Comparative Analysis Report: The Benefits of Using Intelligent Transportation Systems in Work Zones

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Foreword

This report is part of a series of Federal Highway Administration (FHWA) products that examines the use of Intelligent Transportation Systems (ITS) in work zones. This document provides a summary of the findings of a national FHWA study to quantify the benefits of ITS applications for work zone traffic management. A summary report of this study was published in April 2008 (Report No. FHWA-HOP-08-021). Also, a cross-cutting study (Report No. FHWA-OP-02-025) and four case studies on the use of ITS in work zones were published earlier.

All of these documents are available at http://www.ops.fhwa.dot.gov/wz/its/index.htm. The summary report of this study and the earlier reports were also published in hardcopy. To request a hardcopy of the summary report or the earlier reports, please send an email with the name of the publication you are requesting, number of copies needed, and shipping directions to workzonepubs@dot.gov. More information on applications of ITS in work zones is available in other documents, including Intelligent Transportation Systems in Work Zones — A Cross-Cutting Study.

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Executive Summary

This report presents the results of a Federal Highway Administration study that examined the use of Intelligent Transportation Systems (ITS) for work zone traffic management. Congestion and safety issues often arise in and around work zones as agencies work to implement necessary construction and maintenance projects. Degraded facilities, narrowed lanes, and lane restrictions often result in unpredictable, unstable traffic flow. With recent efforts that focus on improving work zone operations, including the recently implemented Work Zone Safety and Mobility Rule, State Departments of Transportation (DOTs) are looking to tools and applications that can help improve mobility and safety by actively managing traffic through the work zone. ITS applications are one tool that agencies can use to mitigate traffic impacts caused by construction.

A number of states have used ITS for work zone traffic management. These systems often take the form of mobile, portable traffic monitoring and management to provide information to motorists to help with route choice, provide advance warning of slowed or stopped traffic, and ease overall frustration due to not knowing what to expect. To promote further use of ITS technology to monitor and manage traffic through the work zone, more information is needed on the quantified benefits of use and the lessons learned by agencies that have tested and implemented these systems.

The purpose of this study is to highlight "before and after" or "with and without" analyses that quantify the mobility and safety benefits of using ITS applications for work zone traffic management. The study focused on sites that provided an opportunity for comparison of traffic conditions both with and without ITS. The study team focused on sites with the best potential for adequate data prior to system deployment (and with impacts from construction) for comparison with traffic conditions during system deployment. Five sites were assessed for this study. This study also examined findings from other work zone ITS research as compared with the findings presented from the five study sites.

The study team analyzed data from sites in the District of Columbia, Texas, Michigan, Arkansas, and North Carolina. For some of the sites, it was difficult to determine quantifiable benefits due to issues with deployment schedules and difficulties in implementing data collection plans due to varying construction schedules. Other sites showed clear, quantified benefits. Some key lessons learned that can help deploying agencies are presented for all sites. Additionally, quantitative benefits information is included for several sites, such as:

- Reductions in aggressive maneuvers at work zone lane drops (Michigan) – Forced merges were seven times less frequent and dangerous merges were three times less frequent when the ITS system was on (flashers on).
- Significant traffic diversion rates and lower observed mainline volumes (Texas, District of Columbia) in response to appropriate messages displayed during congested conditions, and an enhanced ability to manage traffic and incidents during

construction. In Texas, an average of 10 percent diversion (range of 1 to 28 percent) was observed, while in the District of Columbia an average of 52 percent (range of 3 to 90 percent) lower mainline volume (combination of diversion, demand reduction, and congestion) was observed.

- Improved ability to react to stopped or slow traffic (Arkansas) – 82 percent of surveyed drivers felt that the ITS system improved their ability to react to stopped or slow traffic.
- Driver perception of improved work zone safety (Arkansas) – 49 percent of surveyed drivers indicated that that the ITS electronic messages made them feel safer, 17 percent were neutral, 32 percent disagreed, and 2 percent did not answer.

Introduction

Purpose

In 2003, the Federal Highway Administration (FHWA) developed plans for a study to quantify the benefits of deploying Intelligent Transportation Systems (ITS) for mitigating impacts caused by highway construction and maintenance. The Work Zone Mobility and Delay Reporting Assessment began in August 2003 to document the tangible benefits of work zone ITS in a quantitative way. This study was intended to increase the body of knowledge regarding the effects of deploying work zone ITS so that practitioners have additional information to draw from in designing and deploying ITS in work zones.

In the recent past, some owner-agencies across the nation have deployed portable ITS technologies to monitor traffic and manage mobility and safety during construction. Portable systems provide a solution for deployment, maintenance, operation, and remobilization of monitoring systems, especially since the roadway characteristics often change dramatically during construction. Most of these systems take the form of mobile traffic monitoring and management through the use of portable sensors to collect traffic data and integrated portable changeable message signs (PCMS) to display speed and/or delay information in real-time. Agencies also often integrate a Web site into the overall system to provide motorists with pre-trip information to allow for better trip planning. A few agencies have also used portable ITS to help manage merging behavior approaching work zone lane closures.

Site Selection - Process and Criteria

To supplement a list of potential sites developed by FHWA, the study team performed research to learn about additional sites across the country. Out of over 30 initial sites, the study team eliminated more than 20 because they were not specifically work zone systems or because the deployments were already underway (which meant that there was little or no chance for comparison “without” data). The study team then developed a master site list and a technical memorandum that highlighted information on the sites that provided the best opportunity to quantify the benefits of using technology to mitigate the mobility, safety, and delay impacts caused by highway work zones.

The study team held conversations with deploying agency representatives to discuss the main goals and objectives of each system deployment, the schedule for construction, the status of system deployment, and estimated capacity reduction and construction impacts to traffic. The study team then applied primary and secondary site assessment criteria, as shown below, to the potential sites to determine which deployments would provide the best opportunity to measure impacts in and around the work zone. Some of the sites on this narrowed list of 10 potential sites did not appear to provide an opportunity for a quantitative evaluation. Other sites/systems had a design and concept of operations that would likely have proven very difficult to evaluate given cost constraints. The study team applied the criteria to help narrow the list and choose five sites to study.

Primary site selection criteria included:

- Availability of archived data and the infrastructure for data collection.
- Anticipated availability of “before” data (before the work zone).
- Anticipated availability of “without” data (work zone without ITS applications).
- Deployment probability.
- Status of ITS system deployment schedule.
- Existing relationships with either the vendor or the deploying agency that would facilitate a cooperative effort.
- Anticipated availability of data from other evaluations at the site.
- Location type (rural, urban, downtown).
- Typical volume/capacity or level of congestion.
- Percentage of local traffic versus through traffic, percent trucks, percent commuter traffic.
- Roadway type and number of lanes.
- Construction schedule.
- The State’s ability to articulate specific goals and objectives for what it hoped to accomplish by using the system.
- Primary purpose or goal for using the system (safety versus mobility).
- Type of system being implemented.
- Type of traveler information to be provided by the system.

Secondary site selection criteria included:

- Existence of a traffic management center for support/data.
- Size of construction project.
- Contractor’s ability to change schedule for increased productivity.
- State’s experience with the use of ITS in work zones.
- Geographic location.
- System vendor.

Where appropriate, a rating of “high,” “medium,” or “low” was applied to each site for each criterion. For classification-based criteria such as location type, each site was classified based on its characteristics. Once this step was completed, the study team further eliminated sites based on these primary and secondary criteria, to remove those sites that may not be appropriate for inclusion in this project.

Based on discussions with local contacts and a preliminary assessment, the study team selected two sites, one in Arkansas’ and one in North Carolina, early on in the process. For the other sites, the study team continued to use the assessment criteria to develop summary pros and cons and made recommendations based on this information. The study team also ranked the narrowed list of sites based on which sites illustrated the greatest opportunity to see quantified benefits.

Based on this process, the study team chose two additional sites—one in Texas and one in Michigan. The recommended sites are those where construction showed significant potential to have a measurable impact on traffic conditions, creating a situation where ITS could be used to reduce this impact. The study team chose the fifth site in the District of Columbia because the study team and local agency representatives expected significant construction impacts, especially due to the urban setting and high demand for the network.

Timing of the Evaluations

Planning for the evaluations often required long lead time ahead of data collection and analysis. For each site, the study team spent several months gathering and documenting information from stakeholders for use in developing the evaluation plans. The study team began by contacting stakeholders to determine system status, plans, goals and objectives, and progress on the deployment, followed by evaluation planning, data collection and analysis, and reporting. While the time for each site evaluation varied in length, the following bullets highlight the timeframe in which the study team performed data collection and analysis for each site.

- Arkansas – Spring/Summer 2004.
- North Carolina – Summer 2004.
- Michigan – Fall 2004.
- Texas – Summer 2006.
- Washington, DC – Summer 2007.

The original length of the overall study was less than 1 year. However, due to several issues, the overall study spanned a period of several years. The issues that hindered the evaluation included the initial difficulty in finding sites that met the selection criteria (e.g., there was an absence of clear goals and objectives for some systems from which measures could be developed), construction delays, and ITS deployment delays.

Common Measures and Metrics for Work Zone ITS Evaluations

The initial project plan for this study included a long list of potential measures and metrics for use at each site. Early evaluations included several metrics, but some proved difficult to quantify due to issues such as limited or incomplete data and difficulties determining whether the metric was positively influenced by the ITS deployment. Latter site evaluations included a smaller set of the most promising metrics. For example, rate of diversion was the primary metric for the Texas site, where the main objective of using the system was to divert traffic around the work zone during congested periods.

The study team sought to quantify benefits at a number of sites for comparative results. The study team designed this approach to avoid drawing conclusions from one site or one system. This approach limited the resources that went toward any one site but allowed the study team to focus on the most logical metrics that directly related to the goals and objectives for the deployment. The study team focused most resources per site on the primary goals and objectives.

The following paragraphs outline common measures and metrics and their application across some of the sites.

Mobility

Deploying agencies cited improved mobility as a main goal for the ITS deployment at each site. Within mobility, more specific measures included delay, travel time, and reduced demand. However, many of the systems had limited detector coverage and none of the deployments had enhanced travel time data such as through license plate recognition technology. While improved mobility was a key goal cited at all of the sites, system design and layout often made it difficult to specifically measure.

For the Arkansas site, the study team measured mobility impacts through user surveys. For the Texas and DC sites, the study team measured improvements in mobility by collecting data on diversion rates that would reduce demand on the mainline and thereby improve mainline mobility. One limitation of this approach involved data collection on the alternate routes, in that it was too costly to collect alternate route data and difficult to design data collection plans since it was impossible to know in advance when the traffic conditions would trigger the systems to recommend alternate routes.

Safety

Agencies also cited safety benefits as a main goal for several of the deployments, although agencies were reluctant to cite specific safety measures such as reduced crash rates when referring to goals and objectives for the system. Additionally, it is very difficult to draw conclusive findings from safety performance measures such as number of crashes and crash rates since data quality and quantity are often limited, and researchers face a significant challenge in determining whether a crash was specifically caused by the work zone (i.e., whether or not it would have still happened had the work zone not been in place).

For the Michigan site, the main objective was to reduce aggressive maneuvers at the lane drop. Therefore, safety was a primary metric, and the study team quantified the reduction in observed aggressive maneuvers and forced merges as a surrogate measure for safety performance. At the early sites, the study team investigated crash analysis but it was difficult to draw a meaningful conclusion due to the limited timeframe for collecting data and the several month long lags in reporting crash data. Crash and crash rate analyses did not produce significant findings at the sites due to common reporting issues and the need for long periods of time during which to collect data.

Effectiveness of Work Zone Information Dissemination

The objective of ITS can often be to provide real-time information on work zone conditions in the field. Deploying agencies often take this idea one step further and develop a plan for ensuring the information was not only real-time but was also useful to motorists in helping them plan their trip. For example, posting “work zone ahead expect delays” is not as specific as “30 minute delays ahead.” The more specific the message, the better motorists can make information decisions about which route to take.

At the Arkansas site, the study team used two metrics to determine the effectiveness of the system. These metrics included “Travelers will use the work zone ITS” and “The use of ITS in the work zone will improve trip planning.” While the main focus of this study was to quantify the benefits of each system, the study team analyzed the effectiveness of the information where practical. For the DC and Texas sites, travelers avoided mainline congestion but may have experienced some congestion in some cases on the alternate routes.

System Performance

This metric is less about quantifying the benefits of a system, and more about evaluating how well a system performed in the field. Data analysis at each site proved useful in helping the study team determine how well the system performed. Additionally, error logs and missing data often gave indications of the overall performance. System algorithms are often proprietary, making it challenging to determine with confidence how well the system performed based on its design.

Other metrics such as productivity, worker exposure to hazards, and construction efficiency proved more difficult to measure and were not analyzed at most sites (except Arkansas) due to burdensome data collection needs and challenges with determining the specific cause of a benefit. Additionally, the systems may have indirectly affected measures such as productivity because measuring the direct, quantified impact proved difficult. The other work zone ITS studies analyzed as part of this project focused mainly on direct traffic impacts. For the Arkansas site, the study team evaluated user perspectives on system performance, functionality, and benefits to motorists.

The following sections highlight in detail the measures and metrics analyzed at each site, along with the results of each site evaluation. The sites are presented in reverse chronological order with the most recent site first.

DC-295 Washington, DC

In 2006, the District of Columbia Department of Transportation (DDOT) deployed an ITS system on Highway 295 in Washington, DC. The system covers an approximately 7 mile stretch of DC-295, with some components on adjacent routes. DDOT designed and procured the system to help alleviate congestion and provide real-time information to motorists in the field and via a Web site. DDOT's main goals for the ITS system were to monitor conditions and improve mobility and safety through the work zone. The location and system layout are shown in Figure 1.

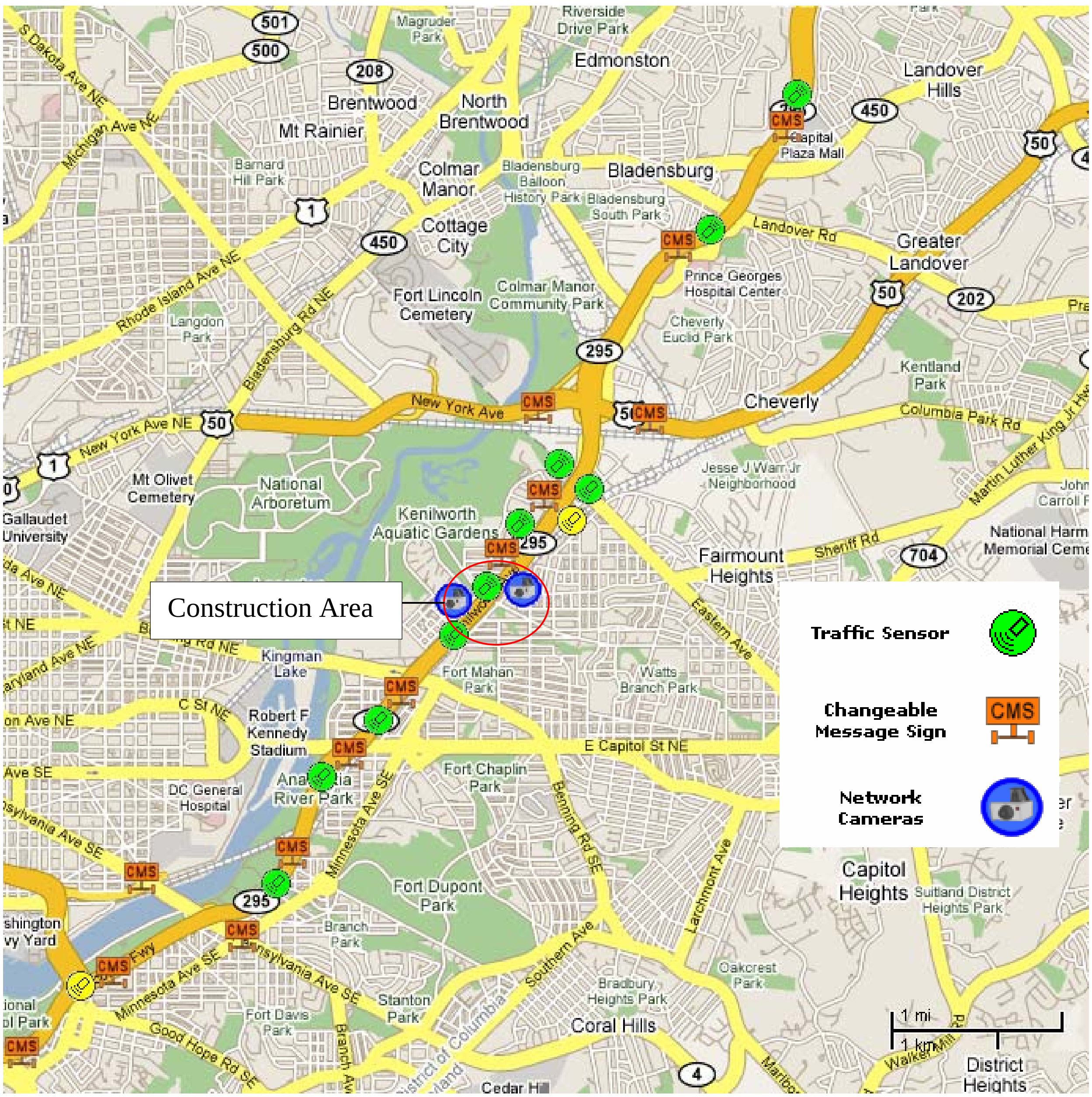

Figure 1. DC-295 Work Zone Area and ITS Layout

Based on predetermined delay and speed thresholds, the system provided real-time delay and speed information and, as needed, recommended alternate routes via dynamic message signs (DMS) for high congestion periods. The main goal of the system was to monitor conditions and manage traffic during lane closures due to their potential to produce abnormally large traffic backups and create potential for crashes outside the work zone.

The main objectives of the system were to:

- Reduce work zone-related congestion through a heavily traveled urban corridor.
- Provide delay and speed information to warn motorists of slowed traffic ahead.
- Provide information to commuters and DOT personnel via a Web site.
- Build public confidence in real-time traveler information.

The main objective of this evaluation was to determine the effect of the system on traffic conditions and quantify the benefits of the system.

Study Site Work Zone

DDOT incorporated a special provision for the Real-Time Work Zone System (RTWS) for both the northbound and southbound directions of Kenilworth Avenue (DC-295) from Foote Street to Lane Place Bridge over Nannie Helen Burroughs Avenue, in Northeast Washington DC.

Kenilworth Avenue is a barrier separated, six-lane freeway and serves as a major highway link between other major routes within the District, including I-395, and the Baltimore-Washington Parkway. DC-295 is a heavily traveled commuter route, carrying over 100,000 vehicles daily between Maryland and Washington, DC.

DDOT issued the Notice to Proceed for construction on April 2, 2007. The project consisted of the widening of Kenilworth Avenue to include improved shoulders and the realignment of the Nannie Helen Burroughs Avenue intersection with Kenilworth Terrace and Kenilworth Avenue on and off ramps. Improvements were also made to the intersections of Lane Place, 42nd Street, Jay Street, and Hayes Street with the collector-distributor road of Southbound Kenilworth Avenue. The Kenilworth Avenue bridge section over Nannie Helen Burroughs Avenue was replaced by a new two-span steel multi-girder superstructure. Several other bridges were reconstructed utilizing steel multi-beam superstructures and widened to provide semi-integral abutments. Other work included installation of traffic signals, lighting, and signing.

ITS Description

DDOT designed the ITS system to monitor traffic conditions within and in advance of the work area from each direction. The system components included:

- A central base station equipped with processing software and wireless communications to link the system components.

- 13 portable DMS remotely controlled via the field station.
- 8 portable speed sensors.
- 2 portable Remote Traffic Microwave Sensors (RTMS).
- 3 pages to provide notification to designated personnel when congested conditions occur or when devices malfunction.
- 2 video cameras to provide live video feeds of the work zone area.

DDOT moved some of the components and added several new components to allow the system to account for an additional ongoing Maryland DOT construction project.

Measures and Metrics

The system vendor collected and archived traffic data from November 1, 2006, through August 15, 2007, resulting in more than 1 million data records. Since the system detectors covered a large area, the data collection plan for this site relied solely on system detector data for analysis. The data archives allowed the study team to establish a baseline prior to ITS implementation (without ITS) for comparison with the period when the system was active (with ITS).

The study team developed a database tool to catalogue and display data from the nearly 1 million records provided by the system vendor. Due to its limited use in comparison of construction-related traffic patterns, baseline data collected prior to the construction start date of April 2, 2007, was used as back up information. The system was turned on to traffic on April 13, 2007. Data for 11 days prior to system start were available for comparison with data archived between April 14, 2007 and August 15, 2007 (when the ITS was actively deployed).

The study team developed two key hypotheses based on the goals for the system. The hypotheses and associated measures and data sources for testing each are shown in Table 1 below.

Table 1. Hypotheses and Measures for Evaluation

Hypothesis	Measures of Effectiveness	Data Sources
The use of ITS in work zones will divert travelers to alternate routes during times of work zone congestion	Demand patterns on mainline and alternate routes	Sensor data
The use of ITS in work zones will reduce congestion	Demand patterns on mainline and alternate routes, queue lengths	Direct observations, sensor data

Findings

The archived data for this site showed some general trends, especially in the level of recurring congestion for this area. The study team observed the distinct commute pattern into the District in the morning (southbound) and out of the District in the afternoon (northbound) from the data. DDOT anticipated that adding in capacity restrictions from the work zone would add non-recurring congestion to this daily pattern. Therefore, the system covered the corridor along a stretch of approximately 10 miles.

The data suggests higher levels of recurring congestion for the area than non-recurring congestion caused by the work zone. This may be in part due to the early phases of work – construction is scheduled to continue into 2008, and additional activities in the future may impact traffic to a greater extent than observed within the timeframe of this study. However, several findings indicate positive benefits of the system during the 2007 construction season.

Construction Activity Information

To assess the level of impact from construction activities, the study team obtained construction log information and capacity reduction information from the DDOT construction management consultant. Construction inspectors and field engineers recorded information in activity logs for each day that work occurred as shown in Tables 2 and 3. Time periods of interest included those in which lane closures were in place and those in which incidents occurred. The recorders made notes on incidents within the work zone and at the approaches, maximum queue lengths, and specific activities that occurred. The study team parsed applicable notes for the days of interest during the periods both "without ITS" and "with ITS." While crashes likely occurred along the corridor during construction, the DDOT construction management consultant cited no documented work zone-related crashes during the data collection time period.

Table 2. Construction and Lane Closure Information

Date	Time of Day (Beginning)	Time of Day (End)	Crashes Observed	Maximum Observed Queue Length	Activity Notes
4/5/2007	10:00 AM	3:30 PM	--	1200 feet	Closed northbound outside lane on Kenilworth Avenue (clear and grub)
4/6/2007	10:00 AM	2:00 PM	--	200 feet	Closed lane on northwest service road (clear and grub)
4/9/2007	10:00 AM	3:30 PM	--	200 feet	Closed southbound lane near bridge 48 for deck demolition
4/10/2007	10:00 AM	3:30 PM	--	200 feet	Closed southbound lane near bridge 48 for deck demolition
4/10/2007	10:00 AM	3:30 PM	--	200 feet	Phase 1 – early maintenance of traffic plan implementation
4/11/2007	10:00 AM	3:30 PM	--	200 feet	Closed southbound lane near bridge 48 for deck demolition
4/12/2007	10:00 AM	3:30 PM	--	1200 feet	Closed lane on southbound Kenilworth Avenue (demolition)

All lane closures occurred during off-peak hours. Of the "without ITS" days where lane closures were in place, the data for the southbound direction showed recurring congestion trends from approximately 7:00 a.m. until approximately 10:00 a.m. Data for one day showed recurring congestion from approximately 3 p.m. until approximately 6 p.m.

Table 3. Construction and Lane Closure Information

Date	Time of Day (Beginning)	Time of Day (End)	Crashes Observed	Maximum Observed Queue Length	Activity Notes
4/13/2007	10:00 AM	3:30 PM	--	1200 feet	Closed southbound lane for MOT Pavement Marking
4/14/2007	10:00 AM	3:30 PM	--	200 feet	Closed southbound lane for Phase I – Early MOT
4/16/2007	10:00 AM	3:00 PM	--	1200 feet	Closed southbound lane to place portable concrete barrier
4/17/2007	10:00 AM	3:00 PM	--	200 feet	Closed southbound lane to place portable concrete barrier
4/18/2007	10:00 AM	3:30 PM	--	200 feet	Closed southbound lane for pavement marking and to place portable concrete barrier
4/19/2007	10:00 AM	3:30 PM	--	1200 feet	Closed northbound lane for Phase I – MOT
4/20/2007	10:00 AM	3:30 PM	--	1200 feet	Closed northbound lane for Phase I – MOT
4/24/2007	10:00 AM	3:30 PM	--	1200 feet	Closed southbound lane to install storm water catch basin
4/25/2007	10:00 AM	3:30 PM	--	1200 feet	Closed southbound lane to install storm water catch basin
4/28/2007	10:00 AM	3:00 PM	--	1200 feet	Closed southbound lane for MOT pavement marking
5/14/2007	10:00 AM	2:00 PM	--	1200 feet	Closed southbound lane for MOT pavement marking
5/15/2007	10:00 AM	3:30 PM	--	1200 feet	Closed southbound lane for MOT pavement marking
5/16/2007	10:00 AM	3:30 PM	--	1200 feet	Closed southbound lane to place portable concrete barrier
5/17/2007	10:00 AM	3:00 PM	--	1200 feet	Closed southbound lane to place portable concrete barrier
5/18/2007	10:00 AM	3:30 PM	--	1200 feet	Closed southbound lane to place portable concrete barrier
6/2/2007	4:00 AM	2:00 PM	--	1200 feet	Closed northbound lane for MOT pavement marking
6/4/2007	10:00 AM	3:30 PM	--	1200 feet	Closed northbound lane for MOT pavement marking
6/5/2007	10:00 AM	3:30 PM	--	1200 feet	Closed northbound lane to place

Date	Time of Day (Beginning)	Time of Day (End)	Crashes Observed	Maximum Observed Queue Length	Activity Notes
					portable concrete barrier
6/7/2007-6/14/2007	10:00 AM	3:30 PM	--	1200 feet	Closed northbound and southbound lanes to demolish median (daily)
6/18/2007-6/30/2007	10:00 AM	3:30 PM	--	1200 feet	Closed northbound and southbound lanes to demolish median (daily)

Project managers documented similar information for July and August to assist with the analysis. In some cases, the data showed queues that were longer than those documented by project personnel (likely recurring queues not caused by the work zone directly). In other cases, sensor data did not show any congestion on some of the days where project managers documented some work zone related queuing. Consequently, documented queues were relatively short and non-recurring congestion appeared to be managed to a minimum extent as part of the maintenance of traffic plans (i.e. off-peak lane closures, etc.).

Traffic Queue Analysis

The study team began the analysis by sorting traffic data from system detectors for preliminary inspection to determine the potential for use in the analysis. The archived traffic data consisted of more than 1 million records covering a time period from November 2006 through August 2007. The data set was very complete and inspection showed reasonable patterns of traffic volumes, speeds, and associated DMS messages. Data were not available for a small number of days and other short time periods due to communication interrupts and archiving issues.

The study team performed an analysis to compare queues documented by construction managers with those observed by the system. Since the system covered a large area with multiple detector locations (this site had a very large number of detectors compared with most of the other sites), the potential for determining queues was high. Documented queues extended to a maximum of approximately 1/4 of a mile, while queues from system detector data reached nearly 2 miles in some instances. The study team calculated queues using detector spacing for time periods where speeds dropped below 30 miles per hour (mph). Figure 2 shows average southbound speed by time of day for April 13, 2007, the first day the DMSs were turned on to traffic. The resulting queue was approximately 1 mile compared with the 1/4 mile estimate. The longer queue length could be caused by recurring congestion or an incident outside of the work zone area. Due to the large difference between estimated and observed queue lengths on nearly all of the data collection days, the analysis of queues before and after implementation proved inconclusive. The wide gap between observed queue and system detected queue may have been caused by the determination of what constitutes a queue. The 30 mph threshold is common for a rolling queue and is easier to determine from data as opposed to field observations, but the sensitivity to observed speed may differ due to the level of recurring congestion normally seen in urban areas such as Washington, DC.

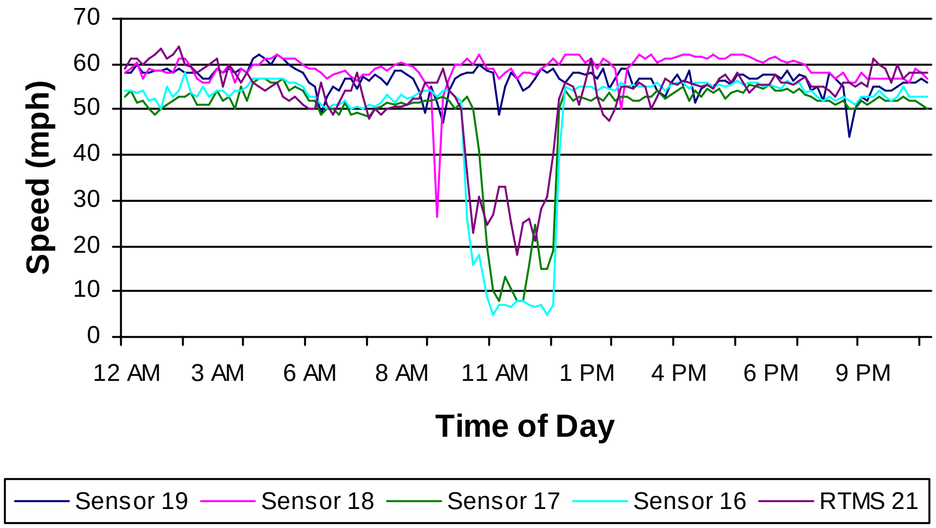

Figure 2. Average Speed by Time of Day – April 13, 2007

Based on the data shown in Figure 2, the system posted messages showing 55 to 60 minute delays on DC-295 and recommended, on DMSs located on a perpendicular route, that motorists seek an alternate to DC-295.

Traffic Volumes and Diversion Patterns

The study team also analyzed volume levels for days with and without ITS that experienced similar impacts from construction or had similar levels of congestion. Since most "without ITS" days showed mostly recurring congestion during peak hours and showed no congestion during lane closure time periods, the study team compared some of the "without ITS" days to "with ITS" days to see if the volumes changed when messages recommended alternate routes. The study team also compared some days within the "with ITS" period to see if volume levels showed interesting trends.

For two similar Tuesdays (April 10 and May 15), the volume levels were almost exactly the same except from approximately 10 a.m. until 1 p.m., a time period where the system posted delay information and recommended that motorists seek an alternate route to southbound DC-295 (see Figure 3). During this time period, as much as a nearly 90 percent less volume was observed on May 15 compared with April 15. As shown in Table 4, the data showed 3 to 89 percent lower observed mainline volumes, with an average of 52 percent over these nine observations. This shows that the system likely reduced delay substantially for motorists by providing them with information to better enable them to choose an alternate route. It should be noted that based on the data available, it is not possible to determine what portion of the lower mainline volume was due to diversion versus demand reduction versus congestion.

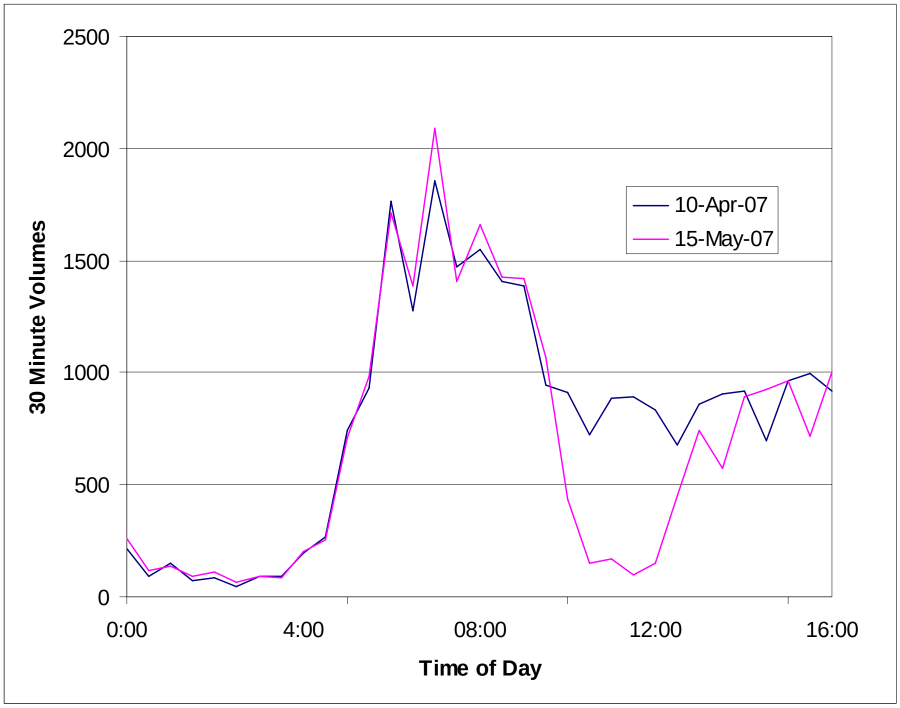

Figure 3. Volume Levels by Time of Day

Table 4. Percent Change in Volume by Time Period

Time Period	Observed Volumes for April 10, 2007	Observed Volumes for May 15, 2007	Difference	Percentage Difference
10am – 10:30am	912	435	477	52%
10:30am – 11am	723	151	572	79%
11am – 11:30am	886	168	718	81%
12pm – 12:30pm	890	98	792	89%
12:30pm – 1pm	831	148	683	82%
1pm – 1:30pm	679	452	227	33%
1:30pm – 2pm	862	742	120	14%
2:30pm – 3pm	908	574	334	37%
3:30pm – 4pm	921	890	31	3%

During periods of congestion, volume counts are impacted because queuing and congestion allow fewer vehicles to cross in front of the sensor due to lower speeds. An exact measure of demand involves estimating the number of vehicles in the queue—these vehicle estimates should be added to the volume counts to get a true demand value. Due to the sporadic nature of speeds below the queue threshold and the absence of expected patterns (the study team often observed queues at two sensors but free flow conditions at a sensor in between the two), the data proved inconclusive. This limitation is inherent in many studies, as the data collection plan would need to account for field observations and normally is too costly and difficult to plan for. It is important to understand the effects of congestion on throughput; however, the very large change in volume shows that, by alerting motorists on another route to avoid DC-295, the system likely had a positive impact on travel through the corridor.

For the northbound direction, the study team compared one day "without ITS" to one day "with ITS." These two dates were April 6 and April 20, respectively. No clear trend was apparent from the data, although the study team observed similar large percentage differences in volumes for some time periods. On April 20, the system recommended that motorists seek an alternate route from 2:22 p.m. until 4:10 p.m.—a timeframe that showed lower volumes during the "without ITS" period, as seen in Figure 4. The posted messages showed the delay and recommended that motorists seek an alternate. The difference was that the delay was lower in this case than the previous case—posted delays did not exceed 15 minutes on April 20.

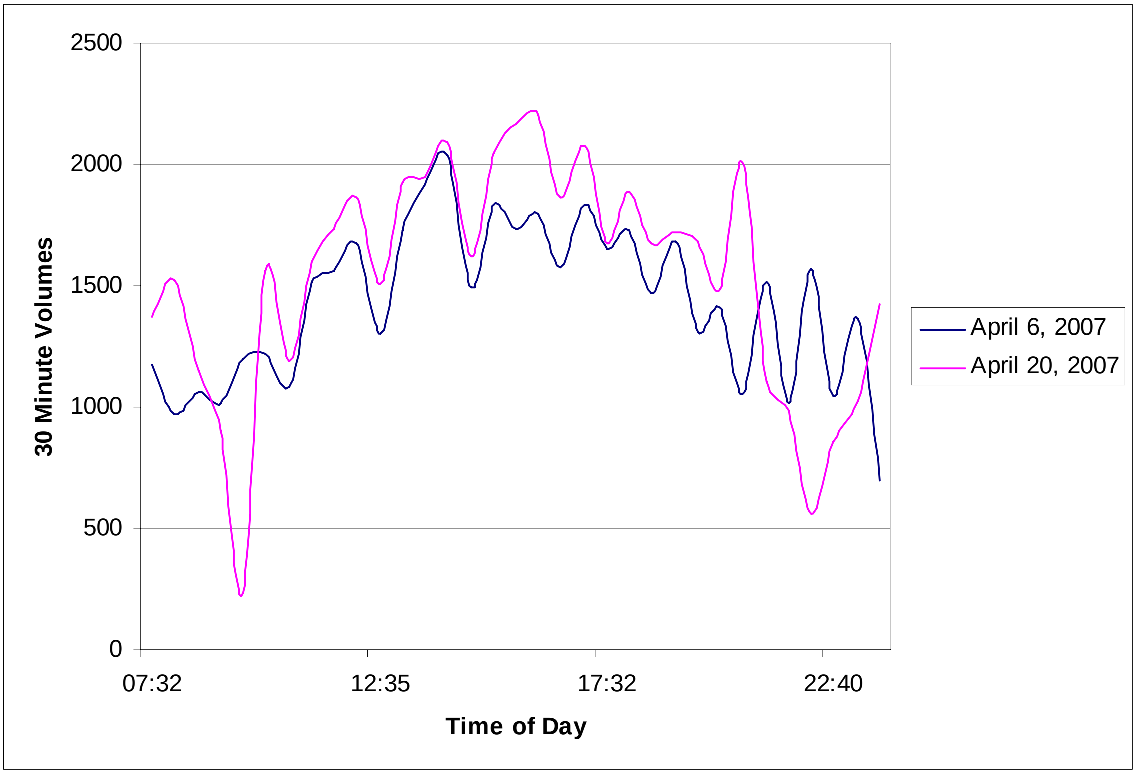

Figure 4. Volume Levels by Time of Day

The data displayed above shows the best examples, from all the data, of how motorists were impacted. While the system alleviated congestion on the mainline, alternate routes should also be monitored to the extent feasible to avoid shifting congestion to another route or corridor. For this study, the study team was unable to observe the alternate routes due to cost.

DMS Messages

Throughout the deployment, the system posted 85 different types of messages at different times. The system often posted delay, speed ahead, and other caution messages warning motorists of the construction activities ahead.

The system used several preprogrammed messages, and operators had the ability to override the system and post messages manually as needed. Examples of the types of messages and variations are shown below.

Messages Showing Delay

- X MINUTE DELAY AHEAD PLEASE USE CAUTION.

Messages Showing Speed Ahead

- X MPH SPEED AHEAD SLOW DOWN.
- X MPH SPEED AHEAD PREPARE TO STOP.
- X MPH SPEED DC-295 SLOW DOWN.
- X MPH SPEED DC-295 PREPARE TO STOP.

Example Test Message

- MESSAGE MESSAGE MESSAGE TEST TEST TEST.

Messages Encouraging or Requiring Diversion

- X MIN DELAY AHEAD SEED ALT. ROUTE.
- X MIN DELAY ON 295-S SEEK ALT. ROUTE.
- X MIN DELAY DC-295N SEEK ALT. ROUTE.
- X MIN DELAY ON DC-295S SEEK ALT. ROUTE.
- X MIN DELAY ON DC-295 SEEK ALT. ROUTE.
- S CAP ST BRIDGE CLOSED TRUCK & VEHICLE TRAFFIC.
- S CAP ST BRIDGE CLOSED VIRGINIA TRAFFIC USE 295S.
- S CAP ST BRIDGE CLOSED USE NEW YORK AVENUE.

Messages Showing General Traffic Conditions

- BRIDGES FREEZE BEFORE ROADWAY DRIVE W/CAUTION.
- S CAP ST BRIDGE CLOSED TRUCK & VEHICLE TRAFFIC.
- WORK ZONE DC-295 PLEASE USE CAUTION.
- WORK ZONE AHEAD.
- WORK ZONE AHEAD PLEASE USE CAUTION.

Other Messages

- CLICK IT OR TICKET.
- SOCCER GAME AT RFK THURSDAY 5PM-9PM.
- DRIVE WITH CARE.

DDOT added sensors and message boards on June 29, 2007, to account for a construction project in nearby Maryland. DDOT purchased two additional sensor trailers and one additional message board for the Maryland project. The additional sensor trailers allowed DDOT to detect congestion due to the Maryland project and to alert motorists approaching that project within the DC project area. The system combined delays from the two projects as appropriate to determine the total delay. Also, DDOT used the additional message board to expand motorist information south to the South Capitol Street Bridge, which allowed messages relating dates and times of the bridge closing to be conveyed to travelers. The system also posted South Capitol Street Bridge status messages on the Baltimore-Washington Parkway in Maryland and before the exits to Route 50 and New York Avenue.

Overall, the real-time information system deployed on DC-295 in Washington, DC appeared to effectively divert traffic to unsigned, unspecified alternate routes during times of significant congestion. There was an average of 52% lower mainline volume observed (combination of diversion, demand reduction, and congestion). It should be noted that the results include potential reduced throughput due to queues and congested conditions (likely significant for the higher end of the range). However, even considering the congestion impacts on throughput, these results show that the system likely reduced delay substantially for motorists by providing them with information to better enable them to choose an alternate route. It should also be noted that this is an urban area with a large number of commuter trips. Based on the data available, it is not possible to determine what portion of the lower mainline volume was due to diversion versus demand reduction versus congestion.

Tips and Lessons Learned

Deployment Tips and Lessons Learned

Coordinate with neighboring States and local agencies. DDOT coordinated with other local agencies in addition to coordination with the Maryland State Highway Administration on the neighboring construction project. When the South Capitol Street Bridge was closed, DDOT coordinated with the local jurisdictions to divert over 72,000 vehicles for a 2-month period while the construction was ongoing. The coordination process helped DDOT plan for outreach to the media to help motorists avoid the already congested DC-295 corridor while it was under construction.

Flexibility in system configuration is important. DDOT successfully modified the original system layout to account for impacts from a separate construction project in a neighboring state.

Allow time for obtaining right of way use permits for equipment installation. The vendor used by DDOT noted that time was required to get approval of these permits before they could place the equipment in the field.

Secondary benefits of managing recurring congestion along heavily traveled urban corridors may also be achieved. DDOT successfully used the system to manage recurring congestion along the heavily traveled DC-295 corridor.

Evaluation and Research Tips and Lessons Learned

A successful evaluation of a work zone ITS deployment relies heavily on the cooperation of each entity involved. As the final evaluation performed under this study, the study team reaffirmed many of the previous evaluation and research lessons learned from the other sites. For this study all parties were helpful in obtaining necessary information.

Need to be able to verify conditions in the field as they occur. Often, with archived data, evaluators are unable to validate data and findings as conditions occur in the field. A measure in addition to volume is commonly needed to measure the level of congestion and congestion impacts on throughput.

I-35 Hillsboro, Texas

In October 2006, The Texas Department of Transportation (TXDOT) implemented an ITS system in a construction work zone in Hillsboro, Texas. The purpose of the system was to monitor conditions and improve mobility and safety through the work zone along I-35, 35W, and 35E in Hillsboro County. TXDOT designed the system to provide motorists with real-time information on downstream conditions and to provide alternate route guidance during times of heavy mainline congestion. TXDOT sought to warn motorists of speed variability issues and to lessen traffic delays caused by capacity reductions and rubber-necking in the work zone.

TXDOT designed an ITS system for a work zone on Interstate 35 south of Waco in Hillsboro County, as shown in Figure 5.

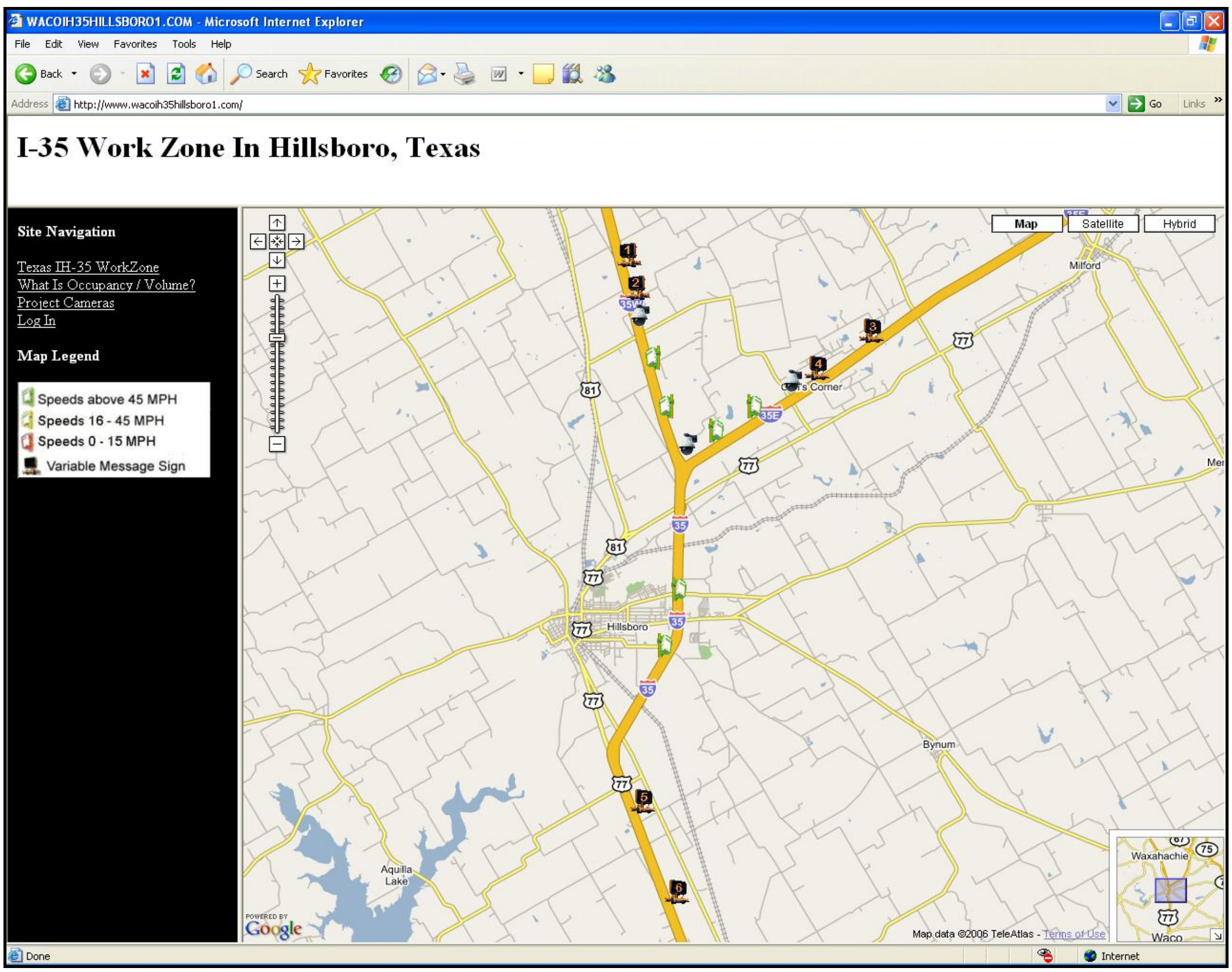

Figure 5. I-35 Work Zone and Signed Alternate Routes (Taken from TXDOT's Web Site)

Based on predetermined speed and occupancy thresholds, the system provided real-time delay information and recommended alternate routes via dynamic message signs (DMS).

TXDOT operators also monitored traffic conditions in the work zone through the use of three wireless closed circuit video cameras.

The main objectives of the system were to:

- Reduce demand and congestion (by actively diverting traffic approaching the work zone).
- Provide delay information and route guidance to motorists enroute to warn them of slowed traffic ahead.
- Provide trip planning information to commuters and system management information to DOT personnel via a Web site.

The main objectives of the evaluation were to:

- Determine traveler response to the work zone information.
- Determine the effect of traveler response on traffic conditions.
- Determine whether the system detected congestion as it occurred and posted the appropriate messages.

Study Site Work Zone

TXDOT installed the work zone between milepost (MP) 364 and MP 374, north of Waco. As shown in Figure 17, I-35 splits north of Waco into I-35E leading to Dallas and I-35W leading to Fort Worth. All three highways have similar characteristics and are four-lane divided freeway facilities. TXDOT set up lane closures in each direction in order to reconstruct the main interchange and rehabilitate and reconstruct pavement and structures along the route.

The contractor began construction in July 2006 with an estimate for completion of mid-2008. Two separate construction projects were planned for the general area. Lane closures on the south end of the corridor near exit 364 occurred from October 2006 through February 2007. For the second project, the contractor restricted capacity by closing one lane in each direction during late 2006 and early 2007. The latter project is located on I-35 at the I-35E / I-35W interchange near milepost 371. Work will continue through 2008.

TXDOT expected long queues and delays, especially on I-35W southbound near the split. For northbound I-35, the existing geometry is such that each lane directs traffic to either I-35E or I-35W. That is, the two lane section splits into one lane for I-35E traffic and another separated lane for I-35W traffic. I-35 branches off into two directions to the north and becomes I-35E and I-35W. A large portion of the traffic along the corridor is commuter traffic, as many of the exits along the work zone area serve farm land and provide access from rural roads. Major attractors that might impact traffic patterns were not prevalent along the corridor, especially around exits that are in close proximity to the work zone.

ITS Description

The TXDOT deployment work zone ITS was made up of three individual systems meant to alleviate non-recurring congestion along the I-35 corridor. Since the I-35 roadway configuration consisted of three different approaches to the work zone, three independent traffic monitoring systems were used. Alternate routes were signed for each of the three traffic flows. While one vendor provided the entire system, it acted as three independent closed loop systems, one for each approach to the work zone. While this document may reference the "system," it refers to the entire vendor-provided solution made up of three components.

The primary goal of the system was to monitor this project's work zones and automatically provide alternate route advisory information to the traveling public based on significant travel times through the work zone. A secondary goal of the system was congestion management of non-recurring traffic conditions because of high traffic volumes, weather, and incidents.

The system consisted of the following components:

- Six solar powered portable side-fire microwave detection trailers
- Six solar-powered portable changeable message signs
- Three portable video (camera) trailers
- A system server, Web host, and associated communication equipment and software
- A Web site for use by TXDOT and the general public.

For each approach to the work area, two sensors monitored traffic and sent messages to two PCMS based on pre-determined speed and occupancy thresholds, as shown in Table 5.

Table 5. Example Queue Thresholds - 35W Southbound

Normal Traffic Flow through Work Zone >=55MPH	**Speed Average 40<x>55MPH @5min Lane Occ>20%**	**Speed Average 25<x>40MPH @5min Lane Occ>30%**	**Speed Average 10<x>25MPH @5min Lane Occ>40%**	**Speed Below 10MPH @5min Lane Occ>50%**
WORKZONE AHEAD 2 MILES	WORKZONE AHEAD 2 MILES	WORKZONE AHEAD 2 MILES	WORKZONE AHEAD 2 MILES	WORKZONE TRAFFIC STOPPED
NO DELAYS -x:xxPM-	MODERATE DELAYS -x:xxPM-	EXPECT DELAYS -x:xxPM-	LONG DELAYS -x:xxPM-	USE ALT ROUTE

TXDOT dynamically adjusted queue thresholds, had message pre-emption capabilities, and had notification capability to alert appropriate personnel of problems. In addition to the vehicle count, speed, and classification data, streaming video was made available from three portable camera trailers. TXDOT also implemented a public Web site to allow access to current system operational status and to view existing traffic conditions. TXDOT procured the system through the prime construction contractor.

Measures and Metrics

The study team focused traffic data collection efforts on measuring diversion rates at freeway exit ramps to test driver response to the system. To supplement the system detector data, the study team collected data through three additional queue trailers with side-fire radar at three key diversion locations along the corridor that provided access to the signed alternate routes. The study team installed sensors upstream of the work zone and system detectors downstream of the PCMS to collect mainline and ramp volume, speed, and occupancy at each location. Original plans included travel time runs on the mainline and alternate routes. However, data collection in this regard proved too costly and difficult to properly capture conditions during impact periods.

The study team compared baseline data prior to ITS implementation (without ITS) with the period when the system was active (with ITS). The study team collected data from the three supplemental detectors from October 3, 2006, until February 4, 2007, and the vendor archived system detector data beginning October 4, 2006 and message logs beginning October 23, 2006. The system was turned on to traffic on October 26, 2006. Figure 6 shows the location of the three supplemental data collection queue detectors (labeled Q1, Q2, and Q3).

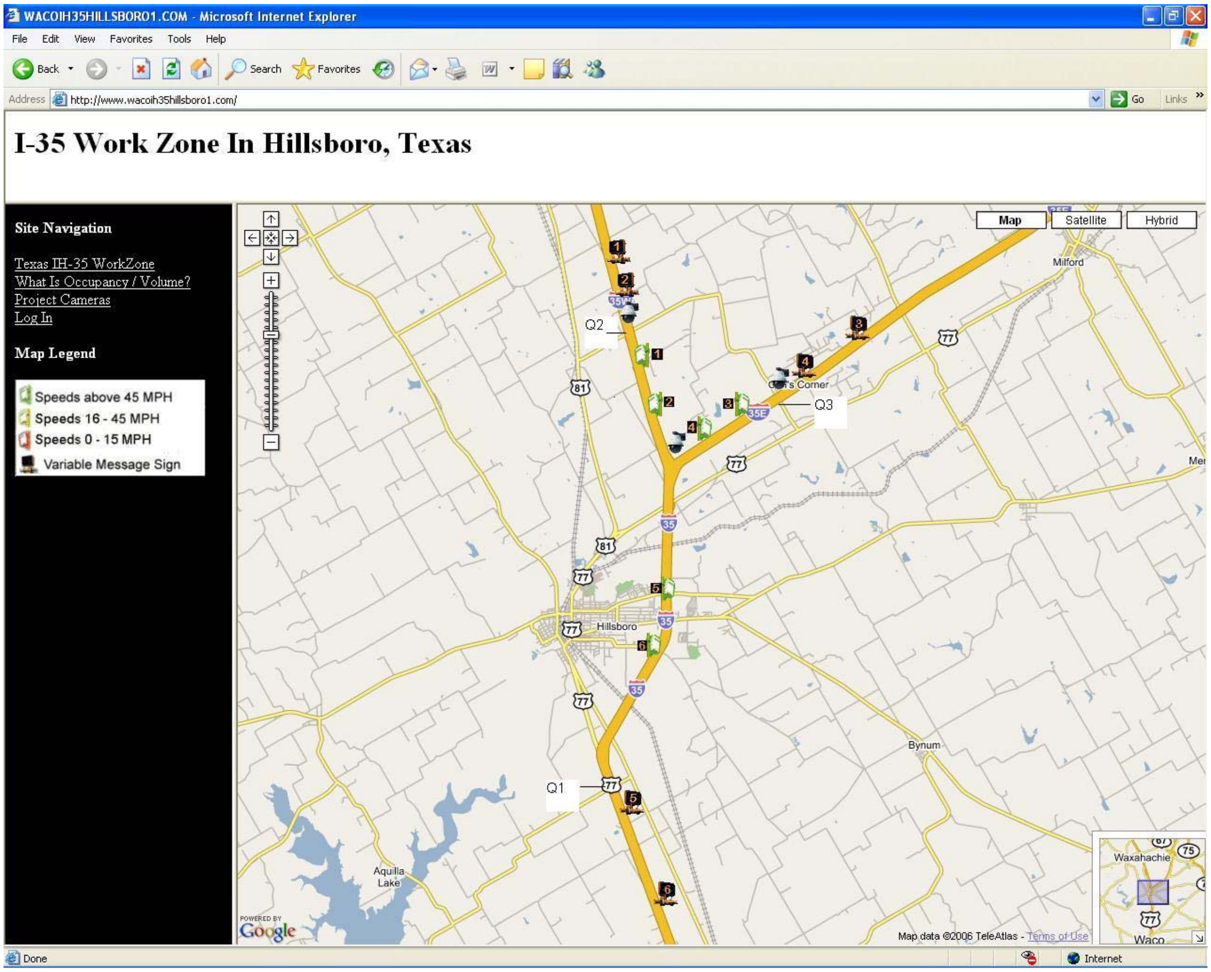

Figure 6. Modified Corridor Map Showing Data Collection Sensor Locations

The success of the evaluation hinged upon the accuracy and completeness of several key data elements, including:

- Traffic volumes and average speed and occupancy measurements at each sensor location.
- Message logs showing the times and dates that the pre-determined messages were activated.
- Time-specific information on construction activities and delay observations as noted by inspectors in DOT construction logs.

The study team developed several hypotheses based on the goals for the system. The key hypothesis, associated measures, and data sources for testing each are shown in the following table.

Table 6. Key Hypothesis, Measures, and Data Sources for Evaluation

Hypothesis	Measures of Effectiveness	Data Sources
The use of ITS in work zones will divert travelers to alternate routes during times of work zone congestion	Diversion rates at exit ramps with and without the system and with construction; diversion rates during construction or an incident compared with normal patterns	System detector data, supplemental data from three additional queue detectors

Findings

The study team mainly focused data collection efforts on testing the level of diversion around the work zone during periods of congestion. The site showed that, during times of very heavy congestion, motorists will follow the diversion guidance posted on message boards. Large percentages of traffic diverted on several occasions when the system recommended the alternate route.

For this site, the study team designed the data collection plan to help answer several key questions including:

Question: Did the system detect the congestion as it occurred?

Findings: It appears that the system detected congestion and displayed appropriate messages, although the minimum diversion message post time was likely too short in some cases.

Question: Did the system post appropriate messages when it detected congestion?

Findings: The system posted travel times for conditions at or near free flow travel times, "Slow Traffic Ahead" and similar messages when speeds dropped, and diversion messages when occupancy met the appropriate threshold.

Question: Did motorists respond to the diversion messages—and how?

Findings: When the system posted messages recommending the signed alternate routes, large percentages of traffic diverted. Major incidents during heavy traffic periods (such as holiday weekends) were a main cause for active diversion, more so than typical construction activity and lane closures. During major incidents or high construction impact periods combined with high demand, the system diverted an average of 10 percent of mainline traffic to alternate routes. Diversion was as high as 28 percent during the study observation period.

The key hypothesis was found to be true for this deployment based on observations. The system diverted large amounts of traffic during incident and construction impact periods compared with normal conditions.

The following sections provide additional detail from the analysis.

Construction Activity Information

TXDOT provided construction activity information from inspector logs and from a template provided by the study team. The study team matched the information provided with the data patterns and trends from the data collection period. Tables 7 and 8 highlight the initial information provided by TXDOT.

Table 7. Construction and Lane Closure Information (October 2006)

Date	Time of Day (Beginning)	Time of Day (End)	Crashes Observed	Mile Marker Location/ Description	Activity Notes
10/3/2006	8:30 AM	9:00 AM	Yes	35W SB mm1	Three separate crashes – lanes open
10/3/2006	9:00 AM	9:40 AM	Yes	I-35 SB mm 370	Two vehicle crash – lanes open
10/3/2006	8:15 AM	8:45 AM	Yes	I-35 SB mm 369	One vehicle crash – lanes open
10/12/2006	6:30 PM	1:30 AM	--	I-35 SB at exit 368B	Inside lane closed for construction

Table 8. Construction and Lane Closure Information (November-December 2006)

Date	Time of Day (Beginning)	Time of Day (End)	Crashes Observed	Mile Marker Location/ Description	Activity Notes
11/14/2006	9:00 AM	9:45 AM	Yes	I-35 NB mm368	One vehicle involved
11/20/2006	7:00 PM	10:00 PM	--	I-35 SB mm368B to 370	Lane closed for pothole repair
12/13/2006	4:30 AM	11:15 AM	Yes	35E SB mm372	Lane closed due to crash and barrier rail repair
12/13/2006	4:00 AM	5:00 AM	--	35W SB mm2 to mm5	Lane closed for crack seal work
12/13/2006	7:00 PM	10:00 PM	--	35W NB	Lane closed for construction activities
12/14/2006	3:15 PM	3:50 PM	Yes	35W NB at split	Two vehicle crash – lanes open
12/14/2006	3:30 PM	4:00 PM	Yes	I-35 NB US77 Exit Ramp	Three vehicle crash – lanes open

The study team noted any days where the detectors captured traffic impact periods (any condition other than free flow) but field condition information was not available. TXDOT reviewed its logs and incident database and provided additional information as available. Information was not available for several time periods where traffic data showed delays and queuing.

Several significant incidents and crashes occurred November 23-26, 2006, over the heavily-traveled Thanksgiving Holiday weekend. The traffic data showed significant delay and queuing and heavier than normal volumes. During this time period, the system activated several times to divert traffic. Since the work zone was not active with lane closures and construction activity over the holiday weekend and observations by inspectors were not captured, the study team does not have many of the specific details on the extent of the traffic impacts from the crashes. However, as shown in the following sections, several data points were useful in the analysis.

System Detector Traffic Data

The study team sorted and analyzed traffic data from system detectors and the supplemental data collection detectors to quantify the impacts from construction and to identify periods of impact where additional information would be useful. The archived traffic data from each detector consisted of more than 500,000 records covering a time period from October 2006 through February 2007. Each message consisted of a volume count, an average speed value, and an average occupancy value by lane for both lanes in each direction along I-35, I-35E, and I-35W. The data set for each sensor appeared to be very complete and the data appeared reasonable.

The study team observed one incident during construction and prior to system deployment. A lane closure was in place on October 12 and 13, 2006, on northbound I-35. Figure 7 highlights consistent volume patterns for this baseline time period. The green line (ramp counts) shows no distinct spike in volume based on the conditions. While the study team only had limited observations to analyze during the "without ITS" period, one can logically conclude that motorists (especially through trips) would not be comfortable diverting to an unfamiliar roadway without knowledge of the impact to their trip.

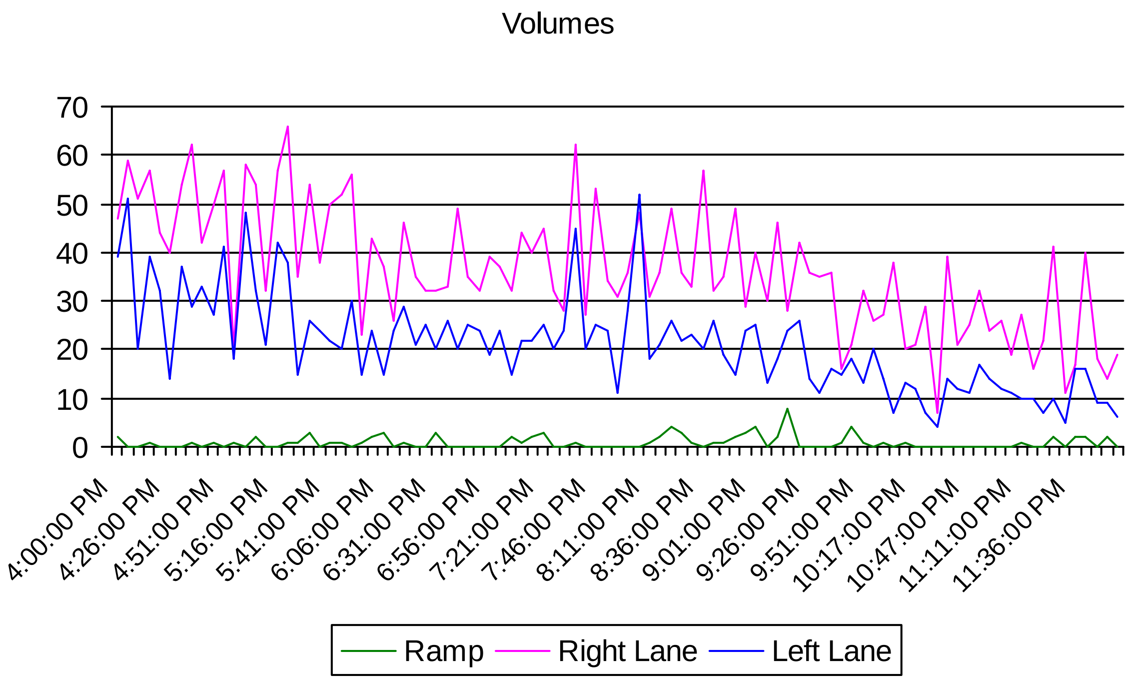

Figure 7. Volume Patterns (Q3: 35E SB) – October 12 Lane Closure (Without ITS)

Figure 8 shows high occupancy values at the system detector location within the work zone between 9 p.m. and 11 p.m. These values showed enough impact to warrant diversion (50 percent occupancy) of traffic during this time period. However, a large percentage of traffic did not divert to the signed alternate routes.

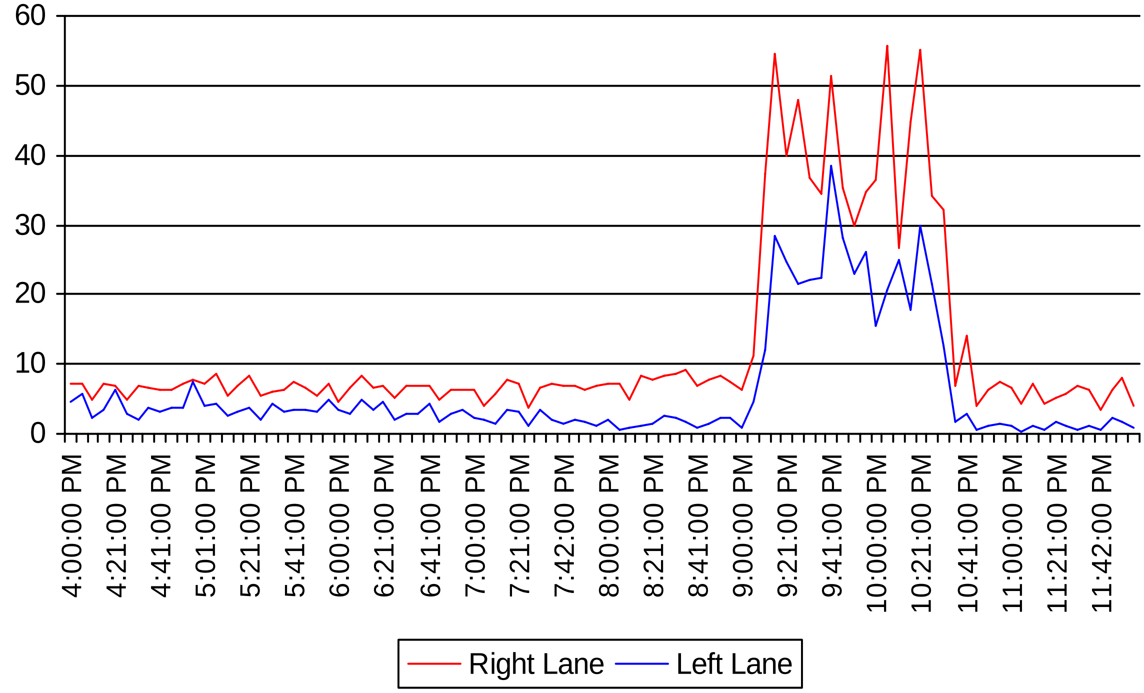

Figure 8. Occupancy Values (System Q4: 35E SB) – October 12 Lane Closure (Without ITS)

The study team also analyzed traffic data during construction and with ITS, mainly focusing on days where the system actively diverted traffic. For a major crash on November 26, 2006, involving a tractor trailer, the data showed higher than normal ramp volumes during a nearly 5 hour period where the system actively diverted traffic. Figure 9 shows high occupancy values detected by the system. The incident likely included traffic shifts and lane closures, but validation based on specific information proved difficult due to the limited availability of such information.

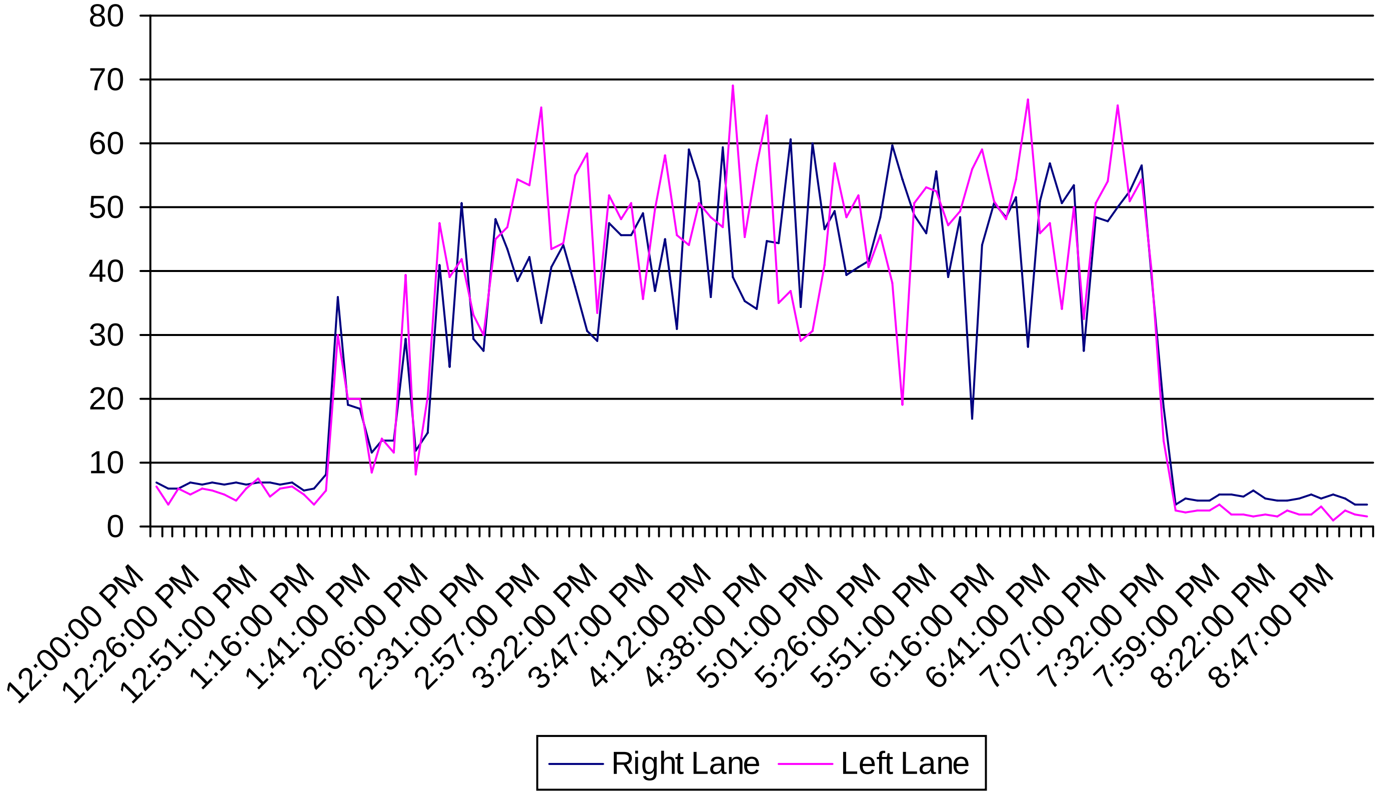

Figure 9. Occupancy Values (System Q1: I-35 NB) – November 26 Incident (With ITS)

Figure 10 shows trends in ramp volumes during the same period on November 26, 2006. The general trend shows that motorists used the guidance provided by the system and diverted around the impact area.

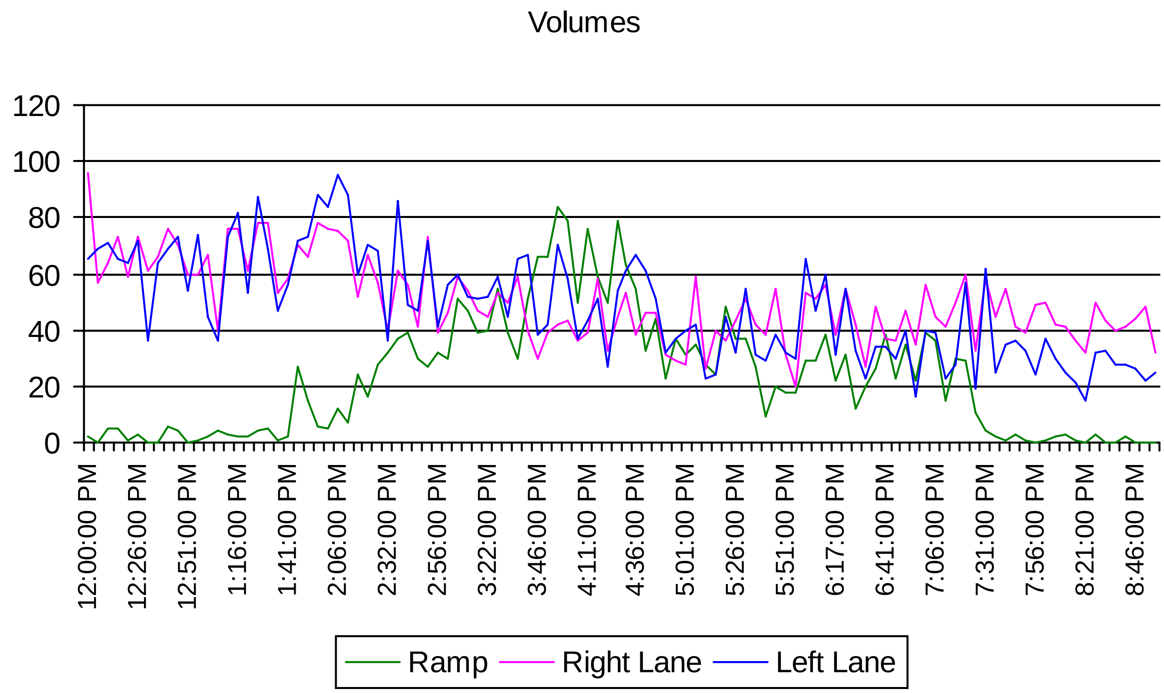

Figure 10. Volumes (Q2: I-35 NB) – November 26 Incident (With ITS)

The study team also analyzed actual diversion levels based on the percentage of traffic using the ramp at each diversion point compared with similar days during the same month. The following table highlights the percentage of traffic that diverted for another incident that occurred on November 23, 2006. While the total volumes varied, the percentage of total volume using the ramp changed significantly when the system advised motorists to divert.

Table 9. Diversion Rates for November 23rd Incident Compared with Other Thursdays in November

Date	Detector	Volumes		Percent Diversion	Number of Records	Active Diversion Time Period
		Ramp	Total			
11/9/2006	q01	70	1479	4.7%	68	From 10:10 AM to 11:51 AM
	q02	35	1409	2.5%	100	From 10:23 AM to 12:43 PM
	q03	14	1423	1.0%	96	From 10:20 AM to 11:57 AM
11/16/2006	q01	113	2090	5.4%	98	From 10:10 AM to 11:51 AM
	q02	61	1926	3.2%	137	From 10:23 AM to 12:43 PM
	q03	15	1305	1.1%	86	From 10:20 AM to 11:57 AM
11/23/2006	q01	985	3596	27.4%	97	From 10:10 AM to 11:51 AM
	q02	934	3356	27.8%	136	From 10:23 AM to 12:43 PM
	q03	383	3354	11.4%	96	From 10:20 AM to 11:57 AM
11/30/2006	q01	77	1328	5.8%	96	From 10:10 AM to 11:51 AM
	q02	72	1463	4.9%	144	From 10:23 AM to 12:43 PM
	q03	17	1138	1.5%	103	From 10:20 AM to 11:57 AM

The Thanksgiving weekend incident showed a similar pattern, as outlined in Table 10. Similarly, the total mainline traffic volume was significantly higher, but the diversion rates as a percentage of total mainline traffic were also significantly higher. A 27 percent difference in ramp to total traffic occurred compared with other similar days of the week as a result of the alternate route guidance displayed.

Table 10. Diversion Rates for November 26th Incident Compared with Other Sundays in November

Date	Detector	Volumes		Percent Divert	Number of records	Time Period
		Ramp	Total			
11/5/2006	q01	23	558	4.1%	13	From 5:59 PM to 6:12 PM
	q02	68	5735	1.2%	294	From 2:13 PM to 7:32 PM
	q03	16	3659	0.4%	157	From 4:12 PM to 6:46 PM
11/12/2006	q01	15	514	2.9%	13	From 5:59 PM to 6:12 PM
	q02	75	5851	1.3%	295	From 2:13 PM to 7:32 PM
	q03	28	3854	0.7%	157	From 4:12 PM to 6:46 PM
11/19/2006	q01	17	451	3.8%	12	From 5:59 PM to 6:12 PM
	q02	74	5467	1.4%	298	From 2:13 PM to 7:32 PM
	q03	32	3301	1.0%	158	From 4:12 PM to 6:46 PM
11/26/2006	q01	35	482	7.3%	11	From 5:59 PM to 6:12 PM
	q02	2332	8084	28.8%	314	From 2:13 PM to 7:32 PM
	q03	966	5549	17.4%	166	From 4:12 PM to 6:46 PM

Overall, the study team found 1 to 28 percent reduction in mainline traffic volume (with an average of 10 percent reduction) during congested periods, lessening the demand for restricted mainline capacity. These results are based on 20 observation periods during which the system actively diverted traffic due to congestion from construction or incidents.

No data collection activities occurred on the alternate routes, making it difficult to determine the operational performance of the two- and four-lane alternates during diversion periods. Additionally, due to the limited number of system detectors (two in each direction), the study team was not able to draw meaningful conclusions about how well the diversion rates improved mainline conditions and travel times.

Dynamic Message Sign Data

The system archived message logs from October 2006 until February 2007. The archives included more than 650,000 records. The study team observed some small quantities of missing or anomalous information.

Throughout the deployment, the system posted variations of different messages at different times. On occasion, the system posted a message recommending an alternate route for very short periods followed by a different message. For each approach, the system was consistent in posting a general message on the upstream message board and a more specific message, such as recommending the alternate route, downstream.

The system used several preprogrammed messages, and operators had the ability to override the system and post messages manually as needed. Variations of the following messages were posted at different times throughout the deployment.

Messages Showing Delay

- WORKZONE AHEAD 2 MILES MODERATE DELAYS.
- WORKZONE AHEAD 2 MILES EXPECT DELAYS.
- SLOW TRAFFIC AHEAD MODERATE DELAYS.
- SLOW TRAFFIC AHEAD EXPECT DELAYS.
- ROAD WORK AHEAD 2 MILES MODERATE DELAYS.
- ROAD WORK AHEAD 2 MILES LONG DELAYS.
- ROAD WORK AHEAD 2 MILES EXPECT DELAYS.

Messages Showing No Delay

- WORKZONE AHEAD 2 MILES NO DELAYS.
- TRAVEL TIME X MIN NEXT X MILES.
- ROAD WORK AHEAD 2 MILES NO DELAYS.

Messages Encouraging Diversion

- TRAFFIC STOPPED AHEAD USE ALT IH35 ROUTE.
- TRAFFIC STOPPED AHEAD ALT RTE EXIT 364A.
- ROAD WORK TRAFFIC STOPPED USE ALT ROUTE.

- ALT IH35 EXIT NOW 3 FOLLOW ROUTE MARKERS.
- ALT IH35 EXIT NOW 364A FOLLOW ROUTE MARKERS.
- ALT IH35 EXIT NOW 374 FOLLOW ROUTE MARKERS.

Messages Showing General Traffic Conditions

- SPEED AHEAD X MPH X MIN NEXT X MILES.
- SPEED AHEAD X MPH REDUCE YOUR SPEED.
- SPEED AHEAD X MPH REDUCE SPEED NOW.
- SLOW TRAFFIC AHEAD BE PREPARED TO STOP.

Other Messages

- SLOW ICE WARNING.
- DRIVE SAFELY.

Overall, the system posted consistent messages and, based on the archived data, appeared to function properly. The system provided a benefit to travelers during periods of mainline congestion by providing alternate route recommendations and reducing demand for the mainline freeway.

Tips and Lessons Learned

Deployment Tips and Lessons Learned

The study team uncovered several lessons learned to the benefit of TXDOT and others interested in deploying similar systems.

Begin work on the deployment at the early concept stages of the planning process. The deployment at this site was delayed due to lead time in procuring the system. To achieve the maximum benefit, ITS should be operational prior to any lane restrictions.

In design and implementation of ITS for work zone applications, agencies should involve the construction contractor as early as possible and to the fullest extent possible. TXDOT experienced unanticipated delays in modifying the contract to include the ITS system. Agencies risk not achieving their goals if the system is viewed as a "pass through" to a vendor and not the responsibility of the contractor.

Personnel from the implementing agency should have real-time access to archived system data to identify any issues and monitor system functionality. For the TXDOT site, a Web site provided real-time information display, but archived data access was more time consuming and not easily accessed on short notice.

Evaluation and Research Tips and Lessons Learned

Prioritize and focus on a small number of metrics that provide the best opportunity to quantify benefits. Diversion patterns at this site proved very useful in assessing the response to diversion-based messages.

US-131 Kalamazoo, Michigan

In the summer of 2004, the Michigan Department of Transportation (MDOT) deployed ITS technology in a work zone on US-131 in Kalamazoo. MDOT deployed the Dynamic Lane Merge (DLM) System in the northbound direction of US-131 just south of the M-43 freeway. Such systems are deployed to control traffic at merge areas by promoting early merge (smoothing flow by creating a no passing zone upstream of the closure) or late merge (encouraging motorists to use both lanes to minimize queue spillover). Dynamic Early Merge Systems, such as the one deployed at this site, smooth traffic flow at merge areas by activating an enforceable no passing zone upstream of the taper. MDOT has successfully used this type of system on multiple occasions in the past to mitigate impacts caused by work zone capacity reductions. The study team collected data during a two-week period in September 2004 to evaluate the benefits of the system.

The main objectives of the system deployment were to:

- Reduce aggressive driving at the merge point where two lanes were reduced to one in each direction.
- Smooth traffic flow through the merge area.
- Potentially reduce delay from aggressive passing at the merge area.

The main objectives of the evaluation were to:

- Quantify ITS impacts on aggressive driving.
- Quantify safety and mobility impacts.
- Verify that the work zone ITS functioned as designed.

For an early merge DLM system, MDOT previously identified an effectiveness range (demand that warrants use of the system) of 2,000 to 3,000 vehicles per hour for two-to-one lane drop configurations. The effectiveness range exceeds capacity since queue conditions cause aggressive maneuvers and forced merges. While these numbers exceed the capacity of one lane on a freeway, the effectiveness range includes the level of demand that is needed to improve conditions over what would have been observed without the early merge system. As shown in the following figure, a sample set of past peak hour volume counts for I-131 fell within this range.

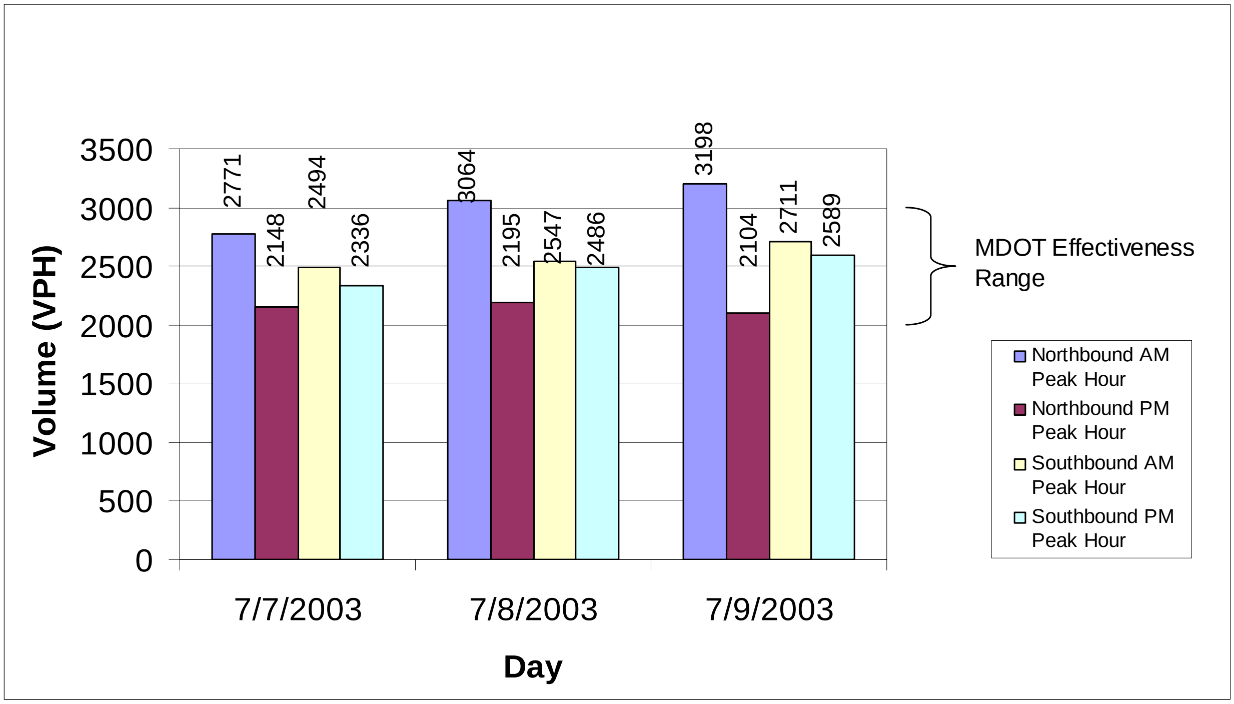

Figure 11. 2003 Peak Hour Volume Counts on US-131

The system deployment schedule mirrored the construction schedule, leaving little opportunity for establishment of baseline conditions (the "without ITS" scenario). Since demand levels were similar in both directions, the study team had planned to analyze the southbound approach to the merge area as the "without ITS" condition and the northbound approach as the "with ITS" condition. While this approach was not exactly the same as a true before and after study, it was designed to try to provide a reasonable comparison of a traditional merge setup with a dynamic merge setup. From the past volume data, the northbound and southbound afternoon peak period showed the most similar demand levels. The study team collected data for each afternoon peak period.

Study Site Work Zone

US-131 is a four lane divided freeway with a normal speed limit of 70 mph that connects Kalamazoo and Grand Rapids, Michigan. The contractor set up the work zone along US-131 from north of M-43 (exit number 38) to north of M-89 (exit number 49) in the cities of Kalamazoo and Plainwell. MDOT reduced the speed limit through the work zone from 70 mph to 60 mph. The northbound Annual Average Daily Traffic (AADT) is approximately 29,000 and the southbound AADT is approximately 23,000. MDOT deployed the system in the northbound direction, although demand levels in both directions fell within the range for implementation based on the 2003 traffic counts. The work zone was approximately 11 miles in length from beginning sign to end sign. The DLM system was deployed in the approximately one mile section of roadway leading up to the merge point just south of the lane closure.

The contractor commenced construction on June 3, 2004, and finished on November 19, 2004. The construction involved pavement rehabilitation and included concrete and asphalt overlays. The contractor performed the first and second phases on the northbound and southbound sides of the highway, respectively. During the first phase, the contractor shifted traffic and set up two-way traffic (one lane in each direction) on the northbound side. The contractor used the same traffic control configuration for Phase II, but this time transferred all traffic to the southbound side (two way traffic, one lane in each direction). Concrete barriers separated traffic during each phase.

ITS Description

MDOT designed the DLM System to require traffic to merge early to smooth traffic flow and reduce aggressive driving at the merge point. MDOT installed five trailers 1500 feet apart prior to the merge point, each equipped with lighted "Left Lane Do Not Pass When Flashing" signs. The trailer closest to the merge was always flashing. MDOT equipped each trailer with a Remote Traffic Microwave Sensor (RTMS) unit, with the exception of the trailer furthest from the work zone. MDOT procured the system through a vendor subcontract through the prime construction contract.

The closed loop system operated based on traffic occupancy. For example, when sensor #1 detected the threshold occupancy, sensor #1 sent a message to sensor #2 alerting it to activate the flashing lights. The occupancy thresholds for sensors 1, 2, 3, and 4 were 5 percent, 7 percent, 9 percent, and 11 percent, respectively. Each sensor had a 5-minute minimum activation period.

The Dynamic Lane Merge System was comprised of the following components:

- 4 sets of traffic sensors.
- 5 trailers with a flasher, solar power equipment and batteries.
- Message signs.
- Communication devices.

The layout for the system is shown in the following figure.

Figure 12. DLM Layout Along Northbound US-131

Measures and Metrics

The study team developed a set of hypotheses and associated measures of effectiveness (MOEs) around the key goals for the system, as shown in Table 11.

Table 11. Measures and Metrics for the Michigan DLM deployment

Hypothesis	Measures of Effectiveness	Data sources
The use of ITS in work zones will enhance the safety performance of the highway	Crashes, incidents, aggressive maneuvers, citations issued	Crash data, direct observations, citation logs
The use of ITS in work zones will reduce traveler delay	Travel times through the merge area, average speeds, and average and maximum queue lengths	Direct observations, system data, travel time runs

While the study team originally intended to use the southbound side (without ITS) as the comparison site, congestion was not an issue on the southbound side, which meant that it would not be a good comparison. Therefore, the study team compared the time periods when the system was flashing (i.e. activated) with the time periods when the system was not flashing (i.e., not activated—trailers upstream of trailer 1 were not flashing), all for the northbound direction of travel instead of comparing northbound to southbound.

The study team collected data for a 2-week period from September 20 through October 1, 2004. During this period, study team members performed travel time runs, using Global Positioning System (GPS)-equipped vehicles, in each direction from 3:30 p.m. until

6 p.m. each weekday. The study team also collected traffic count data along two mainline areas and seven ramp areas to determine demand at different locations with the merge areas. A modem was installed on one trailer and MDOT archived sensor data for August, September, and October for use in the evaluation.

Findings

Hypothesis 1: The Use of ITS in Work Zones Will Enhance the Safety Performance of the Highway

Since one of the main deployment objectives was to reduce aggressive maneuvers, the study team collected data on several different types of aggressive driving behavior for analysis. During each travel time run, a passenger in each vehicle observed driver behavior within both the northbound and southbound merge areas. Notes were recorded based on the following categories.

- Lane straddling by tractor-trailers or other vehicles to block vehicle passing.
- Motorists illegally passing in the northbound US-131 passing lane when the dynamic lane merge signs are flashing "Do Not Pass."
- Dangerous merges, or forced early merges (people slamming brakes to merge, forcing vehicle into other traffic lane, people responding to flashing "Do Not Pass" signs improperly, etc.)
- Forced merges at/near the lane drop.

Study team members also noted observations that describe the environment at each of six specified areas shown in Figure 13. The study team observed conditions to:

- Document which of the five dynamic merge signs were flashing in the northbound travel direction during each pass through the area
- Document an enforcement presence or lack thereof for each run along with any incidents that may have affected the traffic flow during the travel time run (crash, construction vehicles, stalled vehicle, etc.).

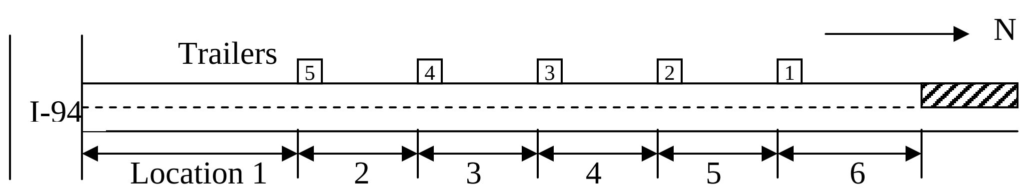

Figure 13. DLM System Setup

Tables 12 and 13 show the aggregate daily observations within each area for the two-week period. The information in the tables classifies the aggressive maneuvers into separate categories based on type, and also shows whether the study team observed the system flashing (at least one trailer except the first since it was always flashing) and whether police were present. Study team members noted only one instance of queuing in the southbound direction and there were no forced merges observed at the lane drop. While conducting the travel time runs, the study team made observations as noted in the tables for metrics such as whether the system was activated; whether lane straddling, illegal passing maneuvers, or dangerous merge maneuvers occurred; whether police officers were present; whether there were incidents; whether there were forced merges; and whether queues were present.

Table 12. Aggregate Aggressive Driving Observation Classifications by Date (Northbound)

Date	# of Runs	On Flash?	Lane Straddling	Illegal Passing	Dangerous Merge	Police	Incident	Forced Merge	Queue
09-20-04	15	0	0	28	8	0	2	4	0
09-21-04	12	0	0	22	3	0	1	2	0
09-22-04	13	0	0	25	1	4	3	2	1
09-23-04	13	0	0	39	4	0	0	1	0
09-24-04	13	52	16	70	5	0	0	0	16
09-27-04	12	0	0	26	0	3	8	0	1
09-28-04	13	0	1	27	2	0	0	2	0
09-29-04	13	0	0	39	0	0	0	5	0
09-30-04	13	0	0	30	1	0	0	0	0
10-01-04	13	18	2	58	1	0	0	2	2
Total	130	70	19	364	25	7	14	18	20

Table 13. Aggregate Aggressive Driving Observation Classifications by Date (Southbound)

Date	# of Runs	Lane Straddling	Illegal Passing	Dangerous Merge	Police	Incident	Forced Merge	Queue
9-20-04	12	0	0	5	0	0	0	0
9-21-04	13	0	0	20	0	0	0	0
9-22-04	12	0	0	18	0	0	0	0
9-23-04	11	0	0	12	1	0	0	0
9-24-04	12	0	0	15	0	0	0	0
9-27-04	12	0	0	19	0	0	0	0
9-28-04	12	0	0	26	1	0	0	0
9-29-04	12	0	0	15	0	0	0	0
9-30-04	12	0	0	22	0	0	0	0
10-1-04	10	0	0	22	3	0	0	1
Total	118	0	0	174	5	0	0	1

Figure 14 highlights the significant differences in observed dangerous merge maneuvers for similar time periods at both approaches to the work zone. Since the probe vehicles were moving during data collection, an accurate exposure value or dangerous merge rate was unknown. While the southbound direction did not experience oversaturated conditions making quantitative comparisons difficult, the study team generally noted much higher total daily dangerous merge observations even with lower volumes in the southbound direction. The percentage of higher northbound traffic is also shown to highlight the fact that, even though traffic was lower in the southbound direction, more forced merges occurred.

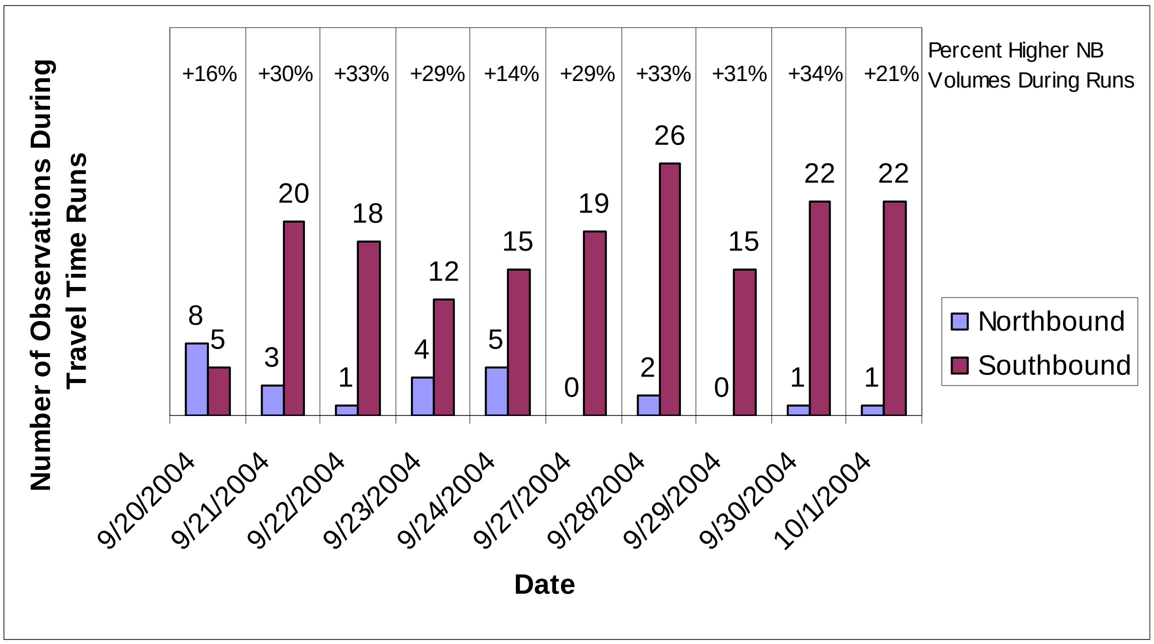

Figure 14. Dangerous Merge Maneuvers by Approach

On the northbound approach, several days included traffic conditions that were sufficient enough to activate the DLM "Do Not Pass" flashers. Other days included lighter traffic (the flashers remained off). The study team compared traffic changes on the northbound approach when the flashers were on and off. This approach has the advantage of comparing the traffic and run conditions that existed on the northbound, but it does not constitute a true "without ITS" condition because the flashers on the trailer closer to the taper were always flashing. The flashers on Trailers 2, 3, 4, and 5, which cover locations 5, 4, 3, and 2, respectively, were on 2 out of the 10 days during data collection. Also, the study team noted police presence 2 of the 8 days the flashers were off. The study team excluded data from the days where police were present to avoid issues with traffic behavior and pattern changes due to police presence.

The 2 days that the flashers were on were compared with the 6 remaining days that the flashers were off (see Table 14). Comparisons were made on a "per-run" basis, addressing the issue of unequal number of runs between the two groups.

Table 14. Statistics for 2 Days Flashers Were On and 6 Days They Were Off

System Status	# of runs	Lane Straddling	Dangerous Merges	Forced Merges	Queue
Trailer Flashes Off	79	1 (0.01/run)	18 (0.23/run)	14 (0.18/run)	0
Trailer Flashes On	26	18 (0.69/run)	6 (0.23/run)	2 (0.08/run)	18

The results of the comparisons show that there was a significant reduction in the number of forced merges when flashers were on, potentially reducing the risk of collisions near the merge taper. Queues were present on the days the flashers were on, indicating that vehicles likely merged in advance of the taper to avoid forced merges at Location 6. Lane straddling was significantly higher on the days that the flashers were on, indicating that some larger vehicles, including trucks, wanted to discourage illegal passing when the flashers were on. As shown in the table, the number of dangerous merges and forced merges were affected by the flashers.

Traffic citation information and crash data were also analyzed for both work zone approach areas. From July 1, 2004 through October 31, 2004, there were 67 warnings and 135 citations issued for violations of the northbound no passing zone. From June 15, 2004, through October 31, 2004, there were 23 crashes at the northbound work zone approach.

From June 1, 2004, through November 30, 2004, law enforcement officers documented 14 crashes at the southbound work zone approach. The time period for this data collection was longer due to additional activity at the north end of the construction area. Sorting data to a less aggregated level would have posed a burden on Sheriff’s Office representatives. Therefore, no further analysis was performed.

Based on the effect of “Do Not Pass” flashers in the work zone, the study team concluded that the DLM system enhanced safety by reducing the number of forced merges at the lane drop, thus the hypothesis, “The use of ITS enhanced the safety performance of the highway during construction,” is valid. The study team was unable to use crash and citation statistics to further prove the hypothesis.

Hypothesis 2: The Use of ITS in Work Zones Will Reduce Traveler Delay

MDOT also anticipated positive impacts to traveler delay through use of the system. Changes in travel times, average speeds, and queue lengths were the main data sources sought in the evaluation. The system detectors collected volume, speed, and occupancy data in two to three minute time increments. The probe vehicles recorded second by second speed data while traversing the corridor. The study team designed the data collection plans to use the system detector data to estimate average and maximum queue lengths.

The study team compared travel time data for the northbound and southbound directions to determine traveler delay, and analyzed travel time data for the 6 days that the flashers were off compared to travel times on the southbound approach. The data indicate that the travel times were significantly different even though the traffic volumes were similar.

This result indicates that there were factors other than ITS that influenced the travel times in the northbound and/or southbound directions. The differences in road and traffic characteristics on northbound and southbound, as well as the length of the probe vehicle run necessary to traverse the corridor in each direction, may have affected the travel times.

Therefore, the study team used the same approach used in Hypothesis 1 to compare travel times on the northbound approach. The study team compared travel time data for 2 days when "Do Not Pass" lights were flashing with data from the 6 days when the lights were not flashing. A t-test showed no significant volume count difference between the two groups (Pvalue = 0.55).

The study team found that the travel time when lights were flashing was significantly higher than when lights were not flashing (Pvalue < 0.001). This increase in travel time (nearly doubled at times from a baseline travel time of 4 to 5 minutes) is expected when drivers obey the "Do Not Pass" sign as vehicles potentially reduce speed and merge at locations further away from the taper, forming an organized queue of vehicles with smoother flow through the bottleneck. Vehicles lining up in the open lane earlier than without the flashers increased the distance drivers traveled on the single lane, thus increasing the lane density and reducing the speed. Lining up vehicles in the open lane, even though slightly increasing the travel time, is a more sound traffic management technique than allowing traffic flow breakdown due to forced merges or dangerous maneuvers. From these results, the study team deems the second hypothesis, "The use of ITS in work zones will reduce traveler delay," inconclusive. The DLM system, such as was used in Michigan, may help reduce traveler delay when traffic is high enough to warrant additional activation time.

Analysis of RTMS Sensor Data

As mentioned previously, the system archived RTMS data at the second, third, fourth, and fifth trailers. Traffic demand levels through several of the locations are the same because no ramps are present. Figure 15 shows daily vehicle counts from a representative RTMS sensor and manual detectors on US 131 between Stadium Rd and route M-43.

The study team compared RTMS and tube count data for 9 of the 10 days during data collection. Data from September the 28, 2004, was discarded because of missing data. A paired t-test showed that average RTMS daily counts were 10 percent higher than daily northbound tube counts (Pvalue = 0.01). The study team is not able to draw additional conclusions from the data other than lessons learned and actions that may enhance the quality of data archived.

MDOT effectively deployed the DLM system on I-94 and, due in part to effective enforcement (a qualitative MDOT observation), realized benefits from use of the system. As noted from the reduction in aggressive maneuvers, the system positively impacted driver behavior and smoothed traffic flow at the work zone taper. One of the two hypotheses was proven valid during this evaluation.

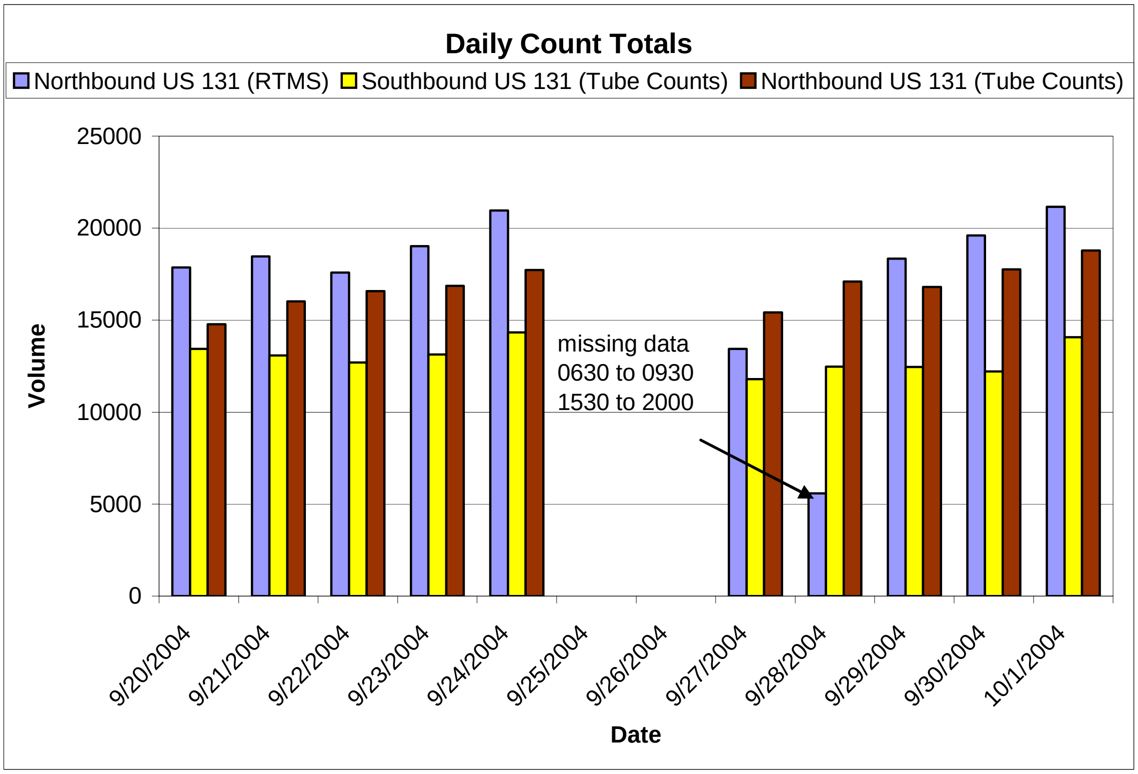

Figure 15. Daily Traffic Counts by Approach and Detection System

Tips and Lessons Learned

Deployment Tips and Lessons Learned

Educating the police enforcement community about the system when it is first deployed is extremely beneficial MDOT held meetings with the local police agencies to ensure adequate understanding of the system, thereby maximizing the benefits of enforcement**.** Police presence is an important aspect of this type of deployment, as motorists may be less likely to violate the no passing zone when police are present.

Implementing agencies should use the media to the fullest extent possible to help educate the public on the deployment. In Michigan, the DOT often invites the media to the job site to learn about the system, why it is being used, and how it works. MDOT stated that media representatives were a very important stakeholder in the process of deploying the lane merge system in Kalamazoo.

Evaluation and Research Tips and Lessons Learned

The reliability of the archived data collected was lower than expected. During this evaluation, the study team relied on archived data for some of the analysis. The reliability was lower than expected potentially due to some communication interruptions as detectors sent data back to a main computer.

Evaluators should observe field conditions to the fullest extent possible and feasible. This helps to adequately monitor and validate archived data.

I-30 Little Rock to Benton, Arkansas

In 1999, Arkansas decided to undertake the rehabilitation of over 50 percent of their Interstate highway infrastructure. As a result, in 2000 the Arkansas Highway and Transportation Department (AHTD) began rehabilitation and re-construction on more than 350 miles of roadway. The AHTD also looked at tools to help mitigate the potential impacts from construction.

Figure 16. Arkansas I-30 Work Zone Location

Most relevant to the study of ITS in work zones are the three work zones that utilized ITS to improve traffic safety and mobility during the time of construction. Specifically, one of the three Arkansas projects using ITS included the widening of approximately 17 miles of I-30 from Sevier Street in Benton (mile marker 115) to Geyer Springs Road in Little Rock (mile marker 133). A key portion of the work zone is shown in Figure 16. The primary objective for using ITS in this location was to improve the safety of travelers by providing advance warning of slowed traffic or congested downstream conditions.

Study Site Work Zone

Prior to the beginning of construction, this 17-mile section of I-30 had an Annual Average Daily Traffic (AADT) of 63,000 vehicles. In 2001, as documented by the Highway Performance Monitoring System, sections of this stretch of I-30 experienced greater than 20 percent truck traffic. According to personnel at AHTD, there is an average of approximately 40 percent truck traffic during the day, which increases to 75 percent at night. The large volumes of truck traffic created the potential for large work zone impacts due to their size and impact on mobility.

The AHTD administered construction in this area for seven projects including widening the Interstate to six lanes, removing and replacing the concrete roadway, reconstructing nine interchanges, installing a concrete barrier wall in the median, and converting all of the frontage roads to one-way. The seven projects that made up this extensive work zone were as follows:

1. **I-30 from Sevier St. to West of Alcoa Road (from mile mark 115.7 to 119.6) -** This project included widening the roadway to six lanes, removal and replacement of the existing concrete, installation of a concrete barrier wall in the median, and conversion of frontage roads to a one-way direction. Completed: Winter 2004.
2. **I-30 at the Hwy. 5 Crossover –** This project included bridge work at the crossover. Completed: March 2003.
3. **I-30 at the Alcoa Road Interchange (at mile mark 120.7)** - This project included removing and replacing the existing interchange. Completed: Spring 2003.
4. **I-30 west of Alcoa Rd. to west of Pulaski Co. line (from mile mark 119.6 to 125.6)** - This project included concrete reconstruction and widening to six lanes, modification of the Bryant/Reynolds Road interchange, ramp relocations, installation of a concrete barrier wall in the median, and conversion of frontage roads to a one-way direction. Completed: Spring 2005.
5. **I-30 at the Mabelvale West Interchange (at mile mark 128) –** This project included removing and replacing the existing interchange. Completed: Summer 2003.
6. **I-30 from west of the Pulaski Co. line to I-430 (from mile mark 125.6 to 129.7)** - This project included concrete reconstruction and widening to six lanes, modification of the Alexander interchange, ramp relocations, installation of a concrete barrier wall in the median, and conversion of frontage roads to a one-way direction. Completed: Summer 2005.
7. **I-30 between I-430 and Geyer Springs Road (from mile mark 129.7 to 133) –** This project included concrete reconstruction and widening to six lanes, modification of Baseline Road, Mabelvale Pike and University Ave. interchanges, ramp relocations, installation of a concrete barrier wall in the median, and conversion of frontage roads to a one-way direction. Completed: Winter 2005.

ITS Description

To improve the safety of travelers, the AHTD installed an Automated Work Zone Information System (AWIS) covering the entire I-30 Little Rock to Benton work zone corridor. AHTD procured the system from a vendor through the construction contract and leased the system for the duration of its use.

The complete system of monitoring equipment for the I-30 smart work zone included 47 vehicle detector sensors, 4 radio transmitters, 15 dynamic message signs (DMS), and 8 stationary video cameras mounted on trailers in and around the work zone. Figure 17 illustrates the location of the various work zone sensors and message signs. Equipment on Highway 5 and Interstate 430 also served to inform motorists when they were approaching a construction area. After detecting a change in Interstate traffic speeds, the AWIS system evaluated its own accuracy by performing a system check of other sensors. Within approximately 5 minutes, computers determined whether one of nine levels of severity warranted communication with the message boards and radios to report the situation. When the sensor system detected significant delays, flashing beacons on HAR alert signs advised motorists entering the broadcast area that the message was “Urgent When Flashing, Tune To 1490 AM.”

While the roadside message boards and radios required the 5-minute relay time, sensor-recorded traffic speeds transmitted almost instantaneously to the Web site (www.arkansasinterstates.com). Web site visitors were able to see a complete view of traffic conditions throughout the work zone (see Figure 17). Color-coded roadway segments (green, yellow, red) between sensors indicated whether traffic was flowing, slowed, or stopped. Hovering the mouse over any of the equipment icons called up a live video image or displayed the text and audio messages motorists were receiving on the road.

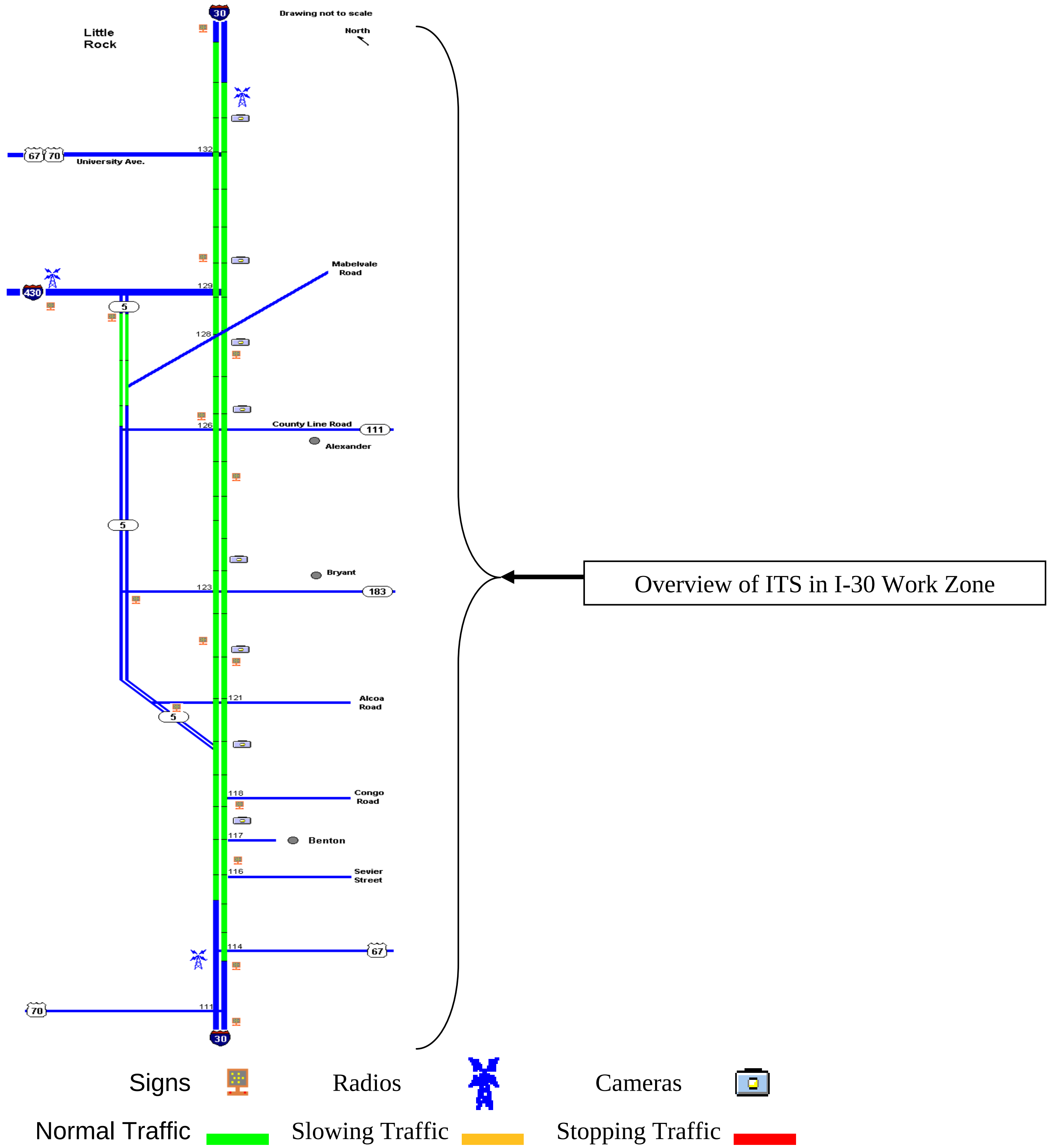

Figure 17. Overview of I-30, Little Rock to Benton, Arkansas Work Zone[1] [2]

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1 Map depicting work zone layout courtesy AHTD.

2 U.S. Geological Survey, from "The National Atlas of the United States of America. General Reference," 2001. Map courtesy of the Perry-Castañeda Library Map Collection at The University of Texas at Austin, <http://www.lib.utexas.edu/maps/us_2001/arkansas_ref_2001.jpg> (August 1, 2005).

Measures and Metrics

The main areas of evaluation for this work zone encompassed the following: safety, user perspectives, mobility, and productivity.

To evaluate these primary areas of interest, the study team developed the following 11 hypotheses:

1. The use of ITS in the work zone will reduce travelers' exposure to hazard.
2. The use of ITS in the work zone will enhance the safety performance of the highway.
3. Travelers will use the work zone ITS.
4. The use of ITS in the work zone will improve trip planning.
5. The use of ITS in the work zone will improve traveler tolerance of work zone delays.
6. The use of ITS in the work zone will improve the confidence of travelers driving in the work zone.
7. The ITS information will be readily understood by users.
8. The use of ITS in the work zone will improve incident response and clearance times.
9. The use of ITS in the work zone will divert travelers to alternate routes during times of work zone congestion.
10. The use of ITS will improve the productivity of contractors and travelers.
11. The ITS will be reliable and accurate.

The study team used the following information sources to assess the hypotheses:

- Private vehicle driver surveys (a copy of the survey is provided in Appendix A).
- Commercial vehicle driver surveys (a copy of the survey is provided in Appendix B).
- State Police personnel interviews.
- Construction manager interviews.
- Traffic counts (using tube data and Remote Traffic Microwave Sensor data).
- System detector data.
- Personal experience from the study team site visits.
- Crash data were reviewed but were not feasible to use for this study, as explained in the relevant hypothesis below.

The study team used the driver surveys to asses 8 of the 11 hypotheses. A description of how the surveys were administered is provided in Appendix C. The survey responses were coded in a database and checked for consistency using statistical analysis software.

A total of 297 commercial vehicle drivers (CVD) and 319 private vehicle drivers (PVD) participated in the surveys. Of these, 286 CVD and 306 PVD surveys were suitable for further analysis. The 24 surveys that were not used were discarded due to incomplete responses pertaining directly to the ITS devices. The following section presents the findings of the analyses pertaining to each hypothesis. Appendix D includes statistical test summaries for each of the survey questions.

Findings

Hypothesis 1: The Use of ITS in The Work Zone Will Reduce Travelers' Exposure To Hazard

The objective of the study team was to study this hypothesis using a combination of data obtained from a review of crash records, and from surveys of police personnel, private drivers, and commercial drivers.

To answer this hypothesis using crash data, the study team contacted the Arkansas State Police (ASP) to obtain crash records for I-30 from two time frames: after the establishment of the work zone but before the ITS and after the establishment of the work zone and with the ITS. The objective of the study team was to determine if there was a statistically significant reduction in the number of crashes from the period *with the work zone and no ITS* to the period *with the work zone and with the ITS* – indicating a decrease in travelers' exposure to hazard. Unfortunately, crash data were only available in the originally recorded hard copy accident data collection forms. Furthermore, in developing an analysis approach based on the crash records, it was determined that the complexity of the work zone phasing and configuration would throw any results into question. Hence, based on the high cost associated with converting and analyzing these data, coupled with the multiple compounding factors noted at this work zone, this means of analysis was infeasible. The following list summarizes the major compounding factors encountered that may have impacted the potential to develop a sound safety analysis:

- Prior to implementing the work zone on I-30 in Arkansas, the frontage/service roads were two-way frontage roads. These would possibly impact any safety analysis, as I-30 exits directly to the frontage road in many instances.

- Following implementation of the work zone but prior to the ITS, the first stage of construction was the rendering of two-way frontage roads into one-way frontage roads. This may have skewed the data because it may have contributed to accidents by confused drivers.

- Following the conversion of the frontage roads, the full work zone was put in place along with the ITS. The layout of the work zone included two lanes of traffic bounded by concrete Jersey barriers with minimal to no shoulders, potentially also impacting the safety performance of the work zones.

- Throughout the frontage road conversion process and the design and re-design of the work zone over the various phases of construction, the on- and off-ramp configurations changed repeatedly. In some instances, a full stop was required before entering the highway; in others, just a yield. In many cases, there was limited roadway length for acceleration.

- The work zone included multiple pavement cuts. In some instances, steel plates covered the pavement cuts resulting in possible safety degradation due to an uneven roadway surface.

- The concrete Jersey barriers did not have adequate drainage. According to AHTD personnel, heavy rains caused water to channel between the barriers and accumulate on the roadways, thus potentially impacting safety during weather events.

Consequently, the study team addressed this hypothesis using the survey responses to questions aimed at gauging whether the drivers felt safer and whether they were better prepared to react to hazards or delays. To determine this, two survey questions about the DMS were asked of the private and CVDs on I-30. See Appendices A and B for the survey questions and the scale for responses used in the survey.

In total, 292 PVDs and 263 CVDs responded to the question “Because of the info on the signs I am better prepared to react to slow or stopped traffic.” The average rating for PVDs was 1.76, and for CVDs was 1.68 (where 1 is completely agree and 2 is somewhat agree). These numbers indicate that with the electronic messages the drivers felt better prepared to react to slower traffic. In fact, 82 percent of the PVDs and CVDs combined (457 drivers) agreed with this statement. A single sample one-tailed t-test with 95 percent confidence showed that the drivers do agree that the electronic message signs better prepared them to react to slow or stopped traffic (see Tables in Appendix D for statistical summaries for each question).

The second question, which asked the driver to indicate whether or not the DMS makes them feel safer in the construction zone, had positive responses, but not at the same level as the first question. The 292 PVDs and 263 CVDs that answered the second question had an average rating of 2.80, which is slightly more agreeable than neutral (neutral equaling 3). The average rating for the PVDs alone was 2.81 and for the CVDs alone was 2.78, which indicates similarity in the two populations. As illustrated in Figure 3, 49 percent (274) of the 564 drivers that used the DMS indicated that the DMS made them feel safer in the construction zone, 17 percent were neutral, 32 percent disagreed, and 2 percent did not answer this question (See Figure 18). A t-test showed that the drivers do agree that the DMS made them feel safer traveling through this construction zone.

These results may indicate that the DMS are indeed reducing driver exposure to hazard by making 82 percent of roadway users feel better prepared to react to slow or stopped traffic. This result should, however, be carefully considered in light of the finding that about half of the respondents (49 percent) actually feel safer as a result of the DMS.

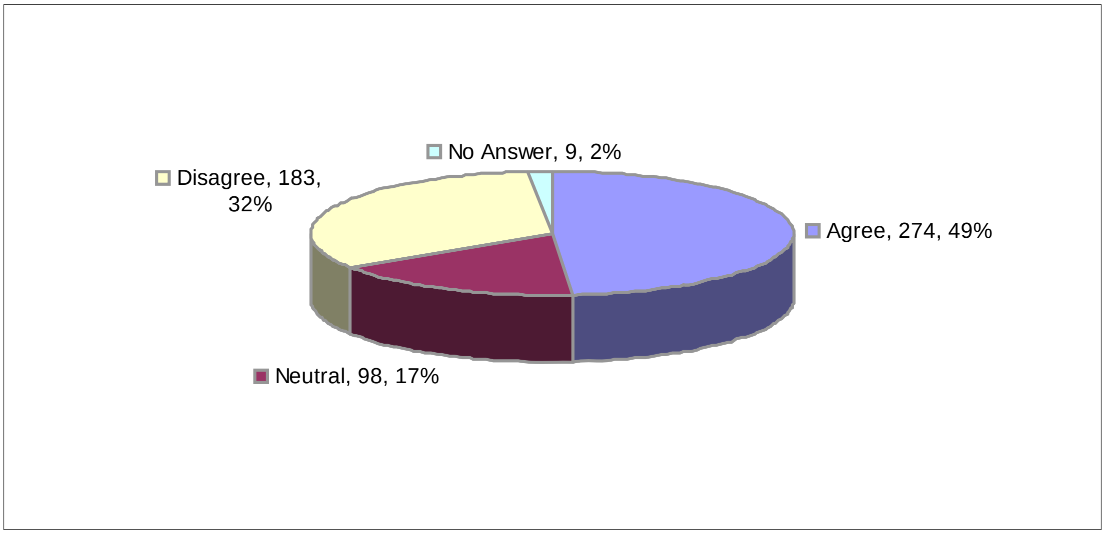

Figure 18. Distribution of Driver's Opinions on the Statement "DMS Makes Drivers Feel Safer in the Construction Zone" (Private & CVDs)

Hypothesis 2: The Use of ITS in the Work Zone Will Enhance the Safety Performance of the Highway

Initially, the study team planned to use crash records to quantify the safety performance of I-30 with and without ITS. However, as indicated in Hypothesis 1, the crash data remained in the originally recorded hard copy accident data collection forms and was not cost effective to collect, organize, and use for this research.

To answer this hypothesis, interviews with State police personnel and construction project management personnel were conducted to determine whether those people most closely tied with the work zone felt that the ITS was improving safety. The following are their responses to the given questions regarding the safety level of the work zone with the ITS.

Interview Conducted with Arkansas State Police Personnel 9/27/04

On September 27, 2004 the Site Coordinator for this project conducted an interview with a Captain in the Arkansas State Police who is familiar with the work site.

1. In your opinion, has the ITS on I-30 improved your incident response capabilities?

- *Yes.*

1a. Explain

- *At times, CCTV (closed circuit television) can be used to view the work zone. Also DMS is a big help in diverting traffic during an incident. It is better than a patrol car.*

1b. Please provide examples:

- *Faster response time - If traffic couldn't be diverted with the DMS, the only way the responding officer could access the incidents on the I-30 work zone was to use the frontage road to get close, then climb over the New Jersey barrier to get to the scene.*

- *Faster clearance time – Since the traffic is already diverted, startup after clearance is quicker.*

Interview Conducted with Project Management Personnel

In June 2004, the study team conducted an interview with the project management personnel in charge of overall activities of the construction project.

1. Do you feel the ITS had an impact on the safety of the construction workers (in the work zone)?
– *Yes.*

2. If so, how?
– *Gives early warning to motorists about lane shifts.*

3. Could you provide examples?
– *They had to shift traffic onto the frontage roads three times in a short period and the message boards helped them control the traffic.*

4. Do you feel that the ITS affected the number of crashes in the work zone?
– *Yes, it helped slow down traffic.*

5. Do you feel that the ITS affected the severity of crashes?
– *Yes, it helped slow down traffic.*

6. Do you think the ITS helped the authorities in their ability to respond to these incidents?
– *No, I do not think the police used the information from the CCTVs.*

From these interviews, it is evident that the people working within the construction zone feel that the ITS has improved the safety of both the workers and the travelers. Some components of ITS, such as CCTV, can be further utilized for incident management in work zones. It is interesting to note that the police directly stated that the CCTV was useful, while the contracting personnel did not believe that the police were using that technology. This may indicate the need for better communication between work zone stakeholders.

Hypothesis 3: Travelers Will Use the Work Zone ITS

This third hypothesis addresses whether or not the travelers on I-30 used the available work zone ITS. For this particular work zone, three primary ITS components helped users determine if they should use I-30 or an alternate route. These were as follows: Arkansas' Pave the Way Web site (www.arkansasinterstates.com), DMS throughout the work zone, and the highway advisory radio (HAR) station. The surveys asked participants if they had used/seen/heard each of the ITS components. The following question was used to obtain ITS usage rates for this section of interstate: "Do you use any of the following sources to get information about traffic conditions on this section of I-30?" Some of these sources, such as CB radio, local radio, and television, were not part of the ITS.

As shown in Figure 19, drivers of both private and commercial vehicles used DMS most often, followed by the sources of information that are not considered ITS, such as television, local radio, and CB radio. A great majority of respondents (~95 percent) used the DMS in the work zone. This is explained by the fact that the signs are on display throughout the work zone and the user does not have to invest any time to locate or use the DMS. Approximately one quarter (24 percent) of the drivers on I-30 have used the HAR, and about half of those drivers felt that the broadcast quality was too poor to hear properly, which could indicate why the usage is so low.

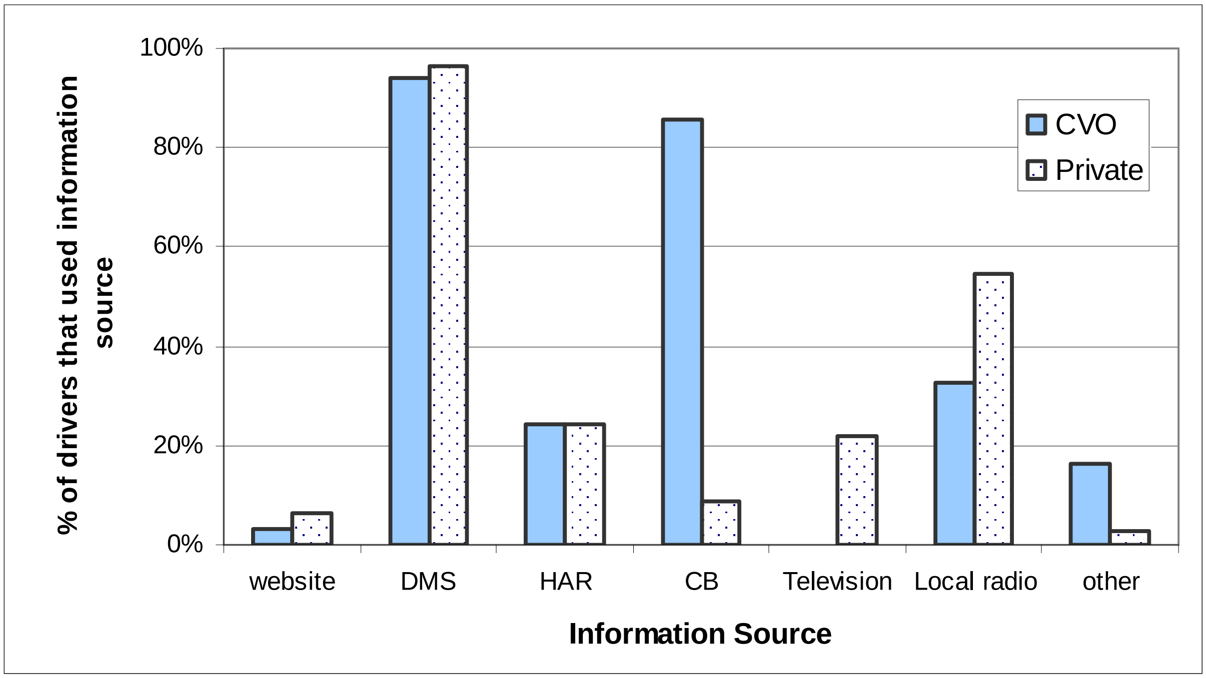

Figure 19. Distribution of Sources Used to Get Information about Traffic Conditions on I-30

Approximately 7 percent of private drivers and 3 percent of CVDs reported that they had used the ITS Web site. Of these people (23 respondents in total), 38 percent had only used the site once (usually out of curiosity). Despite this low usage rate it is interesting to note that of all the people surveyed (592 combined PVDs and CVDs), 24 percent of the drivers (142 respondents) reported that they had heard about the Web site. This indicates that 80 percent of the people that had heard about it had not used it. The most common responses as to why the person did not use the Web site were: they did not care, did not have the time, or were "too lazy."

The study team examined the characteristics of the drivers who visited the Web site. The average age of this group was similar to the average age of the non-Web users (80 percent falling between the ages of 26-55 with the largest single category being those drivers aged between 36 and 45). The study team did not perform additional statistical analysis due to the small number of drivers who visited the Web site.

In addition to the survey results, the activity of the arkansasinterstates.com Web server was analyzed to determine the extent of usage. The Web site activity is stored in two servers operated by AIM Hosting Services; the first server records the non-camera image contents, while the second is dedicated to the camera image content. The period of time for which the information from both servers was available was August 16, 2004, to September 15, 2004. On average, 200 users visited the Web site 350 times each day as illustrated in Figure 20. About 68 percent of the visitors used the Web page only once per day. On average, 40 people per day visited the camera contents. As a whole, these 40 users loaded about 100 pages (each page being an image at a certain location) on a daily basis.

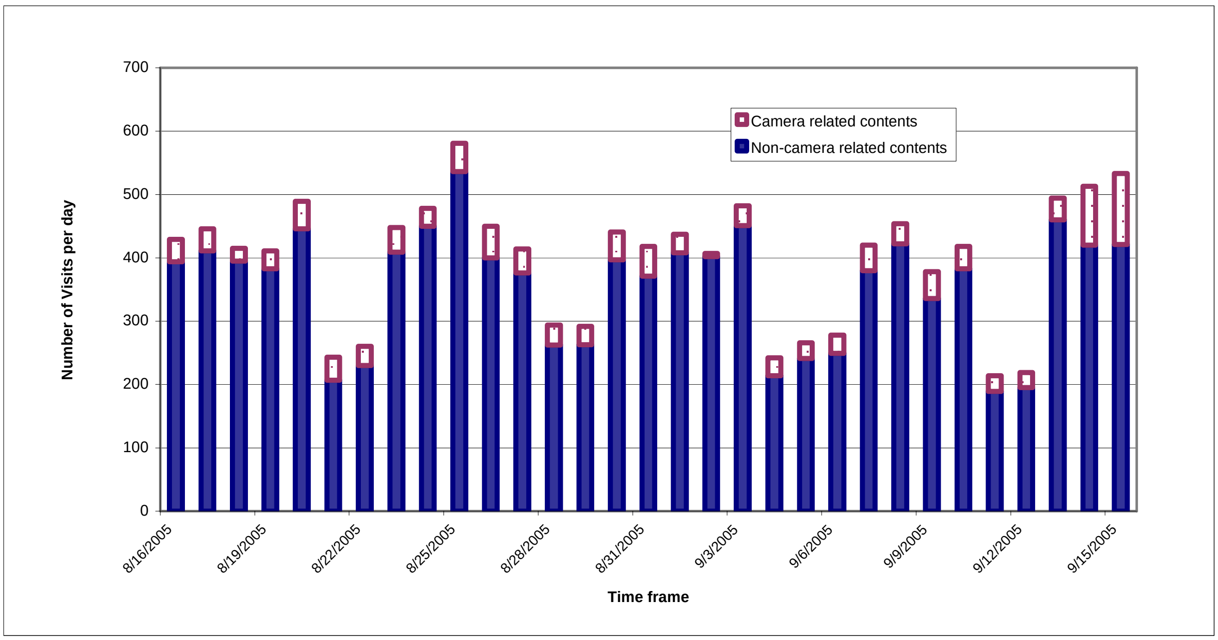

Figure 20. Activity in Work Zone Webpage Servers (8/16/2005 was a Tuesday)

The average visit length during the analysis period was about 30 minutes, indicating that users likely had some interest in the Web page content. The most active hours on the Web site were from 8 a.m. to 9 a.m. and from 5 p.m. to 6 p.m.—showing interest in work zone traffic appeared during peak periods.

The servers also contained data related to the location of the visitors. About 36 percent of the site visits identified in the U.S. originated from Arkansas, followed by visits from the states of Virginia (32 percent) and Texas (5 percent). The remaining visits included a distribution across all other states and unidentified locations.

These findings help support the hypothesis "Travelers will use the work zone ITS." The findings indicate that DMS are heavily used, HAR is moderately used, and a minimal number of the surveyed drivers use the Web site.

Hypothesis 4: The Use of ITS in the Work Zone will Improve Trip Planning

This hypothesis addresses the trip planning benefits that users may experience as a result of the ITS. The study team examined the hypothesis by analyzing the responses to survey questions pertaining specifically to each of the three ITS components (Web site, DMS, and HAR). The questions differed by ITS component, as did the findings.

Web Site

The two survey questions used to determine if the Web site improved trip planning were: "For what reasons do you use the I-30 Web site?" and "The info on the Web site improves my ability to avoid delay on this section of I-30."

In response to the first question, out of all of the drivers included in this study (592), six drivers (1 percent) said that they do use the Web site to plan the route they would take, and two drivers (0.3 percent) said they use the Web site to plan the time they would start the trip. Note that this percentage is consistent with the statistics garnered from the Web site servers. Given the AADT of 63,000 and the average number of Web users (200), the usage percentage comes out comparable at .3 percent. Narrowing the scope of the analysis to the 26 drivers who use the Web site, 7 were CVDs and 19 were PVDs. Out of the 7 CVDs and the 19 PVDs, 2 CVDs (29 percent) and 4 PVDs (21 percent) answered that they used the Web site to plan the route they will take, and 2 private drivers (11 percent) said they use the Web site to plan the time they would start the trip.

From these 26 drivers, 23 also responded to the second question involving the Web site's ability to improve trip planning. On average, drivers responded with an average level agreement of 2 (2 indicating that they somewhat agree). A t-test with 95 percent confidence level showed that the 23 drivers agree that the Web site was able to improve trip planning. From these two survey questions, one can infer that the Web site had a low usage, but its few users believed the Web site helped them in trip planning.

DMS

To determine if users readily understood the DMS, the study team studied the responses to the following three questions:

- "Has the information on the signs ever caused you to exit this section of I-30 to find an alternate route?"
- "The messages are detailed enough to help me make decisions about my route."
- "The signs are located in the right places to help me make decisions about my route."

Two hundred fifteen CVDs and 239 private drivers responded to the first question. Of these respondents, 20 percent (44) of the CVDs and 50 percent (120) of the PVDs said that the signs have caused them to change their route. The low number of CVDs that responded positively is most likely due to the fact that truck drivers do not have very many alternate routes, as heavy vehicles are only allowed on certain roads. During the interviews, the CVDs made it clear that in most cases, once they had taken a route, it was too late to change it regardless of the traffic. A PVD can take any exit available.

In response to the other two questions, on average, both CVDs and private drivers indicated that they somewhat agree that the signs are detailed enough and are located in the correct places for a different route to be taken if there is significant delay. Using a t-test with 95 percent confidence, drivers indicated that they agree that the DMS contain enough detail and are located in the correct places.

Considering the agreement of drivers in response to these questions, and the fact that 50 percent of the private drivers who answered the first question said that they have used the DMS for advisories as to whether to stay on I-30, there is some indication that DMS in the work zone assisted in providing drivers with the information required to make routing decisions. The effectiveness of DMS on trip planning depends on how far upstream the messages are delivered. This is especially true for commercial vehicle travel.

HAR

The study team used the responses from two questions to assess the utility of HAR. These two questions are: “Have the highway advisory radio messages ever caused you to exit this section of I-30 to take an alternate route?” and “The messages are detailed enough to help me make decisions about my route.”

For the first question, 17 CVDs out of 286 (6 percent) and 30 private drivers out of 306 (10 percent) said that they had taken an alternate route due to the HAR. Similar to the responses related to the DMS benefits, a lower percentage of CVDs used the HAR to make decisions about their route.

The average rating for the second question was 1.93, indicating that the drivers agreed (1 is completely agree; 2 is somewhat agree) that the messages were detailed enough to help them make decisions about the routes. The same trend described in the previous question holds in this case, where more private than commercial drivers agree that messages are detailed enough to make decisions about their route. However, with the low number of users, it is difficult to say whether the HAR is improving trip planning.

Hypothesis 5: The Use of ITS in The Work Zone Will Improve Traveler Tolerance of Work Zone Delays

To answer this hypothesis, responses were reviewed from the following survey question: “Just having the information makes me feel less bothered by the delays in the construction zone.” This question applied to two components of the ITS: the DMS and the Web site. For the DMS, both PVDs and CVDs were asked to rank their agreement with the stated question. For the Web site, only private drivers were asked. For both the Web site and the DMS, responses averaged a “neutral” or “somewhat disagree” level of agreement with the given statement. Figure 21 shows the distribution of responses for the DMS. Figure 22 presents the distribution of the responses from the private drivers for the Web site.

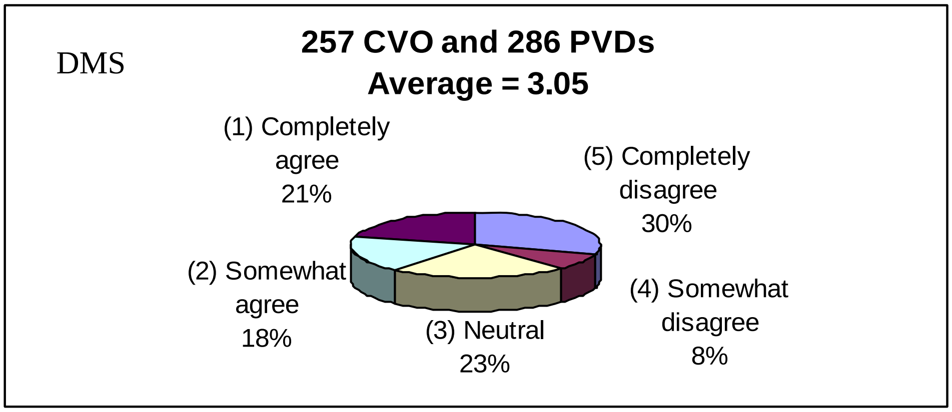

Figure 21. Distribution of Responses to the Statement, "Just Having The DMS Information Makes Me Feel Less Bothered By The Delays In The Construction Zone."

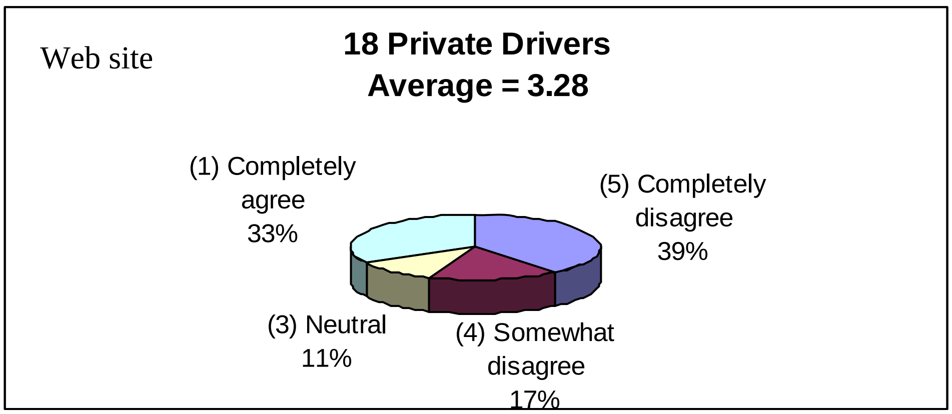

Figure 22. Distribution Of Responses To The Statement, "Just Having The Web site Information Makes Me Feel Less Bothered By The Delays In The Construction Zone."

Although the average rating for the participants was neutral, about 39 percent of drivers (215 drivers) agreed that having the information on DMS made them feel less bothered in driving through the construction zone. The DMS messages were general in terms of traveler/delay information (e.g. specific travel times were not posted) and changed based on speed thresholds. They also posted specific mile-marker information. For the Web site, 6 of the 18 drivers (~33 percent) agreed that the information on the Web site made them feel less bothered in driving through the construction zone.

Hypothesis 6: The Use of the ITS in the Work Zone Will Improve the Confidence of Travelers Driving in The Work Zone

To determine if ITS improves traveler confidence, the responses to the following questions were used: "Because of the info on the signs, I am better prepared to react to slow or stopped traffic" and "I feel safer traveling through this construction zone because of the electronic messages." Both CVDs and private drivers received these questions, but the questions pertained only to DMS (not the Web site or HAR). DMS was the focus of this question because once in the midst of the work zone, DMS is the only form of ITS immediately accessible; it does not require internet or a radio. These questions also served to partially answer Hypothesis 1 (the use of ITS in the work zone will reduce traveler's exposure to hazard) because drivers' confidence and drivers' exposure to hazard are closely related. As discussed in Hypothesis 1, a t-test with 95 percent confidence showed that the drivers agreed that the DMS better prepared them to react to slow or stopped traffic and made them feel safer traveling through the construction zone. Assuming that drivers feel more confident when they are better prepared to stop or slow down, the evidence presented here supports the hypothesis under investigation.

Hypothesis 7: The ITS Information Will Be Readily Understood By Users

Survey questions for each of the three components of ITS (Web site, DMS, and HAR) served to answer the given hypothesis for drivers of both private and commercial vehicles on I-30. The two questions differed for the different components of ITS, as did the findings. Each of the components will be discussed separately to answer this hypothesis.

Web Site

The responses the drivers gave to the question requesting level of agreement with the statement "The Web site is easy to use" served in the study of whether drivers readily understood the Web information. Twenty-four drivers answered this question, and twenty-three of them agreed that the Web site was easy to use. The 24th driver (a CVD) gave a neutral answer to this question, which may be due to the driver only visiting the Web site once. With overwhelming agreement of the few Web site users surveyed (24), one can conclude that the Web site is easy to use.

DMS

The responses to two questions served to address the seventh hypothesis pertaining to DMS. These two questions requested a ranking of agreement with the statements "The messages are easy to understand" and "The messages are detailed enough to help me make decisions about my route."

About 94 percent of CVDs (269 drivers) and 96 percent of PVDs (295 drivers) said "yes," they had used the DMS. Of these respondents, 261 CVDs and 287 private drivers responded to both questions. The drivers who responded to both questions strongly agreed the messages were easy to understand. They gave an average rating of 1.26, where 1 means completely agree and 2 means somewhat agree. They also agreed that the messages were detailed enough to help them make decisions about their route. The average rating for this question was 1.78. Both of these findings were significant at a 95 percent level. These findings indicate that the DMS messages were easy to understand and that the DMS were detailed enough to help drivers to make decisions about their routes.

HAR

The responses to the following two questions facilitated the study of Hypothesis 7 pertaining to HAR. These two questions requested ratings of the statements: "The radio broadcast quality is too poor to hear properly" and, "The messages are detailed enough to help me make decisions about my route."

About 24 percent of CVDs (69 drivers) and 24 percent of PVDs (74 drivers) said "yes," that they had used the HAR. Of these respondents, 60 CVDs and 64 private drivers responded to both questions. Of these combined 124 drivers, the average response to the quality of the broadcast was 2.57 (where 2 means somewhat agree and 3 means neutral). However, the drivers did agree that the messages were detailed enough to help them make decisions about their route. The average rating for this question was 1.93. Both these findings were significant at a 95 percent level. From this, one can conclude that about half of the people who would like to use the HAR can hear the broadcast clearly. When they could hear it, the broadcast was understood and detailed enough on average. Perhaps the proper course of action would be to increase the signal strength so more people who would like to use the HAR are able.

Hypothesis 8: The Use of ITS in The Work Zone Will Improve Incident Response and Clearance Times

Incident response and clearance times with and without ITS in the work zone could not be used for comparison because the data were unavailable. To answer this hypothesis, an interview with police personnel was used to determine if the police department felt that the incident response and clearance times improved due to the ITS. The following are the interview responses.

Interview Conducted With a Captain and a Dispatcher at the Arkansas State Police

The Captain indicated that the ITS on I-30 improved their incident response capabilities. He explained that at times, CCTV could be used to view the work zone. He also noted that the DMS is a big help in diverting traffic during incidents; it was better than a patrol car. The Captain provided the following examples:

- *Faster response time - If traffic couldn't be diverted, the only way the responding officer could access the incidents on the I-30 work zone was to use the frontage road to get close, and then climb over the New Jersey barrier to get to the scene.*
- *Faster clearance time – Since the traffic is already diverted, startup after clearance is quicker.*

The interviewer also spoke with a radio dispatcher working with the state police who suggested some improvements to the ITS. The interviewer summed up the dispatcher's comments with the following statement:

> The dispatcher preferred to see live images of the work zones. The dispatcher had to "refresh" the image anytime she needed to see what was going on. This occurred whenever a cell phone call reporting an incident was received. Work zone images were of limited value because the actual crash site was not always in the image. The dispatcher would have preferred to have more cameras or to have pan, tilt, zoom (PTZ) abilities so they can focus on the crash site.
>
> It was also said that the CCTV could help determine what emergency vehicles needed to respond to incidents. However, given the camera image quality and standard operating procedures, the police said a trooper had to actually be on the

scene to make this determination. They may believe this because they do not have PTZ ability that would allow them to most effectively use the CCTV.

These were some suggestions to further improve the ITS utility to the state police. From these responses, it can be seen that the State police department does feel that the ITS in the work zone somewhat improves response and clearance times; however, effective and efficient response could be greatly improved by the addition of greater camera functionality.

Hypothesis 9: The Use of ITS in the Work Zone Will Divert Travelers to Alternate Routes During Times of Work Zone Congestion

To answer this hypothesis vehicle counts were taken at six exit ramps, DMS message records were collected for 15 message boards, and mainline volume counts were collected for I-30 at each of the off ramp locations (see Figure 23 and Table 15). The study team collected these data over a 4 day time span between Monday, May 17, and Thursday, May 20, 2004. The goal was to correlate the off-ramp volumes and mainline volume data with the messages displayed on the upstream DMS.

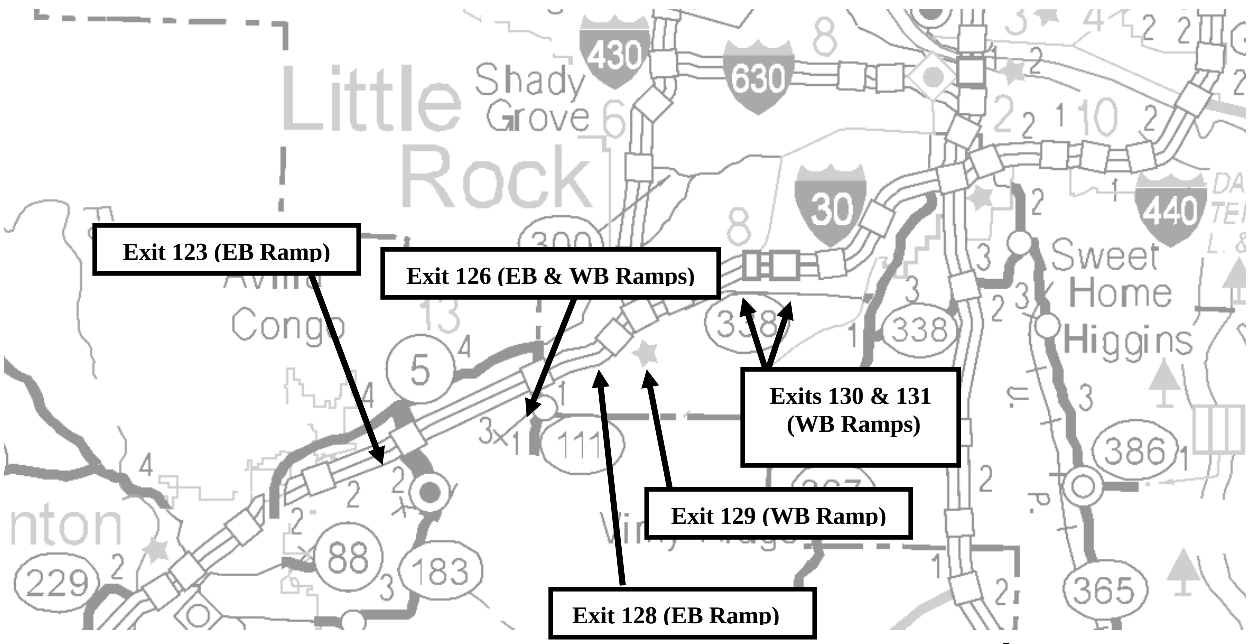

Figure 23. Location of Ramps Used for Hypothesis No. 9[3]

[3] Map courtesy of the Arkansas Highway and Transportation Department Map Planning Section (http://www.ahtd.state.ar.us/maps/2004%20state%20highway%20map/statehwymap3-8-04_state.pdf).

Table 15. Location of DMS Used for Hypothesis No. 9

Message Board ID	Highway	Direction	Mile Marker
S01	I-30	EB	111
S02	I-30	EB	114
S03	I-30	EB	116
S04	I-30	EB	118
S05	I-30	EB	122
S06	I-30	EB	126
S07	I-30	EB	128
S08	I-30	WB	136
S09	I-30	WB	128
S10	I-30	WB	126
S11	I-30	WB	123
S12	H-5	EB	
S13	H-5	EB	
S14	H-5	WB near 430	
S15	I-430	EB	

Unfortunately, the data sets contained large gaps in the data and much of the message board and exit ramp data was unusable because the DMS were too far from the ramps to assume that the drivers reading the boards would exit at the given ramp. After combining the useable data, the only data left was from four off ramps (eastbound exits 123, 126, and 128; westbound exit 126), each with an average of 2 days of consecutive data, including one upstream DMS and the corresponding mainline volume counts. Over the full useable data set, there were 12 separate instances when ramp volumes were available and the DMS (at eastbound exits 123, 126, and 128; westbound exit 126) displayed "Delays Possible" messages. Seven of the 12 cases happened during the peak a.m. or late afternoon, and the other five cases occurred during the night (when there were lower volume counts).

From this data there was not enough evidence to suggest a relationship between the DMS messages and diverting traffic. For example, on May 17, 2004, the DMS upstream of the eastbound ramp at exit 128 displayed delay messages for short periods of time, while volumes on ramp fluctuated from 10 to 36 vehicles in a 15-minute period. While on May 17 the DMS message remained the same, the ramp volume fluctuated by a factor of three. On May 18 and May 19, ramp volume fluctuated with a similar magnitude but no delay messages were displayed. Thus, the data did not indicate a clear association between ramp traffic volume and the display message.

In examining the peak a.m. cases, large volumes of traffic exited I-30 at the same time the DMS were displaying "Delays Possible." It would seem that the messages were, indeed, diverting traffic. However, these diversions could easily be due to normal trip planning; the exiting travelers may have been planning on getting off at the given exit regardless of the traffic conditions. Given these confounding factors, more data is needed to answer the hypothesis "The use of ITS in work zones will divert travelers to alternate routes during times of work zone congestion."

Hypothesis 10: The Use of ITS Will Improve the Productivity of Contractors and Travelers (Both Private and Commercial)

This hypothesis includes two sections: improving productivity for contractors and improving productivity for travelers. To address the section on travelers the survey data were used. The survey questions used for this hypothesis were the same as Hypothesis 4 and, consequently, results for these two hypotheses were the same. The following are the conclusions from Hypothesis 4:

- Web site – It has the potential to improve the productivity of travelers. Even though the servers show a stable number of daily visits, the Web site usage among the surveyed drivers was very low.
- DMS –They appear to be improving the productivity of travelers.
- HAR – It appears to be improving productivity for those drivers who use it.

To answer the question of improving productivity for contractors, a separate questionnaire was developed. The work zone project contract manager responded to this questionnaire during an in-person interview. The questionnaire contained four questions applicable to this hypothesis; two of these were direct questions and two were indirect.

The two indirect questions were "Do you feel the ITS had an impact on the safety of the construction workers (in the work zone)?" and "Do you feel the ITS helped you or your subcontractors to carry out the construction?"

For the first question the response was: "Yes… Gives early warning to motorists about lane shifts. They had to shift traffic onto the frontage roads three times in a short period and the message boards helped them control the traffic." For the second question, the interviewee agreed that the ITS helped carry out the construction for planning and implementing lane closures, and planning and implementing alternate routes, but not for planning for and changing on-and off-ramp configurations. These questions add insight to the situation but do not answer the question posed.

The two direct questions were, "Did the ITS have a negative impact on any of your operations?" and, "Do you feel that the ITS improved your productivity (or your subcontractor's productivity) by helping you complete the work?"

For the first question the answer was yes, there were negative impacts caused by the ITS. The interviewee stated, "The portable CCTV got in the way of construction operations and the contractor had to have them moved." For the second question the answer was no, the ITS did not improve productivity. He commented, "The message boards were spread out too far to be a big help." The results indicated that ITS in the work zone may not directly improve a contractor's productivity but may help them indirectly to manage the work zone better.

Hypothesis 11: The ITS Will Be Reliable and Accurate

The study team relied on two data sources to answer this hypothesis: 1) traffic volume data collected by the ITS were compared to AHTD maintained RTMS traffic volume data to verify the ITS accuracy, and 2) survey data were used to determine if drivers found the ITS reliable and accurate.

To verify the accuracy of the ITS traffic volume counts, AHTD collected the traffic volume data for the period from May 21 to June 20, 2004, which was compared to corresponding data archived by the ITS. Each of the two databases had some missing sections of data. Days with missing data were removed to prevent a biased selection of hours (night or day hours). In all, the data used represented 10 full days between June 2 and June 16. A total of 240 hourly volume pairs were analyzed for both eastbound and westbound volume counts along I-30. Figure 13 shows the detector location at Raymar Rd.

The study team compared volumes from detectors number 62 and 26 (from ITS) to the I-30 volumes AHTD collected at Raymar Rd. overpass (Figure 24). Note that the distance between the overpass and location of the ITS sensors was not substantial and no point of exit occurred within that distance. For the 10-day period, the ITS-counted eastbound traffic volume (detector 26) was 543,606 and the AHTD-counted volume was 407,046 vehicles. For the same period, the ITS-counted westbound traffic volume (detector 62) was 604,242, and the AHTD-counted volume was 437,026 vehicles. The ITS-counted volumes were 34 percent higher for eastbound traffic and 38 percent higher for westbound traffic than the AHTD volumes. The ITS eastbound and westbound volumes combined were 36 percent higher than the combined AHTD volume. A t-test showed that the combined volume from the ITS detectors was significantly different with a 95 percent confidence level. These findings suggest that the westbound ITS detector was tallying additional traffic (perhaps part of the eastbound traffic) and the eastbound ITS detector was tallying additional traffic (perhaps part of the westbound traffic) at these locations.

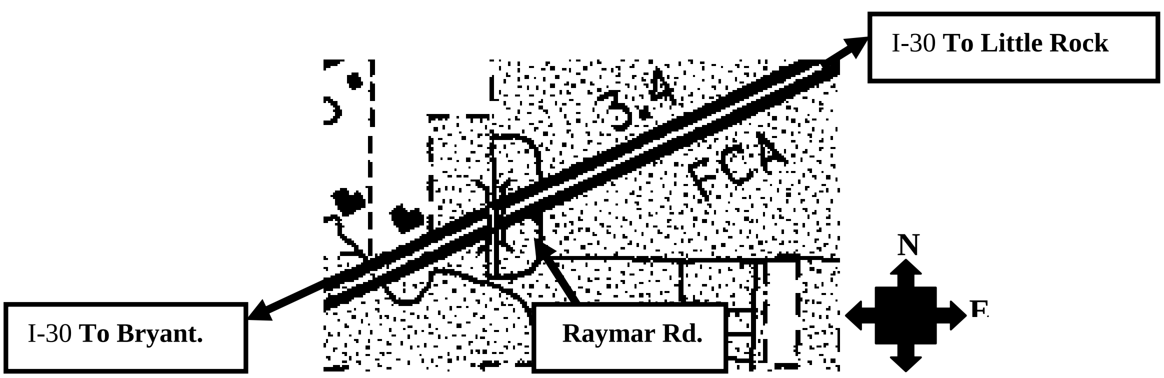

Figure 24. Locations of Detectors Used for Hypothesis 11[4]

Additionally, a comparison was made between the data from the ITS detectors (numbers 63 and 25) neighboring the detectors in question and the AHTD data at the Raymar Rd. overpass. Results showed an average underestimation of 64 percent for eastbound volumes and overestimation of 65 percent for westbound volumes by the ITS detectors. However, the ITS eastbound and westbound volumes combined were less than 1 percent lower than the AHTD data. A t-test showed that the combined volume from the ITS detectors was not different than the AHTD data with a 95 percent confidence level.

[4] Note: occupancy in this case is a measure of vehicle density in the lane.

The data collected by AHTD served as the reference volume because the eastbound and westbound daily volumes and the volumes over the whole study period were similar. The volumes on both directions are expected to be similar at this location because the work zone is located within a populated area where local drivers travel in both the eastbound and westbound directions. In addition, intercity drivers would use I-30 in both directions without a significant bias toward one direction.

To determine the impact of this calibration on the messages that users would see, a study of the corresponding DMS data was undertaken. The study team also compared messages displayed on DMS located on the eastbound at mile post 122 (called S05) to the speed, volume, and occupancy data collected at ITS detectors 25 and 26 to determine if there was a correlation. The comparison showed that the displayed messages did not match the data from detector 25, but there was some correspondence between the messages and the data from detector 26. For example, when the vehicle count at detector 26 was about 3300 vph and the average speed dropped below 40 mph, the sign displayed the message: “slowing traffic ahead, at mile marker 123, delays possible.” It is reasonable to expect similar volumes at detectors 25 and 26 due to their proximity. Thus, the traffic conditions at detector 25 should similarly correspond to the displayed messages. However, the vehicle counts at detector 25 never exceeded 1338 vph in the 10-day-period and so did not trigger the above mentioned messages.

Similarly, the study team compared messages displayed on the DMS located on the westbound at mile post 126 (called S10) to the speed, volume, and occupancy data collected at ITS detectors 62 and 63. The data showed that the displayed messages did not correspond to the data from the detectors. Detectors 62 and 63 indicated significant changes in traffic conditions, with fluctuations on vehicle counts from 1000 vph to 4000 vph and average speeds from 55 mph to 40 mph. But, the displayed message on the DMS during the whole 10-day period was: “Buckle Up, Drive Safely, Caution Trucks Entering And Leaving The Roadway.”

Based on these comparisons, the study team concluded that while the combined volume from ITS detectors 25 and 63 was similar to the volume from AHTD, the directional volumes were significantly different. For ITS detectors 26 and 62, the combined volume was significantly higher than the AHTD volume. As a result, it seems that the ITS detectors were not counting the directional volumes accurately at these locations during the analysis period. Whether the detectors were working accurately at other time periods or the detectors at other locations were working properly is not known because no reliable reference data is available for comparison. It should also be noted here that the configuration of the work zone was very complex and the ITS sensors were often operating in areas with minimal room for adjustment. As a result, the sensors could “cross-shoot” lanes if not properly readjusted to the work zone layout.

To perform additional analysis regarding the perceived accuracy of the system, survey questions for each of the three types of ITS (Web site, DMS, and HAR) were asked of the PVDs and CVDs on I-30. All of the questions were “rate-your-agreement”-style questions. The questions differed for the different components of ITS, as did the findings. Each of the components will be discussed to answer this hypothesis.

Web Site

The response to the following question requesting a level of agreement with the statement "The info on the Web site is accurate" served to determine if the Web site was giving accurate information as perceived by the users. The average rating of the 24 drivers who answered this question was a 1.7. This value falls between completely agree (1) and somewhat agree (2). Using a t-test with 95 percent confidence, the drivers agreed that the Web site was giving accurate information.

DMS

The responses to the following question requesting the ranking of agreement to the statement "The messages are accurate" served to assess the accuracy of the messages given by DMS. Ninety-four percent (269) of CVDs and 96 percent (295) of private drivers responded "yes" to using DMS. Of these respondents, 256 CVDs and 287 private drivers responded to the question regarding the accuracy of the signs. The average rating of these combined 543 drivers to the DMS message was 1.75. Performing a t-test for the responses shows that the drivers found the DMS messages accurate at a 95 percent significance level. These findings support the conclusion that participants feel the DMS were giving accurate messages.

HAR

The responses from three questions were used to assess the utility of HAR. These three questions requested participants to rank their level of agreement with the following statements, "The messages are useful," "The messages are accurate," and "The messages are updated frequently enough."

Twenty-four percent (69 drivers) of CVDs and 24 percent (74 drivers) of PVDs responded "yes" to using HAR. Of these respondents, 60 CVDs and 56 private drivers responded to all the three questions stated above. Of these combined 116 drivers, the average response to whether the messages were useful was 1.74 (a rating higher than for "somewhat agree"). The average response to the accuracy was 2.0, or somewhat agree. The average response for whether or not the messages were updated frequently enough was 2.27, or somewhat agree. Using a t-test at 95 percent significance showed that the drivers agreed that HAR was useful, accurate, and updated frequently enough.

The specific statistical summaries for each set of survey question responses can be found in Appendix D.

Summary of Findings - Arkansas

The analysis presented in this report represents multiple sources of data, analysis methodologies, and outcomes. The following Table presents a summary of the findings for each hypothesis including comments on the analysis.

Table 16. Summary Findings for Each Hypothesis

Hypothesis	Findings	Comments
The use of ITS in the work zone will reduce traveler's exposure to hazard.	Drivers agree that the ITS in the work zone reduced their exposure to hazard.	A large percentage of the surveyed drivers (82%) agreed that the ITS system improved their ability to react to slow or stopped traffic A large percentage of surveyed drivers (49%) agreed that they felt safer traveling through the work zone because of the electronic messages, 17% were neutral, 32% disagreed, and 2% did not answer.
The use of ITS in the work zone will enhance the safety performance of the highway.	The police officer and construction manager in the work zone agreed with this hypothesis.	People working within the construction zone feel that the ITS has improved the safety of both the workers and the travelers.
Travelers will use the work zone ITS.	Travelers used the components of the ITS that were most available. The highly-used DMS were present in the work zone making them readily available to drivers to read. HAR was used moderately. The Web site had a low utilization among the surveyed drivers	DMS was observed by 95% of surveyed drivers. HAR was used by 24%. Web site was used by 5%.
The use of ITS in the work zone will improve trip planning.	Web site: Improves trip planning, but the usage among the surveyed drivers was very low.	The Web site does improve trip planning, but only 5% of surveyed drivers used it. On average, 350 daily visits were registered in the Web site from August 16 to September 15, 2004.
	DMS: Improves trip planning for PVDs, but has a lower impact for trucks.	DMS in the work zone improve trip planning for PVDs (50% agreement). CVDs have a fixed route and DMS are less effective for trip planning.
	HAR: Some of the people who used it improved their trip planning.	24% of drivers used the HAR to improve their ability to plan their routes.
The use of ITS in the work zone will improve traveler tolerance of work zone delays.	ITS improves tolerance for at least some drivers.	About 1/3 of the drivers said the use of ITS make them feel less bothered in the construction zone.

Hypothesis	Findings	Comments
The use of the ITS in the work zone will improve traveler confidence driving in the work zone.	The DMS improve traveler confidence for most drivers.	Drivers' confidence is increased because their ability to react to slow or stopped traffic is increased, and they feel safer driving through the construction zone.
The ITS information will be readily understood by users.	Web site: Readily understood.	With almost unanimous agreement, one can conclude that the Web site is easy to use or readily understood by users.
	DMS: Readily understood.	Information is easy to use and detailed enough for the majority of the I-30 users.
	HAR: Understood by only those who could hear the broadcast clearly.	Increase the signal strength so that more people can use the HAR.
The use of ITS in work zones will improve incident response and clearance times.	ITS assists professionals with incident response and clearance times.	ITS does help improve incident response and clearance times; however, it can be improved to enhance its utility.
The use of ITS in work zones will divert travelers to alternate routes during times of work zone congestion.	Not enough data to state any findings.	Data were collected for 7 off ramps and 15 DMS over 4 days; however, conclusive findings were not found.
The ITS will improve the productivity of contractors and travelers.	Contractors: ITS does not improve productivity, but ITS does help manage the work zone better.	ITS had some negative impacts on construction operations (portable closed circuit video unit got in the way) and did not improve productivity, but using the ITS system for traffic management helped manage the work zone.
	Travelers: ITS improves motorists' ability to plan their trips.	The Web site had a low usage (5%), but its few users believed the Web site helped them in trip planning.
The ITS will be reliable and accurate.	Drivers felt that the Web site was accurate.	The Web site gives accurate information, but its use is very limited by surveyed drivers (5%).
	DMS are accurate enough for the majority of the users.	Most drivers (79%) felt that the DMS messages were accurate.

Hypothesis	Findings	Comments
	Drivers felt that HAR was useful, accurate, and frequently updated.	Of the 24% of drivers who use HAR, 81% said the HAR is useful, accurate, and updated frequently.
	Directional volume counts by work zone ITS differed significantly from data collected by AHTD.	At one location, traffic volume was overestimated by 34% on the eastbound and overestimated by 38% on the westbound direction. A second set of detectors revealed an underestimation of 64% on the eastbound and overestimation of 65% on the westbound.

Tips and Lessons Learned

Deployment Tips and Lessons Learned

Work zones are highly variable environments. As a result the ITS must be similarly flexible. For example, the work zone examined here was large, complex (included 7 separate projects by 2 contractors), and had a constantly changing configuration. As a result, the calibration of the ITS became a major issue requiring one full-time employee working long hours to maintain all sensors.

ITS is only one part of a successful work zone. The aim of outfitting this work zone with ITS was to improve safety. While there is some indication that the ITS system reduced travelers' exposure to hazard and made the work zone safer, fatal crashes in the I-30 work zone were not fully avoided. ITS can be a valuable part of effective work zone management, but other safety and mobility strategies should also be used as part of a coordinated transportation management plan (TMP).

The recognition of system requirements by all parties affiliated with the work zone and ITS deployment is key. For example, the emergency dispatchers' use and requirements for the system are very different from those of the contractors. A more detailed study of user requirements coupled with revised operating procedures may enhance the system's capability to improve safety and mobility.

Advertising the Web site to a greater audience in various media is important. This is especially true given the high level of satisfaction experienced by the work zone ITS Web site users in comparison to the low level of the number of users.

Evaluation and Research Tips and Lessons Learned

Obtaining crash records can be more difficult than presumed. The lack of existing electronic crash records in a maintained database rendered several of the safety hypotheses infeasible for study by any means other than user surveys and interviews.

Development of a data collection plan should include some forecasting or methodology to accommodate data providers or key stakeholder personnel that may be retiring. For example, difficulties experienced in obtaining police records were compounded by the retirement of the police chief.

Data collection activities should be coordinated as closely as possible with the construction contractors. For example, tubes in place to collect ramp volume data had to be moved before the end of the designated collection period due to construction on the selected ramp.

I-40 Winston – Salem, North Carolina

Over the past several years, the North Carolina Department of Transportation (NCDOT) has undertaken several construction projects involving the deployment of ITS technologies to help mitigate the impacts to traffic. NCDOT sought to alleviate work zone issues such as back-of-queue crashes and traffic delays caused by capacity reductions and movement of materials and trucks to and from work sites via open travel lanes. NCDOT has successfully deployed several ITS systems in different work zones across the state. Benefits from those early deployments included enhanced real-time information for motorists on downstream conditions, better trip planning through information dissemination via Web sites, as well as no fatal crashes.

In early 2004, NCDOT designed an ITS system for a work zone shown in Figure 25 on Interstate 40 west of Winston Salem. The goal of the ITS system was to monitor conditions and improve mobility and safety through the work zone along I-40 between the NC 801/I-40 interchange in Davie County and the SR 1101/I-40 interchange in Forsyth County.

Figure 25. I-40 Work Zone and Signed Alternate Routes

Based on predetermined delay and travel time thresholds, the system provided real-time delay information and, if delays exceeded 25 minutes, recommended alternate routes via dynamic message signs (DMS).

The main objectives of the system were to:

- Reduce demand and congestion (by actively diverting traffic).
- Provide delay information to warn motorists of slowed traffic ahead.

- Provide information to commuters and DOT personnel via a Web site.
- Build public confidence in real-time traveler information.

The main objectives of the evaluation were to:

- Determine traveler response to the work zone information.
- Determine the effect of traveler response on traffic conditions.
- Verify that the work zone ITS functioned as designed.

Study Site Work Zone

NCDOT installed the work zone between milepost (MP) 180 and MP 184, west of Winston-Salem. This section of I-40 is a four lane divided rural Interstate that has Annual Average Daily Traffic (AADT) of 48,000 vehicles per day. NCDOT set up lane closures in each direction in order to rehabilitate pavement and replace deteriorating concrete slabs.

NCDOT began construction on March 23, 2004, with three phases of work. In Phase I, NCDOT milled and paved shoulders and set up off-peak lane closures. In Phase II they replaced concrete slabs and implemented contract provisions allowing for 72-hour lane closures. In Phase III they closed lanes for paving operations and restricted work to nighttime hours. They also planned to perform concurrent bridge painting/maintenance work on I-40 approximately 5 miles east of the work zone. Due to schedule changes, they performed the work later in the summer after Phase III was completed. NCDOT also had to modify the original system configuration to account for the bridge painting/maintenance project.

Generally, the construction contract did not permit lane closures Monday through Friday between 6 a.m. and 9 a.m. (eastbound) and between 4 p.m. and 7 p.m. (westbound) as part of a strategy to lessen impacts to traffic. However, the contract permitted lane closures during Phase II (slab replacement) for up to 72 hours for concrete curing. The contract prohibited lane closures during special events or on holidays.

ITS Description

NCDOT designed the ITS system to monitor traffic conditions within and in advance of the work area from each direction. The system components included:

- A central base station equipped with processing software and wireless communications to link the system components.
- 10 portable DMS remotely controlled via the central computer base station.
- 10 portable traffic sensors linked to the central computer base station.

NCDOT designed the system as shown in Figure 26. They re-mobilized it several times throughout the summer, and used an alternate configuration later in the deployment for the separate bridge painting project with weekend lane closures. NCDOT procured the system using a special provision through the prime construction contract.

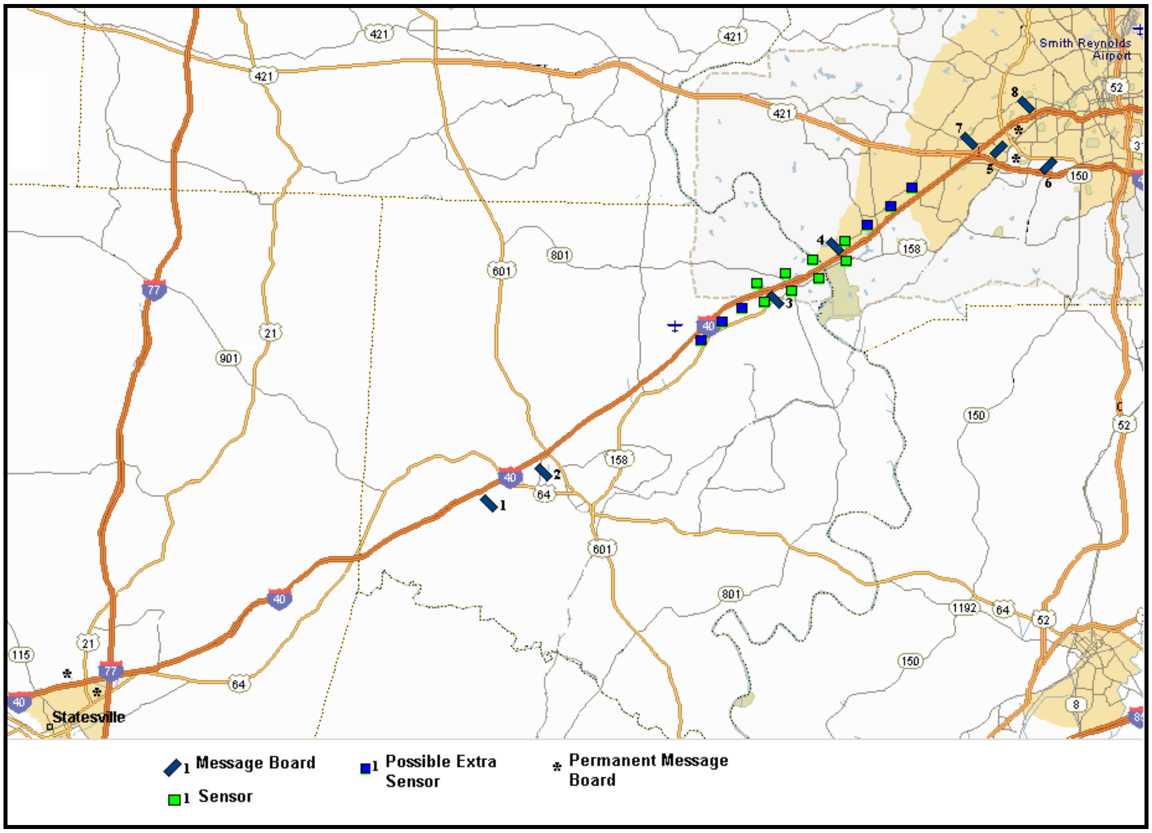

Figure 26. I-40 Smart Work Zone Deployment Near Winston Salem

NCDOT designed the system to provide real-time operational status of the work zone via the central base station computer and via the Internet on a dedicated project Web site. They also designed it to notify the appropriate personnel, by pager and email, when a malfunction occurred in the system or once the delay through the work zone exceeded 25 minutes. They programmed the system to display appropriate messages and alternate route information via the DMS when warranted.

Each traffic sensor communicated with the computer base station to activate the appropriate DMS whenever the prevailing traffic speed slowed to 55 mph. Once the system activated, it automatically displayed the preprogrammed delay messages in real-time on the DMS. NCDOT designed the system to calculate, via simple algorithms, real-time delay for display on the portable DMS. The system calculated delay and displayed information on the portable DMS to the nearest minute for delays up to 15 minutes after a 5-minute delay was observed. For delays exceeding 15 minutes, the system displayed information on the DMS rounded to the nearest 5-minute increment. The system posted updated delay information every minute. The Web site updated delay information simultaneously with the information displayed on the DMS.

For westbound traffic, the system encouraged motorists to take 421 west from Winston-Salem, and then to take either 601 south or I-77 south to rejoin I-40. For eastbound traffic, the system encouraged motorists to take 601 north at exit 170, then 421 east to rejoin I-40 at Winston-Salem. NCDOT formally signed these alternate routes prior to construction. Motorists familiar with the area may have also deemed US-158 a possible alternate route. However, US-158 is a two-lane highway that runs parallel to I-40 and was not a preferred alternate route due to lower capacity compared to US-421. The main detour route adds approximately 10 miles to the trip compared with the mainline route.

Measures and Metrics

The study team collected traffic data throughout the network to supplement the system detector data. The study team performed road tube counts at each key alternate route decision point. The study team also counted traffic on ramps along with mainline sections after each ramp to establish diversion patterns based on the work zone condition information displayed by the system, especially for times when the system actively diverted traffic around the work zone. The plan established a baseline prior to ITS implementation (without ITS) for comparison with the period when the system was active (with ITS).

The success of the evaluation hinged upon the accuracy and completeness of several key data elements, including:

- Traffic volumes and average speed and occupancy measurements at each sensor location.
- DMS logs showing the times and dates that the pre-determined messages were activated.
- Time-specific information on construction activities and delay as well as crash observations as noted by inspectors in DOT construction logs.
- Historical crash data.
- Supplemental traffic counts around the network and travel times observed through the work zone.

The study team developed several hypotheses based on the goals for the system. Each hypothesis and associated measures and data sources for testing each are shown in Table 17.

Table 17. Hypotheses and Measures for Evaluation

Hypothesis	Measures of Effectiveness	Data Sources
The ITS system will provide accurate, timely, and reliable information	Correlation between work zone conditions and messages posted, system uptime/downtime, field observations	System logs, project engineer records, interviews
The use of ITS in work zones will divert travelers to alternate routes during times of work zone congestion	Demand patterns on mainline and alternate routes	Sensor data, supplemental traffic counts
The use of ITS in work zones will reduce traveler delay	Travel time, average vehicle speed, work zone throughput, alternate route travel times	Direct observations, system data, travel times
The use of ITS in work zones will reduce congestion	Travel times, queue lengths	Direct observations, system data, continuous count station data

Hypothesis	Measures of Effectiveness	Data Sources
The use of ITS in work zones will enhance the safety performance of the highway	Crashes, incidents	Crash data, work zone inspector diaries
The use of ITS in the work zone will reduce traveler exposure to hazard	Demand patterns, travel times, speed variability	Direct observations, system data, continuous count station data, evaluation-specific devices

The system archived data to support the evaluation and hypothesis testing. The study team collected baseline data (without ITS) from April 18 through May 10, 2004, during Phase II of construction. The study team collected all other data (with ITS) between June 14 and June 29, 2004, during Phase III (data collected on June 14, 2004, fell within Phase II). While the type of construction differed during each, both phases were similar in lane closure configuration. However, NCDOT restricted lane closures during Phase III to nighttime hours. The system detectors archived data from May 22, 2004 until July 16, 2004

Findings

The study team made several interesting observations throughout the deployment, one of which showed that the ITS system never reached its full potential as it never fully activated to encourage diversion. The level of demand was generally lower than the threshold for full activation. Several weeks of construction occurred along the corridor prior to full implementation of the system. The traffic impacts during the time period prior to deployment may have warranted full activation for active diversion. Additionally, local motorists may have chosen to take alternate routes during peak period commutes, thereby lowering demand. As a result of the system not reaching its full potential, the supplemental traffic count data collected for the diversion study were not analyzed.

Several schedule and data issues hindered the full assessment of each hypothesis; however, an assessment of data and other information from the overall deployment uncovered useful insights that are outlined in this section and in the lessons learned below. The study team made several interesting observations throughout the deployment, one of which showed that the ITS system never reached its full potential as it was never fully activated to encourage diversion. The level of demand was generally lower than the threshold for full activation. Several weeks of construction occurred along the corridor prior to full implementation of the system. The traffic impacts during the time period prior to deployment may have warranted full activation for active diversion. The deployment process took NCDOT longer than expected and the system was not available during the first phases of construction. Based on the analysis, which showed some inconsistencies in the data, the study team suspects that there potentially may have been some issues with system function or data archiving. *Consequently, all hypotheses were inconclusive due to limitations in the information available for analysis.*

Construction Activity Information

With the original intent of assessing impacts to traffic, the study team obtained construction activity and capacity reduction information. NCDOT construction inspectors and field engineers recorded information in activity logs for each day that work occurred as shown in Tables 18 and 19. Time periods of interest included those in which lane closures were in place. The recorders made notes on crashes within the work zone and at the approaches, maximum queue lengths, and specific activities that occurred.

Table 18. Construction and Lane Closure Information (without ITS)

Date	Time of Day (Beginning)	Time of Day (End)	Crashes Observed	Maximum Observed Queue Length (WB/EB)	Activity Notes
4/19/2004	9:00 AM	7:30 PM	--	1 mile	Closed Eastbound Inside lane, for concrete pavement repair
4/20/2004	6:30 AM	6:30 PM	--	1 mile / 1 mile	Set lane closure in the Westbound Outside lane, and Eastbound Inside lanes
4/21/2004	6:30 AM	6:30 PM	--	1 mile / 1 mile	Set lane closure in the Westbound Outside lane, and Eastbound Inside lanes
4/22/2004	7:00 AM	5:00 PM	--	1 mile / 1 mile	Set lane closure in the Westbound Outside lane, and Eastbound Inside lanes
4/23/2004	7:00 AM	3:00 PM	--	1 mile / 1 mile	Set lane closure in the Westbound Outside lane, and Eastbound Inside lanes
4/27/2004	7:00 AM	6:00 PM	--	1 mile / 1 mile	Set lane closure in the Westbound Inside lane, and Eastbound Inside lane
4/28/2004	6:30 AM	4:00 PM	--	1 mile	Set lane closure in the Westbound Inside lane
4/29/2004	6:30 AM	6:30 PM	1	1 mile	Set Barrier wall in the Eastbound Outside lane, for Slab Removal
4/30/2004	7:00 AM	3:30 PM	--	1 mile	Barrier still in place for concrete to cure
5/1/2004	7:30 AM	3:30 PM	1	1 mile	Barrier still in place for concrete to cure
5/2/2004	---	---	--	1 mile	Barrier still in place for concrete to cure
5/3/2004	6:00 AM	4:30 PM	--	1 mile	Set Lane Closure Eastbound Outside, removing barrier wall
5/4/2004	7:00 AM	5:00 PM	--	2 miles	Extending Lane Closure, Westbound Outside Lane
5/5/2004	7:00 AM	5:00 PM	--	1 mile	Set Lane Closure in the Westbound Outside

Date	Time of Day (Beginning)	Time of Day (End)	Crashes Observed	Maximum Observed Queue Length (WB/EB)	Activity Notes
5/6/2004	7:00 AM	4:00 PM	--	1 mile	Extending Lane Closure, Westbound Outside Lane
5/7/2004	6:30 AM	3:30 PM	1	1 mile	Set Lane Closure in the Eastbound Outside
5/8/2004	---	---	--	1 mile	Barrier still in place for concrete to cure
5/9/2004	---	---	--	1 mile	Barrier still in place for concrete to cure
5/10/2004	7:00 AM	5:30 PM	--	1 mile	Lane Closure set in Eastbound Outside lane

Table 19. Construction and Lane Closure Information (with ITS)

Date	Time of Day (Beginning)	Time of Day (End)	Crashes Observed	Maximum Observed Queue Length	Activity Notes
6/14/2004	6:00 AM	7:30 PM	--	2.5 miles	Set Lane Closure Westbound Inside and Eastbound Inside lanes
6/15/2004	6:00 AM	11:30 PM	--	1.5 miles	Set Lane Closure Westbound Outside
6/22/2004	7:00 PM	12:00 AM	--	2.5 miles	Westbound Outside lane closure
6/23/2004	12:00 AM	7:30 AM	--	2.5 miles	Westbound Outside lane closure
6/24/2004	5:00 PM	12:00 AM	--	2.5 miles	Set Lane Closure Eastbound Outside
6/25/2004	12:00 AM	5:00 AM	--	2.5 miles	Set Lane Closure Eastbound Outside
6/28/2004	5:00 PM	12:00 AM	--	2.5 miles	Set Lane Closure Eastbound Inside
6/29/2004	12:00 AM	10:30 AM	--	2.5 miles	Set Lane Closure Eastbound Inside and Westbound Inside

The study team parsed applicable notes for the days of interest during the periods both "without ITS" (Table 18) and "with ITS" (Table 19). Interestingly, field notes highlighted longer maximum queue lengths during periods of nighttime construction. The observed maximum queue lengths were also shorter without the system in place. Three crashes occurred prior to system implementation and no crashes occurred while the system was operational. The system may have been useful in alerting motorists to slowed traffic approaching the work zone. NCDOT described the early crashes as "back-of-queue-related."

System Detector Traffic Data

The study team sorted and analyzed traffic data from system detectors to identify deficiencies and potential for use in the analysis. The archived traffic data from each detector consisted of more than 200,000 records covering a time period from May 22 through July 16, 2004. Each message consisted of a volume count, an average speed value, and an average occupancy value by lane for both lanes in each direction.

Through analysis of the traffic data, the study team identified limitations that hindered some of the original plans for analysis. A key indicator of problems with the traffic data was a large variation in daily demand. The study team developed volume summaries for each day from system archives, and extremely large variations existed with a sharp increase in late June (as shown in Figure 27). The chart shows data from system detector #9 as an example. All other detectors showed similar patterns of variation. Detector #9 monitored westbound traffic and was the closest detector to the work zone. Based on traffic patterns, a reasonable daily volume per direction is 20,000 to 25,000 vehicles per day. Traffic volume data appear to be reasonable for several days.

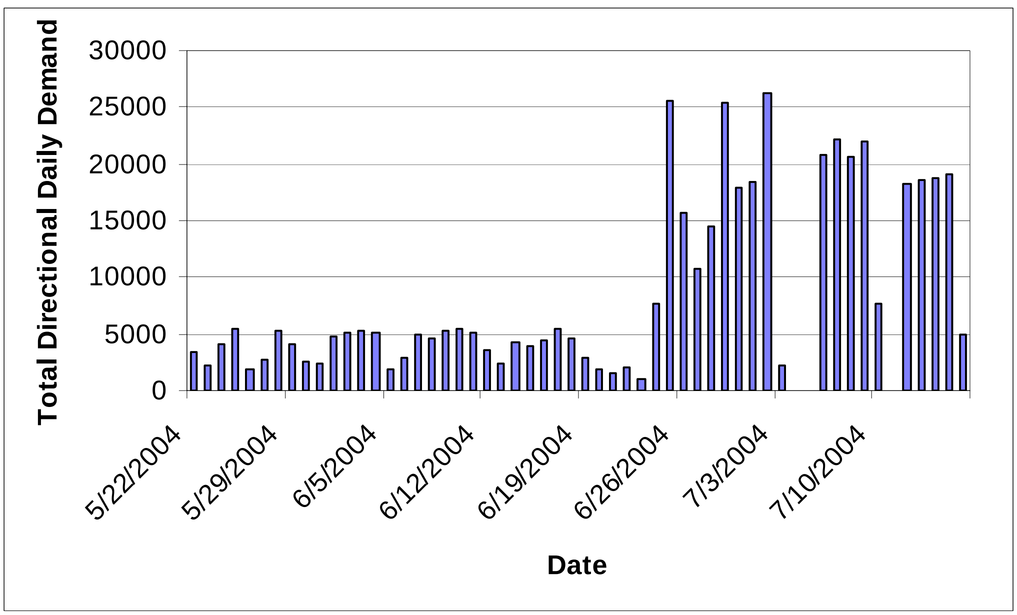

Figure 27. Daily Volume Totals Reported by System Detector #9

The analysis highlighted missing volume data for most days in June along with portions of July 3-6 and July 10-12. The system did not record data for July 4, 5, and 11. The reason that the system log volume data did not match expected, reasonable traffic volumes was unclear. System integrators cited a potential problem in the way the system wrote data to logs early in June, a problem that was not evident in a clear pattern or trend in the data. Sensor operational issues could also be an explanation for the missing data.

Speed and occupancy data were plotted for each detector for several days when lane closures were in place. The system detector data did not show a clear trend in low speeds and high occupancy values for any given day that matched the construction inspector logs. However, the study team observed apparent gaps in data during each day in which construction activities took place.

With the exception of a small number of data points, the occupancy values recorded by the system appeared reasonable. Less than 1 percent of all occupancy values observed were higher than 12 percent occupancy—a value where traffic flow borders on unstable operations.[5] However, some data points may not have been archived.

The system recorded average speeds for each time period listed, while a large amount of observations showed a speed reading of "240" (a default value recorded when an accurate average speed measurement could not be determined). Table 20 shows the percentage of undetermined average speed observations by sensor and the total number of observations where the system made no determination of speed. For some sensors, the system recorded a large portion of the total speed measurements as "240." Additionally, sensors 5 and 7 had much lower total observations than the remaining sensors. Clearly, some issues existed with the data set.

Table 20. Average Speed Values Reported As "240"

System Detector	Lane 1 (240)	Lane 2 (240)	Total (Values)	Percentage Lane 1 (240 to Total)	Percentage Lane 2 (240 to Total)
1	3057	10804	24566	12%	44%
2	19748	4975	23551	84%	21%
3	8182	7330	25287	32%	29%
4	7740	10617	25433	30%	42%
5	4895	6390	15651	31%	41%
6	15132	2551	22200	68%	11%
7	2726	1449	6255	44%	23%
8	7813	2417	23073	34%	10%
9	3256	1800	23671	14%	8%
10	4442	1934	25336	18%	8%

Dynamic Message Sign Data

The system archived message logs for the same time period as traffic data. The archives included more than 100,000 records. The study team observed missing data for the same time periods in the message logs as were observed in the traffic data logs. However, the study team made some important observations from the message logs.

Throughout the deployment, the system posted nearly 30 different messages at different times. The system often posted delay messages, but the study team did not observe messages showing delays other than 15 or 30 minutes. On multiple occasions, the system posted delay messages for very short periods followed by a general message showing no delay through the work zone. In

[5] May, Adolf D., "Traffic Flow Fundamentals," Prentice-Hall, New Jersey, 1990, page 194.

addition, message boards in sequence along the same approach to the work zone were inconsistent.

The system used several preprogrammed messages, and operators had the ability to override the system and post messages manually as needed. In addition to the pre-determined messages listed below, some message signs were blank during several time periods, often after the testing period was complete. A few messages included a mix of words and random letters and symbols.

Messages Showing Delay

- 15 MINUTE DELAY / EXIT 180 TO EXIT 184.
- 15 MINUTE DELAY / SLOW MOVING TRAFFIC.
- I-40 15 MIN DELAY / NEAR CLEMMONS EXIT 184.
- I-40 15 MIN. DELAY / NEAR CLEMMONS EXIT 184.

Messages Showing No Delay

- I-40 WORKZONE INFO / NO DELAY EXIT 180 TO 184.
- I-40 WORKZONE INFO / NO DELAY EXIT 184 TO 180.
- REALTIMETRAFFIC INFO / NO DELAY NEXT 4 MILES.
- SPEED LIMIT 65 / DRIVE SAFELY.

Example Test Message

- MESSAGE SIGN TEST / DRIVE WITH CAUTION.

Messages Encouraging or Requiring Diversion

- 30 MIN DELAY AHEAD / USE EXIT 170 AS ALT.
- I-40 CLOSED AHEAD / TAKE 421 TO I-77.
- I-40 CLSD AT EXIT 182.
- I-40 CLSD AT EXIT 182 / EXPECT DELAYS.
- I-40 CLSD AT EXIT 182 / TAKE 421 TO I-77.

Messages Showing General Traffic Conditions

- CAUTION CAUTION CAUTION / LEFT LANE CLOSED / 2 MILES AHEAD.
- I-40 WORKZONE ALERT / TRAFFIC SLOWING AHEAD.
- REALTIMETRAFFIC INFO / TRAFFIC SLOWING AHEAD.
- REDUCED SPEED AHEAD / USE CAUTION.
- ROAD WORK AHEAD / DRIVE SAFELY.
- ROAD WORK ON I-40 / EXPECT DELAYS ON I-40.
- SLOW MOVING TRAFFIC / DRIVE FRIENDLY / EXPECT DELAYS.
- SLOW TRAFFIC AHEAD.

Other Messages

- BUCKLE UP / DRIVE SAFELY.
- CAUTION CAUTION CAUTION / ONE LANE ROAD AHEAD / PREPARE TO STOP.
- FLAGMAN AHEAD / SHELBY FARMS MUSIC / PREPARE TO STOP AHEAD.

On several occasions (especially for weekend activities), NCDOT moved message boards to different locations. NCDOT remobilized the system during one complete road closure on westbound I-40 from Friday June 4, 2004, at 8:53 p.m. until Saturday June 5, 2004, at approximately 5:17 p.m. NCDOT moved six of the message boards to different locations and posted the following messages:

- I-40 CLOSED AHEAD / TAKE 421 TO I-77.
- I-40 CLSD AHEAD / TAKE 421 TO I-77.

The study team was aware of the planned closure, but decided not to collect supplemental data that weekend due to the short duration and limited options for through travelers. Prior to the closure, NCDOT provided information to the media on the planned activities and alternate routes. A local newspaper article[6] cited delays on I-40 and US-158, the alternate route for local traffic and motorists who misunderstood the I-40 message signs. The article referenced a message sign that mentioned exit 182 as the last exit prior to the closure. A local reporter interviewed motorists who said they were confused and thought they would reach 421 at that exit.

The system also posted the message "30 MIN DELAY AHEAD / USE EXIT 170 AS ALT" during the complete closure on June 5, 2004, for 3 minutes at approximately 11:00 a.m. and 7 minutes at approximately 12:00 p.m. The system used two versions of the message, with the difference being the presence of a period after "MIN" in the alternate version of the message listed above. The system posted these messages randomly, once on DMS005 and once on DMS003, during the complete directional closure.

Exit 170 is the I-40 off ramp to US-601, which was one of the signed alternate routes. NCDOT did not have information on the exact system layout during the weekend closure, although they may have moved the boards to locations where they targeted eastbound motorists prior to exit 170 and the work zone. The two occasions on June 5, 2004, were the only observations from the data where the system posted 30 minute delays along with alternate route information—the fullest extent to which the system could activate.

Despite some data inconsistencies, the study team found very useful information from this evaluation. Although the deployment did not allow for the quantitative assessment of system benefits desired, the study team uncovered several lessons learned to the benefit of NCDOT and others interested in deploying similar systems.

Tips and Lessons Learned

Deployment Tips and Lessons Learned

The ITS schedule needs to be linked to the construction schedule to maximize use and benefit of the system. At this site, the system was deployed after several weeks where significant traffic impacts had occurred. To achieve the maximum benefit, ITS should be operational prior to any lane restrictions.

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[6] Patrick Wilson, "Traffic meets drivers detoured from Interstate 40," *The Winston-Salem Journal,* June 6, 2004, http://www.journalnow.com.

Delays occurred not only at lane drops, but also within the work zone due to slow moving trucks that deliver materials to the site. NCDOT learned this lesson from past deployments, so for this deployment, NCDOT placed extra sensors within the work area.

In design and implementation of ITS for work zone applications, agencies should involve the construction contractor to the fullest extent possible. Local NCDOT representatives cited the need to involve the construction contractor to the extent that they are fully aware of goals and objectives for the system, even if the contractor is not involved in the procurement of the system.

ITS deployments for work zone applications require communications and technology experts along with traffic engineering experts. A hardware / software / communications expert should be in regular (e.g., daily) contact with a traffic engineer to ensure full system functionality and that the ultimate goals of the system are achieved. For this deployment, NCDOT engineers coordinated with vendor communications experts to deploy the system.

The vendor and the implementing agency should discuss in sufficient detail the concept of operations for the system, reach an understanding of exactly how it will process information, and determine what messages to post. Technology can easily become a “black box” where data are input and actions result. A champion for the deployment should be familiar with all aspects of system functionality and should guide the vendor.

Implementing agencies should use verification techniques to validate the outputs of the system and refine system operating procedures as needed prior to implementation. Agencies should perform a dry run using a test data set to simulate traffic condition information to monitor the system and verify output. Agencies should also develop performance metrics prior to system implementation to establish specific means of monitoring how well the system worked during the deployment. For this deployment, observation and analysis of interim data proved difficult due to the level of effort needed to access and view preliminary data sets. Therefore, NCDOT relied on the vendor to ensure system functionality and accuracy.

The system should use message board controls to prevent conflicting messages from being displayed along the same approach to the work zone area. At this study site, message logs showed that motorists observed conflicting messages, including delay warnings followed by free flow condition messages.

Personnel from the implementing agency should have real-time access to archived system data to identify any issues and monitor system functionality. A Web site could easily provide password protected access to the data being used by the system to make decisions. The Web site for this project provided access to real-time data but did not provide access to the data archives.

Deploying agency representatives should engage personnel responsible for use of supplemental components (such as NCDOT’s permanent DMS for use during high delay periods) on a regular basis to ensure that everyone is current on the concept of operations and their roles and responsibilities. The North Carolina deployment relied on a portable work zone system as well as using some components of a permanent traffic management system.

Evaluation and Research Tips and Lessons Learned

A successful evaluation of a work zone ITS deployment relies heavily on the cooperation of each entity involved, including the implementing agency, the vendor, and especially the personnel responsible for successful completion of the construction project. For this evaluation, all parties were helpful in obtaining necessary information. Priorities must be set as the needs of the evaluation can often place a burden on personnel involved with system deployment and operation.

In developing an evaluation plan, evaluators should focus on a prioritized set of metrics that will provide the greatest opportunities to test the benefits of the system. In depending on the use of a specific data source, evaluators should test a sample data set to identify any irregularities and to confirm the format needed for analysis.

Research into the use of non-intrusive detector data to quantify traffic flow conditions in work zones is warranted. This evaluation highlights a greater understanding of detector outputs, but additional work is needed to compare actual traffic conditions with data observed through microwave sensors.

Overall Findings

This study quantified benefits of ITS deployments for work zone applications and also documented key lessons learned from these deployments and previous experience. This study provides practitioners with information on what to expect when deploying similar systems, and also provides key insights into how to design them and tie the design to the objectives for system operation. Agencies interested in deploying similar systems can benefit from the findings of this study. Interested agencies can also use the lessons learned from the deploying agencies to advance their knowledge and to assist with planning, design, and operation of a work zone ITS deployment. This study helps progress current implementation and supplements current research through findings of a quantitative nature for the effects of mobile traffic monitoring and management systems.

The following sections outline the findings across the sites, provide tips and lessons learned from this study, and show how the findings of this study compare with other studies. This chapter concludes with some ideas for future work.

Findings on Key Measures Across Sites

Several sites in this study (NC, TX, DC) focused on diversion and demand reduction, while one (MI) focused on controlling merge conditions. The Arkansas site focused on general work zone condition information, where surveys proved most useful in capturing information on benefits. This study produced several quantitative benefits and provided information and outcomes similar to those anticipated.

Among the two diversion-based sites with quantitative benefits (TX, DC), the results were somewhat different. TXDOT signed the alternate routes and posted messages specifically advising motorists to take one alternate route. A large portion of the trips along the mainline route were likely through trips. DDOT did not sign specific alternate routes, and posted general messages advising motorists to seek an alternate route. A large portion of the trips along the mainline route in Washington, DC were likely commuter trips. It should be noted that based on the data available, it was not possible to determine what portion of the lower mainline volume observed at the DC site was due to diversion versus demand reduction versus congestion. Some of the lower observed mainline volumes in the District of Columbia were likely due to the high percentage of local trips to total trips, since local drivers are more likely to be aware of the work zone and able to divert to another familiar route to avoid the area. The main trip type is important in determining how to design the diversion plans. The findings from the sites with active diversion noticeably expand the body of knowledge regarding work zone ITS, as quantitative information on diversion rates was not abundant prior to this study.

The Michigan site showed quantitative benefits in smoothing traffic at the merge point. The dynamic lane merge site showed results similar to that of previous studies, while expanding on comparisons between time periods with activation and no activation. The Arkansas site provided information on the opinions and reactions of drivers as stated directly in survey responses and showed benefits based on user surveys that indicated the system helped motorists better plan for and make trips.

Overall, the benefits from this quantitative study were positive. The results of the key measures used in this study are summarized in Table 21.

Table 21. Comparison of Key Measures by Site

Location	Type of System Used	System Objectives	Key Performance Measures	Benefits Based on Relative Change in Measures
District of Columbia	Real Time Information System	Provide delay and travel speed information and reduce congestion by actively diverting traffic	Traffic Diversion, Queue Lengths	3% to 90% lower observed mainline volumes (with an average of 52%) over 9 observation periods by warning motorists prior to entering the mainline, compared with similar days of the week*
Texas	Delay Monitoring System	Provide delay information and reduce demand and congestion by actively diverting traffic	Traffic Diversion	1% to 28% reduction in mainline traffic volume (with an average of 10% reduction) over 20 observation periods where the system actively diverted traffic during congested periods, lessening the demand for restricted mainline capacity
Michigan	Dynamic Merge System	Reduce aggressive driving, smooth traffic flow and reduce delay at merge point	Aggressive Maneuvers	Significant reduction in forced and dangerous merges when flashers were on (by a factor of seven for forced merges, and a factor of 3 for dangerous merges), potentially reducing the risk of rear-end and side-swipe collisions near the merge taper
		Reduce delay from aggressive passing at the merge area	Travel Times	Increase in travel times (from an average of 4 minutes to 7 minutes) when lights were flashing due to slightly longer queues prior to merge
Arkansas	Work Zone Information System	Improve traveler safety by providing real-time information to motorists	Survey Response to Safety-Related Questions	82% of surveyed drivers felt that the ITS system improved their ability to react to stopped or slow traffic. 49% of surveyed drivers agreed that they felt safer traveling through the work zone because of the electronic messages, 17% were neutral, 32% disagreed, and 2% did not answer.
North Carolina	Delay Monitoring System	Provide delay information and reduce demand and congestion by actively diverting traffic	Traffic Diversion	N/A – system did not fully activate

*Combination of diversion, demand reduction, and congestion

Cross-Cutting Tips and Lessons Learned

The study team observed several common keys to success and lessons learned across agencies when deploying work zone ITS applications.

A critical element to using work zone ITS successfully is for agencies to map out a decision-making process when planning for ITS for work zone traffic management. The process should involve setting goals and objectives for what the owner-agency wants the system to do. Agencies should consult vendors and inquire about specific solutions, but the solution should match the overall goals and objectives for the deployment that are established by the agency. The goals and objectives should be kept current as the deployment progresses, and agencies should monitor how well the system is meeting the intended goals.

Based on this study, several key considerations are identified that should be considered for every ITS deployment:

- The intensity of construction activities and anticipated traffic mobility and safety impacts.
- The level of demand for the area under construction.
- Availability and adequacy of alternate routes, especially when diversion is planned.
- Needed enhancements to ensure that alternate routes operate efficiently during construction (signal timing changes, minor improvement projects prior to mainline construction, etc.).
- Access to and availability of other mode choices during the construction period.

Assessing these considerations during system design and development is important to help ensure that the ITS is needed and can be used effectively, both of which are key to knowing if an ITS deployment in a particular work zone is likely to be a good investment.

In each site studied, a champion was active in selling the concept and ensuring momentum for the deployment continued at an appropriate pace to lead to the successful deployment of the system. Additionally, each site had the appropriate leadership from a group of individuals within the agency to ensure appropriate levels of communication across different groups with the transportation agency and external to the agency with groups such as law enforcement, contractors, and vendors.

The owner-agencies typically hired a vendor who in turn directly provided or procured the services of a local firm to provide hardware, communications, and on-site maintenance and support. However, in some cases, the construction contractor hired the vendor. Irrespective of the arrangement, proper communication channels should remain open between the owner-agency, the construction contractor, the design consultant (if applicable), and the vendor to ensure system success.

In addition to these overall tips and lessons learned, the study team made some observations that apply to specific aspects of system development and deployment, as outlined in the sections below.

Planning

- Agencies should develop goals for the system based on systematic consideration of the potential impacts to traffic from the planned construction activities so that the system design is appropriate for the conditions.
- Goals and objectives for the system should be as specific and detailed as possible (e.g., to reduce aggressive maneuvers at the work zone taper) to maximize benefits from appropriate system design.
- The system concept should be designed around the detailed goals and objectives to ensure adequate mitigation of expected impacts.
- Demand levels and capacity restrictions from construction should be studied early on to identify the potential impacts from construction and validate the need for a portable traffic management system.
- If the agency is also implementing other countermeasures to mitigate traffic impacts (such as night work only), the agency needs to consider how much this will lessen the impact/usage of the ITS system and factor that into its decision on whether to deploy ITS for the given work zone.
- The construction contractor should be involved to the greatest extent possible in system deployment to allow for proper timing in deployment, and to ensure that the contractor understands the importance of the system and the placement of the system components. This may help ensure that the system is active within the appropriate time periods and locations during construction.
- The system deployment schedule should be tied to the construction activity schedule to ensure that the system is deployed at the right time to maximize the effectiveness of the investment.
- Adequate time should be allotted for system procurement, installation, and testing so that the deployment covers early construction impact periods.
- Right–of-way use permits may be required prior to equipment installation, may take extra time to complete, and should be accounted for to ensure the deployment covers the early construction impact periods.
- All stakeholders should be involved early in system planning and throughout design to ensure roles and responsibilities are adequately communicated.
- Educating stakeholders who may not be familiar with work zone ITS, such as the media, the public, and law enforcement, is important in ensuring the cooperation needed for system success.

Design

- Agencies should design work zone ITS systems with flexibility in mind since work zones are highly variable environments and system adjustments may be needed during deployment.
- Adequate communication must occur between communications experts (ITS vendors) and traffic and construction engineers (owner-agency) to effectively plan, design, operate, and maintain the system.
- Vendors can assist agencies with determining the best design for a deployment by gaining a solid understanding of the owner-agency's goals for alleviating impacts from the work zone.
- The system design should include proper evaluation of detector spacing and coverage to obtain the accuracy and precision of data needed for the system, particularly if system goals include displaying real-time travel time information.
- Agencies should consider effects on local streets from diverting traffic around the work zone.

Operation and Maintenance

- Agencies can benefit from hiring a software/system vendor that has a local partner company that supplies hardware, message boards, and can be more readily available to perform routine inspection and maintenance of the system.
- Leasing system components from a vendor or local hardware company can save on long-term maintenance and replacement costs.
- Agency personnel should validate system detector data through various means, such as observation of field volumes compared with data archived from the same time period, as a check that the system is functioning as intended.

Prior to starting this study, the study team assumed that work zone ITS systems would be "off-the-shelf," tested, proven solutions. This proved to not be the case in several instances. While the hardware, software, and communications technology may be tested and may operate correctly, these systems must be planned and designed from scratch for each work area to have the maximum effectiveness. Sensor location, message board location, types of information posted, and algorithms for calculating the metrics upon which the system will activate could benefit from standardization or guidance. Vendors have proprietary solutions that likely differ in process. Uniform guidance on planning and designing the systems would likely prove useful for agencies.

Comparisons with Results of Other Studies

The findings of this study are comparable to previous research for several of the sites, and go beyond previously available knowledge on benefits for others. The following sections outline some of the previous research and show how the findings of this study compare with other studies.

Two system types are identified for comparison. The first is the type of system that physically controls traffic conditions such as the Michigan Dynamic Lane Merge System. The second is more of a monitoring and information dissemination system that provides motorists with real-time information so that they can make informed route choice decisions, such as those deployed in Arkansas, North Carolina, and Texas. Both have an element of controlling traffic to improve the operational performance of the work zone.

Previous lane merge studies showed significant reductions in aggressive maneuvers at the work zone taper similar to the findings of this study. For sites with the potential for longer queues, agencies have implemented and studied the late merge system, which also showed direct benefits. The traffic monitoring systems have proven more difficult for measuring quantified benefits, as the benefits are typically indirect in that these systems generally provide enhanced information to motorists. The systems that display alternate route guidance have been implemented to a greater degree recently, including those studied for this project.

Enforceable Merge Systems

Michigan DOT undertook several studies in the recent past to evaluate the effectiveness of the Dynamic Lane Merge System. The system merges traffic early in locations where queue spillback is at acceptable levels. MDOT cited an effectiveness range of 3,000 to 3,500 vehicles per hour for the three-to-two merge situation, and 2,000 to 3,000 vehicles per hour for the two-to-one merge situation. Queuing will occur in both situations and is needed to warrant use of the system since queue conditions create a potential for forced merges. For the I-94 deployment[7] (three-to-two merge), the average number of aggressive maneuvers during the peak hour decreased from 2.88 to 0.55. For a two-to-one deployment on M-53 in Grand Rapids, Michigan, the average number of aggressive maneuvers decreased from 68.0 to 32.0 during the morning peak period, and decreased from 38.0 to 9.0 during the afternoon peak period. The percent reduction in aggressive maneuvers for the Michigan site in this study was higher than previous studies; however, the total number of observed aggressive maneuvers was lower.

For higher traffic locations, agencies have successfully used the Late Merge System to smooth merges at the work zone taper. The Late Merge System allows traffic to use both lanes on one approach and advises motorists via dynamic message signs to take turns merging from each lane. Minnesota DOT found that discontinuous lane usage increased to 60 percent at one sensor location on I-494.[8] While MnDOT was not able to perform a true before and after comparison

[7] *Development And Evaluation of an Advanced Dynamic Lane Merge Traffic Control System For 3 to 2 Lane Transition Areas in Work Zones*. Michigan Department of Transportation, 2004.

[8] *Evaluation of 2004 Dynamic Late Merge System*. Minnesota Department of Transportation, 2004.

(temporary traffic control conditions both with and without ITS), evaluators observed minimal queues during the course of the study. Research has shown that the late merge system is better for higher traffic levels and where the availability of queue storage is low, while the early merge system is a tool for lower demand, higher queue storage locations. However, a system of message signs and sensors that can adjust automatically between the early merge and late merge concept may be most beneficial to owner-agencies. This type of active merge system has been used in Minnesota.

Traffic Information Systems

Some agencies have tested and used mobile traffic monitoring and management systems to provide real-time information to motorists. These systems display information about work zone conditions, but can also play an important role in alleviating traffic congestion due to incidents. It is often more difficult to evaluate the benefits of these types of systems in a quantifiable way, especially for metrics such as safety. For example, a system may provide advance warning of queued conditions to reduce speed variability and the potential for rear end collisions. But, with many common limitations in evaluating crash records for safety performance, agencies may find it difficult to quantify the benefits. Such benefits are needed to build support from decision makers to continue use of such systems.

Some systems are also designed to provide information but with one direct outcome in mind, such as to reduce speed at a work zone to improve the safety performance of the work zone. A Midwest Smart Work Zone Initiative Study of a speed monitoring and display system found a significant reduction in speed (5 mph) near the work zone taper. Three other deployments along I-80 near Lincoln showed similar results. The study team observed a 3 to 4 mph reduction in mean speed, a 2 to 7 mph reduction in 85th percentile speed, and about 20 to 40 percent increase in vehicles complying with the speed limit.[9]

Some studies have tested diversion around work zones based on real-time information. Some systems actively divert traffic by providing guidance to motorists, while others provide general delay information and allow motorists to make route decisions. The limitation of the latter concept is that likely only motorists familiar to the area will divert without the direct guidance to do so. For areas with mainly through traffic, this concept should be considered in the design stages to ensure the intended outcome is realized. A study of the effectiveness of an Automated Work Zone Information System on Interstate 5 in California showed diversion rates of 9 percent to 12 percent based on condition information.[10] Similar studies in Nebraska and Kentucky showed very little diversion based on general condition information. While the traffic makeup is unknown for the sites mentioned (commuter versus through trips), specific guidance for motorists on when to divert to alternate routes will, under the appropriate conditions, have a better result. For example, a study of a North Carolina Smart Work Zone deployment found that, "…alternate route usage is increased in the range of 10 to 15 percent with the presence of a

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[9] McCoy, Patrick and Geza Pesti. *Smart Work Zone Technology Evaluations: Speed Monitoring Displays and Condition-Responsive, Real-Time Travel Information Systems*. Midwest Smart Work Zone Deployment Initiative, 2000.

[10] Chu, Kim, Chung, and Recker. "Evaluation of Effectiveness of Automated Work Zone Information Systems." TRB 2005 Annual Meeting Compendium.

Smart Work Zone that provides specific information about delays and alternate routes."[11] In general, practitioners in North Carolina have observed, "…some increase in usage of alternate routes," across their various deployments of work zone ITS.[12]

Additional Comparative Data

A recent FHWA review of work zone ITS benefits[13] produced the following documented results:

- Between 50 percent and 85 percent of drivers surveyed said that they changed their route at least sometimes in response to travel time, delay, or alternate route messages provided by work zone ITS.
- Reductions in queue lengths from 56 percent to 60 percent are possible, with simulations indicating system-wide reductions in total delay may range from 41 percent to 75 percent.
- Speed monitoring displays (SMD) reduce speeds in work zones by 4-6 mph. One study found a 20-40 percent reduction in vehicles traveling 10 mph or more over the speed limit when SMD were used.

The results of this study are comparable to the other studies referenced herein, with some additional insights into deployment and assessment of ITS for work zone applications. The results from this study for the lane merge system is comparable to that of past evaluation projects such as those performed by Minnesota DOT and Michigan DOT, while the benefits of providing alternate route information are further substantiated through this study. Some previous studies focused more on changes in performance measures and statistical analyses related to metrics such as speed. Additionally, this study provides further evidence of the general benefits of properly planned and design work zone ITS deployments.

[11] Bushman, R. and Berthelot, C. *Effect of Intelligent Transportation Systems in Work Zones – Evaluation of North Carolina Smart Work Zones Final Report*. Transportation Research Center, University of Saskatchewan, 2004.
[12] Kite, S. "North Carolina's Smart Work Zone Experience." Presented at the ITS Virginia Meeting, 2004.
[13] FHWA, Intelligent Transportation Systems for Work Zones: Deployment Benefits and Lessons Learned. http://www.its.dot.gov/jpodocs/repts_te/14320.htm

Suggested Future Work

This report highlights benefits from five deployments of ITS for work zone traffic management. Some benefits from these deployments were qualitative, such as enhanced coordination within and outside of an agency for work zone impact mitigation and greater public satisfaction with the work zone. Other benefits were quantitative such as a percentage reduction in traffic during congested periods, lower delay, and increased safety from automated traffic management. The sites showed benefits resulting from trying new techniques such as ITS to help mitigate the overall impacts caused by work zones. Agencies interested in new tools to combat work zone congestion and safety issues will benefit from the results included in this report.

Several areas can benefit from additional research and investigation. These areas for action are highlighted in the following list.

- Investigate the impacts on alternate routes – Many ITS applications focus on using corridor level capacity to alleviate mainline congestion. Studies are often limited to data collection on the mainline only due to increased cost and difficulty in determining when to collect data (such as travel times using probe vehicles) on alternates. Quantifying corridor-level impacts will be useful for practitioners.
- Investigate the potential for traffic simulation for ITS – Some models could be used to estimate potential benefits from ITS designs, similar to modeling alternative traffic control plans. Further investigation into this as a tool would be useful.
- Research thresholds for system activation – Different systems operate based on unique parameters. Further research into appropriate system activation metrics and thresholds, along with guidance for vendors and practitioners on how to set thresholds, will be useful for this industry.
- Develop training for planning and deployment of ITS for work zones – A training course would be useful to practitioners who are interested in deployment but don’t know where to start. The course should cover all aspects and provide practitioners with an opportunity to perform exercises in planning for a deployment.

APPENDIX A

ARKANSAS – PRIVATE DRIVER SURVEY

I-30 Little Rock to Benton Construction Zone Survey

1. HOW OFTEN do you travel on this section of I-30?
- ❑ Almost every day
- ❑ 1 – 4 times per week
- ❑ A few times a month
- ❑ Once a month or less
- ❑ This is my first time

2. For WHICH REASON do you most often travel this section of I-30?
- ❑ Commuting to/from school or work
- ❑ Local delivery
- ❑ Errands
- ❑ Traveling through on vacation
- ❑ Traveling through on business
- ❑ Other (please specify) ____

3. Have you heard of Arkansas' *Pave the Way* **Web site** (www.arkansasinterstates.com)?
- ❑ Yes; Where did you hear about it?

  ____
- ❑ No (skip to Question 4)

3a. Have you visited the portion of the Web site that provides info about the I-30 construction zone?
- ❑ Yes
- ❑ No; Why not?
  - ❑ I don't think the Web site would be helpful (skip to Question 4)
  - ❑ I don't have convenient access to the Web when I would need it (skip to Question 4)
  - ❑ Other ____ (skip to Question 4)

3b. HOW OFTEN do you visit the portion of the Web site that provides info about the I-30 construction zone?
- ❑ Almost every day
- ❑ 1 – 4 times per week
- ❑ A few times a month
- ❑ Once a month or less
- ❑ Only visited once

3c. For WHAT REASONS do you use the I-30 Web site? (Please mark all that apply.)
- ❑ To check the status of traffic conditions
- ❑ To find out what is causing a delay
- ❑ To plan the route I will take
- ❑ To plan what time to start my trip
- ❑ Other, (please specify)________________________________

3d. Rate your level of agreement/disagreement with the following statements about the I-30 Web site:

	Completely Agree 1	Somewhat Agree 2	Neutral 3	Somewhat Disagree 4	Completely Disagree 5	Not Sure
The Web site is EASY to use	❑	❑	❑	❑	❑	❑
The info on the Web site is ACCURATE	❑	❑	❑	❑	❑	❑
The info on the Web site improves my ability to avoid delay on this section of I-30	❑	❑	❑	❑	❑	❑
Just having the information on the Web site makes me feel less bothered by delays in the construction zone	❑	❑	❑	❑	❑	❑

4. Have you ever read the **electronic message signs** in this section of I-30?
❑ No; Why not? ____________________ (Skip to question 5)
❑ Yes

4a. Has the information on the signs ever caused you to exit this section of I-30 to take an alternate route?
(Please mark all that apply.)
❑ No, Nothing about the electronic message signs causes me to change my route
❑ No, I have no alternate route
❑ Yes, When the signs read "Traffic Slowing Ahead, Delays Possible"
❑ Yes, When the signs read "Traffic Stopped Ahead, Expect Delays"
❑ Other (please specify)
____

4b. Rate your level of agreement/disagreement with the following statements about the electronic message signs:

	Completely Agree 1	Somewhat Agree 2	Neutral 3	Somewhat Disagree 4	Completely Disagree 5	Not Sure
The messages are EASY to understand	❑	❑	❑	❑	❑	❑
The messages are ACCURATE	❑	❑	❑	❑	❑	❑
The messages are DETAILED enough to help me make decisions about my route	❑	❑	❑	❑	❑	❑
The signs are located in the right places to help me make decisions about my route	❑	❑	❑	❑	❑	❑
Because of the info on the signs, I am better prepared to react to slow or stopped traffic	❑	❑	❑	❑	❑	❑
I feel safer traveling through this construction zone because of the information on the signs	❑	❑	❑	❑	❑	❑
Just having the information makes me feel less bothered by the delays in the construction zone	❑	❑	❑	❑	❑	❑

5. Have you ever tuned into the **highway advisory radio** on this section of I-30?
- ❑ No; Why not?_________________________________ (skip to question 6)
- ❑ Yes

5a. Have the highway advisory radio messages ever caused you to exit this section of I-30 to take an alternate route? (Please mark all that apply.)
- ❑ No, Nothing about the highway advisory radio system causes me to change my route
- ❑ No, I have no alternate route
- ❑ Yes, When it states that there is a delay
- ❑ Yes, When it states that there is a lane closure
- ❑ Other (please specify) ____

5b. Rate your level of agreement/disagreement with the following statements about highway advisory radio:

	Completely Agree 1	Somewhat Agree 2	Neutral 3	Somewhat Disagree 4	Completely Disagree 5	Not Sure
The radio broadcast quality is too poor to hear properly	❑	❑	❑	❑	❑	❑
The messages are USEFUL	❑	❑	❑	❑	❑	❑
The messages are ACCURATE	❑	❑	❑	❑	❑	❑
The messages are updated frequently enough	❑	❑	❑	❑	❑	❑
The messages are DETAILED enough to help me make decisions about my route	❑	❑	❑	❑	❑	❑

6. Do you use any of the following sources to get information about traffic conditions on this section of I-30? (Please mark all that apply and please circle the one you rely on the most)
- ❑ *Pave the Way* Web site – www.arkansasinterstates.com
- ❑ Electronic message signs
- ❑ Highway advisory radio
- ❑ CB radio
- ❑ Local radio station (please specify) ______________________________
- ❑ Local television station (please specify) ___________________________
- ❑ Other (please specify) ____

7. Please stop me when I read the category that contains your age
- ❑ 16 - 25
- ❑ 26 - 35
- ❑ 36 - 45
- ❑ 46 - 55
- ❑ Over 55

Gender: M F

Date: **Time:** **Interview Conducted By:**

APPENDIX B

ARKANSAS – COMMERCIAL VEHICLE DRIVER SURVEY

I-30 Little Rock to Benton Construction Zone Survey

1. HOW OFTEN do you travel on this section of I-30?
- ☐ Almost every day
- ☐ 1 – 4 times per week
- ☐ A few times a month
- ❑ Once a month or less
- ❑ This is my first time

2. Considering the trip that took you through this section of I-30 <u>today</u>,

what was your ORIGIN? ________________________________

what is your DESTINATION? ____________________________

3. Why did you CHOOSE to travel on this section of I-30 <u>today</u>? (Please mark <u>all that apply</u> and please circle the <u>most important</u> reason)
- ❑ Part of a fixed dispatch route
- ☐ Shortest distance
- ☐ Thought it would be the quickest
- ☐ Roadside amenities (i.e. good restaurants, cheap gas, etc)
- ☐ No other feasible route
- ☐ Other (please specify) ____________________________________

4. In general, what must you do to TAKE AN ALTERNATE ROUTE? (Please mark <u>all that apply</u>)
- ☐ Nothing, I can reroute at will
- ☐ Call my Dispatcher
- ☐ Call my Customer
- ☐ I am not allowed to take alternate routes
- ☐ Other (please specify) ____________________________________

5. Have you heard of Arkansas' *Pave the Way* Web site (www.arkansasinterstates.com)?
- ❑ Yes; Where did you hear about it? ______________________________________
- ❑ No (skip to question 6)

5a. Have you personally used the portion of the Web site that provides info on the I-30 construction zone?
- ❑ Yes
- ❑ No; Why not?
  - ❑ I don't think the Web site would be helpful (skip to Question 6)
  - ❑ I don't have convenient access when I would need it (skip to Question 6)
  - ❑ Other ___________________________________ (skip to Question 6)

5b. HOW OFTEN do you use the I-30 Web site?
- ❑ Almost every day
- ❑ 1 – 4 times per week
- ❑ A few times a month
- ❑ Once a month or less
- ❑ Only visited once

5c. Before entering the construction zone, WHEN do you usually access the I-30 Web site?
- ❑ 6 hours or less before
- ❑ 6 – 12 hours before
- ❑ 12 – 24 hours before
- ❑ More than one day before

5d. FROM WHERE do you access the I-30 Web site?

- ❑ At home/terminal before starting trip
- ❑ En route via wireless internet
- ❑ En route at fixed internet access point (i.e. truck stop)
- ❑ Other (please specify) ___________________________

5e. For WHAT REASONS do you use the I-30 Web site? (Please mark <u>all that apply</u>.)

- ❑ To check the status of traffic conditions
- ❑ To find out what is causing a delay
- ❑ To plan the route I will take
- ❑ To plan the time I will start my trip
- ❑ Other (please specify)___________________________________

5f. Rate your level of agreement/disagreement with the following statements about the I-30 Web site:

	Completely Agree 1	**Somewhat Agree 2**	**Neutral 3**	**Somewhat Disagree 4**	**Completely Disagree 5**	**Not Sure**
The Web site is EASY to use	❑	❑	❑	❑	❑	❑
The info on the Web site is ACCURATE	❑	❑	❑	❑	❑	❑
The info on the Web site improves my ability to avoid delay on this section of I-30	❑	❑	❑	❑	❑	❑
Using the info on the Web site improves my ability to provide an on-time delivery	❑	❑	❑	❑	❑	❑

5. Does your dispatcher use Arkansas' *Pave the Way* Web site (www.arkansasinterstates.com)?

- ❑ No (skip to question 7)
- ☐ Yes
- ☐ Unsure

5a. May we have your dispatcher's contact info (optional)?

Name:_____________________ Phone Number:______________

6. Have you ever read the **electronic message signs** in this section of I-30?

- ❑ No; Why not? ______________________________ (Skip to question 7)
- ❑ Yes

6a. Have the electronic message signs ever caused you to exit this section of I-30 to find an alternate route?

(Please mark <u>all that apply</u>)

- ❑ No, nothing about the electronic message signs has caused me to change my route
- ❑ No, I have no alternate route
- ❑ Yes, when the signs have read "Traffic Slowing Ahead, delays possible"
- ❑ Yes, when the signs have read "Traffic Stopped Ahead, expect delays"
- ❑ Other (please specify)

____

6b. Rate your level of agreement/disagreement with the following statements about the electronic message signs:

	Completely Agree 1	Somewhat Agree 2	Neutral 3	Somewhat Disagree 4	Completely Disagree 5	Not Sure
The messages are EASY to understand	❑	❑	❑	❑	❑	❑
The messages are ACCURATE	❑	❑	❑	❑	❑	❑
The messages are DETAILED enough to help me make decisions about my route	❑	❑	❑	❑	❑	❑
The signs are located in the right places to help me make decisions about my route	❑	❑	❑	❑	❑	❑
Because of the info on the signs, I am better prepared to react to slow or stopped traffic	❑	❑	❑	❑	❑	❑
I feel safer traveling through this construction zone because of the electronic messages	❑	❑	❑	❑	❑	❑
Just having the information makes me feel less bothered by the delays in the construction zone	❑	❑	❑	❑	❑	❑
Using the info on the electronic messages improves my ability to provide on-time delivery	❑	❑	❑	❑	❑	❑

7. Have you ever tuned into the **highway advisory radio** on this section of I-30?

❑ No; Why not? ________________________________ (Skip to question 8)

❑ Yes

7a. Have the highway advisory radio messages ever caused you to exit this section of I-30 to take an alternate route? (Please mark all that apply.)

❑ No, Nothing about the highway advisory radio system causes me to change my route

❑ No, I have no alternate route

❑ Yes, When it states that there is a delay

❑ Yes, When it states that there is a lane closure

❑ Other (please specify)

____

7b. Rate your level of agreement/disagreement with the following statements about highway advisory radio:

	Completely Agree 1	Somewhat Agree 2	Neutral 3	Somewhat Disagree 4	Completely Disagree 5	Not Sure
The radio broadcast quality is too poor to hear properly	❑	❑	❑	❑	❑	❑
The messages are USEFUL	❑	❑	❑	❑	❑	❑
The messages are ACCURATE	❑	❑	❑	❑	❑	❑
The messages are updated frequently enough	❑	❑	❑	❑	❑	❑
The messages are DETAILED enough to make decisions about my route	❑	❑	❑	❑	❑	❑

8. Do you use any of the following sources to get information about traffic conditions on this section of I-30? (Please mark all that apply and please circle the one you rely on the most)

❑ *Pave the Way* Web site – www.arkansasinterstates.com
❑ Electronic message signs
❑ Highway advisory radio
❑ CB radio
❑ Local radio station (please specify) ___________________________________
❑ Other (please specify) ____

9. Please stop me when I read the category that contains your age

❑ 18 - 25
❑ 26 - 35
❑ 36 - 45
❑ 46 – 55
❑ Over 55

10. How long have you been driving commercial vehicles?

❑ Less than 1 year
❑ 1 – 5 years
❑ 5 – 10 years
❑ 10 – 20 years
❑ Over 20 years

Gender: M F

Date: **Time:** **Interview Conducted By:**

APPENDIX C

ARKANSAS – DESCRIPTION OF SURVEY ADMINISTRATION

The surveys administered as part of this project were performed as “intercept surveys.” Four personnel were utilized to administer the surveys. These personnel intercepted both private and commercial drivers at four different service stations in and around the I-30 work zone. The service stations used as part of this study are described in detail here.

1) Pilot Travel Center – I-30 Exit 121 – (Alcoa Exit) – This location served as an interview site for westbound commuters and CVDs. It has low prices, 8 pumps, a Subway franchise, and a lot of business. It is located at an exit used by nearby subdivision dwellers.

2) JJ’s Truck Stop and Restaurant – I-30 Exit 106 (Military Road Exit) –This location was used to interview westbound commercial drivers. It is a moderately large truck stop with a busy adjacent restaurant that caters to truck drivers. The restaurant has a lot of truck driver business and was used to conduct the interviews.

3) Conoco – I-30 Exit 123 (Hwy 183 Exit) – This location was used to interview eastbound commuters in both the a.m. and p.m. peak periods. It was not particularly busy, but was the best location for eastbound traffic.

4) Petro Truck Stop – I-40 East of Little Rock – Exit 161 (Galloway) – This truck stop served as a great location to interview eastbound commercial drivers who had gone through the I-30 work zone. Given the location of this truck stop on I-40, some preliminary questions were asked to screen eastbound I-30 drivers from those whose routes that did not include the subject work zone.

At each location the survey personnel were instructed to follow the script presented here.
“Good Morning/Afternoon/Evening,

I am working for the United States Department of Transportation to assist them in understanding the benefits of using technology during roadway construction projects. One such project is on I-30 between Little Rock and Benton. Have you ever traveled in any portion of that work zone?

[If “no,” say thank you and end the conversation; if “yes,” continue.]

Would you be willing to participate in a short survey (~5 minutes) regarding the technologies installed in the I-30 work zone?

[If “no,” say thank you and end the conversation; if “yes,” continue.]

For your reference, during this survey, whenever I say, “this section of I-30” I am referring to the section of I-30 that is under construction running from Little Rock to Benton.

Let’s begin the survey.”

APPENDIX D

ARKANSAS STATISTICAL SUMMARIES

The following tables highlight statistical results for the Arkansas survey data. In each table, the number of respondents to the question is shown by n (e.g., n=555).

Table 22 presents the statistical test results of whether drivers agreed that because of the info on the electronic message signs, they were better prepared to react to slow or stopped traffic. A single sample one-tailed t-test with 95 percent confidence showed that the drivers agreed that the electronic message signs better prepared them to react to slow or stopped traffic.

Table 22. Drivers' Agreement with the Statement That DMSs Better Prepare Them To React to Stopped or Slow Traffic

Dataset (n = 555)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs combined – drivers were better prepared to react to slower traffic with the DMS	1.72 ± 0.05
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-25.60
Tabulated t-value (p=0.05)	-1.645
Outcome	Reject Null hypothesis at p=0.05

Table 23 presents the statistical test results for drivers' agreement with the statement that DMS makes them feel safer. A t-test showed that the drivers did agree that the DMS made them feel safer traveling through this construction zone.

Table 23. Driver's Agreement with the Statement That DMS Makes Them Feel Safer

Dataset (n = 555)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs combined – DMS makes drivers feel safer in the construction zone	2.80 ± 0.07
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-2.86
Tabulated t-value (p=0.05)	-1.645
Outcome	Reject Null hypothesis at p=0.05

Table 24 presents the statistical test results for drivers' agreement that the Web site improved trip planning. A t-test with 95 percent confidence level showed that the 23 drivers who used the Web site agreed that the Web site was able to improve trip planning.

Table 24. Drivers Agree The Web Site Improved Trip Planning

Dataset (n = 23)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs - The info on the Web site improves my ability to avoid delay on this section of I-30	2.00 ± 0.29
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-3.45
Tabulated t-value (p=0.05)	-1.717
Outcome	Reject Null hypothesis at p=0.05

Tables 25 and 26 present the statistical test results for drivers' agreement that the DMS messages contained enough detail and that the signs were located in the right places. Using a t-test with 95 percent confidence, drivers indicated that they agreed that the DMS contained enough detail and were located in the correct places

Table 25. Drivers Agree DMS Contain Enough Detail

Dataset (n = 552)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs Combined - DMS messages are detailed enough to help me make decision about my route	1.78 ± 0.05
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-24.40
Tabulated t-value (p=0.05)	-1.645
Outcome	Reject Null hypothesis at p=0.05

Table 26. Drivers Agree DMS Are Located in the Right Places

Dataset (n = 542)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs Combined – DMS are located in the right places to help me make decisions about my route	2.10 ± 0.06
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-15.00
Tabulated t-value (p=0.05)	-1.645
Outcome	Reject Null hypothesis at p=0.05

Table 27 presents the statistical test results for drivers' agreement that the HAR messages were detailed enough to help them make decisions. The average rating for this question was 1.93, indicating that the drivers agreed (1 is completely agree; 2 is somewhat agree) that the HAR messages were detailed enough to help them make decisions about their routes.

Table 27. Drivers Agree HAR Messages are Detailed Enough to Help Them Make Decisions

Dataset (n = 121)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs - HAR messages are detailed enough to help me make decisions about my route	1.93 ± 0.11
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-9.73
Tabulated t-value (p=0.05)	-1.658
Outcome	Reject Null hypothesis at p=0.05

Tables 28 and 29 present the statistical test results for whether drivers agreed that the dynamic message signs were easy to understand and detailed enough to help them make decisions. At a 95 percent confidence level, results were significant when drivers were asked if the DMS are detailed enough and easy to understand.

Table 28. Driver Response to Statement that DMS are Easy to Understand

Dataset (n = 548)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs - DMS messages are easy to understand (only drivers that also answered "The messages are detailed enough to help me make decisions about my route."	1.26 ± 0.03
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-58.00
Tabulated t-value (p=0.05)	-1.645
Outcome	Reject Null hypothesis at p=0.05

Table 29. Driver Response to the Statement that DMS are Detailed Enough to Help Me Make Decisions

Dataset (n = 548)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs - DMS messages are detailed enough to help me make decisions about my route (only drivers that also answered "The messages are easy to understand.")	1.78 ± 0.05
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-24.40
Tabulated t-value (p=0.05)	-1.645
Outcome	Reject Null hypothesis at p=0.05

Tables 30 and 31 present the statistical test results for whether drivers felt that the HAR broadcast quality was too poor to hear, and whether the messages were detailed enough to help them make decisions. The findings on whether HAR broadcasts were too poor to hear was significant at a 95 percent confidence level. However, drivers agreed that the messages were detailed enough to allow them to make better decisions about their routes.

Table 30. Drivers Response to Statement that HAR Broadcast Quality is Too Poor to Hear

Dataset (n = 124)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs - Radio broadcast quality is too poor to hear properly (only drivers that also answered ("HAR messages are detailed enough to help me make decisions about my route.")	2.57 ± 0.14
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-3.07
Tabulated t-value (p=0.05)	-1.658
Outcome	Reject Null hypothesis at p=0.05

Table 31. Drivers' Response to Statement that HAR Messages are Detailed Enough to Help Make Decisions

Dataset (n = 120)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs - HAR messages are detailed enough to help me make decisions about my route (only drivers that also answered "Radio broadcast quality is too poor to hear properly.")	1.93 ± 0.11
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-9.73
Tabulated t-value (p=0.05)	-1.658
Outcome	Reject Null hypothesis at p=0.05

Table 32 provides the statistical test results for whether drivers agree that the information on the Web site is accurate. The average rating of the 23 drivers who answered the question on whether the Web site is accurate was a 1.7. This value falls between completely agree (1) and somewhat agree (2). Using a t-test with 95 percent confidence, the drivers agreed that the Web site was giving accurate information.

Table 32. Drivers Agree the Information on the Web Site is Accurate

Dataset (n = 23)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs – The info on the Web site is accurate	1.70 ± 0.25
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-5.20
Tabulated t-value (p=0.05)	-1.717
Outcome	Reject Null hypothesis at p=0.05

Table 33 presents the statistical results for whether drivers found the DMS messages to be accurate. Performing a t-test for the responses shows that the drivers found the DMS messages accurate at a 95 percent significance level. These findings support the conclusion that participants feel the DMS were giving accurate messages.

Table 33. Drivers Find the DMS Messages To Be Accurate

Dataset (n = 543)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs – DMS messages are accurate	1.75 ± 0.05
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-25.00
Tabulated t-value (p=0.05)	-1.645
Outcome	Reject Null hypothesis at p=0.05

Tables 34, 35, and 36 provide the statistical test results for whether drivers found the HAR messages to be useful, accurate, and updated frequently enough. Using a t-test at 95 percent significance showed that the drivers agreed that HAR was useful, accurate, and updated frequently enough. The scale included completely agree (1), somewhat agree (2), neutral (3), somewhat disagree (4), completely disagree (5), and not sure.

Table 34. Drivers Find HAR Messages To Be Useful

Dataset (n = 115)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs – HAR messages are useful (only drivers that also answered "HAR messages are accurate," and "HAR messages are updated frequently enough.")	1.74 ± 0.10
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-12.6
Tabulated t-value (p=0.05)	-1.658
Outcome	Reject Null hypothesis at p=0.05

Table 35. Drivers Find HAR Messages to Be Accurate

Dataset (n = 114)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs – HAR messages are accurate (only drivers that also answered "HAR messages are useful," and "HAR messages are updated frequently enough.")	2.00 ± 0.11
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-9.09
Tabulated t-value (p=0.05)	-1.658
Outcome	Reject Null hypothesis at p=0.05

Table 36. Drivers Find HAR Messages To Be Updated Frequently Enough

Dataset (n = 98)	Level of agreement (Mean ± Standard Error)
Private drivers & CVDs – HAR messages are updated frequently enough (only drivers that also answered "HAR messages are useful," and "HAR messages are accurate.")	2.27 ± 0.14
Statistical Comparison Results (Null Hypothesis: Mean of the dataset is equal to or greater than 3; Alternative Hypothesis: Mean of the dataset is less than 3)	
Calculated t-value	-5.21
Tabulated t-value (p=0.05)	-1.658
Outcome	Reject Null hypothesis at p=0.05

Note: Of the 616 surveys, only two PVDs and three CVDs did not provide gender information, 7 PVDs and 13 CVDs did not give age information, and four CVDs did not give their driving experience.

Table 37 presents the statistical test results for the question of whether the combined volume from the ITS detectors was significantly higher than the AHTD Tube data. A t-test showed that the combined volume from the ITS detectors was significantly different – higher - with a 95 percent confidence level.

Table 37. Combined Volume From The ITS Detectors (62 and 26) Was Significantly Higher Than The AHTD Tube Data

Dataset (n = 240)	Hourly volume difference between tube data and ITS detectors (in percentage) (Mean ± Standard Error)
May 21 – Jun 20, 2004. Detectors No 62 & 26 (RTMS), and data from I-30 & Raymar Rd (Tube data)	-42.4 ± 2.1
Statistical Comparison Results (Null Hypothesis: Mean of the differences equals 0; Alternative Hypothesis: Mean of the differences does not equal 0)	
Calculated t-value	-20.19
Tabulated t-value (p=0.05)	1.960
Outcome	Reject the null hypothesis at p=0.05

Table 38 presents the statistical results for the question of whether the combined volume from the ITS detectors was different than AHTD's tube data. A t-test showed that the combined volume from the ITS detectors was not different than the AHTD data with a 95 percent confidence level. Tables 37 and 38 test significance for two different sources of ITS detector data.

Table 38. Combined Volume From The ITS Detectors (63 and 25) Was Not Different Than The AHTD Tube Data

Dataset (n = 240)	Hourly volume difference between tube data and ITS detectors (in percentage) (Mean ± Standard Error)
May 21 – Jun 20, 2004. Detectors No 63 & 25 (RTMS), and data from I-30 & Raymar Rd (Tube data)	0.071 ± 0.17
Statistical Comparison Results (Null Hypothesis: Mean of the differences equals 0; Alternative Hypothesis: Mean of the differences does not equal 0)	
Calculated t-value	0.42
Tabulated t-value (p=0.05)	1.960
Outcome	Fail to Reject null hypothesis at p=0.05

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16. Abstract
This document provides quantitative benefits of using Intelligent Transportation Systems in highway construction and maintenance work zones. The technical report covers case study sites in the District of Columbia, Texas, Michigan, Arkansas, and North Carolina. The document provides insights into the mobility and safety benefits of ITS for work zone traffic management.

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