OVERVIEW OF THE WORK ZONE INTELLIGENT TRANSPORTATION SYSTEMS IMPLEMENTATION GUIDE

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ABSTRACT

Work zone intelligent transportation systems (ITS) involve the use of a broad range of communications-based information and electronics technologies to enhance transportation and improve safety and mobility in and around work zones. The systems are portable and temporary in most cases, although some deployments may use either existing fixed infrastructure or become a permanent system.

Recently, an implementation guide was developed to aid public agencies, design consultants, construction firms, and industry with respect to work zone ITS design, deployment and operation. Work zone ITS is one possible operational strategy of many potential solutions that an agency can include in a transportation management plan (TMP). This paper summarizes the information in that guide, describing the key steps for successfully implementing ITS in work zones. The paper helps illustrate 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.
INTRODUCTION

Work zone intelligent transportation systems (ITS) involve the use of a broad range of communications-based information and electronics technologies to enhance 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. Work zone ITS can also be used to manage traffic, such as through variable speed limits, ramp metering, automated enforcement, or dynamic lane merge.

Table 1 provides a listing of various work zone ITS applications. 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 may be deployed individually or be grouped together depending on the work zone. Thus, each 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.

Work zone ITS technology has evolved from an experimental concept to a mainstream tool available to practitioners to help mitigate work zone safety and mobility impacts. However, it is just one possible operational strategy of many potential solutions that an agency can include in a transportation management plan (TMP) for a project. Deciding if work zone ITS is an appropriate strategy, determining the appropriate work zone ITS design to best address the anticipated safety and mobility impacts, and then getting the system deployed and operating, can be a daunting process. Recently, the Federal Highway Administration (FHWA) has developed and released an implementation guide for work zone ITS, and a case study report providing examples illustrating how the guide can be applied (1,2). This paper provides an overview of the implementation guide.
<table>
<thead>
<tr>
<th>Work Zone ITS</th>
<th>Brief System Description</th>
<th>ITS Components</th>
<th>Issue(s) being Addressed</th>
<th>Example of Deployment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time Traveler Information</td>
<td>Drivers provided information about current travel conditions; can be used to encourage diversion</td>
<td>Traffic data, Changeable Message Signs (CMS), Communications</td>
<td>Congestion/delay, Safety, Driver awareness</td>
<td>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. <a href="http://www.i15core.utah.gov/">http://www.i15core.utah.gov/</a></td>
</tr>
<tr>
<td>Queue Warning</td>
<td>Signs provide warnings to drivers about stopped or slow traffic ahead</td>
<td>Traffic data, CMS, Communications</td>
<td>Safety (crashes)</td>
<td>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. <a href="http://www.ops.fhwa.dot.gov/wz/resources/news/wznews_detail.asp?id=618">http://www.ops.fhwa.dot.gov/wz/resources/news/wznews_detail.asp?id=618</a></td>
</tr>
<tr>
<td>Dynamic Lane Merge (early merge, late merge)</td>
<td>Signs encourage drivers to merge at a specified point based on current conditions</td>
<td>Traffic data, CMS, Communications</td>
<td>Delay, Aggressive driving behavior, Safety, Queue length</td>
<td>Dynamic lane merge systems on I-95 and evaluated by Florida DOT have shown potential to enhance safety and operations. <a href="http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_CN/FDOT_BD548-24_rpt.pdf">http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_CN/FDOT_BD548-24_rpt.pdf</a></td>
</tr>
<tr>
<td>Incident Management</td>
<td>Enables faster detection of incidents for quicker response and clearance time</td>
<td>Cameras, Traffic data, Communications, CMS</td>
<td>Incident response and clearance time, Delay, Secondary crashes</td>
<td>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. <a href="http://www.ops.fhwa.dot.gov/wz/technologies/albuquerque/index.htm">http://www.ops.fhwa.dot.gov/wz/technologies/albuquerque/index.htm</a></td>
</tr>
<tr>
<td>Automated Enforcement</td>
<td>Automated system detects and captures images of speeding vehicles for enforcement purposes</td>
<td>Cameras, Radar, Communications</td>
<td>Speed management, Safety, Safety of law enforcement personnel</td>
<td>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. <a href="http://onlinepubs.trb.org/onlinepubs/trbnews/trbnews2779po.pdf">http://onlinepubs.trb.org/onlinepubs/trbnews/trbnews2779po.pdf</a></td>
</tr>
<tr>
<td>Entering/ exiting vehicle notification</td>
<td>Signs can warn drivers of a slow-moving construction or emergency vehicle entering or exiting the roadway</td>
<td>Sensors, CMS, Communications</td>
<td>Safety</td>
<td>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. <a href="http://www.roadsbridges.com/case-fire">http://www.roadsbridges.com/case-fire</a></td>
</tr>
<tr>
<td>Performance Measurement</td>
<td>Monitor and archive traffic conditions data to support real-time traveler information, modify operations, and support evaluation</td>
<td>Sensors, Communications, Archive database</td>
<td>Congestion/delay, Safety, Evaluation</td>
<td>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.</td>
</tr>
</tbody>
</table>

Source: Battelle
THE WORK ZONE ITS IMPLEMENTATION PROCESS

Overview

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 approach presented in the implementation guide follows a six-step systems engineering process 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 (1). This process is illustrated in Figure 1. This approach applies to any size project or deployment but the level of analysis needed will vary and should be scaled to the project complexity and scope. The sections that follow summarize the key considerations involved in each step.

Figure 1. Overview of the Work Zone ITS Implementation Process

Step 1. Assessment of Needs

Each work zone ITS implementation should begin with a thorough assessment of needs. It is critical to first understand what the system needs to accomplish, and for whom those accomplishments are intended, before design and deployment decisions can be made effectively. Needs assessment involves consideration of the following questions:

- What are the user needs?
- What are the system goals and objectives?
- Who are the stakeholders?
- Who should be on the project team?
- What, if any, existing ITS resources are available?

User needs should be identified in the context of the overall expected impacts of the work zone, and in coordination with the TMP development process for the project. This ensures that a larger perspective is taken, which is important because there may be more than one TMP strategy that can address particular needs, such that a work zone ITS may not be the best strategy alternative to implement. User needs should also be defined as specifically as possible. A statement such as “a need exists to warn approaching drivers when queues develop upstream of short-term lane closures that move locations from day to day” is preferable to the generic statement “a need exists to
provide motorists information about work zone congestion.” Also, although the traveling public is often a key user, the needs of agency personnel and contractors, law enforcement personnel, etc. relative to safety and mobility should also be considered. For example, a contractor need might be to “minimize the number or location of work zone sensors in the work space” so that the project critical path can be maintained.

The goals and objectives should then address the user needs, and be aligned with the overall TMP development and execution effort. System goals and objectives should follow SMART criteria, meaning that they are Specific, Measurable, Attainable, Relevant, and Time-bound. It is critical at this point 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 were to be deployed, what would it do to address user needs?

In general, the system should be adequately robust to consider the full impact of the work zone. As shown in Figure 2, 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.

Another key group that should be considered during system planning is stakeholders. 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. Stakeholders must be involved early on for a successful ITS implementation. Typically, this involvement will occur as part of a larger meeting agenda, such as on the TMP or the project alternatives and schedule. Meanwhile, the project team is the actual working group whose members are drawn from the stakeholder organizations identified above. 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 most metropolitan areas, existing ITS resources in the corridor or region can be applied to help manage the work zone and help to control system acquisition and deployment costs. The maintaining agency for these resources can explain the availability of ITS resources for use. If resources are available, care must be taken to ensure that the resources themselves will remain operational over the duration of the project and access to the systems and data is readily available. In some cases, some agencies include requirements in the bid documents that permanent ITS devices be maintained in an operational state throughout the duration of the project. Also, it may be desirable to supplement 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.

**Step 2. Concept Development and Feasibility**

The next step in the process is to further elaborate and specify the operational concept and feasibility of the system. Key considerations in this step include the following:

- What is the overall work zone ITS concept of operations?
- What ITS solutions are available?
- What are potential benefits of an ITS deployment?
- How much will an ITS deployment cost?
- What are the potential institutional and jurisdictional challenges?
- Are there legal and policy issues to address?
• How can project feasibility be established?
• How can buy-in be obtained from internal and external stakeholders?

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 document includes the user needs and objectives, 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 3 illustrates how a concept-of-operations might be portrayed graphically.

Figure 3. Illustration of a Concept-of-Operations Graphic.
Potential ITS solutions for work zones currently include stand-alone, commercial off-the-shelf (COTS) products to serve specific functions; customized work zone ITS solutions that are specially designed to meet a precise traffic management need, and can involve permanent or temporary enhancements to permanent ITS already in place in the corridor; and 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. However, work zone ITS applications are continuously evolving to better address issues. Additionally, emerging connected vehicle technologies that incorporate vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications will present major opportunities for communications and data gathering for work zones.

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, and will vary from project to project. Likewise, costs of a work zone ITS deployment will vary depending on the scope of the work zone, procurement method used, type of system implemented, and the system goals and objectives being achieved.

Assessing project feasibility is another critical consideration in this step. 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. Such applications are more likely to draw additional scrutiny from the media, the public, business owners, and local politicians. Development and use of a simple criteria checklist, such as shown in Table 2 (for illustrative purposes only) is one way in which work zone ITS feasibility could be objectively assessed. It is helpful at this stage to confirm stakeholder buy-in to ensure support moving forward.
Table 2. Example of a Work Zone ITS Feasibility Assessment (1)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Score</th>
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<tbody>
<tr>
<td>Factor 1 – Duration of work zone: Long-term stationary work will have a duration of:</td>
<td></td>
</tr>
<tr>
<td>• &gt;1 construction season (10 points)</td>
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<tr>
<td>• 4-10 months (6 points)</td>
<td></td>
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<tr>
<td>• &lt;4 months: procurement and installation timeline is available prior to work starting (3 points)</td>
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<tr>
<td>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:</td>
<td></td>
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<tr>
<td>• Significant (10 points)</td>
<td></td>
</tr>
<tr>
<td>• Moderate (6 points)</td>
<td></td>
</tr>
<tr>
<td>• Minimal (3 points)</td>
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<tr>
<td>Factor 3 – Queuing and Delay: Queue lengths are estimated to be:</td>
<td></td>
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<tr>
<td>• ≥2 miles for periods ≥2 hours per day (8 to 10 points)</td>
<td></td>
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<tr>
<td>• 1-2 miles for periods of 1-2 hours per day (6 to 8 points)</td>
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<tr>
<td>• ≤1 mile, or queue length estimates are not available but pre-construction, recurring congestion exists for periods &lt;1 hour per day (4 points)</td>
<td></td>
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<tr>
<td>Factor 4 – Temporal Aspects of Traffic Impacts: Expected traffic impacts are:</td>
<td></td>
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<tr>
<td>• Unreasonable for a time period that covers more than just peak hours (10 points)</td>
<td></td>
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<tr>
<td>• Unreasonable during most of both morning and afternoon peak hours in either direction (6 points)</td>
<td></td>
</tr>
<tr>
<td>• Unreasonable during most of a peak hour in either direction (3 points)</td>
<td></td>
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<tr>
<td>• Unpredictable; highly variable traffic volumes (1 point)</td>
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</tr>
<tr>
<td>Factor 5 – Specific Issues Expected (0 to 3 points each based on judgment)</td>
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</tr>
<tr>
<td>• Traffic Speed Variability</td>
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<tr>
<td>• Back of Queue and Other Sight Distance Issues</td>
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<tr>
<td>• High Speeds/Chronic Speeding</td>
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<tr>
<td>• Work Zone Congestion</td>
<td></td>
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<tr>
<td>• Availability of Alternate Routes</td>
<td></td>
</tr>
<tr>
<td>• Merging Conflicts and Hazards At Work Zone Tapers</td>
<td></td>
</tr>
<tr>
<td>• Work Zone Hazards/Complex Traffic Control Layout</td>
<td></td>
</tr>
<tr>
<td>• Frequently Changing Operating Conditions for Traffic</td>
<td></td>
</tr>
<tr>
<td>• Variable Work Activities (That May Benefit From Using Variable Speed Limits)</td>
<td></td>
</tr>
<tr>
<td>• Oversize Vehicles (Percent Heavy Vehicles &gt; 10%)</td>
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<tr>
<td>• Construction Vehicle Entry/Exit Speed Differential Relative to Traffic</td>
<td></td>
</tr>
<tr>
<td>• Data Collection for Work Zone Performance Measures</td>
<td></td>
</tr>
<tr>
<td>• Unusual or Unpredictable Weather Patterns Such as Snow, Ice, and Fog</td>
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</table>

Total Score

If the total score is:
• ≥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

Step 3. Detailed System Planning and Design

At this point in the process, work begins on the development of system requirements and specifications, performance measures for assessing system objectives, and deployment and operations/maintenance plans. The key considerations in this step include:
• determining system requirements and specifications,
• developing the system design,
• developing a testing strategy,
• planning for operations and maintenance,
• determining staff training needs for those operating and using the work zone ITS,
• planning for public outreach,
• investigating system security,
• planning for evaluation, and
• estimating system benefits and costs.

Most of these considerations at this step in the process are self-explanatory. The National ITS Architecture can help in defining requirements/specifications/designs, and should be consulted when developing such systems (3). Meanwhile, 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. The test plan does not need to be extensive in all cases; simple validation may be sufficient for a COTS system, for example. Public outreach efforts about the work zone ITS should ideally be integrated within the overall public information plan developed as part of the TMP for the project. Finally, ensuring system security measures are included and applied is also critical, especially for systems that are providing traveler information. There have been various instances in which failure to secure system devices through passwords, cabinet locks, etc. have led to the posting of messages by vandals, creating embarrassment for the agency (see Figure 4).

Figure 4. Consequences of failing to provide adequate security to system components.

Planning for evaluation is also a key consideration in step 3, to be implemented as part of efforts in step 6. 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. 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. Data collection and archiving requirements need to be established at this stage so they can be considered in developing contract requirements to ensure that the necessary information is available during and after deployment. 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. Figure 5 illustrates how an evaluation process for a work zone ITS deployment might be constructed. Depending on the particular application, not all of these components may be needed.

Step 4. Procurement

The procurement options available for work zone ITS depend on the characteristics of the ITS needed. Traditionally, ITS procurement for work zone applications has primarily been for either COTS or customized ITS solutions. However, the potential now exists for agencies and contractors to purchase data collected by private-sector data providers to accomplish many of the same purposes. Key considerations at this step include:

- assessing procurement options;
- deciding on direct or indirect procurement;
- determining the procurement award mechanism;
- issuing a request for proposals; and
- selecting the preferred vendor, consultant, or contractor.

Overall, the type of work zone ITS selected will influence the procurement options, which will impact the choices for procurement award mechanisms, as shown in Figure 6.
Figure 5. Illustration of an evaluation process for ITS applications in work zones (1).
Figure 6. Relationship between Work Zone ITS type, procurement method, and award mechanism (1).

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. Under direct procurement, an agency would either purchase work zone ITS from a vendor or consultant, or lease it. If purchased, the agency owns the equipment/service provided/data and is free to use it as deemed necessary. However, the agency also has responsibility for maintenance of the system, and replacement of any components that become inoperable. If leased, the vendor owns the equipment/services provided/data, provided to the agency for a given period of time. Maintenance, and possibly operations, efforts are handled by the vendor and incorporated into the lease price.

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. For an indirect procurement approach, the primary responsibilities 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.

Indirect procurement methods include:

- 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 accomplished and monitored through the incorporation of work zone ITS.

Other characteristics regarding procurement methods are illustrated in Table 3.

Table 3. Summary of Work Zone ITS Procurement Options (f)

<table>
<thead>
<tr>
<th>Method</th>
<th>Key Characteristics</th>
</tr>
</thead>
</table>
| Purchasing                                  | • 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                                     | • 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 repair 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 |
| Specific requirement for ITS in bid documents| • 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 | • 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) |
| Indirect Agency Procurement                 | • 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 |
| As a value-added element                     | • 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 |

Source: Battelle
Step 5. System Deployment

The planning, design, and procurement efforts culminate in the actual deployment of the selected work zone ITS. 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 ITS 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 project 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. Consequently, deploying the system should be done in coordination with the deployment of other TMP strategies.

System deployment includes initial implementation, as well as scheduling decisions, systems acceptance testing, and handling major deployment issues. Since it is critical that a work zone ITS deployment be functioning at the beginning of a project or major phase change for which it is intended, scheduling is likewise critical. Scheduling decisions should plan for sufficient lead time to deploy, sufficient calibration time and effort, and the potential for the unexpected to occur. System acceptance testing is part of this process, and should follow the testing plan developed in Step 3. Driver capabilities should be re-examined at this time to verify that the system will be satisfactory from a human factors perspective. Messages should follow guidance currently available to ensure that they are clear, concise, and credible (4, 5). Regarding major deployment issues, construction design or plan changes can 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.

Step 6. System Operation, Maintenance, and Evaluation

Once the work zone ITS has been deployed and is functioning as intended, efforts turn towards ensuring that it continues to function as intended over the duration of the project or phase. Key considerations in this step include:

- dealing with changing work zone conditions,
- using and sharing the ITS information,
- maintaining adequate staffing,
- leveraging public support, and
- conducting system monitoring and evaluation.
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. Similarly, 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.

Evaluation should include both system monitoring/performance and TMP effectiveness. 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. 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. Thus, a work zone ITS evaluation must be carefully coordinated with field personnel to ensure that the evaluation is both appropriate and meaningful. System monitoring may identify areas where modifications might be made to improve the performance of the work zone ITS. Modification of a work zone ITS application will depend on both the scope of the system and the duration of the work zone. Some adjustments to the deployment can be made without significant change orders or other efforts, but additional costs may be incurred in some instances.

Another key way that work zone ITS information can be used is for evaluation of overall TMP 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, for agency process reviews, and assessment of work zone policies and procedures as required in federal regulations. In addition, sharing of the work zone ITS information with the various stakeholders is one benefit gained by bringing them in early in the implementation process.

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.

REFERENCES