul style="list-style-type: none"> Incident response and clearance time Delay Secondary crashes | The Big I project in New Mexico incorporated an incident management system to provide accurate information, support quick identification of incidents, and help to manage area traffic. http://www.ops.fhwa.dot.gov/wz/technologies/albuquerque/index.htm |
| Variable Speed Limits (VSL) | Can provide speed harmonization and calm traffic for slow or stopped traffic ahead | <ul style="list-style-type: none"> VSL CMS Traffic data Communications | <ul style="list-style-type: none"> Speed management Safety | In 2008, VSL signs were used by Utah DOT in a work zone on I-80 and by Virginia DOT on the I-495/I-95 Capital Beltway. (http://www.udot.utah.gov/main/uoconowner.gf?n=7828313631638132 , http://www.virginiadot.org/vtrc/main/online_reports/pdfs/10-r20.pdf) |
| Automated Enforcement | Automated system detects and captures images of speeding vehicles for enforcement purposes | <ul style="list-style-type: none"> Cameras Radar Communications | <ul style="list-style-type: none"> Speed management Safety of law enforcement personnel | Some states utilize speed-radar photo enforcement in work zones, including Illinois, which uses vans with retrofitted equipment to reduce speeds through work zones and work zone fatalities. http://onlinepubs.trb.org/onlinepubs/trnews/trnews277rpo.pdf . |
| Entering/exiting vehicle notification | Signs can warn drivers of a slow-moving construction or emergency vehicle entering or exiting the roadway | <ul style="list-style-type: none"> Sensors CMS Communications | <ul style="list-style-type: none"> Safety | Pennsylvania DOT used an innovative system for a unique problem involving emergency vehicle access. The system utilized siren-activated pre-emption technology on emergency vehicles to activate CMS alerting oncoming vehicles that a slow-moving emergency vehicle would be entering the roadway. http://www.roadsbridges.com/case-fire |
| Performance Measurement | Monitor and archive traffic conditions data to support real-time traveler information, modify operations, and support evaluation. | <ul style="list-style-type: none"> Sensors Communications Archive database | <ul style="list-style-type: none"> Congestion/delay Safety Evaluation | Both Ohio and Indiana DOTs have established policies on acceptable work zone queue length and duration. Work zone ITS can monitor and archive traffic data that can be used to evaluate performance measures, including those used in performance-based contracting. |

Source: Battelle

Benefits that are possible with work zone ITS

ITS work zone systems have the capability to provide significant benefits to agencies and to those affected by the mobility and safety impacts of road construction and maintenance work zones. Many agencies have already begun to experience benefits and to pass those experiences on to others. In general terms, potential benefit impact areas associated with the use of ITS in work zones are as follows:

- **Safety** – ITS can help to minimize the consequences of work zones on both traveler and worker safety. Credible warnings of the presence of unexpected queues, notification and reassurance of travel times to reduce driver stress, and credible warnings of construction vehicle access and egress are examples of how work zone ITS can improve the safety of both travelers and workers. Systems that automatically adjust the speed limit of the work zone to current conditions, automate enforcement of traffic laws, or help to quickly identify when incidents have occurred in work zones can also significantly improve safety. For example, the use of an incident management system in a New Mexico work zone reduced average incident clearance time by 20 minutes and is believed to have reduced the frequency of secondary crashes.³
- **Mobility** – Reduced travel time delay is a primary benefit of many work zone ITS applications. Travelers making adjustments to their route, departure time, or mode choices based on information provided by ITS, or the use of alternate traffic management practices (e.g., dynamic lane merging, VSL) via ITS can reduce delay. For example, real-time traveler information induced up to 19% diversion away from a route with a work zone in California.³ These adjustments benefit not only those travelers who made changes to their trips, but others who continued to travel through the work zone. Mobility benefits will be especially high on facilities that serve a large amount of commercial vehicle traffic, as the value of commercial vehicle travel time is very high.
- **Improved work productivity and durability** – Work zone ITS can also improve agency and contractor productivity and efficiency, ultimately reducing the number of days that the work zone is present and reducing contractor operating costs. Reduced congestion and improved mobility can allow the contractor to use fewer trucks to bring materials

into the work space during certain work operations. Better control over material delivery time can result in more durable, high-quality construction. Real-time monitoring of traffic volumes can allow agencies and contractors to initiate lane closure activities as soon as conditions will allow each day or night, rather than wait for a prescribed time that is typically based on a worst-case estimate of traffic demands. Further, the use of ITS in and around work zones can allow for the automation of functions that would normally have to be performed manually by agency personnel. For example, work zone ITS can be deployed to monitor and archive traffic conditions continuously, and the resulting data can assist agencies in imposing penalties on contractors for creating excessive delays or queues during a project. Archived data from work zone ITS can also be used to evaluate traffic control plan changes or analyze and estimate impacts in future similar work zones.

- **Customer satisfaction** – Information gathered and provided by work zone ITS can lead to increased customer satisfaction. ITS allows agencies to update motorists about changes in traffic conditions in the same fashion they occur—in real time. The relative ease of relaying information to the media, websites, social media, and phone applications can enable more frequent updates, as well as wider access to this information. To improve customer satisfaction by reducing delay, a project in Utah used an advanced traffic management system to monitor traffic and post comparative travel time information on CMS, as shown in Figure 3.³ On the CMS, an arrow to the left indicated the travel time to Lehi using I-15 (accessible to the left) and an arrow pointing ahead indicated the travel time via an alternate route (State Street). In Little Rock, Arkansas, 82 percent of drivers surveyed agreed that an Automated Work Zone Information System improved their ability to react to slow or stopped traffic.⁴ Awareness of real-time work zone conditions can improve the favorable perception of the agency to travelers, business owners, residents, and users within the agency.

Purpose and organization of this document

The purpose of this document is to provide guidance 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. Work zone ITS is one possible operational strategy of many potential

³For more information and other examples, see: <http://www.ops.fhwa.dot.gov/wz/its>

⁴Additional information can be found at: <http://www.itsbenefits.its.dot.gov/ITS/benecost.nsf/ID/76C9F2DE2BF5DB1D85257603004E031D?OpenDocument&Query=Home>.



Figure 3. Sequencing comparative travel time sign at a decision point for two different routes to the town of Lehi that was used for a project in Utah.

Source: FHWA

process should be applied to determine the feasibility and design of work zone ITS for a given application by walking through the key phases, from project concept through operation. In addition, the guide discusses evaluating the effectiveness of the system in achieving stakeholder goals (an important but often overlooked activity).

The guide identifies where and how existing regional and statewide ITS architectures should be considered for consistency and interoperability with currently deployed ITS elements, especially when the systems will become part of a permanent deployment.⁶

solutions that an agency can include in a transportation management plan (TMP). A TMP, as required by the work zone Safety and Mobility Rule⁵, lays out a set of work zone management strategies—work zone traffic control, public information and outreach, transportation operations—that the agency will use to manage the impacts of a particular road project. Considering whether to deploy work zone ITS on a project and designing and deploying a system should be done as part of work zone impacts assessment and TMP development and implementation.

This document summarizes key steps for implementing ITS in work zones. Successful implementation of ITS applications in work zones requires a systematic approach to provide a technical solution that accomplishes a specific set of clearly defined objectives. The document illustrates how a systems engineering

This document is organized into chapters corresponding to the steps in the development and implementation process, which are shown in Figure 4. Each chapter addresses the challenges and barriers that agencies may face in deploying ITS applications. Lessons learned are included where appropriate (and compiled in Appendix C), to provide information on how other agencies have overcome these challenges and potential barriers.

This document is intended to guide users through the deployment of any work zone ITS, regardless of its scale. Although the overall scope of the envisioned project will ultimately determine the complexity and level of effort required during planning, the steps included in this document should apply equally to the range of deployments, from small-scale, temporary deployments lasting a few months to complex, multi-year ITS deployments that may eventually be incorporated into permanent traffic monitoring and management systems.

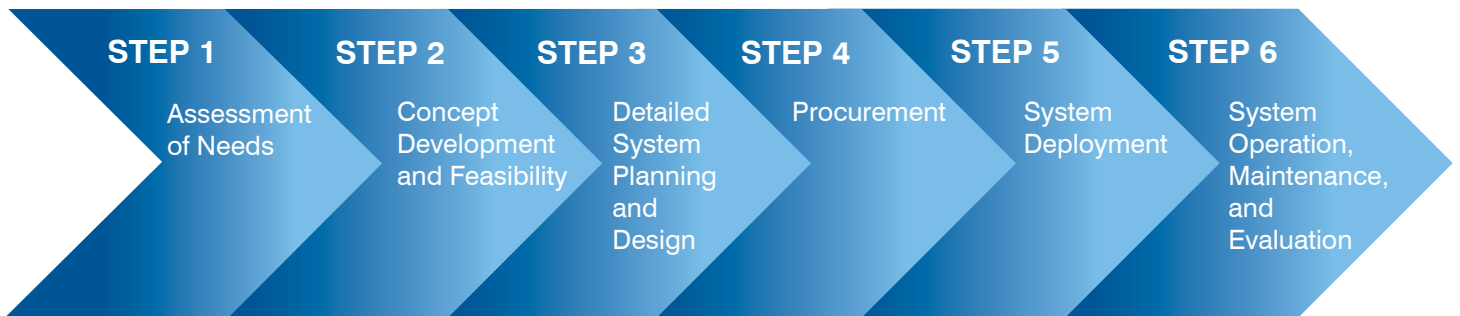


Figure 4. Overview of the implementation process.

Source: Battelle

⁵ More information on the Rule (23 CFR 630 Subpart J) is available at: http://www.ops.fhwa.dot.gov/wz/resources/final_rule.htm

⁶ More information on ITS architecture is available at: http://ops.fhwa.dot.gov/its_arch_imp.



This section describes key activities or considerations that should be addressed in Step 1 of the implementation process, in which the work zone needs are established and preliminary information is gathered. The sub-steps that will be explored in Step 1 are depicted in Figure 5.

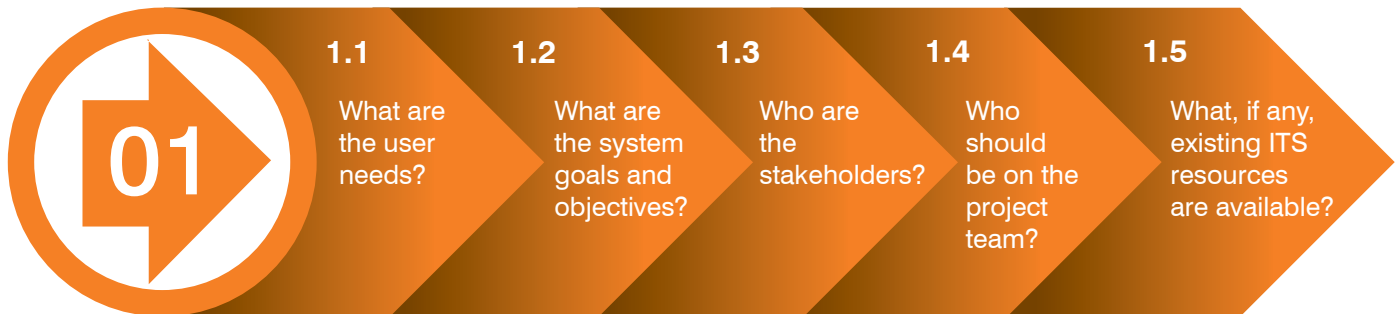


Figure 5. Sub-steps to be explored in Step 1.

Source: Battelle

1.1 What are the user needs?

Users are those who will use and directly benefit from the outputs of the work zone ITS system. Most often, user needs are in reference to travelers, but user needs may also be identified for the agency or contractor. Each work zone presents different challenges and unique circumstances that affect user needs. Table 2 provides examples of some of the issues that may be encountered in a work zone and need to be addressed.

The first sub-step in Step 1 is to determine what issues/needs exist for the work zone. This should be performed in the context of an overall assessment of the expected impacts of the work zone, and in coordination with the transportation management plan (TMP) development process for the work zone.⁷ This larger perspective is important because there may be more than one TMP strategy that can address the need, and work zone ITS may not be the best alternative to mitigate these issues. Determining the user needs first will help an agency better decide whether work zone ITS will adequately address the problem at hand and if it is the most suitable solution. Work zone ITS should be intentionally applied as a carefully designed solution to a well-defined problem.

⁷ More information on work zone impacts assessment and TMP development is available at http://www.ops.fhwa.dot.gov/wz/resources/final_rule/guidance.htm.



Example: McClugage Bridge rehabilitation, Peoria, Illinois.

This project provides an example of the importance and value of considering user needs early in the work zone planning process. The McClugage Bridge consists of two independent spans, each serving one direction of US 24/US 150 travel through Peoria and across the Illinois River. During the rehabilitation effort, the eastbound span of the bridge was closed completely, and traffic in both directions of travel was placed on the westbound span. The Illinois DOT and the contractor elected to use both a movable barrier system and work zone ITS to try to address mobility problems expected from the bridge closure. However, officials found that the movable barrier provided sufficient peak period and peak direction capacity through the work zone that the congestion that was feared never materialized. As a result, the work zone ITS never had to be activated during the project.

Not all user needs will automatically imply that work zone ITS is required. Analysis in subsequent steps of concept development may indicate that some other approach to mitigating the problem to address the user need is more appropriate, or may verify that the work zone ITS solution is needed. In this example, greater consideration of the effect of the moveable barrier may have indicated that there was not a significant user need to warn approaching traffic about travel conditions, such as stopped traffic.

Satterfield, C. Moveable Barrier Solves Work Zone Dilemma. In *Public Roads*, Vol. 65, No. 1, July/August 2001, pp. 26-29. Accessible at: <http://www.fhwa.dot.gov/publications/publicroads/01julaug/workzone.cfm>.

Table 2. Examples of site-specific issues and problems.

Examples of mobility issues or problems:

- Long-term capacity reductions will create daily peak-period delays.
- A contractor is managing material deliveries from the batch plant to the job site and needs to know when and how much the travel time between the two locations is changing over time because of congestion.
- Loss of shoulders will make effects of incidents more severe and longer-lasting. Ability of emergency services to reach incidents will be hampered.
- Geometric constraints upstream of the project will make it critical to minimize queue lengths due to any lane closures.
- Ridesharing and transit users during the project need to be given a travel time advantage to promote mode shift.
- Off-peak short-term lanes closures will create unexpected queues, and significant diversion is needed to keep queues at reasonable lengths.

Examples of safety issues or problems:

- Nighttime lane closures will create queues and large-speed differentials, increasing rear-end crash risk.
- Constrained geometrics are likely to necessitate a reduced speed limit through the project, but those constraints will make enforcement of the reduced speed limit very difficult.

Examples of productivity issues or problems:

- Haul vehicle difficulties to access and egress the work space will delay material deliveries, and increase the number of vehicles required to support work tasks.
- A contractor is managing material deliveries from the batch plant to the job site and needs to know when and how much the travel time between the two locations is changing over time because of congestion.

When identifying and describing the user needs for a particular project, it is important to be as specific as possible. For example, the Illinois DOT identified unexpected queue formation at work zones in semi-rural areas as a concern. They specified that these concerns existed whenever a temporary lane closure or long-term road closure was required, and whenever a vehicle stall might occur (because of a lack of emergency shoulders to move the vehicle out of travel lanes). Trying to reduce the effects of unexpected queues, coupled with the unpredictability of the events causing those queues, was the specific user need to be addressed. Similarly, the Texas DOT also had a user need to reduce the effects of unexpected queues during construction projects along I-35. However, in defining their needs they also desired to minimize the amount of equipment deployed within each of the several projects that were ongoing simultaneously along the 90+ mile corridor. They also wanted to be able to accurately detect and measure the length of queue that developed at each temporary lane closure installed so that forecasts of delay impacts from the closure could be disseminated to motorists farther upstream. Thus, their specific user needs were somewhat different from those of Illinois DOT, even though both were concerned about the same general issue.

Another consideration are regulatory requirements or agency policies associated with monitoring and assessing the impacts of a work zone. For example, an agency's policy may limit work zone delays to 20 minutes. Work zone ITS can be used to monitor if a work zone is meeting the agency's target. 23 CFR Subpart C (sometimes referred to as the 1201 rule from the SAFETEA-LU Highway Authorization Act of the 109th U.S. Congress)⁸ establishes minimum requirements for agencies for real-time information, including work zone lane closure information for long-term construction projects. The Work Zone Safety and Mobility Rule (23 CFR 630 Subpart J) requires agencies to use work zone safety and operational data to improve projects and agency policies, processes, and procedures regarding work zone safety and mobility management. Work zone ITS is one of the possible ways to gather data for use in assessing work zone performance.

1.2 What are the system goals and objectives?

An agency must clearly articulate its goals at the outset of the project to best ensure deployment of a system that will satisfy those objectives. Although general goals or objectives for the system may be stated as

agency policy, it is the responsibility of staff engineers and planners to translate general goals into specific, measurable, and, most importantly, attainable objectives for the project and the work zone ITS (e.g., no more than 20-minute delays or 2-mile queues). The goals and objectives should address user needs identified in Step 1.1 and through impacts assessment, and also support TMP development. System goals and objectives should also follow SMART criteria, meaning that they are Specific, Measurable, Attainable, Relevant, and Time-bound. The key factor in this step is to set realistic objectives for the system and avoid the creation of unrealistic expectations that result in diminished credibility in the system's outputs. In other words, if a work zone ITS would be deployed, what would it do to address user needs?

Those engaged in the goal-setting process should periodically check to ensure that goals or objectives have corresponding means of measurement. In other words, how will success of a system be measured during and after it is deployed? It will be important to match data availability and/or processing capabilities of the system with the desired goals and objectives. For example, if a queue length threshold is established for the project, the system should be capable of providing reasonable queue length estimates. Conversely, if delay is the desired metric, a system that directly measures travel time and delays might be more appropriate.

In general, the system should be adequately robust to consider the full impact of the work zone. As shown in Figure 6, for example, the area of ITS influence due to a work zone may include adjacent routes. It is likely that at least some drivers will divert, regardless of whether messages encourage taking an alternate route. This additional traffic may cause congestion on those adjacent routes and should be considered when planning for the ITS. If diversion is expected, ITS devices may be required on alternate routes as well as the mainline. These alternate routes will need to be monitored and managed in order for benefits to be achieved. While the ITS zone on the mainline may extend upstream from the work zone beyond the length of the expected queue (e.g., a queue warning system), and perhaps upstream from a diversion point (e.g., real-time travel information system with comparative travel times or suggesting alternate routes), ITS could also be considered on alternate routes that could be impacted. The FHWA report "Advancing Metropolitan Planning for Operations: The Building Blocks of a Model Transportation Plan Incorporating Operations – A Desk Reference" may serve as a useful guide for this step.⁹

⁸The text of Section 511.309 can be found at: <http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=66686edfa10d4ace67b3e67bbc442ef7&rgn=div5&view=text&n ode=23:1.0.1.6.16&idno=23>.

⁹Available at: <http://www.ops.fhwa.dot.gov/publications/fhwahop10027/>

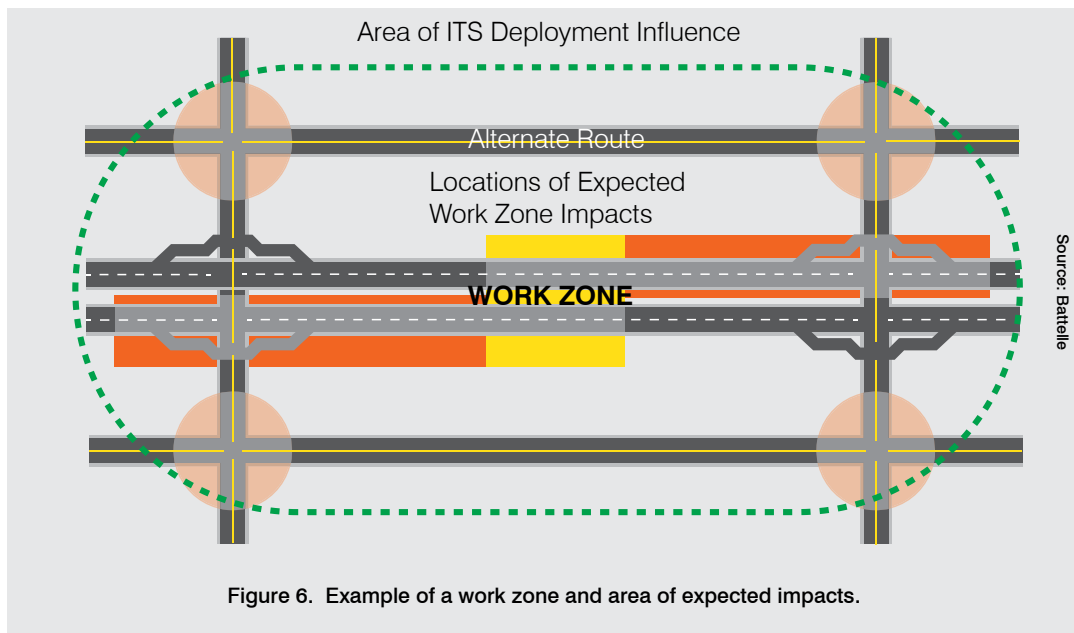


Figure 6. Example of a work zone and area of expected impacts.



Key point: Work zone ITS is one of several tools available to address specific safety and mobility issues in work zones.

If goals and objectives become more manageable to achieve through a different technique, that technique should be selected instead of ITS. Other strategies may be more economical and effective in meeting goals and objectives



Tip: Have realistic expectations.

Although some ITS applications may be promoted as a catch-all solution to safety and capacity problems, field testing has not always shown conclusive benefits. Work zone ITS should be well designed and smartly applied to scenarios in which benefits are most likely to be achieved.



Tip: Be sure that the work zone ITS fully captures the range of impacts for which it is intended.

This is particularly important for deployments that are intended to convey delay or queue length information to users. In some deployments, work zone impacts periodically extended beyond the limits of the ITS devices. When this happened, the system was unable to provide accurate information. More importantly, the motorists sat through several minutes of delay before encountering a message that there were delays and reduced speeds in the work zone. This severely limited the credibility, usefulness, and benefits of the system.

1.3 Who are the stakeholders?

Stakeholders should be engaged early in the project development process to ensure that a full range of possibilities can be considered. Stakeholders include any person or organization that may be affected by construction, and all agencies that are directly involved with motorist assistance, law enforcement, and providing traveler information. Stakeholders are a broader group than users, and include those who are not intended to be primary users of an ITS deployment. Potential stakeholders include:

- State DOT (including those with ITS expertise)
- City transportation agencies
- Metropolitan Planning Organizations
- County transportation agencies
- FHWA Division Office
- Service patrol/contractors
- Construction contractors
- State and local police departments
- Fire departments
- Emergency medical services
- Local businesses
- Shopping centers and other major traffic generators
- Major commercial trucking companies
- Motorists
- Media
- Residents
- Public officials
- Other incident management agencies.

Stakeholders should include policy makers, as well as staff from agencies involved in the deployment, operation, and maintenance of both the work zone and the ITS application. Although not all of these groups may have a direct interest in all of the project's objectives, they may be able to offer valuable insight that expands the original vision to achieve greater benefits.

If the project is within an area that has already developed a regional ITS architecture, many of the stakeholders would have already been identified. This would be a good place to start to establish a core team to further define the system concept. This group can also help identify other potential work zone information sharing opportunities between jurisdictions and agencies.

Stakeholders must be involved early on for a successful ITS implementation. Input from these groups can result in better deployment plans. It is unlikely, especially for smaller projects, that stakeholders will convene for a meeting solely about ITS; instead discussion regarding ITS will likely be part of a larger agenda, such as on the TMP or the project alternatives and schedule. It is important to ensure that ITS is included on this larger agenda to help stakeholders understand the possible deployment and gain their input and support. Smaller working groups should be developed and convened regularly to keep all stakeholders informed about the progress of an ITS deployment. The goals of such a working group should include keeping stakeholders informed, creating opportunities for input and participation, providing feedback, creating an informed consensus, and identifying the need for system adjustments during deployment. Working group discussions might be combined with related meetings such as those on maintenance of traffic.

Stakeholders need to have input in developing the goals and objectives of the implementation and should review strategies and plans to make sure their needs are being met to the fullest extent possible. Ideally, this input will be gathered as part of the project impacts assessment and TMP development process to support an efficient and coordinated process for work zone management. Stakeholders should review critical steps in system development and should be influential when decisions are being made.



Tip: Stakeholder agencies, besides the deploying agency, need to be involved early.

Coordination with other agencies is a primary issue that should be considered both in developing and implementing an ITS work zone. This will be important for determining how the system can work within each agency's existing procedures.



Example: I-15 CORE Project in Utah.

Utah DOT traffic operations personnel were incorporated early in the project planning process and strived to be proactive in addressing the various mobility concerns that could develop. During the planning process, it became apparent that it would be extremely beneficial to upgrade the arterial signal systems in Provo and Orem to become compatible with the Utah DOT centralized signal system. Utah DOT approached the cities of Provo and Orem and established cooperative agreements to convert their systems to the statewide signal control system in order to better manage travel on the arterial streets adjacent to the freeway.

1.4 Who should be on the project team?

The next step is to assemble the project team. The project team is the actual working group whose members are drawn from the stakeholder organizations identified in the previous step. It is recommended that the number of people on this team be small because this team will be conceptualizing and planning the project. While it is important to involve a wide range of stakeholders from the very beginning of the project, it is also important to keep working groups small so that these groups can actually get things done. Thus, not all stakeholders will have a representative on the project team. Instead, the project team will be responsible for interfacing with stakeholders that are not on the project team to keep them informed and receive their input. In addition, it is also important not to expect that all stakeholders will be fully “sold” on the project at first. Instead, the lead agency must have patience with “non-believers,” allowing them time to develop trust in the system, as well as trust in other groups involved in the project.

1.5 What, if any, existing ITS resources are available?

Taking an inventory of existing ITS resources in the corridor or region that can be applied to help manage the work zone can help to control system acquisition and deployment costs. For example, there may be a permanent traffic detector within or adjacent to the work zone that can provide archived or real-time data to help predict and/or monitor traffic conditions

leading up to and throughout the work zone. There may be permanent CMS upstream of the work zone that can display warnings of stopped or slow traffic ahead or encourage diversion to alternate routes, as presented in Figure 7. Closed-circuit television (CCTV) cameras in the area might also be particularly useful for helping to monitor traffic and check for incidents. Any road weather information systems (RWIS)/environmental sensor stations (ESS) in the area can help determine current weather and road conditions that will affect traffic flow. Additionally, the availability of a local traffic management center (TMC) can be very beneficial, as staff could operate ITS for the work zone. An existing traveler information website for the agency or geographic area can be used to provide updates on work zone conditions to the public.

The maintaining agency for these resources can explain the availability of ITS resources for use. For example, CMS may be needed for emergency messages, or it may not be preferred that a message is displayed for all hours due to concerns of burning out the lighting mechanisms and long term maintenance costs. Discussions about stakeholders concerns may result in some creative solutions, such as agreement to place messages on during peak hours of travel.

If existing ITS resources are available and are planned to be used for work zone management purposes, care must be taken to ensure that the resources themselves will remain operational over the duration of the project



Colorado DOT

Figure 7. Existing ITS resources can be used to help manage the work zone and reduce costs.

and access to the systems and data is readily available. The need to temporarily disconnect power or communication lines in the work zone may render permanent ITS devices near the work zone inoperable or inaccessible, or they may even be removed if they are directly in the work area. Construction equipment or vehicles have the potential to block sensors or cameras unexpectedly and repeatedly. To avoid such issues, some agencies include requirements in the bid documents that permanent ITS devices be maintained in an operational state throughout the duration of the project. Agencies may also include disincentive clauses in a contract that are applied if the ITS equipment does not work during peak hours. Functionality of ITS equipment is particularly important in congested areas where the television, radio, and/or social media traffic updates rely on information from the ITS equipment.

In some cases, it may be desirable to mesh or replace available ITS resources with additional temporary devices obtained specifically for a particular work zone. An example of this might be the purchase and installation of portable traffic sensors, cameras, and CMS within and near a work zone on a facility that is not currently covered in a regional ITS, and having the operators within the TMC monitor and manage those temporary devices in addition to the permanent ITS components they normally operate. In such instances, it is important to bring the key decision-making personnel from the center in early in the planning process to help identify needs and issues. The center may need to increase staff to handle the increased workload, for example, and need financial support through the project budget to do so. There will likely be specifications as to how temporary devices must be configured and operated (i.e., National Transportation Communications for ITS Protocol (NTCIP)-compliant cameras) in order to integrate data feeds into the operator consoles.



Example: Use of Permanent ITS Infrastructure during Construction.

- I-15 CORE Project in Utah. When Utah DOT officials determined that I-15 needed to be widened through the cities of Orem and Provo, they enlisted the regional ITS center in Salt Lake City to assist in managing traffic during construction. A number of value-added items were proposed by the winning design-build (DB) team that centered around the enhancement of the existing system. System officials worked closely with the DB team and with Utah DOT project officials to coordinate the purchase, implementation, and integration of technology at critical locations to help mitigate project impacts. In addition, system officials identified other components that were needed in the region to help support traffic management during construction, and that could also be useful additions to the system once construction was complete. These components were procured and installed in time to be useful for the construction project.
- Las Vegas. The Freeway and Arterial System for Transportation (FAST) is a transportation management system in Las Vegas. FAST operators have a fairly wide range of tools at their disposal to help address construction and maintenance activity-related impacts. FAST provides a convenient dissemination outlet of both advance notification and real-time roadwork-related traffic information via the roadside CMS and its website. FAST operators are trained to both identify the need for CMS messages and to properly design and post them. For certain roadwork activities, FAST operators may also make signal timing changes to support use of arterials as detour routes if either the freeway or another arterial is affected by

Key Takeaways

- Plan with the end in mind. Start with identifying work zone issues and user needs, and what the goals are for the work zone. Then consider possible solutions/strategies, including ITS, that can address those needs.
- Use a coordinated approach. Consider work zone issues, needs, and possible mitigation strategies in the context of overall impacts assessment and TMP development for the work zone to most effectively address issues and use resources.
- The main product of Step 1 is a preliminary framework of user needs, goals and objectives, and existing ITS resources in the area around which ITS or some other solution for the work zone can be developed. These outputs will be used in Step 2 for the development of a concept of operations.
- Additionally, stakeholders and a project team have been identified in Step 1, who will respectively provide periodic feedback and more direct input to the project moving forward.



This section describes key activities or considerations that should be addressed in Step 2 of the implementation process, in which a system concept for the ITS deployment is developed. The sub-steps that will be explored in Step 2 are depicted in Figure 8.

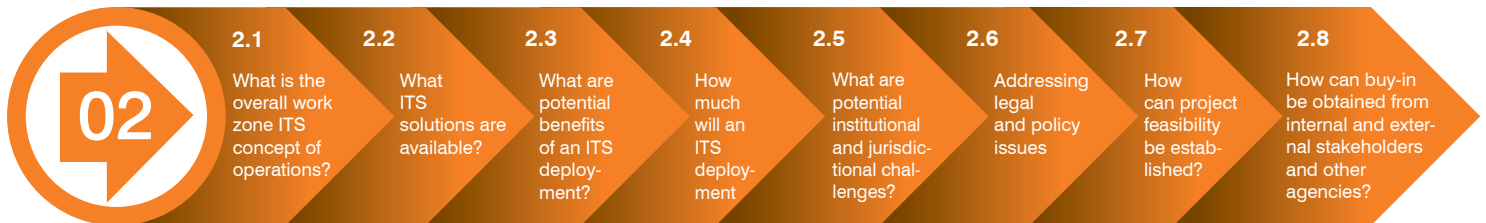


Figure 8. Sub-steps to be explored in Step 2.

Source: Battelle

2.1 What is the overall work zone ITS concept of operations?

The development of a work zone ITS concept of operations should take place in the early stages of the planning process. It should answer the question, how does the agency envision that the system will operate within the work zone? A concept of operations includes user needs and objectives that were developed in Step 1, as well as justification for and description of the proposed system, operational policies and constraints that will govern how the system is deployed, and scenarios describing how the system will function. Developing a concept of operations helps ensure the agency has thought through what it needs out of the system, which generally leads to a more successful work zone ITS deployment. Figure 9 shows the general

outline of a formal concept of operations document based on the Institute of Electrical and Electronics Engineers (IEEE) 1362-1998 standard document. For a small work zone ITS deployment, the developed concept of operations document may be significantly scaled back, as seen in a concept of operations developed for a Minnesota DOT work zone ITS deployment.¹⁰

Even though a concept of operations starts to formalize the type of system that is envisioned, it is important to note that this document is solution-agnostic, describing how the system will operate but not prescribing the technology components to be installed. For example, a concept of operations should not dictate whether radar or video detection should be used, even if in some situations there may be only one viable alternative that exists.

¹⁰ Document can be found at: http://www.dot.state.mn.us/guidestar/2006_2010/icone/iconeconceptofops.pdf

| |
|---|
| 1. SCOPE |
| 1.1 Identification 1.2 Document Overview 1.3 System Overview |
| 2. REFERENCED DOCUMENTS |
| 3. CURRENT SYSTEM OR SITUATION |
| 3.1 Background, Objectives, and Scope 3.2 Operational Policies and Constraints 3.3 Description of the Current System or Situation 3.4 Modes of Operation for the Current System or Situation 3.5 User Classes and Other Involved Personnel 3.6 Support Environment |
| 4. JUSTIFICATION FOR AND NATURE OF CHANGES |
| 4.1 Justification for Changes 4.2 Description of Desired Changes 4.3 Priorities among changes 4.4 Changes Considered but not Included 4.5 Assumptions and Constraints |
| 5. CONCEPTS FOR THE PROPOSED SYSTEM |
| 5.1 Background, Objectives, and Scope 5.2 Operational Policies and Constraints 5.3 Descriptions of the Proposed System 5.4 Modes of Operation 5.5 User Classes and other Involved Personnel 5.6 Support Environment |
| 6. OPERATIONAL SCENARIOS |
| 7. SUMMARY OF IMPACTS |
| 7.1 Operational Impacts 7.2 Organizational Impacts 7.3 Impacts During Development |
| 8. ANALYSIS OF THE PROPOSED SYSTEM |
| 8.1 Summary of Improvements 8.2 Disadvantages and Limitations 8.3 Alternatives and Trade-offs Considered |
| 9. NOTES |
| 9.1 Acronyms and Abbreviations 9.2 Terms and Definitions |

Figure 9. General outline showing the sections of a formal concept of operations document based on the IEEE 1362-1998 standard.

The concept of operations should clearly describe all activities associated with operation of the system, from the data flows between system components to information flows between the agency and the public. Creation of data flow diagrams, information flow diagrams, and communication charts can be valuable in helping agency staff define how the system will ultimately operate, as well as in guiding decisions affecting the overall strategy for the system. An example graphic that could be used to help staff visualize the layout of the ITS deployment is shown in Figure 10. Potential strategies can vary from simple automated systems that provide traveler information upstream of the work zone to systems that serve as virtual TMCs.

Agency staff should clearly describe the operational system strategy at the outset of the project, with particular attention to how this strategy will fit within their overall construction project. In addition, the concept of operations for the ITS deployment should make sense in the context of the existing roadway network. For example, if CMS will be used to provide messages about delay or stopped traffic ahead, it would make sense to place the signs prior to exits to alternative routes. The concept of operations can be a working document during planning stages, and can be updated as needs change and system functionality is considered. The concept of operations can also include multiple subsystems, e.g., a queue warning system, incident detection system, and VSL system.

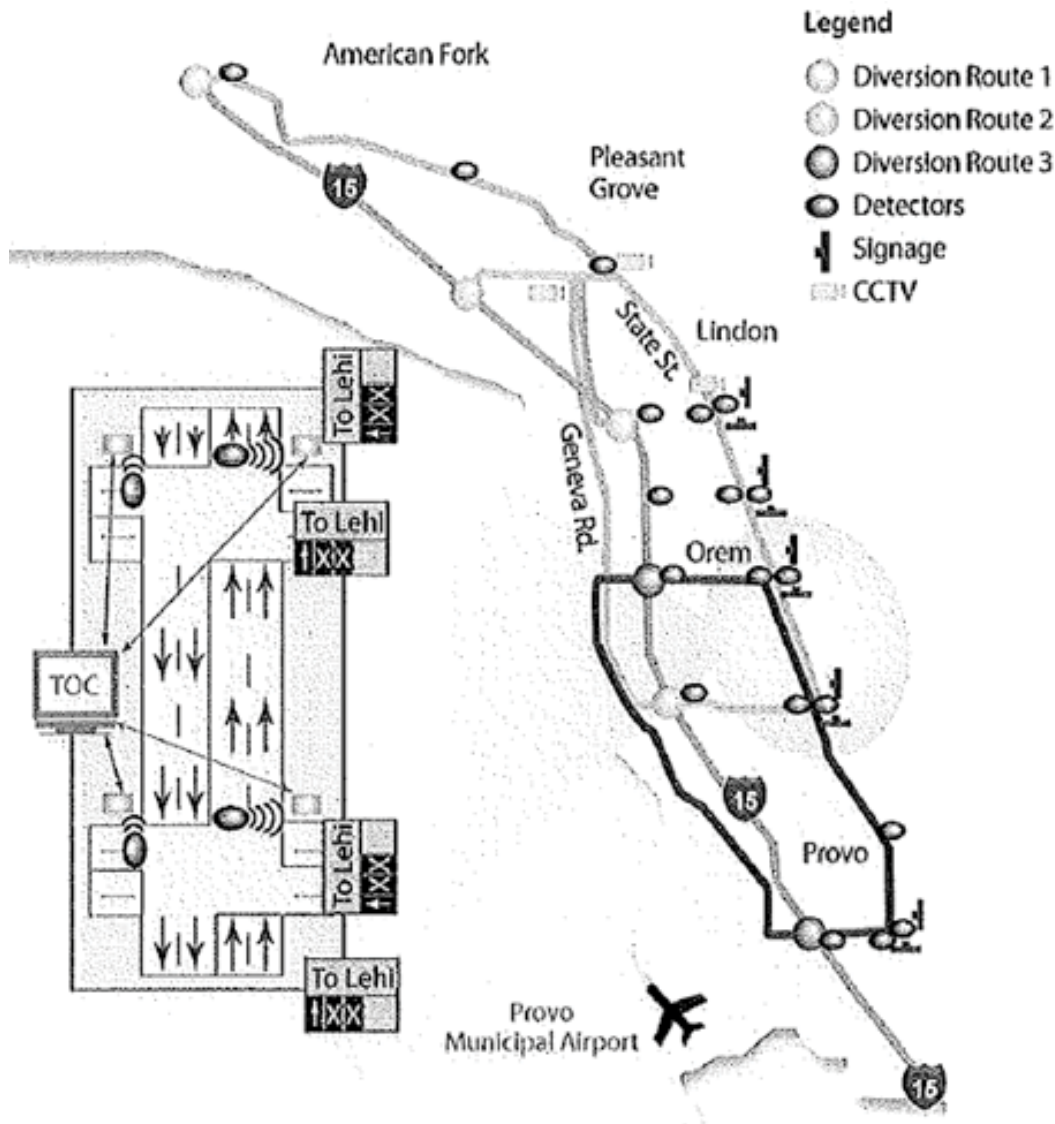


Figure 10. High-level sketch for the concept of operations of a work zone ITS deployment in Utah. Source: Utah DOT.



Key point: Not all ITS deployments are complicated and expensive.

For example, an additional temporary traffic sensor or two may be all that is needed to expand or enhance an existing permanent ITS deployment to be an effective tool for managing traffic impacts at a particular work zone. This was the approach taken during the I-15 CORE project in central Utah.

2.2 What ITS solutions are available?

ITS technology is one tool that can be used by agencies and contractors to address a wide range of concerns or needs in a work zone. Systems can vary widely based on concerns being addressed. They also vary in scale. Not all ITS deployments are complicated and expensive.

ITS can take many forms in work zone applications. In general terms, these systems are comprised of components in the field, communications links, a TMC, and/or archived data. The National ITS Architecture provides a framework for planning, designing, and integrating ITS components.¹¹ Additionally, permanent ITS applications may already be in place in part of the work zone area, and may be useful as components for work zone ITS. More specifically, systems include one or more of the following components, which are detailed in Table 3:

- Sensors that collect data on current traffic conditions
- Communications equipment to transfer the data or information developed from that data

- Software that processes and analyzes the collected data, as well as available supplemental (e.g., weather data or traffic data from alternate routes) and archived data (e.g., historic traffic data), converting it to information for use by other components or by various end users
- Electronic equipment to disseminate the information to the end users or to implement traffic control or management decisions that were based on that information.

These systems are available in a variety of configurations. These configurations can impact the procurement options that are available to an agency, which will be discussed in more detail in Step 4 of the document. In general, the three main categories of ITS are:

- Stand-alone, commercial off-the-shelf (COTS) products to serve specific functions (i.e., smart work zone systems that can perform queue warning, travel time and delay information dissemination, dynamic late or early merge warnings at lane closures, etc.);

Table 3. ITS components.

| ITS Component | Types |
|-----------------------------------|--|
| Sensors | <ul style="list-style-type: none"> • Spot speed/volume/occupancy sensors • Cameras (manual visual monitoring and automated video detection) • Point-to-point travel time sensors (automated vehicle identification, or AVI; radio frequency identification, or RFID; automatic vehicle location, or AVL; Bluetooth; cellular telephone tracking) • Emissions sensors • RWIS/ESS • Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) |
| Communications Systems | <ul style="list-style-type: none"> • Cellular • Wireless (Wi-Fi), private or public • Satellite communications • Dedicated short range communications (DSRC) |
| Software and Electronic Equipment | <ul style="list-style-type: none"> • Portable CMS (PCMS) • Dynamic Signs • Specialized signs (e.g., variable speed limit operations) • Highway Advisory Radio (HAR) • Websites • Smart phone/tablet applications • Social Media • Text Alerts |

Source: Battelle

¹¹ For more information about the National ITS Architecture, see Appendix A, and http://ops.fhwa.dot.gov/its_arch_imp

- Customized work zone ITS solutions that are specially designed to meet a precise traffic management need, such as the deployment of temporary sensors or temporary ramp metering devices at selected problem locations to be integrated into and operated using an existing TMC. This type of system may require additional services, such as system design support and software development and integration;
- Services or data only (no equipment) that provides the agency with information to monitor, manage, and/or measure the performance of traffic within and around the work zone. The agency makes use of what others have already deployed and does not need to procure equipment to obtain the data.

The FHWA Work Zone Mobility and Safety Program provides numerous case studies and resources available to help transportation professionals familiarize themselves with the current state of the practice on ITS in work zones.¹² Topics include the benefits of using ITS in work zones, automated work zone information systems, traffic management systems including dynamic lane merge systems and speed management systems, PCMS, and work zone ITS deployment examples.



Example: Current strategies and how they can be used.

- The Michigan Department of Transportation deployed ITS during a total closure of I-496 in downtown Lansing. This \$2 million system used 17 cameras and six queue detectors to gather and process data on current conditions, and 12 CMS to display advance traveler information to the public to help alleviate traffic congestion resulting from the full closure of a major freeway.
- The New Mexico Department of Transportation deployed ITS during the reconstruction of the I-40 and I-25 “Big I” interchange in Albuquerque. The \$1.5 million system used eight cameras, eight modular CMS; four arrow dynamic signs; four all-light emitting diode (LED) portable CMS trailers; four portable traffic management systems, which integrate cameras and CMS on one fully portable unit; and four HAR units, all linked electronically to the temporary Big I TMC to better manage incidents during the project.

Work zone ITS applications are continuously evolving to better address issues. The Transportation Research Board (TRB),¹³ American Association of State Highway and Transportation Officials (AASHTO),¹⁴ and American Traffic Safety Services Association (ATSSA)¹⁵ have committees and conference sessions that focus on work zone operations. These serve as forums for practitioners to share information on the latest applications and emerging technologies.

Additionally, emerging connected vehicle technologies that incorporate V2V and V2I communications will present major opportunities for communications and data gathering for work zone systems. Portable information devices such as smartphones and tablets provide increased opportunities for information dissemination by agencies, but must be used carefully because of the safety concerns associated with distracted driving.

Communications are a critical component of ITS. Table 4 summarizes the different communication systems that have been used and some key considerations for each communication option.

A factor to be considered is how various communication options are affected by physical features of the work zone, such as terrain, foliage, number and size of buildings in the area, and other wireless networks in use nearby. Wireless systems may not perform as well due to interruptions in the line of sight.

Two groups of professionals may be helpful to an ITS project manager when dealing with communications issues: state DOT maintenance personnel, and local radio contractors. Public agency maintenance personnel responsible for other communications systems used by the state can provide valuable assistance. Typically, these other communication systems are installed in the field and must meet high performance standards similar to what the ITS work zone system will require. This consideration is even more important in rural areas, where communication options become more limited due to lack of key infrastructure.

The FCC has identified unlicensed bands in the 2.4 GHz range that are suitable for supporting a variety of data and voice communications. The availability of unlicensed communications has stimulated many

¹²Available at: <http://www.ops.fhwa.dot.gov/wz/its>.

¹³Available at: <http://www.trb.org>.

¹⁴Available at: <http://www.transportation.org>. For information specific to work zone ITS, see: <http://ssom.transportation.org/Pages/ITSinWorkZones.aspx>

¹⁵Available at: <http://www.atssa.com>.

Table 4. Communication options, advantages, and disadvantages.

| | Advantages | Disadvantages | Comments |
|--------------------------------|--|---|---|
| Cellular (commercial wireless) | <ul style="list-style-type: none"> • Good in areas lacking landline systems • Common system interfaces available | <ul style="list-style-type: none"> • Coverage may be limited, especially in rural areas away from major traffic corridors • Commercial system that may be “oversold” and subject to availability of signal • System is sensitive to terrain and time of year if deployed in areas with heavy foliage | When using wireless Internet, the agency needs to ensure that system Internet protocol (IP) address has high enough priority, so that information flows through the network as quickly as possible. |
| Private Wi-Fi networks | <ul style="list-style-type: none"> • Inexpensive for localized communications between devices • Wide area coverage is possible but more costly • Not dependent on commercial cellular service | <ul style="list-style-type: none"> • Lengthy license application may be required • Intermodulation studies may be required • Terrain may affect coverage • Additional infrastructure such as antenna towers may be needed for longer-range communications • Frequency availability may be limited | |
| Satellite System | <ul style="list-style-type: none"> • Good for areas lacking landline systems or cellular coverage that require internet access or long-range communications • Not dependent on location or terrain for strength of signal (urban or rural) | <ul style="list-style-type: none"> • Commercial system may be “oversold” and subject to availability of signal • Cost may be higher relative to other systems • Signal strength may fade during severe weather and heavy rain | Compare the different options to see which system provides the best fit based on project needs. |
| High frequency radio | <ul style="list-style-type: none"> • Wide area coverage • Good in areas lacking landline systems • Not dependent on commercial cellular service • Inexpensive | <ul style="list-style-type: none"> • Lengthy license application may be required • Intermodulation studies may be required • Terrain may affect coverage depending on frequency available • Additional infrastructure, such as antenna towers, may be needed • Frequency availability may be limited • Others may illegally use the same frequency causing the message to be “jumbled” or “walked on” | Highway advisory radio systems use cellular due to issues with availability of Federal Communication Commission (FCC) license. |

Source: Battelle

communications vendors to produce the necessary equipment. As such, the costs for implementing such connectivity have been reduced dramatically. The Unlicensed National Information Infrastructure (UNII) band does not require licensing, and many communications products operate on this band.

For ITS, determining the appropriate type of communication is key. Depending on the type of contracting arrangement (if any), it may be up to the contractor to select types of communications equipment that satisfy the requirements and specifications. Specifications can be written to allow for a desired equipment model or brand to be used, if the agency has a particular piece of equipment in mind (e.g., satellite communications for areas where cellular communications do not exist, such as mountainous areas).



Tip: Systems need to have reliable communications.

The communications network for an ITS application is vital to the operation of the system and must be reliable. Issues that may impact communications need to be addressed early in the system development and deployment process. What may seem like a trivial issue at the outset may evolve into a more difficult problem when deploying or operating the system. Such issues include whether adequate cellular capacity is available and whether there are obstructions to signal transmission due to geography or terrain.

2.3 What are the potential benefits of an ITS deployment?

As indicated previously, benefits of ITS in work zones are realized by the public, businesses, the contractor, and by the agency. Benefit impact areas associated with the use of ITS in work zones can include safety, mobility, improved work productivity and durability, and customer satisfaction. Table 5 provides a summary of benefits that have been experienced for various work zone ITS.

2.4 How much will an ITS deployment cost?

Developing general cost estimates for various alternatives can be extremely useful in developing a plan for a realistic system. A first step is to examine the cost of similar systems deployed elsewhere in the state or in neighboring States. It is also beneficial to develop early cost estimates for the deployment options. If there are no other systems available for comparison in one’s own state or nearby, the next step is to examine similar systems deployed in other locations in the U.S. and even worldwide. These cost comparisons are made

more difficult by factors that may differ between regions, such as labor rates and availability of certain types of communications.

The cost of ITS in work zones can vary widely and is influenced by the scope of the overall work zone, procurement method, the type of system, and system goals:

- **Scope of the overall work zone** – The relative cost of ITS seems to be largely dependent on the scope of the overall work zone, such that the portion of the cost due to the ITS may be smaller in larger work zones and vice versa.
- **Procurement Method** – The cost of the work zone ITS can be very different for a system that is leased versus one that is purchased, or even a data purchase.
- **Type of system** – A more labor-intensive, complex, and specialized system is likely to be more expensive than a more standard work zone ITS deployment.
- **System goals** – Although sometimes agencies will develop a general plan and then inquire about the costs associated with implementing the plan, an

Table 5. Examples of benefits for various work zone ITS.

| Work Zone ITS | Issue(s) being Addressed | States with Studies of Example Deployments ¹ | Example of Benefits |
|--|--|---|--|
| Real-time Traveler Information | <ul style="list-style-type: none"> • Congestion • Delay • Safety | CA, DC, NE, OR | 16-19% reduced traffic volumes (diversion) on affected route (CA) |
| Queue Warning | <ul style="list-style-type: none"> • Safety (crashes) | IL | Significantly reduced speed variance; reduced vehicle conflicts; queuing crashes reduced 14% despite an increase in both lane closures and vehicle exposure. |
| Dynamic Lane Merge (early merge, late merge) | <ul style="list-style-type: none"> • Delay • Aggressive driving behavior • Travel speed • Safety • Queue length | FL, MI, MN | Reduced forced and dangerous merges by factors of 7 and 3, respectively (MI) |
| Incident Management | <ul style="list-style-type: none"> • Incident clearance time • Delay | NM | Reduced average time to respond and clear incident from 45 minutes to 25 minutes (NM) |
| Variable Speed Limits (VSL) | <ul style="list-style-type: none"> • Speed management • Safety | VA, UT | Greater speed compliance vs. static signs; reduced average speed and variation (UT) |
| Automated Enforcement | <ul style="list-style-type: none"> • Speed management | MD, IA, IL, OR | Significantly reduced speeds by 3-8 mph (IL) |
| Entering/Exiting Vehicle Notification | <ul style="list-style-type: none"> • Safety | MN, PA | Signs warn drivers of a slow-moving construction or emergency vehicle entering or exiting the roadway to reduce crash risk. |

¹Additional information on these case studies can be found at: <http://www.ops.fhwa.dot.gov/wz/its>.

Source: Battelle

agency will be better able to develop an estimate if it has clearly defined its system goals and objectives and the concept of operations.

These factors can cause the cost of work zone ITS to range from several thousand dollars to several million dollars. As a rough estimate, purchasing a few sensors to add to an existing TMC might cost about \$5,000 plus an additional \$5,000-\$10,000 for integrating them with the existing system. Purchasing a larger system that includes four sensors, a PCMS, and some operations support for communications and data software for a simple queue warning system might cost about \$125,000, while doubling this to a system with eight sensors and two PCMS might increase the costs to about \$200,000.

There are several ways an agency may achieve potential cost savings. As already discussed, any existing ITS infrastructure and resources can be used to help manage work zone conditions, reducing the need for some temporary resources. During a work zone project, some agencies choose to accelerate deployment and use of ITS components intended for a future permanent system. In both of these cases, the permanent ITS is not an additional cost for the work zone project, other than any additional capabilities that may be used for work zone management. Finally, the modularity of the work zone ITS can be assessed to separate “wants” from “needs” to accomplish system goals and objectives. Identifying essential ITS elements in the system up front can help to avoid excessive cuts that compromise the value of a system just to save money.

Several tools are available to help agencies develop an accurate estimate of ITS alternatives. The ITS Benefits and Unit Costs Database¹⁶ contains unit cost estimates for over 200 ITS technologies. In addition, ITS Deployment Analysis System (IDAS) is a software tool that estimates the costs and benefits of ITS investments.¹⁷ Finally, FHWA’s “Operations Benefit/Cost Analysis Desk Reference” might serve as useful guidance to agencies.¹⁸

Note that early project estimates are often insufficient to cover work zone ITS needs, and the funding amount is difficult to change by the time those who would identify a need for work zone ITS are involved in a proposed project. This re-emphasizes the need to engage stakeholders early, including staff that handle permanent ITS within the transportation agency, and to conduct work zone ITS deployment considerations with the context of TMP development so they are included in traffic management cost estimates.

2.5 What are potential institutional and jurisdictional challenges?

Institutional and jurisdictional challenges are often more difficult to overcome than the technical issues associated with technology deployment. Typical institutional or jurisdictional challenges for deploying an ITS application in a work zone include:

- Lack of adequate funding provided in the construction contract
- Lack of staff expertise in work zone ITS design, deployment, or operations
- Effects of delays or traffic diversion on other routes or neighboring jurisdictions
- Coordinating operations and incident response between agencies during incidents within the work zone
- Issues relating to command and control of existing ITS assets, when using existing ITS infrastructure for work zones
- Potential duplication of roles already performed by different departments
- Changing long standing operational procedures
- Increased or new maintenance requirements
- Convincing management to try something new
- Acknowledging and quantifying end user benefits for justification of work zone ITS
- Assuring acceptable system performance.

The best means of identifying and mitigating many of these challenges is to be as inclusive as possible during the development of system objectives and the overall system strategy. Discussions with all key stakeholders can help to identify potential issues at the earliest stage of the system development process. This is especially important when planning ITS to be used in work zones near jurisdictional boundaries. Agencies in the adjacent jurisdiction should be contacted at the earliest possible point in the project planning stage. Furthermore, these initial contacts should take advantage of any existing inter-agency relationships. By engaging stakeholders early to identify possible issues, time is more likely to be available to make any necessary adjustments in staffing, policies, or resources prior to the work zone ITS deployment. These discussions can lead the way to not only avoiding problems during the duration of the work zone, but can also lead to long-term coordination between jurisdictions on a wide variety of other issues.

¹⁶Available at: <http://www.benefitcost.its.dot.gov>.

¹⁷More information about IDAS can be found at: <http://idas.camsys.com>. IDAS is available for purchase from the McTrans Center for Microcomputers in Transportation at the University of Florida at: <http://mctrans.ce.ufl.edu>.

¹⁸Available at: <http://www.ops.fhwa.dot.gov/publications/fhwahop12028>.

For many agencies, a major barrier to the deployment of ITS in work zones is the reluctance to try something new. This could stem in part from a lack of staff expertise. Information is available on different types of systems and potential benefits to help educate decision-makers and practitioners to overcome this barrier. Peers at other agencies may be useful resources. The FHWA Peer-to-Peer Program for Work Zones can provide peer connections, and conducted a work zone ITS peer exchange in May 2013 that provided valuable information exchange amongst peers.¹⁹ The deploying agency should seek multiple resources to gain a fuller understanding of any unfamiliar system. One barrier to ITS use can be that DOT staff with ITS expertise are in a different department from those doing road design and construction, and those two groups often do not interact regularly. Sharing expertise between those who know ITS and those who know work zones can increase the chances for an effective ITS procurement and deployment. In some cases, it may be desirable to hire staff that have more expertise and familiarity with work zone ITS for this and future deployments.

2.6 Addressing legal and policy issues

A number of legal issues must be considered in planning to use ITS in work zones. The most obvious question is whether the type of system being designed is permitted in the current laws and regulations. For example, if the agency desires to use automated enforcement as part of a VSL deployment, it is important to know whether automated enforcement legislation is in place in that jurisdiction. Other legal issues to be considered include the potential increased liability for placing ITS equipment in the work zone and archiving of certain data collected by ITS components. For example, some agencies have discovered legal implications related to collecting and storing video images of crashes. Additionally, the agency should consider possible liability issues about how warnings and messages are given (e.g., if the ITS fails to detect a queue and issue the appropriate warning, has liability been increased?). In considering these issues, the agency should also consider the overall benefits of having a system and any work zone risks (e.g., for crashes) it may help mitigate as well.



Example: Automated Speed Enforcement in work zones.

Several states, including Illinois, Maryland, Washington, and Oregon, allow the use of automated speed enforcement in work zones. Each of these states has required enabling legislation before deployment of these systems. As an example, the legislation for Washington state* includes:

- Restrictions on the locations where automated speed enforcement would be allowed
- Specified only images of the vehicle and vehicle license plate were allowed
- Requires the automated speed enforcement zone be clearly marked
- Specifies the method for notifying registered vehicle owner and vehicle owner responsibilities

*See Engrossed Substitute House Bill 1175 of the 62nd Legislature, 2011 Regular Session for Washington: <http://apps.leg.wa.gov/documents/billdocs/2011-12/Pdf/Bills/House%20Passed%20Legislature/1175-S.PL.pdf>

2.7 How can project feasibility be established?

Based on the steps outlined above, key stakeholders should assess the overall feasibility of the original approach and the need to revisit overall objectives for the system. For example, objectives for the system may simply be outside the available budget, in which case objectives might be constrained. Another key consideration in assessing project feasibility is whether ITS is the best TMP strategy to deploy to address the identified needs, or if other non-ITS options may be better for the given situation.

Assessing project feasibility is especially important when planning work zone applications that involve more risk, such as larger deployments that involve more cost or deployments that may involve sensitivities. Examples of these types of deployments may include automated speed enforcement (in this case, due to higher political risk) or route diversion from highways to local roads. Such applications are more likely to draw additional scrutiny, encounter additional challenges, and may incur higher costs that should be considered when assessing project feasibility.

¹⁹For more information, including the materials from the work zone ITS peer exchange, see: <http://www.ops.fhwa.dot.gov/wz/p2p/index.htm>.

In addition to the project manager, key stakeholders that should participate in this step include senior agency managers, contracts personnel, and engineering staff. Senior managers are needed because they may have originally defined the operating strategy that may have to be revised, and because they can provide accurate information on the availability of funding and other key resources. Contracts personnel can identify various contracting options available, as well as discuss advantages and disadvantages of each of these options. Engineering staff may be needed if questions arise regarding the feasibility of the project schedule or technical approach. In some cases, it may be helpful to have engineering staff perform modeling to help establish the need for a system and to assess how likely impact mitigation is to occur in the event that a system is deployed. For example, modeling of the work zone may show long queues that become manageable if 10 percent of traffic diverts, which may be achievable with real-time traveler information provided by ITS.

Numerous sets of criteria have been developed and could be used to establish project feasibility. Some criteria, such as those developed by Michigan DOT, are specific to various ITS, e.g., dynamic lane merge system, real-time information system, and PCMS with radar capabilities. Similarly, criteria have been developed for advanced traveler information systems under the Smart Work Zone Deployment Initiative.²⁰ These criteria consider factors such as queue lengths, average daily traffic (ADT) and peak period traffic volumes, availability of alternate routes, and sight distances. North Carolina DOT developed criteria for use of an ITS-based SMARTZONE system in work zones based on whether the location is urban/suburban, rural, or mountainous.

FHWA drafted a general set of scoring criteria that agencies can tailor as desired for their use as one possible way to assess the feasibility for ITS (see Table 6). The intent for these criteria was to assist decision makers by providing a structured approach to considering the need for work zone ITS on specific projects. For each result, other mitigation treatments should be considered, as applicable, in addition to work zone ITS since ITS is only one possible solution for stakeholders to use to address a given issue in a work zone and may not be the best alternative.

Table 7 presents another possible way to consider when to use work zone ITS. It can be used as a general application guide to assess the characteristics and conditions existing or anticipated in a given work zone that would help justify implementation of one or more of the systems.

Table 7 attempts to illustrate how some of these applications may be designed to address certain conditions, but could also address other conditions through some modifications to the typical deployments or the introduction of a human operator who could make real-time adjustments in how the systems respond. Similarly, some work zone issues could be addressed through more than one type of system. As an example, a real-time traveler information system could address work zone conditions where unexpected or variable periods of travel delays and congestion will arise, and there is potential to encourage route, departure, and mode choice diversions through the provision of real-time information. However, these same conditions could also be addressed through implementation of a work zone incident management system. Whereas a typical work zone traveler information system will operate autonomously based on a limited set of rules, the incident management system would rely on an operator present to monitor and detect incidents to also modify the information dissemination devices if needed to encourage diversion.

An ITS application may not be appropriate for every work zone nor be the best solution for a given issue. Other alternatives should also be examined. The expected project location, project impacts, and project duration are likely to influence whether or not a particular ITS solution merits consideration. Other factors like traffic volumes and project layout will also influence whether or not work zone ITS are applicable for a particular project. For example, if the concern is potential congestion in a work zone, one solution can be to use ITS to monitor traffic conditions and provide traveler information. Some other possible mitigation strategy alternatives to using ITS are a public information campaign to reduce travel demand in the area; maintaining more lanes by using the shoulder to carry traffic; conducting work at night when traffic volumes are generally lower; including lane closure restrictions in the contract to affect less traffic and minimize impacts; a motorist assist patrol to quickly identify and address vehicle breakdowns and other incidents; or using a movable barrier to provide an additional lane for peak period traffic flow.

²⁰See "Criteria for Portable ATIS in Work Zones" by Alan J. Horowitz at: http://ssom.transportation.org/Documents/2005_horowitz_atis_criteria.pdf

Table 6. Example set of scoring criteria to establish feasibility of work zone ITS. (Source: FHWA)²¹

| Criteria | Score |
|--|-------|
| Factor 1 – Duration of work zone: Long-term stationary work will have a duration of: <ul style="list-style-type: none"> • >1 construction season (10 points) • 4-10 months (6 points) • <4 months; procurement and installation timeline is available prior to work starting (3 points) | |
| Factor 2 – Impact to traffic, businesses, other destinations, or other users (e.g., extremely long delays, high risk of speed variability, access issues) for the duration of work is expected to be: <ul style="list-style-type: none"> • Significant (10 points) • Moderate (6 points) • Minimal (3 points) | |
| Factor 3 – Queuing and Delay: Queue lengths are estimated to be: <ul style="list-style-type: none"> • ≥2 miles for periods ≥2 hours per day (8 to 10 points) • 1-2 miles for periods of 1-2 hours per day (6 to 8 points) • ≤1 mile, or queue length estimates are not available but pre-construction, recurring congestion exists for periods <1 hour per day (4 points) | |
| Factor 4 – Temporal Aspects of Traffic Impacts: Expected traffic impacts are: <ul style="list-style-type: none"> • Unreasonable for a time period that covers more than just peak hours (10 points) • Unreasonable during most of both morning and afternoon peak hours in either direction (6 points) • Unreasonable during most of a peak hour in either direction (3 points) • Unpredictable; highly variable traffic volumes (1 point) | |
| Factor 5 – Specific Issues Expected (0 to 3 points each based on judgment) <ul style="list-style-type: none"> • Traffic Speed Variability • Back of Queue and Other Sight Distance Issues • High Speeds/Chronic Speeding • Work Zone Congestion • Availability of Alternate Routes • Merging Conflicts and Hazards At Work Zone Tapers • Work Zone Hazards/Complex Traffic Control Layout • Frequently Changing Operating Conditions for Traffic • Variable Work Activities (That May Benefit From Using Variable Speed Limits) • Oversize Vehicles (Percent Heavy Vehicles >10%) • Construction Vehicle Entry/Exit Speed Differential Relative to Traffic • Data Collection for Work Zone Performance Measures • Unusual or Unpredictable Weather Patterns Such as Snow, Ice, and Fog | |
| Total Score | |
| If the total score is: <ul style="list-style-type: none"> • ≥30 – ITS is likely to provide significant benefits relative to costs for procurement • ≥10 and <30 – ITS may provide some benefits and should be considered as a treatment to mitigate impacts • <10 – ITS may not provide enough benefit as a treatment to justify the associated costs | |

²¹This is not the only way or criteria that could be used. Agencies can tailor this to their needs or use their own criteria.

Table 7. Possible work zone ITS applications to consider for various critical project characteristics.

| Critical Project Characteristics | Work Zone ITS Applications | | | | | | | | |
|---|----------------------------|--------------------------------|---------------------|--------------------|----------------------|------------------------|--|-------------------------|-------------------------|
| | Queue warning | Real-time traveler information | Incident management | Dynamic lane merge | Variable speed limit | Automated enforcement* | Construction vehicle entrance and exit warning | Temporary ramp metering | Performance measurement |
| Frequent planned lane closures are expected, which will create queues that cause high speed differentials between queued and approaching traffic | ● | ● | | ○ | ● | | | | |
| Emergency shoulders will be closed through the work zone and frequent stalls and fender-benders are expected to occur that will cause queues because they cannot be quickly moved to the shoulder | ● | ● | ● | | | | | | |
| Travel times and delays through the work zone will be highly variable and real-time information can improve pre-trip and real-time route choice, departure time, and possibly mode choice decisions | | ● | ○ | | | | | | |
| Roadway access for emergency response vehicles will be significantly constrained by the project, increasing response and clearance times | | | ● | | | | | | |
| Frequent incidents are expected to occur within the project | ○ | ● | ● | | | | | | |
| Having an operator able to view an incident within the project and assist responders in bringing appropriate equipment to the site will significantly reduce incident duration | | | ● | | | | | | |
| A long-term lane closure will create a v/c condition that is very close to 1.0, and improved flow rates through the lane closure could reduce the likelihood that a queue would form, or reduce its duration significantly when a queue did form | | | | ● | | | | ● | |
| The potential exists for queue spillback from the work zone into upstream interchanges or intersections (and resulting increase in cross-street congestion and rear-end crashes) due to an unequal utilization of all lanes, such that the encouragement of the use of all lanes for queue storage would reduce that probability of spillback conditions. | | ○ | ○ | ● | | | | | |
| Work activities will frequently occur for which lower speed limits would be beneficial to have on a temporary basis (i.e., during temporary lane closures on freeway mainlanes, for temporary full road closures, during periods construction vehicle/equipment access into and out of the work space from the travel lanes, etc.) | | | ○ | | ● | | ○ | | |
| Traffic speeds through the project vary widely due to oversaturated conditions during the peak period, and the timing and extent of congested travel will vary significantly day to day | | ○ | | | ● | | | | |
| A reduced speed (and thus speed limit) is believed to be necessary because of work zone hazards that are not readily apparent to motorists and so will not likely result in lower speeds driven | | | | | | ● | | | |
| The project plans limit ability of enforcement to operate (no shoulders, barrier on both sides, long stretches between interchanges) | | | | | | ● | | | |
| Access to and from the work space occurs directly from the travel lanes | | | | | | | ● | | |
| A high number of construction vehicle deliveries into the work space will be required during the project | | | | | | | ● | | |
| The location and design of the access points could create confusion for motorists (i.e., access to the work space looks like an exit ramp and is near an existing actual exit ramp) | | ○ | | | | | ● | | |
| Little or no acceleration lane is available for construction vehicles entering the travel lanes from the work space | | ○ | | | | | ● | | |
| Capacity reductions in the work zone now create an oversaturated condition due to merging ramp vehicles | | | | | | | | ● | |
| Temporary ramp geometrics have constrained acceleration lane lengths | | | | | | | | ● | |
| Work activities have temporarily disabled one or more permanent ramp meters within the limits of an operational ramp metering system | | | | | | | | ● | |
| Work zone ITS is already being deployed for other purposes | | | | | | | | | ● |
| Project documents include traffic mobility performance requirements (i.e., maximum allowable delays) that must be monitored to ensure and quantify compliance and subsequent incentives or penalties to be issued (performance specifications of mobility impacts [delay or queues]) | | | | | | | | | ● |
| The agency chooses the project for assessment purposes as part of its federally-mandated bi-annual process review | | | | | | | | | ● |

* Assumes that the state transportation code allows use of automated speed enforcement in work zones

Source: Battelle

● Characteristic could be addressed with this work zone ITS application

○ Characteristic could be addressed with this work zone ITS application if some modification(s) were made or real-time actions taken by an operator.



Key Point: Whether to use ITS to address a work zone need has to be assessed because work zone ITS may not be the only or best way to address a particular issue.

For example, project staff at case study sites in Effingham and Mount Vernon, IL considered whether to use ITS the need for queue warning. Because of the need for automatic queue warning and delay information dissemination, staff at both projects considered alternatives and decided early on that some type of work zone ITS would be deployed. There had been previous efforts by Illinois DOT to warn drivers approaching a work zone with queues through the use of either enforcement personnel positioned upstream of the work, or through the use of Illinois DOT staff with truck-mounted CMS. The difficulties of predicting when queues would occur, having sufficient staff available to schedule during those times, and keeping the warning device (enforcement vehicle or the truck-mounted CMS) in the proper location relative to the end of the queue reduced the practicality of these approaches. Illinois DOT staff were also concerned with the potential liability associated with sometimes, but not always, being able to have an enforcement vehicle or truck-mounted CMS present when queues were expected.

Stakeholders should consider the differences in costs, as well as benefits that each alternative would provide. For example, even though an ITS deployment would likely cost more than a public information campaign, the ITS deployment provides real-time information and can monitor the work zone status. While a public information campaign is good for steady state conditions or specific events, ITS is good for a dynamic work zone in which roadway configuration may change on a frequent basis.

In weighing the benefits and cost of different strategies for addressing work zone issues, it is helpful to keep in mind that work zone ITS can give multiple benefits that sometimes exceed the primary objectives. For example, a work zone ITS deployment may enable traffic management in real-time, better deal with changing traffic conditions, and provide data for both performance monitoring and assessment of benefits, even though initial objectives may have been focused on providing information to travelers. More benefits may be provided by work zone ITS than cheaper alternative solutions (e.g., public information campaigns that only address the initial objective).

Several analytical tools have been developed for use in evaluating work zone traffic control strategies. The FHWA has developed a traffic impact analysis spreadsheet, known as QuickZone.²² QuickZone can estimate the delay impacts of various work scheduling or configuration alternatives, such as doing work at night instead of during the day or of diverting the traffic to various detour routes during different phases of the construction. The FHWA Traffic Analysis Toolbox includes guides for work zone modeling and simulation.²³ These documents provide guidance on using analytical tools in work zone planning and management, including work zone analysis, selecting a modeling program, and approach.

2.8 How can buy-in be obtained from stakeholders and other agencies?

Ideally, buy-in from core stakeholders should be achieved during Step 1. However, some agencies may choose to wait until the vision for the system is more mature before bringing in the entire spectrum of stakeholders listed previously. The size and magnitude of the work zone, as well as the expected complexity and scale of deployed ITS technology in the work zone, will impact the timing. For example, if a simple off-the-shelf system is being deployed, a general notification to key stakeholders should be sufficient. However, other cases will require more active participation, closer coordination, and stakeholder buy-in earlier, such as a case where ramp metering or a transit or truck bypass is being considered for a work zone.

The scope of the work zone project will affect the level of stakeholder buy-in required, as well as how difficult it will be to attain it. Buy-in for temporary or short-term work zone projects that do not affect long-term operations will generally be easier to obtain than similar buy-in for long-term projects requiring permanent changes in procedures or staffing responsibilities, although the costs may be harder to justify for shorter-term projects. As complexity or duration of the project increases, so too does the requirement for greater contact with affected agencies.

Peer-to-peer contact, i.e., developing inter-agency relationships among staff at the same level, is typically the most effective form of interaction. These relationships should be developed at the line supervisor and even the operator level, depending on the scope of the project. Cross-training, i.e., having staff from a different agency work alongside host agency staff for

²²More information about QuickZone is available at http://ops.fhwa.dot.gov/wz/traffic_analysis/quickzone/. QuickZone is available for purchase from the McTrans Center for Microcomputers in Transportation at the University of Florida at: <http://mctrans.ce.ufl.edu>.

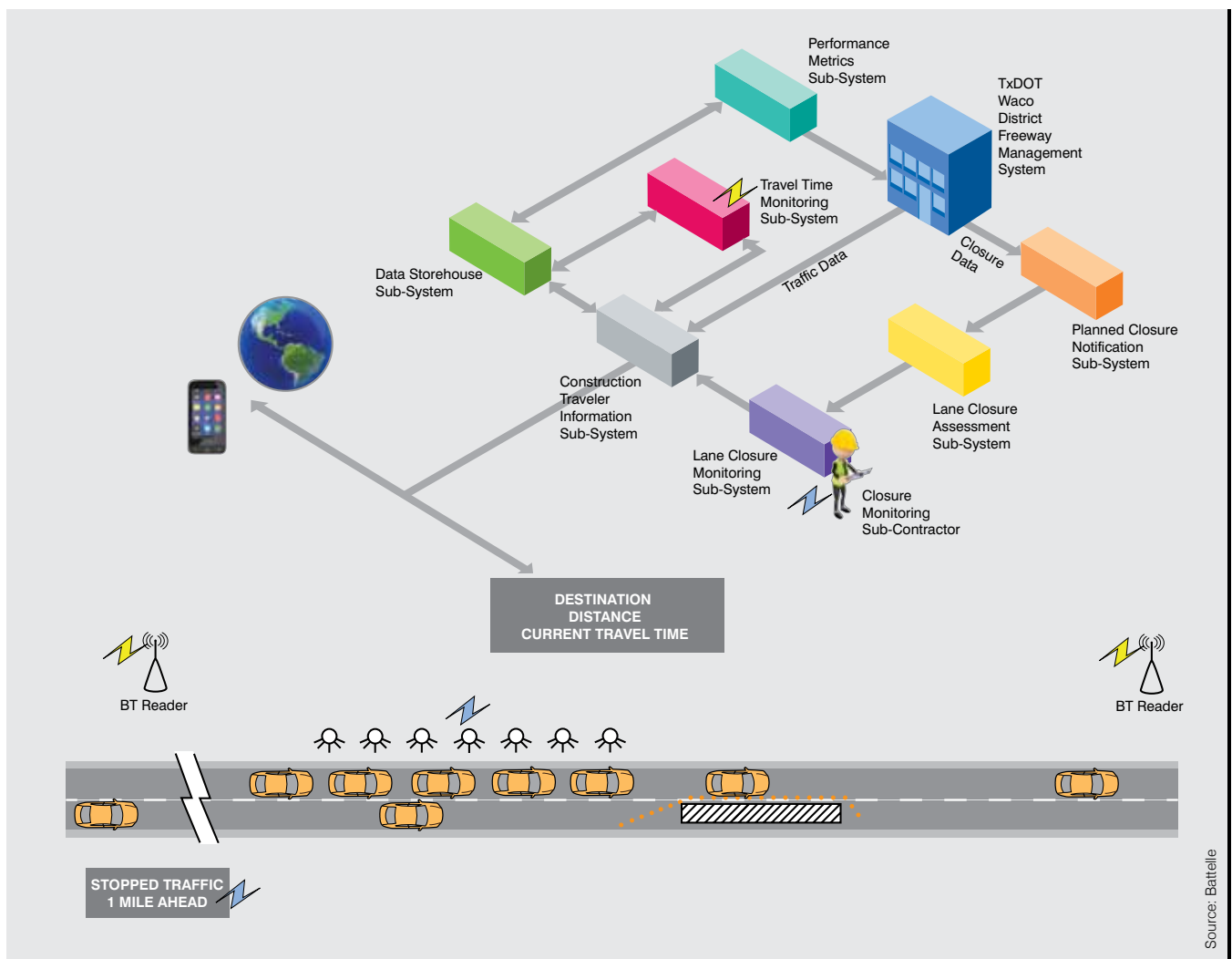
²³More information on the FHWA Traffic Analysis Tools, specifically Work Zone Modeling and Simulation Guidance in Volumes VIII, IX, and XII can be found at: <http://ops.fhwa.dot.gov/trafficanalysisstools>.

a fixed period of time, has been effective in fostering better working relations and understanding of key needs. Another useful tool in obtaining buy-in from varying stakeholders is to communicate the estimated benefits

for each individual agency being recruited. Answering the question “What’s in it for me?” is an effective way to elicit support from other agencies.

Key Takeaways

- The main product of Step 2 is a concept of operations report. This report builds on information gathered and established in Step 1, and documents a vision for the system, such as the one illustrated in Figure 11. It should incorporate the goals and objectives of the system and the system strategy, and serve as a guide for system development. The report should also provide a summary of the processes in Steps 1 and 2 and document stakeholder input. The report should be scalable to the extent and complexity of the system.
- Engage ITS staff as a source of expertise.
- Achieving a broad level of consensus in this step is a prerequisite to moving to Step 3. Presenting the results of Step 2 to a stakeholder group is essential. Agencies sometimes skip this consensus-building step and move on to requirements and design. When that happens however, the agency will likely get mired in unanticipated questions and issues from stakeholders later that would have been easier to address sooner.



Source: Battelle

Figure 11. The product of this step should include concept of operations scenarios, such as this graphic for a work zone traffic management system.



The main objectives of Step 3 are to develop system requirements and specifications, develop performance measures for the system objectives, and prepare plans for deployment and subsequent operations and maintenance. The product of this step will be the overall Work Zone ITS System Plan. Sub-steps to developing the plan are depicted in Figure 12. These steps should be done within the context of TMP development, implementation, and evaluation for coordination with other TMP strategies.

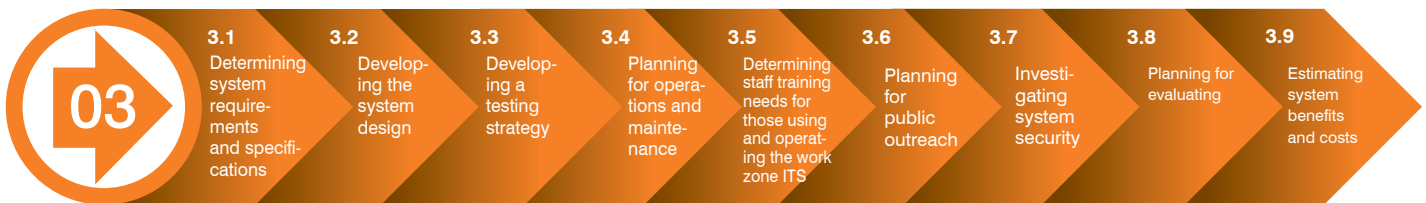


Figure 12. Sub-steps to be explored in Step 3.

Source: Battelle

3.1 Determining system requirements and specifications

The objectives of the ITS work zone application and the manner in which it would operate to achieve these objectives are documented in the concept of operations developed in Step 2. The next step is to develop system requirements. These requirements define what the system will do. System requirements and specifications will be most effective if they also define performance targets and requirements. Typically, a trade-off exists between the amount (and cost) of system features and components (i.e., spacing and coverage of sensors, number and types of information dissemination devices, and services to be provided, etc.). Defining performance targets and requirements provides a basis for deciding what features and components are critical to achieve system objectives. All requirements should link with specific user needs and/or operational policies and

constraints established in the concept of operations documents to preserve traceability. No requirement should exist that does not link to a user need, operational policy, or operational constraint, and vice versa.

By conducting a thorough and well-focused requirements generation process, agency staff will better manage stakeholder expectations, ensure that the key needs identified earlier are addressed, and gain consistent understanding of and buy-in for the system, and will be able to develop a more realistic estimate of the project deployment schedule and cost. The level of effort required for this activity depends on whether the agency has used a system of similar capabilities in the past and has past requirements and specifications (its own or from a peer agency) from which to work, and how many unique or unusual objectives exist. The National ITS Architecture²⁴ can help define requirements and

²⁴For more information, see: <http://www.iteris.com/itsarch/>

specifications, and should be consulted and followed when designing such systems. For more complex projects, the requirements documentation process should be done in two levels to include first high-level requirements, then detailed requirements.

Some examples of system requirements that have been developed by state DOTs for several types of work zone ITS are available from AASHTO.²⁵ The examples are from several State DOTs, including Michigan, Minnesota, Missouri, and North Carolina, and cover real-time traveler information systems, speed management, and dynamic lane merge systems. An example of requirements for a work zone ITS are presented in Figure 13 below.

Requirements will necessarily vary for various types of systems, deployments, and agencies. As an example, a Minnesota project team developed this set of physical, functional, system, and maintenance requirements for the deployment of a traffic monitoring system in a work zone.

Physical Requirements

1. The system shall be self-contained in a traffic barrel.
2. The traffic barrel shall be indistinguishable from other traffic barrels to passing drivers.
3. The device shall meet crash safety standards for use on the National Highway System.

Functional Requirements

1. The system shall detect speed of vehicles travelling towards the sensor.
2. The system shall detect the volume of vehicles travelling towards the sensor.
3. The system shall have a cellular modem for communication to the central office when cellular access is available.
4. The system shall have a satellite modem for communication to the central office when cellular access is not available.
5. The system shall report speeds within three miles per hour of actual speeds.
6. The system shall be configurable to report data every minute.
7. The system shall be configurable to operate in a continuous data collection mode.

System Requirements

1. Data requirements
 - a. The system shall report data in real time.
 - b. Real time data shall be available from a designated website.
 - c. The system shall report data to the central office.
 - d. The system shall report adjustable binned historical data.
 - i. System shall report 85th percentile speed data.
 - ii. System shall report 50th percentile speed data.
 - iii. System shall provide a binned speed curve.
 - e. Binned historical data shall be downloadable from a designated website.
 - i. Historical data shall be downloadable in Microsoft Excel format.
 - f. The system shall be capable of providing per vehicle speed records.
2. Website requirements
 - a. Data recorded by the device shall be available on a designated website.
 - b. Historical data on the website shall be password protected.
 - c. The website shall provide a mapping function that pictorially illustrates the location of the devices.
 - d. The website shall provide a mapping function that pictorially displays speed data in a color-coded format.
 - e. The website shall provide both graphed and tabular historical data.
 - f. The website shall produce an XML feed that can be parsed by the DOT's traffic management software.

Maintenance Requirements

1. System setup shall only require one person.
2. System shall be powered with a sealed 12-volt battery.
3. System shall function for a minimum of 14 days on a single battery charge.
4. System battery shall be replaceable in the field without losing data.
5. System shall recharge within a 12-hour period when connected to 120 VAC power.

These requirements can be found at: http://www.dot.state.mn.us/guidestar/2006_2010/icone/iconefinalrequirements.pdf.

Figure 13. Requirements for a work zone ITS deployment in Minnesota.

Source: Minnesota DOT

²⁵The AASHTO work zone ITS website can be found at: <http://ssom.transportation.org/Pages/ITSinWorkZones.aspx>.

As part of the system requirements and specifications process, agencies should consider the potential need for, or opportunities of, establishing interoperability and connectivity with other ITS components and transportation management system components in the region. Doing so can result in significant economies of scale and expand the potential range of influence of a work zone ITS. For example, a work zone traveler information system could be designed to feed information to an agency's existing traveler information website or 511 system, rather than establishing a separate website or not making the information available online to the public and others. A work zone incident management system may be best accomplished by installing temporary devices in and around the work zone to monitor and view traffic conditions, and sending the data and images back to the regional TMC already in place, as depicted in Figure 14, rather than developing a separate temporary TMC for the project or relying solely on DOT project staff to monitor the images. The FHWA publication *Designing for Transportation Management and Operations: A Primer* would be a useful resource for these considerations.²⁶

Work zones are often dynamic and frequently changing throughout a project. Consequently, the system requirements and specification definition process should also address if and how the system must respond to changes in the work zone environment over time. Whether it be a change in device location to accommodate major traffic switches, adjustments in the thresholds being used to activate certain control and management functions, or provisions in a contract

that determine when the system is no longer needed, it is important to think through and capture these requirements at this point in the design process. With respect to system duration considerations, work zones can be finished ahead of schedule or be delayed. Consequently, it is often a good idea to include contingency plans within the system design process. Adding a contingency plan could increase costs somewhat, but may be preferable to having to retrofit the system after the fact.

3.2 Developing the system design

Development of the system design will take into consideration much of the documentation assembled in previous steps. The concept of operations from Step 2 describes how the system will work, and system requirements and specifications provide more specific details for what the system needs to do. In this step, the hardware and software interfaces, site plans for the system components, and the integration of the COTS elements are designed. It is important that the design team or contractor has access to all of this documentation when developing the system design, especially if innovative contracting methods are used.

The project team will establish the number and type of technological components during system design, if not already identified through the development of the requirements and specifications in substep 3.1. Alternatively, an agency may choose to allow a contractor to propose all or some aspects of the work zone ITS system design, given the requirements and specifications that the agency has developed. The system design provides additional detail regarding



Source: FHWA

Figure 14. The Las Vegas Freeway and Arterial System for Transportation (FAST) provides regional support for work zone activities.

²⁶This document can be found at: <http://www.ops.fhwa.dot.gov/publications/fhwahop13013/index.htm>

the placement of components within the project area. Strategic placement of components such as sensors and PCMS is important for the work zone ITS deployment to be effective. For example, PCMS used for a queue warning system need to be placed upstream of the maximum expected queue length.

This is also an appropriate time to consider driver capabilities to verify that the system being planned for and/or designed will be satisfactory from a human factors perspective. Motorists can only process a limited amount of information while driving. It is important that any messages planned for display on CMS follow current guidance to ensure that the information is clear, concise, and credible. Characteristics of the devices and their deployment locations should also be considered. For example, the Manual on Uniform Traffic Control Devices²⁷ provides specifications for CMS, stipulating that the size of the text on a message display must be sufficiently large and visible (a minimum of 18 inch characters for freeway conditions) so that drivers do not have to slow down to give themselves more time to read. Message boards should be positioned away from obstructions that might limit viewing times, such as piers, abutments, parked construction equipment, etc. In areas with significant truck traffic, the agency should consider whether some message boards need to be on the left as well as the right side of a multi-lane road for visibility. The location should also be far enough upstream of key decision points to allow drivers time to process the information and take appropriate action.

The California DOT "Systems Engineering Guidebook For ITS" may serve as a useful reference during this step.²⁸

3.3 Developing a testing strategy

Development of a coherent testing strategy to validate the functionality and accuracy of the ITS is a key component of successful deployment of the system in the demanding environment represented by a work zone. (Note: testing involves validation of the ITS functionality and accuracy before activation, while evaluation assesses the ITS system performance after activation.) The test plan can be prepared by an outside contractor, but should be closely scrutinized by the agency. The test plan does not need to be extensive in all cases; simple validation may be sufficient for a COTS system. Inadequate testing could fail to detect problems in system component operation until after the system is activated for the public.

The test plan should be scheduled to provide sufficient time for resolving any problems that may arise, as well as retesting, in case any part of the system fails the initial testing. Tests should be established for each detailed level requirement defined in Step 2. A table listing all detailed level requirements in one column and corresponding tests in the adjacent column is a useful tool for ensuring that the test plan is adequate. There should be one test for each requirement and a requirement for each test. If either a requirement or a test is missing its corresponding element, the table is not complete.

Acceptance testing typically consists of the following tests:

- **Functional testing** – requirement-by-requirement testing of the system's ability to meet specifications as envisioned.
- **Performance testing** – evaluates how well the system performs under various conditions
- **Throughput testing** – measures how quickly the system processes a discrete event of data transfer or how quickly the system responds to operator input
- **Storage testing** – measures the ability of the system to store data or handle the operation of multiple programs simultaneously
- **Stress testing** – evaluates system operation under the peak load it is expected to encounter
- **Failure mode testing** – evaluates the system's ability to diagnose, report, and respond to failures (e.g., field devices, central system computer, power)
- **Operability testing** – tests the system's ability to operate for long periods without failing (e.g., central software crash).

Test plans for the system should include the following elements:

- Test schedule developed as part of the overall project schedule, including sufficient time for resolving any problems that may arise, as well as retesting in case any part of the system fails the initial test
- Consistent test data used to populate files and databases prior to collection of actual data
- Data sheets used to record test data
- Expected test results including detailed level specifications that define expected system operating parameters (e.g., system reporting every 2 minutes), or other expected results if not called for in the specifications
- Requirements table listing requirements and corresponding tests

²⁷Available at: <http://mutcd.fhwa.dot.gov>.

²⁸Available at: http://www.dot.ca.gov/newtech/docs/se_guidebook_ver1-12_14_05.pdf

- Test reports that tell the project team how well the system performed.

3.4 Planning for operations and maintenance

During the planning step, the agency needs to consider what will be needed for operating and maintaining the work zone ITS. For example, incorporation of work zone ITS components into a permanent ITS deployment may place additional demands on TMC staff. This needs to be recognized during the planning process. Ideally, these types of needs should be addressed as part of TMP development and implementation. Automated systems may require fewer agency operational considerations since operations and maintenance may be handled by the vendor.

The level of effort required for system maintenance planning depends largely on how the ITS portion of the work zone is procured. For example, some DOTs have procured work zone ITS as part of a larger construction contract, and maintenance was the responsibility of the contractor. Operations and maintenance are frequently overlooked in ITS application development.

In general, work zone ITS deployments tend to be concerned primarily with corrective maintenance issues, due to the short life span of these deployments. Short-term maintenance issues include tasks such as replacement of power source for the equipment (e.g., recharging or replacing batteries); minor adjustments of the location of system signs and detectors to reflect queue lengths that are different from what was anticipated; movement of equipment due to work zone configuration changes; and troubleshooting and repairing malfunctions. Longer-term issues, such as system enhancements, are less of a consideration.

Implementing agencies should carefully plan for maintenance needs when determining the response requirements for system uptime and penalties for system downtime. For example, the agency should specify if someone needs to be on-site 24/7, what response times are expected (e.g., within 4 hours, 24 hours), and what penalties will be assessed if a system is down and at what point (e.g., after 2 hours) the penalties will begin.

It is also important that provisions be made to maintain functionality of existing ITS. Many projects result in power (and thus system functionality) being lost, for example, unless special arrangements for maintaining capabilities are made in advance.

Due to the limited duration typical of work zones, operations and maintenance responsibilities can be

included with the procurement of the system. For example, an agency can pay a contractor a “per day” fee for the ITS application that includes operation of the ITS. The “per day” fee technique can result in significant staff time cost savings for the agency, as agencies are not required to dedicate staff to these projects or maintain inventories of spare parts. The agency should not be overly prescriptive regarding operational aspects of the ITS, such as requiring that the system process data on-site; vendors may be able to more cheaply process data off-site, and send it back to the field, as needed.



Example: Operations and Maintenance costs – I-70/I-57 Project in Effingham, Illinois.

Operations and maintenance costs can vary significantly for various reasons. A traffic management system was procured as part of the overall bid by the contractor for a work zone project on the I-70/I-57 interchange in Illinois. This was budgeted at \$1,800/month over 25 months (\$45,000 total) for 70 devices. Illinois DOT intended for the system to remain operational and used during 3 other contracts that were scheduled to occur within the section over the next several years. The next contract that was let also included this component, but was bid at much a different value: budgeted at \$29,767/month over 25 months (\$744,187 total) with only a few devices added from the previous contract. Agency and contractor understanding of desired operational conditions is important for requesting and submission of bid requests because the bid costs can vary greatly.

3.5 Determining staff training needs for those using and operating the work zone ITS

The amount of training needed will be determined by the approach that will be taken to procure, operate, and maintain the system. If the system will be leased, operated, and maintained by the vendor or a contractor, training of agency staff will focus primarily on operational aspects of the system. This can be very important as the agency, contractor, and vendor work to fine-tune the system. For example, for a recent work zone ITS deployment in Illinois, the agency, contractor, and vendor worked together to identify ways to improve the queue-end warning system, calibrating it to generate messages from queue length data, and make adjustments as necessary throughout the course of the project. However, if the agency will be responsible for operating and maintaining the ITS, agency staff will need to receive in-depth training on all aspects of the system. Agency staff will need to learn about each component of the system, and how the components work together, as well

as system set-up, maintenance requirements, testing techniques, and troubleshooting. The agency will need to determine the most appropriate people to receive the training, which would most likely be provided by the system supplier. Redundancy in staff training should be included to account for staff turnover and absences.

The National Highway Institute (NHI) offers courses addressing a wide variety of aspects of ITS.²⁹ The curriculum covers several topics of interest to project managers of work zone ITS, including systems engineering, project management, telecommunications, software acquisition, and ITS procurement.

The Consortium for ITS Training and Education (CITE),³⁰ composed of numerous university and industry partners, offers a wide variety of ITS online courses on topics that include incident and emergency management, transportation management, systems engineering, and rural ITS.

Other resources include ITS courses available through the Local Technical Assistance Program (LTAP).³¹ Also, some agencies that operate and maintain permanent ITS have developed their own curriculum.

3.6 Planning for public outreach

An important step in the planning process is to determine the amount and type of public outreach that the agency wants to pursue to alert local residents and businesses to the system and its capabilities, including web-based information. For example, how useful would it be to display real-time traffic information on a website if nobody knew that the website existed or how to access it? Carefully prepared press releases and involvement in community meetings are some of the strategies employed with success by state agencies.³² A number of agencies have learned that proactively working with the media has been a highly successful means of reaching out to the public. The media provides the agency with a free means of disseminating information to the public. It is important to plan for public interaction throughout the course of the project and should be done within the context of TMP development, implementation, and evaluation for the project, in order to keep the public informed and receive their feedback. An example of a press release is exhibited in Figure 15.

The FHWA offers a guide about “Work Zone Public Information and Outreach Strategies” that is designed to help agencies plan and implement effective public information and outreach campaigns to mitigate the negative effects of work zones.³³



Tip: It is important to use a proactive approach in building public awareness of the project and the information that the ITS application will provide.

Successful techniques include holding press conferences, issuing news releases, and keeping local media (especially those the public turns to for traffic information) up to date.

²⁹More information about the ITS curriculum is available on the ITS Professional Capacity Building (PCB) Program website at: <http://www.pcb.its.dot.gov>.

³⁰More information at: <http://www.citeconsortium.org>.

³¹The LTAP resource database can be searched at: <http://www.ltap.org/resources/searchdbs.php>.

³²Note that the Manual of Uniform Traffic Control Devices (MUTCD) prohibits the display of website addresses on CMS and PCMS.

³³This guide is available online at: http://www.ops.fhwa.dot.gov/wz/info_and_outreach/public_outreach_guide.pdf.

NEWS RELEASE

STATE OF NEW HAMPSHIRE, DEPARTMENT OF TRANSPORTATION
Charles P. O'Leary, Commissioner

For Immediate Release
October 8, 2007

Contact: David Rodrigue
I-93/ITS Project Manager
(603) 271-6862
Public Information Office
(603) 271-6495

NHDOT DEPLOYS "SMART WORK ZONE" ON I-93 PROJECT IN SALEM

PURPOSE IS TO INFORM MOTORISTS OF WHAT TO EXPECT AHEAD

The New Hampshire Department of Transportation (NHDOT) has deployed a Smart Work Zone System as part of the Interstate 93 Exit 1 rebuilding project. The primary goal of this system is to provide a safe and efficient travel corridor through the work zone by alerting motorists about what is happening along the road ahead.

The Exit 1 Smart Work Zone consists of changeable message signs that provide information to motorists as they travel through the work zone, traffic sensors that measure vehicle volumes and speed, and a mounted camera that provides images of traffic through the construction corridor.

Motorists will be able check travel conditions in the work zone via the internet and will receive vital incident or road construction information through changeable message signs strategically located within three miles north and south of the project area. Motorists will be able to use this information to prepare for stopped or slowed traffic ahead, or they may choose an alternative route. The idea is to let the motorist decide what action to take. Also benefiting from the Smart Work Zone will be emergency personnel responding to incidents on I-93 in the vicinity of Exit 1 in Salem.

The Smart Work Zone has a website link that may be accessed through the I-93 project website at www.rebuilding93.com. This website link provides the traveling public an Internet location to view the messages displayed on the message signs, the speeds measured through the work zone and an image of the traffic on I-93.

The volume, speed and queue (length of stopped or slowed vehicles) data will be collected and used by the NHDOT to evaluate the impact of the work zone on traffic in this portion of the I-93 corridor.

-XX-

Public Information Office - P.O. Box 483 - 7 Hazen Drive - Concord, New Hampshire 03302-0483
Telephone: (603) 271-6495 Fax: (603) 271-3914 web address: www.nhdot.com

3.7 Investigating system security

Agency staff need to take system security into consideration to ensure that access to the ITS application is protected from unauthorized intrusion. System security is especially critical for systems providing traveler information. Most COTS and permanent ITS deployments rely on a multi-level architecture that grants varying levels of access to the system, depending on the attributes of the user. Some users, for example, will be granted the ability to review the system operating conditions on a website, but not be able to change operational strategies or access more detailed data. Other user may be designated managers of the system, and be allowed to make certain changes to the system. Typically, one or two users may be designated as the system administrator, with the greatest level of access and control privileges granted to them.

In addition, agencies also need to consider the vulnerability of the system's physical components. Sturdy locks and strong passwords should be placed on cabinet doors and computer access points, respectively, where possible. All keys and passwords for the equipment should be stored away from the devices. Also, many agencies position devices in locations where it is difficult for thieves to access and steal the device. Although these are basic security procedures, several locations around the country have experienced security violations where PCMS were programmed to display a false message (see Figure 16), which was made possible by easily guessable or visible system passwords. Easily portable components, such as solar panels, trailer tires, and barrels with sensors have also been stolen. Advances in global positioning satellite (GPS) and other technology in recent years has made monitoring and tracking of equipment easier, reducing theft and vandalism problems.



Figure 16. PCMS in several states have been illegally accessed and had messages changed.



Example: Work Zone ITS Security Issues.

Vandalism was a problem on the I-40 reconstruction project in West Memphis, Arkansas. Although securely locked, the control center trailer was broken into by vandals, who ripped the system wires from their connections and destroyed the monitor for the computer. The vandalism resulted in several days of downtime while a replacement computer was sent from the system developer, and damaged wiring was reconnected.

At a separate project in Illinois, a set of portable traffic sensors was stolen. However, officials used the location tracking technology built into the device to identify their location in the thief's garage, making apprehension and recovery of the equipment by local law enforcement personnel very easy.

3.8 Planning for evaluation

Evaluation is the rational assessment of how well system goals and objectives are being achieved, and it is an essential ingredient in good project management. The most effective evaluations occur when the goals and objectives for a work zone ITS are explicitly stated, measurable, and agreed to by all stakeholders. Considerations for evaluation at the early stage of the project, particularly during concept development and development of requirements, can greatly facilitate subsequent evaluation of the system. Although evaluation should be considered during each step of the process, formal planning for evaluation cannot occur until the system is well defined.

The primary purposes of evaluations are to:

- Identify changes needed to fine tune and optimize existing system operation or design and improve performance. In this way, the deployment is more likely to meet or exceed established goals and objectives.
- Understand and quantify the benefits of the system, which can help to identify future work zone ITS investment decisions (by documenting conditions for a successful implementation).
- Document lessons learned.

Planning for evaluation should begin with a determination of the appropriate scope for the evaluation. The scope for the evaluation establishes the extent of the assessment (e.g., effort, level of detail, how frequently evaluation will be done for the project) and might be based on the complexity of the system, as well as the duration and scale of the project.

Quantifying benefits need not be overly complex: for example, a North Carolina Smart Work Zone system was observed to have fewer crashes compared to other work zones without the technology.³⁴ Another example of quantified benefits was documented in the case of a California automated work zone information system that reduced traffic demand through the work zone, having a maximum average peak delay 50 percent lower than expected.³⁵ Public satisfaction is also valuable, and comments and feedback from the public can be a useful gauge of the value of a system. In Little Rock, Arkansas, for example, 82 percent of drivers surveyed agreed that an Automated Work Zone Information System improved their ability to react to slow or stopped traffic.³⁶

An evaluation includes, at a minimum, periodic monitoring of the data and analysis of performance measures, which necessitates a plan to collect and archive relevant data to adequately assess system performance. For example, an evaluation of a traveler information website might include counting hits or user sessions. Tracking visitor sessions or “visits” to the website is recommended as a tool to easily compare between sites. Trends on website usage may also assist in evaluating other facets of the work zone project, such as the effectiveness of a public awareness campaign and whether a website is a good investment that should be included on future ITS deployments.

Evaluation can benefit the agency responsible for the deployment of the work zone, as well as the traveling public. The lessons learned can be used for adjustments to the current system and can also be incorporated into future work zone applications. By framing a plan for a robust evaluation early, an agency can plan data collection activities, rather than piecing together available shreds of data after the project. This is also a time to consider data needs for agency process review. In addition, evaluation results can serve as a valuable resource for other agencies and planners. In general, the need exists for more data collection to better quantify benefits. Ensuring that work zone ITS will archive data in a format and level of completeness to allow the analyst to drill down to detailed impacts will allow agencies to better quantify those types of impacts, and develop strategies to minimize their occurrence in the future.

Several FHWA documents provide useful guidance for the use of work zone safety and mobility performance measures. First, *A Primer on Work Zone Safety and Mobility Performance Measurement*³⁷ offers information for understanding data requirements for generating useful performance measures. A companion document, the *Work Zone Performance Measures Pilot Test*³⁸ summarizes lessons learned through the identification and testing of a candidate set of work zone mobility-related performance measures at five projects nationwide. A third document, *Guidance on Data Needs, Availability, and Opportunities for Work Zone Performance Measures*³⁹ provides more in-depth information and guidance on the usefulness of various measures, and the data necessary to develop and use them effectively.



Tip: Helpful hints for planning an evaluation.

- Evaluations can be either qualitative or quantitative; however, the best evaluations employ a combination of both types of information.
- Examining the role of research in the evaluation step of the project will help clarify the types of analyses that can be performed to produce benefits data.
- The most effective evaluations occur when the goals and objectives for a work zone ITS are explicitly stated, measurable, and agreed to by all stakeholders.
- It is helpful to provide a mechanism for the public to offer feedback on the project. Several agencies have used comment sections on the project websites to collect this feedback.
- The formality and magnitude of an evaluation should match the level of the ITS deployment. An informal evaluation may be sufficient for simple systems, while a more formal evaluation would be better suited for a larger-scale deployment.

The ITS JPO at USDOT has developed a six-step process for evaluating ITS projects, which is shown graphically in Figure 17, and should be considered at this stage of the project. Some of these steps will be carried out later during and after system deployment, but the planning should occur now.

³⁴Additional information can be found at: <http://www.itsbenefits.its.dot.gov/ITS/benecost.nsf/ID/AAD0A64995FF6FFA8525733A006D5298?OpenDocument&Query=Home>.

³⁵Additional information can be found at: <http://www.itsbenefits.its.dot.gov/ITS/benecost.nsf/ID/F1F2919AE17E081285257172005C8569?OpenDocument&Query=Home>.

³⁶Additional information can be found at: <http://www.itsbenefits.its.dot.gov/ITS/benecost.nsf/ID/76C9F2DE2BF5DB1D85257603004E031D?OpenDocument&Query=Home>.

³⁷This is available online at: <http://ops.fhwa.dot.gov/wz/resources/publications/fhwahop11033/fhwahop11033.pdf>.

³⁸This is available online at: <http://www.ops.fhwa.dot.gov/wz/resources/publications/fhwahop11022/>.

³⁹FHWA-HOP-13-011, February 2013, http://www.ops.fhwa.dot.gov/wz/decision_support/performance-development.htm.

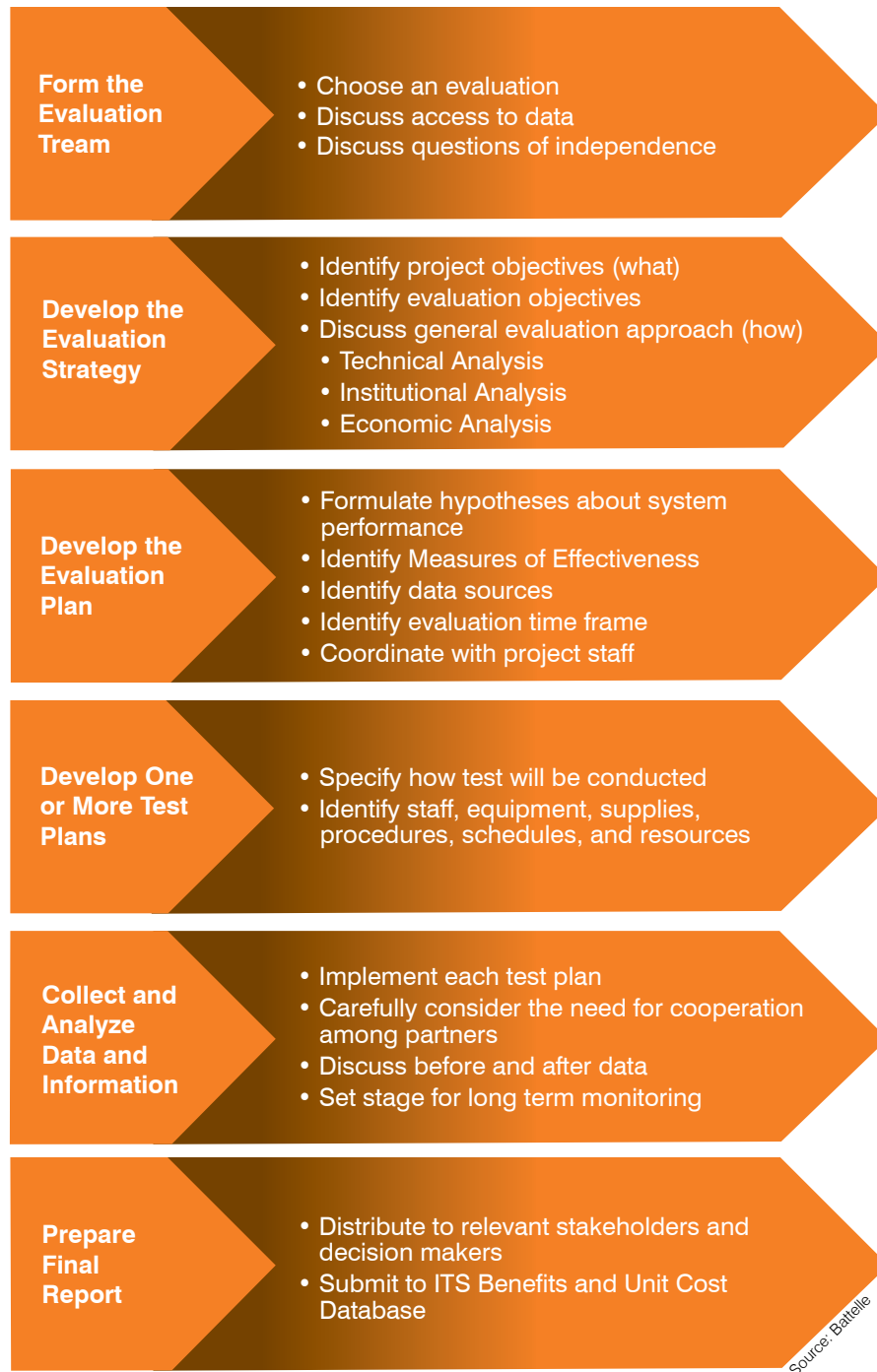


Figure 17. Overall evaluation process for ITS applications in work zones.

The *ITS Evaluation Resource Guide*⁴⁰ contains a more detailed explanation of this six-step process, as well as a discussion of evaluation measures that correspond to overall ITS goal areas – safety, mobility, efficiency, productivity, environmental impacts, and customer

satisfaction. Sample evaluation strategies, evaluation plans, test plans, and final reports are also available for downloading from the website. Table 8 presents some example criteria that might be used for a work zone ITS evaluation.

⁴⁰Available online at: http://www.its.dot.gov/eval/eguide_resguide.htm.

Table 8. Example evaluation criteria.

| Evaluation Objective | Hypothesis | Measures of Effectiveness | Required Data |
|---|---|---|--|
| Mobility – Reduce delay and optimize travel times through the construction corridor by providing advanced traveler information | The ITS will reduce travel time through the corridor during construction. | <ul style="list-style-type: none"> • Change in travel time over baseline conditions in the primary direction during construction • Change in the overall corridor-wide travel time reliability • Change in travel time on recommended or viable alternate routes | <ul style="list-style-type: none"> • Observed corridor travel time during construction • Observed travel time variability • Observed alternate route travel times during construction • Observed queue lengths before and after ITS on mainline routes |
| Safety – Improve traveler safety in the construction corridor | The ITS implementation will reduce crash risks during construction. | <ul style="list-style-type: none"> • Changes in the number of crashes or crash severity occurring in the corridor • Changes in speed variability along the corridor during construction • Change in the number of conflicts that occur in the corridor during construction | <ul style="list-style-type: none"> • Historical crash data • Real-time crash data • Observed speed variability during construction • Observed number of conflict situations occurring during construction |
| Customer Satisfaction – Improve travel satisfaction for corridor users during construction | The ITS will result in improved satisfaction among corridor users. | <ul style="list-style-type: none"> • Corridor traveler perceptions • Corridor traveler behavioral response to system components • Update frequency and perceived accuracy of provided information | <ul style="list-style-type: none"> • Opinions of corridor travelers serving on a panel survey • Traffic volumes on alternate routes and mainline • Wide distribution of customer satisfaction surveys |
| Institutional – Improve coordination among implementing agencies. | The ITS will result in improved coordination among implementing agencies. | <ul style="list-style-type: none"> • Number of institutional issues | <ul style="list-style-type: none"> • Documented institutional issues |

Source: Battelle

3.9 Estimating system benefits and costs

A key part of system planning is estimating system benefits and costs. In estimating the benefits that the system will have on traffic, mobility and safety are both key factors to consider. Estimation of these impacts will become easier as results become available from more ITS in work zone deployments. At present, traffic modeling and traffic flow theory can be used to estimate impacts on delay through factors such as diversion of traffic around the work zone. The level of effort spent to evaluate potential system impacts should be proportional to the size, duration, and complexity of the work zone. A complex 25-mile, 3-year work zone would require a more extensive evaluation of system impacts than that for a simple 1-mile, 2-month work zone. In

estimating system impacts, it is important to consider the whole area that the ITS deployment will influence (see Figure 6).

By this stage, the general cost estimates developed in Step 2 can be refined based on better-defined system characteristics. When refining cost estimates, agencies should be sure to consider ancillary costs such as required training, agency labor, outreach activities, and system maintenance. It is also recommended that agencies include a reserve or contingency fund to pay for unexpected items, such as fixing system integration and communications problems (e.g., costs for cellular modems and pagers, etc.).

System costs will vary widely depending on whether the system is purchased or leased, and whether labor associated with operating and maintaining the system is provided internally by agency staff or by an outside contractor. These procurement options and issues will be discussed further in the next section.

The ITS JPO maintains an ITS Benefits and Unit Cost Database to assist users with estimating system and unit costs of ITS elements and deployments across the country.⁴¹

Key Takeaways

- The main products of Step 3 are detailed system plans that build on the concept of operations from Step 2. The concept of operations describes the objectives of the system and how it would operate to achieve the objectives. Step 3 develops the system requirements and specifications that define what the system will do and ideally include performance targets.
- Documentation should include plans for system testing, operating the deployed system, the staffing approach, any necessary public outreach, system security considerations, and evaluation throughout and at the conclusion of the project. It is important to plan for each of these aspects to avoid issues later with system deployment and to ensure that data will be available for system evaluation.
- The most effective evaluations occur when the goals and objectives for a work zone ITS are explicitly stated, measurable, and agreed to by all stakeholders. Then it is much easier to pick appropriate performance measures for evaluation and to know what data to collect to best determine system success and value.

⁴¹The database is available online at: <http://www.benefitcost.its.dot.gov>; the website has instructions on how to contribute.



The objective of Step 4 is to procure the work zone ITS. This requires first considering a number of options, based on the type of deployment being procured. Sub-steps to developing the plan are depicted in Figure 18.

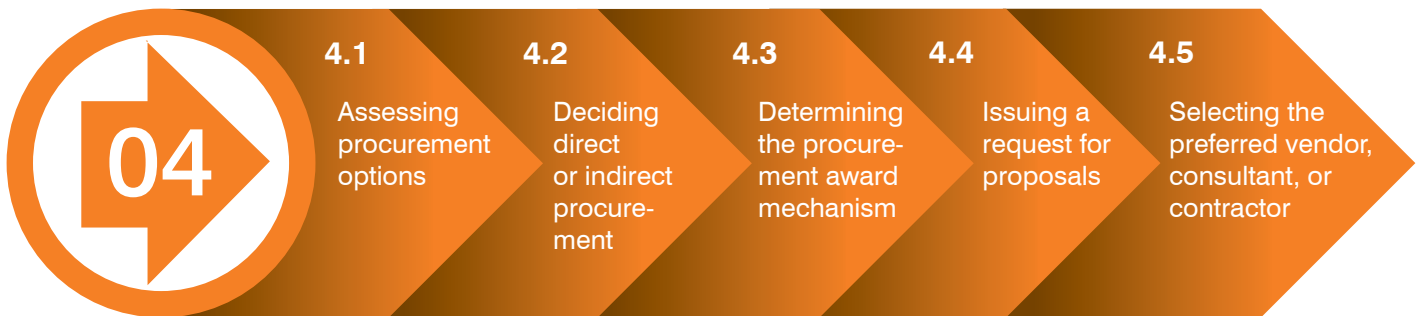


Figure 18. Sub-steps to be explored in Step 4.

Source: Battelle

4.1 Overview of procurement approaches

In many ways, the procurement options available for work zone ITS depends on the characteristics of the ITS needed. Traditionally, ITS procurement for work zone applications has primarily been for either COTS or customized ITS solutions. An agency or contractor would obtain the equipment, software, and operational expertise to gather, process, and use data to monitor conditions, measure performance, disseminate information to drivers, and otherwise manage traffic through and around the work zone. However, the potential now exists for agencies and contractors to purchase data collected by private-sector data providers for similar purposes.

An agency can *directly* procure ITS equipment, services, and/or data for its own use and dissemination as part of work zone safety and mobility management efforts, or can procure these items *indirectly* through specification of the ITS needs as part of the roadway construction or maintenance contract. A number of alternatives then exist within these two basic approaches. These approaches and alternatives are described in the following sections. It is important to realize that the type of work zone ITS selected will influence the procurement options, which will impact the choices for procurement award mechanisms in the next step, as shown in Figure 19.

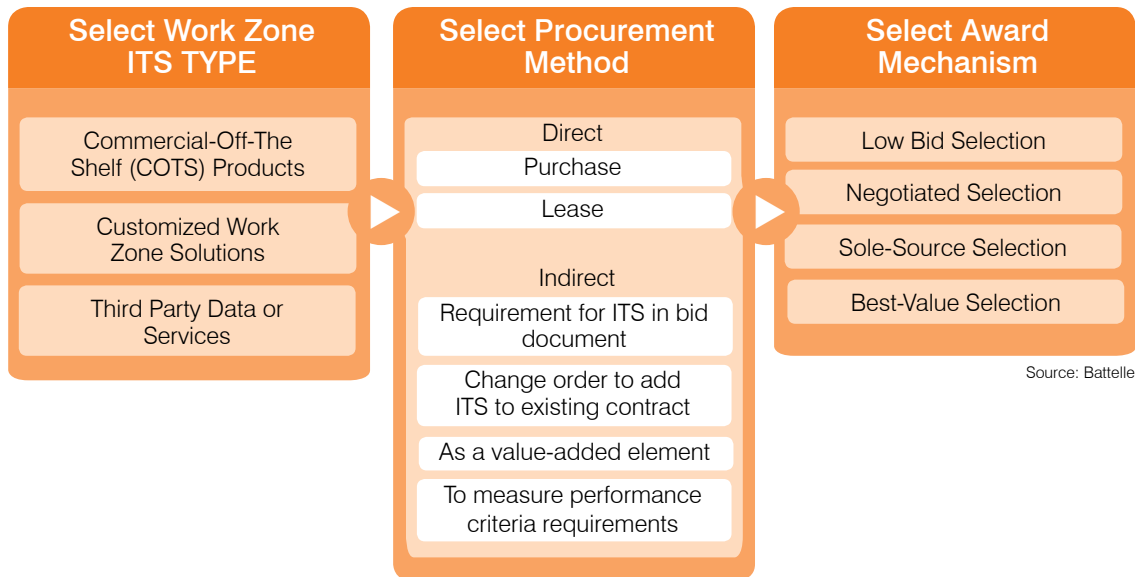


Figure 19. Agencies must select the work zone ITS type first, which could impact the type of procurement method and award mechanism that are used.

Procuring private-sector data

The procurement of private-sector data is a relatively new approach for agencies. Two types of private-sector data providers exist:

- Private-sector information providers that supplement their motorist travel time information to meet agency needs; or
- Vendors who install, operate, and maintain sensors for the agency and provide the data from the sensors to the agency in the desired format.

The first type is the private-sector information service providers who focus on providing real-time travel time information to drivers on an ongoing basis. These providers typically rely heavily on probe-based travel time data sources, and have developed sophisticated data fusion and travel time and congestion location

dissemination capabilities. Recently, these providers have begun marketing their data to agencies who wish to establish or supplement traffic condition monitoring or performance measurement capabilities on various routes in their jurisdiction. In essence, these companies license the data to the agencies rather than sell the data, as restrictions often exist in how the data can be used or distributed by the agency.⁴² As of 2013, the number of contracts (non-work zone) established to obtain this type of data has been limited and is generally negotiated between the data provider and the agency. In one example, the agency paid \$800 per mile per year for access to the data in real time (plus an initial \$200 per mile the first year).⁴³ If the agency is only interested in historical data (for computing a priori work zone performance metrics as an example), it is anticipated to cost less to have access to the data.⁴⁴

⁴²Turner, S. et al. *Private Sector Data for Performance Measurement – Final Report*. Report No. FHWA-HOP-11-029. FHWA, U.S. Department of Transportation, Washington, DC. July 2011.

⁴³Middleton, D. et al. *Synthesis of TxDOT Uses of Real-Time Commercial Traffic Data*. Report No. FHWA/TX-12/0-6659-1. Texas Transportation Institute, College Station, TX. January 2012.

⁴⁴Edwards, M.B. and M.D. Fontaine. Investigation of Travel Time Reliability in Work Zones with Private-Sector Data. *In Transportation Research Record: Journal of the Transportation Research Board No. 2272*. TRB of the National Academies, Washington, DC. 2012. pp. 9-18.

The second type of private-sector data availability involves the installation, operation, and maintenance of sensors at locations requested by the agency. This type of private-sector data allows the agency to leverage private-sector experience, supplement existing resources, and lower agency risk. One vendor offered bi-directional spot speed data to agencies for \$110 per location per month in 2012, providing all installation, operation, and maintenance of the sensors, and providing the data in the format designated by the agency.⁴⁵



Key Point: Procurement of ITS need not conform to a traditional approach.

The Minnesota DOT issued a stand-alone, design-bid-build, best-value contract to facilitate work zone ITS for a set of three simultaneous construction projects with separate contractors on a single stretch of highway. This mechanism helped assure contractor qualifications and expertise for designing, deploying, and operating a single, quality ITS, along with performance-based considerations for the projects.

The Minnesota DOT has also discussed issuing a general contract to have an ITS contractor on call. The ITS contractor would engage stakeholders and provide input and recommendations for work zone ITS early on for selected projects the agency believes will require it, stay abreast of rapidly changing technologies, and help the agency use ITS to its maximum potential.

4.2 Deciding between direct or indirect procurement

Direct Work Zone ITS Procurement Approaches

An agency has the option of directly **purchasing** work zone ITS from a vendor or consultant, or **leasing** it. The difference between these two approaches is in the duration of availability of the equipment/service/data, and who owns it, and in the operations and maintenance responsibility.

Purchase: The agency owns the equipment/service provided/data and is free to use it for as long as deemed necessary. An agency typically also has the responsibility for maintenance of the system, and replacement of any components that become inoperable due to accidents, wear, or neglect. This maintenance could be performed by in-house staff if properly trained, or purchased from a service consultant.

Lease: The vendor owns the equipment/services provided/data, and the agency obtains the equipment/service/data for a predetermined length of time (i.e., the term of the lease). When that term is completed, the

vendor retains ownership of the equipment and access to the services/data end. Maintenance, and possibly operations, efforts are handled by the vendor and incorporated into the lease price.

In determining whether to purchase or lease work zone ITS, an agency must consider the following:

- Anticipated duration of usage;
- Whether the agency expects to use similar equipment on future projects and when;
- Expertise on staff to operate, troubleshoot, and maintain the system;
- Reliability of the equipment hardware and software being considered;
- Source of funds to be used; and
- Agency policies and regulations.

Purchasing work zone ITS is sometimes an agency's preferred approach. Longer duration work zones, or the desire to use ITS on multiple work zones that are scheduled in sequence, often make purchasing more cost-effective than leasing. Similarly, purchasing is usually more appropriate for deployment of equipment that is integrated into a permanent regional ITS and will remain as part of that system after the work zone is completed.

For other situations, leasing work zone ITS is the preferred option. The procurement of private-sector traffic data by an agency will almost always be a leasing arrangement unless already available for use through existing contracts for permanent applications. Agencies that do not have expertise on staff to support the operation and maintenance of a work zone ITS deployment may be better served by leasing it and relying on the vendor to provide that expertise. These contracts can specify and restrict allowable downtime when issues with the system arise, levying fines or reduced reimbursement if the ITS deployment has not resumed operations by a certain time. For COTS deployments, leasing does appear to be the preferred method of most vendors and many agencies. Maintenance and removal by a vendor puts the responsibility for proper operation, quality control, and updating of equipment/using newer technologies on the vendor.

Most agencies allocate their available transportation funds into different categories for different purposes, with restrictions on how those funds can be used (much of the federal funding received by state agencies has restrictions on how it can be used as well). Some funds

may only be used for capital equipment purchases, for example, whereas other funds may be designated for operations and maintenance purposes with a restriction that such funds cannot result in agency ownership of any capital equipment.

Agencies typically also follow different procedures depending on how the specific work zone ITS deployment is categorized. For example, it may be feasible to either purchase or lease a COTS system because it can be procured through a traditional low-bid process. However, a customized deployment that requires system design support as well as software design and integration, could be categorized as an information technology project and be subject to additional procedures and regulations and may not be suitable for low bid.

Indirect Work Zone ITS Procurement Approaches

In addition to the approaches available for agencies to directly procure work zone ITS, there exist a number of approaches where agencies can indirectly procure it. With indirect procurement, in most cases, the actual procurement (purchase or lease) is done by the construction contractor rather than the agency, and thus the agency would not be directly responsible for the later substeps in the procurement process, or even in Step 5 for the system deployment or Step 6 for system operations. Instead, for an indirect procurement approach the primary responsibility of the agency will be in oversight of the work zone ITS and evaluation of the system both throughout and at the conclusion of the project. The indirect procurement methods include the following:

- Line item specification or special provision of the desired ITS functions or components in the original bid documents;
- Change order addition during the project to achieve the desired ITS functions or components (via specification or special provision);
- Assigned additional value to work zone ITS components included within best-value bid proposals (such as for design-build projects); and
- Incorporation of traffic performance requirements into the bid documents that could be monitored through the incorporation of work zone ITS.

The first two approaches above would ensure that ITS is deployed, while the latter two approaches may (but not necessarily) result in an ITS deployment.

One of the most common ways for ITS to be indirectly incorporated into a work zone project is for the agency to specify through a line item in the bid documents that it be provided as part of the contractor requirements

for performing the work. This approach requires a specification or special provision outlining the purpose, functions, and possibly operational requirements of the system (e.g., messages to be presented on PCMS, speed thresholds at which different messages are to be displayed, response time and maintenance requirements such as allowable downtime before penalty when issues arise, etc.). The contractor has the option for either purchasing or leasing the system. Overall, vendors prefer for specifications or special provisions to be very precise in the types and amount of equipment to be procured, as it allows them to be competitive when providing bids. However, agency personnel tasked with establishing the specification or special provision often do not have the technical expertise to create such a precise specification without unduly biasing it towards a particular type of technology or vendor. The actual system to be procured by the contractor and the amount to be paid by the agency to the contractor may be accepted initially by the agency, or may be part of negotiations between the agency and the contractor selected. Agencies should also be aware that if a project is delayed that specifications may need to be updated prior to issuing a request for bids to ensure it addresses current needs and system options.

Another way for ITS to be indirectly procured by an agency is by issuing a change order to an existing contract to add the system. This approach is used when the need or value of an ITS deployment is identified after the initial construction contract has been awarded. A change order may also be needed to further enhance the equipment or capabilities of ITS that have already been deployed. Like a line item bid approach, a specification or special provision is needed for bidding purposes. Both purchase or lease options are again possible, and different approaches can be used even if the change order is an addition to an already-deployed system (e.g., a system initially purchased could be enhanced through the leasing of additional equipment procured through a change order). This approach can result in slightly higher costs than those obtained during the initial project bid, as the contractor attempts to account for the additional time and cost to his or her operations in executing the change order.

A third indirect method of work zone ITS procurement is through the assignment of value to ITS deployments proposed as part of a design-build or best-value bidding process. (Note that the fourth method, the specification of performance criteria, may be included in a design-build process also.) For this approach, a consultant-contractor team develops needs, objectives, and methods for deploying work zone ITS and incorporates a proposed plan for the ITS deployment into their bid. The agency then considers the value of the proposed work

zone ITS deployment, typically using a point system and assessment process. Ideally, the value and scoring criteria that the agency uses in proposal evaluation would be based on the agency’s assessments of expected impacts that could occur during the project and the potential for the proposed ITS deployment to mitigate those impacts. It is important to note that this approach may not result in an actual ITS deployment, since a winning contractor or contract team may not be one that actually proposes the use of ITS.

The fourth and final method of indirect work zone ITS procurement involves specification of performance criteria in the construction contract alongside a requirement for the contractor to verify said performance. In this case, the contractor (or subcontractor) determines the best approach to meet and verify performance requirements. Although this approach would not

specifically require that ITS be used, the contractor could decide that an ITS solution is the best or only approach towards meeting the requirement of monitoring performance. This method would be best suited for well-defined mobility measures, such as maximum travel times or delays allowed. Agencies would designate any incentives to be awarded if monitored impact thresholds are maintained, as well as any penalties that will be incurred if such thresholds are exceeded.

A listing of the key advantages and disadvantages of each of the procurement approaches are summarized in Table 9. Theoretically, indirect procurement could involve equipment/COTS systems, data from third-party vendors, or a combination of both. To date, indirect procurement has involved mainly ITS equipment, particularly COTS systems. However, a more complex approach is certainly possible. For instance, a

Table 9. Summary table of procurement methods.

| | Method | Key Characteristics |
|-----------------------------|--|---|
| Direct Agency Procurement | Purchasing | <ul style="list-style-type: none"> • Can be most cost-effective approach for very long duration projects or when system is to be re-used on other projects • Necessary when components are to be integrated into permanent regional ITS and retained after the work zone is completed. • Agency has maximum control over the system • Data licensing agreements for private-sector data can involve some restrictions on use and dissemination |
| | Leasing | <ul style="list-style-type: none"> • Agency limits or eliminates need for ongoing maintenance and updating their technology • Agency not required to maintain expertise on staff for set up, troubleshooting, maintaining, and updating equipment • Maintenance and removal by vendor allows them to ensure proper operation, quality control over equipment used, and up-to-date equipment • A preferred method by vendors and agencies for COTS deployments • Direct engagement with vendor keeps high focus on work zone ITS |
| Indirect Agency Procurement | Specific requirement for ITS in bid documents | <ul style="list-style-type: none"> • Contractor has responsibility for determining and selecting a vendor (agency does not make vendor selection) • Contractor determines whether to purchase or lease the system • Agency can retain ability to negotiate with the contractor regarding pricing and other aspects of the ITS deployment • Agency does not have direct link to vendor to provide input on set-up and adjustments during operation |
| | Change order to add ITS for existing construction contract | <ul style="list-style-type: none"> • Contractor has responsibility for determining and selecting a vendor (agency does not make vendor selection) • Contractor determines whether to purchase or lease the system • Agency can retain ability to negotiate with the contractor regarding pricing and other aspects of the ITS deployment, but may cost more than including it in the original contract • Enhancements to existing work zone ITS by a contractor can be procured by a different approach than used for the original system (purchase versus lease) |
| | As a value-added element | <ul style="list-style-type: none"> • Design-build or contractor team develops ITS needs, objectives, and methods and may not have all the traffic data to tailor the ITS • Agency determines value of the proposed ITS deployment, and considers it within the overall transportation management approach being proposed • Winning contractor or contract team may not propose an ITS solution |
| | To measure performance criteria requirements in a contract | <ul style="list-style-type: none"> • Contractor decides best approach to meet the defined need to monitor impacts • Monitoring of impacts is commonly tied to incentive and/or disincentive clauses that depend on whether or not the impacts exceed a threshold • System may or may not be used to improve traffic operations |

contractor could, in cooperation with the highway agency, choose to purchase travel time data from a third-party data provider in real time with the intent to disseminate that information via portable or permanent CMS in advance of the work zone. Dissemination could involve manual monitoring of the data coming in from the third party and creation/posting of the travel times, or could potentially even be automated.

4.3 Determining the procurement award mechanism

Historically, ITS procurement has been accomplished through various award mechanisms, depending on the type of system needed. These mechanisms include:

- Low bid selection (commonly referred to as sealed bidding);
- Negotiated selection (based on evaluation of a technical approach, qualifications, and experience submitted as a proposal);
- Sole source selection (to obtain services or equipment when no competitors exist); and
- Best value selection (a weighted combination of the low-bid and negotiated selection mechanisms).

Often, direct procurement of COTS systems can be safely awarded through low-bid mechanisms, whereas more complex customized solutions and private-sector data are usually procured through one of the other mechanisms. The effectiveness of low-bid selections depends significantly on the quality of the bid specification itself. As noted previously, specifications that are too prescriptive technology-wise can result in only a single bidder (if the bidder is aware that they are the one, this can result in a higher bid price). On the other hand, specifications that are too general can result in procurement of lower-quality, less durable equipment or systems.

For indirect procurement through line item project bids or change orders, however, a COTS procurement will often be a negotiated or best-value selection. In some instances, a contractor may simply identify a work zone ITS vendor they prefer to work with, which could be considered a type of sole-source procurement. However, most agencies will include provisions in the bid documents to approve the system and vendor, as well as to limit the amount by which the contractor can increase the bids for profit purposes. The proposal of a work zone ITS as a value-added feature for a particularly large complex design-build project has occurred in a few instances in recent years, and may become more commonplace in the future as agencies develop procedures on how to objectively consider the value of these features in the overall bid package. Theoretically,

the project bid document could require a contractor to provide multiple bids from work zone ITS vendors and to select the low-bid option. To date, however, it does not appear that many agencies are willing to be so prescriptive, relying instead on the contractor to work up their best price with a vendor they feel gives them the best opportunity at being successful and profitable.

Although there has not been a significant amount of experience with procuring data from third-party vendors specifically for work zone purposes, it would seem that all of these approaches would be valid for work zone data procurement as well, depending on the location of the work zone (e.g., third-party data is not always sufficient on lower-volume facilities or for overnight hours).

4.4 Issuing a request for proposals or bids

After the procurement award mechanism has been selected, the agency has everything necessary to procure the system if the agency is directly procuring the system or system components. For a complex, uniquely designed system, this may involve the development and issuance of a request for proposals (RFP).

The RFP should contain clear specifications for the system, including any additional resources needed for operations and maintenance. The products of previous steps should contain all of the information necessary for inclusion to the RFP. The system requirements and system design are particularly important items to include, as is the testing strategy in order for the contractor to understand the desired system.

The structure of a given RFP will vary greatly based on a number of factors. Depending on the extent to which the agency plans to operate and maintain the system, staffing needs and maintenance considerations should also be included in the RFP document. It could be valuable to consult with several vendors or contractors in advance to research various options available in order to draft.

A separate consideration is the option of hiring an independent evaluator of the ITS deployment. An independent evaluator can assist an agency with making an unbiased comprehensive assessment of the deployed system. If an independent evaluator is preferred, this will be done through a separate RFP process. It is recommended that the contract be awarded early enough for the evaluator to make recommendations for data collection or documentation throughout the implementation.

If the need is more for a COTS system by the agency for which the agency has a good idea as to the functions, devices, and operating criteria to be used, a request-for-bid may be used in lieu of the more complex RFP for an agency's direct purchase. In these situations a purchase specification of the desired components and performance of the system are issued for vendors to follow. In a request-for-bid approach, lowest cost typically controls the award selection.

When a work zone ITS is to be procured indirectly, as part of an overall construction contract, the contractor has the primary role in determining what to provide. For these situations, the agency will normally include a special specification in the overall bid package. It is then up to the contractor to identify the technology, system, and if necessary, subcontractor to help meet the specification. Depending on how the specification is written, the agency may have some opportunity to work cooperatively with the contractor in selecting the ITS technology and subcontractor. Typically, this collaboration occurs more often once a contractor determination has been made, so as to keep from influencing the overall bid process.

4.5 Selecting the preferred vendor, consultant, or contractor

For direct work zone ITS procurements by the agency that involve an RFP, the next step is for all proposals that have been received to be evaluated by the agency and the winning proposal selected. The review team should verify that the proposed system will meet the required objectives for the needed ITS before delving further into the details of the proposal and evaluating it. It can be helpful to include someone with ITS and traffic management expertise who is familiar with the project TMP on the review team.

The final selection of the winning proposal should be based on the award mechanism established in substep 4.3 using the criteria established in the RFP in substep 4.4. Generally, the specified set of criteria from the RFP is used by those evaluating the proposals to rank the proposals in various categories. If the proposal includes additional elements, these can be considered for the potential value added to the required system in comparison to the higher costs that may be incurred, depending on the award mechanism. This may be particularly applicable for best value or design-build (DB) procurements.

Upon selecting the winning proposal, notification should be sent to the contractor with clear guidance regarding next steps. This should include information regarding a kick-off meeting. A kickoff meeting provides a forum to

discuss schedule information, expectations regarding system deployment and agency communications, and any changes that have occurred since the RFP was issued.

For simpler procurements, such as for a direct agency procurement of a COTS system for which a purchase specification and request-for-bid was issued, the process is very straightforward. The agency first verifies that the specifications included in the request-for-bid can be met by the vendors providing a bid, and then selects the lowest bid from those deemed to be acceptable.

Finally, procurements of a system or system components indirectly by a contractor as part of the overall contract may or may not involve the agency as part of the selection process, depending on when the procurement process is initiated (i.e., as part of the initial bid package or through a change order) and how the bid specification was crafted. Desirably, some level of involvement is incorporated into the bid specification (such as the requirement that the system be approved by the agency), since few contractors have enough experience with work zone ITS to be able to assess which vendor and/or subcontractor will best provide devices or a system that will best meet the requirements of the specification. Even then, it is still up to the contractor to first find the vendor/subcontractor, and then bring them to the negotiation table to bet agency approval of the selection.



Example: Massachusetts Service Contract.

The Massachusetts DOT has entered into a two-year service contract directly with a vendor to deploy, calibrate, and oversee operations of smart work zone equipment at projects as directed by the agency. Emphasis has been on short-duration projects where the Massachusetts DOT is pushing for construction to be accelerated. The Massachusetts DOT purchased the equipment directly and so will retain it at the end of the service contract. The Massachusetts DOT spent slightly more than \$370,000 on three pan-tilt-zoom capable portable camera trailers, nine portable traffic sensors, and three portable changeable message signs. The on-call portion of the contract consists of a \$30/day deployment cost of the equipment, and a \$1,000/month hosting charge for web-based monitoring of the system components.

Key Takeaways

- In this step, the procurement type and mechanism is determined, an RFP is issued, and a proposal is selected.
- In procuring work zone ITS, there are three different perspectives: the contracting agency that desires work zone ITS, the contractor responsible for the overall construction project, and the vendor who supplies work zone ITS. Lessons learned from each of these perspectives were gathered from five FHWA-sponsored case studies that examined deployments of ITS in work zones in Effingham, Illinois; Mount Vernon, Illinois; Salt Lake City, Utah; Orem/Provo, Utah; and Las Vegas, Nevada in 2012; interviews with agency officials from five States that are active in work zone ITS; and interviews with four experienced work zone ITS vendors. These lessons are provided below.

General Agency Perspectives

- Methods for estimating potential benefits and costs of work zone ITS are not well developed, such as expected diversion rates, resulting reduction in road user costs, or expected reductions in incident rates. Further, work zone ITS and its estimated benefits must compete for other construction (“hard-dollar”) needs when assessing whether work zone ITS is actually the best use of funds.
- Once implemented, it is often hard for an agency to assess whether the work zone ITS was beneficial. Agencies want equipment to be activated as soon as it is deployed to get the most out of their investment and to preempt liability concerns should an incident occur in the work zone when the system is inactive. If the agency leaves the system turned off to get data for a true “before” condition for comparison, criticism may result for not using equipment that has already been paid for and is supposed to alleviate issues caused by the work zone. Other methods of estimating impacts, such as through simulation models, are time-consuming and are not guaranteed to provide realistic estimates.
- Current agency procurement processes are difficult to apply to bid estimation for work zone ITS because there are not enough unit price experiences. Differences in various system objectives, designs, roadway and work zone characteristics complicate matters in trying to establish average unit pricings.
- Agencies should verify the qualifications of any ITS subcontractors that the contractor may propose or select. Contractors have limited experience with procuring work zone ITS technology and may be more focused on the main project, making the skills and capabilities of the subcontractor critical for a successful work zone ITS deployment.
- A separate ITS contract can allow for a better functioning work zone ITS, since that is the primary focus of the contract. With these contracts, the direct interaction between the agency and the vendor can reduce the time it takes to make the system work properly or make any necessary modifications.

- Language in separate contracts should include provisions for cooperating with adjacent projects since nearby projects may affect the work zone and functioning of the ITS.
- Best value contracts are useful, particularly if the vendor is required to demonstrate past successes and incorporate those proven technologies and strategies in their bid. Vendors with successful past experiences are more likely to reduce the time needed to make the system function properly, which is critical since the first days of deployment are critical to retain driver respect and attention.
- Agency access and use of third-party traffic data can be challenging, as the roadway segments used by the vendor may or may not line up well with actual work zone project limits, or even with how the agency defines segments within its own roadway inventory files.
- If third-party data is obtained for the purpose of post-hoc performance assessment of a work zone, the price of the “historical” data is likely to be relatively low but the data itself may be aggregated to a level that inhibits analyses of detailed work activities (i.e., a temporary lane closure occurring on a particular day or night). Conversely, leasing of real-time data for work zone monitoring and dissemination will typically allow for detailed assessment of specific work zone impacts, but will likely cost more to obtain.

Construction Contractor Perspectives

- Most contractors have very limited experience with procuring work zone ITS technology, and so many contractors rely on subcontractors for expertise. Generally, the technical knowledge needed for work zone ITS is much different than what normally exists on contractor staff. Contractors need to seek out qualified and experienced subcontractors to ensure that work zone ITS needs are sufficiently met.

- The addition of work zone ITS to a contract through a change order can be daunting for some contractors, who tend to be risk-averse. If the contractor does not have experience with similar issues or work zone ITS, the change order may be resisted and/or priced higher than might otherwise have occurred if included in the original bid documents, and the agency may have difficulty obtaining what was desired.
- Benefits to the contractor of a work zone ITS deployment, such as reduced delivery times or reduced litigation potential, are typically not considered or quantified by the contractor.
- Work zone ITS is often a small piece of an overall construction contract and therefore may not seem to warrant much effort or attention by the contractor.

Vendor Perspectives

- Not all agencies adequately verify that all required aspects of the bid specifications are met by the selected vendor prior to deployment of the system, or even once the system is deployed. The specification often does not spell out exactly what will happen should the system not meet the criteria in the contract (such as overall accuracy of each sensor, or the accuracy of the overall travel time that is estimated through the system).
- As a result, some vendors may propose on a project even if they are less than fully certain that they meet all the specification elements, since the consequences of not fully meeting the full specification are outweighed by the potential benefit of winning the contract.
- Some vendors prefer bid specifications that specify how much of each type of equipment is to be procured and deployed for a given work zone, so that competitive bids can be developed. Others prefer that the specifications only identify the functions and level of performance required, and allow the vendor to propose the number and location of devices that would meet the specification.
- Agencies who would like to see innovation in best value proposals should consider stating so in the bid documents. Otherwise, best value procurement requirements could restrict vendors from proposing innovative strategies that may be new but untested, given rapid changes in work zone ITS technologies.
- A standalone ITS contract allows the vendor to focus on the work zone ITS, as opposed to an indirect procurement where the contractor has its primary focus on the construction project itself.



Tip: Strategies for Successful Procurement.

- Agencies need to consider the necessary personnel experience for operating and maintaining work zone ITS before deciding whether to purchase or lease work zone ITS, so that the procured system can be effectively operated and maintained.
- Regardless of whether ITS is procured directly by an agency or indirectly through a construction contract, it is important that there be expertise available locally (either on agency, contractor, or vendor staff) who are tasked with day-to-day responsibility for operations and maintenance of the system to enable quick response and resolution of issues.
- Typically, for indirect procurements it is better to include work zone ITS as part of the construction contract than as an addition through a change order to minimize costs and reduce frustration. In addition, change orders over a given amount or percent on a project may require high-level administrative approval before procurement, which can delay when the system can be obtained and deployed.
- While change orders are not the preferred procurement approach, agencies should also recognize the potential need for change orders to modify or enhance the system once it is implemented and operational experience is gained regarding actual work zone impacts.
- Hybrid approaches that mix two or more of the procurement approaches discussed herein are possible. For example, an agency may choose to purchase a COTS system itself through a low-bid selection process, and then hire a vendor to deploy, calibrate, and operate the system on an as-directed basis through a low-bid or other type of selection process. As another example, an agency could specify that the contractor obtain a COTS system for the purpose of providing queue warning protection upstream of temporary lane closures, considering the payment for the system as a type of mobilization cost. Then, each time the system needs to be deployed, a per-use or per-day fee could be negotiated with the contractor to cover labor costs for deployment, operation, and retrieval.
- In some cases, agencies will specify that project funding will be withheld if ITS components are not maintained in a satisfactory operating condition as one way of increasing its importance with the contractor.
- It is important to remember that 3rd party traffic data collected primarily by vehicle probes can provide good work zone travel time and delay information, but will be less sensitive to the onset of queues that form until the queues reach a substantial length. Only those vendors that can provide spot speed data will be effective for supporting queue detection and warning systems.



STEP 5

SYSTEM DEPLOYMENT

The planning, design, and procurement efforts culminate in the actual deployment of the selected work zone ITS. Although considerable effort may have already gone into earlier steps in getting ready for deployment, this is the point at which things can really get busy. Unlike permanent ITS deployments which are typically the objective and focal point of efforts, a work zone ITS deployment must be matched to the overarching goal of completing whatever construction project or projects are necessitating the work zone in the first place. A work zone deployment becomes another cog in the overall project to be coordinated, managed, and otherwise adjusted so as to achieve the main desired goal: to complete the tasks required correctly, on time, and within budget while at the same time minimizing the impacts of those tasks upon the public, especially the traveling public.

As those who have been involved in performing and completing a work zone project can attest, project coordination involves chasing a constantly changing target in many cases. Field changes in project scope, phasing, scheduling, etc. can all affect how a work

zone ITS component fits and will work as a mitigation strategy. Even if such changes in a project do not occur, it is not known for certain how effective a particular ITS application will be until it is deployed. Consequently, field adjustments to the system are often necessary. Additional equipment may be needed because impacts exceed what was anticipated, or system operation may need to be altered to improve driver understanding and response to the system. These changes may be needed immediately upon deployment, or develop when the project changes to a new phase with a different maintenance-of-traffic (MOT) approach. As such, system deployment is not so much as step as it is a process.

System deployment includes initial implementation, as well as scheduling decisions, systems acceptance testing, and handling major deployment issues, as depicted in Figure 20. Deploying the system should be done in coordination with the deployment of other TMP strategies.

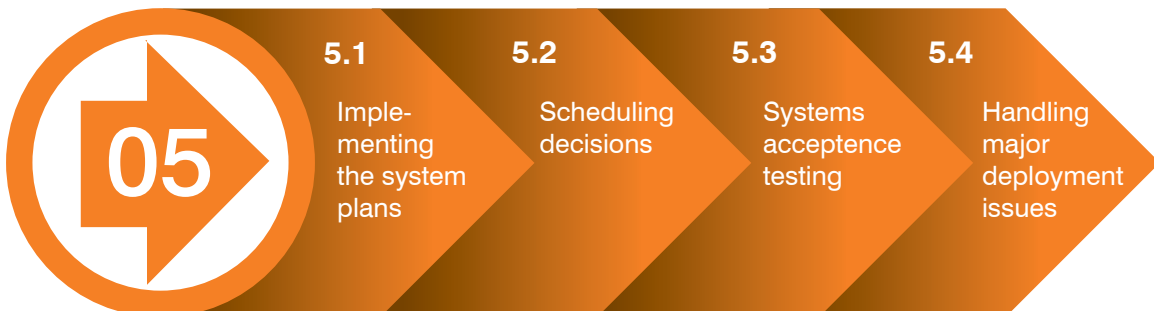


Figure 20. Sub-steps to be explored in Step 5.

Source: Battelle

5.1 Implementing the system plans

The role of an agency during system deployment depends on the size and complexity of the system, whether it is a COTS system or a unique system designed to address a highly specialized need, and whether it is to operate independently or be integrated into other ITS operational components in the region. For small, COTS systems that are intended to operate independently, agency involvement during deployment may consist of the project engineer and inspectors keeping track of the system and monitoring and validating the information being collected and disseminated. For larger and/or more novel or complex deployments and deployments that involve integration with existing ITS components, the level of agency involvement may span across several offices and divisions, and require significant staff time to test, troubleshoot, validate, monitor, and maintain the system.

Personnel with expertise in ITS deployment must be available through all steps of the deployment. For COTS systems, that expertise often resides with the vendor; for customized system designs, such expertise may need to reside with the agency or the consultant hired to design and oversee the deployment of the system. For customized system designs or deployments that are connected to existing permanent ITS infrastructure, it is also vital that key staff understand the overall vision developed in Step 2 and the requirements defined in Step 3. Subcontractors may look at each requirement individually, but not take into account the overall system vision. Such a “stove pipe” analysis can result in an installation that, while consistent with the literal system requirements, does not support the overall vision and other TMP strategies as intended.

5.2 Scheduling decisions

Scheduling can play a major role in the deployment of ITS applications for work. Testing and ultimate system calibration can take longer than anticipated, for example. It is critical that a work zone ITS deployment be available and functioning at the beginning of a project or major phase change for which it is intended, as this is the time when drivers first encounter unexpected conditions and need real-time information.

Scheduling decisions could include:

- **Plan for sufficient lead time to deploy:** Some agencies that are incorporating work zone ITS deployments into their construction contracts require that the system be operating before actual construction work starts. Contractors need to allow sufficient time for this requirement in their overall project scheduling.

Agencies or their consultants who are deploying work zone ITS themselves to support a particular project need to plan sufficient lead time as well.

- **Plan for sufficient calibration time and effort:** Systems that provide real-time travel time and delay information to motorists typically require some level of calibration to fine tune the values presented. Normally, this will need to occur after work and its associated congestion have begun. Efforts should be taken to ensure the availability of staff to assist during the calibration process very early in the project. Continued display of inaccurate travel times or delays will significantly erode credibility of the system with drivers, and make it more difficult to get drivers to react to the real-time information.
- **Consider the potential for the unexpected to occur:** It can be difficult to predict in advance the traffic impacts that a work zone might generate, and thus the amount of coverage needed for a work zone ITS deployment. It can be beneficial for agencies to have contingency plans, or at least have options available to them, with regards to modifying the system slightly. For example, an agency can designate that the contractor obtain an initial work zone COTS system meeting a set of specifications and equipment requirements as part of the original bid process. However, if additional equipment or functionalities are later found to be required, the potential implications for using a change order process to obtain that additional equipment or functionality should be thought through.

Agencies should ensure that as much time as possible be built into the implementation process and construction schedule, especially with regard to system calibration and sensor programming. Systems can be developed and deployed in short timeframes when needed. Additionally, flexibility is important for the ITS deployment schedule due to uncertainties in the construction project schedule. The initiation or conclusion of a construction project, or individual phases of a project, often change due to a variety of factors. While delays may be more common, sometimes projects or project phases can begin or end earlier than planned with only short notice from the construction contractor or agency staff. If ITS changes are necessary between phases, paying closer attention to the schedule is warranted to minimize ITS downtime. On the other hand, the steps outlined in this guide do require time to complete, and so it is important to allow for sufficient time.

**Tip: Allow start-up time when deploying a system.**

Problems will arise—such as the operation of sensors, communications (wireless or wired), calibration, or software—and will take time to address. These “bugs” require time to locate and address. Failure to allow for sufficient start-up time can lead to less than optimal performance of the system during the initial days of the project. Unfortunately, this is often the time at which the system is most needed, as drivers are encountering unexpected conditions due to the capacity and operational constraints imposed by the MOT plan, are surprised, and need and would benefit significantly from having improved information and guidance in how to best accommodate the work zone.

**Tip: Quickly deploying work zone ITS is possible but can require extra resources.**

Although it is desirable to begin the process for considering, planning, designing, and deploying a work zone ITS early in the overall project development process, circumstances sometimes dictate that an accelerated timeline be followed. It is important to recognize when such circumstances arise and to dedicate enough resources to be successful in meeting that timeline. For example, a work zone ITS deployment used on the Big I (I-40) project in Albuquerque, New Mexico, was able to go from concept to full operation in only 15 weeks. However, to accomplish this, the agency had to employ several experienced ITS contractors for the ITS design, system selection, and system installation.

5.3 System acceptance testing

Before the work zone ITS is activated, system acceptance testing must be conducted. These tests should be comprehensive to ensure that all system requirements and user needs are met. System acceptance testing will follow the testing strategy proposed in substep 3.3 and will validate the functionality and accuracy of the work zone ITS to make sure the system is working as planned.

Following the test plans from substep 3.3, data sheets should be used to record test data and compare recorded results with expected results. Test reports should be compiled that document how well the system performed and any modifications that need to be made prior to system activation.

As applicable, driver capabilities should be re-examined at this time to verify that the system will be satisfactory from a human factors perspective. Messages displayed on CMS should follow current guidance to ensure that the information is clear, concise, and credible. Characteristics of the devices and their deployment locations should also be checked. For example, the size of the text on a message display must be sufficiently large and visible (a minimum of 18 inch characters for freeway conditions) so that drivers do not have to slow down to give themselves more time to read. Message boards should be checked to be sure they are positioned away from obstructions that might limit viewing times, such as piers, abutments, parked construction equipment, etc.

5.4 Handling major deployment issues

Issues identified in system acceptance testing that are likely to affect deployment include problems with communications, power, sensors, and other system components deployed in the field. Communications can especially be a challenge in rural areas. While it is impossible to anticipate every possible contingency that could arise during deployment, availability of staff experienced in the deployment of ITS is one of the best means of mitigating issues that arise during deployment.

The key is to prevent issues from arising in the first place by selecting an experienced/qualified contractor and providing sufficient time within the schedule to handle issues that are not anticipated. Maintaining flexibility is crucial, as unexpected things like parked construction vehicles, construction equipment storage, or law enforcement positioning in front of sensors can cause issues that will need to be addressed. Developing and sustaining good working relationships among project team members are helpful for when issues arise. Frequent communication within the team can also assist in this process by helping to establish a positive working relationship among contractors, ITS subcontractors (if used), and government agencies.

Other issues like construction design or plan changes can also affect the ITS deployment. For example, an initial decision to keep a particular entrance ramp open during a major freeway reconstruction project may be changed based on poor safety performance of similar entrance ramps experienced at an ongoing project immediately upstream. If the initial decision was to deploy a work zone ITS with temporary ramp metering at that entrance ramp, the ramp metering component might need to be eliminated.

Key Takeaways

- In this step, the work zone ITS is deployed following the system plans, schedule, and system acceptance test plans.
- Coordination of the deployment with other aspects of the project, including other TMP strategies, is important.
- Deployment of the ITS must be considered a process. It should follow the implementation plan developed but be flexible to deal with changes in overall work zone scope and scheduling, unanticipated driver needs and responses, and a wide range of field conditions and actions which could influence system operations. An example of such demonstrated flexibility is evident in the following case study in Salt Lake City.

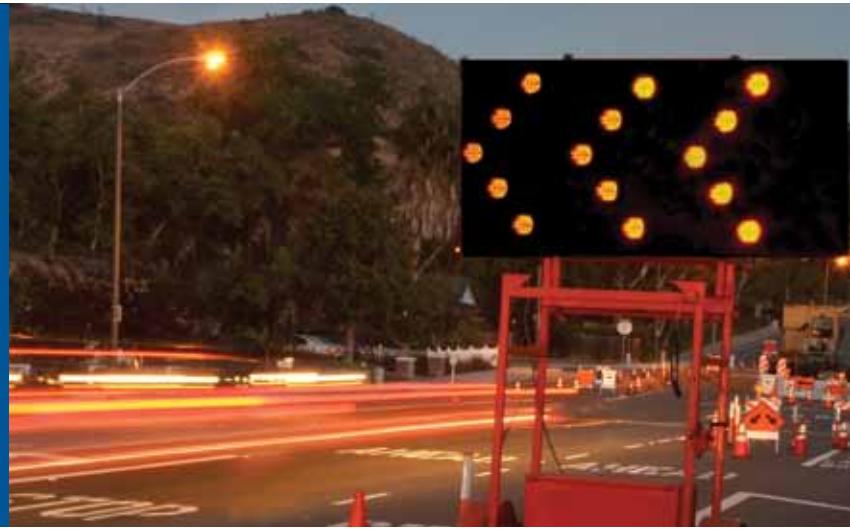


Example: Testing performance specifications – Salt Lake City, Utah.

Utah used performance-based specifications for work zone traffic control during a design-build project on SR 154 (Bangerter Highway) in Salt Lake City, developing and implementing a travel time monitoring system that used a Bluetooth address matching system. Utah DOT and the contractor spent a considerable amount of time once the antennas were deployed to fine-tune the overall operation of the system. A number of settings on the devices themselves had to be calibrated depending on how traffic was behaving near the antenna itself. Some of the calibration involved settings on the antenna itself, others in terms of how the data coming in from the detectors are handled during processing. It took the Utah DOT/contractor team a significant amount of time to understand the nuances of the system and to get the system to operate as desired. Another aspect of system operation that took some time for Utah DOT and the contractor to reach a consensus on was the minimum number of Bluetooth matches between antenna locations needed in a given time period to develop a good travel time estimate. Once calibrated, the system worked as intended, and yielded significant benefits to both Utah DOT and the contractor.

STEP 6

SYSTEM OPERATION, MAINTENANCE, AND EVALUATION



This step covers system operation and maintenance and includes sections on dealing with changing work zone conditions, using and sharing ITS information, maintaining adequate staffing, modifying the strategy and plan based on operational results, and leveraging public support, as depicted in Figure 21.

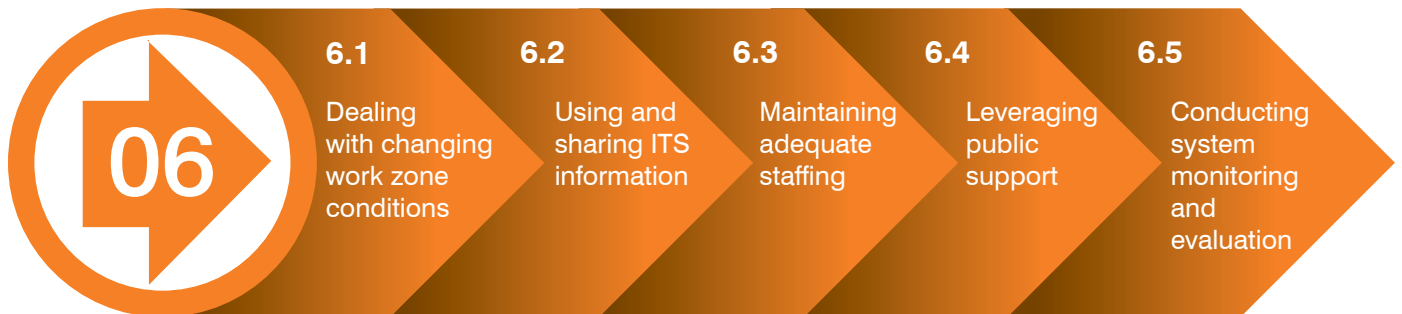


Figure 21. Sub-steps to be explored in Step 6.

Source: Battelle

6.1 Dealing with changing work zone conditions

One of the challenges for agencies operating ITS applications in work zones is maintaining system performance while adapting the system to changing work zone conditions and roadway geometries. The system may have to be repositioned or adjusted for various phases of construction that may involve different lane shifts or capacity reductions, for example. Other unexpected activities, such as parked construction vehicles, construction equipment storage, or law enforcement positioning in front of sensors, can cause issues that will need to be addressed in a timely manner.

Flexible and proven work zone ITS that can be dynamic or react in real-time is important for meeting real-time conditions. Not surprisingly, most agencies select highly portable systems built around proven

technologies and wireless communications. Some systems have capabilities to communicate via cellular network or satellite depending on whether or not cellular communication is available in an area.

The provision of power for work zone ITS is another important consideration. Many work zones are located in rural areas that will not have convenient, direct access to power. However, if a wired power source is used, fewer options may be available for moving the system as changes in the work zone arise. Portable systems are typically powered through batteries with solar arrays for charging, or by having vendor staff continuously charging spare components and switching out charged components as needed. Power levels of batteries should be monitored periodically to ensure adequate charge, particularly if overcast conditions may have reduced solar charging.

Supporting a changing work zone requires significant coordination among the construction team, agency staff, and ITS operators. These challenges illustrate the importance of these considerations in system planning in Step 2, as well as developing close working relationships in the earliest stages of the planning process.



Key Point: Sometimes conditions in the field may differ from what was expected during systems planning and design, and adjustments may be needed.

For example, queues may be longer or shorter than what was estimated before construction actually started. Personnel should monitor conditions in the field such that if queues regularly extend beyond the system signs (or detectors), the agency/contractor can consider adjusting the placement of the system components to make the most effective use of the system or adding additional devices to extend coverage.

6.2 Using and sharing ITS information

Information gathered from the work zone ITS might be used internally for traffic management purposes and to inform the use of other TMP strategies. Information about the work zone may provide insights about adjusting work zone hours, the lane closure schedule, the procedure to identify incidents, or fine tuning of alternate routes, diversion messages, or public outreach efforts.

Additionally, the benefits of the stakeholder relationship-building conducted in earlier stages of the project begin to appear. It is important to keep the stakeholders informed throughout the system operation step to ensure that cooperation and support for the effort continues. Discussion regarding the work zone ITS might be combined with related meetings such as those on maintenance of traffic, which are a venue for sharing ITS information, getting stakeholder input, and coordinating with other TMP strategies and the rest of the project. However, it is also important not to overload stakeholder partners with too much information.



Tip: Manage expectations.

It is important to assess and update expectations based on true experiences of the deployment in the work zone. The deployment may have greater or lesser impacts than originally anticipated, and it is important for stakeholders to understand why that is the case.

Work zone ITS differ in how they relay information to travelers via various media for pre-trip (i.e., website, email, text message) or en route (i.e., CMS or PCMS, HAR, in-vehicle navigational aids) decision making. In some systems, this information delivery is fully automated, whereas other systems require human confirmation of current traffic conditions and specific messages. Fully automated systems must be thoroughly and regularly tested to ensure that they are measuring conditions properly and that they are supplying the correct information for those measured conditions. Other ITS must be managed by operators, and require personnel to be available at all times while the system is running to confirm the conditions and to approve the message to be delivered to the travelers. Whichever option an agency chooses, the information delivered to travelers must be accurate; otherwise the public will lose confidence in the system.

Controls should be placed on message boards to prevent conflicting messages from being displayed along the same approach to the work zone area, to prevent messages from changing too often, and to prevent display of unhelpful information (e.g., work zone speed is 85 miles per hour). In addition, personnel from the implementing agency should have real-time access to archived system data in order to identify any issues and monitor system functionality. A website could easily provide password protected access to the data being used by the system to make decisions.

One of the most valuable products of ITS work zone applications is the development of real-time information that can be disseminated to a wide variety of users. ITS work zone systems collect data from several different types of roadside systems, process the data, and – with minimal human interaction – translate those data into valuable information for facility operators, emergency responders, and the traveling public. Provision of information can be a key in developing and maintaining stakeholder relationships, especially those involving agencies in other jurisdictions. Users of the information provided by the system may include state DOTs, the public and road users, nearby businesses and employers, media outlets, contractors, trucking companies, fleet operators, emergency services providers, motorist assistance patrols, neighboring jurisdictions, and third party traveler information providers.

A common method of information dissemination is through websites operated by state DOTs and other agencies. These websites also frequently include closed circuit television (CCTV) imagery from the ITS, which tend to be popular with travelers. Dissemination of this high



Tip: It is important to ensure that information delivered to the public is as accurate as possible.

If inaccurate information is provided, the public can quickly lose confidence, resulting in negative public relations.

quality information not only contributes to the operation of the system, but also builds credibility for the operating agency with the traveling public.

Finally, it is important that data be archived or reported in a way that will be accessible and useful for evaluation of effectiveness. Data are required for project performance monitoring in real time, for post-project assessments of impacts that could be fed back to project designers to aid future project designs, and for agency process reviews, and assessment of work zone policies and procedures as required in federal regulations.

For example, many agencies specify maximum delay or queue length/duration thresholds that will be tolerated as part of their overall bid documents for a project. However, very few employ any type of actual monitoring efforts to aid field inspectors in determining if such threshold are being exceeded (and thus a need to shut down the activity causing the impacts), or to implement any type of penalties or damages for violating the thresholds. Archived work zone ITS data can provide an accurate, objective measure for such efforts.

As another example, work zone ITS data can be used during the project to help accelerate project activities and result in a quicker overall project with reduced impacts to the public. Many agencies have established hours that lane closures are restricted from occurring on high-volume roadways due to concerns over excessive delays and queues. However, oftentimes these restrictions are not tailored to the travel patterns that exist at a given project, but are agency-wide restrictions. During one recent arterial reconstruction project in Salt Lake City, work zone ITS was used to by the contractor to justify requests to Utah DOT to increase the allowable lane closure hours, still avoiding peak travel times and directions, that allowed the project to be completed faster than expected and not result in significant queues or delays for the traveling public.

As part of post-project assessments and overall process reviews, having more data available allows for a more thorough analysis and better conclusions. Work zone ITS, depending on the technology deployed, can assist an agency in assessing the frequency, duration, and

magnitude of impacts that actually occurred. These can then be provided back to the work zone designers to compare against the results of their analyses. If their initial analyses were incorrect, it is often possible to determine the reasons for the incorrect outputs (i.e., error in estimating work zone capacity, diversion rates, etc.). This is an approach that the Michigan DOT has used regularly for its major work zones across the state. Consolidated across several projects, these work zone ITS data can also aid an agency in conducting its required bi-annual work process review. Basic performance measures can be determined for each project, such as⁴⁵:

- Maximum person throughput during peak hour;
- Average per-vehicle delay during lane closure hours;
- Percent of time when delays exceed the established maximum threshold;
- Percent of travelers experiencing a traffic queue; and
- Change in peak-period buffer time through a project.

Once project-specific measures are obtained and examined, it is also possible to aggregate across projects to develop an agency-wide perspective of performance. Examples of process-level measures for an agency could include:

- Percent of projects where delays exceeded the maximum threshold;
- Percent of projects experiencing increases in peak-period buffer indices by more than xx percent; and
- Percent of projects experiencing traffic queues greater than some maximum threshold for some maximum duration.



Tip: Carefully consider how to set up automated information delivery and sharing with other agencies.

Particularly with an automated information delivery system, it is possible to deliver too much information for the agency and its partner agencies to process effectively. The frequency, usefulness, and volume of information delivered to managers and partners needs to be appropriate or it will likely be discarded or ignored. Many ITS applications can be set to automatically deliver texts or e-mails to the agency or partners such as the media and public safety agencies. If the thresholds for delivery of these messages are not carefully considered, a recipient may be inundated with information and unable to sort out what is useful.

⁴⁵Ullman, G.L. et al. Guidance on Data Needs, Availability, and Opportunities for Work Zone Performance Measurement. Report FHWA-HOP-13-011. FHWA, U.S. Department of Transportation, Washington, DC, March 2013.

6.3 Maintaining adequate staffing

If operations and maintenance are contracted out, it is the contractor's responsibility to ensure that adequate, trained staff is available. However, if in-house staff are engaged, the agency must take steps to ensure that it has multiple staff members trained in system operations, maintenance, and troubleshooting. If these steps are not taken, the retirement or vacation of a key person may cripple the operation of the system or result in additional costs. It is in the agency's best interest to select a set of project personnel who are expected to be available for the duration of the project.

6.4 Leveraging public support

A common thread that runs through comments made by agency personnel responsible for implementing ITS in work zones is the need to engage the public during the earliest stages of the project. Publicizing the advanced features of the work zone system and the type of information that will be available to the public is the first stage in developing public support for these systems. In this early stage, while it is important to share potential system benefits with the public, it is likewise important to temper expectations of the system, in case any of the benefits do not ultimately develop. Support from the public and elected officials combined with quantified benefits will help to ensure long-term funding availability for appropriate applications of ITS in future work zones.

6.5 Conducting system monitoring and evaluation

It is important to monitor the work zone ITS during its operation to ensure that it is working correctly and meeting the needs of its users, and that the vendor is meeting contract obligations. The data collected and analyzed over the course of the project can then be used as part of a more comprehensive evaluation at the conclusion of the project. In some instances, it may be necessary to modify the deployment to improve operations based on the results from system monitoring.

6.5.1 System monitoring

System monitoring and evaluation will be conducted based on the evaluation plan from Step 3. Data should be collected throughout the course of the ITS deployment according to the plan. Various data elements can be analyzed periodically throughout the course of the project to assess the system performance. It is expected that some data elements will be monitored and analyzed more frequently than others, e.g., on a daily, weekly, monthly, quarterly basis. Data should be used to determine whether system modifications are needed, and also assess the impacts of work zone operations on safety and mobility in the work zone.

Data alone will not be able to address all aspects of the ITS deployment that need to be monitored. Agency staff also need to make observations in the field, which can be logged as qualitative data. Together, the quantitative data and qualitative observations will help ensure that the system is working correctly or identify any changes that may need to be made. For example, system monitoring may show that it takes a long time to recover from the queues that develop before the system puts diversion messages on the PCMS. This may lead to changing the threshold for when diversion messages are displayed (e.g., from 3 mile queues to 2-mile queues). Depending on the location, scale, and duration of the project, it may be desirable to have cameras in the field for staff to monitor traffic conditions from an off-site location to validate sensor data and system-generated PCMS messages with observations. If issues are identified, they should be addressed immediately with the appropriate staff, i.e., contractor, vendor, or agency. It is important for the agency to then ensure that adjustments have corrected the problem and are made in a timely manner.



Tip: Questions to consider as you monitor the system during deployment.

- Is the system working correctly? Are messages accurate based on conditions?
- Is the vendor meeting the contract? Are issues being addressed promptly?
- What are the data saying about work zone operations and safety and mobility in the work zone?
- Does the system need to be adjusted (e.g., adjust thresholds, change the wording or timing of PCMS messages, reposition sensors, add sensors)?

System monitoring must be in line with the expectations of all groups that require feedback regarding the work zone ITS deployment. While system monitoring occurs for the entirety of the deployment, the detail of any ongoing monitoring and evaluation reports will likely vary at different intervals throughout the course of the project. Some DOTs maintain dashboards with various performance measures, which may require certain inputs from the deployment on a monthly basis, for example. Agency managers may request updates on a weekly basis, with more detailed reports on a quarterly basis. System monitoring must be scheduled in a way that meets these expectations.

Many work zones consist of multiple phases and many different tasks, which may or may not impact travelers. An evaluation of a work zone ITS deployment should be designed to evaluate effectiveness during those times and locations where impacts were expected to be most

significant. The average delay per vehicle computed over an entire project may be very small, for example, if most of the work occurs off the roadway and only one or two days of work involves reductions in travel lanes. During those one or two days of lane closures, though, the average delay per vehicle will be much higher, and the effect of the work zone ITS on this delay is what will be of most interest to the agency. In other words, a work zone ITS evaluation must be carefully coordinated with field personnel to ensure that the evaluation is both appropriate and meaningful.

The work zone ITS evaluation should be done within the context of the TMP implementation, monitoring, and evaluation of the project. Data collected by the work zone ITS and the evaluation of the work zone ITS deployment may also inform an evaluation of other TMP strategies being used.

6.5.2 System modification

System monitoring may identify areas where modifications might be made to improve the performance of the work zone ITS. Discussions with stakeholders can also help to identify adjustments that are needed to system operation or information delivery mechanisms, content, and timing. For example, it may become apparent that additional sensor coverage is needed in a certain location because feedback from customers indicates that travel times being posted to PCMS are not as accurate as expected. In other instances, equipment (e.g., CMS) might be more effective if repositioned or by changing CMS messages for better user understanding.

Modification of a work zone ITS application will depend on both the scope of the system and the duration of the work zone. Adjustments to the deployment can sometimes be made without significant change orders

Example: Making modifications to work zone ITS deployments – Illinois.

Agency and contractor staff should monitor work zone conditions, whether formally or informally, to identify ways to improve the system. A traffic management system was procured as part of the overall bid by the contractor for a work zone project on the I-70/I-57 interchange in Effingham, Illinois. Several PCMS were deployed as per the bid specification. Initially, PCMS displayed messages as called out in the contract, as shown on the left in Figure 22. However, as both Illinois DOT and the contractor gained experience with the system and with how motorists responded to the various messages presented, changes to some PCMS messages were made, deviating from the contract. This included the display of specific speeds downstream as shown on the right in Figure 22. For example, the presentation of a given speed (as opposed to a generic “REDUCE SPEED AHEAD” message) was felt to elicit greater compliance by approaching motorists.

Other modifications may require additional funding. On a different project on the I-57/I-64 interchange in Mount Vernon, Illinois, queues occurred that were longer than originally expected. A change order was executed to add sensors and PCMS to the work zone traffic monitoring system that had already been deployed.

or other efforts. Many of these adjustments do not require funding, but some may have additional costs that could pose a challenge for funding. Ideally, costly changes will be avoided through good system planning. In some cases, there may simply not be enough time to evaluate the system thoroughly, make changes, and then implement those changes in the midst of an ongoing construction project. However, some informal assessment of the system is always possible in order to verify the system is operating properly.



Source: FHWA

Figure 22. PCMS messages were modified from a generic message (left) as stated in the contract to a more specific message (right).

6.5.3 Final evaluation

At the conclusion of the system deployment, a final evaluation should be conducted. A major objective of the final evaluation is to document lessons learned and benefits of the ITS deployment. This might include the collection of some final qualitative data from stakeholders, e.g., surveys or interviews. Analysis of all collected quantitative and qualitative data that has been collected over the course of the project should be conducted as described by the evaluation plan developed in substep 3.8. Examples of the results of two such evaluations are presented below.

The results, conclusions, and recommendations of the evaluation should be documented in a final report. These results can be used not only by the project partners for continual refinement of similar systems at other locations, but also by others wanting to implement similar systems in the future. The report might also be utilized to justify investments in work zone ITS deployments. ITS evaluation final reports can be entered in the ITS Benefits and Unit Cost Database,⁴⁶ so that the evaluation results can be shared with other interested transportation professionals.

Key Takeaways

- In this step, the work zone ITS becomes operational in the field with appropriate staff operating and monitoring the deployment, as necessary.
- Flexibility is important. Agency or contractor staff need to be available to make adjustments, as necessary, due to changing work zone conditions and findings from ongoing system monitoring and evaluation.
- A final evaluation should be conducted to include findings from any available data and detail the benefits and lessons learned from the system.



Example: Effectiveness of a work zone ITS deployment – Effingham, Illinois.

A work zone ITS was deployed at the I-70/I-57 interchange in Effingham to mitigate the potential for end-of-queue crashes occurring due to traffic incidents or temporary lane closures within the project limits. An assessment of crashes occurring during the two construction seasons of the deployment suggests that the system was useful and effective. From the first year to the second year of construction, the number of lane closure days increased, as did the amount of traffic exposure through the project. Even so, preliminary analysis by the Illinois DOT found that crashes decreased slightly, including end-of-queue crashes. Specifically, from 2010 (prior to system implementation) and 2011 (after system implementation) saw nearly a 14 percent decrease in queuing crashes, and an 11 percent reduction in injury crashes, despite a 52 percent increase in the number of days when temporary lane closures were implemented in the project. Although it is not certain whether the queuing frequencies and conditions between the two years were similar, the trends were very encouraging.



Example: Effectiveness of work zone ITS deployment – Comparative Analysis.

An FHWA study of work zone ITS deployments revealed that 50 percent to 80 percent of surveyed drivers diverted at least sometimes due to messages provided on travel time, delay, or alternate routes. The same study noted 56 percent to 60 percent reductions in queue lengths were possible. Finally, it was found that speed monitoring displays could reduce speeds by 4-6 mph, with one study finding a 20 percent to 40 percent reduction in vehicles traveling at least 10 mph over the speed limit with these devices present. (see http://www.its.dot.gov/jpodocs/repts_te/14320.htm).

⁴⁶The database is available online at: <http://www.benefitcost.its.dot.gov>; the website has instructions on how to contribute.

Appendix A. National ITS Architecture

National ITS Architecture provides a framework for planning, designing, and integrating ITS. It provides important standards for hardware components and software that will allow for integration with other systems. The architecture includes:

- Function – what the system will do;
- Location – where the information will reside; and
- Integration – path that allows information to flow among the physical components.

The use of ITS in work zones has grown to the point that steps have been taken toward its inclusion in the *National ITS Program Plan* and the National ITS Architecture 7.0.⁴⁷ The work zone related portions of the National Architecture can help to define the functionality of the work zone system and are also useful in developing functional specifications.

The Maintenance And Construction Operations (MCO) User Service Description features work zone management and safety as one of its main functional areas. The MCO User Service underscores the value of work zone information and smart work zones when states and regions establish regional ITS architectures for ITS deployment. MCO User Service functional areas include:

- Maintenance Vehicle Fleet Management: monitors and tracks locations and conditions of fleets of maintenance, construction, and specialized service vehicles
- Roadway Management: monitors and forecasts conditions and manages treatment of roadways during various travel conditions
- Work Zone Management and Safety: supports effective and efficient roadway operations during work zone activities
- Roadway Maintenance Conditions and Work Plan Dissemination: coordinates work plans and communicates conditions

⁴⁷For more information about the National ITS Architecture, see http://ops.fhwa.dot.gov/its_arch_imp

MCO User Service Requirements that pertain to work zone management and safety are:

| | | | |
|----------------|--|--------------|--|
| 8.1.3 | Maintenance and Construction Operations shall provide a Work Zone Management and Safety (WZMS) function, which provides support for the effectiveness, safety, and efficiency of roadway operations during all work zone activities. This function includes interactions among Traffic Managers, Supervisors, Dispatchers, Field Crews, Construction Crews, Public Safety Organizations, Information Service Providers, and Travelers. | 8.1.3.2.1 | WZMS shall collect information concerning work zone activities, including but not limited to: |
| | | 8.1.3.2.1(a) | Location |
| | | 8.1.3.2.1(b) | Nature / type |
| | | 8.1.3.2.1(c) | Scheduled start time |
| | | 8.1.3.2.1(d) | Duration |
| | | 8.1.3.2.1(e) | Lane shifts |
| | | 8.1.3.2.1(f) | Staging areas |
| | | 8.1.3.2.1(g) | Length of work zone |
| 8.1.3.1 | WZMS shall monitor, control, and direct activity in the vicinity of work zones. | 8.1.3.2.1(h) | Scheduled phases of work zone configuration |
| | | 8.1.3.2.1(i) | Alternate routes |
| 8.1.3.1.1 | WZMS shall provide information about work zones, including but not limited to: | 8.1.3.2.1(j) | Anticipated delays for travel route |
| | | 8.1.3.2.1(k) | Anticipated delays for diversion route |
| 8.1.3.1.1(a) | Anticipated delays | 8.1.3.2.2 | WZMS shall correlate planned activities with actual work. |
| 8.1.3.1.1(b) | Alternate routes | 8.1.3.2.3 | WZMS shall support preparation of reports on work zone activities. |
| 8.1.3.1.1(c) | Suggested speed limit | 8.1.3.2.4 | WZMS shall provide information on work zone activities to other agencies, including but not limited to: |
| 8.1.3.1.2 | WZMS shall provide support for automated speed enforcement around work zones. | 8.1.3.2.4(a) | Other maintenance and construction operations systems |
| 8.1.3.1.3 | WZMS shall be able to divert vehicles around work zones via automated lane changing techniques. | 8.1.3.2.4(b) | Commercial vehicle fleets |
| | | 8.1.3.2.4(c) | Emergency vehicle fleets |
| 8.1.3.1.3.1 | WZMS shall collect information used to support automated lane changing, including but not limited to: | 8.1.3.2.4(d) | Traveler information systems |
| | | 8.1.3.2.4(e) | Traffic management systems |
| 8.1.3.1.3.1(a) | Volume | 8.1.3.3 | WZMS shall provide systems that communicate reliable, accurate, and timely traveler information, including but not limited to: |
| 8.1.3.1.3.1(b) | Occupancy | | |
| 8.1.3.1.3.1(c) | Speed | 8.1.3.3(a) | Location, including lane closure information |
| 8.1.3.1.3.1(d) | Headways | 8.1.3.3(b) | Alternate route / detour |
| 8.1.3.1.3.1(e) | Vehicle characteristics | 8.1.3.3(c) | Work zone speed limit |
| 8.1.3.1.3.1(f) | Merging distance | 8.1.3.3(d) | Delay |
| 8.1.3.1.3.2 | WZMS shall support archiving of field data. | 8.1.3.4 | WZMS shall support the provision of vehicle intrusion warnings. |
| 8.1.3.1.3.3 | WZMS shall support use of field data for developing AHS-merging strategies. | 8.1.3.5 | WZMS shall be capable of tracking individual crew movements. |
| 8.1.3.2 | WZMS shall support the management of data about work zones. | | |

Appendix B. Summary of Resources Reported in this Document

Primary resources

- FHWA Work Zone Mobility and Safety Program – numerous resources to help transportation professionals familiarize themselves with work zone planning, analysis, and traffic management and with the current state of the practice on ITS in work zones (<http://www.ops.fhwa.dot.gov/wz>).
- American Traffic Safety Services Association (ATSSA) ITS Council. “ITS Safety and Mobility Solutions: Improving Travel Through America’s Work Zones.” This describes various ITS applications for work zones and potential benefits, considerations for use, and system layouts (http://www.atssa.com/galleries/default-file/2008July21_ITS_Safety_and_Mobility.pdf).
- American Association of State and Highway Transportation Officials (AASHTO) – a work zone ITS site as part of its System Operations and Management Subcommittee, including evaluation reports, sample specifications/standards, and drawings (<http://ssom.transportation.org/Pages/ITSinWorkZones.aspx>).

Published documents and resources to support ITS strategic planning

- “Best Practices of Rural and Statewide ITS Strategic Planning” (http://ntl.bts.gov/lib/jpodocs/repts_te/13608.pdf).
- “Regional ITS Architecture Guidance” by the National Architecture Team (<http://www.ops.fhwa.dot.gov/publications/regitsarchguide/raguide.pdf>).
- The ITS Architecture Implementation Program (http://ops.fhwa.dot.gov/its_arch_imp).
- Research and Innovative Technology Administration (RITA) ITS JPO (<http://www.its.dot.gov>).
- FHWA guide “Work Zone Public Information and Outreach Strategies” – designed to help agencies plan implement effective public information and outreach campaigns to mitigate the negative effects of work zones (http://www.ops.fhwa.dot.gov/wz/info_and_outreach/public_outreach_guide.pdf).
- The FHWA Peer-to-Peer Program for Work Zones – contains materials from a Work Zone ITS Peer Exchange Workshop conducted in May 2013 (<http://www.ops.fhwa.dot.gov/wz/p2p/>).

Helpful publications for work zone ITS solutions

- “Advancing Metropolitan Planning for Operations: The Building Blocks of a Model Transportation Plan Incorporating Operations – A Desk Reference” (<http://www.ops.fhwa.dot.gov/publications/fhwahop10027>).
- “Designing for Transportation Management and Operations: A Primer” (<http://www.ops.fhwa.dot.gov/publications/fhwahop13013/index.htm>).
- The FHWA ATDM program presents numerous strategies that may be effectively utilized in work zones (<http://www.ops.fhwa.dot.gov/publications/fhwahop12032>).
- The Caltrans “Systems Engineering Guidebook For ITS” (http://www.dot.ca.gov/newtech/docs/se_guidebook_ver1-12_14_05.pdf).

Guidance for the use of work zone safety and mobility performance measures

- “A Primer on Work Zone Safety and Mobility Performance Measurement” offers information for understanding data requirements for generating useful performance measures (<http://ops.fhwa.dot.gov/wz/resources/publications/fhwahop11033/fhwahop11033.pdf>).
- “Work Zone Performance Measures Pilot Test” summarizes lessons learned through the identification and testing of a candidate set of work zone mobility-related performance measures at five projects nationwide (<http://www.ops.fhwa.dot.gov/wz/resources/publications/fhwahop11022>).
- “Guidance on Data Needs, Availability, and Opportunities for Work Zone Performance Measures” provides more in-depth information and guidance on the usefulness of various measures, and the data necessary to develop and use them effectively (http://www.ops.fhwa.dot.gov/wz/decision_support/performance-development.htm).

Use of private sector data for work zone performance measurement

- Middleton, D. et al. Synthesis of TxDOT Uses of Real-Time Commercial Traffic Data. Report No. FHWA/TX-12/0-6659-1. Texas Transportation Institute, College Station, TX. January 2012.
- Edwards, M.B. and M.D. Fontaine. Investigation of Travel Time Reliability in Work Zones with Private-Sector Data. In Transportation Research Record: Journal of the Transportation Research Board No. 2272. TRB of the National Academies, Washington, DC. 2012. pp. 9-18.
- Turner, S. et al. Private Sector Data for Performance Measurement – Final Report. Report No. FHWA-HOP-11-029. FHWA, U.S. Department of Transportation, Washington, DC. July 2011.

Professional development in work zone ITS

- The National Highway Institute (NHI) offers courses addressing a wide variety of aspects of ITS, including systems engineering, project management, telecommunications, software acquisition, and ITS procurement (<http://www.pcb.its.dot.gov>).
- Web-based courses are available through the Consortium for ITS Training and Education (CITE, <http://www.citeconsortium.org>).
- LTAP resources are also available for work zones and ITS (<http://www.ltap.org/resources/searchdbs.php>).

Helpful resources for evaluating and comparing options for ITS deployment

- Benefit/cost analysis is one useful tool in evaluating and comparing multiple options for ITS deployment, including the option not to deploy ITS in the work zone at all. The ITS Benefits and Costs Database (www.benefitcost.its.dot.gov) can be a useful resource. The database includes unit cost data for many of the ITS items related to work zones.
- The ITS Deployment Analysis System (IDAS) is a software tool that estimates the costs and benefits of ITS investments (<http://idas.camsys.com>).
- QuickZone is a spreadsheet developed by the FHWA, which provides a general and quick work zone traffic impact analysis capability (Information at: <http://www.fhwa.dot.gov/research/topics/operations/travelanalysis/quickzone/>).
- The FHWA Traffic Analysis Toolbox includes guides for work zone modeling and simulation (<http://ops.fhwa.dot.gov/trafficanalysistools>).
- Criteria for Portable ATIS [Advanced Traveler Information Systems] in Work Zones: Lane Merge, Travel Time and Speed Advisory Systems, Horowitz, 2005 (<http://www.ctre.iastate.edu/smartwz/details.cfm?projectid=10>).
- Operational and Safety Benefits of Using ITS in Work Zones, Fontaine, 2005 (<http://ssom.transportation.org/Pages/Sept2005Workshop.aspx>).
- The USDOT ITS Joint Program Office (USDOT ITS JPO) has developed the ITS Evaluation Resource Guide to assist agencies in conducting evaluations of ITS projects (http://www.its.dot.gov/eval/eguide_resguide.htm).
- The work zone performance measures primer is a useful source of information for understanding data requirements for generating useful performance measures (<http://ops.fhwa.dot.gov/wz/resources/publications/fhwahop11033/fhwahop11033.pdf>).
- The “Operations Benefit/Cost Analysis Desk Reference” might also serve as useful guidance for benefit-cost analyses (<http://www.ops.fhwa.dot.gov/publications/fhwahop12028>).

Appendix C. Issues for Consideration

Below is a list of key points and tips that have been presented throughout this work zone ITS implementation guide.

Step 1 – Assessment of Needs

- **Key Point: *Work zone ITS is one of several tools available to address specific safety and mobility issues in work zones.*** If goals and objectives become more manageable to achieve through a different technique, that technique should be selected instead of ITS. Other strategies may be more economical and effective in meeting goals and objectives.
- **Tip: *Have realistic expectations.*** Although some ITS applications may be promoted as a catch-all solution to safety and capacity problems, field testing has not always shown conclusive benefits. Work zone ITS should be well designed and smartly applied to scenarios in which benefits are most likely to be achieved.
- **Tip: *Be sure that the work zone ITS fully captures the range of impacts for which it is intended.*** This is particularly important for deployments that are intended to convey delay or queue length information to users. In some deployments, work zone impacts periodically extended beyond the limits of the ITS devices. When this happened, the system was unable to provide accurate information. More importantly, the motorists sat through several minutes of delay before encountering a message that there were delays and reduced speeds in the work zone. This severely limited the credibility, usefulness, and benefits of the system.
- **Tip: *Stakeholder agencies, besides the deploying agency, need to be involved early.*** Coordination with other agencies is a primary issue that should be considered both in developing and implementing an ITS work zone. This will be important for determining how the system can work within each agency's existing procedures.

Step 2 – Concept Development and Feasibility

- **Key point: *Not all ITS deployments are complicated and expensive.*** For example, an additional temporary traffic sensor or two may be all that is needed to expand or enhance an existing permanent ITS deployment to be an effective tool for managing traffic impacts at a particular work zone. This was the approach taken during the I-15 CORE project in central Utah.
- **Tip: *Systems need to have reliable communications.*** The communications network for an ITS application is vital to the operation of the system and must be reliable. Issues that may impact communications need to be addressed early in the system development and deployment process. What may seem like a trivial issue at the outset may evolve into a more difficult problem when deploying or operating the system. Such issues include whether adequate cellular capacity is available and whether there are obstructions to signal transmission due to geography or terrain.
- **Key point: *Whether to use ITS to address a work zone need has to be assessed because work zone ITS may not be the only or best way to address a particular issue.*** For example, project staff at case study sites in Effingham and Mount Vernon, IL considered whether to use ITS the need for queue warning. Because on the need for automatic queue warning and delay information dissemination, staff at both projects considered alternatives and decided early on that some type of work zone ITS would be deployed. There had been previous efforts by Illinois DOT to warn drivers approaching a work zone with queues through the use of either enforcement personnel positioned upstream of the work, or through the use of Illinois DOT staff with truck-mounted CMS. The difficulties of predicting when queues would occur, having sufficient staff available to schedule during those times, and keeping the warning device (enforcement vehicle or the truck-mounted CMS) in the proper location relative to the end of the queue reduced the practicality of these approaches. Illinois DOT staff were also concerned with the potential liability associated with sometimes, but not always, being able to have an enforcement vehicle or truck-mounted CMS present when queues were expected.

Step 3 – Detailed System Planning and Design

- **Tip: *It is important to use a proactive approach in building public awareness of the project and the information that the ITS application will provide.*** Successful techniques include holding press conferences, issuing news releases, and keeping local media (especially those the public turns to for traffic information) up to date.

• Tip: Helpful hints for planning an evaluation.

- Evaluations can be either qualitative or quantitative; however, the best evaluations employ a combination of both types of information.
- The most effective evaluations occur when the goals and objectives for a work zone ITS are explicitly stated, measurable, and agreed to by all stakeholders.
- Examining the role of research in the evaluation step of the project will help clarify the types of analyses that can be performed to produce benefits data.
- It is helpful to provide a mechanism for the public to offer feedback on the project. Several agencies have used comment sections on the project websites to collect this feedback.
- The formality and magnitude of an evaluation should match the level of the ITS deployment. An informal evaluation may be sufficient for simple systems, while a more formal evaluation would be better suited for a larger-scale deployment.

Step 4 – Procurement

• Key Point: Procurement of ITS need not conform to a traditional approach. The Minnesota DOT issued a stand-alone, design-bid-build, best-value contract to facilitate work zone ITS for a set of three simultaneous construction projects with separate contractors on a single stretch of highway. This mechanism helped assure contractor qualifications and expertise for designing, deploying, and operating a single, quality ITS, along with performance-based considerations for the projects. The Minnesota DOT has also discussed issuing a general contract to have an ITS contractor on call. The ITS contractor would engage stakeholders and provide input and recommendations for work zone ITS early on for selected projects the agency believes will require it, stay abreast of rapidly changing technologies, and help the agency use ITS to its maximum potential.

• Tip: Strategies for Successful Procurement.

- Agencies need to consider the necessary personnel experience for operating and maintaining work zone ITS before deciding whether to purchase or lease work zone ITS, so that the procured system can be effectively operated and maintained.
- Regardless of whether ITS is procured directly by an agency or indirectly through a construction contract, it is important that there be expertise available locally (either on agency, contractor, or vendor staff) who are tasked with day-to-day responsibility for operations and maintenance of the system to enable quick response and resolution of issues.
- Typically, for indirect procurements it is better to include work zone ITS as part of the construction contract than as an addition through a change order to minimize costs and reduce frustration. In addition, change orders over a given amount or percent on a project may require high-level administrative approval before procurement, which can delay when the system can be obtained and deployed.
- While change orders are not the preferred procurement approach, agencies should also recognize the potential need for change orders to modify or enhance the system once it is implemented and operational experience is gained regarding actual work zone impacts.
- Hybrid approaches that mix two or more of the procurement approaches discussed herein are possible. For example, an agency may choose to purchase a COTS system itself through a low-bid selection process, and then hire a vendor to deploy, calibrate, and operate the system on an as-directed basis through a low-bid or other type of selection process. As another example, an agency could specify that the contractor obtain a COTS system for the purpose of providing queue warning protection upstream of temporary lane closures, considering the payment for the system as a type of mobilization cost. Then, each time the system needs to be deployed, a per-use or per-day fee could be negotiated with the contractor to cover labor costs for deployment, operation, and retrieval.
- In some cases, agencies will specify that project funding will be withheld if ITS components are not maintained in a satisfactory operating condition as one way of increasing its importance with the contractor.
- It is important to remember that 3rd party traffic data collected primarily by vehicle probes can provide good work zone travel time and delay information, but will be less sensitive to the onset of queues that form until the queues reach a substantial length. Only those vendors that can provide spot speed data will be effective for supporting queue detection and warning systems.

Step 5 – System Deployment

- **Tip: Allow start-up time when deploying a system.** Problems will arise—such as the operation of sensors, communications (wireless or wired), calibration, or software—and will take time to address. These “bugs” require time to locate and address. Failure to allow for sufficient start-up time can lead to less than optimal performance of the system during the initial days of the project. Unfortunately, this is often the time at which the system is most needed, as drivers are encountering unexpected conditions due to the capacity and operational constraints imposed by the MOT plan, are surprised, and need and would benefit significantly from having improved information and guidance in how to best accommodate the work zone.
- **Tip: Quickly deploying work zone ITS is possible but can require extra resources.** Although it is desirable to begin the process for considering, planning, designing, and deploying a work zone ITS early in the overall project development process, circumstances sometimes dictate that an accelerated timeline be followed. It is important to recognize when such circumstances arise and to dedicate enough resources to be successful in meeting that timeline. For example, a work zone ITS deployment used on the Big I (I-40) project in Albuquerque, New Mexico, was able to go from concept to full operation in only 15 weeks. However, to accomplish this, the agency had to employ several experienced ITS contractors for the ITS design, system selection, and system installation.

Step 6 – Operation, Maintenance, and Evaluation

- **Key Point: Sometimes conditions in the field may differ from what was expected during systems planning and design, and adjustments may be needed.** For example, queues may be longer or shorter than what was estimated before construction actually started. Personnel should monitor conditions in the field such that if queues regularly extend beyond the system signs (or detectors), the agency/contractor can consider adjusting the placement of the system components to make the most effective use of the system or adding additional devices to extend coverage.
- **Tip: Manage expectations.** It is important to assess and update expectations based on true experiences of the deployment in the work zone. The deployment may have greater or lesser impacts than originally anticipated, and it is important for stakeholders to understand why that is the case.
- **Tip: It is important to ensure that information delivered to the public is as accurate as possible.** If inaccurate information is provided, the public can quickly lose confidence, resulting in negative public relations.
- **Tip: Carefully consider how to set up automated information delivery and sharing with other agencies.** Particularly with an automated information delivery system, it is possible to deliver too much information for the agency and its partner agencies to process effectively. The frequency, usefulness, and volume of information delivered to managers and partners needs to be appropriate or it will likely be discarded or ignored. Many ITS applications can be set to automatically deliver texts or e-mails to the agency or partners such as the media and public safety agencies. If the thresholds for delivery of these messages are not carefully considered, a recipient may be inundated with information and unable to sort out what is useful.
- **Tip: Questions to consider as you monitor the system during deployment.**
 - Is the system working correctly? Are messages accurate based on conditions?
 - Is the vendor meeting the contract? Are issues being addressed promptly?
 - What are the data saying about work zone operations and safety and mobility in the work zone?
 - Does the system need to be adjusted (e.g., adjust thresholds, change the wording or timing of PCMS messages, reposition sensors, add sensors)?

Appendix D. Acknowledgements

The authors of this report are grateful for the assistance and feedback provided throughout this project by the FHWA work zone team. Tracy Scriba was FHWA's Task Manager for the project and directly provided invaluable support and guidance throughout the effort. Numerous representatives of the State Departments of Transportation and vendors also provided support in the development of the guidance contained herein. We are most grateful for the assistance of all the individuals who provided suggestions and feedback, and have tried to incorporate all of the helpful input to improve this guide.



U.S. Department of Transportation
Federal Highway Administration

U.S. Department of Transportation
Federal Highway Administration
Office of Operations
1200 New Jersey Ave., SE
Washington, D.C. 20590

www.fhwa.dot.gov/workzones

FHWA-HOP-14-008