

INTELLIGENT TRANSPORTATION SYSTEMS

# for Work Zones



## DEPLOYMENT BENEFITS AND LESSONS LEARNED

### BENEFITS

- Dynamic Lane Merge Improves Capacity, Decreases Travel Time. . . . . 2
- ITS Eases the Pain of Road Closure. . . . . 2

### COSTS

- Arkansas Invests in AWIS, Increases Use of Alternate Routes . . . . . 3

### DEPLOYMENT

- Implementing the Work Zone Safety and Mobility Rule. . . . . 3

### LESSONS LEARNED

- Findings from the Michigan Work Zone Variable Speed Limit System Test . . . . . 3
- ITS for Work Zone Management – Lessons from Experience . . . . . 4

Americans lose 3.7 billion hours and 2.3 billion gallons of fuel every year sitting in traffic jams,<sup>1</sup> and nearly 24 percent of non-recurring freeway delay, or about 482 million hours, is attributed to work zones.<sup>2</sup> To combat the country’s growing transportation congestion problem, the U.S. Department of Transportation launched the *National Strategy to Reduce Congestion on America’s Transportation Network*. One element of this strategy is to promote operational and technological improvements to the transportation system through the use of congestion-reducing technologies such as Intelligent Transportation Systems (ITS).<sup>3</sup> ■

## Work Zones



Using ITS in work zones can improve safety and lessen the delay that can come from reduced capacity and incidents. Well-planned work zones that use ITS technologies to manage traffic and mitigate the impacts of lane closures, detours, and other factors are commonly referred to as “Smart Work Zones.” When work zones use ITS tools in conjunction with sound planning, traffic control, coordination, communication, and impacts estimation, work zone operations can be greatly enhanced and the management of traffic in the work zone area made more efficient. For example, a study of successful technology deployments determined that:

- Between 50 percent and 85 percent of drivers surveyed said that they changed their route at least sometimes in response to travel time, delay, or alternate route messages provided by work zone ITS.<sup>4</sup>
- Reductions in queue lengths from 56 percent to 60 percent are possible,<sup>5</sup> with simulations indicating system-wide reductions in total delay may range from 41 percent to 75 percent.<sup>6</sup>
- Speed monitoring displays (SMD) reduce speeds in work zones by 4-6 mph.<sup>7</sup> One study found a 20-40 percent reduction in vehicles traveling 10 mph or more over the speed limit when SMD were used.<sup>8</sup>

A 2004 Federal Highway Administration survey of ITS deployment found that, of the 43 States who responded, 20 States used ITS in work zones.<sup>9</sup> Findings from this survey showed:

- 19 States use portable dynamic message signs (DMS), 14 use permanent DMS, 8 use highway advisory radio, 5 use temporary speed limits, and 4 use a series of warning signs activated progressively farther from the work site as sensors detect increases in traffic volume.<sup>10</sup>
- When asked why they chose to deploy ITS in work zones, 16 States indicated it was to reduce congestion and 17 said it was to reduce crashes.<sup>11</sup> ■

BENEFITS

## Dynamic Lane Merge Improves Capacity, Decreases Travel Time



Upon seeing signs informing them of a merge ahead, drivers will typically take one of two actions: they will merge early, moving from the discontinuous

lane as soon as possible, typically creating a long, single-lane queue that moves at slow speeds, or they will merge late, waiting until the last opportunity to switch lanes, staying in the discontinuous lane and often forcing a merge at the point of closure.

Dynamic lane merge (DLM) is an ITS technology that can be used in work zones to alleviate the congestion and crashes this mix of reactions can cause. The technology uses electronics and communications equipment to monitor traffic flow and, as queuing increases at approaches to lane closures, regulates the merge, requiring either early merge or late merge depending on traffic conditions.

In the summer of 2003, the Michigan Department of Transportation (MDOT) deployed an *early* merge system.<sup>12</sup> When traffic conditions exceeded preset limits on

traffic volume, vehicle speed, and detector occupancy, the system activated and a “Do Not Pass” message was displayed. When MDOT and Wayne State University assessed the impacts of the DLM system, they found:

- Average travel speed increased from approximately 40 mph to 46 mph during the morning peak period.<sup>13</sup>
- An average of 1.2 crashes per month occurred in the 4 months prior to activation; after activation, no crashes were reported.<sup>14</sup>
- Travel time savings and vehicular fuel savings (system benefits) outweighed the costs if the value of time for delayed motorists is greater than \$3.33 per hour.<sup>15</sup> As of 2004, the U.S. Department of Transportation used a time value of \$11.20 per hour for each person in a car and \$18.10 per hour for a truck driver when calculating user cost of delay.<sup>16</sup>

The cost to MDOT, which leased the system, was \$120,000, including design, installation, calibration, and maintenance. The cost to redeploy the system at

additional work zones, which includes furnishing the devices in operable condition, initial installation, operation, inspection, maintenance, cleaning, and removal at project completion, is about \$30,000.<sup>17</sup>

The Minnesota Department of Transportation (MnDOT) initiated several projects to study the benefits of DLM using a *late* merge system. MnDOT found that:<sup>18</sup>

- The late merge system eliminates confusion over lane use issues and the correct merge point.
- Merge instructions on portable dynamic message signs (DMS) aided in eliminating aggressive driving behavior.
- Near equal usage of both lanes equalized speeds between lanes.
- Increased usage of the discontinuous lane decreased total queue lengths by 35 percent, but vehicle volume through the construction zone was not changed.

A minimum volume of 1,500 vehicles per hour was determined necessary to justify system activation. ■

BENEFITS

## ITS Eases the Pain of Road Closure



Sometimes, there’s just no way around it: lanes have to be closed to perform maintenance or construction activities. But with ITS, normal

congestion associated with lane closures in work zones can be reduced, resulting in fewer crashes and greater safety for motorists and road workers alike.

Illinois required the reconstruction of a 40-mile section of I-55 including the Lake Springfield bridge, which involved closing one bridge span and diverting traffic onto the other span.<sup>19</sup> To minimize the impacts of congestion during the lane closure and rerouting operations, an automated portable real-time traffic control system was used to provide traveler information and traffic control. The system used remotely controlled portable dynamic message signs (DMS), portable traffic sensors electronically linked to a central base station server, and portable closed circuit TV cameras linked to the base station using wireless communications.<sup>20</sup> The DMS displayed real-time information on delays

and lane closures. In addition, the project website included a map with road segments color-coded according to the degree of congestion. The website also enabled users to view the current DMS messages and camera images. Real-time information on the number of citations issued to date was also posted upstream of the work zone. As a result:

- Only two crashes were reported in the I-55 construction area during the 16 months that the ITS was deployed.<sup>21</sup>
- Illinois Department of Transportation staff reported a significant downward trend in the number of violations after the ITS began to display the number of citations issued.<sup>22</sup>

California faced a similar problem when it embarked on a rapid rehabilitation project in 2004 to rebuild I-15 in Devore. First the northbound and then southbound lanes had to be closed and traffic rerouted to the opposite lanes through median crossovers at each end of the construction work zone.<sup>23</sup> A quickchange moveable barrier system was used to switch the two-by-three lane configuration twice each day in an

operation that took less than 30 minutes in live traffic.<sup>24</sup>

To limit disruptions, an automated work zone information system (AWIS) was used, enabling travelers to learn of traffic conditions before they entered the work zone and choose alternate routes based on guidance and travel time information posted on roadside DMS.

As a result of the AWIS deployment:

- Average daily traffic (ADT) volume on I-15 southbound decreased by 19 percent while ADT volume on the I-15 southbound detour route increased by 15 percent.<sup>25</sup>
- ADT volume on I-15 northbound decreased by 16 percent while ADT volume on the I-15 northbound detour route increased by 10 percent.<sup>26</sup>
- ADT volumes on the adjacent major arterials increased by only 2 percent.<sup>27</sup>

Field data indicated that the maximum average peak delay with AWIS was about 50 percent less than the expected maximum delay without AWIS. ■

## COSTS

## Arkansas Invests in AWIS, Increases Use of Alternate Routes

Beginning in 2000, the Arkansas State Highway and Transportation Department (ASHTD) began an effort to rebuild 60 percent of Arkansas' total Interstate miles. Because the presence of work zones can increase congestion and incidents, ASHTD decided to deploy automated work zone information systems (AWIS). These systems provide real-time information to travelers, informing them about traffic and impacts such as lane closures or speed reductions in and around work zones.

One site equipped with AWIS was a 6.3-mile segment of I-40 located in rural Lonoke County. The AWIS deployed at this work zone site included a central system controller, two highway advisory radio (HAR) systems, five traffic radar sensors measuring vehicle speed, five dynamic message signs (DMS) and two supplemental speed stations. The contract, bid for 350 days at \$750 per day plus \$60,000 for the HAR systems, totaled \$322,500.<sup>28</sup>

The engineer overseeing construction at the Lonoke County site expressed his belief that the system prevented rear-end crashes as long as traffic was not backed up past the message boards. He also believed

that the system enhanced congestion management through its ability to allow messages to be manually input into the contractor's field office computer to assist in rerouting traffic.<sup>29</sup>

Another AWIS-equipped site was an 8.6-mile segment of I-40 located in urban North Little Rock. The AWIS deployed at this work zone site included a central system controller, a host computer in the engineer's office, two DMS, queue detection sensors, and five HAR systems. The winning contract was bid for 1,000 days at \$390 per day plus \$100,000 for the HAR systems, totaling \$490,000.<sup>30</sup>

At the North Little Rock site, analysis showed a direct correlation between alternate route traffic and the messages reported on the DMS: overall traffic doubled on the alternate route when the DMS warned of backups or stopped traffic ahead, and truck traffic was nine times higher than usual on the alternate route during these times. In addition, the engineer overseeing construction at this site stated that he thought the system was effective in preventing rear-end collisions and enhancing congestion management.<sup>31</sup> ■

## LESSONS LEARNED

## Findings from the Michigan Work Zone Variable Speed Limit System Test

Static speed limits in work zones may not reflect current conditions, which can lead to low speed limit compliance rates and high variance in vehicle speeds.<sup>32</sup> There has been increasing interest in recent years in the use of variable speed limits (VSL) in work zones as a means of alleviating these problems.

A 2003 study of a Michigan work zone examined the impact of a prototype VSL system and evaluated the effectiveness of the system at improving speed limit compliance and the credibility of speed limits. It also assessed whether safety and traffic flow were improved. The Michigan Department of Transportation (MDOT) opted to lease equipment through a contract that included development, design, installation, calibration, and maintenance over a 6-month period for \$400,900.<sup>33</sup> MDOT wrote the specifications for temporary use of the VSL system so that it could implement the VSL without having to maintain or store the equipment after construction ended.

The VSL leased system included the use of

seven trailers with remote traffic microwave sensor detectors, solar power, controllers with radio frequency communication, and light-emitting diode speed displays. The VSL trailers, placed at ½- to 1-mile intervals, had the capacity to vary the speed limit from 40 mph to 70 mph depending on the nature of the road work.<sup>34</sup>

Given that the VSL system deployed was a prototype unit, the Michigan study determined that it operated reasonably well, although it required constant attention from the contractor to remain operational.<sup>35</sup> The study also found that the system needed more technical refinement, which would presumably occur in a second generation, to increase its effectiveness and decrease the necessary level of oversight.<sup>36</sup>

As a result of using VSL, both the speed limits displayed by the VSL trailers and operating speeds generally increased, average speed was generally below the displayed speed for VSL, and drivers maintained more consistent speeds during non-peak periods, especially at night. ■

## DEPLOYMENT

## Implementing the Work Zone Safety and Mobility Rule

The Work Zone Safety and Mobility Rule was published on September 9, 2004, in the Federal Register and updates and broadens the former regulation at 23 CFR 630 Subpart J to address more of the current issues affecting work zone safety and mobility. All State and local governments that receive Federal-aid funding are required to comply with the provisions of the Rule by October 12, 2007.<sup>37</sup>

The updated Rule has several goals, including:

- To encourage the expansion of thinking beyond the work zone to systems management on a corridor-wide, network, and regional basis.
- To expand work zone impacts management beyond traffic safety and control by using transportation management strategies – including public information efforts and operational strategies such as the use of ITS in work zones.
- To advocate innovative thinking in work zone planning, design, and management.

To achieve these goals, the Rule addresses:

- Policy-level provisions to help agencies implement an overall work zone safety and mobility policy for the management of work zone impacts.
- Agency-level processes and procedures to help agencies implement and sustain work zone policies.
- Project-level procedures to help agencies assess and manage work zone impacts through the development of Transportation Management Plans (TMP) that describe the transportation management strategies that will be used for a project.

Effective work zone management requires a combination of strategies.<sup>38</sup> For some projects, the TMP must contain operational strategies and public outreach in addition to a traffic control plan. ITS can be used as a tool to help meet these requirements, and it can be used as part of an overall strategy to reduce work zone impacts. The agency-level processes and procedures required by the Rule include the use of safety and mobility data to assess work zone performance and manage impacts. Work zone ITS are devices that can help provide the necessary data. ■

**For general information and guidance, see [www.ops.fhwa.dot.gov/wz/resources/final\\_rule.htm](http://www.ops.fhwa.dot.gov/wz/resources/final_rule.htm).**



## LESSONS LEARNED

## ITS for Work Zone Management – Lessons from Experience



Agencies experienced with using work zone ITS have learned lessons along the way that can help others deploy work zone ITS technologies effectively.

The following are lessons learned on how ITS can help to plan, design, operate, and maintain work zones, and are taken from both evaluation research and the ITS Lessons Learned Knowledge Resource.

### Design and Deployment

- **Use existing permanent ITS components to aid in work zone management.**<sup>39</sup> With the largest construction season ever in St. Louis, the Missouri Department of Transportation made a concerted regional effort to link permanent ITS components (dynamic message signs (DMS), traffic sensors, cameras, and transportation management center operations) and temporary work zone DMS with communication along uncovered freeway sections to provide real-time traveler information on work zones. Information was collected from center operators, motorist assistance patrol operators, construction staff, and field observations and was disseminated in real-time via DMS, websites, and various media partners.
- **Deliver accurate information to the public for successful management of work zones.**<sup>40</sup> The New Mexico State Highway and

Transportation Department (NMSHTD) employed an ITS-based mobile traffic monitoring and management system to help move vehicles through an extensive construction area. NMSHTD used ITS in part because frequent changes in traffic patterns and scheduled closures required that travelers be provided with high-quality real-time information. Among the ITS used to distribute this information were DMS, a website, and automated fax and email updates.

- **Assess when it is appropriate to use ITS in a work zone and what type of system best meets the site-specific needs.**<sup>41</sup> Prior to initiating a major bridge and highway reconstruction effort on I-55 south of Springfield, the Illinois Department of Transportation (IDOT) had a number of work zone safety and mobility concerns. To address those concerns, the agency explored how it could use ITS to improve the way approaching motorists were notified of the work zone. As a result of this assessment, IDOT implemented the Springfield Automated Portable Real-Time Traffic Control System, a system that monitored traffic flows in and leading up to the work zone and provided travelers with traffic information via DMS; e.g., “10-15 minute delays.”
- **Maintain flexibility when deploying ITS in highly variable environments.**<sup>42</sup> Arkansas’ effort to reconstruct and repair more than 350 miles of roadway was a large, complex undertaking (including seven separate projects by two contractors) with a constantly changing configuration. As a result, the calibration of ITS became an important issue and required one full-time employee devoted exclusively to maintaining all sensors.
- **Deploy speed monitoring displays (SMD) to discourage speeding through work zones.**<sup>43, 44, 45, 46, 47</sup> On high-speed rural Interstates, speeding is among the most often reported contributing factors for work zone crashes. In Nebraska, a number of studies consistently found that SMDs were effective in reducing vehicle speeds and increasing speed limit compliance. During a 2-year period, SMDs were found to be effective in lowering

speeds and increasing the uniformity of speeds: the highest 15 percent of speeds were reduced by about 5 mph, resulting in speed limit compliance of 90 percent or more.

- **Place portable DMS on the shoulder or median nearest the discontinuous lane when implementing a dynamic late merge system to manage a work zone.**<sup>48</sup> When the Minnesota Department of Transportation evaluated a dynamic late merge system as part of its work zone traffic control strategy, it found that placing DMS on the shoulder or median nearest the discontinuous lane makes the signs much more visible to those drivers who may have a tendency to merge early. The agency determined that the DMS closest to the taper point should be positioned adjacent to the last static merge sign with an arrow so there is no contradiction in instructions from signs at two different locations. This placement also gives an additional buffer zone of distance to complete the merging procedure, which could encourage drivers to use the discontinuous lane.

### Technical Integration

- **Allow for sufficient start-up time when deploying an ITS application.**<sup>49</sup> Unanticipated issues may arise that will take time to address – for example, issues relating to operation of sensors or communications (wireless or wireline), or to license applications, system calibration, or software. In Illinois, a significant amount of time was required for system calibration for queue length detection systems during initial implementation. One suggestion is to add 5 percent to the best estimate of the time required.

**For these and other lessons, visit:**  
[www.itslessons.its.dot.gov](http://www.itslessons.its.dot.gov) ■



\*Variable speed limit sign in a Michigan work zone. Photo courtesy of Michigan State University.

### THERE'S MORE ONLINE!

ITS Applications Overview:  
[www.itsoverview.its.dot.gov](http://www.itsoverview.its.dot.gov)

Work Zone Mobility and Safety Program,  
ITS & Technology:  
[www.ops.fhwa.dot.gov/wz/its](http://www.ops.fhwa.dot.gov/wz/its)

American Association of State Highway  
and Transportation Officials (AASHTO),  
Technology Implementation Group,  
ITS in Work Zones:  
[tig.transportation.org/?siteid=42&pageid=1939](http://tig.transportation.org/?siteid=42&pageid=1939)

American Traffic Safety Services Association  
(ATSSA): [www.atssa.com](http://www.atssa.com)

The online version of this document  
contains a full list of sources:  
[www.its.dot.gov/jpodocs/repts\\_te/14320.htm](http://www.its.dot.gov/jpodocs/repts_te/14320.htm)

# for Work Zones



## Source Information

### Page 1. Introduction

1. U.S. Department of Transportation, *National Strategy to Reduce Congestion on America's Transportation Network*, Washington, DC: May 2006. Report: [isddc.dot.gov/OLPFiles/OST/012988.pdf](http://isddc.dot.gov/OLPFiles/OST/012988.pdf)
2. Federal Highway Administration, Focus on Congestion Relief Webpage, "Congestion Reduction Toolbox: Better Work Zones," [www.fhwa.dot.gov/congestion/toolbox/work\\_zones.htm](http://www.fhwa.dot.gov/congestion/toolbox/work_zones.htm)
3. U.S. Department of Transportation, *National Strategy to Reduce Congestion on America's Transportation Network*, Washington, DC: May 2006. Report: [isddc.dot.gov/OLPFiles/OST/012988.pdf](http://isddc.dot.gov/OLPFiles/OST/012988.pdf)

### Page 1. Work Zones

4. The summary fact **"Between 50 percent and 85 percent of drivers surveyed said that they changed their route at least sometimes in response to travel time, delay, or alternate route messages provided by Work Zone ITS"** is based on four articles:

Document Referenced	Simulated v. Measured Data	Location of Study	Percent Indicating They Changed Route
Zwahlen, H., and A. Russ, <i>Evaluation of the Motoring Public's Acceptance of a Real-Time Travel Time Prediction System in a Freeway Construction Work Zone</i> , presentation to the Transportation Research Board 81st Annual Meeting, January 2002. ITS Benefits Database Entry: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/1ED443F7C9575DBC852572600066ECD5">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/1ED443F7C9575DBC852572600066ECD5</a>	Traveler survey	I-75 near Dayton, Ohio	51.88% changed route "a few times," 19.69% changed route "quite often"
Bushman, R. and C. Berthelot, "Estimating the Benefits of Deploying Intelligent Transportation Systems in Work Zones," presentation to the Transportation Research Board 83rd Annual Meeting, January 22-24, 2004. ITS Benefits Database Entry: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/FC47E6A8BE1A031B852572600069B4FE">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/FC47E6A8BE1A031B852572600069B4FE</a>	Traveler survey	I-95 in North Carolina	85% responded "at least once," 73% changed route "sometimes" or "often"

Document Referenced	Simulated v. Measured Data	Location of Study	Percent Indicating They Changed Route
Chu, L., H. Kim, Y. Chung, and W. Recker, "Evaluation of Effectiveness of Automated Workzone Information Systems," <i>Transportation Research Record 1911</i> , 2005. ITS Benefits Database Entry: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/A70ADBCAC89456AE85257260006E4D77">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/A70ADBCAC89456AE85257260006E4D77</a>	Traveler survey	Santa Clarita, California	78%
Minnesota Department of Transportation, <i>Portable Traffic Management System Smart Work Zone Application: Operational Test Evaluation Report</i> , St. Paul, MN: 1997. ITS Benefits Database Entry: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/ACCC9254FAD906A885257260006FB216">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/ACCC9254FAD906A885257260006FB216</a>	Traveler survey	I-94 near Minneapolis, Minnesota	51%

5. The summary fact “Reductions in queue lengths from 56 percent to 60 percent are possible” is based on two articles:

Document Referenced	Simulated v. Measured Data	Location of Study	Percent Decrease in Queue Length
Bushman, R. and C. Berthelot, "Estimating the Benefits of Deploying Intelligent Transportation Systems in Work Zones," presentation to the Transportation Research Board 83rd Annual Meeting, January 22-24, 2004. ITS Benefits Database Entry: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/2B34D5EAE0CEA2C08525726000739B3C">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/2B34D5EAE0CEA2C08525726000739B3C</a>	Simulated	I-95 in North Carolina	56%
Scriba, T., "Knowing Ahead of Time," <i>Transportation Management + Engineering</i> , May 2005. ITS Benefits Database Entry: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/21AADDD19A082069852572600073D030">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/21AADDD19A082069852572600073D030</a>	Measured	I-95 in North Carolina	60%

6. The summary fact “with simulations indicating system-wide reductions in total delay may range from 41 percent to 75 percent” is based on two articles:

Document Referenced	Simulated v. Measured Data	Location of Study	Percent Decrease in Delay
Bushman, R. and C. Berthelot, "Estimating the Benefits of Deploying Intelligent Transportation Systems in Work Zones," presentation to the Transportation Research Board 83rd Annual Meeting, January 22-24, 2004. ITS Benefits Database Entries: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/2B34D5EAE0CEA2C08525726000739B3C">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/2B34D5EAE0CEA2C08525726000739B3C</a>	Simulated	I-95 in North Carolina	55%-75%

Document Referenced	Simulated v. Measured Data	Location of Study	Percent Decrease in Delay
Chu, L., H. Kim, H. Liu, and W. Recker, "Evaluation of Traffic Delay Reduction from Automatic Workzone Information Systems Using Micro-Simulation," presentation to the Transportation Research Board 84th Annual Meeting, January 2005. ITS Benefits Database Entries: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F090809C3D57058A85257260007450BC">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F090809C3D57058A85257260007450BC</a>	Simulated	Santa Clarita, California	41%

7. The summary fact **"Speed monitoring displays (SMD) reduce speeds in work zones by 4-6 mph"** is based on four articles:

Document Referenced	Simulated v. Measured Data	Location of Study	Decrease in Average Speed
McCoy, P.J., J. Bonneson, and J. Kollbaum, "Speed Reduction Effects of Speed Monitoring Displays with Radar in Work Zones on Interstate Highways," <i>Transportation Research Record 1509</i> , 1995. ITS Benefits Database Entries: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/8F2306948210535B8525726000748E72">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/8F2306948210535B8525726000748E72</a>	Unknown	Unknown	4-5 mph
Garber, N. and S. Patel, <i>Effectiveness of Changeable Message Signs with Radar in Controlling Vehicle Speeds in Work Zones</i> , Virginia Transportation Research Council Report No. VTRC-95-R4, Charlottesville, VA: 1994. Database Entries: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/E03F81943EA3961C852572600075418A">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/E03F81943EA3961C852572600075418A</a>	Measured	Six interstate work zones in Virginia	4 mph
Garber, N. and S. Srinivasan, <i>Effectiveness of Changeable Message Signs with Radar in Controlling Vehicle Speeds in Work Zones</i> , Virginia Transportation Research Council Report No. VTRC-98-R10, Charlottesville, VA: 1998. ITS Benefits Database Entries: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/A820F8AA8A2EB378852572600074CEAE">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/A820F8AA8A2EB378852572600074CEAE</a>	Measured	I-81 and State Rte. 19 in Virginia	6 mph
Fontaine, M.D., P. Carlson, and G. Hawkins, <i>Use of Innovative Traffic Control Devices to Improve Safety at Short-Term Rural Work Zones</i> , Texas Transportation Institute Report No. 1879-S, College Station, TX: 2000. ITS Benefits Database Entries: <a href="http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F61943DF4661F59E85257260007508B4">www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F61943DF4661F59E85257260007508B4</a>	Measured	Rural work zone in Texas	5 mph

8. McCoy, P.J., J. Bonneson, and J. Kollbaum, "Speed Reduction Effects of Speed Monitoring Displays with Radar in Work Zones on Interstate Highways," *Transportation Research Record 1509*, 1995. ITS Benefits Database Entry: [www.itsbenefits.its.dot.gov/its/benecost.nsf/0/8F2306948210535B8525726000748E72](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/8F2306948210535B8525726000748E72)
9. Federal Highway Administration, "Technologies Deployed at Work Zones: 2004 National Summary," ITS Deployment Statistics Database Entry: [www.itsdeployment.its.dot.gov/ResultsStateNational.asp?ID=1086](http://www.itsdeployment.its.dot.gov/ResultsStateNational.asp?ID=1086)

10. Federal Highway Administration, "Technologies Used at Work Zones to Communicate with Vehicles: 2004 National Summary," ITS Deployment Statistics Database Entry:  
[www.itsdeployment.its.dot.gov/ResultsStateNational.asp?ID=1088](http://www.itsdeployment.its.dot.gov/ResultsStateNational.asp?ID=1088)
11. Federal Highway Administration, "Reasons for Deploying ITS Technologies at Work Zones: 2004 National Summary," ITS Deployment Statistics Database Entry:  
[www.itsdeployment.its.dot.gov/ResultsStateNational.asp?ID=1087](http://www.itsdeployment.its.dot.gov/ResultsStateNational.asp?ID=1087)

## Page 2. Dynamic Lane Merge Improves Capacity, Decreases Travel Time

---

12. Federal Highway Administration, *ITS in Work Zones: A Case Study – Reducing Aggressive Driving and Optimizing Throughput at Work Zone Merges in Michigan*, Washington, DC: October 2004. ITS Benefits Database Entry: [www.itsbenefits.its.dot.gov/its/benecost.nsf/0/26DA38163F4820A585257260005234F9](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/26DA38163F4820A585257260005234F9)  
Report: [www.ops.fhwa.dot.gov/wz/technologies/michigan/index.htm](http://www.ops.fhwa.dot.gov/wz/technologies/michigan/index.htm)
13. Ibid.
14. Ibid.
15. Ibid.
16. Frankel, Emil H., *Revised Departmental Guidance: Valuation of Travel Time in Economic Analysis*, February 11, 2003. Document: [ostpxweb.dot.gov/policy/Data/VOTrevision1\\_2-11-03.pdf](http://ostpxweb.dot.gov/policy/Data/VOTrevision1_2-11-03.pdf)
17. Correspondence with Jeff Grossklaus, Construction Staff Engineer, Michigan Department of Transportation, November 2006. ITS Costs Database Entry: [www.itscosts.its.dot.gov/its/benecost.nsf/0/DDE520872475EFCC8525725D0068879B](http://www.itscosts.its.dot.gov/its/benecost.nsf/0/DDE520872475EFCC8525725D0068879B)
18. Minnesota Department of Transportation, *Evaluation of 2004 Dynamic Lane Merge System*, St. Paul, MN: December 2004. ITS Benefits Database Entry: [www.itsbenefits.its.dot.gov/its/benecost.nsf/0/B706D19649FE2EDC852572600059EBF0](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/B706D19649FE2EDC852572600059EBF0)  
Report: [www.dot.state.mn.us/trafficeng/workzone/2004DLMS-Evaluation.pdf](http://www.dot.state.mn.us/trafficeng/workzone/2004DLMS-Evaluation.pdf)

## Page 2. ITS Eases the Pain of Road Closure

---

19. Federal Highway Administration, *Intelligent Transportation Systems in Work Zones: A Case Study – 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*, Washington, DC: October 2004. ITS Benefits Database Entry: [www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F8D7396B1467FC7185257260006120B1](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F8D7396B1467FC7185257260006120B1)  
Report: [www.ops.fhwa.dot.gov/wz/technologies/springfield/index.htm](http://www.ops.fhwa.dot.gov/wz/technologies/springfield/index.htm)
20. Ibid.
21. Ibid.
22. Ibid.
23. Lee, E., and Changmo, K., "Automated Work Zone Information System (AWIS) on Urban Freeway Rehabilitation: California Implementation," presentation to the 85th Annual Meeting of the Transportation Research Board, Washington, DC, January 2006. ITS Benefits Database Entry:  
[www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F1F2919AE17E081285257172005C8569](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F1F2919AE17E081285257172005C8569)
24. Ibid.
25. Ibid.
26. Ibid.
27. Ibid.



### Page 3. Arkansas Invests in AWIS, Increases Use of Alternate Routes

---

28. Tudor, L., et al., "Deployment of Smart Work Zone Technology in Arkansas," presentation to the Transportation Research Board Annual Meeting, January 13, 2003, p. 4. ITS Costs Database Entry: [www.itscosts.its.dot.gov/its/benecost.nsf/0/8CA0144FB5B6EDC085256E4A004ABE9B](http://www.itscosts.its.dot.gov/its/benecost.nsf/0/8CA0144FB5B6EDC085256E4A004ABE9B) and ITS Benefits Database Entry: [www.itsbenefits.its.dot.gov/its/benecost.nsf/0/27669979CF95470685256E3F0056DC8A](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/27669979CF95470685256E3F0056DC8A)
29. Ibid., p 6.
30. Ibid.
31. Ibid., p. 7.

### Page 3. Findings from the Michigan Work Zone Variable Speed Limit System Test

---

32. Michigan Department of Transportation and Michigan State University, *Field Test of Variable Speed Limits in Work Zones (In Michigan), Final Report*, Lansing, MI: September 2003. Report: [tig.transportation.org/sites/aashtotig/docs/VSL%20Entire%20Final%20Report.pdf](http://tig.transportation.org/sites/aashtotig/docs/VSL%20Entire%20Final%20Report.pdf)
33. Correspondence with Mr. Jeff Grossklaus, PE, Construction Staff Engineer, Construction and Technology Division, Michigan Department of Transportation, December 2002. ITS Costs Database Entry: [www.itscosts.its.dot.gov/its/benecost.nsf/0/A66BC990F83CDAE885256E000049F9DD](http://www.itscosts.its.dot.gov/its/benecost.nsf/0/A66BC990F83CDAE885256E000049F9DD)
34. Michigan Department of Transportation and Michigan State University, *Field Test of Variable Speed Limits in Work Zones (In Michigan), Final Report*, Lansing: MI, September 2003. ITS Benefits Database Entry: [www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F3678455A0AF32778525726000648619](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F3678455A0AF32778525726000648619) Report: [tig.transportation.org/sites/aashtotig/docs/VSL%20Entire%20Final%20Report.pdf](http://tig.transportation.org/sites/aashtotig/docs/VSL%20Entire%20Final%20Report.pdf)
35. Ibid., p. 18.
36. Ibid., pp. 39-40.

### Page 3. Implementing the Work Zone Safety and Mobility Rule

---

37. Scriba, Tracy, "The Final Rule on Work Zone Safety and Mobility," presentation to the National Transportation Operations Coalition "NTOC Talks" Webcast, Reducing Congestion – Good Work Zone Strategies that Can Help, February 17, 2005.  
Presentation: [www.ntoctalks.com/webcast\\_archive/to\\_feb\\_17\\_05/to\\_feb\\_17\\_05ts.ppt](http://www.ntoctalks.com/webcast_archive/to_feb_17_05/to_feb_17_05ts.ppt)
38. For general information and guidance, see [www.ops.fhwa.dot.gov/wz/resources/final\\_rule.htm](http://www.ops.fhwa.dot.gov/wz/resources/final_rule.htm)

### Page 4. ITS for Work Zone Management – Lessons from Experience

---

#### Design and Deployment

39. Correspondence with Tyson King, ITS Traffic Engineering Specialist, Missouri Department of Transportation, December 2006.
40. Federal Highway Administration, *Intelligent Transportation Systems in Work Zones: A Case Study – Work Zone Traffic and Incident Management System, Keeping Traffic Moving During Reconstruction of the Big I, a Major Interstate-Interstate Interchange in Albuquerque*, Washington, DC: January 2004. ITS Lessons Learned Knowledge Resource Entry: [www.itslessons.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&F32B8CDEC73AD6C18525707E0061C5B6](http://www.itslessons.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&F32B8CDEC73AD6C18525707E0061C5B6) (Lesson learned point of contact: Allan DeBlasio, U.S. DOT / RITA / John A. Volpe National Transportation Systems Center, 617-494-2032, [allan.j.deblasio@volpe.dot.gov](mailto:allan.j.deblasio@volpe.dot.gov)). Report: [www.itsdocs.fhwa.dot.gov/jpodocs/repts\\_te/13941.html](http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/13941.html)

41. Federal Highway Administration, *Intelligent Transportation Systems in Work Zones: A Case Study – Using an Automated Traffic Information System to Reduce Congestion and Improve Safety During Reconstruction of the I-55 Lake Springfield Bridge in Illinois*, Washington, DC: October 2004, p. 4-3.  
ITS Lessons Learned Knowledge Resource Entry: [www.itslessons.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&A286EB6A08D7ECEB8525725F006CD882](http://www.itslessons.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&A286EB6A08D7ECEB8525725F006CD882)  
(Lesson learned point of contact: William Frey, 217-782-7401, freywr@dot.il.gov).  
Report: [www.itstdocs.fhwa.dot.gov/jpodocs/repts\\_te/13984.htm](http://www.itstdocs.fhwa.dot.gov/jpodocs/repts_te/13984.htm)
42. Federal Highway Administration, “I-30 Little Rock to Benton, Arkansas,” draft chapter in a forthcoming report, expected publication fall 2007. ITS Lessons Learned Knowledge Resource Entry: [www.itslessons.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&871D8AECEDE03CEB8525726000594533](http://www.itslessons.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&871D8AECEDE03CEB8525726000594533)  
(Lesson learned point of contact: Cheryl Lowrance, Mitretek Systems, 202-863-2986, cheryl.lowrance@mitretek.org).
43. McCoy, P.T., G. Pesti, “Smart Work Zone Technology Evaluations: Speed Monitoring Displays and Condition-Responsive, Real-Time Travel Information Systems,” paper presented at the Institute of Transportation Engineers 2001 Annual Meeting and Exhibit, Chicago, IL, August 19-22, 2001.
44. McCoy, P.J., J. Bonneson, and J. Kollbaum, “Speed Reduction Effects of Speed Monitoring Displays with Radar in Work Zones on Interstate Highways,” *Transportation Research Record* 1509, 1995.  
ITS Benefits Database Entry: [www.itsbenefits.its.dot.gov/its/benecost.nsf/0/8F2306948210535B8525726000748E72](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/8F2306948210535B8525726000748E72)
45. Garber, N. and S. Patel, *Effectiveness of Changeable Message Signs with Radar in Controlling Vehicle Speeds in Work Zones*, Virginia Transportation Research Council Report No. VTRC-95-R4, Charlottesville, VA: 1994.  
ITS Benefits Database Entry: [www.itsbenefits.its.dot.gov/its/benecost.nsf/0/E03F81943EA3961C852572600075418A](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/E03F81943EA3961C852572600075418A)
46. Garber, N. and S. Srinivasan, *Effectiveness of Changeable Message Signs with Radar in Controlling Vehicle Speeds in Work Zones*, Virginia Transportation Research Council Report No. VTRC-98-R10, Charlottesville, VA: 1998. ITS Benefits Database Entry: [www.itsbenefits.its.dot.gov/its/benecost.nsf/0/A820F8AA8A2EB378852572600074CEAE](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/A820F8AA8A2EB378852572600074CEAE)
47. Fontaine, M.D., P. Carlson, and G. Hawkins, *Use of Innovative Traffic Control Devices to Improve Safety at Short-Term Rural Work Zones*, Texas Transportation Institute Report No. 1879-S, College Station, TX: 2000.  
ITS Benefits Database Entry: [www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F61943DF4661F59E85257260007508B4](http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/F61943DF4661F59E85257260007508B4)
48. Minnesota Department of Transportation, *Dynamic Late Merge System Evaluation*, St. Paul, MN: October 2003. ITS Lessons Learned Knowledge Resource Entry: [www.itslessons.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&00364CE62DB27A798525707E0061C501](http://www.itslessons.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&00364CE62DB27A798525707E0061C501)  
(Lesson learned point of contact: Firoz Kabir, Mitretek Systems, 202-863-2987, firoz.kabir@mitretek.org).  
Report: [www.dot.state.mn.us/trafficeng/research/data/DynLateMerge.pdf](http://www.dot.state.mn.us/trafficeng/research/data/DynLateMerge.pdf)

### Technical Integration

49. Federal Highway Administration, *Intelligent Transportation Systems in Work Zones: A Cross Cutting Study – Integrated Work Zone Systems for Improving Travel Conditions and Safety*, Washington, DC: November 2002. ITS Lessons Learned Knowledge Resource Entry: [www.itslessons.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&481DB03ED43C6292852571A4004D72C9](http://www.itslessons.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&481DB03ED43C6292852571A4004D72C9)  
(Lesson point of contact: Allan DeBlasio, U.S. DOT / RITA / John A. Volpe National Transportation Systems Center, 617-494-2032, allan.j.deblasio@volpe.dot.gov).  
Report: [www.itstdocs.fhwa.dot.gov/jpodocs/repts\\_te/13600.html](http://www.itstdocs.fhwa.dot.gov/jpodocs/repts_te/13600.html)