Benefits of Using Intelligent Transportation Systems in Work Zones

A Summary Report

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Preface

This report is one in a series of documents developed by the Federal Highway Administration (FHWA) that examines the use of Intelligent Transportation Systems (ITS) in work zones. This document provides a summary of the findings of a national study to quantify the benefits of ITS applications for work zone traffic management. A cross-cutting study and four case studies on the use of ITS in work zones were published earlier.

These documents are available at http://www.ops.fhwa.dot.gov/wz/its/index.htm. To request a hardcopy of this 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.

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Executive Summary

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 to focus on improving work zone operations, including the recently implemented Work Zone Safety and Mobility Rule, state Departments of Transportation (DOTs) are looking for tools and applications that will improve mobility and safety by actively managing traffic through the work zone. Intelligent Transportation System (ITS) applications are one tool that agencies are using to try to mitigate traffic impacts caused by construction.

The purpose of this study was to perform 'before and after' analyses to quantify the mobility and safety benefits of using ITS applications for work zone traffic management. A number of states have used ITS for work zone traffic management, and these systems often take the form of portable traffic monitoring and management. Work zone ITS systems provide information to motorists to help with route choice. These systems also provide advance warning of slowed or stopped traffic, which prepares motorists to respond to traffic conditions ahead and eases frustration for motorists who do not know what to expect. Work zone ITS also can be used to manage merging approaching lane closures and for speed management. As both the number of work zones and the use of ITS technology to monitor and manage traffic through the work zone increases, more information is needed on the quantified benefits of use as well as the lessons learned by agencies that have tested and implemented these systems. This information will lead to more effective implementations and allow agencies to learn from the past experiences of others.

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.

The study team evaluated ITS systems from sites in North Carolina, Arkansas, Michigan, Texas, and the District of Columbia. For some of the sites it proved difficult to determine quantifiable benefits due to issues with both deployment schedule and implementing data collection plans due to varying construction schedules. However, some key lessons learned and benefits were discovered from each site using work zone ITS. Some key benefits include:

- Reductions in aggressive maneuvers at work zone lane drops (Michigan) – Forced merges were 7 times less frequent, and dangerous merges were 3 times less frequent when the ITS system was on (flashers on).
- Significant traffic diversion rates (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 the ITS electronic messages made them feel safer. 17 percent were neutral, 32 percent disagreed, and 2 percent did not answer.

Table of Contents

Introduction

State Departments of Transportation (DOTs) often apply technology in the form of Intelligent Transportation Systems (ITS) to monitor and manage traffic flow, especially in major urban areas. With the active, dynamic nature of work zones, permanent systems can play an often limited role in managing traffic during construction and maintenance activities. While video monitoring from permanent cameras can be beneficial for managing work zones, real-time data is hindered by detection issues such as lane shifts and traffic shifts.

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, along with integrated portable changeable message signs (PCMS) to display speed and/or delay information in real-time. Agencies also often integrate a website 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.

With an increasing presence of construction and maintenance work zones and increased use of portable work zone ITS applications to manage them, the need arises to evaluate the effectiveness of different applications and quantify the benefits of their use. Some states, including Arkansas, Michigan, Minnesota, Iowa, Kansas, Missouri, North Carolina, Wisconsin, and Nebraska, along with local Universities and consultants, have evaluated a limited number of previous deployments to assess benefits and improve system designs. 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.

While many sites were considered, five were chosen based on multiple factors including:

- Estimated certainty of deployment and construction schedules.
- Clarity of the purpose/goals for using the system and ability to measure them.
- Diversity in type of system.
- Likelihood of system activation (e.g., volume/capacity or level of congestion).
- Local participation.
- Ease of gathering information and data for evaluation.

While these factors were ultimately the most important, the study team applied a detailed list of site selection criteria in choosing the sites. **Figure 1** highlights the locations of the selected sites and the type of system studied at each site.

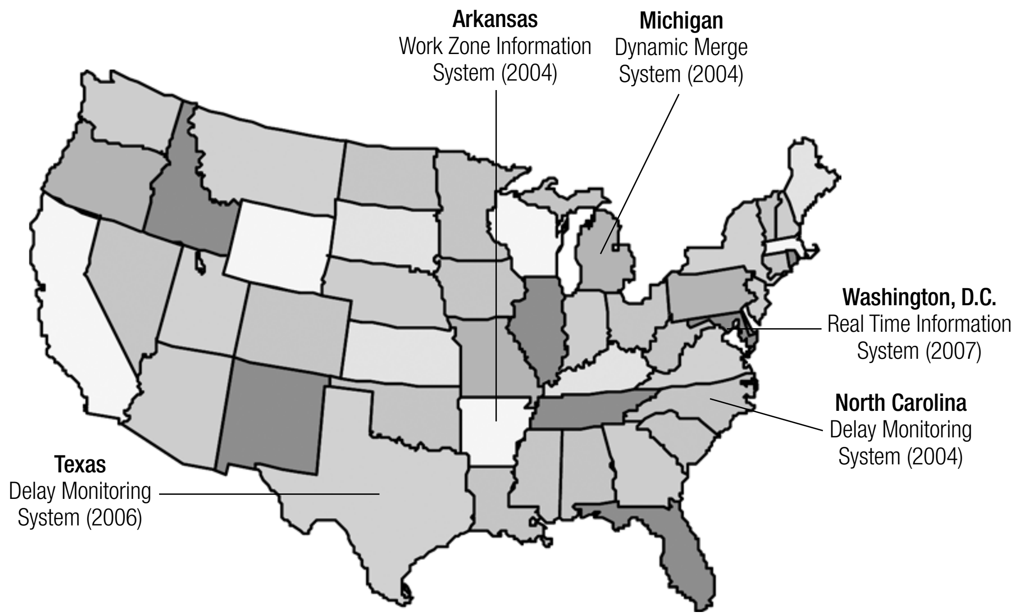

Figure 1. Work Zone ITS Evaluation Sites

Through research prior to and early in the project, the state of the practice appeared to be the use of tested, proven, "off the shelf" work zone ITS systems. However, some of the systems of focus for this study resembled that of a pilot test that, when combined with data issues, made quantification of benefits difficult. Therefore, one of the evaluation goals included for each site was also to verify that the system functioned as designed.

The types of measures that could be used to test performance of the system were also an important consideration as they related to the overall deployment goals. The study team developed a detailed list of hypotheses, associated measures of effectiveness, and relevant data sources. **Table 1** highlights some examples of the key hypotheses and measures used at one or more of the study sites.

Table 1. Examples of Key Hypotheses, Measures of Effectiveness (MOEs), and Data Sources

Hypothesis	MOE(s)	Data Sources
The ITS system will provide accurate, timely, and reliable information.	Correlation between work zone conditions and actual message posted on electronic signs.	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.	Traffic counts on mainline and alternate routes.	System data, continuous count station data, evaluation-specfic devices.
The use of ITS in work zones will reduce traveler delay.	Work zone travel times, average vehicle speed, work zone throughput, queue lengths.	Direct observations, system data, travel time runs.
The use of ITS in work zones will reduce congestion.	Travel times, queue lengths.	Direct observations, system data, evaluation-specific devices, continuous count station data.
The use of ITS in work zones will enhance the safety performance of the highway.	Crashes, incidents, crash frequency and severity (with and without ITS), aggressive maneuvers, citations.	Crash data, work zone inspector diaries, direct observations, citation logs.

The study team considered additional measures as needed to support each site. The study team applied these measures to the respective sites and analyzed the deployment to quantify the benefits and uncover important lessons learned.

The following sections discuss each of the evaluation sites, highlighting the site characteristics, type of system deployed, and results from each study site. The sites are presented in reverse chronological order with the most recent site first.

DC-295 in Washington, D.C.

Work Zone and System Description

In 2006, the District of Columbia Department of Transportation (DDOT) deployed an ITS system on Highway 295 in Washington, DC. The system covered 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 website. DDOT's main goals for the ITS system were to monitor conditions and improve mobility and safety through the work zone by managing traffic during lane closures due to their potential to produce abnormally large traffic backups and create potential for crashes outside the work zone. The location and system layout are shown in **Figure 2**.

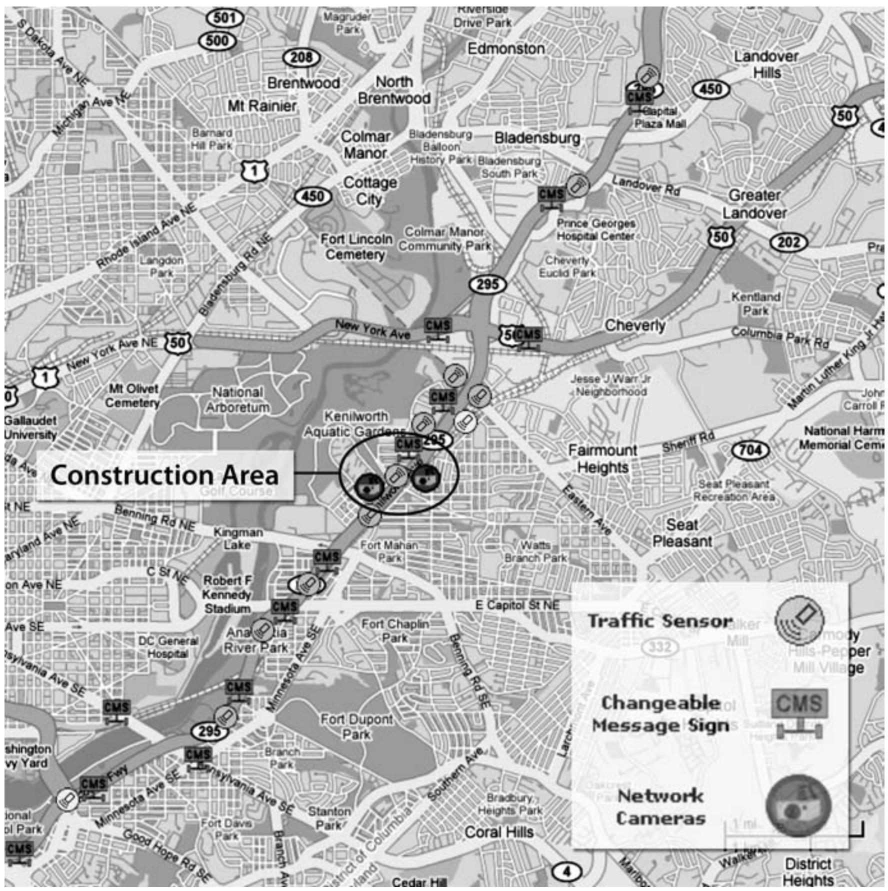

Figure 2. DC-295 Work Zone Area and ITS Layout

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.

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. DDOT procured the system through an existing contract with the design consultant.

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

Focus of the Evaluation

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 and encourage diversion (when significant delays occurred).
- Provide information to commuters for trip planning and to DOT personnel for condition and system monitoring via a website.
- Build public confidence in real-time traveler information.

The study team focused on queue lengths and diversion rates for this site. Since the system detectors covered a large area along DC-295, the study team used only archived system data in the analysis and did not find a need to place supplemental detectors to archive additional data.

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 one million records covering a time period from November 1, 2006 through August 15, 2007.

Findings

The study team calculated queues using detector spacing for time periods where speeds dropped below 30 miles per hour. The calculated queues were much longer (often more than five times longer) than those documented by construction managers as queues that were caused directly by the lane closures. Due to the large difference between estimated and observed queue lengths on nearly all of the data collection days (based on mostly recurring congestion and not congestion caused by the work zone), the analysis of queues before and after implementation proved inconclusive.

The study team also evaluated demand patterns to test diversion when the system activated. The results showed that the volume levels changed significantly when the system posted delay information and recommended that motorists seek an alternate route to southbound DC-295. During one time period, the system observed as much as 90 percent less volume during system activation.

Overall, the data showed 3 to 90 percent lower observed mainline volumes compared with similar days of the week (with an average of 52 percent reduction) by warning motorists prior to entering the mainline. These results are based on nine observation periods where delays were significant enough for the system to recommend alternate routes. For about two thirds of the data collection period, the system collected baseline data, but did not provide messages to drivers. During the portion of the data collection period where the system was “on” and providing messages to drivers, there were limited observations where the system recommended alternates.

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

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 also may be achieved. DDOT successfully used the system to manage recurring congestion along the heavily traveled DC-295 corridor.

Key Finding

The real-time information system 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).

I-35 in Waco, Texas

Work Zone and System Description

In October 2006, The Texas Department of Transportation (TxDOT) implemented an ITS system in a construction work zone on I-35, south of Waco, in Hillsboro County. The purpose of the system was 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 the system as shown in **Figure 3**. The system consisted of six microwave sensors, six message boards, a central processing and communications unit, and three wireless closed circuit video cameras. TxDOT procured the system through the prime construction contractor.

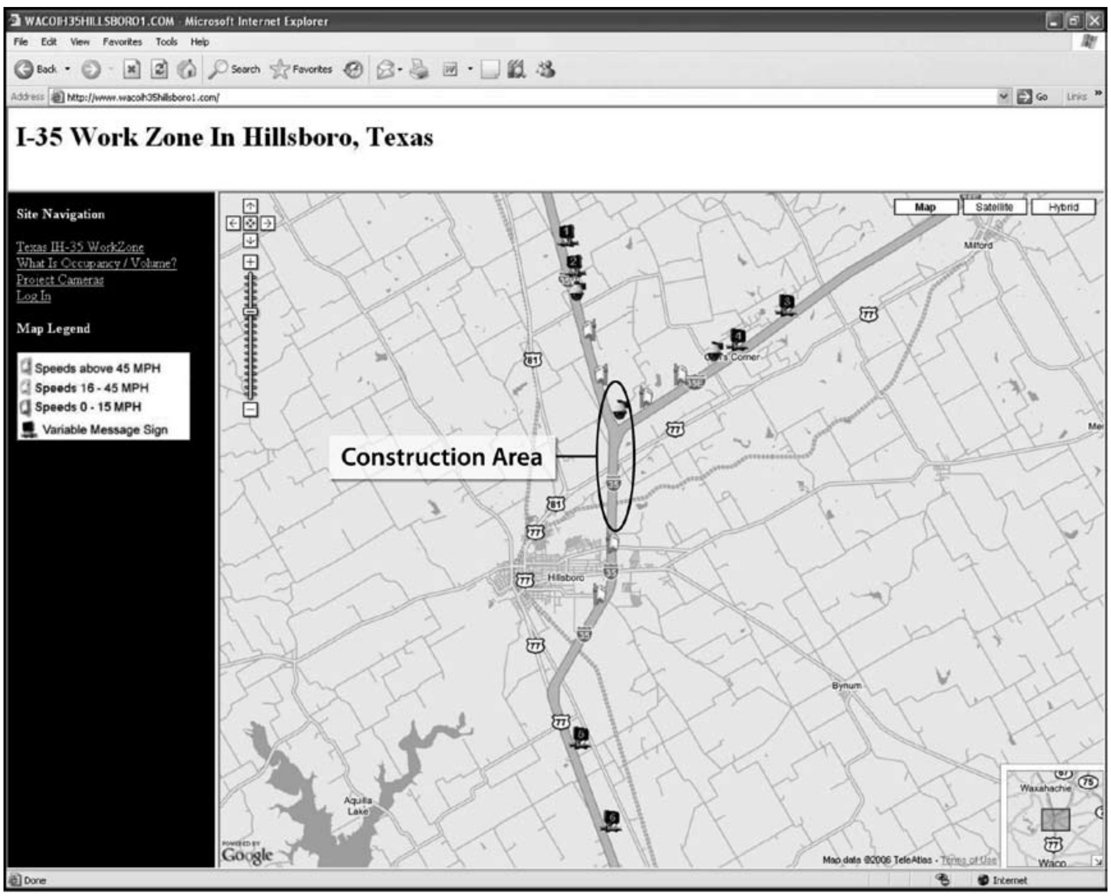

Figure 3. I-35 Work Zone and Signed Alternate Routes (Taken from TxDOT's Website)

Based on predetermined speed and occupancy thresholds, the system provided real-time delay information and recommended alternate routes via DMS. TxDOT operators also monitored traffic conditions in the work zone through the use of three wireless closed circuit video cameras.

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

Focus of the Evaluation

The main objective for this deployment was to reduce demand and congestion through active diversion of traffic approaching the work zone. Diversion was encouraged by providing real-time information and route guidance to motorists en-route to warn them of downstream conditions, and by providing trip planning information via a website.

The study team mainly focused data collection efforts on testing the level of diversion around the work zone during periods of congestion. The study team collected ramp and mainline volume, speed, and occupancy data from microwave sensors placed at each diversion point to quantify the level of ramp usage for “with” and “without” ITS conditions. The study team archived data from October 3, 2006 through February 4, 2007.

Findings

The evaluation 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. 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. The study team was not able to determine the impact of the diversion on mainline delays/travel times because the system had only two sensors collecting speeds (spot detection) over a short distance, and to determine travel times across the entire route (from the diversion point through the end of the work zone) would have required more sensors to provide better accuracy.

Key Finding

During major incidents or high construction impact periods combined with high demand, the system diverted an average of 10% of mainline traffic to alternate routes. Diversion was as high as 28%.

TxDOT signed appropriate alternate routes for use during periods of diversion, but did not monitor congestion on these alternate routes. It also should be noted that for the 20 times that the system actively diverted traffic, incidents were more typically the cause of congestion than construction. Congestion due to construction was not a long term problem.

The system detected congestion and displayed appropriate messages, although the minimum display time for diversion messages was likely too short in some cases. 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. 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 than typical construction activity and lane closures. In these cases, the system detected and reacted to the congestion caused by incidents just as it would for congestion caused by construction activity. It should be noted that this is a rural area with a large number of through trips and drivers unfamiliar with the area.

Tips and Lessons learned

The study team identified several lessons learned that can benefit those 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.

Key Finding

The real-time information system effectively diverted traffic to specific, signed alternate routes during times of significant congestion.

US-131 in Kalamazoo, Michigan

Work Zone and System Description

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 a Dynamic Lane Merge (DLM) System in the northbound direction of US-131. The system did not cover the southbound direction. MDOT had 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 system deployment area is shown in **Figure 4**. The construction area covered approximately 11 miles, immediately north of the beginning of the lane closure merge point shown in the figure.

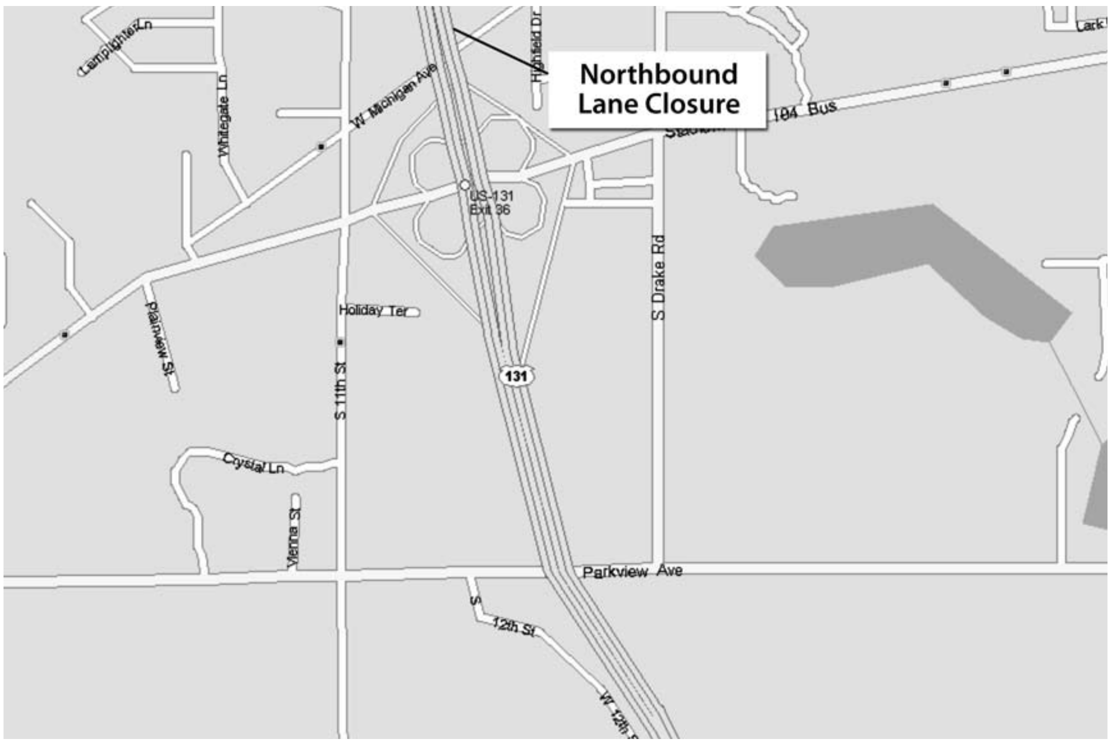

Figure 4. Location of Dynamic Lane Merge System

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 using a subcontract with the vendor 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 five-minute minimum activation period.

Focus of the Evaluation

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 resulting from aggressive passing at the merge area.

The system deployment schedule mirrored the construction schedule, leaving little opportunity for establishment of baseline conditions (the "without ITS" scenario). Since construction was occurring in both directions and demand levels were similar in both directions, the study team planned to use 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 would have provided a reasonable comparison of a traditional merge setup with a dynamic merge setup. From the past volume data, the north-bound and southbound afternoon peak hours showed the most similar demand levels, so the study team focused data collection efforts on each afternoon period.

The study team collected data for a two-week period from September 20 until 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 pm until 6 pm each weekday. The study team also collected traffic count data along two mainline areas and seven ramp areas to determine demand at different locations within the merge areas. The study team also collected data on forced merges (last minute merges near the lane drop), dangerous merges (quickly merging after passing a vehicle), and lane straddling during the travel time runs. A modem was installed on one trailer and MDOT archived sensor data for August, September, and October for use in the evaluation.

The study team focused on two main hypotheses for this system, including:

- The use of ITS in work zones will enhance the safety performance of the highway.
- The use of ITS in work zones will reduce traveler delay.

Findings

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 results of the comparisons show that there was a significant reduction in the number of forced merges when the system was activated and the 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 to avoid forced merges approaching the taper. The study team observed three times the number of dangerous merges and seven times the number of forced merges during periods where the flashers were off compared with periods where the flashers were on.

Based on the effect of “do not pass” flashers in the work zone, the study team concludes that the DLM system enhanced safety by reducing the number of forced merges and dangerous 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. It should be noted that there was occasional police presence, and the study team noted it in the data. However, we were unable to directly link the police presence to the effects on traffic.

The study team compared travel time data for two days when “do not pass” lights were flashing with data from the six days when the lights were not flashing. To ensure that the travel time comparisons would be meaningful, the study team checked for differences in volume counts between the two days. The study team found no statistically significant difference in volume count between the two days, and thus, the travel time comparison should be meaningful.

The study team found that the travel time when lights were flashing was significantly higher than when lights were not flashing. This increase in travel time is expected when drivers obey the “Do not pass” sign, as vehicles potentially reduce speed and merge at locations further away from the taper and form an organized queue of vehicles with smoother flow through the bottleneck. By having vehicles line up earlier in the open lane, the distance drivers traveled on the open lane increased, thus increasing the density and reducing the speed for that lane. For lower volume situations, lining up vehicles in the open lane, even though slightly increasing the travel time, is often a better option (if queue storage is available) 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.

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.

Key Finding

The DLM system improved safety with a reduction in the number of forced merges by a factor of seven, and a reduction in the number of dangerous merges by a factor of three at the lane drop, and by smoothing traffic flow through the work zone taper.

I-30 Little Rock to Benton, Arkansas

Work Zone and System Description

In 1999, Arkansas decided to undertake the rehabilitation of over 50 percent of their Interstate highway infrastructure. As a result, the Arkansas Highway and Transportation Department (AHTD) began construction in 2000 on more than 350 miles of roadway. Most relevant to the study of ITS in work zones are the three work zones that utilized ITS with the goal of improving traffic safety and mobility during the time of construction. One of these 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 5**.

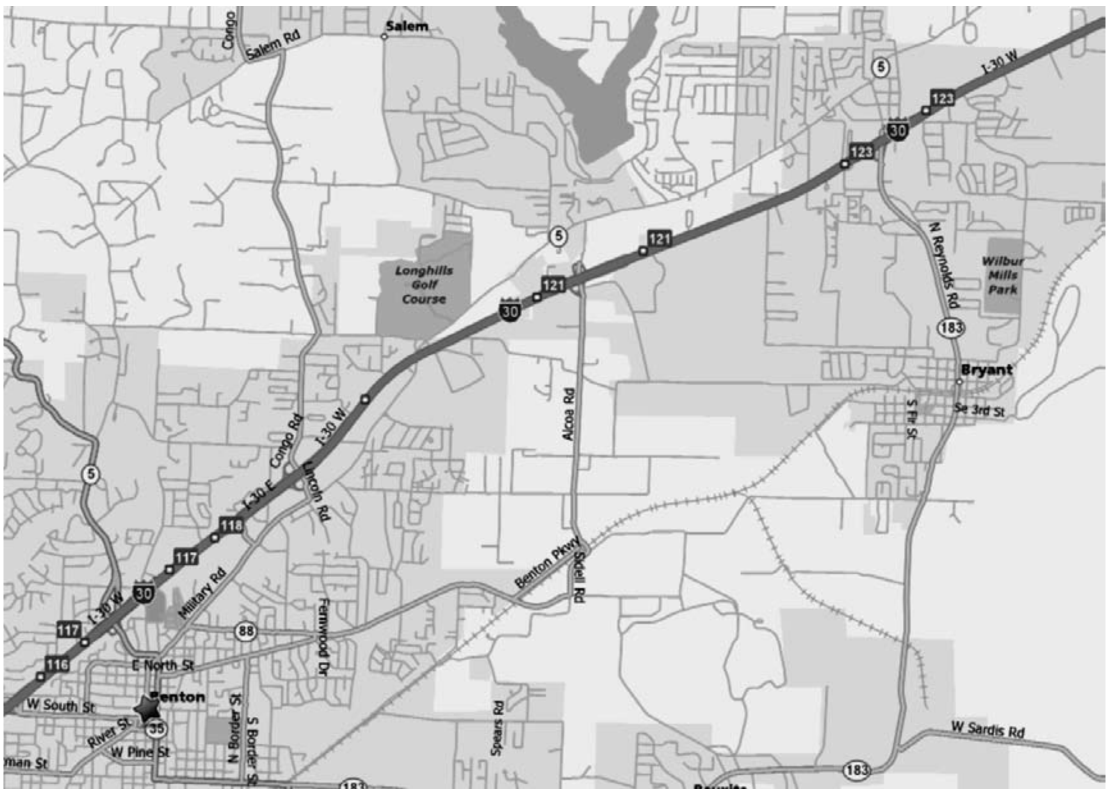

Figure 5. Arkansas I-30 Work Zone Location

Prior to the beginning of construction, this 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, when this I-30 project was constructed in 2004, there was an average of approximately 40 percent truck traffic during the day increasing 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.

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.

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. 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 highway advisory radio (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 website (www.arkansasinterstates.com). By clicking on the Central Arkansas Projects icon on the ArkansasInterstates.com home page and then on the I-30 project on the Central Arkansas map, site visitors could see a complete view of traffic conditions throughout the work zone. Color-coded roadway segments (green, yellow, red) between sensors indicated whether traffic was flowing well, slowed, or stopped. Hovering the mouse over any of the equipment icons revealed a live video image (for the cameras) or displayed the text and audio messages motorists were receiving on the road (for the DMS and HAR).

Focus of the Evaluation

The main objective for this system was to improve the safety of travelers by providing advance warning of slowed traffic or congested downstream conditions. Based on this system objective, the study team conducted a driver survey and used the driver surveys and traffic volume data to assess several hypotheses. A total of 297 commercial vehicle drivers (CVD) and 319 private vehicle drivers (PVD) participated in the surveys. The study team collected traffic and survey data from May 17, 2004 through June 20, 2004.

The study team also conducted an initial review of the available crash data but determined that it was not feasible to use the crash data for this study. The level of detail available in the crash records did not support the level of analysis needed for this study and converting the hard copy crash records to an electronic database was cost prohibitive. The study team also held an in-person interview with the contract manager for the work zone to assess a hypothesis regarding the impact of ITS on contractor productivity.

Findings

Of these, 286 CVD and 306 PVD surveys were suitable for further analysis. The 24 surveys not used were discarded due to incomplete responses pertaining directly to the ITS devices. The study team observed the following findings (highlighted in **Table 2**) for selected hypotheses.

Table 2. Findings for Selected Hypotheses

Hypothesis	Findings	Comments
The use of ITS in the work zone will reduce travelers' exposure to hazard.	Drivers agree that the use of ITS in the work zone reduces 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 felt that the ITS 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 were 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 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 made them feel less bothered in the construction zone.
The ITS system will improve the productivity of contractors and travelers.	Contractors: ITS does not improve the 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 for traffic management helped manage the work zone.
	Traveler: ITS improves motorists' ability to plan their trip.	The web site had a low usage, but its few users believed the web site helped them in trip planning.
	DMS are accurate enough for the majority of the users.	Most drivers felt that the DMS messages were accurate (79%).

Tips and Lessons Learned

Work zones are highly variable environments. As a result the ITS system 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 system 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).

I-40 in Winston Salem, North Carolina

Work Zone and System Description

Over the past several years, the North Carolina Department of Transportation (NCDOT) has undertaken several construction projects that included 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, which may be more likely to occur in work zones due to capacity reductions and movement of materials and trucks to and from work sites via open travel lanes.

In early 2004, NCDOT designed an ITS system for a work zone shown in **Figure 6** on Interstate 40 west of Winston Salem. The goal of the ITS system was to monitor traffic 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 State Route 1101/I-40 interchange in Forsyth County. 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, and 10 portable traffic sensors linked to the central computer base station. NCDOT procured the system using a special provision through the prime construction contract.

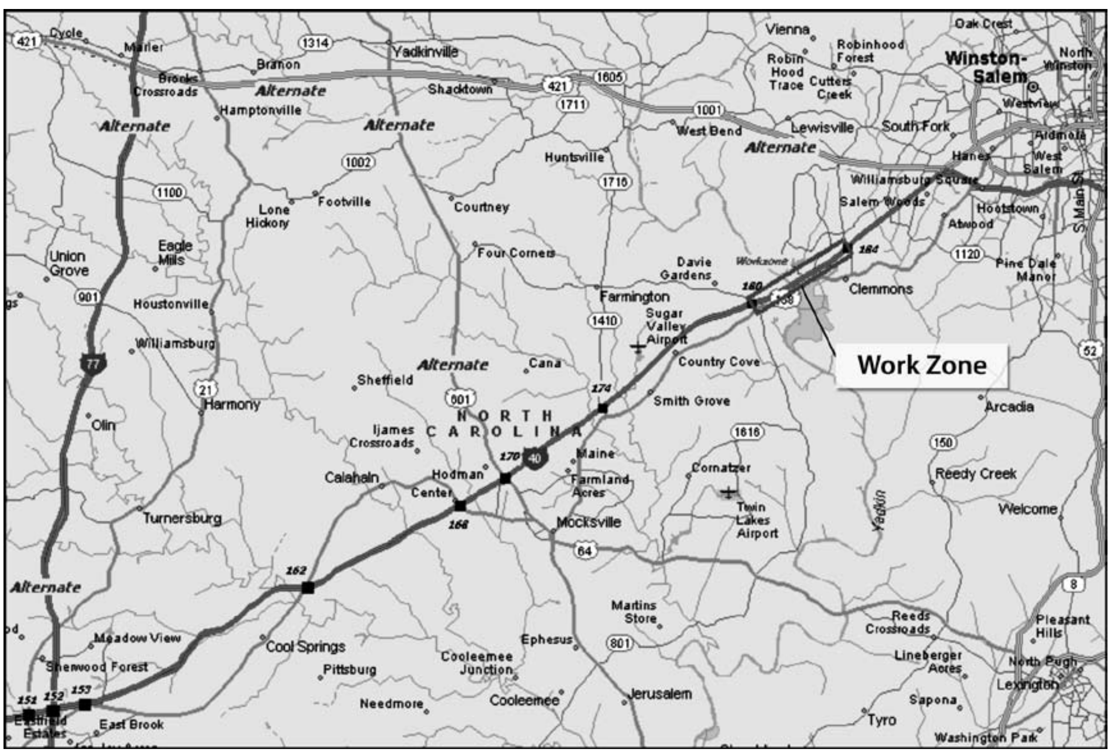

Figure 6. I-40 Work Zone and Signed Alternate Routes

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 DMS.

Focus of the Evaluation

The evaluation focused on key performance metrics directly related to several main objectives for the system as defined by NCDOT. 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 pre-trip planning information to commuters and allow system monitoring by DOT personnel via a project website.
- Build public confidence in real-time traveler information.

The study team collected traffic and construction data from May 22, 2004 through July 16, 2004.

Findings

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.*

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.

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.

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.

Personnel from the implementing agency should have real-time access to archived system data to identify any issues and monitor system functionality. A website could easily provide password protected access to the data being used by the system to make decisions. The website 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.

Common Institutional Issues, Tips, and Lessons Learned

The study team observed several common issues, tips, and lessions learned across agencies when deploying work zone ITS applications.

Overall

- In several sites studied, a champion was active in selling the concept of using work zone ITS and ensuring that momentum for the deployment continued at an appropriate pace to lead to the deployment of the system.
- Each site had the necessary leadership from a group of individuals within the agency to ensure appropriate levels of communication across different groups with the transportation agency, as well as 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 cases where the owner agency hires the vendor directly, the owner agency is responsible for providing the vendor with proper access to the work area.

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 by “x” percent) 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 largest 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. Communication is needed to help ensure that the optimal placement of the ITS components is balanced with the contractor’s need for adequate and convenient workspace. The contractor also should provide information on construction activity changes, thereby letting the vendor make necessary changes to the system component locations. 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 and 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 to manage local impacts.

Operation and Maintenance

- Agencies can benefit from hiring a software/system vendor who 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.

Summary

This study quantifies benefits of ITS deployments for work zone applications and also documents key lessons learned from previous experience. Agencies interested in deploying similar systems can benefit from the findings of this study. Interested agencies also can use the tips and 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 to fill a specific gap in current research by providing findings of a quantitative nature for the effects of mobile traffic monitoring and management systems. While some studies have shown benefits, they often are limited due to difficulties with data collection, difficulties in measuring effects due to timing of construction activities, and limited funding for research and evaluation.

This study produced several quantitative benefits and provided information and outcomes as anticipated. 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 provides information on the opinions and reactions of drivers as stated directly in survey responses. 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. Additionally, 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.

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

- 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.

Overall, the benefits from this quantitative study were positive, as shown in **Table 3**.

Table 3. Key Measures by Site

Location	Type of System Used	System Objectives	Key Performance Measures	Benefits Based on Relative Change in Measures
District of Columbia System	Real Time Information	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 and 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 7 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	To 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	To provide delay information and reduce demand and congestion by actively diverting traffic.	Traffic Diversion	N/A – system did not fully activate.

* Reduction includes potential reduced throughput due to queues and congested conditions (likely significant for the higher end of the range).

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. 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 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. The following sections outline some of the previous research and show how the findings of this study compare with other studies.

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

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 lane drop, and 2,000 to 3,000 vehicles per hour for the two-to-one lane drop. Queuing will occur in both of these travel conditions and is needed to warrant use of the system since queue conditions create a potential for forced merges. For the I-94 deployment[1] (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.

[1] Datta, T. and Schattler, K. 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/Wayne State University, 2004.

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 changeable message signs to take turns merging from each lane. The Minnesota Department of Transportation (MnDOT) found that upstream usage of the lane that is closed downstream increased to 60 percent at one sensor location on I-494.[2] While MnDOT was not able to perform a true before and after comparison (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, as has been pilot tested in Minnesota, may be most beneficial to owner-agencies. No sites using the late merge concept were available for study during the course of this project.

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 also can 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 often needed to build support from decision makers to continue use of such systems.

Some systems are also designed to provide information but with direct outcomes in mind, such as to reduce speed at a work zone thereby improving the safety performance of the work zone. A Smart Work Zone Deployment 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 percent to 40 percent increase in vehicles complying with the speed limit during system deployment.[3] For another study, 46 percent to 73 percent of motorists said they slowed down when they observed speed advisory messages approaching the work zone.[4]

[2] MnDOT / URS. Evaluation of 2004 Dynamic Late Merge System. Minnesota Department of Transportation, 2004.

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

[4] Fontaine, M. Operational and Safety Benefits of Work Zone ITS. ITS in Work Zones Workshop, 2005.

Some studies have tested diversion around work zones based on real-time information. Some systems actively divert traffic by providing alternate route guidance to motorists, while others provide general delay information and allow motorists to make route decisions. The limitation of the latter concept is that only motorists familiar to the area are likely to divert without the specific guidance to do so (some states offer specific alternate route guidance, lessening the burden on motorists to find their own route). 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 general condition information.[5] 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 should, 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 Smart Work Zone that provides specific information about delays and alternate routes."[6] In general, practitioners in North Carolina, on average, have observed, "…some increase in usage of alternate routes," across their various deployments of work zone ITS.[7]

The results of this study are comparable to the other studies referenced herein. Additionally, this study provides further evidence of the benefits of properly planned and design work zone ITS deployments. Examining the effectiveness of these systems over extended periods of time is an area that warrants further research.

[5] Chu, Kim, Chung, and Recker. Evaluation of Effectiveness of Automated Work Zone Information Systems. Transportation Research Board Annual Meeting Compendium, 2005.

[6] 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.

[7] Kite, S. North Carolina's Smart Work Zone Experience. Presented at the ITS Virginia Meeting, 2004.

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