Mitigating Work Zone Safety and Mobility Challenges through Intelligent Transportation Systems

Case Studies

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16. Abstract

This report documents several case studies of how agencies used work zone intelligent transportation systems (ITS) to mitigate safety and mobility issues in work zones. The report illustrates how to apply a systems engineering-based decision-making process to designing, selecting, and implementing a system to address work zone needs. The report presents the steps followed by the agency/contractor in this decision-making framework for five specific projects. The work zone ITS deployments documented provide examples of selecting and deploying commercial off-the-shelf (COTS) systems; a tailored design and integration of ITS for a specific work zone purpose; and using and supplementing permanent ITS deployments for work zone management purposes. Tips are provided for how to effectively apply ITS to other work zones.

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LIST OF ABBREVIATIONS

ADT	Average Daily Traffic
BYU	Brigham Young University
CMS	Changeable Message Signs
CCTV	Closed-Circuit Television
COTS	Commercial Off-The-Shelf
DB	Design-Build
FHWA	Federal Highway Administration
FAST	Freeway and Arterial System for Transportation
I-15 CORE	I-15 Corridor Expansion
IDOT	Illinois Department of Transportation
ISP	Illinois State Police
ITS	Intelligent Transportation System
JPO	Joint Program Office
LVACS	Las Vegas Arterial Control System
MOT	Maintenance-of-Traffic
NCHRP	National Cooperative Highway Research Program
NDOT	Nevada Department of Transportation
NTP	Notice-to-Proceed
PCMS	Portable CMS
PTS	Prepare-to-Stop
RFP	Request for Proposals
SMD	Smart Monitoring Device

STM	Smart Traffic Monitoring
TOC	Traffic Operations Center
TMP	transportation Management Plan
UDOT	Utah Department of Transportation

CHAPTER 1 - INTRODUCTION

Intelligent Transportation Systems, or ITS, is the application of electronics, communications, and/or information processing to improve the efficiency and/or safety of surface transportation systems *(1)*. ITS can improve transportation safety, mobility, and societal productivity through the integration of advanced communications technologies into the transportation infrastructure and in vehicles. ITS encompasses a broad range of wireless and wire line communications-based information and electronics technologies *(2)*.

One application where ITS can have substantial benefits is in work zones. ITS has been successfully used in work zones for several purposes, including:

- Traffic monitoring and management,
- Provision of traveler information,
- Incident management,
- Safety enhancement,
- Capacity enhancement,
- Enforcement,
- Performance-based contracting, and
- Work zone planning.

Work zone ITS has seen ongoing technological development for more than 10 years. A significant amount of testing has occurred to prove concepts, identify and address challenges in communications, and automate decision algorithms for control and information dissemination. From this, much has been learned and documented in various case studies *(3-11)*. However, work zone ITS is now evolving from being an developmental strategy for improving safety, operations, and productivity to more of a "mainstream" tool available to the work zone planner/designer and developers of transportation management plans (TMPs) to mitigate specific safety and mobility challenges that can exist on a project.

A range of approaches to using technology and data, including ITS, in work zones are now available. These include:

- Commercial off-the-shelf (COTS) systems[1],
- Tailored systems,
- Third-party traffic data, and
- Application and enhancement of permanent ITS for work zone purposes.

A number of COTS systems are now available to provide traffic monitoring and meet specific traveler information dissemination needs. Most commonly, these systems are implemented to mitigate safety concerns that arise from non-recurrent congestion developing because of the

[1] Stand-alone, commercially available products that 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.).

work zone, to provide real-time travel time and delay information, and to improve motorist awareness and reduce anxiety about travel conditions ahead.

The second work zone ITS deployment option that occurs less frequently (but which is still a viable approach) is the tailored design and integration of specific ITS devices into a customized system to meet unique work zone traffic management and control needs. Creation of a traffic monitoring system to assess contractor compliance with a mobility-based performance specification would be an example of this approach.

Still another option for implementing work zone ITS is to use (and possibly supplement) existing permanent ITS technologies (where available) to address work zone safety and mobility challenges. The breadth of coverage of permanent ITS has increased significantly across the U.S. in recent years. With proper planning, these systems can (and should) be used to effectively manage traffic during the work zone period. In some cases, additional devices are needed to address temporary bottlenecks or other impacts in and around the work zone or to maintain system capabilities when the permanent devices are temporarily disabled and/or removed.

The primary objective of this report is to document several case studies of work zone ITS used to mitigate safety and/or mobility issues in the work zone. It is valuable to understand how agencies and contractors are deciding when, where, and what to apply (i.e., the decision-making process), as well as the results of those decisions. This report provides examples of the decision-making processes and steps followed by the agency/contractor in designing, selecting, and implementing a system and the deployment results.

The report follows a traditional systems engineering design process as a roadmap to describe each implementation. In general, a systems engineering design process consists of these steps:

1. Define the problem,
2. Specify requirements of a solution,
3. Identify and evaluate alternatives, as necessary,
4. Select, design, and implement the best solution, and
5. Evaluate (i.e., describe the lessons learned).

Successful implementation of ITS applications in work zones requires a systematic approach to provide a technical solution that accomplishes a set of clearly defined objectives. A systems engineering process should be applied to determine the feasibility and design of work zone ITS for a given application by walking through key phases, from project concept through operation. Although the overall scope of a given project ultimately determines the complexity and level of effort required during planning, a systems engineering process should apply equally to the range of deployments, from small-scale, temporary deployments lasting a few months using COTS systems to complex, multi-year ITS deployments that may eventually be incorporated into permanent traffic monitoring and management systems.

Work zone ITS deployments at five case study sites are presented to illustrate four types of applications:

1. Mitigating High-Speed Rear-End Work Zone Crashes: Illinois DOT Experiences in Effingham and Mount Vernon - examples of selecting and deploying COTS systems.

2. Traffic Mobility Performance Specification Monitoring: The Utah DOT Bangerter Highway Project Experience - an example of a tailored design and integration of ITS for a specific work zone purpose.

3. Managing Traffic During Construction: The Utah DOT I-15 CORE Project Experience – an example of supplementing existing permanent ITS.

4. Managing Work Zone Traffic: The Las Vegas Transportation Management Center (FAST) Experience - examples of using permanent ITS for work zone management purposes.

The report concludes with a summary of key concepts drawn from the case studies to assist practitioners with deciding when and how to apply ITS to address safety and mobility issues in their work zones. Additional information on planning, procuring, deploying, and evaluating work zone ITS can be found in *Work Zone Intelligent Transportation Systems Implementation Guide* (FHWA-HOP-14-008).

CHAPTER 2 - MITIGATING HIGH-SPEED REAR-END WORK ZONE CRASHES USING COMMERCIAL OFF-THE-SHELF ITS: EFFINGHAM AND MOUNT VERNON, IL

Work zones often have the effect of reducing the capacity of a facility even when lanes are not closed. Queues can result when traffic demand exceeds the reduced capacity. Queues on uninterrupted flow facilities are typically unexpected by motorists, especially if the queues occur outside of large metropolitan areas. This typically leads to an increased risk of rear-end crashes between approaching vehicles and those already in the queue (as has been shown in multiple studies of work zone crash characteristics). Typically, speed differentials between vehicles approaching the queue and vehicles already in queue are fairly high (up to 60 mph or more), such that the rear-end crashes that do occur are generally quite severe.

The Illinois Department of Transportation (IDOT) has observed these trends in its interstate work zones in recent years, including at least one crash that resulted in multiple fatalities and received significant media exposure. As a result, the agency has become very proactive in trying to reduce rear-end crashes at its interstate work zones where traffic queues are expected to occur occasionally.

Two interstate reconstruction projects in central Illinois serve as case studies of the decisions involved and actions taken to implement intelligent transportation system (ITS) solutions to address work zone rear-end crash concerns. In both instances, commercial off-the-shelf (COTS) systems were chosen and implemented. However, the selected system vendors and the general design and layout of the systems themselves differed, and slightly different approaches were taken by agency and contractor staff to develop specifications, procure, and operate the systems. The end result in both cases was a successful implementation that agency, contractor, and vendor personnel all perceived as accomplishing the desired project objectives.

OVERVIEW OF THE PROJECTS

I-70/I-57 Interchange, Effingham, Illinois

The I-70/I-57 interchange is located in central Illinois. I-70 is a four-lane facility that serves as a major east-west freeway and freight corridor across the United States, and is also the major route between St. Louis and Indianapolis. I-57 is also a four-lane facility serving as a major route connecting Chicago with points south. For a section of approximately 6 miles, these routes are concurrent. IDOT determined that there was a need to reconstruct and improve the area where this section is located (Figure 1). The reconstruction project occurred between December 2010 and October 2012.

Google Maps, modified by Battelle.

Figure 1. Map. I-70/I-57 Interchange Project, Effingham, Illinois.

The 2010 annual average daily traffic (ADT) of these two routes where they are concurrent was approximately 45,000 vehicles per day, with 45 percent trucks (which could become as much as 90 percent trucks at night). Although a fairly high volume for a four-lane section, prior to construction, traffic generally operated uninterrupted at interstate speeds throughout the day and night. During reconstruction, however, capacity reductions created by the required reductions/elimination of shoulders, lane shifts, temporary lane closures, etc. were expected to generate periods of congested, stop-and-go traffic. This project was located on a rural interstate where drivers would not anticipate having to stop.

The I-57/I-64 Interchange, Mount Vernon, Illinois

Located approximately 70 miles south of Effingham, the I-57/I-64 interchange at Mount Vernon, Illinois, was another project location where IDOT officials elected to specify and implement work zone ITS technology to protect against rear-end crashes and provide drivers with delay information to help facilitate real-time diversion decisions. Like the I-70/I-57 project, this project was located in a rural area where drivers would not anticipate having to stop. Also similar to the I-70/I-57 interchange in Effingham, the I-57/I-64 interchange included a section where both routes ran concurrently on a four-lane cross-section. However, the length of the concurrent route was less, approximately 4 miles. Figure 2 illustrates the project location.

The 2011 ADT in this section was 39,610 vehicles per day with 33 percent trucks, which the interchange could typically accommodate. IDOT initiated a 2.5-year project to reconstruct and widen the interchange. The proposed improvement included construction of new continuously reinforced concrete pavement in both directions and a new third lane added in the median. The project was constructed in several stages between 2011 and 2013. During one stage, one lane northbound on I-57 and one lane westbound on I-64 were to be closed to eliminate the need to construct temporary pavement to accommodate the two normal lanes of traffic. The lane closures were expected to create congestion during certain days and times, which could lead to rear-end crashes that IDOT wanted to avoid. During other phases, reduced lane and shoulder widths, lane shifts, and other construction-related conditions were expected to reduce capacity and also increase the potential for occasional traffic queues to form.

Google Maps, modified by Battelle.

Figure 2. Map. I-57/I-64 Project Location in Mount Vernon, Illinois.

APPLICABILITY OF THE ENGINEERING DESIGN PROCESS TO THE CASE STUDIES

Defining the Problem

Key Problems

1. Unpredictable queues leading to severe rear-end crashes
2. Lengthy delays when queues form

The primary problem that concerned IDOT personnel in both project locations (I-70/I-57 and I-57/I-64) was the potential for rear-end crashes to occur due to occasional traffic queues caused by the project that would be unexpected by drivers on the rural interstate. Some severe traffic crashes attributable to work zone queues at past projects had raised the issue to one of the top safety concerns for the department. The project work conditions that were anticipated to potentially cause such queues differed slightly for each location, but in both cases the ability to predict when (or even how often) such queues would be created would be highly limited. In addition, the effects of any incidents that occurred within the project limits would be exaggerated due to the loss of available shoulders.

Finally, although the safety concern about queues was the major problem, the resulting delays generated by such queues were also a concern to project staff.

For the I-70/I-57 project, the frequency of queue formation was not estimated beforehand, but was expected to be relatively low and unpredictable. For the I-57/I-64 project, IDOT performed an analysis using the Federal Highway Administration (FHWA) QuickZone traffic analysis tool[2] to determine how far back the queues would typically develop if a lane were closed. Based on their estimate, they anticipated up to 3 or 4 miles of queue in the northbound I-57 direction. They based this on upstream ADT values that they factored out to hourly volumes.

Specifying Key Requirements of a Solution

For both projects, a primary requirement of a solution was the ability to detect and warn approaching traffic whenever traffic slowed and formed queues. A second requirement was that the solution be able to encourage travelers to use nearby alternative routes when queues and delays became significant. The determination of what constituted "significant" delay and congestion could be made later in the process.

Solution Requirements

1. Automatic detection of slow/queued traffic
2. Ability to warn approaching motorists of slow/queued traffic
3. Encourage diversion by informing motorists of current delays

Although not necessarily defined explicitly as a solution requirement by staff at either project, it was generally understood that the warnings needed to occur in near real time without requiring either IDOT or other personnel to take action to initiate the solution. In both projects, it would be difficult to justify constant staff time devoted to monitoring conditions and then initiating a response if and when queuing occurred at a work zone.

Specifically for the I-70/I-57 project, the work zone ITS requirements (termed the work zone transportation management system, or WZTMS by IDOT) were based on the following overall objectives:

- Reduce the frequency and severity of rear-end collisions in slowed or stopped traffic,
- Provide real-time delay information to travelers for major traffic movements within the project, and
- Direct traffic onto alternate route detours when necessary (i.e., for full interstate closures).

Early in the planning process for the I-57/I-64 project, a decision was made to employ a smart work zone traffic monitoring system. IDOT District staff worked with its central office staff, FHWA, and Illinois State Police (ISP) to incorporate a description and specifications for a "smart traffic monitoring system" as a bid item in its contract bid documents.

[2] For more information, see: http://ops.fhwa.dot.gov/wz/traffic_analysis/quickzone/

Identifying and Evaluating Alternatives

Based on the need for automatic queue warning and delay information dissemination, staff at both projects decided early on that some type of work zone ITS would be deployed. There had been previous efforts by IDOT 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 IDOT staff with truck-mounted changeable message signs (CMS). The difficulty 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. IDOT 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. To address these concerns, and to provide continuous and near real-time detection and warning, an automated system was needed.

For the I-57/I-64 project, IDOT had also considered an additional non-ITS solution knowing that capacity values dropped significantly in past work zones when 11 foot lanes were used, as vehicles would not drive next to large trucks in those conditions (trucks tended hug the lane line). In the past, they had provided a regular 12 foot lane and a narrower lane next to it, and attempted to get trucks to use the wider lane (i.e., TRUCKS USE LEFT LANE), but that technique did not work very well due to a lack of compliance and issues when approaching a left lane closure. Consequently, this non-ITS solution was not selected.

Selecting, Designing, and Procuring the Best Solution

Overview

Based on the decision to use work zone ITS to address its needs for queue detection and warning and encouraging diversion, IDOT incorporated a description and specifications for a "smart traffic monitoring system" as a bid item in its contract bid documents. Selection of the actual system was handled by the contractor, in consultation with IDOT staff. Design specifications included in the two project documents did vary quite substantially in terms of their length and specificity; yet both yielded systems that performed very similar functions following fairly similar logic.

Common items specified in both sets of system provisions included the following:

- Internet-based software to allow IDOT and contractor to monitor components of the system in real time,
- Capability to compute travel times and delays for each direction and update frequently,
- Automatic ability to determine messages to display to motorists based on a predetermined algorithm,
- Posting of predetermined messages on appropriate CMS,
- Ability to allow operators (including IDOT staff) to override the system to post messages as needed, and
- Capability to operate automatically on a continuous (24/7) basis.

However, the two projects differed in terms of the types of details included in specification of system components to be deployed.

The I-70/I-57 Solution

For the I-70/I-57 area, project staff developed a special provision document outlining the required number of devices and functions of the system. The document development process involved brainstorming discussions with various IDOT district and project staff and several manufacturers, and review of similar documents previously used by IDOT and others. In particular, traffic sensors capable of collecting data on both traffic volumes and speeds across multiple lanes of traffic were specified. The sensors were to be of a type not degraded by inclement weather conditions including precipitation, fog, darkness, dust, or road debris.

A WZTMS was part of a special provisions document describing an “automated, portable, real-time work zone system” to be deployed. Specific requirements of the system included:

- 25 CMS, capable of remote control via a central computer base station,
- 25 portable traffic sensors linked to the central base station,
- 20 remote video cameras linked to the central base station,
- 1 central base station with appropriate software and either wireless or dedicated phone line communications to link with the traffic management system components, and
- A password-protected project website (with color-coded map display) that project personnel could use to monitor conditions, check on operational status of the system components, etc.

Additionally, portable solar-powered trailers were included in the system with radar and Wavetronics traffic sensors, and with video surveillance cameras (see Figure 4). Communications between devices was accomplished via cellular modems.

The I-57/I-64 Solution

IDOT District staff worked with its central office staff, FHWA, and Illinois State Police (ISP) to develop the description and specifications for its system to include in the contract bid documents. IDOT chose to pursue a turn-key type of system involving COTS technology rather than developing a system from scratch in-house. The system design requirements for key features and functionalities of the I-57/I-64 project were defined by IDOT through a special provision contract document for “an automated Smart Traffic Monitoring (STM) System.” The contractor was left to identify the vendor they wanted to use (with concurrence of IDOT staff). The contractors, in turn, conducted their own informal assessment of the systems available, and made a choice of system.

The system was to cover both I-64 and I-57 in advance of the project (no mention was made of the amount of roadway in advance that was to be covered). The contractor was to be responsible for furnishing, installing, maintaining, removing, and programming the various system components to make the overall system functional. It should be noted that the provision was much less specific than the system installed in Effingham.

The contract documents for the I-57/I-64 project did not include requirements for volume data or inclement weather condition performance, but specified that the traffic sensor devices to be used (termed "Smart Monitoring Devices" or SMDs) were to be crashworthy in accordance with National Cooperative Highway Research Program (NCHRP) Report 350 (*13*) or be protected by an NCHRP 350-compliant device if placed within the clear zone (30 feet from the edge of pavement). IDOT required the system to be capable of notifying drivers of stopped traffic conditions ahead (speeds less than 30 mph) and to be able to notify drivers of actual traffic backup delay times. The number of devices to be used was to be specified by the project engineer.

Some key components of the special provision for the I-57/I-64 project included:

- Lane Closures: The STM system was to be able to display dynamic messages from the system for lane closures at a single location.

- Schedule: The STM system was to be 100 percent operable seven days prior to the Contractor closing a lane of traffic. The system was then to remain in operation 24 hours a day and 7 days per week until project completion.

- Function: Components of the system were to include Smart Monitoring Devices (SMDs), CMS, and control software for the various communication functions that were required. The system was to collect real time vehicle data at various locations prior to and within the lane closures to alert drivers of delay times through the lane closure, of stopped traffic ahead, and of alternate route options. The control software was to take the real-time vehicle data and communicate appropriate messages on CMS. Messages were to be in real time and dynamic based on the data collected at the STM monitoring points. The system was also to be able to inform the District Office of traffic delays via the internet.

Deploying the Solution

The I-70/I-57 Solution

For the I-70/I-57 project, a system provided by Ver-Mac, Inc. was deployed over a total of 76 miles (beginning 10 to 12 miles upstream of the project in each direction; Figure 3). This provided sufficient advance notification of any queues, and gave timely information on adequate alternative routes so that motorists could access alternative routes if they chose to divert in response to the messages.

Google Maps, modified by Battelle.

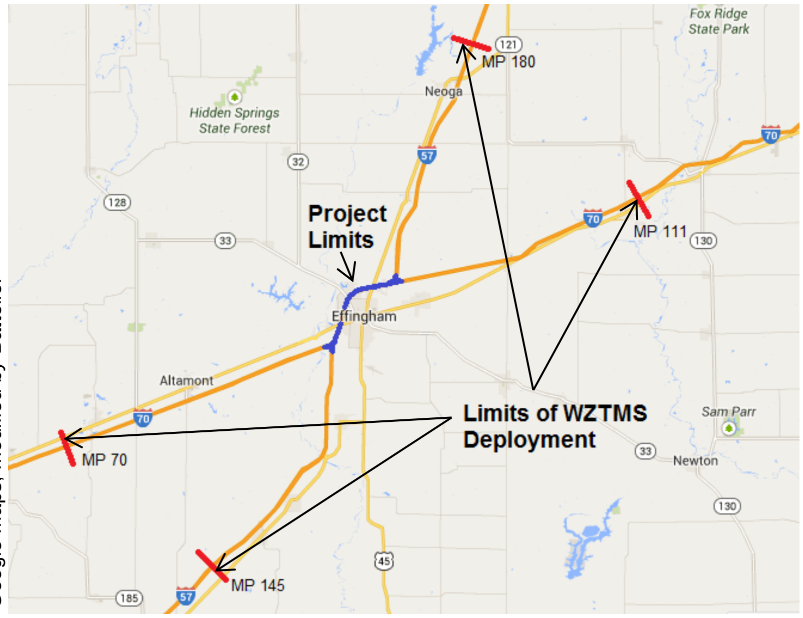


Figure 3. Map. Limits of the I-70/I-57 WZTMS.

FHWA

Figure 4. Photo. Temporary, Solar-Powered Traffic Detection and Camera Systems.

Overall, deployment and operation costs for this project totaled $1.545 million. The special provision called for the contractor/vendor to bid a per month unit price for the system to include all maintenance, operation, and relocation costs of the system. The cost consisted of the following:

- Initial mobilization and deployment of the WZTMS components, budgeted at $1.5 million, and
- Traffic management system operations and maintenance, budgeted at $1,800 per month over 25 months ($45,000 total).

IDOT always intended for the system to remain operational and be used during three other construction contracts that were scheduled to occur within the section over the next several years. The next contract that was let also included both of the above components, but bid at much different values:

- Initial mobilization of additional sensors, signs, cameras, budgeted at $78,750, and
- Traffic management system operations and maintenance, budgeted at $29,767 per month over 25 months ($744,188 total).

The contractor and vendor noted that this particular bid was fairly easy to estimate because IDOT specified exact equipment and the quantities to be procured. If bid requests are more open-ended in describing the desired operational condition, it can be challenging for vendors to compete on an even playing field, particularly if offering helpful additional technologies and innovation for a low-cost bid. At the same time, IDOT officials noted that it was difficult to know in advance how much equipment was needed (and where), and so they had to make some adjustments once the system was deployed (e.g., moving some equipment, obtaining additional devices where more were needed).

A detailed logic tree was developed to determine the two-phase messages to be displayed on the portable CMS (PCMS) based on traffic speeds measured and delays calculated, as shown in Table 1. For this deployment, the only communication of information with the motoring public was via the PCMS. The website developed for the project was for internal contractor/vendor/IDOT use only, and was not integrated into other traveler information sites operated by IDOT.

The entire system was tested for an initial two-week period. The traffic control supervisor (required elsewhere in the project specifications) was required to assist in the day-to-day operation of the system and serve as the on call contact for all notifications from the system. The vendor worked closely with the contractor and IDOT to ensure that the system met all desired specifications, and provided ongoing support to both in teaching them how to use the system and in making adjustments to the system as needed over the course of the project.

Table 1. WZTMS Message Logic for I-57/I-70 Interchange Project. (Source: IDOT)

<table>
<tr><th colspan="2">Traffic Condition Logic</th><th>Phase I Message</th><th>Phase II Message</th></tr>
<tr><td colspan="2">No traffic congestion detected</td><td>NO DELAY TO
<I-57 or I-70></td><td>ROADWORK
XX MILES AHEAD</td></tr>
<tr><td colspan="2">Speeds less than 40 mph detected</td><td>SLOW SPEEDS
AHEAD</td><td>PREPARE
TO STOP</td></tr>
<tr><td colspan="2">Significant delays detected (presented on PCMS farther upstream from the congestion)</td><td>XX MIN
DELAY</td><td>NEXT
XX MILES</td></tr>
<tr><td colspan="2">Even more significant delays detected</td><td>XX MIN
DELAY</td><td>CONSIDER
ALT ROUTE</td></tr>
<tr><td rowspan="2">Delays exceeding a maximum threshold value detected (i.e., 20 minutes)</td><td>Certain signs</td><td>MAJOR DELAYS
> 20 MIN</td><td>ALT ROUTE
EXIT XX</td></tr>
<tr><td>Other signs</td><td>EXPECT MAJOR
DELAYS</td><td>*<Direction>* BOUND
<I-57 or I-70></td></tr>
</table>

The I-57/I-64 Solution

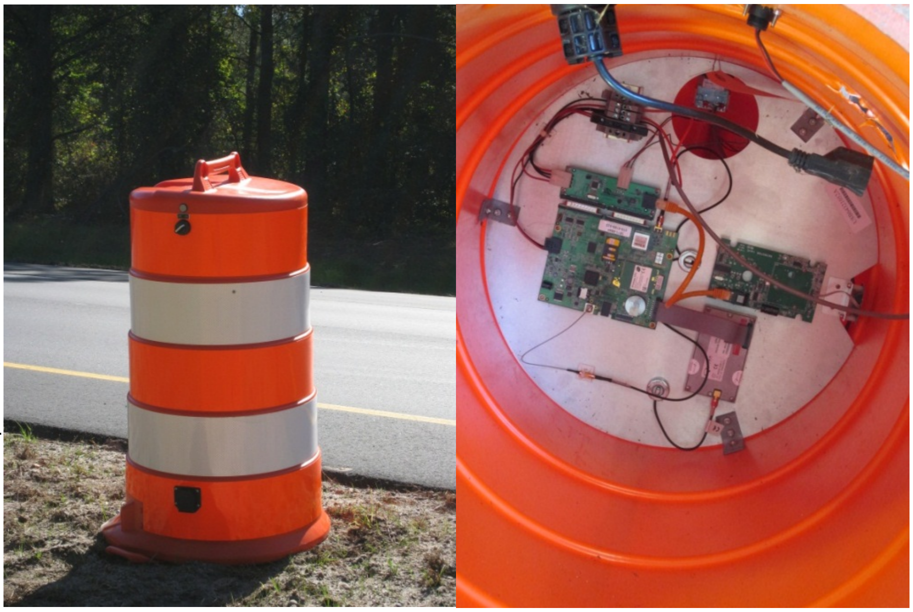
For the I-57/I-64 project, a system using iCone® portable traffic monitoring devices was implemented. The iCone® is a self-contained, battery-powered unit that consists of a radar detector, GPS antenna, cellular and backup satellite communication capabilities, and processor. Figure 5 illustrates the device. Figure 6 illustrates the layout of the iCone devices approaching and through the project.

No quantities were specified in the contract documents. However, the deployed system, as proposed in the winning bid by the contractor, ultimately consisted of the following:

- 32 iCone® devices (with their sensors) placed on all four approaches to the interchange,
- 15 CMS on those approaches, and
- Website portal to monitor the devices, traffic conditions, and messages displayed.

The sensors were spaced approximately 1 mile apart, beginning 3 to 14 miles upstream of the interchange, depending on the direction of travel. As congestion developed upstream from the interchange (most commonly in the northbound direction), messages on that approach communicated that traffic was slow or stopped ahead A distance to the queue and congestion was estimated based on the distance from each PCMS to the last downstream sensor that was reporting travel speeds in excess of 55 mph. It could then be assumed that the upstream end of the queue was someplace between that sensor and the next downstream sensor that was reporting slow travel speeds. To be conservative, the distance to that first downstream sensor would be what was disseminated as the distance to congestion.

If the queue extended beyond 2 miles, the messages changed to encourage drivers to divert to alternate routes. State Route 37 was a convenient alternative around the project, easily accessible at Exit 77. Because the alternate route for the I-57/I-64 project went through the city of Mt. Vernon, city officials were notified about the project and informed about using the route for diversion. Some efforts were also made to notify major shippers in the area. Specific outreach to the motoring public about the system was not performed. IDOT and the contractor/subcontractors were notified of the queue conditions via text messages and email notifications.



Texas A&M Transportation Institute.

Figure 5. Photo. iCone® Portable Traffic Monitoring Devices.

Multi-tiered message logic was developed for the PCMS, depending on their location. Some of the upstream signs were programmed based on the magnitude of delays computed by the system. Delay computations were based on queue lengths detected, which in turn had been calibrated over time by IDOT staff and by contractors who had driven through the project during congested conditions. Other signs closer to the project disseminated slow or stopped traffic messages to help prevent rear-end crashes at the upstream end of the queue. Table 2 illustrates the messages presented based on the current traffic status measured by the system.

The system was procured by the subcontractor, who owns the system, as an initial deployment as part of the construction project. A subsequent force account change order was used to expand the system to add more sensors and PCMS after queues occurred that were longer than originally expected:

- Initial system, budgeted at $1 million, and
- Subsequent force account to expand the system, budgeted at $172,200.

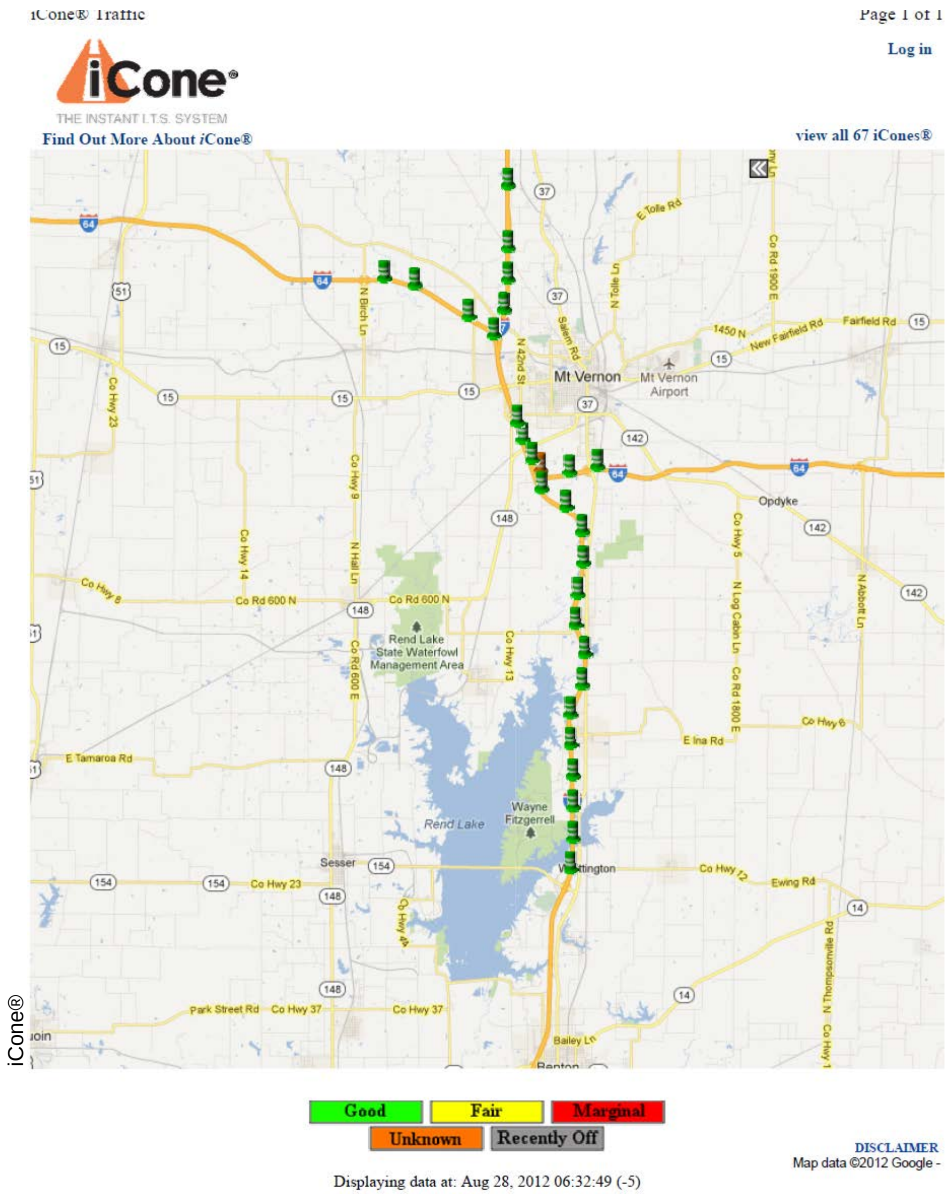


Figure 6. Map. Layout of the iCone® Sensors.

Table 2. PCMS Messages Displayed for Different Traffic Statuses, I-57/I-64 Project, Mount Vernon, Illinois. (Source: IDOT)

PCMS closest to the project	Criteria to Display Message	*Lowest speed downstream > 45 mph*	*Lowest speed downstream 30 to 45 mph*	*Lowest speed downstream < 30 mph*	
	Phase 1 Message	ROADWORK NEXT XX MILES	CAUTION SLOWING TRAFFIC	CAUTION STOPPED TRAFFIC	
	Phase 2 Message	XX MIN THRU ROADWORK	SLOWING XX MILES AHEAD	STOPPED XX MILES AHEAD	
PCMS farther upstream from the project	Criteria to Display Message	*Delay < 5 minutes*	*Delay 5 to 25 minutes*	*Delay 26 to 45 minutes*	*Delays > 45 minutes*
	Phase 1 Message	ROADWORK NEXT XX MILES	XX MIN DELAY AHEAD	XX MIN DELAY AHEAD	XX MIN DELAY AHEAD
	Phase 2 Message	XX MIN THRU ROADWORK	N/A*	CONSIDER ALT RTE EXIT XX	FOLLOW ALT RTE EXIT 77

*One-phase message that would periodically flash

Evaluation and Lessons Learned

Usage Statistics and Performance Evaluations

Statistics collected from both projects indicate that work zone ITS to warn traffic about queues and delays was an appropriate tool to deploy. As illustrated in Table 3, the relative frequency of activation of the PCMS was less on the I-70/I-57 project than on the I-57/I-64 project. This would be expected, as the latter imposed a long-term lane closure northbound that reduced capacity continuously and led to regular oversaturated (queued) conditions.

Table 3. Operational Data from the Two Projects. (Source: IDOT)

Performance Metric	I-70/I-57 Interchange	I-57/I-64 Interchange
Warning Message Activation Frequency:	• Typically 0-6 activations of prepare-to-stop (PTS) messages per month	• 189-246 activations per month (mostly Northbound) for any queue message • 29-68 activations per month for extended queues (when messages were activated for delays of 5 minutes or more)
Message Activation Duration:	• 0-90 hours total per month, depending on sign • 2-254 minutes per occurrence	• 2-510 minutes per occurrence for any queue message (average message display duration = 42 minutes) • 5-210 minutes per occurrence of extend queues (delay messages activated) (average message display duration = 30 minutes)

IDOT and contractor personnel at both projects checked the travel times being displayed on the PCMS by conducting drive through runs, and monitored equipment status and displays to ensure that the system functioned as intended. Both project staffs had positive experiences with the systems, and believed the systems were helpful in reducing queues and managing traffic (e.g., encouraging some traffic to divert to alternate routes). System performance was monitored regularly through the internal website for the system, and any failures in devices were investigated and remedied.

A preliminary analysis of the I-70/I-57 project crash statistics 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.

Lessons Learned

A number of lessons were learned by personnel associated with both projects. These are summarized below.

Teamwork is important – Success of these systems required a team perspective, including IDOT personnel, the contractor, and the vendor, as well as close coordination and cooperation throughout the duration of the project to maximize the effectiveness of the system.

Camera coverage is useful, but not necessarily essential, for a successful system – At the I-70/I-57 project, traffic cameras were not specified by IDOT but were included in the final system deployed. Both IDOT and the contractor subsequently commented that the cameras were valuable for identifying and verifying when and where traffic issues arose and quickly determining how to best respond to mitigate the issues. However, the lack of cameras on the I-57/I-64 project was never mentioned as a problem by project staff. This could be due in part to the different project lengths involved. The I-70/I-57 work zone ITS covered significantly more interstate mileage than did the I-57/I-64 project. In addition, the loss of shoulders, reduced lane widths, etc. throughout the I-70/I-57 project meant that a stall or crash anywhere within the system coverage limits was fairly likely to cause a traffic queue. Conversely, the bottleneck location at the I-57/I-64 project was constrained to right at the interchange itself, a much more concentrated location that could be reasonably inspected other ways. Consequently, camera coverage to view reasons for traffic queues that developed was considered important at the one project, but less so at the other.

Calibrate to slightly overestimate delays – Project personnel at the I-57/I-64 project noted that they found (primarily through anecdotal conversations with friends and neighbors) that it was more acceptable to the public to slightly overestimate delays when disseminating this information, but not acceptable to underestimate delays. Consequently, calibration of the systems relative to the delays calculated and presented on the signs should ensure that the delays being presented, if in error slightly, err towards the side of overestimation.

A good system specification requires balance – Experiences from the two system deployments indicated a need to provide enough detail in the specifications to allow vendors to bid competitively, but not so much that it excludes many of the vendors from participating. The key is in understanding what features, data, functions, etc. are essential to meeting the system objectives. The area in which the two projects differed significantly was in the types of traffic sensor device capabilities specified, as well as the number of devices required. The I-70/I-57 project outlined the type and number of traffic sensors required in high detail, whereas the I-57/I-64 project specification regarding traffic sensors was more general.

The I-70/I-57 project specified the use of traffic sensors that could provide detailed volume, speed, and lane occupancy data, whereas no such constraint was added to the specification for the I-57/I-64 project. Ultimately, both types of systems appeared to work well for detecting and warning about queued traffic conditions. Since it was possible to quickly calibrate the length of queues detected at the I-57/I-64 project to delays experienced by motorists (because the location and capacity of the bottleneck remained fairly constant over the course of the project), this could be done with speed sensors, feeding an algorithm to convert queue length to estimated delay. At the I-70/I-57 project, the capacity reductions that caused queues varied, as did the location of the queue itself, so the algorithm to estimate delays required more detailed volume and occupancy data. Similarly, differences existed between the two projects in terms of the crashworthiness requirements of the traffic sensor devices. At the I-57/I-64 project, crashworthiness of the traffic sensors was deemed important in light of their location adjacent to moving traffic. Conversely, most of the traffic sensors used at the I-70/I-57 project could be located behind temporary barriers or other protective devices and so this feature was not considered to be as critical at the I-70/I-57 site.

Achieving the proper level of system specificity in contracts is likely to continue to be a challenge for agencies going forward, as arguments can be made supporting both approaches. A more prescriptive specification, defining equipment capabilities very precisely as well as the number of such devices, typically yields vendor bids that are truly an "apples-to-apples" comparison and thus allow for a true low-bid selection to occur. The main caveat to this is that the specificity of the devices should be only what is necessary to achieve the overall results of the system, rather than being a way (whether real or perceived) to exclude other vendors whose technology does not meet the specification. It is fairly easy to include specifications that seem innocuous, but that have the effect of eliminating bidders.

Conversely, a less prescriptive specification generally allows for more innovation by the vendor to deliver a system that meets the desired functions and level of performance that is desired, but is more difficult to assess across multiple bidders. The lack of screening and pre-implementation testing to verify system compliance of desired functions and performance standards can further hamper efforts to compare systems to a less prescriptive specification.

System adjustments are likely to be required after initial deployment – Work zone ITS, even COTS systems, need to have capabilities incorporated into the specifications to allow for adjustments to be made in the field once the technology has been installed and calibrated. IDOT and contractor personnel from both projects indicated the need to "tweak" things early on in deployment as information about actual traffic conditions, construction-related geometric constraints, and other site-specific details were determined. For example, messages posted on the PCMS at the I-70/I-57 project were adjusted slightly from the logic specified in Table 1 once installed as a way to improve overall system operations. As Figure 7 shows, the original generic “REDUCE SPEED AHEAD” message called for in the specification was altered to display actual average speeds to be encountered downstream, as it was determined that the posting of a specific speed appeared to be interpreted as a more accurate message and prompted greater driver reaction to the message. Such changes were made as both IDOT and the contractor gained experience with the system and with how motorists responded to the various messages presented.

At the I-57/I-64 project, initial estimates of queuing expected in the northbound direction once the interstate was reduced to one lane proved to be very inaccurate. IDOT officials indicated that they used ADT values from an upstream sensor, and factored them down to typical hourly volumes to evaluate using QuickZone. Almost immediately after deploying the system and closing the lane, a traffic queue developed that extended upstream nearly 11 miles, far beyond the system coverage that had been initially bid based on IDOT’s original expected queue lengths. A force account was subsequently used to add more devices to the system to protect against queues growing beyond the limits of the system. In addition, a logical detour route (state route 37) northbound around the project involved a trip that was 26 minutes longer than via I-57. After the system was deployed, project personnel determined that once a queue reached 2 miles, delays were approximately 20 to 25 minutes. Thus, the system logic was changed to encourage diversion via delay messages once queues reached 2 miles, instead of the 3 to 4 mile queue threshold that was initially planned for triggering delay messages to be disseminated. Finally, a related field modification was also required early on to close an entrance ramp from Hwy 37 onto I-64 westbound to prevent those diverting from trying to rejoin I-57 at the interchange rather than traversing the entire diversion route.

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Figure 7. Photo. Messages Displayed on Portable CMS were Altered to be More Specific (Bottom) than what was Required in the Initial Special Provision (Top).

CHAPTER 3 - TRAFFIC MOBILITY PERFORMANCE SPECIFICATION MONITORING USING ITS: BANGERTER HIGHWAY, UT

The Utah Department of Transportation (UDOT) has interest in moving toward performance-based specifications for its projects, including performance specifications related to work zone traffic control. Rather than prescribing how a project is to be completed with respect to temporary traffic control sequencing and methods, a performance-based specification establishes key safety and mobility requirements and thresholds that have to be met, and allows the contractor to determine how best to complete the project while conforming to those specifications. For example, a transportation agency would specify that travel delays within the limits of a project not be increased by more than some duration or some percent of normal travel times, and it would be up to the contractor to determine how to complete the work in a manner that did not exceed those thresholds.

The advantage to this approach is that it allows the contractor to be more innovative and have more control over how to best complete the project. However, this approach requires the agency to monitor the work zone and determine if and when the contractor is not meeting the specification. UDOT pilot tested the use of Bluetooth matching technology for monitoring point-to-point travel times as a way to assess the feasibility of a mobility-related performance specification on a roadway improvement project.

OVERVIEW OF THE PROJECT

A design-build (DB) project on the Bangerter Highway (SH 154) in Salt Lake City, an arterial with signal operations at major intersections, offered an opportunity to test the potential of using a traffic mobility performance-based specification and assigning liquidated damages according to conformance with that specification. Figure 8 illustrates the project limits. The project involved the construction of three continuous flow intersections and one grade-separated interchange from August 2011 to April 2012. The intersections served a significant amount of traffic (56,000 vehicles per day on Bangerter Highway, and between 18,000 and 31,000 vehicles per day on the cross-streets at each of the intersections).

While UDOT was interested in the concept of performance measurement for work zone mobility, it was not confident in moving to a performance-based specification directly. Therefore, the decision was made to bid the project with traditional prescriptive requirements for traffic control in terms of restrictions on hours of allowable lane closures and maximum number of lanes that could be closed. At the same time, a hypothetical performance specification was developed and would be tracked during the project. Then comparisons would be made between the liquidated damages that arose due to violations of the prescriptive traffic control requirements and those that would have arisen if the performance-based specification had been used.

Google Maps, altered by Texas A&M Transportation Institute.

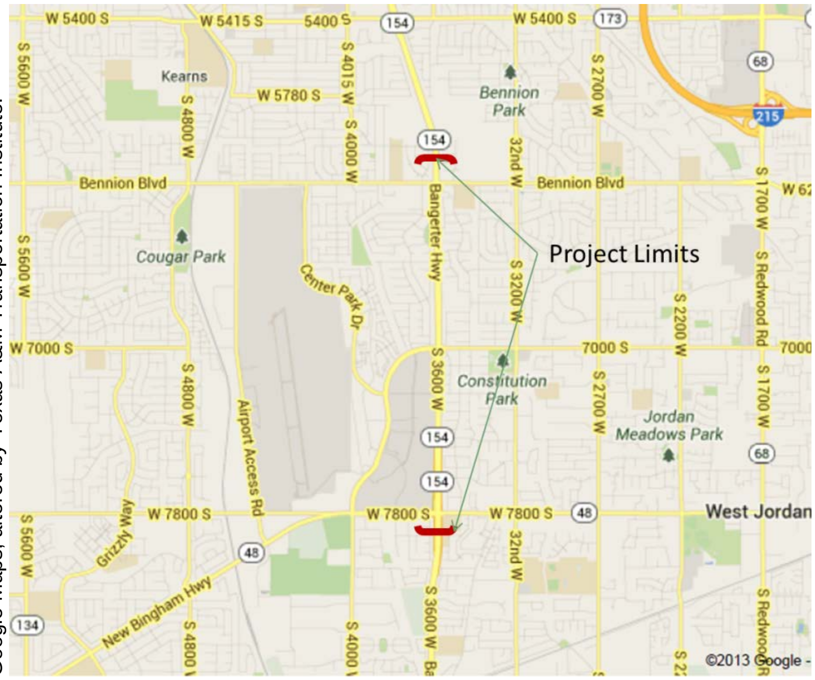

Figure 8. Map. Location of the Bangerter Highway Project.

APPLICABILITY OF THE ENGINEERING DESIGN PROCESS

Defining the Problem

Key Problems

1. Increased travel time and delays
2. Delays to turning and cross-street traffic

UDOT was concerned about travel times and construction-induced delays for both through traffic along Bangerter Highway and for turning traffic to and from the highway and cross streets. Certain travel movements in the corridor already experienced delay during peak travel times, and construction had the potential to significantly increase the delays. To limit the potential for increased delays, UDOT could impose limitations on the contractor through prescriptive specifications or encourage the contractor to minimize traffic delays through a performance-based specification. As noted in the previous section, UDOT chose to look at both approaches for this project. To track the performance-based specification, UDOT needed to assess baseline delay, determine reasonable performance thresholds, monitor traffic conditions, and assess what amount of measured delay was due to construction-related impacts. The presence of baseline delay and several cross streets and turning movements increased the complexity of this effort.

Initial discussions with the contractor about the pilot test effort also identified another key challenge: the contractor would not be able to effectively monitor traffic conditions on their own. As a result, they would not be able to quickly detect if a situation had developed that caused them to violate the specification. This would hamper their speed in responding to the problem and lead to longer violation periods and increase the liquidated damages.

Specifying Requirements of a Solution

> **Solution Requirements**
>
> 1. Ability to directly measure travel times and delays of individual vehicles
> 2. Include several origin-destination pairs within the project limits

UDOT identified 48 movements for monitoring of both through traffic on the mainline and for left and right turns at the various intersections. A key requirement for the solution was that it be possible to directly measure travel times and delays of individual vehicles. Furthermore, it was deemed important to be able to measure these travel times/delays for several different origin-destination pairs within the project limits, as the potential existed for the contractor to adversely affect multiple traffic movements at multiple locations within the project.

Identifying and Evaluating Alternatives

A technology option was required to effectively address the specified solution requirements since a non-technology solution would not be able to capture the desired measures. Existing permanent intelligent transportation systems (ITS) in the corridor included cameras and coordinated traffic signal timing, but these were not adequate to monitor movements within the corridor. Since the project was a pilot test effort, the deployment did not follow a typical UDOT ITS deployment approach. The DB consultant/contractor and UDOT worked together to determine the specific requirements of technology needed. Several technologies were considered, such as the use of Sensys magnetometers in the travel lanes, portable traffic monitoring devices, and Bluetooth address matching systems. Ultimately, a Bluetooth solution was determined to be the best choice because current infrastructure did not allow the accurate measurement of cumulative delay through the project segment, which had many access points. A Bluetooth solution most efficiently enabled the ability to measure total delay of various traffic movements through the project limit. Figure 9 illustrates a Bluetooth antenna installation.

JUB Engineers, Inc.

Figure 9. Photo. Example of a Bluetooth Antenna Installation.

Selecting, Designing, and Implementing the Best Solution

A concept of operations was developed for a system that provided the contractor and UDOT with notification when travel times of one of the movements exceeded normal or "typical" values. These baseline values were generated from the Bluetooth system prior to the work zone initiation and validated by traffic simulation runs. Extensive simulation of the corridor was performed to determine what delays would likely occur for the maintenance-of-traffic (MOT) being implemented in each phase of the project. A two-tiered notification process was initially envisioned that would be used to implement a performance-based delay specification. If delays exceeded the first tier threshold, a disincentive penalty would be invoked during the time that the delay exceeded the threshold (if a delay-based performance specification had been enacted on the project). If delays grew to the point that they exceeded the second tier threshold, a higher disincentive penalty would then be enacted. The contractor later requested that a warning level be included lower than the tier 1 threshold, so that there would be some opportunity for the contractor to rectify the situation before financial penalties started accruing.

Once Bluetooth was selected as the solution for this project, UDOT analyzed the project area to determine locations where accurate Bluetooth addresses on a specific roadway segment or intersection approach could be obtained and where the antenna would not be an obstruction to the construction itself.

UDOT has a fairly well-structured process for procuring ITS equipment and services. For this pilot test effort, however, UDOT deviated from that process. Concerns about the time required to go through the traditional procurement process led UDOT to have the contractor purchase the devices on its project contract, and then assign them back to UDOT.

The Bluetooth antennas were either solar or battery powered, and included both GPS and cellular communication capabilities. Prices per device were approximately $4,000 for the battery-powered antenna, and $5,000 for the solar-powered antenna. A total of 10 units were procured and deployed, at a total cost of about $40,000. Another $33,000 was spent on system operation (data access) and maintenance costs for the vendor. Additional costs expended by UDOT and the contractor were not calculated.

Bluetooth detectors were installed by either securing them to roadside infrastructure and/or mounting them high enough to deter theft and vandalism. Data were transmitted from the antenna at regular intervals to a server that matched Bluetooth addresses detected at successive antennas and computed the elapsed time between them. Four cameras were already located within the project, installed under a previous traffic operations center (TOC) contract. The cameras were useful for reviewing conditions in the field when the Bluetooth system indicated that delays were increasing.

Once the antennas were deployed, UDOT and the contractor spent a considerable amount of time calibrating 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, and others in terms of how the data coming in from the detectors were handled during processing. Both UDOT and the contractor team spent a significant amount of time to understand the nuances of the system and to get the system to operate as desired. UDOT and the contractor found it challenging to reach a consensus on the minimum number of Bluetooth matches between antenna locations needed in a given time period to develop a good travel time estimate. Ultimately, a value of 5 Bluetooth matches per 15-minute time period was adopted as the minimum.

Once calibrated, the system worked as intended, and yielded significant benefits to both UDOT and the contractor. The early warning thresholds implemented for the project allowed both parties to become aware of operational problems within the project much sooner than would have been possible otherwise. In many cases, the warning notification led the TOC personnel to use cameras to quickly identify that an incident had occurred and dispatch response personnel. More importantly for the contractor, the availability of the data emboldened the contractor to request the relaxation of lane closure restriction times. The standard UDOT prescriptive MOT requirements in the contract prohibited lane closures each weekday from 6:00 to 9:00 am and from 3:00 to 6:00 pm. The Bluetooth system allowed contractors to request the reduction of those windows at certain locations during certain phases (and in some cases, eliminate one or the other entirely) because the operations data indicated it would result in acceptable impacts.

Although the deployment was primarily a pilot test of the potential usefulness of performance-based contracting of work zone traffic control, UDOT did reach out to some of the local businesses in the corridor who were interested in the system. Periodic updates were provided about what the system was indicating regarding traffic conditions, as well as how the system would have worked in terms of contractor penalties had the specification actually been in place for the contract. Overall, the businesses viewed the potential use of the system favorably. UDOT also reached out through corridor community teams to explain to commuters the reason for the system and how the system operates. Initially, there was some public concern over privacy issues. However, once assured that the Bluetooth addresses were not retained and could not be traced back to them, these fears were alleviated.

Evaluation and Lessons Learned

Usage Statistics and Performance Evaluations

UDOT and the contractor monitored both travel times (directly computed from the Bluetooth system) and the corresponding average speeds on the various segments and movements of interest. Figure 10 illustrates an example of these types of data, as well as data regarding Bluetooth device detections per analysis interval. Specifically, these plots show the individual Bluetooth data and mean travel times and speeds over the course of a day for a given segment, as well as the number of Bluetooth devices detected. Over time, it was possible to establish confidence intervals around the average travel times, and allow both UDOT and the contractor to distinguish between normal day-to-day fluctuations in traffic conditions and truly unusual conditions that warranted attention and remedial actions. Figure 11 shows another example of a data plot generated by the system data to depict the ratio of current travel time versus free flow travel time by time of day with a 95% confidence interval.

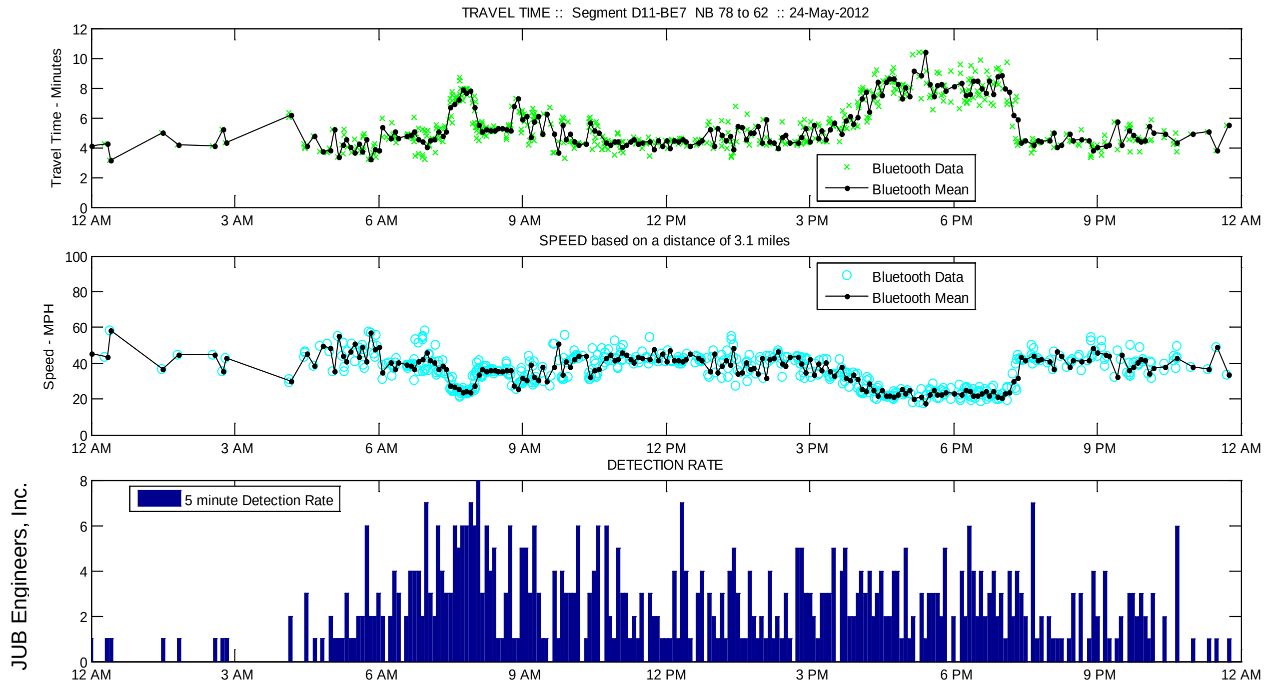

Figure 10. Graph. Example of a Travel Time and Average Segment Speed Plots by Time of Day.

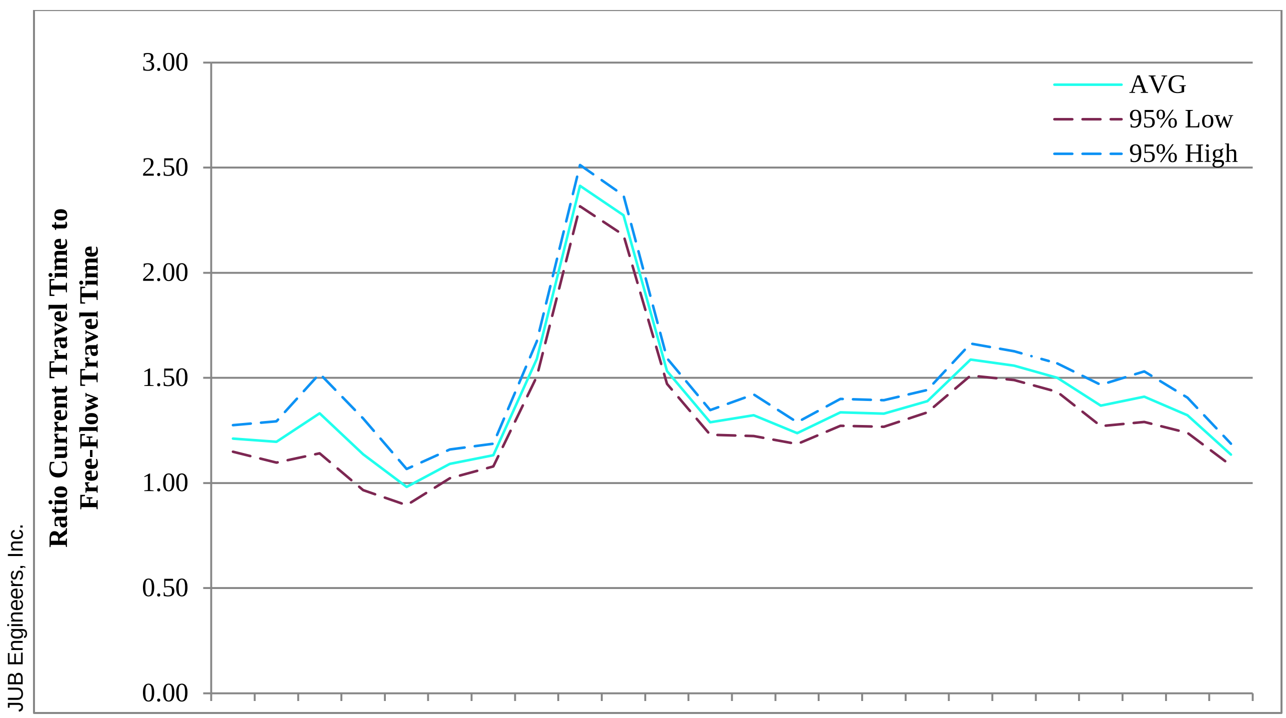

Figure 11. Graph. Example of a Travel Time Confidence Interval Plot by Time of Day.

The system worked well after UDOT and the contractor became familiar with it and developed an understanding of how to tailor it to the needs of the project. UDOT indicated that they are investigating other projects on which to employ this type of technology. They noted that this pilot test project was a DB contract that allowed the contractor much more flexibility and input in the MOT process, where a performance-based specification might be more suitable. It was unclear whether specification language could be drafted in a way that would be acceptable to contractors in a more traditional design-bid-build environment where the MOT approach (and construction methods in many cases) had already been set by UDOT.

UDOT and the contractor continuously monitored the performance of the system. In addition, they performed a case study of applying the performance-based specification versus their traditional prescriptive-based MOT specification during an instance where the contractor experienced some equipment problems (a striper truck broke down, which did not allow them to open up a travel lane in time). Penalties that would have been instituted with the performance-based specification had it been effect were compared to penalties that would have been incurred by the contractor through the prescriptive-based specification in the contract. Overall, UDOT and the contractor estimated that the prescriptive specification resulted in a $75,000 penalty for the contractor, whereas the performance-based specification would have resulted in a $68,000 to $69,000 penalty. The similarity of these two values gave UDOT confidence that a performance-based specification could indeed be established and would yield reasonable and defendable financial penalty outcomes for the contracting community if enforced.

Lessons Learned

The main intent of the pilot test of the Bluetooth technology was to assess the potential usefulness of a performance-based specification for work zone traffic mobility. ITS was used to enable UDOT to monitor actual traffic conditions to assess compliance with the theoretical specification. UDOT, working with the contractor, identified a number of lessons learned that they intend to apply in the future to eventually use this approach (as appropriate) on key projects where maintenance of traffic mobility is particularly critical.

Lessons learned from this testing effort are summarized below.

It is important to ensure that the level of monitoring effort match the needs of the project – For this testing effort, UDOT and the contractor monitored 48 different movements through the project. In retrospect, there were only a few key movements that were of primary interest. A reduced set of travel times would have reduced the data analysis burden, and likely led to similar ability by UDOT to monitor construction impact on travelers.

Adequate advance time is needed between Bluetooth detector installation time and the start of the project – The calibration efforts undertaken by UDOT and the contractor to get the devices and overall system operating at a high degree of accuracy and reliability took about 2 weeks.

Bluetooth reader placement and settings will affect monitoring accuracy on routes with many access points for businesses – Bluetooth readers use an antenna with a circular detection range. Vehicles with Bluetooth devices enter into that circular detection field, are read, and then exit. Normally, this process will take only 1-2 seconds. However, if the reader is located near businesses or at signalized intersections, vehicles may sit within the detection zone for a fairly long time and be detected repeatedly. Proper calibration of the reader and processing system to use the appropriate detection time of the device (i.e., first detection, last detection, etc.) at a given reader may be needed to maximize the accuracy and reliability of the data obtained.

A significant traffic simulation effort is needed to establish realistic and acceptable thresholds – UDOT and the contractor found that it was not sufficient to look at only peak operating periods with the simulation. A contractor may choose to implement lane closures and other actions during off-peak conditions, and the impacts of those actions may be of interest to an agency. Such actions would need to be monitored and penalties for excessive impacts identified during those times as well.

An ability to identify and document non-construction-related impacts that may occur (i.e., incidents) is important – The ability to separate actions due to contractor decisions and behaviors from events out of the contractor's control will be important for implementing any type of performance-based specification for work zone mobility. Some incidents may be the result of contractor decisions (e.g., a rear-end crash due to a queue that occurred when the contractor closed a lane) while others may not be. Distinguishing between the two—or determining appropriate allocations when responsibility is shared—will be an ongoing challenge for agencies and contractors to reach agreement on in the future.

CHAPTER 4 - MANAGING TRAFFIC DURING CONSTRUCTION BY SUPPLEMENTING EXISTING PERMANENT ITS: I-15 CORE, UT

Many agencies across the country have some roadway mileage where permanent intelligent transportation system (ITS) technology has been deployed for transportation management purposes. When road maintenance or rehabilitation/reconstruction occurs within or near these permanent deployments, agency staff and personnel may use these systems to minimize the impacts of the road work activity. This chapter provides an example of how the Utah Department of Transportation (UDOT) combined temporary work zone-specific ITS efforts with their existing transportation management system on I-15 through Orem-Provo to help manage traffic during construction.

OVERVIEW OF THE PROJECT

I-15 serves as the main north-south artery in Utah. Within the Orem/Provo region, UDOT conducted a 24-mile widening and reconstruction project, as shown in Figure 12. Called the I-15 Corridor Expansion (I-15 CORE) project, this $1.725 billion project involved the addition of two lanes in each direction of travel and the widening and reconstruction of 10 interchanges and 63 bridges. This design-build (DB) project had the potential to significantly disrupt public mobility and safety, as well as freight movement, so UDOT desired an aggressive construction schedule. As a result, the project had full closures at night, interchange closures, and peak period lane reductions on I-15. The notice-to-proceed (NTP) was given in January 2010, with project completion set at 35 months. It was one of the most aggressive schedules for a project of this size ever let in Utah (and possibly the U.S.).

UDOT has extensive permanent ITS capabilities. The UDOT traffic operations center (TOC) is a computer-controlled system designed to monitor and manage traffic flow on freeways and key surface streets throughout the State. System components include closed-circuit television (CCTV) cameras, electronic changeable message signs (CMS), the 511 Travel Information Line, coordinated traffic signals, ramp meters, traffic speed and volume sensors, pavement sensors, and weather sensors. The center is connected to smaller traffic control centers in Salt Lake City and Salt Lake County. The existing freeway traffic management system that was already in place along the corridor (initially implemented for the 2002 Winter Olympics in Salt Lake City) was used and enhanced to facilitate the management of travelers through the corridor during the I-15 CORE project.

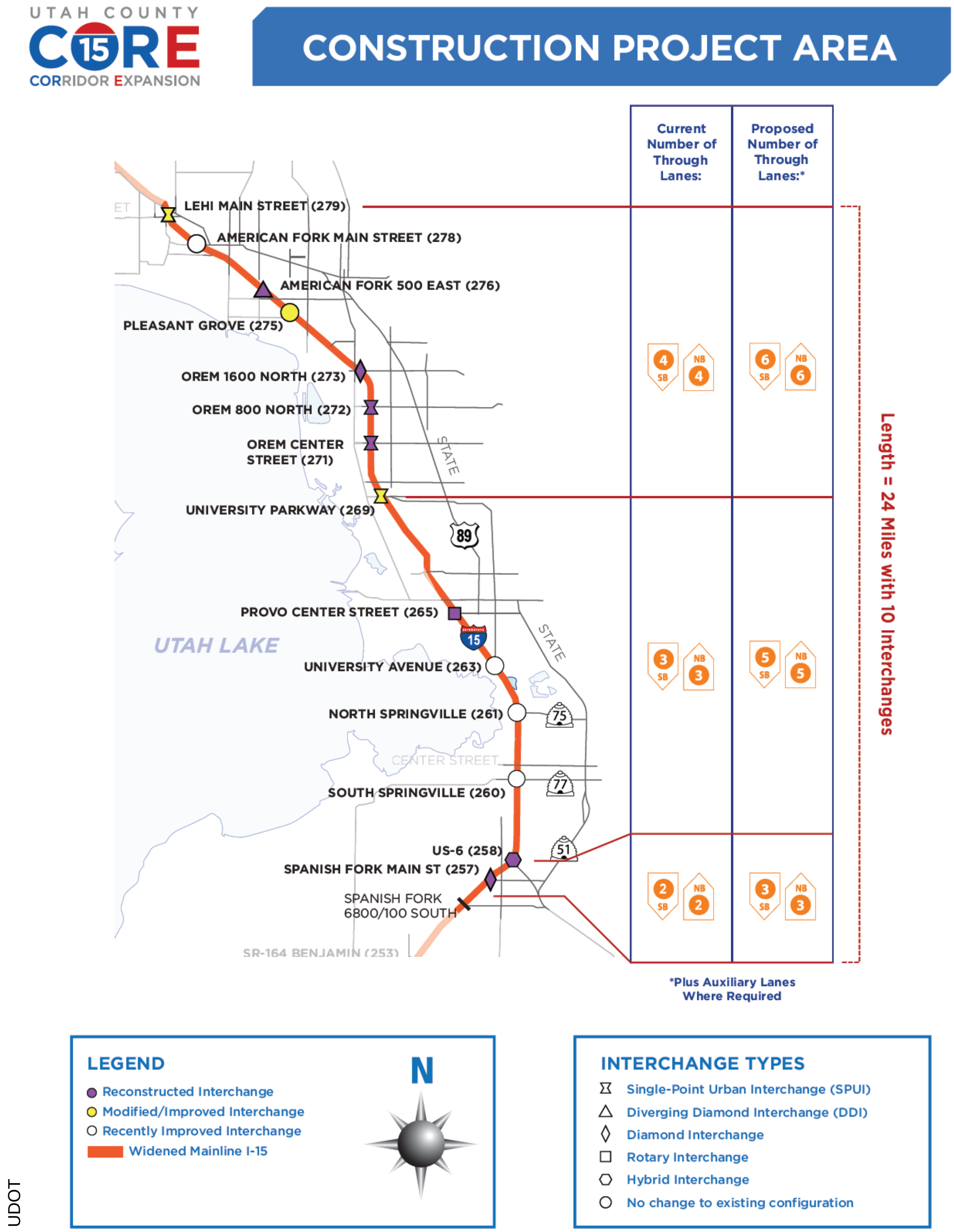

Figure 12. Map. I-15 CORE Project.

APPLICABILITY OF THE ENGINEERING DESIGN PROCESS TO THE CASE STUDIES

Defining the Problem

Key Problem

1. Lack of convenient alternative routes when I-15 lanes are closed
2. Increased effects of incidents and special events due to temporarily closed shoulders and other capacity reductions

As part of the project development process, UDOT established three key project goals:

- Minimize inconvenience to the public,
- Uphold the public trust, and
- Maintain regional mobility.

The project posed significant challenges to meeting these goals. The biggest challenge was that only one alternative detour route (an arterial) was available adjacent to the freeway. Thus, the region would have limited ability to absorb any diverted traffic from I-15 during periods of temporary capacity reductions. In addition, lane shifts, the restriction of shoulders, and other temporary geometric constraints could increase the effect of incidents and special events occurring in the region. Additionally, there was the potential for congestion to develop in locations along I-15 where existing ITS infrastructure was limited or non-existent, thereby limiting the ability of TOC personnel to respond quickly and properly to any issues that arose. Therefore, efforts focused on ways to maximize the traffic-carrying capacity of the arterial street system and on providing travelers with accurate travel information to assist them in making trip decisions.

A regional travel demand model was used to develop an understanding of how travel patterns might change during construction. A work zone delay analysis program developed by UDOT staff (similar to QuickZone) was then used to further estimate possible project impacts. Additional analyses were done by the various DB teams during their maintenance-of-traffic (MOT) designs that were required as part of their bids.

Specifying Key Requirements of the Solution

As part of the DB proposal request, UDOT established basic traffic mobility requirements regarding allowable times and dates for freeway lane closures and let the contractor develop the rest of the MOT plan. The three main solution requirements involved the coordination of traffic signal systems within Orem and Provo, making solutions compatible with existing TOC components, and aiding travelers with making trip decisions.

Solution Requirements

1. Coordination of traffic signal systems within Orem and Provo
2. Compatibility of solutions with the existing TOC
3. Aid travelers in making trip decisions

Given the availability of the existing UDOT TOC, emphasis was put on determining how to enhance the current capabilities of the system to maximize its potential benefit for managing traffic during construction. The TOC was heavily involved in the development of a request for proposals (RFP), and TOC staff were integrated in the project management team to facilitate identification and implementation of traffic management strategies as needed during construction. Other entities on the project management team included consultant staff, ITS deployment consultants, and local signal contractors.

Identifying and Evaluating Alternatives

Because UDOT has significant permanent ITS capabilities in place, they focused on alternatives that would make use of these capabilities. UDOT wanted to integrate efforts to manage work zone impacts with its existing TOC, so all alternatives identified and considered were assessed with an eye towards compatibility with that system and with the potential for keeping those improvements in place once the project was completed. A windshield survey was performed in the corridor early in the planning process to determine what "holes" in traffic management infrastructure existed (especially camera coverage). As part of the alternatives identification, vehicle detectors, CCTV cameras, traffic signal control systems, and CMS were inventoried to identify locations where additional temporary or permanent infrastructure was needed.

It became apparent during the project planning process that it would be extremely beneficial to upgrade the arterial signal systems in Provo and Orem to become compatible with the UDOT centralized signal system. This would allow for the use of an existing ITS capability during the project, while improving the TOC capabilities long-term after the completion of the project. Cooperative agreements were established between UDOT and the cities to help define how the signals would be operated and coordinated, and the systems upgraded to be compatible with the UDOT system. UDOT also decided to make strategic investments in permanent ITS infrastructure, using its normal capital and operating budgets and procurement procedures, to expand its capabilities within the corridor.

Selecting, Designing, and Implementing the Best Solution

While some identified needs were for temporary devices during construction, the long-term needs of the TOC were considered as part of the implementation process. Portable traffic sensor stations were procured as part of the project in a few instances until permanent sensors could be installed (see Figure 13). In other locations, a need was identified for a few temporary ramp metering systems to maintain management capabilities until the widening effort on I-15 was completed and such metering would not be required. In addition, the winning DB team examined traffic management needs in the corridor, and proposed an arterial travel time monitoring and information system for the alternate route, State Street, as a value-added component to its proposal to aid travelers in making trip decisions.

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Figure 13. Photo. Temporary ITS Devices along I-15.

Improvements were subsequently made to several signalized intersections, adding left turn phases and right turn overlaps to improve overall signal operations and flexibility to deal with changing traffic patterns that might develop. A “mini” TOC was created and housed in the project offices to allow staff to monitor MOT setup and view issues in the corridor in real time. A number of incident detour plans were developed for the corridor, and courtesy patrols in the corridor were enhanced. Two years prior to the I-15 reconstruction, ramp meters were installed knowing they would be reconstructed as part of the I-15 project. Plans were made to maintain all devices during construction to allow project staff to manage delays. Close coordination between the UDOT TOC and public involvement staff further helped to minimize delays throughout the life of the project.

Some of the additional ITS devices identified as being needed for the project were paid for through normal TOC funding mechanisms. Other additions were then incorporated into the project bidding requirements. Some of the technology (such as the northbound travel time arterial system on State Street) was proposed by the winning team as a value-added concept that was accepted by UDOT, but handled directly by the contractor. In general, UDOT has a well-structured process for obtaining ITS equipment and services. No specific issues or problems with procurement were identified during the case study. It was noted that the procurement process for ITS in general has evolved as needed over the past 20 years.

As noted above, the winning DB team proposed a value-added real-time arterial travel time system for the alternate route, State Street, to improve route choice by providing motorists comparative travel times along the arterial and via the adjacent interstate (see Figure 14).

A series of six sensor "pucks" per location was installed in one lane of the arterial every 0.5 to 1 mile. Electronic vehicle "signatures" were tracked from location to location along the arterial from which travel times could be calculated. The winning team also proposed additional courtesy patrol vehicles in the corridor (UDOT was operating 3 vehicles prior to construction) to further reduce the response time and magnitude of incidents on traffic delays.

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(a) Northbound travel time via I-15 (b) Northbound travel time via State Street

Figure 14. Photo. Sequencing Travel Time Sign on State Street Northbound.

The freeway ITS and arterial signal system operated on a fiber optic backbone, which was maintained throughout the construction process. Some radios were purchased and installed on the project and connected to the fiber optic backbone in a few instances to maintain functionality of some of the devices. As with most ITS deployments, UDOT established a significant testing protocol of devices and subsystems as they were brought online, both for any construction-related implementations (such as the supplemental temporary ramp metering systems), as well as any of the final build devices that were installed (such as the travel time signs as shown in Figure 15).

FHWA

Figure 15. Photo. Hybrid Travel Time Signs for I-15.

Although UDOT retained responsibility for operating the ITS deployment during construction, the DB team was assigned maintenance responsibility for keeping devices operating, communications flowing, etc. Some training was needed to bring the DB team up to speed on some of the systems (signal timing, ramp metering). Failure to keep the system functioning warranted withholding of payment.

The TOC was operated weekdays between 6 am and 10 pm, and from 10 am to 8 pm on Saturdays. The center was also staffed for special events or construction activities outside of these windows as needed. TOC staff managed information disseminated on the various signs in the corridor, and monitored the various ramp meters to ensure they continued to function as intended. The TOC goal was to “stay ahead of the congestion curve” as long as possible. Staff also monitored conditions on the arterial street system and had large number of timing plan alternatives that could be implemented quickly as conditions warranted.

Evaluation and Lessons Learned

Usage Statistics and Performance Evaluations

Overall, UDOT was happy with the operation of the system and believed that it significantly reduced the number and magnitude of delays and congestion that would have been incurred during construction if the system had not been in place and operational.

UDOT performed traveler surveys in the corridor every quarter during the project. The surveys consistently demonstrated a high level of customer satisfaction and support of the traffic management actions undertaken by UDOT. UDOT also prepared annual reports about the project, documenting the following items:

- Key traffic management and control actions implemented,
- Public awareness and involvement activities undertaken,
- Number of full I-15 closures performed at night,
- Peak period lane reductions on I-15 enacted,
- Interchange closures,
- Actions implemented during major special events, and
- Preview of work and closures anticipated for the next year.

UDOT focuses on travel times, delay, and speed as primary measures of effectiveness for ITS deployment. Both duration and magnitude of delays are considered. These measures were continuously monitored during the I-15 CORE project. Table 4 summarizes some of the impacts of construction activities documented in the annual reports.

Table 4. Summary of Impacts of I-15 CORE Construction. (Source UDOT)

Measure	2010	2011
Full I-15 Closures: Number of nights	30	32
Maximum delays Typical delays	50 minutes 15 to 30 minutes	45 minutes 15 minutes
Maximum queue Typical queues	3 miles 0.5 to 2 miles	2.5 miles 0.25 to 2 miles
Maximum duration of congestion Typical duration of congestion	180 minutes 60 to 90 minutes	180 minutes 15 to 120 minutes
Peak period lane reductions: Number of days	76 northbound, 99 southbound	76 northbound, 104 southbound
Typical queues	2 miles	2 miles

UDOT also used the ITS devices to help mitigate the impacts of construction on certain special events that occurred during the year. These events included Brigham Young University (BYU) football and basketball games, the July 4th fireworks celebration, large concerts, and snowstorms. Special timing plans on the arterials were developed to encourage more use of those streets, and information about alternate routes and parking access points were disseminated via CMS and the media.

The system was instrumental in encouraging diversion away from I-15 during certain phases of the project, and in accommodating that traffic on the arterial street system. Diversion rates around 20 percent were routinely accomplished, and on nights when full closures of I-15 were implemented, up to 50 percent diversion prior to the point of closure was noted. UDOT expects the approach taken on I-15 regarding the use of ITS to be the model for all future major projects of this type.

The effectiveness of the arterial street travel time system was somewhat limited, but was still considered a worthwhile addition to the project. Initially, it was envisioned that diversion from I-15 would occur primarily in the northbound direction, with State Street being used by trips originating south and east of the interstate when traffic conditions were degraded on northbound I-15. The vehicle detection technology used to track vehicles was found to track only about 1 percent of the vehicles using the northbound arterial, and led to sizeable errors (30 to 40 percent) in travel time estimates being generated. UDOT noted that they adjusted the times on those signs and on the I-15 travel time signs under congested conditions to encourage or discourage diversion from the freeway.

The availability of mobility-related data from the various ITS components also benefited the project contractor. UDOT staff noted that there were instances where lane and ramp closure restrictions were relaxed at the contractor's request, once staff had the opportunity to review the traffic data and determine that relaxing the restrictions would not adversely affect travel conditions. In this way, construction time windows were able to be effectively maximized.

Lessons Learned

Include maintenance of ITS devices in the list of conditions warranting liquidated damages – Although UDOT retained responsibility for operating the ITS deployment during construction, the DB team was responsible for keeping the various ITS devices in the corridor operational. Initially, the contractor was not always timely with making whatever repairs and adjustments were needed to keep the devices working, to the point that UDOT decided to withhold payment on the project until repairs were made. Adding ITS device maintenance as an item with liquidated damages for non-performance could help ensure that the contractor understands the importance the agency is placing on keeping the system operational at all times.

Leverage the ability of contractors to innovate on how to best accommodate traffic during construction – UDOT was pleasantly surprised with several ideas that the winning contractor presented in their MOT approach to the project. Using contracting approaches that allow (and reward) contractors for innovative approaches to managing traffic provides benefits to the contractor, the department, and ultimately, to the traveling public.

Verify that proposed innovations and technologies will operate as advertised – The arterial street travel time system that the contractor proposed was envisioned to be a good value addition to the project. However, the technology suffered from a number of issues, ranging from a deployment approach that limited the ability of the system to track vehicles from sensor location to sensor location along the corridor to problems with the sensor devices themselves. It would be preferable to more fully assess the viability of the proposed installation before it is deployed.

Consider using temporary ramp meters if peak-period demands will exceed the reduced work zone capacity during construction – Ramp metering along many of the ramps on I-15 allowed UDOT to effectively manage peak traffic demand and travel conditions. As construction progressed on the project and modified travel patterns, there were opportunities to put temporary meters in place to maintain management capabilities at some of the ramps that were not metered. This allowed UDOT to more effectively manage traffic within the project. Once construction was completed and I-15 capacity increased to the point where ramp metering was not needed, it could be removed.

CHAPTER 5 - MANAGING WORK ZONE TRAFFIC USING PERMANENT ITS: LAS VEGAS, NV

As noted in the previous chapter, many agencies have permanent intelligent transportation system (ITS) technology deployed throughout their jurisdictions for transportation management purposes. When road maintenance or rehabilitation/reconstruction occurs within or near these permanent deployments, agency staff can leverage these systems with other work zone mobility and safety efforts to minimize the impacts of the road work activity. This chapter provides an example of a multi-jurisdictional system developed for the Las Vegas metropolitan area to assist in managing traffic during construction and maintenance operations within its boundaries. While the previous chapter described efforts by the system operators to help manage traffic during a major high-impact freeway widening effort on a specific facility, this chapter emphasizes day-to-day efforts to support more typical routine construction and maintenance activities that commonly occur within a metropolitan area.

OVERVIEW OF THE SYSTEM

The transportation management system in Las Vegas is termed the Freeway and Arterial System for Transportation (FAST). FAST comprises both a freeway group and an arterial street group. Local agencies handle basic maintenance needs of the arterial system components (signals, cameras for signal detection), and FAST handles the management and maintenance of closed-circuit television (CCTV) cameras, freeway traffic sensors, ramp metering, and changeable message signs (CMS). Overall, in 2012 FAST had approximately 1,000 devices in the field (sensors, cameras, signs, ramp meters, etc.), with another 200 slated for deployment.

FAST was officially initiated in 2000-2001, although the arterial street component had been around since the mid-1980s as the Las Vegas Arterial Control System (LVACS). FAST is funded through a combination of local sales tax to address arterial street management and the Nevada Department of Transportation (NDOT) to address freeway operations and management.

FAST is used to manage all types of traffic situations within the Las Vegas metropolitan area. The operations control room, shown in Figure 16, is staffed from 5 am to 11 pm Monday through Friday, and from 8 am to 11 pm Saturday and Sunday. Traffic incident management is one of the major functions of FAST, but special event management, management of recurrent traffic congestion, and traffic management during roadwork activities are also within FAST's purview.

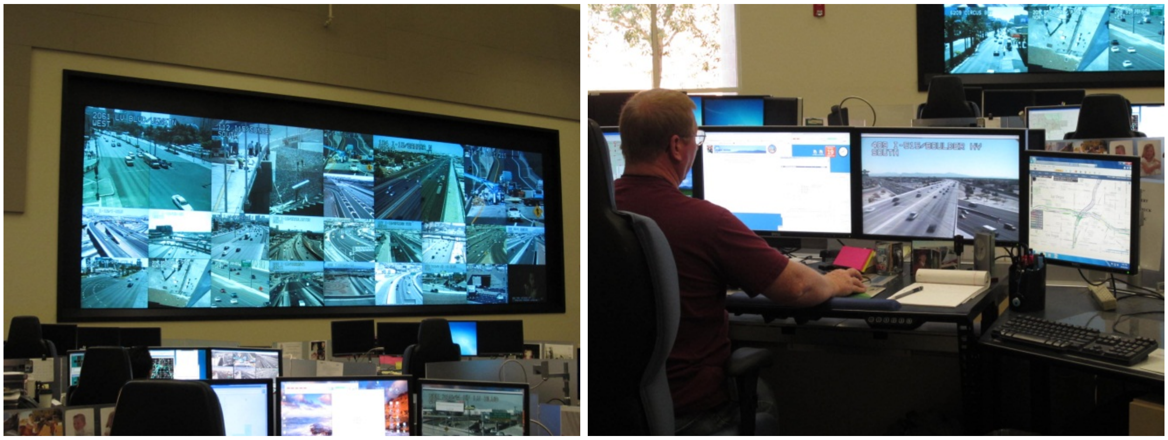

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Figure 16. Photo. The Las Vegas FAST Control Room.

APPLICABILITY OF THE ENGINEERING DESIGN PROCESS

Defining the Problem and Specifying Requirements of a Solution

From a technology perspective, FAST comprises many of the components that are commonly used to manage traffic in a metropolitan area. Plus, the ability to coordinate both arterial street and freeway operations gives FAST an advantage that few transportation management centers across the U.S. possess. In other words, FAST operators have a fairly wide range of tools at their disposal to help address construction and maintenance activity-related impacts.

> **Key Problems and Solutions**
>
> 1. Maximize the use of permanent ITS capabilities that already existed.to manage traffic and reduce traffic impacts during road projects. This requires early coordination during project planning and design.
> 2. Need for continuing evaluation and monitoring of conditions during work activities to develop a better understanding of how travel patterns change within the region during work operations, and estimate how work zone impacts in one part of the system will influence traffic operation on other parts of the system.

One of the key challenges that FAST operators face in assisting with construction and maintenance activity traffic impacts is how to be consistently integrated into the planning and scheduling efforts for these activities. FAST personnel note that while they are often notified about upcoming lane closures and full road closures so that appropriate advance notification messages can be displayed to travelers via the CMS, they also encounter situations in which they were not aware in advance of a lane closure and became aware of it through the normal CCTV monitoring efforts of the system by FAST operators. Once they notice that a lane closure is present, FAST operators can quickly deploy CMS messages upstream to provide additional warning to approaching motorists. However, there is less opportunity at that point to encourage route diversion or other responses by travelers.

Coordination between FAST and construction and maintenance work in the region extends beyond normal day-to-day lane closure notification to work zone planning, programming, and design decisions. As one example, a work zone ITS (consisting of temporary cameras, flow detectors, and portable changeable message signs to be deployed throughout the project) was procured and deployed during a previous I-15 design-build (DB) reconstruction effort north of the US 95 interchange where FAST monitoring and control were not yet present. FAST personnel had not been involved in specification development or procurement of the devices, so the system was not planned for integration with FAST. This limitation was addressed when the DB team later provided funding to FAST to allow them to integrate the data coming from that system into the FAST system. Funding was also provided to allow FAST operators to work overtime to focus specifically on the project area and help manage the temporary system.

Selecting, Designing, and Implementing the Best Solution

FAST provides a dissemination outlet of both advance notification and real-time roadwork-related traffic information via the roadside CMS and its website. Operators are trained to both identify the need for CMS messages and to properly design and post them. Certain roadwork activities may also require signal timing changes to support use of arterials as detour routes if either the freeway or another arterial is affected by work activity.

Most of the support from FAST involves posting work zone information on the CMS(s) upstream of the activity. For example, the operators may post a general warning message about lane closures on I-15 prior to, and during, the actual work operation, as depicted in Figure 17.

I-15 RESTRICTIONS
CHARLSTN TO TROP
SUN 7PM – THUR 7AM

(a) Prior to the work activity

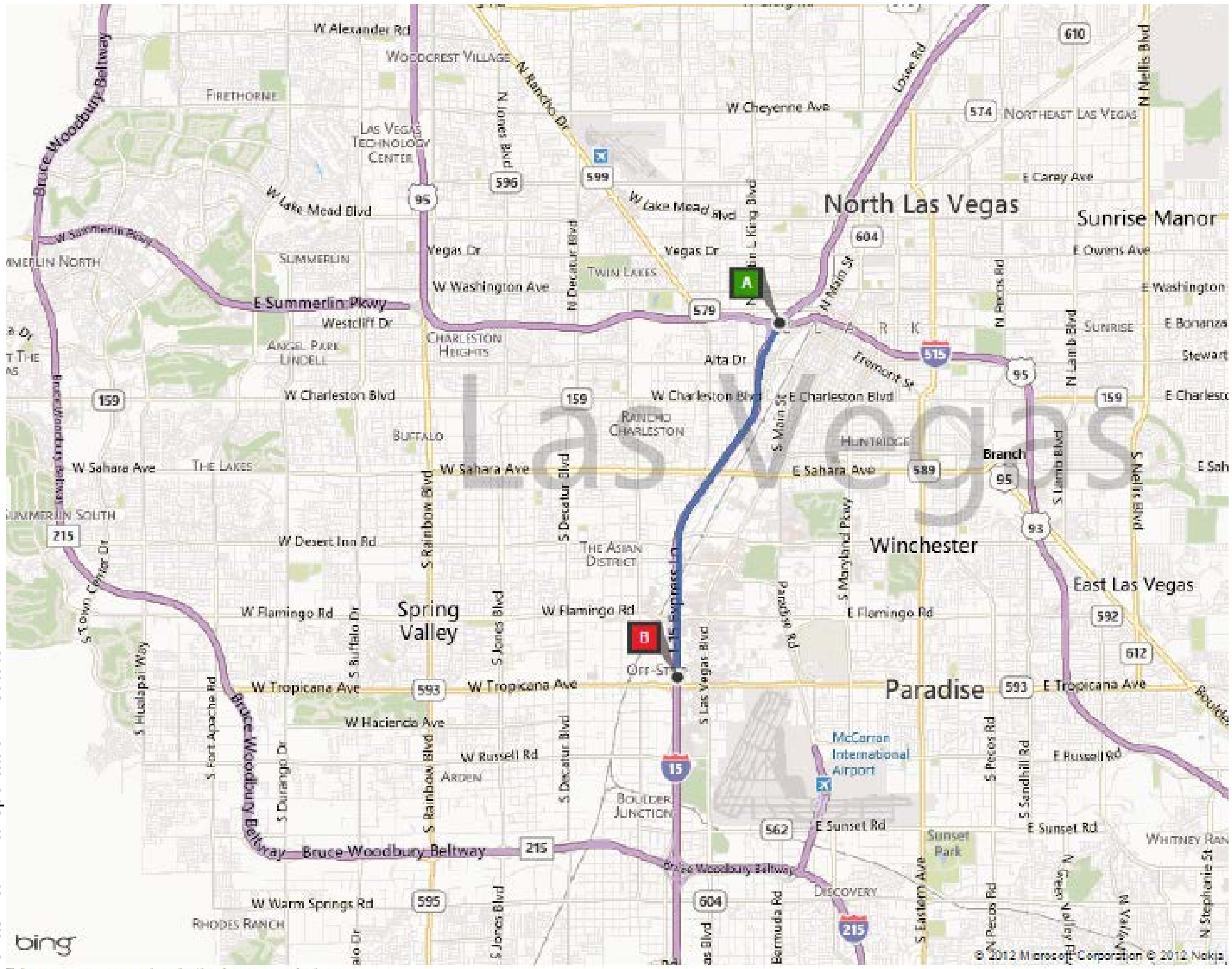
I-15 LANE CLOSURES
EXPECT DELAYS
USE ALTERNATE ROUTES

(b) During the work activity

G.C. Wallace, Inc.

Figure 17. Illustration. Examples of CMS Warning Messages Posted by FAST Personnel for Work Activity on I-15.

Specific diversion routes are typically not provided when a message such as this is posted on a CMS. Rather, the intent is for drivers to decide on their best diversion route to take, given that a lane reduction exists on their intended route. There have been a few work zone projects performed in which FAST personnel modified both traffic signal and ramp metering timings (*12*). One such project was a 5.5 mile crumb rubber overlay project in Fall 2011 on I-15 between the US 95 interchange and the Tropicana Avenue interchange (see Figure 18). For this project, travel on I-15 was restricted to two lanes per direction between Sunday evening and Thursday morning on four consecutive weeks in September-October 2011. A continuous paving operation was also required on one weekend in October (Saturday and Sunday) to complete the job. During that weekend operation, only one lane per direction was maintained on I-15.



Texas A&M Transportation Institute.

Figure 18. Map. Location of I-15 Crumb Rubber Overlay Project, Fall 2011.

FAST personnel monitored cameras and flow detectors throughout the network during the project. In addition, they relied on Google© traffic maps to assess conditions on the key arterials where they lacked surveillance coverage. The reduced capacity of I-15 caused significant diversion to the arterial street system, with MLK Boulevard, Rancho Drive, and Valley View Boulevard serving as major diversion routes southbound, and Valley View, Decatur Boulevard, and Jones Boulevard serving as major diversion routes northbound. Significant increases in traffic also occurred on several of the east-west arterials providing access to I-15 and these north-south arterials. The actual amount of diversion on any of the routes varied day-to-day and hour-to-hour, presumably because of learning effects by drivers experimenting with various diversion alternatives. FAST personnel implemented numerous changes in existing signal timing plans over the course of the project, but found it difficult to establish an optimum timing plan due to the continuously changing travel patterns. One of the primary goals was to minimize "demand starvation" at any of the signals due to upstream intersection traffic signal timing problems. FAST personnel also strived to minimize impacts on the other movements at selected intersections upstream, within, or downstream of the project. In some cases, operators increased signal cycle lengths. In other cases, timing offsets and splits were adjusted.

Evaluation and Lessons Learned

Usage Statistics and Performance Evaluations

Work zone operations and safety have not been regularly or formally evaluated using data from FAST. There have been certain instances, such as the previously mentioned crumb rubber overlay project, where work zone impacts have been assessed using some of the FAST data. The potential effectiveness of the operational changes made on the crumb rubber overlay project was evaluated through post-hoc traffic simulation analyses. The analyses showed that the changes made did improve operations slightly over what would have occurred if the changes were not made. Overall, the changes were determined to have reduced delays by 9 percent and stops by 11 percent in the AM peak period. The benefits in the PM peak period were less pronounced, reducing stops by 3 percent but increasing delay by 15 percent relative to a no change condition.

A key focus area of FAST management personnel is the monitoring of both safety and mobility conditions at all times within the network, and the organization of that data to allow quick and easy extraction of the data for time periods and locations of interest (such as during periods of roadwork activity). FAST personnel have three main sources of data available for monitoring traffic mobility along a particular route. First, speed data from the individual traffic sensors can be downloaded and analyzed to generate contour maps of speed ranges by location and time, as shown in Figure 19. The maps can be generated on multiple days and compared to assess changes in both duration and extent of any congestion that develops.

Both still images and real-time video segments of the CCTV views can also be captured and archived through FAST. Staff will occasionally use this capture and archiving process to check elapsed travel times on particular roadway segments. Personnel will select a unique, easily-identifiable vehicle at one camera location and time, and then look at a downstream camera location until that unique vehicle arrives. The elapsed time between the two camera view captures provides an accurate assessment of roadway segment travel time.

If conditions on a route not covered by surveillance equipment is of interest, operators will also access Google© traffic maps as another method of monitoring traffic conditions within the network. This approach was used during the I-15 overlay project in Fall 2011 to keep track of conditions on key arterials serving as alternate routes to I-15. FAST personnel noted that the data appeared to be fairly accurate and reliable for monitoring the extent of backups within the network.

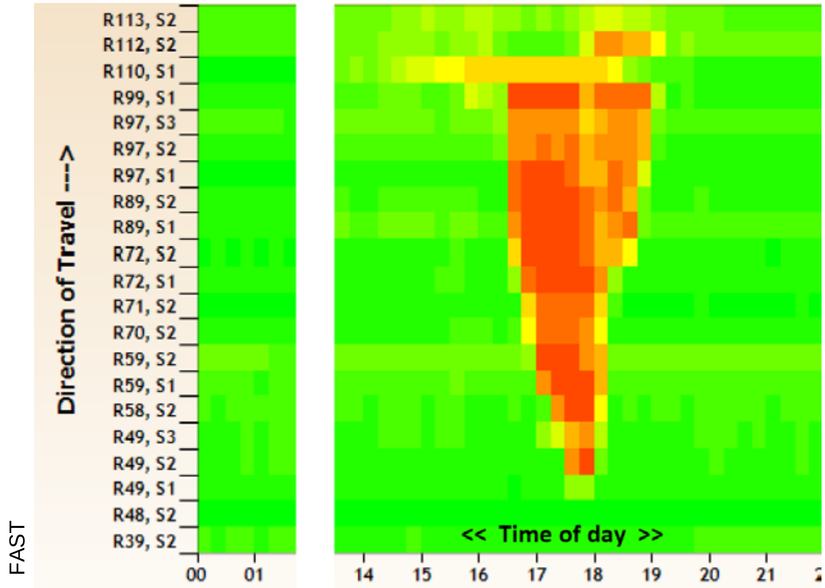


Figure 19. Chart. Example of a Speed Contour Map that can be Generated Using FAST Data.

Operators also identify and document traffic crashes they observe within the network as part of their normal incident management and response duties. Software developers on staff have developed easy-to-use and view safety dashboards of crash data, such as the one shown in Figure 20. Both summary statistics and a map of frequency by location can be viewed. Drop-down menus are used to focus on particular routes, types of crashes (such as work zone-related crashes or severe crashes), time periods, and/or response requirements.

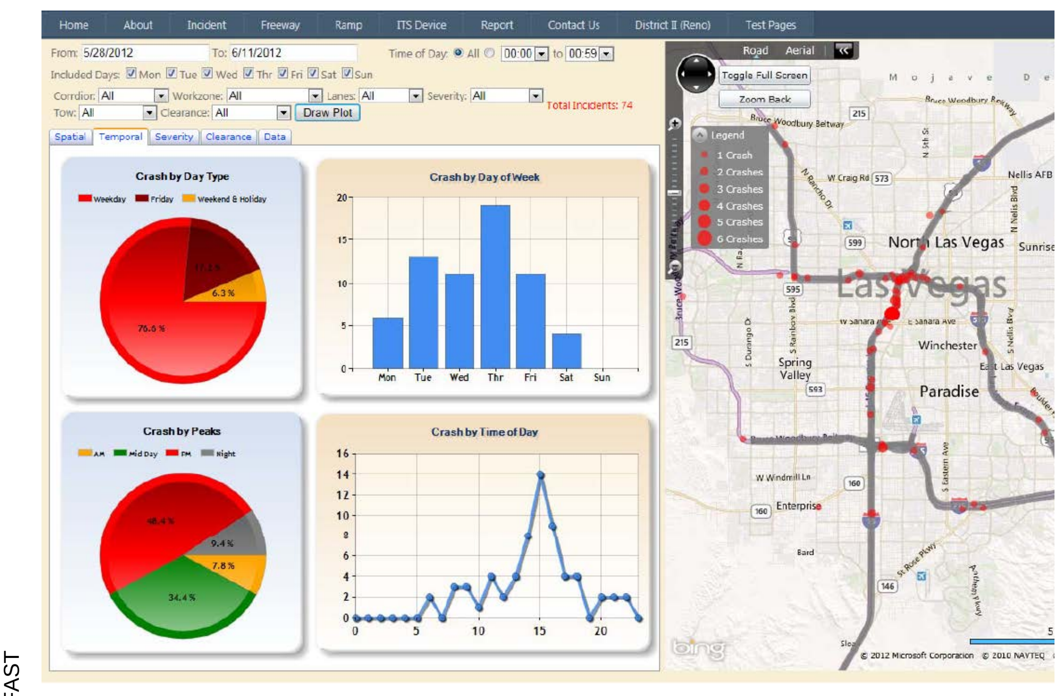


Figure 20. Map. Example of FAST Crash Performance Dashboard.

Lessons Learned

A number of lessons learned were offered by FAST management personnel relative to the use of the system for work zone traffic management and performance measurement. These lessons are summarized below.

It is important to engage permanent ITS personnel early in the work zone planning process – Permanent ITS personnel need to be included early enough in work zone design and scheduling decisions to help determine how best to make use of existing ITS resources (both equipment and personnel). The work zone ITS deployment on the I-15 DB project involved some data sharing between the temporary system and FAST and some informal monitoring of the system by FAST operators. FAST staff think the effectiveness of the work zone ITS could have been enhanced significantly if it had been better integrated into the overall FAST operation, and that earlier involvement in work zone planning would have increased the probability of effective integration. As a result of this and other experiences, FAST management personnel are working with NDOT to become more involved in work zone ITS planning processes in the future so as to maximize the potential effectiveness of overall integration efforts as well as management and response strategies that would be possible. NDOT personnel have agreed that improved coordination with FAST would be beneficial on future work zone ITS deployments.

Work zone crash risk is highest during the first few days of a project, and so advance notification of changes in lane configurations or other temporary traffic control conditions is important – A permanent system such as FAST can be beneficial in getting the word out to travelers a few days in advance of such changes.

Lane shifts and other changes during a work zone project require timely re-calibration of detectors – This recalibration effort takes time and effort. Depending on how the contract is written, the contractor may be required to recalibrate not only the temporary sensors, but the sensors for the permanent system as well. It is important to check that resources have been allocated for this activity by the contractor.

It is important that a good electrical subcontractor with ITS device experience be included on a contractor's team for any project that directly or indirectly interacts with ITS components – A lack of such experience on the contractor team can cause problems in getting system components installed and operating properly. It is important to request and assess contractor qualifications when reviewing project bids.

A better understanding is needed of how traffic-related messages on CMS and other devices affect driving decisions and behavior – The posting of a particular message can lead to significant diversion in some cases, but not in others. Research is needed, possibly at a national level, to better understand what roadway network and message attributes affect driver diversion decisions, and by how much. This would enable operators of permanent and temporary ITS to better tailor messages to the level of response desired.

Establishing and maintaining a good relationship with the media can help maximize the effectiveness of ITS – FAST experiences have shown that being proactive in getting information out to the media can pay dividends by helping to influence the messages that the media is putting forth.

It is valuable to have a good programmer on staff – A good programmer who understands how a particular ITS deployment has been designed and is managed can be extremely useful in designing user interfaces, data archival methods, and other analytical elements that operators and managers can then use effectively as part of their duties.

It is important to organize the incoming data from an ITS deployment in a logical way – Centers such as FAST generate tremendous amounts of data that can overwhelm the system and be of little value for analysis purposes. Mechanisms tailored to organizing the data in a way that allows for easy archiving and subsequent retrieval by location, time, etc. can be very valuable for both real-time work zone traffic management and for performance measurement activities. For example, it makes it easier to see and track trends over time, can aid decision making for lane closure requests, and can improve incident management efforts if operators can quickly assess how previous incidents in the same location and time of day affected travel patterns.

CHAPTER 6 - SUMMARY OF KEY CONCEPTS

As this nation's roadway infrastructure continues to age, more and more work zones will be needed to repair, rehabilitate and reconstruct this infrastructure. At the same time, the demand for travel on this infrastructure is likely to also rise, meaning that the work zones that do occur will generate significant adverse impacts on safety, mobility, traveler satisfaction, and highway work crew productivity.

Fortunately, research and experiences over the past 10+ years have made it clear that properly designed and implemented intelligent transportation systems (ITS), implemented as part of a well thought out transportation management plan (TMP), can help mitigate these work zone impacts. However, ITS is only one tool within a TMP designer's toolbox. A systems engineering decision process should be followed to determine whether an ITS deployment is the best mitigation strategy to deploy for a particular work zone, and to determine the appropriate ITS devices, systems, and/or strategies to implement. Although the overall scope of a given project ultimately determines the complexity and level of effort required for this systems engineering design process during planning, it should apply to the range of deployments, from small-scale, temporary deployments lasting a few months using commercial off-the-shelf (COTS) systems to complex, multi-year ITS deployments that may eventually be incorporated into permanent traffic monitoring and management systems. This process consists of five key steps:

1. Defining the problem.
2. Specifying the requirements of a solution.
3. Identifying and evaluating alternatives, as necessary.
4. Selecting, designing, and implementing the best solution.
5. Evaluating (i.e., describing the lessons learned).

This report documented work zone ITS deployments at five case study sites. These case studies illustrate four different ways in which ITS was used to address certain work zone challenges:

- Using Commercial Off-The-Shelf ITS to Mitigate High-Speed Rear-End Work Zone Crashes,
- Using ITS for Traffic Mobility Performance Specification Monitoring,
- Supplementing an Existing Permanent ITS to Manage Traffic During Construction, and
- Using Permanent ITS to Manage Work Zone Traffic.

Numerous lessons learned can be gleaned from these five case study sites for each step of the engineering design process, as presented below.

DEFINING THE PROBLEM

A well-defined problem is an important first step and the basis for all subsequent steps in the systems engineering process for crafting an appropriate solution, which may or may not require work zone ITS. It is also important to drill down beyond the obvious general concerns about congestion, delays, and crashes to understand the true “problems” underlying those concerns. Failing to define the problem well can result in an overly costly or unnecessary system that fails to address any real need.

In the Illinois case studies, for example, concerns existed over unpredictable queues occurring at work zone bottleneck locations due to varying traffic demands on the facilities, as well as the incidents that occur which could not be quickly moved out of available travel lanes due to a lack of shoulders. Conversely, for the Utah Bangerter Highway case study, lacking the capability to accurately monitor and assess individual motorist delays was the main problem in trying to develop and implement a mobility-related performance specification for contractors. Even the two case studies involving existing transportation management centers had slightly different problems to address relative to work zone mobility and safety management. For the Utah I-15 CORE project case study, the key problems were:

- A lack of convenient alternate routes to rely on when lane and full roadway closures on I-15 were required, and
- The potential for congestion to develop in locations along I-15 where existing ITS infrastructure was limited or non-existent, limiting the ability of traffic operations center (TOC) personnel to respond quickly and properly to any issues that arose.

For the Las Vegas Freeway and Arterial System for Transportation (FAST) system case study, key problems included:

- Being included early enough in work zone design and scheduling decisions to help determine how best to make use of existing ITS resources (both equipment and personnel), and
- Estimating how work zone impacts in one part of the system will influence traffic operation on other parts of the system.

SPECIFY REQUIREMENTS OF THE SOLUTION

The next step in the decision process is the development of well-defined requirements to compare against the strengths of various proposed alternatives. This step should occur without a pre-conceived expectation that a particular solution, such as an ITS deployment, will be used. These requirements define what a solution will do and are intended to be sure that it will meet the needs identified in the previous step. Failing to adequately specify requirements can result in a solution that is not adequate to address the actual work zone needs.

In the Illinois examples, concerns over unpredictable location, time, and extent of queues and delays led to requirements for:

- Continuous monitoring of roadway travel conditions upstream and through the project limits,
- The ability to quickly detect if a queue had formed, and
- Quick notification of the presence of a queue and delays to approaching traffic.

In the Utah Bangerter Highway case study, the requirements were for a mechanism to monitor travel times of individual vehicle movements through the project limits, and an ability to quickly determine if those travel times were above a performance specification that defined what the acceptable travel times were for the various movements.

For the two case study examples involving existing TOC infrastructure, defining the requirements of a solution differed significantly. In the I-15 Corridor Expansion (I-15 CORE) project example, requirements included a need to maximize available capacity on the key alternate route to I-15, and the enhancement of monitoring and control capabilities along I-15 in regions where such capabilities were not fully available. Conversely, for the Las Vegas FAST example, there was a need to improve coordination across agencies in the region (such as between FAST personnel and Nevada Department of Transportation (NDOT) project planning and design staff) in order to maximize the permanent ITS capabilities that already existed. A secondary requirement was a need for continuing evaluation and monitoring of conditions during work activities to develop a better understanding of how travel patterns change within the region during work operations.

IDENTIFY AND EVALUATE ALTERNATIVES, AS NECESSARY

In this step, technologies and strategies that meet the defined requirements should be identified and evaluated to: 1) verify that they will accomplish what is needed, and 2) assess the implications of the alternatives based on cost and how well they will address the identified problem. Although multiple alternatives may meet the specified requirements, cost must be balanced with how well the requirements are met: alternatives may be too costly, unnecessarily robust, or provide additional secondary benefits for minimal additional cost, and a customizable system may be preferred for a unique situation versus a cheaper COTS system.

In all of the case study examples described previously, it was already apparent that ITS was the primary feasible option to address the requirements, and the identification of alternatives involved determining appropriate vendors (in the Illinois case studies) and/or technology options available (as was the situation for the other three case studies). However, it should be noted that the agencies often already had significant experiences (typically less than successful) with some possible alternatives and had already excluded them from consideration. Two of the challenges that exist in evaluating alternatives are the uncertainties in how traffic conditions will actually be impacted during a project, and how each alternative will be able to mitigate the impacts. Consequently, this step and the following one often must rely on past experiences and engineering judgment.

SELECT, DESIGN, AND IMPLEMENT THE BEST SOLUTION

Selection, design, and implementation of the best solution will be dictated in large part by the alternative selected and the procurement method being used. Agency processes regarding permanent ITS selection, design, and implementation in most regions have evolved over time and are fairly well established and are guided by an ITS Architecture. However, this is often less so for work zone-specific solutions. Agencies must balance the need for specificity in their desired solutions to allow fair competition among vendors, but must guard against over-specifying the solution, which has the effect of limiting available competitors.

With regards to work zone ITS solutions, the case studies have demonstrated that it is important to include ITS device maintenance as a condition in the contract, in order to keep the contractor engaged in maintaining device operability throughout the project. The case studies have also shown that the benefit of providing drivers with real-time information is greatest during the first days of the roadwork activity and subsequent phase changes. This makes it important to have an adequate testing period prior to the start of monitoring and performance assessment to validate system operation and develop confidence in and ensure accuracy of the values being generated.

EVALUATING

The final step in the decision process should be an evaluation of how the selected solution met the requirements and addressed the problems initially identified. Agencies gain experience and insight with each deployment, and formally incorporating this learning process into future decisions is enhanced through a proper evaluation and documentation effort. This does not imply that the effort needs to be extensive or exhaustive, however.

From the perspective of work zone ITS solutions, it is apparent that a good data archival structure is important to have to facilitate quick and accurate analysis of work zone impacts that have occurred. The Utah Bangerter Highway case study illustrated that performance-based specifications require significant evaluation to ensure accurate enforcement of penalties. While it is not necessarily important to monitor every movement in a performance-based specification, a mechanism must be established to document non-construction events that cause delays as they occur.

APPENDIX A. ACKNOWLEDGMENTS

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Office of Operations
1200 New Jersey Ave., SE
Washington, D.C. 20590

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