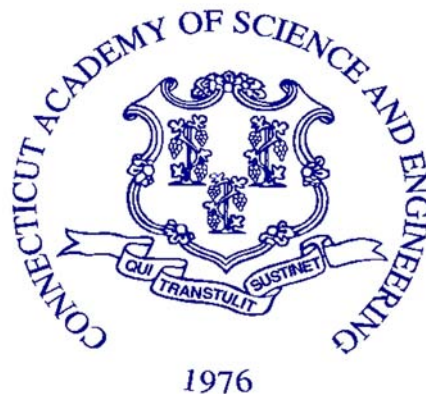


**INFORMATION TECHNOLOGY
SYSTEMS FOR USE IN INCIDENT
MANAGEMENT AND WORK ZONES**

MARCH, 2006

A REPORT BY

**THE CONNECTICUT
ACADEMY OF SCIENCE
AND ENGINEERING**



FOR

**THE CONNECTICUT DEPARTMENT OF
TRANSPORTATION**

INFORMATION TECHNOLOGY SYSTEMS
FOR USE IN
INCIDENT MANAGEMENT
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Richard H. Strauss
Executive Director

Disclaimer

The contents of this report reflect the views of the author, who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Connecticut Department of Transportation or the Federal Highway Administration. The report does not constitute a standard, specification, or regulation.

INFORMATION TECHNOLOGY SYSTEMS FOR USE IN INCIDENT MANAGEMENT
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16. Abstract The Connecticut Department of Transportation (ConnDOT), Bureau of Engineering and Highway Operations is responsible for the acquisition, implementation and operation of technologies for use in Incident Management and Work Zones. The need to cope with incidents affecting traffic has been recognized for decades. In particular, contending with congestion and incidents in highway work zones has been recognized as one of the priority tasks of most state transportation agencies. The goal of this study was to identify information technology systems that could be utilized in Connecticut to improve operations to facilitate the safe and efficient movement of traffic through and around work zones and incident areas. These technologies have the potential to enhance the safety of motorists and roadway workers, improve the mobility of the traveling public, and fuel conservation. The project's objective was to provide a literature-based best practices review of incident management and work zone information technology systems and to identify potential implementation strategies for Connecticut.				
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LIST OF ACRONYMS

Acronym	Description
ADAPTIR	Automatic Data Acquisition and Processing of Traffic Information in Real Time
AHAR	Automatic Highway Advisory Radio
AVI	Automatic Vehicle Identification
CCTV	Closed-Circuit TV
CDPD	Cellular Digital Packet Data
CMS	Changeable Message Sign
CSC	Central System Controller
DLM	Dynamic Lane Merge
GIS	Geographic Information Systems
HAR	Highway Advisory Radio
HELP	Highway Emergency Lender Patrols
HOC	Highway Operations Center
IMTF	Incident Management Task Force
ISDN	Integrated Services Digital Network
ITIP	Intelligent Transportation Infrastructure Program
ITS	Intelligent Transportation System
LED	Light Emitting Diode
MUTCD	Manual on Uniform Traffic Control Devices
NCSA	National Center for Statistics and Analysis
NHTSA	National Highway Traffic Safety Administration
NTCIP	National Transportation Communications ITS Protocol
PCMS	Portable Changeable Message Signs
PTMS	Portable Traffic Management System
PVMS	Portable Variable Message Sign
RDS-TMC	Radio Data System-Traffic Message Channel
RISC	Rapid Incident Scene Clearance
RRS	Roadside Remote Sensors
RTTCS	Real-Time Traffic Control System
TIPS	Travel Time Prediction System
TMV	Traffic Management Vehicle
TRANSCOM	TRANSCOM is a coalition of 16 transportation and public safety agencies in the New York-New Jersey-Connecticut metropolitan region.
VMS	Variable Message Sign
VSL	Variable Speed Limit
WPDS	Wet Pavement Detection System
WZSAS	Work Zone Speed Advisory System
WZSIM	Work Zone Simulation Model

EXECUTIVE SUMMARY

STUDY OBJECTIVES

The goal of this study was to identify information technology systems that could be utilized in Connecticut to improve operations to facilitate the safe and efficient movement of traffic through and around work zones and incident areas. These technologies have the potential to enhance the safety of motorists and roadway workers, improve the mobility of the traveling public, and fuel conservation.

The objective of the project was to provide a literature-based best practices review of incident management and work zone information technology systems and to identify potential implementation strategies for Connecticut. The project examined the application of information technology systems for only the state's limited access highways. The project focused on systems that can be used for work zones and incident management separately.

SUMMARY OF FINDINGS

An intelligent, or automated, portable traffic management system is an integrated system which consists of portable variable message signs (PVMS), vehicle detection systems (such as detectors, cameras and other surveillance equipment), a computer-based control center and communication systems. Based on detected traffic information, the system automatically determines messages to be displayed on the PVMS and may also disseminate the information through highway advisory radio (HAR) and the internet. A comprehensive review of various intelligent portable traffic management systems used in work zones and incident management and speed management technologies used in work zones was conducted; innovative technologies that have the potential to improve highway traffic operations were also identified.

Interviews were conducted with representatives from departments of transportation (DOTs) in several states, including Arizona, Arkansas, Maryland, Minnesota, Missouri, North Carolina, Florida and private industry regarding their experience with and knowledge of work zone and incident management deployment initiatives and innovative technologies. A number of systems and deployment initiatives were reviewed, including the well-known Midwest States Smart Work Zone Program, FHWA's case studies about the application of intelligent transportation systems (ITSs) in work zones, and Michigan's dynamic merge lane systems.

A summary of various portable systems, including their features, deployments, and evaluation results, if any, has been included in this report. The study also describes Connecticut's current operations system based on information and interviews provided by the Connecticut Department of Transportation (ConnDOT).

A summary of findings regarding the deployment of automated portable traffic management systems and future possibilities for ITS applications in work zones and for incident management in Connecticut follows. Suggestions regarding potential innovative technologies for use on Connecticut's primary arterial highway system are also included.

Intelligent Portable Traffic Management Systems

Work Zones

It is suggested that general guidelines for installing intelligent portable systems should include the following:

- Intelligent portable systems should be used only for long-term work zone projects to achieve expected efficiency and safety benefits.
- The presence of congestion and/or specific safety hazards for at least some part of the day is the most basic prerequisite for installing intelligent portable systems.
- Diversion messages provided to motorists should, either explicitly or implicitly, identify potential alternative routes in the area that will significantly improve travel time around work zones.
- Determining appropriate vehicle detection locations to ensure that actual traffic data (travel time, speed and delay) are consistent with estimates that are displayed by the system.

Incident Management

Advanced capability traffic management vehicles (TMVs) similar to those used in a Florida Turnpike Enterprise pilot project, mostly along a heavily-traveled portion of the Florida Turnpike, should be considered for use in Connecticut as a tool to better manage traffic incidents, as well as for use in other disasters and emergencies. These TMVs are equipped with the ability to transmit live video images and voice communication via digital satellite to traffic management centers, as well as with internet communications for email and file transfer, and a digital video recorder. Additionally, emergency responder equipment and supplies are also available on the TMVs. The number of TMVs and where they should be based should be determined in advance to ensure that sufficient traffic management vehicles can arrive at an incident location in a timely manner. Other tools, such as vehicles equipped with mounted variable message signs (VMSs), as are deployed in other states, could also be considered for use in incident areas.

General Considerations

Several general suggestions regarding the use of portable traffic management systems include:

- The decision as to which traffic management system – intelligent or human-operated – to use should be based on project goals and objectives, cost and reliability. Human-operated systems are low cost and have more reliable messages. However, for the traveling public to have confidence in a human-operated system, the displayed messages should be current and should accurately reflect existing conditions. In comparison, intelligent systems can provide current and comprehensive traffic information such as travel time, speed, delay, but cost and reliability issues also should be considered.
- ConnDOT should consider conducting a cost-benefit analysis on a pilot study basis to help determine if the use of portable ITSs is justified. Potential benefits include anticipated reductions in accidents, travel time, environmental impacts and energy

consumption. Additionally a carefully designed safety evaluation strategy that quantifies the system's potential benefits and impacts should be implemented for use prior to and throughout the system's deployment.

- The Texas Transportation Institute's manual on *Dynamic Message Signs Message Design and Display* (Duke, 2004) and the Federal Highway Administration (FHWA)'s handbook on *Portable Changeable Message Signs* (FHWA⁵, 2003) should be considered for use as tools for designing messages to be displayed on PVMSs and VMSs.
- Dynamic lane merge systems can promote the smooth flow of traffic leading into a work zone by creating a dynamic no passing zone upstream of a construction site based on detected traffic volume and back-ups. This type of system, especially where Connecticut's primary arterial highways are significantly congested, can decrease the average number of aggressive driving maneuvers per travel time run.

Future Directions

Work Zone Traffic Operations

Information technology could be utilized to improve operations to facilitate the efficient movement of traffic through and around work zones. The ideal work zone travel information system for use in Connecticut could consist of a traffic data collection system based on speed detectors, surveillance equipment, and other emerging ITS technologies; a central control system located at the state's traffic management center; wireless communication systems; and an information dissemination system, including HARs, VMSs, news media, email alerts, etc.

Priorities for work zone traffic operations in Connecticut should include reducing vehicle speeds (especially truck speeds), preventing recurring long queue back-ups and minimizing the number of accidents in work zones, as lower speeds can potentially reduce the occurrence of such accidents. Basic speed display trailers and innovative systems such as variable speed limit (VSL) and D-25 speed advisory systems, used to warn drivers of downstream traffic speeds, can also be used as speed management tools.

Incident Management

New and developing ITS technologies have the potential for improving incident management systems for the purpose of providing provide better motorist advisory information throughout an incident. The establishment of a comprehensive statewide traveler information system that provides the public with real-time, accurate information through VMSs, HARs, cell phones, news media and other technologies and enables motorists to make alternate route or trip delay decisions when a highway is closed or severely restricted should be considered. Efforts should be made on a continuing basis to further improve cooperation among the various agencies to improve incident response performance and the mobility of the traveling public. On-going training programs that include understanding the priorities and needs of the various response agencies should be provided for responders. Many issues such as criteria for the use of variable messages, vehicle positioning at incidents, emergency light disciplines, and vehicle removal from incident sites, as well as other important issues can be included in these programs. It also

is suggested that consideration be given to exploring the possibility of creating an Open Road Policy that includes a Rapid Incident Scene Clearance Program similar to that developed by Florida.

Develop a Complete Traffic Monitoring System for Connecticut's Interstate System

ConnDOT should examine the question of whether the current number of portable systems utilized in its operations is sufficient to provide efficient and safe operations on the entire Connecticut primary arterial highway system. Consideration should be given to creating a traffic monitoring system that provides complete coverage of the Connecticut interstate system. Such a system – an ITS architecture initiative in Connecticut – would combine various vehicle detection technologies and communication systems to provide the information necessary to assess real-time traffic flow, provide valuable data for the evaluation of new ITS deployment, and enhance the state's incident management capabilities.

Innovative Technologies

There is a wide variety of innovative technologies available to better manage the flow of traffic through both work zones and incident management areas. This study identifies some of these technologies, including non-intrusive technology for vehicle detection, the integration of vehicle navigation systems with current traffic conditions, automatic highway advisory radio (AHAR), work zone intrusion alarms and cell phone tracking for travel time estimation. These systems, as well as emerging technologies, should be monitored and reviewed on a continuing basis by ConnDOT for possibility of utilization in Connecticut.

CONCLUDING REMARKS

The effective management of work zone activities and incidents is intended to enhance safety and operational efficiency for the traveling public and roadway workers. This can be accomplished through an information technology system that includes ITS applications, traffic data collection, data analysis, and traffic information dissemination. Innovative ITS technologies can also be integrated in a complete traffic monitoring system to provide the underpinning infrastructure for delivering traffic information to the public continuously and automatically. ConnDOT should consider further study of emerging innovative technologies and the development of the infrastructure necessary to support such systems in the future while also accommodating current needs. Also, although beyond the scope of this report, further study may be appropriate to determine how best to incorporate the tools and systems utilized for traffic incident and work zone management into the state's broader disaster emergency response operations.

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I. INTRODUCTION

Motor vehicle crashes were rated as a leading or major cause of death in the United States in 2002, according to a recent report from the National Highway Traffic Safety Administration's (NHTSA's) National Center for Statistics and Analysis (NCSA) (NHTSA, 2005). The need to cope with incidents affecting traffic has been recognized for decades. In particular, contending with congestion and incidents in highway work zones has been recognized as one of the priority tasks of most state transportation agencies. Data from the National Work Zone Safety Information Clearinghouse indicate that the number of fatalities in work zones has increased annually since 1999 (http://safety.fhwa.dot.gov/wz/wz_facts.htm). According to the Federal Highway Administration (FHWA)'s ITS Technologies in Work Zones report (2004), the use of intelligent transportation systems (ITSs) has been demonstrated to be effective in increasing safety for both workers and motorists and ensuring a more efficient traffic flow through and around work zones and incident areas. [See www.its.dot.gov/its_overview.htm for an overview of ITSs.]

This study identifies technologies and systems that have emerged and are emerging as potentially powerful tools to assist in managing traffic operations in these areas. Work zone ITSs usually integrate portable variable message signs (PVMSs), highway advisory radio (HAR), and vehicle detection systems into a computerized central control system that automatically determines appropriate messages that are based on current traffic conditions (Fontaine, 2003). They can monitor traffic, provide real-time traffic information to travelers, and improve incident detection, response and clearance in work zones.

These technologies have been used throughout the United States in a variety of applications. For example, variable speed limit systems determine and display speed limits based on detected traffic information; traffic advisory systems provide speed, delay, travel time and alternate route information to travelers; and dynamic lane merge systems facilitate efficient and safe vehicle merging. Some programs and deployment initiatives also have been developed to implement these technologies. The Midwest States Smart Work Zone program – probably the best known – was created by Iowa, Kansas, Missouri, and Nebraska in 1999 (Wisconsin joined in 2001) to deploy and evaluate various ITS-related technologies and systems. FHWA (2004) also developed a series of case studies to examine the use of ITSs in work zones.

The objective of this study was to provide a literature-based best practices review of information technology systems for use in incident management and work zone areas and to identify potential implementation strategies for use of these systems on Connecticut's limited access highways.

The project focused on different portable traffic management systems for work zones and incident management. The scope of the project also included the investigation and understanding of Connecticut's current work zone and incident management operating system, and identification of advanced technologies that have the potential to improve safety and traffic flow within work zone and incident areas.

Despite the success of ITS technologies in many contexts, it is worthwhile to note that improving safety and mobility in work zones requires a multi-faceted approach that involves

the cooperation, initiative and innovation of multiple agencies. FHWA recently updated Regulation 23 CFR Part 630, and renamed the “Work Zone Safety and Mobility Rule” to help state departments of transportation and local agencies meet current and future work zone safety and mobility challenges (Scriba, 2005). The rule calls for development of an overall, state-level work zone safety and mobility policy, standard procedures to support policy implementation, and procedures to evaluate the impacts of projects and systems.

The report that follows was based on published journal articles, proceedings of conferences and symposia, and reports as well as information provided by representatives of state DOTs and federal agencies, professionals in industry and university researchers. The findings of the study reflect the collective decisions of the CASE Study Committee and do not represent the views, positions or policies of ConnDOT.

This report is organized as follows. A summary of Connecticut’s existing traffic operational systems in both work zones and incident management is given in Section II. Section III addresses various portable traffic management systems for use in work zones. A discussion of the application of portable systems in incident management is described in Section IV, followed by a description of some innovative technologies that have potential applications to improve traffic flows in Section V. The final section provides a summary of findings and concluding remarks.

II. CONNECTICUT OPERATION SYSTEM FOR USE IN WORK ZONES AND INCIDENT MANAGEMENT

A. WORK ZONES AND PVMSs

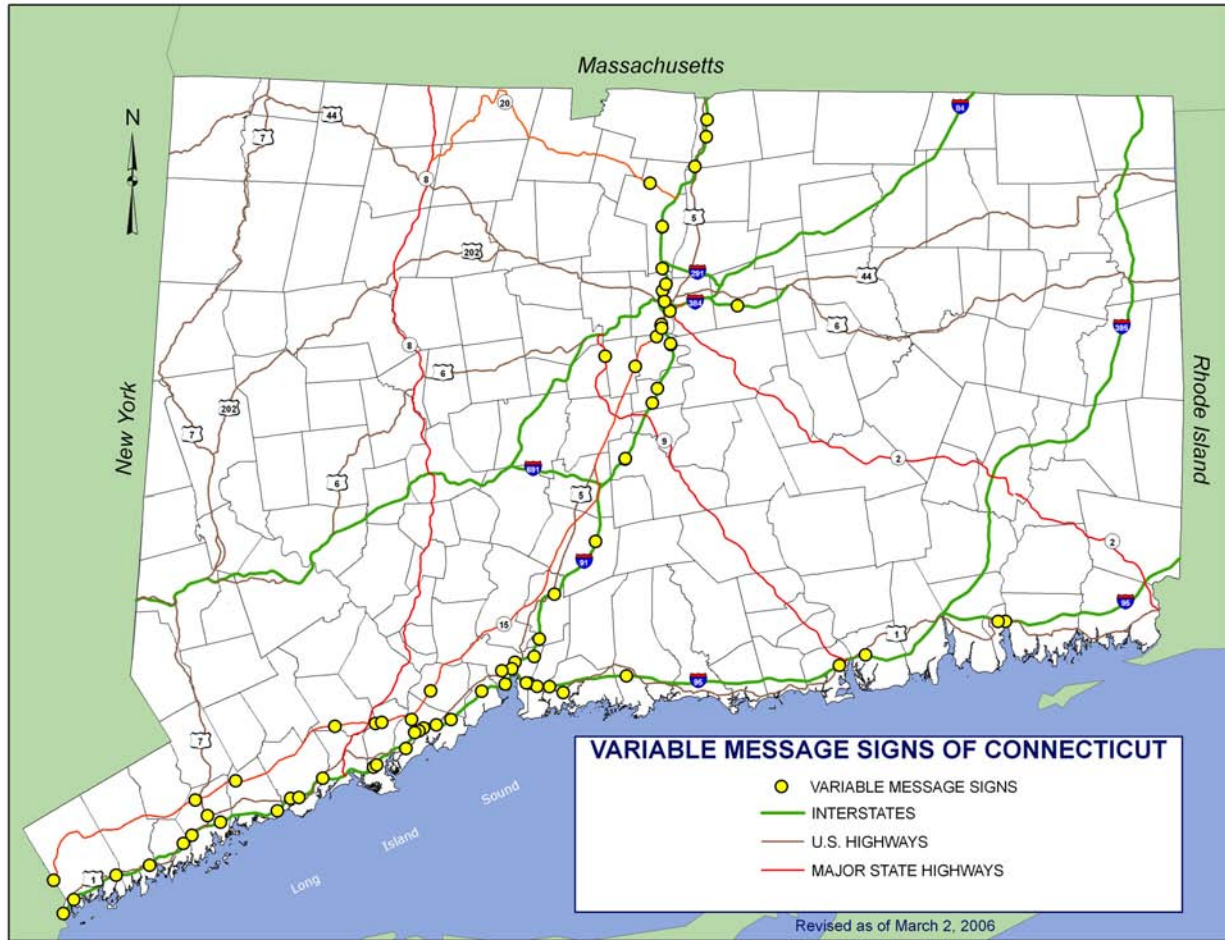
The Connecticut Department of Transportation (ConnDOT) is responsible for traffic control in work zones on Connecticut's state highway system that involve both short and long term operations. The short-term work zones that have traffic control performed by ConnDOT maintenance personnel and some contractors mostly involve maintenance activities such as pothole patching, bridge inspections, pavement marking installation, applications and other roadside work such as guard rail repair and mowing. Longer-term work zones involve larger highway construction projects where the contractor is responsible for traffic control under the supervision of ConnDOT. All traffic control operations on state highways must be in compliance with the *Manual on Uniform Traffic Control Devices (MUTCD)*, 2000, and ConnDOT guidelines.

Currently, a number of PVMSs are being distributed throughout the state. They are usually located in the vicinity of sites that have a history of high incident occurrence, as well as those sites that are determined to be potential congestion areas, such as work zones and freeway-to-freeway intersections or interchanges. In addition to use during incidents and work zone activities, the PVMSs are also used for special events to inform drivers of delays and congestion. The requirements for the placement of PVMSs are more flexible than requirements for the installation of the permanent VMSs, so PVMSs can be more readily deployed within construction zones or incident areas. ConnDOT uses a 1000-foot roadway sight line guideline for installation of permanent VMSs so that drivers can see two sign frames, each of which is displayed for three seconds. Map 1 on page 4 shows the locations of VMSs in Connecticut. For PVMS, sight distance and frame speed may differ because of particular message needs or limited location availability.

Figure 1 on page 4 shows a typical PVMS used by ConnDOT. The following list describes certain capabilities of this product:

- The device is a National Transportation Communications ITS Protocol (NTCIP) compliant controller which enables the VMS to communicate with ConnDOT's central control systems using a federally-adopted communications standard;
- The device includes full matrix displays, in lieu of a specific character matrix, enabling ConnDOT staff to use different character fonts, including 36-inch characters, if necessary, in addition to graphics;
- Some devices which allow for 70° viewing angle LEDs are more flexible than 30° LEDs and afford motorists better visibility, especially when the signs must be quickly deployed without a careful study of the site location to determine the optimal viewing angle. This is a significant advantage of this system.

The remainder of this section discusses some of the operational aspects of this type of PVMS.



Map 1: Variable Message Sign (VMS) Locations in Connecticut
Map courtesy of ConnDOT



Figure 1: A Typical Portable Variable Message System (PVMS)
Photo courtesy of Daktronics (Vanguard® VP-1300 Product Brochure)

Communications - Controlling VMS Messages

Some PVMSs owned by ConnDOT allows them to use wireless cellular modems to communicate and control PVMSs from two Highway Operations Centers (HOCs) located in Newington and Bridgeport. The wireless modems enable operations staff to download messages to the signs from the system's central control software, monitor sign operation for malfunctions and turn messages on and off. In situations where the operations staff is unable to communicate with PVMSs due to cellular reception issues at a particular field location, e.g., Litchfield County, alternative methods are used. The variable sign messages are pre-loaded when cellular communications are active, or the field staff loads the sign messages using a laptop PC. In either case, the messages are turned on and off by the staff in the field. Communication with permanently installed VMSs is accomplished through a fiber-optic connection with dial-up modems serving as a back-up.

Communication - Receiving Traffic Information from a Construction Site

Currently, telephone communication is the primary method for informing the HOCs of traffic conditions at a construction site. ConnDOT staff receives phone calls from the construction inspection staff regarding traffic delays. However, it has been difficult to quantify the extent of the delays and queue since the on-site personnel are often working within the work zone area and not where the traffic queues form upstream of the work zone area.

Solar Power System

During the summer, PVMSs that are equipped with solar power systems can run for months without requiring re-charging due to the stronger sunlight and warmer temperatures. Even the best batteries do not hold a charge as well in colder temperatures, when the batteries need to be re-charged every 3-4 weeks. Moreover, the temperature must be monitored closely so that the batteries do not freeze in very cold conditions. Nevertheless, the solar charging systems are still used in the winter as long as the solar panels can be orientated towards the sun's path.

Video Cameras

Most PVMSs that are currently in use are not equipped with video cameras. However, cameras are installed on semi-permanent VMSs and planned for use on others along the I-84 corridor westerly from Southington to Newtown in work zone areas for this on-going, long-term construction project. Telephone circuits need to be installed to enable video to be sent back to the appropriate HOC. These circuits allow images from the cameras to be viewed in close to "real time" (30 frames per second). These semi-permanent VMSs were selected since a permanent VMS system along this area of I-84 is not currently in operation and is not scheduled for installation for at least five years. The camera-equipped, semi-permanent VMSs enable HOC staff to monitor work zone and incident delays or events and to provide motorists with traffic and alternative routing information. Also, ConnDOT is evaluating the use of semi-permanent, camera-equipped VMSs for use in other long-term work zones where permanent VMSs are not available.

System Constraints

Some of the limitations of this type of PVMS system are as follows:

- PVMSs are not equipped with a real-time vehicle detection system.
- PVMSs do not generate messages that can be displayed automatically.
- Messages usually do not display specific values in terms of delay and queue length, nor do they specify alternative routes.
- Cellular coverage at PVMS sites is not consistent, and trying to send video over cell service would not work well due to low transmission speed.
- The PVMS power system is affected by winter operating conditions: batteries may freeze in cold temperatures and solar power is not sufficient. However, ConnDOT's PVMSs are generally stored in maintenance facilities during the winter, unless they need to be used for incident management purposes for relatively short periods of time, as they are not used in work zone operations due to the very limited nature of these operations during the winter.
- Camera coverage must be provided separately.
- In certain areas, roadside clear zones are not of adequate width for the safe placement of PVMSs.

B. INCIDENT MANAGEMENT

Incident Management consists of a centralized effort focused on detecting, responding to, and clearing incidents to recover traffic flow. Connecticut's incident management policy ensures that highway users receive the maximum possible benefit of an active incident management program that minimizes the impact of traffic-related incidents. ConnDOT, Connecticut Department of Motor Vehicles (DMV), the Connecticut Department of Public Safety (DPS), and the Connecticut Department of Environmental Protection (DEP) are given shared responsibility and authority for implementing this policy cooperatively and expeditiously through a series of programmed activities. The agencies involved in implementing this policy have accepted and agreed to promote the concept of a team approach.

The Incident Management Task Force (IMTF), directed by the Connecticut Transportation Strategy Board, is working on improving the efficiency, coordination and management of the response to and clearance of incidents on the state's highways. The IMTF comprises representatives from ConnDOT, DMV, DPS, and DEP, as well as representatives from the Connecticut Chiefs of Police Association, Connecticut Fire Chiefs Association, Towing and Recovery Professions of Connecticut, emergency management services, and regional planning organizations with incident management councils. Other agencies, such as the Federal Highway Administration, the US Coast Guard, public transportation providers, and other groups and agencies involved in emergency response efforts are invited to send participants either on a continuing ad hoc basis or as participants in relevant discussions of the IMTF.

Working together with other agencies in the IMTF, ConnDOT follows prescribed incident management protocols during each phase of an incident: notification/ detection, verification, dissemination of motorist information, response, site and traffic management, and clearance.

After the first call is received, the incident is verified through the highway camera system, police, or the media; when applicable the operations center staff activates the VMSs and HAR to advise the motoring public, contacts ConnDOT management staff and advises TRANSCOM—a coalition of 16 transportation and public safety agencies in the New York-New Jersey-Connecticut metropolitan region. TRANSCOM was created in 1986 to provide a cooperative, coordinated approach to regional transportation management, especially during large incidents on the major through routes of the states. TRANSCOM maintains a website (www.trips123.com) for Regional Traveler Information, to notify the public, media and others along the I-95 corridor from Maine to North Carolina, if required. To improve incident management response, ConnDOT has developed response protocols for freeway closures which include pre-planned diversionary routes and traffic control in coordination with local public agencies. Also, ConnDOT is planning within the next year to gain access to the DPS's INTERCAD (computer-aided dispatch) system in an effort to improve incident management notification and inter-agency coordination.

C. REAL-TIME INFORMATION AND TECHNOLOGY

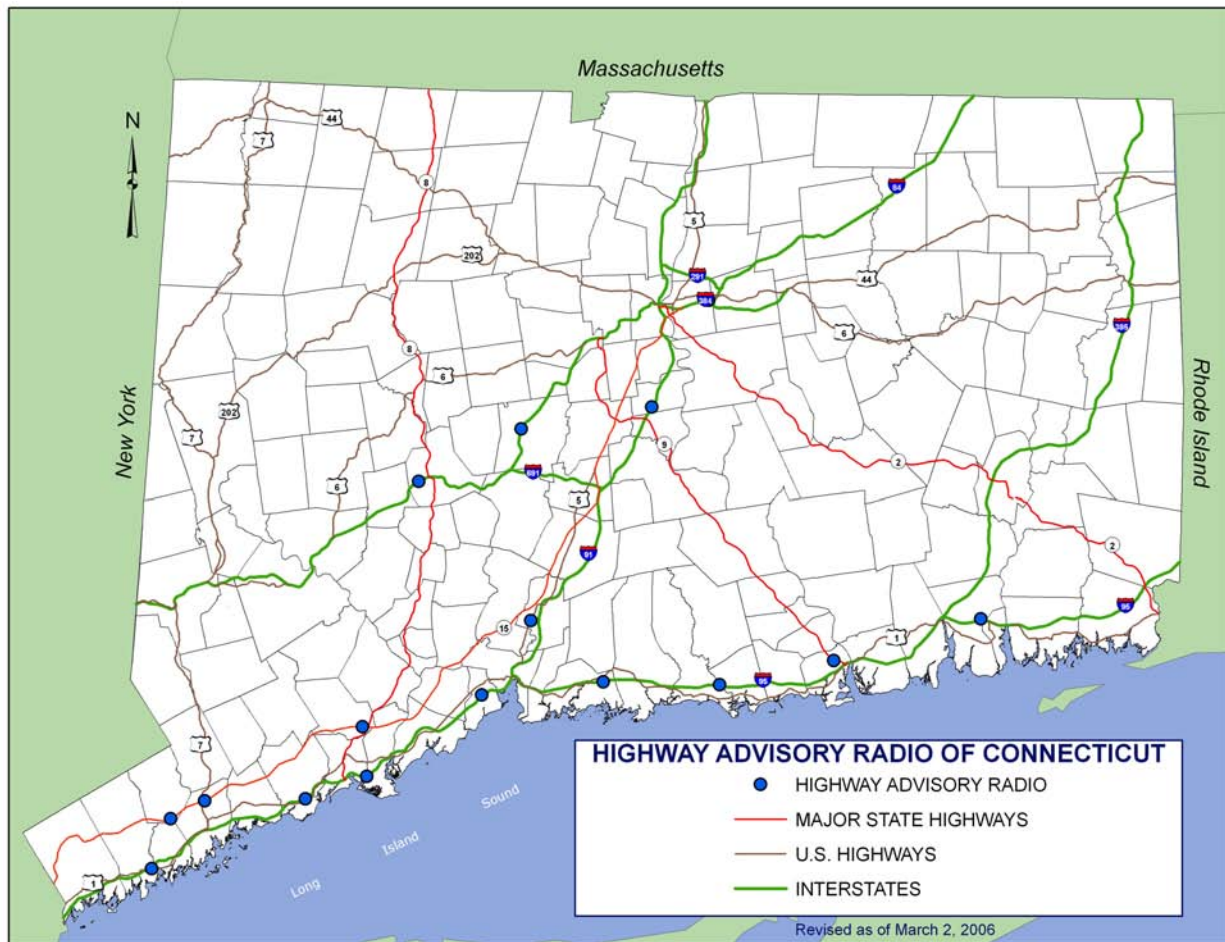
It is important to provide real-time information concerning travel conditions on Connecticut's major highways to drivers during both incident and non-incident periods. Currently, ConnDOT uses several methods to disseminate traveler information: VMSs, HARs, commercial radio and television broadcasts, the ConnDOT website and TRANSCOM.

ConnDOT also has implemented an "email to subscribers" system. The state is divided into four regions, with subscriptions available by region. Additionally, it may also be possible to provide route-to-route subscriptions to subscribers.

The HAR is controlled by the ConnDOT HOCs. The following criteria have been identified:

- Coverage area – generally a 5-mile radius.
- Terrain affects coverage because the radio signals are line-of-sight and therefore can be blocked by hills, buildings and dense trees.
- Available frequencies on AM band limit the system's effectiveness because they are subject to interference by pirate stations (unlicensed, illegal stations broadcasting in violation of the law).
- A number of locations are currently in operation and expansion of the system is planned.

In addition, pending the availability of funding, Connecticut is planning to deploy a 511 telephone traveler information system statewide. By dialing 511, motorists will be able to get a variety of information on traffic conditions including incident, delay, alternate routes, weather conditions, transit information, as well as other travel-related information. 511 is a nationwide number reserved by the Federal Communication Commission (FCC) for traveler information.



III. PORTABLE TRAFFIC MANAGEMENT SYSTEMS FOR USE IN WORK ZONES

Intelligent portable traffic management systems have been widely implemented across the United States. Interviews were conducted with representatives of various state DOTs (including North Carolina, Arizona, Arkansas, Missouri, Maryland, Minnesota, Florida and others) about their work zone deployment initiatives and programs. A literature search and review of current practices also was conducted. This section of the report addresses each system in terms of features, deployments and evaluation results. It also includes a description of a Speed Feedback system, which is not considered an intelligent traffic management system, but serves as a vehicle speed management tool for use in work zones.

A. SPEED FEEDBACK (SPEED MONITORING DISPLAY)

Speed Feedback, also referred to as Speed Monitoring Display, detects and displays the speed of approaching vehicles to encourage drivers to comply with the reduced work-zone speed limits. State highway agencies in Iowa, Kansas, Nebraska and Wisconsin deployed Speed Feedback signs as part of the Midwest Smart Work Zone deployment initiative (<http://www.fhwa.dot.gov/rnt4u/ti/safespeeds.htm>). Speed Monitoring Display units are currently utilized by ConnDOT.

One such system that is utilized by the above-referenced states is the SpeedGuard Radar Speed Reporting system developed by Speed Measurement Laboratories, Inc. (Meyer, 2000). It is a portable, self-contained trailer unit, equipped with radar to measure the speeds of approaching vehicles. The recorded speeds are displayed on a 24-inch panel with photocell-equipped LED numerals that automatically adjust brightness, as shown in Figure 2. The system is powered by three 12V DC heavy duty marine batteries, which can last for up to a week. The message “Your Speed” is mounted on the trailer beneath the variable message display. A speed limit sign can be mounted on a rack above the display or the trailer itself can be placed next to an existing sign.



Figure 2: SpeedGuard Radar Speed Reporting System
From the report “SpeedGuard Radar Speed Reporting System - Nebraska” (McCoy, P.),
with permission from Geza Pesti, Texas Transportation Institute

The SpeedGuard system was deployed in a work zone along I-80 in Nebraska in 1998 and was positioned 1,250 feet in advance of the 900-foot lane closure taper (Meyer, 2000). It was found to be effective in both lowering speeds and increasing the uniformity of vehicle speeds traveling through the work zone. At 750 feet downstream of the system, the 85th percentile speed and the mean of the 15 highest speeds were reduced from 65 mph by about 5 mph, enough to be under the speed limit. The effect was similar for both passenger and non-passenger cars, with a 90% or greater compliance rate during both day and nighttime operating conditions.

Finally, the SpeedGuard system can also be equipped with an alarm horn to warn the workers of vehicles approaching at dangerous speeds and a camera for photo-enforcement, although the latter is illegal in nearly all states. A study in Kansas regarding the Speedguard system (Meyer, 2000) found that when it was used in conjunction with a law enforcement officer for speed enforcement, the speed of vehicles approaching the work zone was reduced. However, vehicle speeds increased around 4-5 mph downstream of the patrol car.

McCoy, Bonneson, and Kollbaum (1995) examined the effectiveness of speed displays at a rural interstate work zone in South Dakota. The speed monitoring display trailer was placed in the median next to the left traffic lane at the beginning of the merge-area taper. As motorists approached the merge area, their speeds were displayed on the speed monitoring display. The study indicated that the speed monitoring display reduced mean vehicle speeds by 4 mph (i.e., from 60.5 to 56.5 mph). The study also indicated a reduction in the percentage of vehicles that were exceeding the speed limit through the work zone. The percentage of passenger cars speeding through the work zone was reduced by 20–25%. The percentage of speeding trucks was reduced by about 40%.

In a similar study, Garber and Fontaine (1996) used a PVMS with a radar unit to examine speed reductions at rural interstate work zones in Virginia. In this study, the radar and the PVMS system were set up approximately 300–600 feet upstream from the merge area. The radar was carefully placed to detect only one vehicle at a time. Vehicles that drove above a selected threshold speed activated the PVMS system, which in turn displayed a “YOU ARE SPEEDING, SLOW DOWN” message. The speeding motorists were videotaped as they passed through the work zones to capture any vehicle speed changes. This study found that the mean speed of all traffic was reduced by only approximately 0.7 mph at the PVMS location. Once inside the work zone, however, this reduction increased to approximately 1.4 mph. The 85th percentile speed reduction of about 8 mph led to the conclusion that the PVMS system, coupled with a radar unit, has an impact on reducing speeds of the fastest segment of the driving population.

Recently, Pesti (2005) presented the evaluation study of an innovative speed feedback system – the D-25 Speed Advisory Sign System (Figure 3) – which was developed by MPH Industries. Instead of displaying approaching vehicle speeds, the D-25 system reports downstream vehicle speeds. The system was designed to warn drivers of stopped or slow-moving traffic ahead and thereby enable them to reduce the speed of their vehicles and to avoid rear-end collisions. A deployment of this D-25 system consisted of three speed trailers placed at approximately 1/4-mile intervals in advance of a work zone on I-80 near Lincoln, Nebraska. Each trailer was equipped with an LED speed display, a radar unit for measuring the speed of downstream traffic, two flashing strobes to warn drivers of downstream problems, a “SPEED OF TRAFFIC AHEAD” sign mounted over the speed display, and a “USE EXTREME CAUTION WHEN FLASHING” sign mounted beneath the speed display. The three speed trailers were operated

independently. When a traffic slowdown was detected, the strobe lights began flashing. When there was no slowdown, the strobe lights were off. The results of the analysis indicated that the speed messages were effective in reducing the speed of vehicles approaching queued traffic during time periods when congestion was building. After deployment of the system, vehicles began decelerating sooner and reduced their speed over a longer distance. The change in mean deceleration due to the speed advisory system was statistically significant at the 95% confidence level. In addition to the advisory speed messages, vehicle approach speed and trailer location also significantly affected vehicle deceleration. Due to the limited time available for the field studies, the long-term effectiveness of the speed advisory system could not be determined.



Figure 3: D-25 Speed Advisory System (Pesti, 2005)

From the proceedings of the Transportation Research Board Annual Meeting (2005): "Alternative Way of Using Speed Trailers: Evaluation of D-25 Speed Advisory Sign System," with permission from Geza Pesti, Texas Transportation Institute

Each of these studies examined the effectiveness of the use of a speed display or an advisory system in reducing vehicle speed. Although each study utilized a different deployment and evaluation method, most did not identify whether or not their results in speed reduction were statistically significant. Also, the design of sample size was not revealed in most of the studies.

B. VARIABLE SPEED LIMIT (VSL) SYSTEMS

One of the stereotypical situations from the perspective of drivers is that low speed limits are posted in very long marked construction work zones where construction activities occur miles apart. The use of variable speed limits can be particularly useful in these situations. VSL systems are introduced by dynamically changing the posted regulatory speed limit. They provide real-time information on the appropriate speed limit for current conditions based on traffic flow, traffic speed, weather and other inputs. The use of VSL systems in work zones may result in lower speed variance, greater speed compliance, greater credibility of speed limits and

improved travel conditions. FHWA participated in cooperative agreements with three states—Michigan, Maryland and Virginia—to evaluate the use of variable speed limits in work zones, although the Virginia study was canceled due to legal disputes among technology vendors. The following summarizes the field test results in Michigan.

Michigan DOT deployed a VSL system in one direction within an 18-mile work zone on I-96 during the 2002 construction season. The VSL system/trailer (Figure 4) used in Michigan was developed and deployed by NES Worksafe and International Road Dynamics (IRD). This VSL system/trailer detected vehicle density, speed, and weather. These data were analyzed by a virtual traffic management center or a field unit to establish and display a condition-responsive speed limit on signs based on pre-programmed criteria.

As described in the evaluation study conducted by Michigan State University (Lyles, 2003), the system suffers from a lack of real portability, which limits its ease of use in the often restricted work zone environment. The results were similar to those that might be expected of a prototype, as opposed to a fully tested and refined system. Some modifications were made during the evaluation of the system, including improving communications with individual VSL trailers and between trailers, flexible vehicle sensors, and the algorithms for setting speed limits, etc. There were positive effects on average speeds (increased) and travel time (decreased) through the VSL deployment area. However, the system had relatively minor positive impact on the effectiveness of driver behavior in work zones in which it was used. Effects on the 85th percentile speed and speed variance were either undetectable or inconsistent. The percentage of vehicles exceeding certain thresholds (e.g., 60 mph) did, however, decrease when the system was in operation. This relatively minor impact may have been due to the topography of the area and the existence of ramps and bridges associated with a freeway-to-freeway interchange that resulted in significant restrictions being placed on the speed limits that could be used. For example, the on- and off-ramps resulted in the need to restrict the maximum speed limit.

The study found that overall travel speeds (and related measures) were often affected more by the geometry and weaving traffic within the confines of the freeway-to-freeway interchanges than they were by the posted limits. It was suggested that VSL systems will have different applicability in different types of work zone situations. For example, they will have more utility in longer and “simpler” work zones—long zones with short areas of actual work. These limitations notwithstanding, it was determined that VSL systems can present far more credible information to the motorist, responding to both day-to-day changes in congestion as well as significant changes as motorists travel through a given zone.

Regarding the enforceability of VSL, Michigan DOT and the Michigan Department of State Police (MSP) have the legal authority to set speed limits in work zones within the state. These agencies have a memorandum of understanding (MOU) in place whereby MSP provides “on call” extra/strategic enforcement in work zones around the state. Under terms of the MOU, MSP provided enforcement during the 2002 construction season for the VSL test site when requested by Michigan DOT personnel. However, the study results concluded that the addition of enforcement personnel in the VSL deployment area seemed to have no effect on average speed, speed variance, or percentages of higher-speed vehicles.

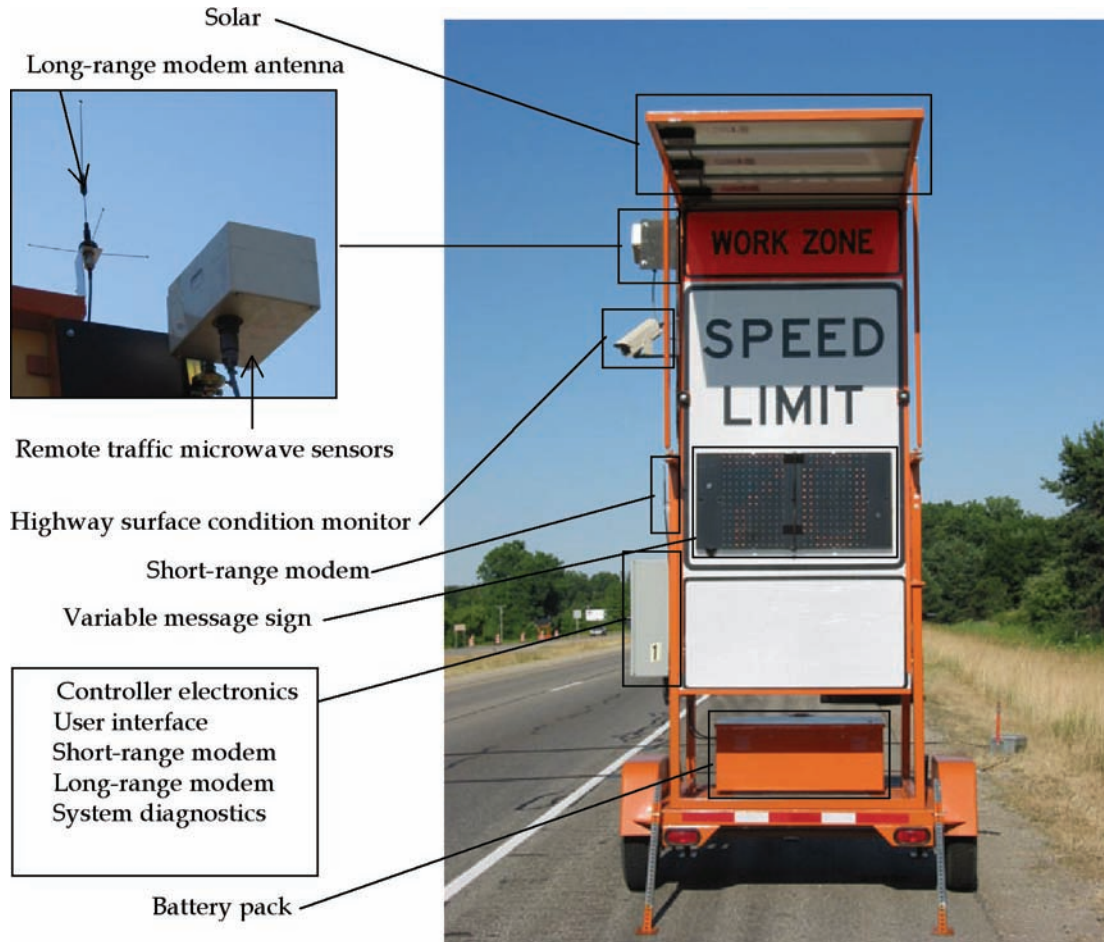


Figure 4: Variable Speed Limit System (Lyles, 2003)

From the report: "Field Test of Variable Speed Limits in Work Zones (in Michigan)" (Lyles, R.W., W.C. Taylor, and J. Grossklous), with permission from Professor Richard W. Lyles, Michigan State University

C. TRAFFIC INFORMATION ADVISORY SYSTEMS

Traffic information advisory systems are systems which use various technologies to detect traffic flow information in a work zone and provide advance warning to drivers via PVMSs, HAR, or flashing beacons on fixed-message signs. Sometimes the information is also disseminated through websites. The messages used to convey the warning vary. Some messages simply advise drivers of the presence of slow-moving or stopped traffic ahead. Others provide travel time estimates and alternate route suggestions. In general, three types of messages are used (Fontaine, 2003), as listed below:

- Speed-advisory messages: The upstream PVMSs display a message that alerts drivers that speeds are slower ahead.
- Travel-time or delay advisory: On the basis of speed data, travel time or delay is calculated. The message shows an estimation of either travel time or delay through the work zone.

- Diversion guidance: A message on possible alternate routes may be displayed or motorists may be advised to use an alternative route. This is typically determined based on a delay calculation.

Several such systems have been field deployed and are discussed below.

1) Automated Data Acquisition and Processing of Traffic Information in Real Time (ADAPTIR)

ADAPTIR is a portable, condition-responsive work zone traffic control system that is capable of providing drivers with real-time information about work zone traffic conditions via PVMs and HAR (McCoy, 2000). It was developed by the Scientex Corporation through a cooperative agreement with FHWA and the Maryland State Highway Administration. The system was field tested in Maryland during the summer of 1997 to manage congestion related to beach traffic at Ocean City, Maryland and at Route 100 upstream of the interchange to I-97 in Hanover, Maryland in January 1998. Both projects resulted in improvements, such as communications, to the ADAPTIR. Following these field tests, the system was also utilized in Kentucky, Illinois, Arkansas, and Nebraska.

The following describes the basic function and evaluation results of the system that was utilized in the Nebraska deployment:

ADAPTIR is designed to improve the safety and efficiency of traffic operations in advance of a work zone by advising drivers of lower speeds and delays ahead and encouraging them to use alternate routes. The solar-powered ADAPTIR has the following components:

- One or more PVMs upstream of the work zone;
- HAR to provide more detailed information than PVMs;
- Central system controller (CSC) to run the control software;
- Radar sensors to continuously measure speeds (Figure 5);
- Roadside remote sensors (RRS), as shown in Figure 5, to receive data from radar sensors and under the control of the CSC, program the appropriate messages for the PVMs and HAR.

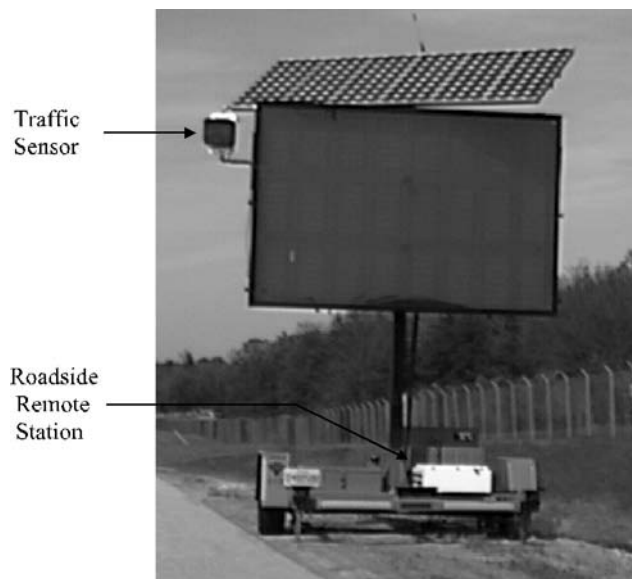


Figure 5: ADAPTIR (ADAPTIR, 2005)

Photo courtesy of the Scientex Corporation (ADAPTIR™ Product Brochure)

Speeds are measured continuously at and downstream of the PVMS. An agency pre-determined speed differential threshold value is used to determine the message that is displayed. A speed differential threshold value of 10 mph was selected for the Nebraska deployment. If the difference between speeds is less than the threshold, the PVMS remains blank. For speed differences of more than the threshold, a two-phase message was displayed – Phase 1: “I-80E Advisory XX: YY AM/PM” and Phase 2: “Reduced Spd Ahd XX MPH,” The collected speeds were also sent to the CSC, which estimated delays every 8 minutes in the off-peak hours and every 4 minutes in peak periods. If the delay was greater than the 5-minute threshold, the Phase 2 message was changed to “XX Min Delay Ahead.” If the delay exceeded half an hour, the PVMS message suggested alternate routes with a Phase 1 message “30 Min Delay Ahead” and Phase 2 “Consider Alt. Route.”

An evaluation study of the Nebraska deployment (McCoy, 2000) showed that ADAPTIR had no effect on speed and lane distribution of traffic within 2,000 feet of the lane closure taper or on the numbers and rates of forced merges in advance of the closure taper. Speed advisory messages during periods of uncongested flow were not effective in reducing speeds, but in congested areas within a work zone, speeds were reduced. Of the three PVMSs on I-80, the one located at 7.8 miles upstream of the work zone (before the alternate route interchange) was not effective, as drivers did not perceive any need to slow down. The other two PVMSs at 3.1 and 1.1 miles upstream had an impact on speeds. The study also suggested that the spacing between the PVMSs influenced the effectiveness of the speed advisory messages. The diversion message was only effective in encouraging 3% of the drivers to divert, and did not discourage drivers from entering the interstate (however, it should be noted that 80% of the drivers were from out of state). Finally, the use of this system did not affect the number or rate of crashes associated with this 2-3 month work zone project.

ADAPTIR was also deployed in Illinois and Kentucky. Fontaine (2003) conducted an interview with field personnel about the ADAPTIR’s deployment in Illinois for a bridge reconstruction

project. The interview revealed that some problems were encountered during initial setup of the system, such as difficulty with the installation of radio communications and the antenna location. Illinois DOT did not perform an evaluation study for this deployment because the expected levels of queuing and delay did not develop. The movable barrier system utilized in this project provided for sufficient capacity on the bridge during construction. The Kentucky Transportation Center conducted an evaluation of an ADAPTIR deployment on Interstate 64 in Franklin County, Kentucky in 1993 (Agent, 1999, Fontaine, 2003). The system did not have long-term problems although communications problems, lightning strikes, and low battery power caused some interruptions in system performance. The evaluation results have shown that the ADAPTIR displayed appropriate speed messages based on current conditions. The measured speed data were validated by using field data. Actual travel times through the work zone were compared to the delay estimation determined by the system. Substantial difference was occasionally found between actual and estimated travel time. The study concluded that this was due to the lack of speed measurements within the actual work zone activity area. The system's radar units were utilized to collect speed data at the work zone lane closure, where vehicles were delayed significantly. Therefore, the speeds measured at the taper often were not representative of travel speeds within the work zone and delays often were overestimated.

2) *Intellizone*

Intellizone, developed by Quixote Transportation Safety and HCI Enterprises, Inc., is a work zone speed advisory system. It consists of a series of detectors that can record speed, volume and occupancy, one or more PVMSs and one mobile command unit placed between the detectors and the PVMSs to link them through wireless communication (King, Sun and Virkler, 2003).

Under uncongested traffic flow conditions, the PVMSs show a warning for the work zone or actual speeds ahead. At lower volumes, the PVMSs show calculated, volume-weighted speeds and when these speeds drop below a predetermined threshold, a "stopped traffic" along with an alternate route message can be displayed at an upstream PVMS, as shown in Figure 6.

An evaluation of the Intellizone system (King, Sun and Virkler, 2003) was carried out on I-70 in St. Louis, Missouri. Study results indicated that drivers were generally satisfied (understood and trusted) the speed advisory signs, and that the speed of vehicles approaching the work zone was reduced, especially in congested periods. For example, the average vehicle speed at 7 miles upstream of the work zone was reduced from 69 mph before the deployment to 63 mph after the deployment of the system. Finally, consistent with other systems, the diversion rates were very small – only 3.6%.



Figure 6: Variable Message Sign (VMS) Messages from Intellizone

From "Evaluation of a Freeway Work-zone Advance Speed Advisory System" (King, T., C. Sun, and M. Virkler), with permission from Professor Carlos Sun, University of Missouri-Columbia

3) Real-Time Traffic Control System (RTTCS)

The RTTCS, deployed by Illinois DOT (IDOT), comprises PVMs, portable traffic sensors, and portable closed-circuit television (CCTV) cameras linked via wireless communications to a central workstation (FHWA¹, 2004). The RTTCS is a customized system. IDOT developed detailed functional requirements for the system, reviewed the approach proposed by the vendor against the functional requirements, and then worked with the vendor to finalize the system design.

A PVMs and traffic sensor are shown in Figure 7. Based on vehicle speed and the presence of vehicles as they pass the sensor stations, the system calculates the delay at each sensor station and then automatically generates messages on the PVMs. The system also displays a real-time delay map on IDOT's website every 5 minutes and sends congestion/incident detection alerts to IDOT staff. CCTV imagery is used to confirm data generated by the system, especially if the system detects an incident.

The RTTCS was deployed for a major bridge and highway reconstruction effort on a 40-mile section of I-55 (for both north and southbound approaches) located in the vicinity of Springfield, Illinois from February 2001 to May 2002. In order to give ample warning to drivers, three-phase PVMs (Figure 8) were deployed, some of which were located 40 miles upstream of the I-55 project work zone.

The FHWA case study report (FHWA¹, 2004) stated that "The system successfully monitored traffic along a busy interstate between Springfield (the state capital) and St. Louis. IDOT reported that the system performed well, with little downtime. IDOT staff said that they would use the system again." Although no official evaluation of the system was performed, IDOT officials were satisfied with the performance of the RTTCS.

Several major benefits of the RTTCS were identified by IDOT staff, including no significant traffic back-ups, and a significant downward trend in the number of traffic violations after the system began displaying these messages. IDOT staff responsible for operations in the work zone reported only two crashes in the construction area during the RTTCS deployment. One of the crashes was attributed to driver fatigue and the other to driving while impaired. The small number of crashes was attributed to the absence of back-ups and to the ample warning drivers received via PVMSs, some of which were located 40 miles upstream of the work zone. The major deployment constraints for the RTTCS are (1) significant time required for system calibration during initial implementation of queue-length detection systems, and (2) the availability of cellular digital packet data (CDPD) coverage in the work zone area.



Figure 7: RTTCS Components - PVMS and Traffic Sensor with Solar Array
Photo courtesy of FHWA (Federal Highway Administration)

Figure 8: RTTCS – 3 Phases Messages

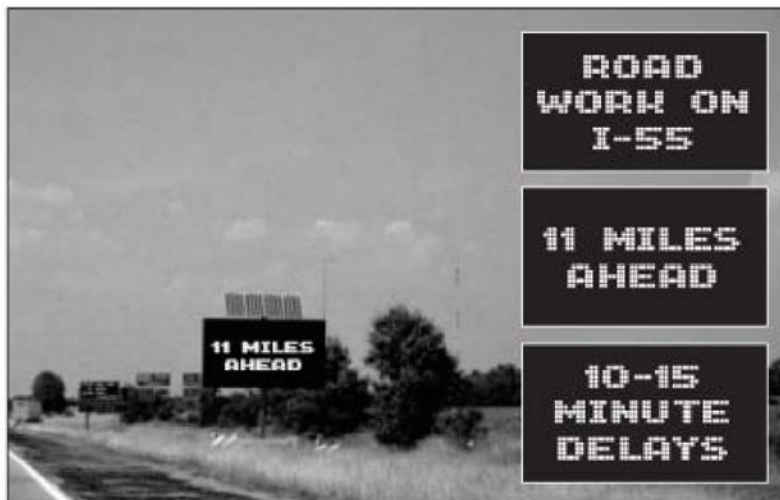


Photo courtesy of FHWA (Federal Highway Administration)

4) Smart Work Zone System Deployment in Minnesota

The smart work zone system in Minnesota, resulting from a partnership involving Minnesota DOT and ADDCO (a company that specializes in traffic solutions and traffic management), is another portable, wireless system. This system uses a video image process technique (Autoscope) to obtain traffic information. The system consists of portable trailer, which houses various components that serve as work zone nodes. The nodes, placed in strategic locations in the work zone and linked together by spread spectrum radio, include both vehicle detection devices and PVMs, as shown in Figure 9. A portable vision machine, mounted at the top of the tower, is used for vehicle detection to provide traffic images, traffic volumes, speeds and incident data. The communication system relies on spread spectrum radio, cellular phones and an Integrated Services Digital Network (ISDN).

The system was deployed on I-94 between downtown Minneapolis and downtown St. Paul, Minnesota and on I-35 in the southern portion of the Twin Cities metropolitan area in 1994-1995 (SRF, 1997). This deployment identified a significant increase in the traffic volume moving through the work zone (3.6% higher in the morning peak period and 6.6% higher in the afternoon peak period) due to the increase in capacity resulting from the more orderly traffic flow; a decrease of over 70% in the speed variability; and a decrease of 9 mph in average speed of traffic approaching the work zone, improving safety. The report also indicated that there were some wireless communication problems during the deployment. However, it is expected that this deficiency has been resolved with improved technology developments in the past few years. Another evaluation study conducted by Nookala, Thompson et al. (1995) indicated that camera placements should be adequately calibrated prior to the beginning of a deployment.



*Figure 9: Smart Work Zone System
Photo courtesy of SRF Consulting Group, Inc.*

5) Travel Time Prediction System (TIPS)

The TIPS, manufactured by PDP Associates, is a portable, automated system for real-time prediction and display of travel time information to motorists in advance of and through work zones (Drakopoulos, 2001). Its purpose is to distribute the traffic volumes between the corridor under construction and an alternate route to reduce travel time through and around the work zone and to enhance safety.

The system collects real-time traffic flow data with radar sensors, processes the data in an on-site computer to compute various travel times between PVMS points and the end of the work zone, and displays travel time information for motorists.

According to the developer, TIPS has a communications range of 20 miles, sensors that can detect traffic flow in each lane (for up to eight lanes), and can provide travel time predictions with an accuracy of +/- 3 min. Communications between system detectors, the on-site personal computer, and the PVMSs are through radios using the 220MHz frequencies that have been allocated to FHWA, with no special FCC permission being required to use these frequencies (see Figure 10). The system is powered by batteries that are charged through solar panels.



Figure 10: TIPS Radio Antenna and Computer

Photo courtesy of Professor Alex Drakopoulos, Marquette University

A TIPS system was deployed in the summer of 2001 along southbound I-94 in Milwaukee and Racine County, Wisconsin. The evaluation, conducted by Drakopoulos (2001), not only focused on the effect on motorist behavior, but also the reliability of the travel time that was displayed. TIPS' performance was, in general, satisfactory, as it was able to follow travel time changes and successfully change drivers' routes during congested periods. Actual travel time was measured by utilizing drivers (students) who were hired specifically to travel through the work zone to report their actual travel times. Volume loop detectors were used to estimate vehicles' diversion decisions by measuring demand on possible diversion routes before and after the study. A comparison showed a lower injury crash frequency for the TIPS work zone after TIPS began operation than for a similar construction zone without TIPS in the opposite direction of travel, which was used as a control site for the safety evaluation. The evaluation report did not provide any conclusive results regarding safety improvements, since the analysis periods were limited to only 69 days before and after the TIPS operation.

Additionally, the system's operation resulted in only very small differences (0-5 minutes) between average actual travel times and travel times predicted by the TIPS system as displayed on the PVMS, but these differences were statistically significantly different from zero at the 0.05 level of significance. The most significant recommendation of the evaluation was to add additional detectors, especially at possible bottleneck locations. The TIPS signs did not provide any guidance about what might happen if an alternative route was chosen. However, alternative routes were marked with fixed signs for the benefit of those drivers who chose to divert.

Zwahlen and Russ (2002) also conducted an investigation of the accuracy of the travel times displayed by TIPS in a work zone on I-75 northbound in the Dayton, Ohio area. The system was in operation daily from July until November, 2000. The evaluation of this deployment included an accuracy analysis between the predicted and actual recorded travel times. Based on the regression analysis of actual times versus predicted times, the system does, on average, a reasonable job in predicting the travel times to the end of the work zone. About 88% of the actual times recorded for each sign, and for all three signs combined, were within a range of ± 4 minutes of the predicted time. However, a few differences (actual-predicted) as great as 18 minutes were observed.

6) *Portable Traffic Management System (PTMS) and Work Zone Speed Advisory System (WZSAS)*

The PTMS and WZSAS are enroute traveler information systems that provide real-time traffic-responsive information to drivers by means of a PVMS placed in advance of a diversion point upstream of the work zone (McCoy, 2000). The objective of these systems is to advise drivers of a work zone ahead and encourage them to divert to an alternate route when there is congestion in the work zone.

The PTMS, developed by Brown Traffic Products, Inc., was deployed in a work zone on I-80, in the vicinity of the Highway 63 interchange, between Lincoln and Omaha, Nebraska in 1998 (McCoy, 2000). This work zone involved an interstate reconstruction project which reduced the two westbound left turn lanes to one lane. This system comprised a video detection system and a PVMS, as shown in Figure 11, which used a wireless communications channel to communicate with the Nebraska Department of Roads (NDOR). The video detection system measured the speed of the vehicles entering the work zone. Under uncongested traffic flow conditions, the PVMS displayed the following two-phase message: Phase 1: "Road Work Ahead" and Phase 2: "Please Use Caution." When three consecutive recorded speeds entering the work zone were below the predetermined threshold of 25 mph, the message changed to "Delays!! Use Alt Route".



Figure 11: *Portable Traffic Management System (PTMS)*

Photo courtesy Patrick McCoy, Author

The PTMS was effective in encouraging approximately 4% of drivers to choose the alternate route during congestion periods (however, 90% of the drivers were from out of state) Suggestions provided by interviewed respondents included: PVMS should specify the alternate route drivers should take; the positioning of the PVMS at 9 miles before the work zone reduced its credibility; and, providing the distance to the work zone would have been helpful. Also, the two-phase message was presented in a sequential format, which displayed each phase for 1.5 seconds and then displayed a blank sign for 1 second to delineate the end of the message. Thus, the available reading time of 3 to 3.5 seconds was too short to enable drivers to see the message twice, as suggested by VMS guidelines identified in the *Manual on Uniform Traffic Control (MUTCD)*, which require a viewing time of 7 seconds.

The WZSAS, a system similar to PTMS, was tested by NDOR in 2002 during the reconstruction of the interchange at I-680 and Dodge Street as part of the larger West Dodge Road improvement project in Omaha (Pesti, et al. 2002). The WZSAS was deployed in advance of a work zone on northbound I-680 between Pacific Street and West Dodge Road. It could not be determined if this system was custom built or commercially provided.

This video detection system (Figure 12) was used to measure the speed of traffic at two selected points in advance of the work zone, with the average speeds being displayed on the two PVMSs placed upstream of the diversion points before the work zone. The control system coordinated the communication between the video detection system and the PVMSs in order to display the appropriate message.

The evaluation of the WZSAS showed that peak-period demands did not change in response to the speed messages after the installation/operation of the system,. Similarly, the effect on the percentage of drivers who selected an alternate route was insignificant. A web-based survey of drivers concluded that the majority of the respondents considered the information accurate and useful, but preferred delay information to speed information for their trip decisions. On a scale of 1 to 10, with 1 being poor and 10 being excellent, 74% of the respondents thought the usefulness of the speed advisory messages rated 5 or above, and 91% of respondents thought the accuracy of the speed advisory messages rated 5 or above. 51% of the respondents indicated that they would like to know the speed of traffic, while 69% said they would like to know the delay time. This indicates that delay information may be more useful than speed information, with 71% of the respondents indicating that if they encountered major congestion on the freeway, they would exit the freeway and take another route.



*Figure 12: WZSAS Camera Mounted Above Roadway
Photo used with permission of Geza Pesti, Texas Transportation Institute*

7) Smart Work Zone Deployment in North Carolina

North Carolina DOT (NCDOT) deployed its first smart work zone on I-95 just north of Fayetteville in 2003 (Bushman and Berthelot, 2002). The system was developed by International Road Dynamics, Inc. (IRD). The system alerted drivers to expected delays and directed them to an alternate route when appropriate. Figure 13 shows delay information that is provided by a PVMS. Trailer-mounted, non-intrusive sensors collected traffic data and analyzed them to estimate delay. When the delay surpassed a pre-set threshold, the system automatically displayed alternate route information on electronic signs. For this project, three PVMSs were positioned on I-95 upstream of the work zone area with at least one sign prior to the alternate route exit. Three additional PVMSs were also provided on the alternate route to guide motorists. The system was also linked to a website to disseminate real-time traffic information to the public for pre-trip planning. A mail survey to 1468 local residents was conducted within two months of the completion of the project; results indicated that local residents were highly positive about this system. All responses from frequent travelers indicated that the system was either sometimes accurate or always accurate in delay estimation. The system also dramatically decreased the queuing back-up. Severe congestion resulting in several miles of back-up was rare during the deployment period. The presence of the smart work zone system allowed NCDOT to react quickly and efficiently to incidents which would possibly cause miles of back-up. The detour route was already in place and the signing was used to divert traffic around the area for a period of 4-5 hours. Without the use of this system, the back-ups would have been much worse.



Figure 13: Smart Work Zone Deployment in North Carolina
Photo courtesy of International Road Dynamics, Inc.

8) New Mexico's Work Zone Traffic and Incident Management System

A work zone traffic and incident management system was deployed by the New Mexico State Highway and Transportation Department (NMSHTD) during the construction of the Big I interchange in Albuquerque, during 2003-2004 (FHWA², 2004). The Big I is located at the junction where I-40 (Coronado Interstate) meets I-25 (the Pan American Freeway). The work zone spanned 111 miles of construction, including 45 new and 10 rehabilitated bridges.

As shown in Figure 14, the system consisted of a series of cameras and sensors to monitor traffic conditions and detect incidents, electronic signs, HAR, a website, and other media to transmit traveler information. Incident detection capability was a major component of the system. Components relied on solar re-chargeable systems for power. Communications equipment for the system included spread spectrum radio, wireless Ethernet applications, and CDPD modems. Also, NMSHTD utilized Highway Emergency Lender Patrols (HELP) vehicles (Figure 15) to effectively deploy system information to expedite incident clearance.



*Figure 14 (right):
Example of ITS equipment
deployed at the Big I
Photo courtesy of FHWA (Federal
Highway Administration)*



*Figure 15 (left):
Highway Emergency
Lender Patrol Vehicle
Photo courtesy of FHWA
(Federal Highway
Administration)*

Incidents were detected through a camera image display that was monitored by NMSHTD. During incidents, NMSHTD notified emergency personnel for dispatch, and to manually activate VMS messages indicating the accident location, lanes affected and whether delays were occurring. However, the amount of delay and length of queue were not displayed. NMSHTD also distributed information via a website, media outlets (radio, newspaper, television), pagers (provided by a commercial paging service), as well as fax and email distribution lists.

The project identified several major benefits of using this ITS system:

- Improved mobility – incident response and clearance time within the work zone was reduced from 45 minutes, historically, to 25 minutes; and
- Safety – over the entire first year of construction in the work zone, traffic incidents were only 7% higher than the previous year, when there was no construction activity. This increase was smaller than what NMSHTD expected due to the complexity of construction within the work zone.

The report identified several lessons learned from the project, including:

- That the ITS systems utilized need to have reliable communications;
- That it is important to allow for start-up time when deploying a system;
- That it is vital that accurate information is delivered to the public.

9) Arizona's Work Zone Travel Time System

The Arizona Department of Transportation (ADOT) used a portable travel-time reporting system to minimize work zone delay during the reconstruction and widening of State Route 68 (SR 68) in northern Arizona from the summer of 2000 to April 2002 (FHWA³, 2004). The \$42 million project involved widening approximately 13.5 miles of an existing two-lane rural highway into a four-lane divided highway. SR 68 is a critical highway for the northwestern region of the state. It generally has a steady volume of traffic from early morning to late evening and also includes a significant amount of recreational vehicle and truck traffic. ADOT used a "Traffic Management Incentive Specification" as an incentive provision in the construction contract for this project that established a \$400,000 bonus fund to encourage the design-build contractor to maintain a target travel time through the work zone.

The travel-time system that was deployed during this project utilized a camera-based license plate matching system manufactured by Computer Recognition Systems to determine travel times through the work zone. The system consisted of two monitoring stations, one at each end of the work zone, and a central processor. Each monitoring station included an inductive loop embedded in the roadway, a control cabinet with a wireless microwave communications system, and two digital cameras (one for each direction of traffic) linked to the cabinet via fiber-optic cable. Cameras at the monitoring stations took pictures of vehicle license plates entering and leaving the work zone and the system used these images to determine vehicle travel times through the work zone. In addition, each camera was equipped with a light source to assist in reading license plates with plastic covers. Figure 16 shows a light and camera at one of the



*Figure 16: Light and Camera Used to Collect License Plate Data
Photo courtesy of FHWA (Federal Highway Administration)*

monitoring stations. The system required access to public utilities for a power source since power requirements for the lighting system made the use of solar power prohibitively expensive.

ADOT personnel monitored the system periodically and reviewed the data submitted by the contractor to identify violations of the travel time provision; the data were used to assess the contractor a disincentive fee, if necessary. The contractor monitored the system to assess whether its work operations were creating excessive delays. If travel times from the system indicated delays, the contractor could adjust work operations to try to reduce congestion. Although no formal system evaluation was performed, ADOT received a great deal of positive feedback from the public. With the use of the travel-time system and the incentive/disincentive clause, the contractor was forced to be innovative in managing construction efforts to minimize impacts on the traveling public. Several conclusions and observations are listed below:

- The system was able to read approximately 60% and match approximately 11% of the license plates photographed during the operation.
- ADOT suggests considering a shorter reporting time frame, such as the 10-minute interval used in the travel-time incentive program, in order to provide a more realistic calculation of average travel times through the work zone.
- ADOT indicated that the maximum travel time used to calculate the disincentive fee should have been closer to the average time it took to travel the project area before construction.
- It was difficult for the system to read license plates when the camera was facing directly into the sun.
- A traffic camera was stolen during the course of the project, and it took approximately two weeks to replace the camera.

- Camera locations were limited by the availability of public utilities for power in this remote location.
- ADOT hopes to have a more automatic procedure to process the travel times received from the contractor.

D. DYNAMIC LANE MERGE (DLM) SYSTEMS

Work zone construction and incident management often involve lane closures. Traffic merge operations for lane closures generally can be divided into early merge and late merge (McCoy and Pesti). Early merge is designed to encourage drivers to merge into the open lane sooner than they would with the conventional merge. Late merge is designed to encourage drivers to remain in their lanes until they reach the merge point at the lane closure taper. Two early merge strategies – static and dynamic – have been used to encourage drivers to merge into the open lane farther in advance of the lane closure. Static strategies provide advance notice at a fixed distance ahead of the lane closure, and include the placement of additional lane closure signs at approximately 1-mile intervals for several miles in advance of the lane closure. The additional signs reduce the chances of drivers encountering congestion without knowing which lane is closed. Dynamic early merge strategies provide advance notice over a variable distance ahead of the lane closure, based on real-time measurements of traffic conditions. One example is the Indiana Lane Merge developed by the Indiana Department of Transportation (Tarko et al, 1998). This system creates a dynamic no-passing zone to encourage drivers to merge into the open lane before reaching the end of a queue caused by congestion, and to prohibit them from using the closed lane to pass vehicles in the queue and merge into the open lane ahead of them.

Research conducted regarding various merge operations includes the following findings. Nemeth and Roupail (1982) found that early merge control such as advance signing and pavement markings reduced the instance of forced merges. A simulation study, Mousa et al. (1990), showed that early merging results in greater travel times through the work zone, and can encourage drivers to pass slower vehicles by using the lane being closed. Generally, under uncongested conditions, early merging will allow for smoother traffic flow. However, under heavier traffic, a late merge can reduce the queue length by more fully utilizing the highway's storage capacity, thereby improving the efficiency of the merge operation. A study of a late merge operation in Pennsylvania found an increase in the capacity of the merge operation of up to 15% (Orth-Rodgers & Associates, Inc., 1995). However, a field study (Beacher, Fontaine and Garber, 2005) of the late merge system in Virginia showed no statistically significant increase in throughput or decrease in the time in queue. The Texas Transportation Institute (TTI) (Walters and Cooner, 2001) also studied the late merge concept in a 3-to-2 lane closure scenario. Results of the TTI study showed that the late merge delayed the onset of congestion at the work zone by 14 minutes. Queue length was also reduced (7,800 to 6,000 ft), but this may have been due to early removal of the lane closure.

Some simulation studies of late merge systems have been done by the University of Nebraska (McCoy et al, 1999), and Beacher, Fontaine and Garber (2005). The University of Nebraska study used the work zone simulation model (WZSIM), a microscopic simulation model, to test the operational performance at volume levels of 500, 1,000, 1,500, and 2,000 vehicles per hour. Results indicated that the late merge was best used during congested traffic conditions. Beacher,

Fontaine and Garber (2005) used VISSIM, a micro-simulator, to determine the potential benefits of the late merge relative to the controls identified in the *MUTCD*. Results of the computer simulations showed that the late merge produced a statistically significant increase in throughput volume versus the early merge for the 3-to-1 lane closure configuration. Although the 2-to-1 and 3-to-2 configurations did not show significant improvement in throughput overall, it was found that as the percentage of heavy vehicles increased, the late merge did foster higher throughput volumes than early merge traffic control.

Based on characteristics of the early merge and late merge, McCoy and Pesti (2001) introduced the DLM concept, in which a system of PVMSs and real-time traffic sensors provide early merge traffic control during uncongested conditions and a transition to late merge traffic control when congestion occurs. The following section describes a dynamic lane merge system deployed in Michigan.

Michigan's Dynamic Lane Merge System



Figure 17: I-94 Dynamic Lane Merge Sign
Photo courtesy of FHWA (Federal Highway Administration)

Michigan DOT (MDOT) deployed a DLM system on westbound I-94 in 2002 and 2003. The system, developed by International Road Dynamics (IRD) Inc., used microwave radar sensors installed on five DLM trailers to detect traffic volume, vehicle speed, and detector occupancy (FHWA⁴, 2004). When the detected conditions surpassed the pre-set thresholds established by MDOT, the system would automatically activate flashing “Do Not Pass” signs, as illustrated in Figure 17. When traffic conditions no longer warranted activation, the system remained active for five minutes and then automatically switched to an inactive mode. MDOT spaced the trailers 1,500 feet apart. The closer the trailer was to the merge point, the lower the Activity Index was for activation. The trailer closest to the merge point was always on. For the DLM deployment, the only communications requirement was to allow the sensors to communicate with each other. In addition, the contractor was able to dial up the system from a remote area to check its status. Overall, MDOT, which also performed evaluations of the system on I-94, which is a 3-2 merge scenario, was pleased with the DLM’s performance.

E. SUMMARY OF EXISTING WORK ZONE PORTABLE TRAFFIC MANAGEMENT SYSTEMS

Table 1 on the following two pages provides a summary and comparison of each system, including basic features and some findings from evaluation studies. Each system identified uses a different detection system to provide traffic information, such as delay, travel time, etc., and identifies positive results in terms of traffic operations improvements. About half of the studies reported safety improvements, which generally are based on before and after studies. Nevertheless, these studies and their sample size were usually not statistically designed. The studies only indicated that the number of crashes had been reduced. The lack of operational and safety data available for the period prior to the start of work in construction work zones, and limitation on quantifying safety data are the primary reasons that safety evaluation results are either very limited or not available at all for most studies.

F. SUGGESTED GUIDANCE FOR THE DEPLOYMENT OF PORTABLE TRAFFIC MANAGEMENT SYSTEMS IN WORK ZONES IN CONNECTICUT

It is important to assess when it is appropriate to use a work zone ITS application and what type of system best meets the site-specific needs. Fontaine (2003) identified guidelines for the application of portable work zone intelligent transportation systems:

- The presence of congestion for at least some part of the day is the most basic prerequisite for installing intelligent portable systems. The estimation of congestion, such as travel speeds and queue lengths, can be carried out through capacity analysis. Such systems probably will be most effective when congestion is somewhat variable from day to day. Researchers found that speed-advisory messages, in particular, are effective only under congested conditions.
- Intelligent portable systems should be used only for long-term construction or maintenance projects, because the cost and time needed to properly install and calibrate the system to existing conditions may be too great to warrant installing the system for short-term projects and maintenance.
- Agencies should identify potential alternative routes in the area and be confident that these routes will significantly improve travel time around the work zone, as well as determining delay, travel time and alternative-route advisories. This only applies if diversion messages are explicitly or implicitly provided. This information should be provided prior to major interchanges near work zones, as well as prior to the closest freeway-to-freeway interchange, since non-local drivers may be reluctant to divert to local area streets/routes.
- Other considerations include: operational/safety benefits for different types of applications (diversion, delay, speed advisories), costs of deployed systems, barriers to deployment (such as legal limits on VSL) and possible benefit/cost numbers for different systems and applications.

INFORMATION TECHNOLOGY SYSTEMS FOR USE IN INCIDENT MANAGEMENT
AND WORK ZONES
PORTABLE TRAFFIC MANAGEMENT SYSTEMS FOR USE IN WORK ZONES

Table 1: Existing Work Zone Portable Traffic Management Systems

Name	Vendor	Deployment Location and Year	Type of Message displayed	Numerical Values in Delay or travel time	Traffic Data Collection Devices	Information Dissemination Devices	Positive Impact	Safety Impact	Other Impact, System Accuracy	Technology Problem and/or others?
ADAPTIR	Scientex Corporation	Maryland, Kentucky, Illinois, Arkansas, & Nebraska. 1997-98	Speed, Delay	Delay	Radar Sensors	VMSS, HAR	Speed effective only at congested flow	No effect on crashes	Small impact to diversion	Not provided
Intellizone	Quitzone Transportation Safety and HCI Enterprises, Inc	Missouri	Speed, Alternate route	Delay	Detectors	VMSS	Drivers satisfied	Not provided	Small impact to diversion	Not provided
RTTCS	Not provided	Illinois, 2001-02	Delay, speed	Delay	Sensors, CCTV Cameras	VMSS, websites	IDOT staff satisfied. Reduce traffic backups, significant downward trend for traffic violations	Two crashes reported during the deployment, no comparison study provided	Not provided	Significant time required for system calibration
SmartZone in MN	ADDCCO	Minnesota, 1994-95	Delay	Delay	Autoscope	VMSS	Increase in demand, decrease in speed variability and speeds	Not provided	Not provided	Communication
TIPS	PDP Associates	Wisconsin 2001	Travel time, Alternate route	Travel time	Radar Sensors	VMSS	Generally satisfied	Injury crash reduced compared to a similar work zone	Statistically significant in travel time prediction	No guidance on alternative route
PTMS/WZSAS	Brown Traffic Products, Inc	Nebraska 1998 and 2002	Speed, Alternate route	Speed	Video detection system	VMSS	Encourage diversion, general information accurate	Not provided	Position VMSS too far, not enough time to read the message	Specify the alternate route, prefer delay to speed info.
SmartZone in NC	International Road Dynamics (IRD) Inc	North Carolina, 2003	Delay, Alternate route	Delay	Non-intrusive sensors	VMSS, websites	Highly positive response from local residents; generally accurate in delay estimation, decrease the queuing back-up	Not provided	Not provided	Not provided
NM's system	Not provided	New Mexico, 2003-04	Accident location, lanes affected and whether delays were occurring	Not provided	Sensors, Cameras	VMSS, HAR, website, public media, pagers	Reduce incident response and clearance time, improve safety to some extent	Traffic incidents analyzed & compared to previous year without construction	No display for the amount of delay and length of queue	Requires reliable comm un. s. start-up time & accurate information

INFORMATION TECHNOLOGY SYSTEMS FOR USE IN INCIDENT MANAGEMENT
AND WORK ZONES
PORTABLE TRAFFIC MANAGEMENT SYSTEMS FOR USE IN WORK ZONES

Table 1 – Continued: Existing Work Zone Portable Traffic Management Systems

Name	Vendor	Deployment Location and Year	Type of Message displayed	Numerical Values in Delay or travel time	Traffic Data Collection Devices	Information Dissemination Devices	Positive Impact	Safety Impact	Other Impact, System Accuracy	Technology Problem and/or others?
Arizona's travel time	Not provided	Arizona, 2000-02	Travel time	Travel Time	Camera-based license plate matching system, inductive loop, digital cameras	None	Contractor was forced to be innovative in improving traffic operations	Reduced exposure of workers to traffic, but not data provided	Read 60% and match 11% of the license plates photographed	Difficult for the system when facing the sun, limited by the availability of public utilities for power
DLM	International Road Dynamic (IRD) Inc	Michigan, 2002-03	Do Not PASS, etc.	Not provided	Microwave radar sensors	VMSS	Decrease stops, aggressive driving increase average speeds	* (See note below)	Gives drivers some time to adapt to the system	Suggest to use where work zone geometry and location do not change frequently
Wet Pavement Detection System	Quixote Transportation Safety	North Carolina, 2002	Wet Pavement Ahead, Observe Speed Limit", "Standing Water Ahead, Reduce Your Speed	Not provided	Precipitation sensors	VMSS	Not provided	A reduction in the crash rate by before and after study	Not provided	Not provided
SpeedFeedback	Speed Measurement Laboratories, Inc	Iowa, Kansas, Nebraska (1998) and Wisconsin	Speed	Speed	Radar	24-inch panel with photocell equipped LED numerals	Nebraska evaluation study: lower speeds and increase the uniformity of vehicles speed	Not provided	Might increase the speed downstream	Not provided
VSL	NES Worksafe & International Road Dynamics (IRD) used in Michigan	Michigan, Maryland and Virginia 2002	Speed limit	Speed	Not provided	sign	Michigan: relatively minor impact	Not provided	Good applicability for long zones with short areas of actual work	Communications, flexible vehicle sensors, and the algorithms for setting limits

* Crash data were analyzed for approximately 4 months during construction but without the DLM system and 2 months during construction with DLM. Prior to system activation, there was an average of 1.2 crashes per month. For the two-month period after the system was implemented, no crashes were reported. The data included crashes that occurred within the lane merge transition area.

IV. PORTABLE TRAFFIC MANAGEMENT SYSTEMS FOR USE IN INCIDENT MANAGEMENT

This section of the report describes the application of portable information technology systems for use in incident management, and investigates the possibility that portable systems can be designed for locations in Connecticut with a history of frequent incidents and used for the purpose of long-term monitoring.

A. INTRODUCTION

There is a primary difference between work zone traffic operations and incident traffic management. Work zones are planned activities where state DOTs and contractors can typically develop strategic traffic control and management plans in advance. A key tool in helping to execute these plans generally includes fixed VMSs or PVMSs with vital instructions or information about current hazards and conditions. In contrast to work zones, incident locations are unplanned events that require tools and resources that can be deployed rapidly to respond to the unpredictable conditions and circumstances to assure effective incident traffic management.

Incidents that utilize the rapid deployment of portable or truck-mounted VMSs often require very specialized, incident-specific information that might not be found in pre-planned message sets. Furthermore, rapidly deployed PVMSs are highly mobile, and need to be changed to reflect changing conditions. Truck-mounted, mobile PVMSs often need to be programmed on-site, which requires drivers or response crews to have the expertise and/or resources on hand to program a message appropriate to the situation, severity, and location.

Currently, a PVMS study is being carried out by the ENTERPRISE program (<http://enterprise.prog.org/>) to investigate how, or if, standardized message sets can be used for rapid VMS deployment. ENTERPRISE is a pool-funded program comprising member agencies from North America and Europe (annual funding from its member agencies is used to support the development of an annual work plan and ITS projects of mutual interest). It is expected that the study will review PVMS systems and identify specific challenges, limitations, constraints, etc.

Rapidly deploying a technology such as PVMSs for incident conditions requires unique applications, approaches and considerations. Section B identifies available practices utilized by Arizona DOT (ADOT) for rapid deployment of PVMSs for incident and emergency conditions. Additional information regarding the applicability of portable systems for use in incident management is provided in Section C.

B. EXISTING PORTABLE SYSTEMS FOR USE IN INCIDENT MANAGEMENT

1) Vehicle-Mounted PVMSs

An interview with ADOT staff indicated that vehicle-mounted portable PVMSs have been applied with great success in the Safford District and others. An example of this type of system is the TM-248 Ver-Mac 2-Line vehicle-mounted variable message board (Figure 18).



Figure 18: An Example of a Vehicle-Mounted PVMS
(<http://www.ver-mac.com/en/products/tcms.html>)

Photo courtesy of Ver-Mac, Inc.

The ADOT Traffic Operations Center indicated that vehicle-mounted variable message boards, generally on 1-ton flatbed trucks, are very frequently deployed in all eight rural districts in Arizona. They are used to warn drivers of incidents ahead and can be moved upstream readily to keep ahead of a growing queue of vehicles. Mechanical failure repairs were the only issue that the ADOT experienced, although they have had insufficient funding to properly maintain and operate the system.

Vehicle-mounted and trailer-mounted PVMSs differ in the following ways:

- Vehicle-mounted PVMSs are typically limited to two lines of information, as compared to three lines of information for trailer-mounted PVMSs.
- Vehicle-mounted PVMSs are more mobile than trailer-mounted PVMSs, thus enabling faster response for on-site incident management.
- Vehicle-mounted PVMSs require a short time when no message is displayed on the PVMS in order to change the message, whereas trailer-mounted PVMS messages can be changed without any downtime. For example, when using the vehicle-mounted PVMS system, a typical message for an accident that is blocking the highway might be: Accident Ahead//Stop Ahead. When the incident has been cleared to allow one lane to be opened, the message would need to be changed. This would require the staff to blank the sign to program in the new message: Accident Ahead//Keep Right, which will result in no warning being displayed for a few minutes.

2) Trailer-Mounted PVMSs

ADOT has also used trailer-mounted PVMSs, HAR and temporary traffic signals for incident management. Their experience in using these technologies indicates that HAR needs to be broadcast using a strong radio signal and that enough HAR advisory/warning signs need to be provided to enable travelers to view the signs, tune their radio to the HAR station, listen to the message, and still have time to select a detour. The use of HAR will be ineffective if drivers are advised of traffic conditions only after they have either entered the impacted incident area or passed the incident site, or if it is used only for the purpose of reducing driver frustration. Also, trailer-mounted PVMSs should be located far enough ahead of an incident to allow drivers

adequate time to make a detour decision. PVMSs are also effectively used for pre-warning ahead of scheduled highway work activities, such as “next weekend expect ____.” ADOT also found that in work zones, temporary traffic signals should be backed up with law enforcement to improve compliance.

3) *Traffic Management Vehicles*

The Florida Turnpike Enterprise has been involved in a pilot project for approximately 1 1/2 years that tests the use of traffic management vehicles (TMV) in an effort to better manage traffic incidents. The TMV is a full-sized van equipped with a 45-foot telescoping boom and a mounted dome camera. The camera has full pan-tilt-zoom capability, and can transmit live video images via digital satellite back to the traffic management center. The TMV also has the capability for voice communications via satellite, and is equipped with a digital video recorder, generator, and emergency responder equipment and supplies. Two TMVs have been utilized in this pilot program to monitor a heavily-traveled portion of the Florida Turnpike system (mostly in the southern counties of Florida on a 100-mile segment of the turnpike, with the vehicles being based at a central location) for AM and PM peak hour periods. When a major incident occurs, the TMV can be deployed to monitor traffic conditions around the incident. Also, the TMVs have been utilized during hurricane emergencies and for special events.

Additionally, the TMVs are used as support for Florida’s Open Roads Policy in its Rapid Incident Scene Clearance (RISC) program. The goal of the Open Roads Policy is to clear damaged vehicles, spilled cargo, and debris as soon as that can be safely accomplished. The Open Roads Policy (Appendix B) articulates the responsibilities of the Florida DOT and the Florida Highway Patrol, and also seeks to gain the endorsement of other agencies and organizations and have them become parties to the established policy. Towing contractors that achieve the 90-minute incident clearance goal receive incentive payments. In 2005, there have been over 50 activations under this program and the 90-minute clearance goal has been met over 90% of the time.



*Figure 19: Florida’s Transportation Management Vehicle (TMV)
“Traffic Management Vehicle” Provided by Eye in the Sky,
Inc. under contract to University of South Florida and Florida’s Turnpike Enterprise.*

C. THE APPLICABILITY OF PORTABLE SYSTEMS FOR USE IN INCIDENT MANAGEMENT

The use of portable systems for incident management also should comply with the guidelines in the *MUTCD* that specifically address PVMSs. The criteria that should be considered include message content and sets, sign sequence, viewing distance, and length. Additional guidance

regarding the rapid deployment of portable/mobile VMSs has been developed by some states, such as:

- Colorado: Colorado DOT identified conditions under which PVMSs should be used for the purpose of incident management, as follows: “Incidents that block lanes for substantial periods of time are ideal for getting information to the traveling public. Messages near the incident can inform motorists of the problem and move cars into open lanes. Signs farther away from the incident can suggest alternate routes.” The use of PVMSs should incorporate various levels of traffic management plans for incident management, including the use of pre-identified traffic detour routes.
- Nebraska: McCoy and Pesti (1999) developed guidelines for the deployment of changeable message signs (CMSs) for use in incident management in the Omaha, Nebraska metropolitan area. The guidelines address the location and placement of CMSs, design and display of CMS messages, alternate routes, and operation of the system during incidents. The potential benefits of CMSs will not be realized unless the CMSs are located properly. Existing guidelines specify that CMSs be located upstream of bottlenecks, high accident locations, and major diversion points in accordance with the minimum distance criteria specified for freeway guide signs in the *MUTCD*. They also suggest that: (1) CMSs should not be located within interchanges and (2) the minimum spacing between CMSs should be at least 3/4 mile. However, these guidelines do not specify what roadway and traffic conditions can be used to justify installation of CMSs.

V. INNOVATIVE TECHNOLOGIES

Innovative technologies that may be used in the future to better manage the flow of traffic through both work zones and incident management areas are identified in this section.

Intelligent Transportation Infrastructure Program (ITIP) Technology

The ITIP technology is provided by the Mobility Technologies Division of Traffic.com. This system includes a sensor station, wireless communication and a traffic operations center. Figure 20 shows a typical installation in which the sensor station has the traffic sensors mounted on short poles that need to be approximately 20-40 feet away from the highway pavement in order to obtain accurate readings. The sensors on each pole are solar powered with battery back-up, and transfer data using wireless communication to minimize intrusion to the rights-of-way. It is also possible to locate the sensors on existing infrastructure, such as highway signs.



Figure 20: Typical Sensor Station Installation (MT, 2005)

Photo courtesy of Traffic.com, Inc. (2005)

The sensor stations use microwave or acoustic, non-intrusive technology to gather lane-by-lane data on travel speeds, lane occupancy, vehicle classification and vehicle counts. The sensors can be located semi-permanently in work zones to improve work zone safety and provide lasting benefits. The poles are mounted on foundations that can be extracted and relocated to avoid construction conflicts. The traffic data are transmitted to the traffic center to be processed and stored. The real-time information is then disseminated through a website (www.traffic.com), TV, radio and other company data services, such as XM satellite radio and NAVTEQ maps. This system is currently installed and providing real-time and archived data in Boston, Chicago, Los Angeles, Philadelphia, Pittsburgh, Providence, San Diego, San Francisco, St. Louis, Tampa, and

Washington, DC. The system is in design and construction in Baltimore, Detroit, Oklahoma City, Phoenix, and Seattle. Hartford is eligible to receive \$2 million of data service from Mobility Technologies under the ITIP program sponsored by the USDOT, subject to funding availability.

The traffic data are also used by some transportation agencies to make traffic control decisions. For example, the Illinois Tollway uses archived data from the previous week provided by the ITIP program to determine how many lanes to allow to be closed and the timing of the closures within work zones (see Appendix A for a graph developed from recent archived ITIP data). Based on the number of vehicles traversing the construction zone, the Tollway determines how many lanes will be required to stay open. Every 1,500 vehicles require an additional lane. The Tollway varies the timing of the closure depending on the daily data from the previous week. Some of the data are not intuitive; for example, based on an interview with Tollway staff, Thursdays have higher traffic levels than Fridays during summer periods. The Tollway also uses the real-time data to monitor contractor compliance in roadway construction activities.

XM NavTraffic and NAVTEQ

XM NavTraffic (2005), the nation's first satellite-based data traffic information service, is provided by NAVTEQ Traffic. Previously, GPS navigation systems calculated routes to a destination without any knowledge of true traffic conditions along a planned route. XM NavTraffic provides NAVTEQ Traffic information overlaid on a navigation road map, allowing the navigation system to show traffic conditions for a driver's chosen route. Traffic flow speed, accidents, road construction or other incidents affecting traffic are graphically represented on the navigation map with an icon at the location of an incident. Currently, the system is integrated as a standard on-board navigation function on the 2005 Acura RL. The system was developed to allow drivers to make the most informed, time-saving routing decisions in real time. However, a recent study of test driving in New York (<http://abcnews.go.com/Technology/wireStory?id=853193>) has shown this service to be deficient in both route-specific and some real-time information. But the study also indicated that the system in other metro areas, such as Chicago and Tampa, might perform better due to the use of different real-time traffic data sources. The Chicago and Tampa data are provided by Traffic.com.

RDS-TMC (Radio Data System-Traffic Message Channel)

Automatic highway advisory radio (AHAR) is an innovative technique which overcomes the need for traditional roadside HAR message boards and manual tuning to the HAR frequency. When a vehicle enters the AHAR zone, a special in-vehicle receiver picks up a message that is transmitted from the AHAR system. The message then automatically tunes the radio to the AHAR station and mutes any regular radio broadcast until the AHAR transmission is complete. A form of AHAR has been implemented in Europe via the "Radio Data System (RDS) - Traffic Management Channel (TMC)" (2005). RDS-TMC relies on a silent data channel broadcast via FM from existing radio stations. This system uses a TMC unit, an advanced radio or in-vehicle navigation system that decodes the incoming data and communicates it via speech announcement or an on-screen display. Information can be received and recalled at any time, in any language. This system also allows drivers to select specific criterion, such as route or area, so that they only receive the information that is relevant to that criterion. The original concept of RDS-TMC was developed in 1984 by the European Broadcasting Union. Since then, efforts have continued to facilitate utilization of this system throughout Europe. In the United States, current

Federal Communication Commission (FCC) regulations do not permit the use of systems that allow for the automatic interruption of commercial radio broadcasts. Therefore, a key challenge for the successful development and implementation of an AHAR system is revision of FCC regulations to permit the automatic delivery of certain real-time traffic information to drivers in vehicles in the United States.

Work Zone Intrusion Alarms

The work zone intrusion alarm system is designed to protect workers from injury caused by errant vehicles entering a protected area within the work zone where workers are working. The system's alarm provides workers an opportunity to react to errant vehicles in time to avoid injury. The work zone intrusion alarm system is composed of a series of sensing lines arranged within a highway work zone adjacent to a perimeter separating the work zone from oncoming traffic. The sensing lines are connected at junction boxes which include pressure switches (William, 1997). A warning alarm, including a siren, is activated by the pressure switch upon the compression of a sensing line when driven over by an errant vehicle. The alarm provides workers critical reaction time to move out of harm's way. These alarms can also alert distracted or drowsing drivers and allow them to steer out of the work zone or brake prior to reaching workers. Currently the system is available in a wide variety of technologies such as infrared, microwave, laser, and pneumatic.

Emerging ITS Technologies (Cell Phones) for Travel Time Estimation

Studies by researchers at the University of California at Berkeley (Ygnace, et al, 2000) and the University of Virginia (Lovell, 2001) have tested the suitability of cell phones for use as traffic probes. This approach to travel time measurement is attractive because it takes advantage of existing infrastructure and because market penetration of cell phones is high and increasing. This approach depends on the adoption of "Enhanced 911" or E-911, an FCC mandate that requires carriers to provide caller locations within 125 meters. While these studies have shown this to be a promising approach for the future, the technology currently does not support it. In addition, there are many institutional barriers, such as privacy concerns and cost-sharing, that currently limit the feasibility of this concept as a travel time data collection technique. Recently, Florida DOT has begun analyzing travel time estimation schemes by using cell phones as dynamic travel probes. (<http://rip.trb.org/browse/dproject.asp?n=9746>). It is expected that development of cell phones for traffic data collection could lead to new traffic control opportunities.

In addition to the use of cell phones for collecting travel time data, the Travel Time Data Collection Handbook from FHWA (Turner et al 1998) identifies a number of emerging ITS technologies that could be used for this purpose, including: probe vehicle methods, license plate matching, Automated Vehicle Identification (AVI) and inductive loop signature matching.

Wet Pavement Detection System (WPDS)

NCDOT installed a Wet Pavement Detection System (WPDS) during its I-85 bridge construction project in western Mecklenburg County in June 2002. During heavy rains, large sections of standing water were observed on the roadway, which was a factor in several hydroplane crashes. NCDOT contacted Quixote Transportation Safety, Inc., to help alleviate the impacts of this temporary hazardous situation. Pavement sensors were installed in the roadway to measure water depth. Two roadside control units were equipped with precipitation sensors to

detect rainfall. PVMSs were placed in advance of the sensor locations. An automated monitoring system collected real-time data from these sensors and selected the display message. If the pavement was dry, the PVMS had a blank display. If the pavement was wet and the water level was below 6 mm, the PVMS message was "Wet Pavement Ahead; Observe Speed Limit." When the water depth rose above 6 mm, the PVMS displayed "Standing Water Ahead; Reduce Your Speed." The evaluation study examined "wet" crashes prior to and after the installation of the WPDS. A comparison of the two time periods found that there was a reduction in the yearly wet-crash and injury rate during the period that the WPDS was in use, and that the WPDS can reduce crashes on days with "heavy precipitation" (Lowry, 2004).

VI. SUMMARY OF FINDINGS AND CONCLUDING REMARKS

This study provides a comprehensive review of the application of various intelligent portable traffic management systems for use in work zones and incident management and speed management technologies for use in work zones, and identifies innovative technologies that have the potential to improve highway traffic operations. The study also describes the current operations of the Connecticut system based on information and interviews provided by and with ConnDOT staff.

Section A summarizes suggestions regarding the deployment of automated portable traffic management systems to ensure their appropriate use. Section B describes various suggestions regarding ITS architecture, speed management and potential innovative technologies for use on Connecticut's primary arterial highways.

A. SUGGESTIONS FOR THE APPLICATION OF INTELLIGENT PORTABLE TRAFFIC MANAGEMENT SYSTEMS

1) *Work Zones*

Various studies have shown that intelligent portable traffic management systems can provide effective temporary traffic control when used appropriately. However, the success of applying such systems depends on many factors such as work zone traffic conditions and patterns, operational and communication requirements, and the capability of the technology. Suggestions for the effective application of automated portable traffic management systems in work zones are summarized as follows:

- Because the cost to properly install an intelligent portable system is usually high and such installation generally requires extensive calibration for existing conditions, intelligent portable systems should be used only for long-term work zones to achieve expected efficiency and safety benefits.
- Research (Fontaine, 2003) has shown that the presence of congestion for at least some part of the day is the most basic prerequisite for installing intelligent portable systems. These systems will probably be most effective when congestion varies from period to period. Late lane merge systems and speed-advisory messages are effective only under congested conditions.
- Intelligent portable systems can determine speed, delays and travel time. When providing diversion messages, either explicitly or implicitly, agencies should identify potential alternative routes and be confident that they will significantly improve travel time around the work zone. Capacity and traffic conditions on alternative routes, such as local streets, should be analyzed to ensure efficiency. Diversion information should be provided at freeway diversion points, such as the closest freeway-to-freeway interchange and major interchanges near the work zones, because non-local drivers may be reluctant to divert to local area streets.

- An intelligent portable system may produce some discrepancies between actual traffic data (e.g., travel time, speed and delay) and those displayed by the system, but this does not necessarily mean that the system has failed. Based on the lessons learned in Kentucky (Agent, 1999), it is important to examine vehicle detection locations in these cases. For example, vehicles are usually delayed significantly at the lane closure, but move reasonably well within the construction work zone. If the speed measured at this taper area is used to estimate travel time through the work zone, it will result in a discrepancy from the field condition.

2) Incident Management

Since incidents are unplanned events, tools and resources that can be deployed rapidly to respond to the unpredictable conditions and circumstances are needed to assure effective incident traffic management. The use of advanced traffic management vehicles (TMVs), similar to those used in the Florida pilot project, should be considered for use in Connecticut as a tool to better manage traffic incidents, as well as for use in other disasters and emergencies. If an incident occurs, the TMVs can be deployed to monitor traffic conditions and incident management activities, and provide real-time information such as live video images and voice communications to the state's traffic management centers. Additionally, other types of transportation management vehicles equipped with mounted variable message signs, similar to those used in other states, can be used to warn drivers of incidents ahead, and can be moved upstream readily, to keep ahead of a growing queue of vehicles. Rapidly deploying traffic management vehicles for incident conditions requires unique applications, approaches and considerations, as listed below:

- The number of traffic management vehicles and where they should be based should be determined in advance, to ensure that sufficient traffic management vehicles can arrive at an incident location in a timely manner.
- Vehicle-mounted VMSs often need to be programmed on-site, which requires drivers or response crews to have the expertise and resources on hand to program a message appropriate to the location and severity of the incident.
- Limitations regarding the use of vehicle-mounted VMSs include: (1) being able to effectively display only two lines of information; and (2) having a short period of time when no message is displayed, in order to change a sign message.

3) General Considerations and Lessons Learned Regarding Portable Traffic Management Systems

Selection of Intelligent or Human-Operated Systems Based on Project Goals and Objectives

FHWA's handbook on Portable Changeable Message Signs (FHWA⁵ 2003) states that a PCMS (or PVMS) can be used to alert and inform motorists during any of the following scenarios: construction or maintenance (e.g., work zone); incident management; special events; and notification of future construction or events. When used to disseminate traffic information to motorists, PVMSs can be integrated with a vehicle detection system and a computerized central

control system to establish an intelligent/automated portable traffic management system which automatically determines appropriate messages based on current traffic conditions. This intelligent/automated type of system has been widely used in several states.

In contrast with intelligent systems, general or human-operated portable systems, currently used by ConnDOT, have certain advantages, including low cost and more reliable messages, since messages are determined by operational staff based upon their evaluation of the situation. However, for the traveling public to have confidence in a human-operated system, the displayed messages should be current and should accurately reflect existing conditions. For example, human-operated systems are generally needed when the goal of the system is for incident detection via cameras so that appropriate messages can be displayed on VMSs. However, human-operated portable systems that require the manual uploading of messages generally do not provide estimation of travel time, delay and speed information to drivers and may be difficult to maintain depending upon both the nature of the scenarios and staffing levels. On the other hand, if the intent of the system is to provide current travel time, speed, queue presence, or delay information, automated systems can be used, but system reliability and cost need to be considered.

Therefore, ConnDOT should determine: (1) the goals and objectives for use of these types of systems; (2) when it is appropriate to use an ITS application in work zones and for incident management operations; and (3) what type of system best meets the site-specific needs to best assure that established goals are achieved.

Safety Evaluation Development

The general expectations for the deployment of a portable system include efficiency and safety improvements. It is difficult to evaluate such safety benefits, since the analysis will be expensive and safety data prior to the deployment are usually not available. It is suggested that ConnDOT and other agencies, as appropriate, develop a carefully designed safety evaluation strategy before system deployment. This strategy should describe the evaluation method, sample size required, how to achieve statistically significant results, possible performance measures and how to collect those performance measures in the field and/or from data sources. The selected performance measures should be appropriate for use in Connecticut, such as the number of systems versus lane miles.

Display Messages

Properly designed messages on VMSs, regardless of whether they are automated or human-controlled, are important for effective communications with the traveling public. Improperly designed messages take longer to read, are more likely to be misunderstood by motorists, and generally lead to a loss of credibility and subsequent desired behavioral changes. TTI's manual on *Dynamic Message Signs Message Design and Display* (Duke, 2004) and FHWA's handbook on *Portable Changeable Message Signs* (FHWA⁵ 2003) provide good information on message design.

For incident management operations, truck-mounted VMSs provide only very limited messages. It is suggested that if this type of system is used, ConnDOT should be particularly careful about the actual size of the characters that are used to ensure that adequate legibility distance and reading times exist for expected vehicle operating speeds. On high-speed highways,

some truck-mounted signs may be capable of displaying only one line of text at the necessary character height. In addition, truck-mounted VMSs reviewed in this study currently require a blank message to be displayed on the sign for a short period of time while the message is being changed.

Cost-Benefit Analysis

ConnDOT should consider conducting a cost-benefit analysis on a pilot study basis to help determine if the use of portable ITSs is justified. At least two alternatives – the base line or “do-nothing different” approach, which assumes that portable ITSs are not utilized, and a second alternative in which portable ITSs are deployed for a construction project or for use in incident management – should be considered. The cost-benefit analysis would be used to identify and quantify the benefits that can be derived from the use of ITS technology in work zones and for incident management; these benefits can then be compared to the likely costs of implementing such technology. Potential benefits include anticipated reductions in accidents, travel time, environmental impacts and energy consumption. Additional benefits in terms of customer satisfaction, productivity and other factors may also be considered.

Dynamic Lane Merging (DLM)

Generally, a dynamic lane merge system promotes the smooth flow of traffic leading into a work zone by creating a dynamic no-passing zone upstream of the construction site. Some of the suggestions and lessons for Connecticut to consider regarding dynamic lane merging are provided below:

- Travel on Connecticut’s primary arterial roadways in many cases is significantly congested. The dynamic lane merge system can help to decrease the average number of aggressive driving maneuvers per travel time run. A reduction in aggressive driving may result in improved mobility and safety.
- It is suggested that the DLM system should be used on construction projects where the work zone geometry and location do not change frequently, because such changes often require recalibrating the detectors.
- It is important to give the driving public time to adapt to the system so that they will know how to comply with the regulatory signs in the DLM-controlled area.

B. FUTURE DIRECTIONS REGARDING THE USE OF ITS APPLICATIONS IN WORK ZONES AND FOR INCIDENT MANAGEMENT IN CONNECTICUT

1) Work Zone Traffic Operations

Components of an Ideal Work Zone Travel Information System

Information technology could be utilized to improve operations to facilitate the efficient movement of traffic through and around work zones. An ideal work zone travel information system for use in Connecticut could include the following components:

- A traffic detection system based on speed detectors, surveillance equipment such as cameras and/or other emerging ITS technologies. Detectors can be mounted on utility poles or other infrastructures, or installed on portable trailers. Advanced non-intrusive technology can be used.
- A central control system, located at the state's traffic management center.
- Wireless communication systems.
- Information dissemination system, including HARs, VMSs, news media, email alerts, etc.

Providing reliable traffic information to the public to assist drivers in making proper decisions is an essential core building block of an ITS traveler information system. Research is needed to identify and develop methods for collecting and estimating accurate travel time based on existing detected data. Additional traffic data collection approaches such as GPS-equipped probe vehicles or a cell phone tracking system also should be considered. These efforts will help to ensure the credibility of the system and provide timely and accurate traffic status information.

Speed Management in Work Zones

Priority objectives in work zone traffic operations in Connecticut include reducing vehicle speeds (especially truck speeds), preventing recurring long queue back-ups and minimizing the number of accidents in work zones. These objectives are correlated, as lower speeds can potentially reduce the occurrence of accidents. Various technologies for speed management in work zones have been reviewed in this report. Speed display trailers are used as a basic speed management tool. However, there are other systems which have demonstrated effectiveness in reducing vehicle speeds around work zones, such as variable speed limit (VSL) and D-25 speed advisory systems.

2) Incident Management

It is suggested that the following future directions regarding incident management be considered:

- New and developing ITS technologies have the potential for improving incident management systems for the purpose of providing better motorist advisory information throughout an incident. The establishment of a comprehensive statewide traveler information system that provides the public with real-time, accurate information through VMSs (especially at key diversion locations), HARs, cell phones, news media and other technologies that enable motorists to make alternate route or trip delay decisions when a highway is closed or severely restricted should be considered.
- Incident management often involves the coordination and cooperative efforts of multiple agencies. Efforts should be made on a continuing basis to further enhance cooperation among the various agencies in order to improve incident response performance and the mobility of the traveling public. On-going training programs that include understanding the priorities and needs of the various response agencies should be provided for responders. Many issues such as criteria for the use of variable

messages, vehicle positioning at incidents, emergency light disciplines, and vehicle removal from incident sites, as well as other important issues, can be included in these programs. Consideration should be given to exploring the possibility of creating an Open Roads Policy that includes a Rapid Incident Scene Clearance Program similar to that developed by Florida.

3) Develop a Complete Traffic Monitoring System for Connecticut's Interstate System

ConnDOT should examine the question of whether the current number of portable systems utilized in its operations is sufficient to provide efficient and safe operations on the entire Connecticut primary arterial highway system. Although portable systems demonstrate the potential to improve safety and efficiency, it is suggested that there is a need for – and consideration should be given to creating – a traffic monitoring system that provides complete coverage of the Connecticut interstate system using systems such as cameras and vehicle detection. Such a system – an ITS architecture initiative in Connecticut – would combine various vehicle detection technologies and communication systems to provide the information necessary to assess real-time traffic flow. Potential traffic monitoring tools include non-intrusion detection, existing in-pavement loop detectors, video verification provided by closed circuit television (CCTV) cameras and a cellular call-in system. It is also expected that complete camera coverage of the primary arterial system will enhance the state's incident management capabilities. It may be possible to reduce the cost of implementing a complete coverage system by installing components, such as vehicle sensors, in the existing highway infrastructure (utility poles and highway signs, etc.).

The use of traffic data continues to expand. In addition to providing real-time information to motorists, a traffic monitoring system that provides complete coverage of the Connecticut interstate system is expected to have the capability to collect and store traffic data, such as travel time, delay information and safety crash data. These data will be valuable for the evaluation of new ITS deployments, such as before and after safety evaluation studies. The traffic information should also be stored in a Geographical Information System (GIS), which would allow for more complete editing and review of this data.

C. SUGGESTIONS REGARDING INNOVATIVE TECHNOLOGIES

There is a wide variety of innovative technologies available to better manage the flow of traffic through both work zones and incident management areas. This study identifies some of these technologies, such as non-intrusive technology for vehicle detection, the integration of vehicle navigation systems with current traffic conditions, automatic highway advisory radio (AHAR), work zone intrusion alarms and cell phone tracking for travel time estimation.

Accurate real-time travel information for travel through work zone and incident areas is essential for maintaining a safe and efficient highway operation. Various innovative technologies can play important roles in achieving this objective. The establishment of traffic monitoring systems which integrate ITS technologies, e.g., non-intrusion vehicle detection, cameras, wireless communications and even AHARs, can provide the underpinning infrastructure for delivering that information continuously and automatically.

Generally, many of the newer innovative technologies may have costs that are relatively high and/or benefits that have not yet been documented. These systems, as well as emerging technologies, should be monitored and reviewed on a continuing basis by ConnDOT for possible use in Connecticut, as may be appropriate.

CONCLUDING REMARKS

The effective management of work zone activities and incidents is intended to enhance the safety and operational efficiency for the traveling public and roadway workers. This can be accomplished through an information technology system that includes ITS applications, traffic data collection, data analysis, and traffic information dissemination.

Traffic sensors and vehicle detectors using traditional and/or non-intrusive technology collect traffic speed and congestion level information, while cameras record images of traffic and incidents. ConnDOT should consider using emerging ITS technologies to increase the coverage of traffic monitoring, verify and gather more traffic information. It is expected that development of these advanced technologies for traffic data collection can lead to a new traffic control opportunities.

Traffic imagery and data can be sent via wireless communications to a centralized traffic management center. More technologically advanced intelligent systems will be able to calculate traffic speeds and travel time and then automatically disseminate this information to drivers. Otherwise, a staff person monitoring the traffic management center would manually send incident information to travelers via PVMSs, HAR, and other media. For intelligent systems, further research is needed to develop a good control algorithm to provide a reliable prediction of travel time and other traffic information.

Traffic information messages usually advise or inform drivers of anticipated delays, alternate routes, and suggested travel speeds. When accurate advisory information is communicated to the drivers upstream of work zones and incident areas as well as to members of the public who intend to make a trip, drivers are able to make more informed choices about alternate routes. Timely and accurate real-time traffic information also enables incident response teams to communicate better among each other and with the traffic management center to more effectively manage an incident. Various methods to disseminate traffic information to the traveling public could include VMSs, PVMSs, HARs, AHARs, email alert systems, a cell phone text message system and the internet. Among them, AHAR is an innovative technique which overcomes the need for traditional roadside HAR message boards and manual tuning to the HAR frequency. AHAR is a very effective way to distribute incident, congestion and other emergency related traffic information to drivers.

Information technology systems connecting roadway sensors, various traffic collection systems, traffic management centers, and drivers via telecommunication lines allow for an efficient exchange of information, which ultimately improves safety and operations on highways. The potential benefits include the following: traffic information is provided at critical locations, allowing travelers the option to take alternate routes; travelers are informed of delays ahead, thereby decreasing the likelihood of rear-end crashes and driver frustration; work in work zones and other repairs can be scheduled so as to avoid peak travel periods to the extent

possible; and agencies can more quickly identify locations where problems develop (i.e., with merges, ramps, or work zone configuration) and implement appropriate changes to improve mobility.

Emerging innovative technologies, although not necessarily in the mainstream of systems currently in use throughout the United States, may five years from now turn out to be some of the most effective technologies for use in incident management and work zones. ConnDOT should consider further study of innovative technologies and the development of the infrastructure necessary to support such systems in the future while also accommodating current needs.

Although beyond the scope of this study, recent experiences with natural disasters, such as the 2005 hurricanes Katrina and Rita, as well as homeland security concerns, identified a need for developing an “incident management” system of a broader scale. Further study may be appropriate to determine how best to incorporate the tools and systems utilized for traffic incident and work zone management into the state’s broader disaster emergency response operations.

Finally, the Federal Highway Administration’s (FHWA) Intelligent Transportation Systems Joint Program Office (JPO) has developed the ITS Lessons Learned Knowledge Resource website at <http://www.itslessons.its.dot.gov/>. It contains valuable information regarding lessons learned on how to plan, design, deploy, operate, and maintain ITS systems. Information searches can be made by lesson categories, application areas, goal areas, as well as by states and countries

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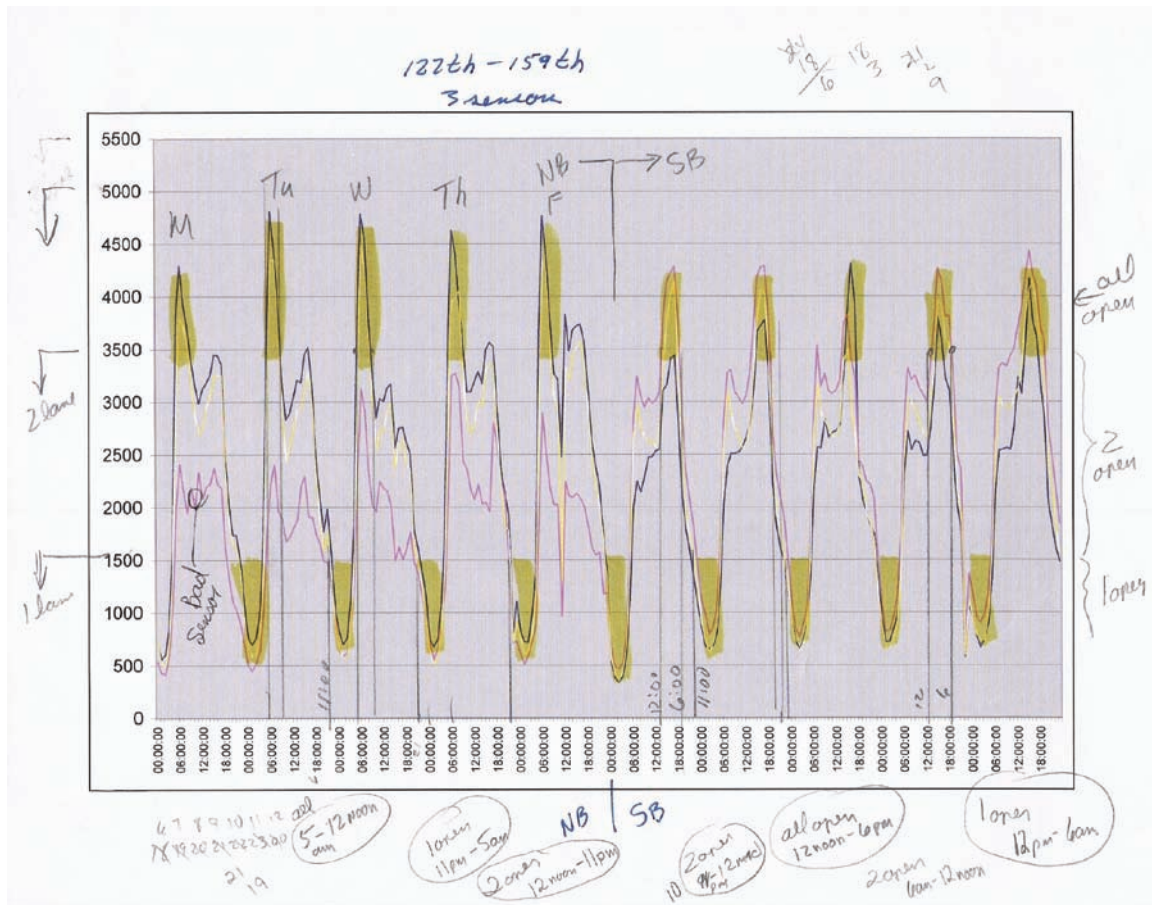
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APPENDIX A

ILLINOIS TOLLWAY: INTELLIGENT TRANSPORTATION INFRASTRUCTURE PROGRAM (ITIP) GRAPH DEVELOPED FROM ARCHIVED DATA

(Courtesy of the Maintenance and Traffic Division, Illinois Tollway)



APPENDIX B

State of Florida

“OPEN ROADS POLICY”

Quick Clearance for Safety and Mobility

This agreement by and between the Florida Highway Patrol (FHP) and the Florida Department of Transportation (FDOT) establishes a policy for FHP and FDOT personnel to expedite the removal of vehicles, cargo, and debris from roadways on the State Highway System to restore, in an URGENT MANNER the safe and orderly flow of traffic following a motor vehicle crash or incident on Florida’s roadways.

Whereas: Public safety is the highest priority and must be maintained especially when injuries or hazardous materials are involved. The quality of life in the State of Florida is heavily dependent upon the free movement of people, vehicles, and commerce. The FHP and FDOT share the responsibility for achieving and maintaining the degree of order necessary to make this free movement possible. Agencies have the responsibility to do whatever is reasonable to reduce the risk to responders, secondary crashes, and delays associated with incidents, crashes, roadway maintenance, construction, and enforcement activities.

The following operating standards are based on the philosophy that the State Highway System will not be closed or restricted any longer than is absolutely necessary.

Be it resolved: Roadways will be cleared of damaged vehicles, spilled cargo, and debris as soon as it is safe to do so. It is understood that damage to vehicles or cargo may occur as a result of clearing the roadway on an urgent basis. While reasonable attempts to avoid such damage shall be taken, the highest priority is restoring traffic to normal conditions. Incident caused congestion has an enormous cost to society.

Florida Highway Patrol Responsibilities

Members of FHP who respond to the scene of traffic incidents will make clearing the travel portion of the roadway a high priority. When an investigation is required, it will be conducted in as expedient a manner as possible considering the severity of the collision. Non-critical portions of the investigation may be delayed until lighter traffic conditions allow completion of those tasks. The FHP will close only those lanes absolutely necessary to safely conduct the investigation. The FHP will coordinate with FDOT representatives to set up appropriate traffic control, establish alternate routes, expedite the safe movement of traffic at the scene, and restore the roadway to normal conditions as soon as possible.

APPENDIX B (CONTINUED)

Whenever practical, damaged vehicles on access controlled roadways will be removed to off ramps, accident investigation sites, or other safe areas for completion of investigations to reduce the delays associated with motorists slowing to “gawk.” Tow trucks will be requested as soon as it is evident that they will be needed to clear the roadway. FHP will assure that all authorized tow operators have met established competency levels and that the equipment is of appropriate size, capacity, and design to meet all standards of the State of Florida.

The FHP will not unnecessarily cause any delay in reopening all or part of a roadway to allow a company to dispatch its own equipment to off-load cargo or recover a vehicle or load that is impacting traffic during peak traffic hours or creating a hazard to the public. The FHP and FDOT will cooperate in planning and implementing clearance operations in the most safe and expeditious manner.

Florida Department of Transportations Responsibilities

When requested by FHP or other emergency agency, FDOT will respond and deploy resources to major traffic incidents 24 hours a day, 7 days per week. Each FDOT District will develop and implement response procedures to meet the goal of providing initial traffic control within **30 minutes** of notification during the assigned working hours of each maintenance yard, and **60 minutes** after hours.

The FDOT, in coordination with FHP, will upgrade traffic controls, determine detour routes, and discuss clearance strategies. When requested, FDOT will provide temporary traffic controls to ensure a safe work zone for all responders and the motoring public.

The FDOT, in cooperation with the FHP, will determine and deploy the necessary heavy equipment and manpower to reopen the roadway if there is a delay in clearing the travel lanes, or if the task is beyond the capabilities of the wrecker service on scene. If cargo or spilled loads [non-hazardous] are involved, FDOT will make every effort to assist in the relocation of the materials in the shortest possible time, using whatever equipment necessary. All such materials or any vehicles relocated by FDOT will be moved the minimum possible distance to eliminate traffic hazards.

FDOT personnel will document all hours and equipment used for traffic control, roadway clearance, and debris clean up. FDOT will place traffic control devices at the scene should any damaged vehicles or cargo remain on the shoulder adjacent to the travel lanes for removal at a later time.

The FDOT and FHP will continually work together to ensure that the needs of motorists on state roadways are being met in the most professional, safe, and efficient manner.

APPENDIX B (CONTINUED)

Therefore, it is agreed as follows:

The FHP and the FDOT will evaluate and continually update and modify their operating policies, procedures, rules, and standards to assure they are consistent with this “**OPEN ROADS POLICY**” agreement.

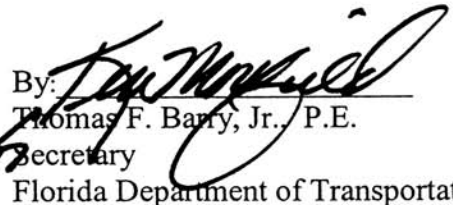
FHP, together with FDOT, will research, evaluate, and conduct training in the most advanced technologies, equipment, and approved methods for the documentation and investigation of crash or incident scenes. FHP, using these techniques, will prioritize the investigative tasks and reopen travel lanes upon completion of tasks that must be conducted, without the impediment of traffic flowing.


Roadways will be cleared as soon as possible. It is the goal of all agencies that **all incidents be cleared from the roadway within 90 minutes of the arrival of the first responding officer**. This goal being made with the understanding that more complex scenarios may require additional time for complete clearance.

It is further agreed that:

FHP and FDOT will actively solicit and enlist other state, county, and local agencies, political subdivisions, industry groups, and professional associations to endorse and become party to this “**OPEN ROADS PHILOSOPHY**” for the State of Florida.

In witness whereof, each party hereto has caused this document to be executed in its name and on its behalf by its duly authorized Chief Executive.

By: 
Thomas F. Barry, Jr., P.E.
Secretary
Florida Department of Transportation

By: 
Col. Christopher Knight
Director
Florida Highway Patrol

Date: 10/30/02

Date: 11-1-02

Reviewed By:


Marianne Quince
Agency's General Counsel Office


Nelson Chapman 10/31/02
Agency's General Counsel Office

REFERENCES

- Agent, K. R. *Evaluation of the ADAPTIR System for Work Zone Traffic Control*, KTC-99-61, Kentucky Transportation Center, Lexington, 1999.
- Beacher, A. G., M.D. Fontaine, and N.J. Garber. "Field Evaluation of the Late Merge Work Zone Traffic Control." *Proceedings of TRB 2005 Annual Meeting*, Washington, DC, January 2005.
- Beacher, A. G., M.D. Fontaine, and N.J. Garber. "Guidelines For Using Late Merge Work Zone Traffic Control: Results Of A Simulation-Based Study," *Proceedings of TRB 2005 Annual Meeting*, Washington, DC, January 2005.
- Bushman, R. and Berthelot, Curtis. *Response of North Carolina Motorists to a Smart Work Zone System*, 2002. Available at http://www.irdinc.com/library/pdf/motorist_reponse_to_north_carolina_smart_work_zone.pdf
- Center for Urban Transportation Research, University of South Florida. "Traffic Management Vehicle Pilot Project." *Annual Report of Operation: June 2004 – June 2005*.
- Dudek, C.L. *Dynamic Message Sign Message Design and Display Manual*, TTI Project 0-4023-P1, Texas Transportation Institute, March 2004.
- FHWA. "ITS Technologies in Work Zones," FHWA-HRT-04-074, also available at http://www.fhwa.dot.gov/rnt4u/ti/pdfs/its_wz.pdf, 2004.
- FHWA¹. "Real-Time Work Zone Traffic Control System - Using an Automated Traffic Information System to Reduce Congestion and Improve Safety During Reconstruction of the I-55 Lake Springfield Bridge in Illinois," *Intelligent Transportation Systems in Work Zones: A Case Study*, FHWA-HOP-04-018, 2004.
- FHWA². "Work Zone Traffic and Incident Management System - Keeping Traffic Moving During Reconstruction of the Big I, a Major Interstate-Interstate Interchange in Albuquerque," *Intelligent Transportation Systems in Work Zones: A Case Study*, FHWA-OP-04-072, 2004.
- FHWA³. "Work Zone Travel Time System - Reducing Congestion with the Use of a Traffic Management Contract Incentive During the Reconstruction of Arizona State Route 68," *Intelligent Transportation Systems in Work Zones: A Case Study*, FHWA-HOP-04-032, 2004.
- FHWA⁴. "Dynamic Lane Merge System - Reducing Aggressive Driving and Optimizing Throughput at Work Zone Merges in Michigan," *Intelligent Transportation Systems in Work Zones: A Case Study*, FHWA-HOP-04-033, 2004.
- FHWA⁵. *Portable Changeable Message Sign Handbook*. FHWA-RD-03-066, 2003.
- Fontaine, M.D. "Guidelines for Application of Portable Work Zone Intelligent Transportation Systems," *Transportation Research Record (1824)*, Transportation Research Board, National Research Council, Washington, DC, 2003, pp. 15-22.

- Garber, N.J., and M.D. Fontaine. *Controlling Vehicle Speeds in Work Zones: Effectiveness of Changeable Message Signs with Radar*. UVA-529242/CE96-102. Prepared for Mid-Atlantic Universities Transportation Center for US Department of Transportation and Virginia Department of Transportation; Department of Civil Engineering, University of Virginia, Charlottesville, VA, 1996.
- Hagen, L. *Best Practices for Traffic Incident Management in Florida*, BC353-47, Florida DOT. 2005.
- King, T., C. Sun and M. Virkler. "Evaluation of a Freeway Work-zone Advance Speed Advisory System," University of Missouri-Columbia, *Midwest Smart Work Zone Deployment Initiative (MsSWZDI)*, 2003.
- Lovell, D. J. "Accuracy of Speed Measurements from Cellular Phone Vehicle Location Systems." *ITS Journal*. Vol. 6, No. 4, pp. 303-325. 2001.
- Lowry, S.D. *Traffic Safety Effects of a Wet Pavement Detection System Installed on a North Carolina Interstate*, North Carolina DOT, 2004.
- Lyles, R.W., W.C. Taylor, and J. Grossklaus. *Field Test of Variable Speed Limits in Work Zones (in Michigan)*, Michigan State University and Michigan Department of Transportation project, 2003.
- McCoy, P.T., J.A. Bonneson, and J.A. Kollbaum. "Speed Reduction Effects of Speed Monitoring Displays with Radar in Work Zones on Interstate Highways." *Transportation Research Record*, No. 1509, 1995, pp. 65-72.
- McCoy, P. "Adaptir," University of Nebraska, Lincoln, *Midwest Smart Work Zone Deployment Initiative (MsSWZDI)*, 2000.
- McCoy, P. "Portable Traffic Management Systems," University of Nebraska, Lincoln, *Midwest Smart Work Zone Deployment Initiative (MsSWZDI)*, 2000.
- McCoy, P.T., G. Pesti, and P.S. Byrd. *Alternative Information to Alleviate Work Zone-Related Delays*. SPR-PL-1(35). University of Nebraska, Lincoln, 1999.
- McCoy, P.T., G. Pesti, *Incident Management - Changeable Message Sign Deployment Guidelines*, University Of Nebraska, Lincoln, 1999.
- McCoy, P.T; and G Pesti, "Dynamic Late Merge-Control Concept for Work Zones on Rural Interstate Highways," *Transportation Research Record (1745)*, Transportation Research Board, Washington, DC. 2001
- McCoy, P. and Pesti, G. *Dynamic Late Merge Control Concept for Work Zones on Rural Freeways*. Available at: <http://ops.fhwa.dot.gov/wz/workshops/accessible/McCoy.htm>
- Meyer, E. "SpeedGuard Radar Speed Reporting System," University of Kansas, *Midwest Smart Work Zone Deployment Initiative (MsSWZDI)*, 2000.

- Mousa, R.M., N.M. Roupail, and F. Azadivar. "Integrating Microscopic Simulation and Optimization: Application to Freeway Work Zone Traffic Control." *Transportation Research Record* No. 1254, Transportation Research Board, Washington, DC, 1990.
- Mobility Technologies (MT). Mobility Technologies' Proposal to District of Columbia Department of Transportation, 2005.
- Nemeth, Z.A., and N.M. Roupail. "Lane Closures at Freeway Work Zones: Simulation Study." *Transportation Research Record* No. 869, Transportation Research Board, Washington, DC, 1982.
- Nookala, M., et al. "Portable Traffic-Management System: An ITS Operational Test." *Proceedings of ITS America Conference*, 1995.
- Notbohm, T., A. Drakopoulos and A. J., Horowitz. "TIPS." WisDOT, Marquette University and University of Wisconsin, Milwaukee, *Midwest Smart Work Zone Deployment Initiative (MsSWZDI)*, 2001.
- Orth-Rodgers & Associates, Inc. *Freeway Construction Work Zone Safety Enhancement Report*. Philadelphia, PA, 1995.
- Pesti, G. "Alternative Way of Using Speed Trailers: Evaluation of D-25 Speed Advisory Sign System," *Proceedings of TRB 2005 Annual Meeting*, Washington, DC, January 2005.
- Pesti, G., et al. "Work Zone Speed Advisory System," University of Nebraska, *Midwest Smart Work Zone Deployment Initiative (MsSWZDI)*, 2002.
- Pesti, G., D.R. Jessen, P.S. Byrd, and P.T. McCoy. "Traffic Flow Characteristics of the Late Merge Work Zone Control Strategy." *Transportation Research Record* No. 1657, Transportation Research Board, Washington DC, 1999.
- RDS-TMC, Available at http://europa.eu.int/comm/transport/themes/network/english/its/html/rds_tmc.html, 2005.
- Scriba, T. and J. Seplow. "Making Work Zones Work Better: The Final Rule on Work Zone Safety and Mobility." *ITE Journal*, April 2005, pp. 38-42.
- SRF Consulting Group. *Portable Traffic Management System Smart Work Zone Application Operational Test Evaluation Report*. Minnesota DOT, 1997.
- Tarko, A., S. Kanipakapatman, and J. Wasson. *Modeling and Optimization of the Indiana Lane Merge Control System on Approaches to Freeway Work Zones*. Final Report, FHWA/IN/JTRP-97/12. Purdue University, West Lafayette, Indiana. 1998.
- Turner, S., Eisele, W., Benz, R., and D. Holdener. *Travel Time Data Collection Handbook*. FHWA-PL-98-035. US Department of Transportation, Federal Highway Administration. March 1998.

Walters, C.H., and S.A. Cooner. *Understanding road rage: Implementation plan for promising mitigation measures*. Research Report 4945-3, Texas Transportation Institute, College Station, Texas.

William, E.D. 1997. *Highway work zone intrusion alarm system*. Available at http://search.globalspec.com/engineering-search/patents/abstract/10206242325/Highway_work_zone_intrusion_alarm_system

XM NavTraffic. 2005. Available at <http://www.xmradio.com/xmnavtraffic/about.jsp>.

Ygnace, J., Drane, C., Yim, Y.B., and R. de Lacvivier. *Travel time estimation on the San Francisco Bay Area Network using cellular phones as probes*. UCB-ITS-PWP-2000-18. UC-Berkeley. 2000.

Zwahlen, H. T. and A.C. Russ. 2002. "Evaluation of Accuracy of Real-Time Travel Time Prediction System in Freeway Construction Work Zone." Paper No. 02-2371, presented at the 81st Annual Transportation Research Board Meeting, Washington, DC, January 13-17, 2002. Published in *Transportation Research Record* No. 1803, 2002, pp 87-93.

MAJOR STUDIES OF THE ACADEMY

2006

- Improving Winter Highway Maintenance: Case Studies for Connecticut's Consideration
- Information Technology Systems for Use in Incident Management and Work Zones
- An Evaluation of the Geotechnical Engineering and Limited Environmental Assessment of the Beverly Hills Development, New Haven, Connecticut

2005

- Assessment of a Connecticut Technology Seed Capital Fund/Program
- Demonstration and Evaluation of Hybrid Diesel-Electric Transit Buses
- An Evaluation of Asbestos Exposures in Occupied Spaces

2004

- Long Island Sound Symposium: A Study of Benthic Habitats
- A Study of Railcar Lavatories and Waste Management Systems

2003

- An Analysis of Energy Available from Agricultural Byproducts, Phase II: Assessing the Energy Production Processes
- Study Update: Bus Propulsion Technologies Available in Connecticut

2002

- A Study of Fuel Cell Systems
- Transportation Investment Evaluation Methods and Tools
- An Analysis of Energy Available from Agricultural Byproducts, Phase 1: Defining the Latent Energy Available

2001

- A Study of Bus Propulsion Technologies in Connecticut

2000

- Efficacy of the Connecticut Motor Vehicle Emissions Testing Program
- Indoor Air Quality in Connecticut Schools
- Study of Radiation Exposure from the Connecticut Yankee Nuclear Power Plant

1999

- Evaluation of MTBE as a Gasoline Additive
- Strategic Plan for CASE

1998

- Radon in Drinking Water

1997

- Agricultural Biotechnology
- Connecticut Critical Technologies

1996

- Evaluation of Critical Technology Centers
- Advanced Technology Center Evaluation
- Biotechnology in Connecticut

1994

- Science and Technology Policy: Lessons from Six Amer. States

1992

- A State Science and Technology Policy
- Electromagnetic Field Health Effects

1990

- Biotechnology (Research in Connecticut)
- Economic Impact of AIDS Health Care in Connecticut

1989

- Science and Engineering Doctoral Education in Connecticut

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CONNECTICUT ACADEMY OF SCIENCE AND ENGINEERING

The Connecticut Academy is a non-profit institution patterned after the National Academy of Sciences to identify and study issues and technological advancements that are or should be of concern to the state of Connecticut. It was founded in 1976 by Special Act of the Connecticut General Assembly.

VISION

The Connecticut Academy will foster an environment in Connecticut where scientific and technological creativity can thrive and contribute to Connecticut becoming a leading place in the country to live, work and produce for all its citizens, who will continue to enjoy economic well-being and a high quality of life.

MISSION STATEMENT

The Connecticut Academy will provide expert guidance on science and technology to the people and to the State of Connecticut, and promote its application to human welfare and economic well being.

GOALS

- Provide information and advice on science and technology to the government, industry and people of Connecticut.
- Initiate activities that foster science and engineering education of the highest quality, and promote interest in science and engineering on the part of the public, especially young people.
- Provide opportunities for both specialized and interdisciplinary discourse among its own members, members of the broader technical community, and the community at large.

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