EXPLORE ITS TECHNOLOGIES FOR WORK ZONES AND WORK ZONE IMPACT AREAS

Technical Memorandum 1: Literature Review

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Glossary of Abbreviations

ADT	Average Daily Traffic
AFAD	Automated Flagger Assistance Device
ANPRM	Advance Notice of Proposed Rulemaking
ASE	Automated Speed Enforcement
ATSSA	American Traffic Safety Services Association
DLMS	Dynamic Lane Merge System
DOT	Department of Transportation
FHWA	Federal Highway Administration
GPS	Global Positioning System
IIHS	Insurance Institute for Highway Safety
ISTEA	International Surface Transportation Efficiency Act
ITS	Intelligent Transportation Systems
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NHWZSP	National Highway Work Zone Safety Program
NPRM	Notice of Proposed Rulemaking
PCMS	Portable Changeable Message Sign
SNPRM	Supplemental Notice of Proposed Rulemaking
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
TMA	Truck Mounted Attenuators
TTC	Temporary Traffic Control
VSL	Variable Speed Limit
WPDS	Wet Pavement Detection System

CHAPTER 1. Introduction

The necessity for maintenance and rehabilitation of existing roadway systems increases as highway infrastructure ages and traffic increases. A work zone, as defined in the Manual on Uniform Traffic Control Devices—MUTCD (FHWA, 2003a), is an area of a highway with construction, maintenance, or utility work activities. Within work zones, the lane(s) under maintenance or rehabilitation should be closed and as a result, the space available for vehicles to pass through the work zones is decreased. This may create disruption to traffic and potential hazards to drivers and highway workers.

In the United States, around 1,000 work-zone-related fatalities occur every year, and work zones on freeways account for nearly 24 percent of non-recurring delay (FHWA, 2008). A study of work zone crash data between 1995 and 1997 found that work zone crashes cost $6.2 billion per year, with an average cost of $3,687 per crash (Mohan and Gautam, 2002). These facts indicate the importance of proper planning and management of work zone projects. During highway maintenance and construction, transportation practitioners need to manage and minimize work zone impacts on traffic safety, mobility, and expectations of the traveling public. Various strategies and technologies have been utilized to help reduce the negative impacts caused by work zones.

The purpose of this technical memorandum is to summarize the state of the art and practice of Intelligent Transportation System (ITS) technologies that have been deployed in work zones to improve safety and mobility. This chapter includes: 1) a brief history of work zone legislation, regulations and initiatives; and 2) objectives of this research project. A comprehensive literature review of work zone ITS technologies is presented in CHAPTER 2.

1.1 History of Work Zone Legislation, Regulations and Initiatives

Much attention has been paid by federal agencies to improving work zone safety and mobility. The following briefly summarizes work-zone-related legislation, regulations and initiatives in the past two decades:

- In 1991, Section 1051 of the Intermodal Surface Transportation Efficiency Act (ISTEA) required that “the Secretary shall develop and implement a highway work zone safety program which will improve work zone safety at highway construction sites by enhancing the quality and effectiveness of traffic control devices, safety appurtenances, traffic control plans, and bidding practices for traffic control devices and services” (ISTEA, 1991).
- In 1995, in response to the ISTEA, the FHWA published a notice to establish the National Highway Work Zone Safety Program (NHWZSP) to enhance safety at highway construction, maintenance, and utility sites (FHWA, 1995). In 1999, the NHWZSP was established.

- In 2002, upon identifying the need to update FHWA's regulation on work zone safety (23 CFR 630, subpart J), an Advance Notice of Proposed Rulemaking (ANPRM) was published by FHWA to solicit comments (FHWA, 2002a).
- In 2003, the FHWA published the Notice of Proposed Rulemaking (NPRM) to amend its regulation that governed traffic safety in highway and street work zones. The regulation in the NPRM was intended to facilitate consideration and management of the broader safety and mobility impacts of work zones in a more coordinated and comprehensive manner across project development stages, and the development of appropriate strategies to manage these impacts (FHWA, 2003b).
- The FHWA received comments that raised concerns about flexibility and scalability in the implementation of the provisions of the proposed rule. In May 2004, the FHWA published a Supplemental Notice of Proposed Rulemaking (SNPRM) to address the comments (FHWA, 2004a).
- In September 2004, the FHWA published the updated (or final) Rule on work zone safety and mobility. The provisions in the final Rule help state departments of transportation (DOTs) meet current and future work zone safety and mobility challenges, and serve the needs of the American people. The Rule requires that each state shall implement a policy for the systematic consideration and management of work zone impacts on all Federal-aid highway projects. All state and local governments that receive Federal-aid highway funding need to comply with its provisions by October 12, 2007 (FHWA, 2004b).
- In 2005, the FHWA published a summary of highway provisions—Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). A number of provisions to address the safety of motorists, pedestrians, and highway construction workers in highway construction work zones are included. (FHWA, 2005a)

In the ANPRM (FHWA, 2002a), "safety" and "mobility" were defined with specific reference to work zones. With the analysis of solicited comments from state DOTs and other agencies, the FHWA finalized the definitions in the final Rule (FHWA, 2004b):

- *Safety* refers to minimizing potential hazards to road users in the vicinity of a work zone and highway workers at the work zone interface with traffic.
- *Mobility* refers to moving road users efficiently through or around a work zone area with a minimum delay compared to baseline travel when no work zone is present, while not compromising the safety of highway workers or road users.

1.2 Research Objectives

To be consistent with the final Rule (FHWA, 2004b), the Federal Lands Highway (FLH) agency needs to implement a policy for the systematic consideration and management of work zone impacts associated with Federal land road projects. In addition, the Federal land management agencies are concerned with the impact of work zones on visitor use and experience and the potential impact on the local economy.

Although ITS technologies have been widely and successfully deployed to support strategies for improving mobility and safety in work zones, it has been recognized by the FLH agency that current ITS resources (e.g., guidance, best practices, case-studies, cross-cutting studies) are not directly relevant to the context and environment of maintaining travel, or for protecting travelers and workers on Federal lands road projects. Given the unique characteristics of Federal land projects (e.g., narrow roadway, remoteness, concern for visitor experience), existing work zone ITS systems may or may not be applicable to such projects. In light of this, it is of importance to explore potential ITS technologies that can be applied to work zones and work zone impact areas on Federal lands

This research project has two distinct objectives: 1) to synthesize existing work zone ITS technologies and identify those applications that are more appropriate on Federal land road projects, and 2) to provide guidance for the consideration and implementation of work zone ITS systems. The results of this project will help FLH to improve work zone safety and mobility as well as improve visitor experience on Federal lands.

CHAPTER 2. Literature Review on Work Zone ITS Technologies

The purpose of work zone traffic control is to provide a safe working area for highway workers and facilitate the safety and mobility of road users. A combination of work zone traffic control devices can be used for this purpose. The FHWA requires the use of crashworthy devices, which have passed a crash test under the guidance of National Cooperative Highway Research Program (NCHRP) Report 350 (Ross et al., 1993; Artimovich, 2004). Work zone traffic control devices were classified into four categories, each of which has its own testing requirements (Artimovich, 2004). The four categories are described below:

- *Category 1: Cones, barrels, and delineators*. These items are small and lightweight, have been in common use for several years, and are known to be crashworthy. Individual crash testing is not needed.
- *Category 2*: *Barricades, sign stands*. These devices are not expected to produce significant vehicular speed change but may otherwise be hazardous. Examples of such devices are barricades, portable sign supports, intrusion alarms, plastic drums, vertical panels, or cones with lights.
- *Category 3: Barriers, crash cushions, TMAs (truck-mounted attenuators)*. These devices are expected to cause significant speed change or other potential harmful reactions to impacting vehicles.
- *Category 4: Trailer-mounted devices*. Examples of such devices are flashing arrow panels, temporary traffic signals, and Portable Changeable Message Signs (PCMS).

In addition to the abovementioned work zone devices, transportation agencies often use ITS technologies to monitor and manage traffic flow and make travel through and within the work zone impact areas safer and more efficient. Work zone ITS systems involve the use of electronics, computers and communication equipment to collect, process, and disseminate information. Most work zone ITS systems use portable sensors to collect traffic data and PCMS to display real-time traffic/traveler information (FHWA, 2002b). Portable systems provide flexible and adaptable solutions since roadway characteristics can change dramatically during highway maintenance and construction.

The evaluation results from cross-cutting studies have shown that ITS technologies are effective in reducing crashes, reducing delays, and reducing costs when properly used in work zones (FHWA, 2002b). ITS technologies in work zones can be applied for different purposes and many systems are deployed to serve a combination of purposes (FHWA, 2009a), which include:

- traffic monitoring and management;
- providing traveler information;
- incident management;
- enhancing safety of both the road users and highway workers;
- increasing capacity;

- enforcement;
- tracking and evaluation of contract incentives/disincentives (performance-based contracting); and
- work zone planning.

This chapter summarizes and provides a comprehensive review of the state of the art and practice of existing work zone ITS systems. Also, common issues and lessons learned from work zone ITS practices are summarized.

2.1 Work Zone ITS Systems

2.1.1 Travel Time System

A travel time system estimates the time required to pass through the work zone and disseminates the information to travelers through PCMS, Internet, or other tools. The public may have access to Internet to obtain pre-trip information and make better decisions (e.g., using alternative routes, cancelling trips, scheduling other times for trips). Travelers approaching the work zone can be more prepared for unexpected situations or may choose an alternate route. Information provided by travel time systems will help reduce motorists' stress and anxiety that can be caused by congestion or incidents.

A travel time system uses vehicle detection sensors to estimate travel time. Travel time information can be obtained through detecting vehicle speeds passing through the work zone. In such a case, travel time is calculated by dividing the length of the work zone by the average speed during a fixed time period (e.g., 10 minutes). Travel time can also be directly obtained through detecting the time that vehicles pass through the work zone. License plate matching or video image recognition technologies can be used for this purpose. Both technologies use at least two (video) cameras to track individual vehicles. More (video) cameras may be necessary in the case that the detection section is too long. Table 1 presents system information of some recent practices that deployed travel time systems in work zones (FHWA, 2004c; SHA, 2005). There was no information regarding quantitative analysis of the impacts of these systems on work zone safety and mobility.

Some of the challenges in the Arizona study are worth noting as the travel time system was deployed in a remote location (FHWA, 2004c). Firstly, the system had trouble reading license plates when the camera was facing directly into the sun, although that was only a problem for approximately one hour per day. Secondly, each camera was equipped with a light source. As using solar power for camera lights was prohibitively expensive, the locations for camera placement were limited by the availability of public utilities for power. Thirdly, because this project was located in a mountainous region, additional equipment was required to provide point-to-point microwave communication. Repeaters were also required to relay signals from the roadside sites to the main transmitter.

Table 1 Travel Time System Practices

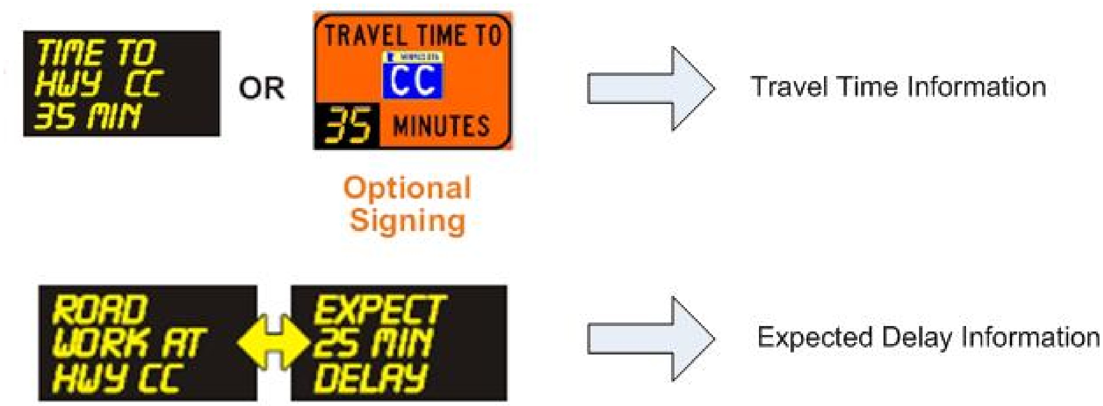
System Information	Arizona (FHWA, 2004c)	Maryland (SHA, 2005)	Maryland (SHA, 2005)
System Location (Length)	Arizona State Route 68 (13.5 mi)	Eastbound I-70 between MD 32 and I-695	Southbound I-95 between MD 23 and MD 212 (7.5 mi); Southbound U.S. 29 between MD 32 and Industrial Pky (11.25 mi)
System Technology	License plate matching	Microwave detection	Video image processing
System Components	• Two monitoring stations and a central processor • Each station included an inductive loop and two digital cameras • Each camera equipped with a light	• Three PCMS • Four microwave sensors	I-95: • Two cameras south of MD 32 with web camera and two cameras north of MD 212 U.S. 29: • Three cameras north of MD 32 and three cameras south of Industrial Pky
Communication Technology	Microwave	20 MHz Radio;	Cellular
Power	Public utilities	Solar power with batteries	Solar power with batteries
Travel Time Interval	• Every 10 minutes to the central processing station • Every 30 minutes to Arizona DOT	N/A	N/A
Information Availability	Arizona DOT (Contractor)	PCMS display; Website	Website

Transportation agencies need to consider the following restrictions when deploying or considering using travel time systems in work zones (ATSSA, 2008). The deployment of travel time systems should be limited to restricted access highways. They are not suitable for highway sections with intersections. Also, the calculations of travel time are considered to be accurate on a route up to 10 miles long. Hence, the PCMS should be located within 10 miles of the destination point. Moreover, a travel time system may be used when the work zone is anticipated to cause 10 minutes of additional travel time. Another study (MnDOT, 2008) suggests 15 minutes or more of delay to warrant the use of a travel time system. Finally, travel time systems are considered a better fit for commuter traffic because regular travelers will notice the time difference (MnDOT, 2008).

2.1.2 Expected Delay Information System

An expected delay information system calculates the increase in travel time due to a work zone and distributes information to travelers of the expected delay time between their current location and a specific destination ahead. Such systems provide information to help calm tempers and ease frustration; they also allow travelers to choose alternate routes at their discretion under congested conditions. Expected delay information can be displayed on PCMS, which are placed in advance of work zones.

As mentioned earlier, travel time estimation is considered to be accurate within 10 miles of the destination location. Thus, travel time systems are better choices for distances of less than 10 miles, while expected delay information systems are preferred for posting time delays for work zones located beyond 10 miles from the motorist's current location (MnDOT, 2008; ATSSA, 2008). With that said, travel time systems and expected delay information systems are not interchangeable. It is worth noting that expected delay information systems are considered better for non-commuter traffic because previous knowledge of the total trip time is not required (ATSSA, 2008). The following figure shows typical travel time and expected delay messages on PCMS.



(Source: MnDOT, 2008)

Figure 1 Travel Time and Expected Delay Messages

2.1.3 Dynamic Lane Merge System (DLMS)

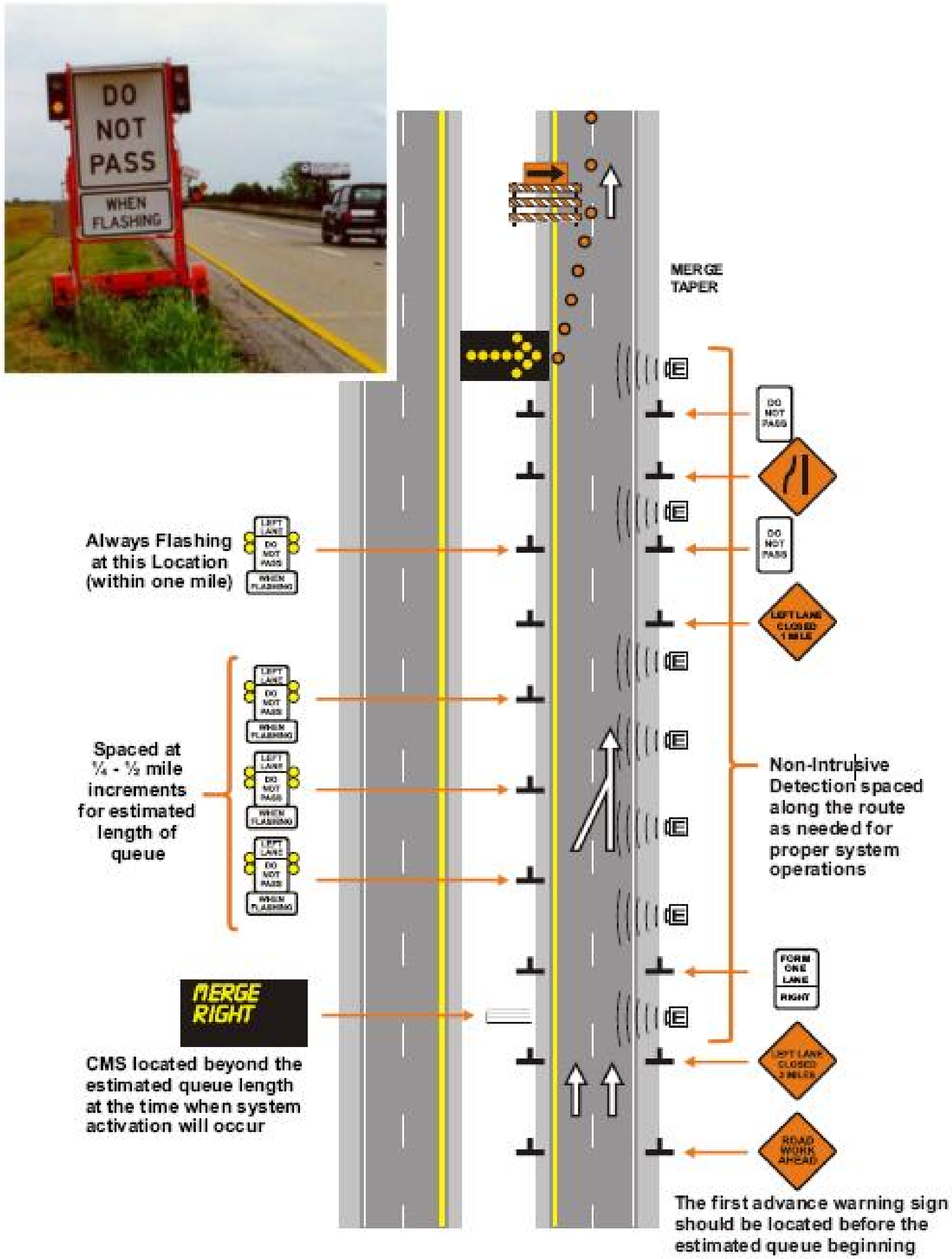
A work zone DLMS is used to control traffic at merging areas when a work zone requires a two-to-one or three-to-two lane drop. DLMS includes two technologies: early merge and late merge. The purpose of early merge is to move vehicles out of the closed lane upstream as soon as possible, while late merge encourages drivers to use all available lanes until they reach the beginning of the merging taper to minimize queues (ATSSA, 2008). Overall, the use of DLMS is to provide positive instructions to motorists and improve driver behavior.

2.1.3.1 Early Merge System

An early merge system uses vehicle sensors to monitor traffic in the open lanes on the approach to the merge area. As queues form at the closure location and extend backward, advanced warning signs with the message “Do Not Pass When Flashing” are activated. When queues in the open lanes are detected beyond the sign, a wireless signal is transmitted to activate the next upstream warning sign. Figure 2 shows an example of advanced warning sign and a layout of an early merge system in a two-to-one lane drop work zone (MnDOT, 2008).

Early merge systems have several potential benefits, including: 1) reducing aggressive driving and unsafe merge maneuvers; 2) providing significant advanced warning so drivers have adequate distance to merge; and 3) giving drivers positive instructions on lane usage and merging points. An early merge system may be used when the following conditions exist: 1) the work zone requires a two-to-one or three-to-two lane drop; 2) typically, traffic volume must exceed 1500 veh./hr to sustain a queue when merging lanes for a two-to-one lane drop; 3) the length of queue is not expected to extend beyond the start of work zone signing; 4) travel speed is high; and 5) there is commuter traffic and sufficient project duration to allow adaption to the system (ATSSA, 2008; MnDOT, 2008).

The Michigan DOT (MDOT) deployed an early merge system on Interstate 94 (I-94) near Detroit from Michigan State Route (SR) 102 to Masonic Boulevard with a distance of approximately 13 miles (FHWA, 2004d). The system was deployed on westbound I-94 in September and October 2002, and August and September 2003. It used microwave radar sensors installed on five dynamic lane merge trailers to detect traffic volume, vehicle speed, and detector occupancy; the detected data were used to calculate an activity index. MDOT pre-set thresholds for the activity index. When the detected conditions surpassed the thresholds, the system would automatically activate the advanced warning signs. The closer the trailer was to the merge point, the lower the activity index was for activation. The evaluation of this system is summarized in the following table. The system was found to be cost-effective and improve work zone safety and mobility.



(Source: MnDOT, 2008)

Figure 2 Layout of an Early Merge System

Table 2 Evaluation Results of the MDOT Early Merge System

Measures	Results
Mobility	Morning Peak Period: • Average number of stops decreased from 1.75 to 0.96 • Stopped time delay unchanged • Average travel time delay decreased from 95 sec./veh. To 69 sec./veh. for every 10,000 feet of travel • Average number of aggressive driving maneuvers per travel time run unchanged • Average travel speed increased from about 40 mph to 46 mph After Peak Period: • Average number of stops unchanged • Stopped time delay unchanged • Average number of aggressive driving maneuvers per travel time run decreased from 2.88 to 0.55 • Average travel speed unchanged
Safety	• Average number of aggressive driving maneuvers per travel time run decreased from 2.88 to 0.55 during the after peak period • Before crash data: 1.2 crashes/month for 4.3 months; After crash data: no crashes reported for 2 months • Less variance of speeds
Cost/Benefit	• Travel time and vehicular fuel savings outweighed the costs even when the value of time is $3.33 per hour.

(Source: FHWA, 2004d)

2.1.3.2 Late Merge System

In work zones with lane closures and congested traffic, drivers in the closure lane merge into the open lane(s) when they feel comfortable, and this behavior sometimes causes sudden interruptions in the open lane(s) and results in higher traffic delay and longer queues. Late merge systems aim at reducing such behavior. When congestion is detected, a late merge system will activate PCMS to provide drivers with lane use instructions (where to merge) with the intent to improve safety and mobility of the congested flow.

Highway agencies may consider using a late merge system under the following conditions (MnDOT, 2008; ATSSA, 2008):

- When traffic demand exceeds the capacity of the open lane;
- Estimated queue lengths may extend beyond an upstream intersection or interchange or extend beyond reasonable placement of advance warning signs; and
- When congestion caused by lane closures varies many times throughout a work day.

Transportation agencies in the United States started using late merge systems a decade ago and since then they have been widely deployed across the country. The following table summarizes the findings from seven late merge system studies. The results show that late merge systems are generally effective in improving traffic safety and mobility.

Table 3 Findings from Dynamic Late Lane Merge System Studies

Author(s)	Study Location (Lane Closure)	Findings
Pesti et al. (1999)	Northbound I-79 north of Canonsburg, Pennsylvania (two-to-one lane drop)	• Higher capacity • Fewer traffic conflicts • The effectiveness of the system was reduced by some motorists' not following the directions
Walters and Cooner (2001)	I-30 in Dallas, Texas (three-to-two lane drop)	• Delayed the onset of congestion at the merge point by approximately 14 minutes • The length of maximum queue decreased from 7,800 feet to 6,000 feet
URS (2003)	US 10, in Anoka, Minnesota (two-to-one lane drop)	• Queue length decreased • Throughput decreased slightly • Incidence of aggressive driver behavior decreased
Meyer (2004)	I-70Eastbound in Kansas City, Kansas (three-two-two lane drop)	• The entrance ramp immediately prior to the merge area significantly affected driver's lane choice • Congestion proved to be much less than expected
Beacher et al. (2005)	US 17 between State Route (SR) 617 and SR 1036, Virginia (two-to-one-lane drop)	• No significant difference in the throughput and queue length
Kang et al. (2006)	I-83 southbound, Maryland (two-to-one lane drop)	• Increase in the overall throughput • Reduction of the maximum queue length • More even distribution of volume between lanes
Grillo et al. (2008)	I-69 near the city of Flint and I-94 in Kalamazoo and Van Buren Counties, Michigan (two-to-one lane drop)	• The percentage of vehicles merged at or near the designated taper location increased • Benefit-cost ratio greater than 1 with a $5/hr value of time

2.1.4 Speed Management System

In 2008, there were 37,261 fatalities on U.S. roadways, and 11,674 (31 percent) were speeding-related (FHWA, 2009b). Aggressive driving behaviors such as speeding are primary factors contributing to major injury and fatality crashes (Njord et al., 2006). Studies have shown higher crash rates at specific highway locations (e.g., work zones) that temporarily set lower speed limits (AASHTO, 1987; Chambless et al., 2002). The higher crash rates in and around work zones are due to two important factors. First, work zone activities are sources of traffic delay, which may lead drivers to become frustrated and exhibit aggressive driving traits. Second, sometimes speed limits in work zones are not appropriate and do not reflect prevailing driving conditions. Under such conditions, drivers may disregard them and drive at their "comfortable" speeds, which pose safety risks to construction workers and road users. Hence, work zone traffic control strategies targeting these two problems could be effective. Several technologies have been used to manage speed in work zones, including (but not limited to) Variable Speed Limit (VSL) systems, speed feedback systems, speed advisory systems, and Automated Speed Enforcement (ASE) systems.

2.1.4.1 Variable Speed Limit (VSL) System

VSL systems incorporate information on traffic (e.g., speed and volume), weather, and road surface conditions to determine appropriate speeds at which drivers should be traveling. VSL systems may consist of multiple roadside monitoring and display trailers with each trailer using detectors to monitor traffic speeds, roadway conditions, and other information. The detected information is used to determine the appropriate speed limit. Speed limit information is displayed on PCMS and the information is temporally and spatially dynamic.

VSL systems have been long used (back to 1960s) in the United States to help reduce driver errors and speeds. As of 2000, the states of Arizona, Colorado, Michigan, Minnesota, Nevada, New Jersey, New Mexico, Oregon, and Washington have had programs that used VSL systems (Robinson, 2000). VSL systems have been widely used in work zones. A survey to transportation agencies found that of the 40 surveys returned, 30 indicated that VSL systems were in use in that state (TRB, 2002).

The following table summarizes the findings of some recent best practices. The positive effects of VSL systems on speeds could have different meanings under different situations. For example, the system deployed in the FHWA (2004e) study was effective in increasing average speed (for congested roadways), while the other three studies reduced speeds in work zones where speeding was a safety concern. The FHWA study (2004e) also found that the system decreased the percentage of vehicles exceeding certain thresholds, which could contribute to safety improvement.

Table 4 Best Practices of VSL Systems

Authors	Study Location	System Components	Findings
FHWA (2004e)	I-96 south and west of Lansing, Michigan	• Remote Traffic Microwave Sensors (RTMS) (trailer-mounted) • Seven trailers with RF communications • A weather / moisture detection sensor	Positive effects: • Increased average speeds and decreased travel time • Percentage of vehicles exceeding certain thresholds (e.g., 60 mph) decreased
Kwon et al. (2007)	I-494 in Twin Cities, Minnesota	• Five sets of radar detectors • Three PCMS • Three sets of Doppler radar sensors • One set of web-based wireless communication system	Positive effects: • 25% to 30% speed reduction during the morning peak period (6:00 to 8:00 a.m.) • reduction in speed variance • 7% increase in throughput during the 6:00 to 7:00 a.m. periods
Hattox III et al. (2007)	SC-219 in Newberry, SC-290 in Spartanburg, and SC-72 in Laurens, South Carolina	At each location: • One laser speed gun • Two radar sensors • Nu-Metrics Histar traffic counters • Flashing beacons	Positive effects: • 3.3 mph reduction in the average mean speed • 4.1 mph reduction in the average mean speed where more than 50% of vehicles were speeding before the deployment of system
Eckenrode et al. (2007)	I-385, I-585, SC-72, and SC-488 and in South Carolina	• (Inexpensive) drone radar	Positive effects: • 2.5 mph reduction in the average mean speed (the effectiveness of drone radar is dependent on the number of radar detectors in the traffic stream) (Note: the use of drone radars is restricted in work zones contained rolling terrain.)
McMurtry et al. (2009)	I-80 north of Wanship, Utah	• Two VSL signs • Five speed detectors (tubes)	Positive effects: • Variation in speeds reduced • Positive driver response

2.1.4.2 Speed Feedback Display System

Speed feedback display systems are another type of work zone speed display. This portable system detects approaching vehicle speeds, informs drivers of their current speeds, and encourages them to slow down if their speeds are over the speed limit. This system can be coordinated with other ITS systems (e.g., stopped or slowing traffic warning systems) to warn a speeding driver to slow down to avoid a severe consequence (ATSSA, 2008).

The speed feedback display system gives drivers immediate feedback on their individual speeds and has been found effective in reducing speeding. Speed-activated CMS deployed during the construction season of 1995 and 1996 on I-81 and U.S. 19 North in Lebanon, Virginia, found 8 to 9 mph speed reductions (Garber and Srinivasan, 1998). In Nebraska, a portable speed detection and warning system placed upstream from an I-80 work zone decreased the highest 15 percent of vehicle speeds by 5 mph as vehicles approached the work zone lane merge area (Maze et al., 2000). A study in Texas showed that speed display trailers could reduce average vehicle speeds by 5 mph and decreased the number of vehicles traveling at excessive speeds in rural work zones (Fontaine et al., 2000). A SpeedGuard system deployed in a five-mile-long construction zone on rural I-70 in Wabaunsee County, Kansas, was found to significantly reduce mean speed, 85th percentile speeds, percent of drivers exceeding the posted limit, and speed variation (Robinson, 2002). Chitturi and Benekohal (2006) found that the speed feedback systems deployed in interstate highway work zones were effective in reducing average speeds, with a 4.4 mph reduction in a few days after the deployment and an additional 2.3 mph reduction after three weeks of operation. The speed feedback display systems deployed in the arterial streets of King County, Washington, also had significant effects on speed reduction, with effects varying at different location (Chang et al., 2005).

2.1.4.3 Speed Advisory System

A speed advisory system is used to inform motorists of slower traffic ahead in work zones and advise them of an appropriate speed. The system uses vehicle detectors in and upstream of work zones to detect vehicle speeds entering the work zones. The average speed is used as the advisory speed to be displayed on a PCMS or a CMS with a static warning sign (see Figure 3) (MnDOT, 2008). In practice, the speed advisory sign should be placed two to three miles before the slow traffic queue (MnDOT, 2008). The potential benefits of speed advisory systems include (MnDOT, 2008):

- Allow drivers to travel through the work zone with minimum braking;
- Smooth the transition between faster and slower moving traffic; and
- Provide an increase in capacity of the roadway through the work zone area.

(Source: MnDOT, 2008)

Figure 3 Example of a Speed Advisory Sign

A pooled-fund study (Pesti, 2002) was conducted to evaluate the effectiveness of a speed advisory system on reducing traffic speeds and speed differentials upstream of traffic slowdowns. The system included three speed trailers placed at approximately ¼-mile intervals in advance of a work zone on I-80 near Lincoln, Nebraska. The results indicated that the speed messages were effective in reducing vehicle speeds approaching queued traffic. Also, the speed profiles observed were generally smoother than those observed before system deployment.

2.1.4.4 Automated Speed Enforcement (ASE) System

Excessive speed (in work zone areas) is considered to be a major contributing factor to vehicle crashes. It is a safety concern for road workers, transportation agencies, and law enforcement agencies. Traditional speed enforcement with police present on site can be effective in this regard, but it can be dangerous to both road users and enforcement officers. In addition, work zone environments may restrict the ability of police officers to set up radar, and violators may have difficulty pulling over within work zones with restricted shoulders. Therefore, ASE systems have been used as an alternative for traditional speed enforcement. ASE systems use one or more motor vehicle sensors to record images of speeding vehicles. Images are then processed and reviewed, and violation notices/citations are mailed to the registered owner of the identified vehicles. The use of ASE systems eliminates the need to stop violators in a work zone.

There are several legal and social issues associated with the implementation of ASE (Fontaine et al., 2002). For instance, as with red-light-running cameras, ASE systems require a local law authorizing the use of speed cameras. ASE systems have been widely used in the United States. As of November 2009, speed cameras are used in more than 40 jurisdictions in over 20 states and the District of Columbia (IIHS, 2009).

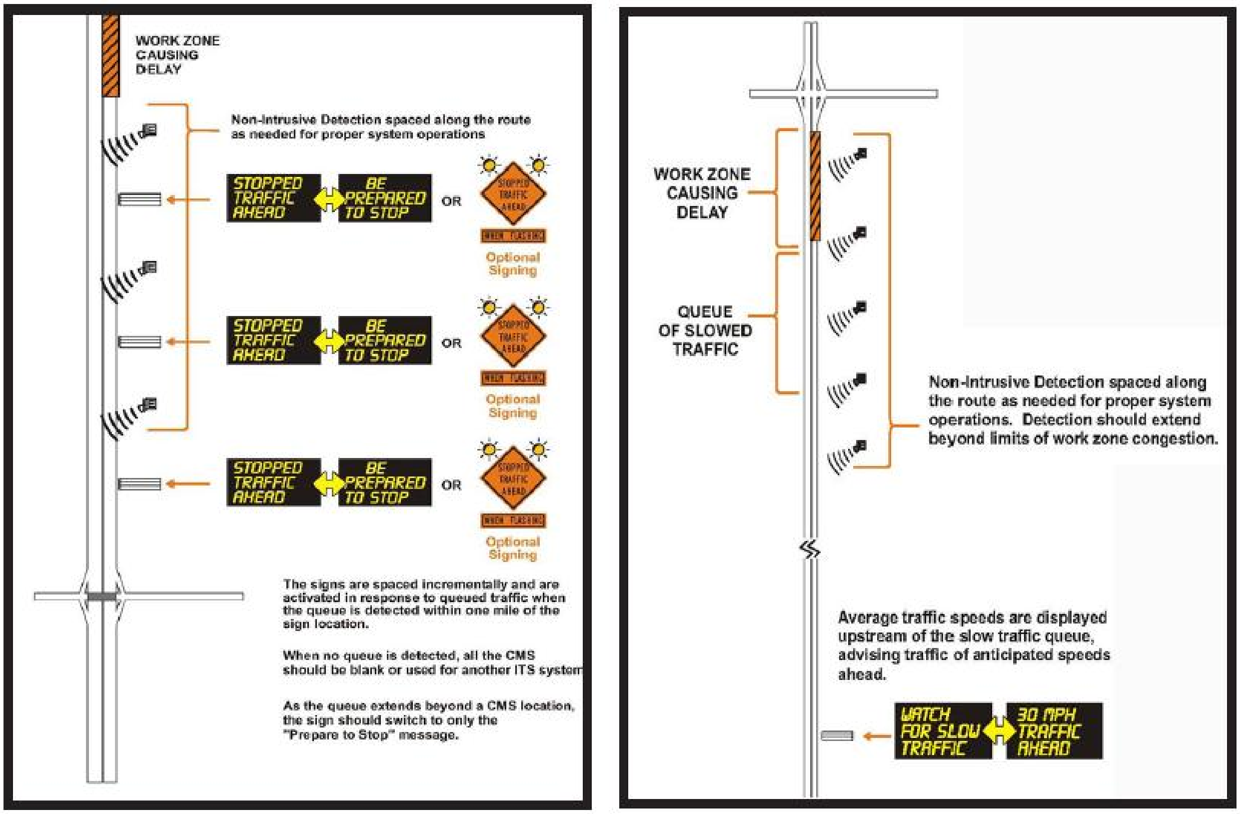
While speed cameras have been used since the 1990s in the United States (mostly on city streets) (Berkuti and Osburn, 1998; Portland Office of Transportation and City of Beaverton, 1997), the concept of ASE in work zones is relatively new. A stand-alone system consisting of a lidar (light detection and ranging—similar to radar) gun mounted above a high-resolution digital camera was deployed in Texas to test the concept of ASE in work zones (Fontaine et al., 2002). Focus groups of law enforcement personnel were used to determine potential acceptance of the system. Comments from law enforcement officers indicated that improvements needed to be made before the system could be used in Texas.

Recently, ASE systems were implemented on I-64 in southern Illinois near St. Louis, and I-55 near Chicago, Illinois (Medina et al., 2009; Benekohal et al., 2009). The results showed that ASE systems significantly reduced the percentage of cars and heavy vehicles exceeding the speed limit. A California study (Chan, 2009) evaluated the performance of an ASE system deployed on a rural two-lane highway. The ASE system determined that 2 to 5 percent of passing vehicles were traveling in excess of 65 mph on a highway with a posted speed limit of 55 mph.

An ASE system may be considered for use under the following conditions (ATSSA, 2008): 1) the roadway section in the work zone area has narrowed shoulders and limited options for speed violators and enforcement officers to exit the travel way; 2) 24-hour enforcement is desired; and 3) law enforcement availability is limited.

2.1.5 Stopped or Slowing Traffic Warning System

Work zones are highly variable environments with changing roadway configurations. Motorists' reactions to work zone conditions (e.g., unexpected transition from posted speeds to a stop position) can cause vehicle crashes. For this reason, it is important to alert drivers of slowing or stopped traffic to reduce rear-end and secondary crashes. A warning system alerting drivers to stopped or slowing traffic, as shown in Figure 4, can serve this purpose.



(Source: ATSSA, 2008)

Figure 4 Layouts of Stopped and Slowing Traffic Warning Systems

The following conditions may warrant the use of a stopped or slowing traffic warning system (MnDOT, 2008; ATSSA, 2008):

- When queue lengths are estimated to vary greatly, day by day and hour by hour;
- When stopped traffic is unexpected, particularly when visibility is restricted or when transitioning from a rural to urban driving environment;
- When lane closures are required on high volume roadways, especially during peak hours;
- When road work is being performed near high volume entrance or exit ramps on high speed roadways; or
- When work is performed at night on a high volume roadway.

2.1.6 Alternate Route Information System

Alternate route information systems provide road users with real-time travel information so that they can better plan their routes. Most alternate route information systems have been developed in the context of emergency, incident, and work zone management (Dunn Engineering Associates, 2006). In work zones, the primary purpose of an alternate route system is to reduce traffic demands on roadway sections under construction and further reduce work zone traffic congestion. Alternate route information can be displayed on PCMS, broadcast on Highway Advisory Radios (HAR) along the route, or be included in GPS (Global Positioning System) systems for truck companies (ATSSA, 2008).

Between April and November 2003, the North Carolina DOT deployed a Smart Work Zone system at two locations on I-95 to provide traffic information on work zones (Bushman and Berthelot, 2004). This system consisted of a number of data collection trailers using non-intrusive traffic sensors to measure traffic flow (speed, volume, and occupancy). One of the key functions of the Smart Work Zone is to disseminate current traffic conditions to drivers so that they can make informed decisions related to the use of alternate routes. When delay time in the work zone was long and using the alternate route would offer a shorter travel time, PCMS displayed the delay time and the suggested alternate route. It was found that the system increased alternate route usage by 5 to 15 percent of mainline traffic. The safety impact of the Smart Work Zone was not quantitatively evaluated due to the limited number of crash occurrences and the variability of time between crashes (Bushman and Berthelot, 2004).

In October 2006, the Texas DOT implemented an ITS system in a work zone on I-35, south of Waco, in Hillsboro County to provide drivers with real-time information on downstream conditions and to provide alternate route guidance during the time periods with heavy mainline congestion (Luttrell et al., 2008). The system included six portable side-fire microwave vehicle detection trailers, six PCMS, three portable video (camera) trailers, a system server, and a web site. When detected traffic speed was below 10 mph and lane occupancy was greater than 50 percent, PCMS displayed “WorkZone Traffic Stopped; Use Alt Route.” The evaluation results indicated that the system diverted an average of 10 percent of mainline traffic to alternate routes during high construction periods or major incidents combined with high demand.

In 2006, the District of Columbia DOT deployed an ITS system on Highway 295 in Washington, DC. A function of this system was to warn motorists of slowed traffic ahead and encourage diversion when significant delays occurred. The results showed 3 to 90 percent lower observed mainline volumes (with an average of 52 percent reduction) were achieved, compared with similar days of the week, by warning motorist prior to entering the mainline (Luttrell, 2008).

2.1.7 Overheight/Overwidth Warning System

When work zones require construction work that decreases clearance heights of bridges, tunnels or overpasses, or significantly reduces lane width, overwidth/overheight loads pose mobility and safety issues, such as hitting portable temporary traffic signals and getting wedged under a bridge structure. Overwidth/overheight warning systems are used to warn drivers of vehicles that are too tall or wide and direct them to use an alternate or escape route. In addition to providing driver alerts, the system can provide warnings to highway workers of approaching oversized vehicles. The implementation of such systems will help prevent damage to roadway structures and work zone devices.

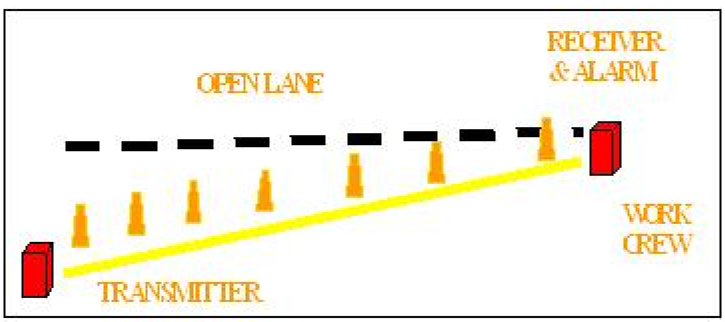
A study by Mattingly (2003) showed that more than ten state DOTs have used overheight warning systems at interchanges, tunnels, and bridges to warn and direct overheight vehicles. It was also found that most states (73 percent) using overheight warning systems believed their systems reduce overheight impacts. To date, however, limited literature, if any, exists that is related to the evaluation of overheight/overwidth warning systems in work zones.

2.1.8 Work Intrusion Warning System

A work intrusion warning system alerts workers and drivers of vehicles that inadvertently fail to follow standard flagging operations or follow a construction truck into a construction zone or work space (MnDOT, 2008). The systems use vehicle sensors to detect errant vehicles entering the closed lane. When an intruding vehicle is identified, PCMS are activated to display “Stop Now,” and sirens and horns will sound in the construction area. The detection may also include radio control devices operated by truck drivers so that they can activate the alarms once they identify intruding vehicles. The system should provide sufficient time for the drivers of intruding vehicles to react appropriately (e.g., using an escape route) (MnDOT, 2008).

The system detects intruding vehicles and warns workers of the danger before the vehicle is seen. This will allow on-foot workers to focus on their work, especially at night when drowsy and impaired drivers are more likely to intrude into a work zone (ATSSA, 2008).

The following figure shows a bird’s eye view of a work zone and a Safety Line™ work zone alarm system. The system consists of a transmitter, a receiver, and an alarm unit. The transmitter is placed at the bottom left of the lower lane, inside of the channelizing devices. The receiver and alarm unit are placed on the right side of the lane dividers, close to the workers. The transmitter projects a dual infrared beam to the receiver. Should a vehicle intrude into the buffer area, the dual transmitted beams would be obstructed thus causing the receiver to activate the alarm and alert the workers (Kocheva, 2008).



(Source: Kochevar, 2008)

Figure 5 Layout of Safety Line™ SL-D12 Work Zone Alarm System

2.1.9 Trucks Merging/Crossing/Exiting Traffic Warning System

This system is used to alert motorists of a slowly accelerating (haul) truck entering, crossing, or exiting the faster moving traffic lane (MnDOT, 2008). The purpose of this system is to reduce primary and secondary crashes involving (haul) trucks. Non-intrusion vehicle detectors are placed along the roadway (or haul road in the case of a truck crossing) as needed for proper system operations. The system may also include radio control devices operated by the truck drivers to activate the warning information. The system may be considered for use under the following conditions (MnDOT, 2008).

- Truck Merging Traffic Warning: 1) when the trucks must utilize the mainline roadway to accelerate; 2) when a truck merge lane can not be provided on the project; 3) when the haul road entrance is visibly obscured to drivers; or 4) when the Average Daily Traffic (ADT) on the roadway is above the level where truck drivers can easily find a gap in traffic and accelerate within the traffic lane without causing traffic to suddenly adjust speed or change lanes.
- Truck Crossing Traffic Warning: when the ADT on the roadway is above the level where truck drivers can easily recognize a gap in traffic and cross safely without causing conflicts with traffic.
- Truck Exiting Traffic Warning: 1) when the trucks must utilize the mainline roadway to decelerate; or 2) the roadway volume is above the level where the traffic must suddenly adjust speed or change lanes.

2.1.10 Hazardous Roadway Warning System

Slippery or rough pavement, flash flooding, limited visibility (caused by fog or smoke), and other hazards on a roadway can cause hazardous driving conditions for traffic in work zones. A hazardous roadway warning system alerts motorists of a hazardous condition on the roadway ahead and advises the drivers of an appropriate action (e.g., stopping, slowing, or diverting) for the situation.

Limited literature exists on the evaluation of hazardous roadway warning systems. A Wet Pavement Detection System (WPDS) was deployed on a 3/4-mile temporary traffic detour around an I-85 bridge construction project in Mecklenburg County, NC (Lowry, 2004). There were large sections of standing water on the roadway during heavy rains when the detour was opened. A before–after study was conducted to evaluate the performance of this system, with 270 days in the before period and 217 days in the after period. It was found that the system reduced the yearly wet crash rate by 39 percent, reduced the yearly injury crash rate by 35 percent, and reduced the average daily crash rate by 58 percent on days defined as having heavy precipitation.

2.1.11 Low-Tech Work Zone Systems/Devices

Low-tech work zone systems/devices are those that do not require vehicle detection, and the information conveyed through these systems/devices are not dynamic to the traffic. Examples of these devices/systems are PCMS, HAR, portable traffic signal systems, and Automated Flagger Assistance Device (AFAD), as shown in Figure 6. These systems/devices are often a component of other work zone ITS systems.

2.1.11.1 PCMS and HAR

PCMS can be used independently to disseminate general work-zone-related warnings to drivers so that drivers could have better trip information and be more prepared for unexpected work zone conditions. HAR are usually combined with static signs or PCMS to disseminate traveler information. The associated static sign or PCMS should inform drivers of the frequency to tune the radio. HAR have been widely used as they can disseminate more information than either static signs or PCMS. Nowadays, some portable trailers combine PCMS and HAR together so that these two devices can be used for system deployment.

(Source: Eidswick et al., 2009; WSDOT, 2009)

Figure 6 Examples of Low-Tech Work Zone Devices/Systems.
(Upper Left: PCMS, Upper Right: HAR; Lower Left: AFAD; Lower Right: Portable Signal.)

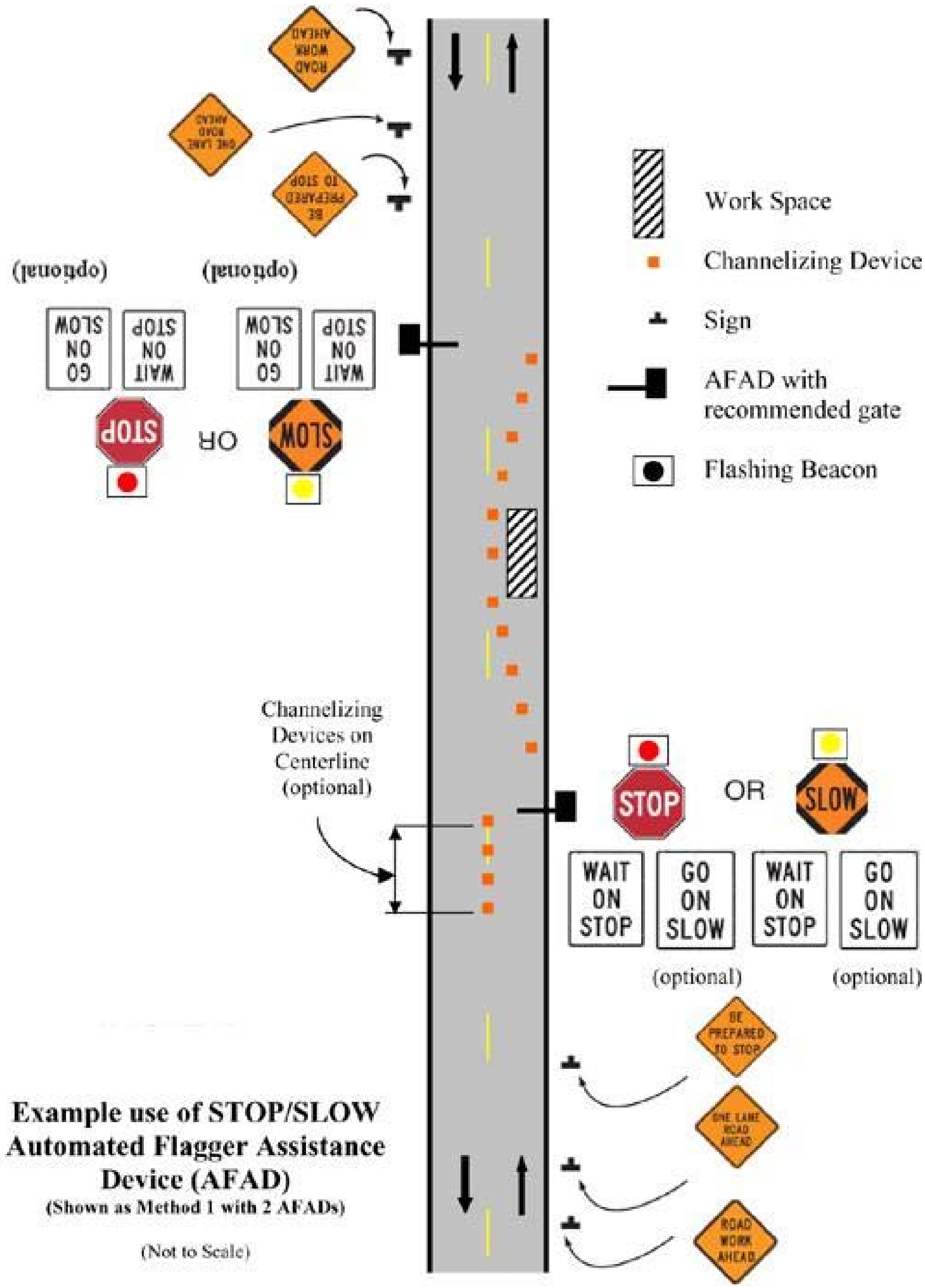
2.1.11.2 AFAD

On January 28, 2005, the FHWA announced the revised Interim Approval for the use of AFADs in temporary highway work zones. AFADs are portable traffic control systems that assist a flagger operation for short-term lane closures on two-lane highways. The AFADs are used to remove one or both flaggers, in a typical flagging operation, from the traveled way in Temporary Traffic Control (TTC) zones. A flagger can operate an AFAD by using a radio control unit or by using a cable directly attached to the AFAD. In either case, the flagger can be positioned well away from the roadway and moving traffic. The primary benefit is to enhance the safety of flaggers while maintaining positive control of traffic approaching the TTC zone (FHWA, 2005b).

AFADs include two types of devices: STOP/SLOW AFAD and RED/YELLOW Lens AFAD. Figure 7 shows an example of a STOP/SLOW AFAD (FHWA, 2003a). This figure illustrates the placement of two STOP/SLOW AFADs, channelizing devices, and signs to guide traffic around a work zone. MnDOT has used AFADs since 1996 and concluded that the device provides a useful tool that, when used correctly, can enhance the safety of flaggers in work zones on two-lane highways (MnDOT, 2005).

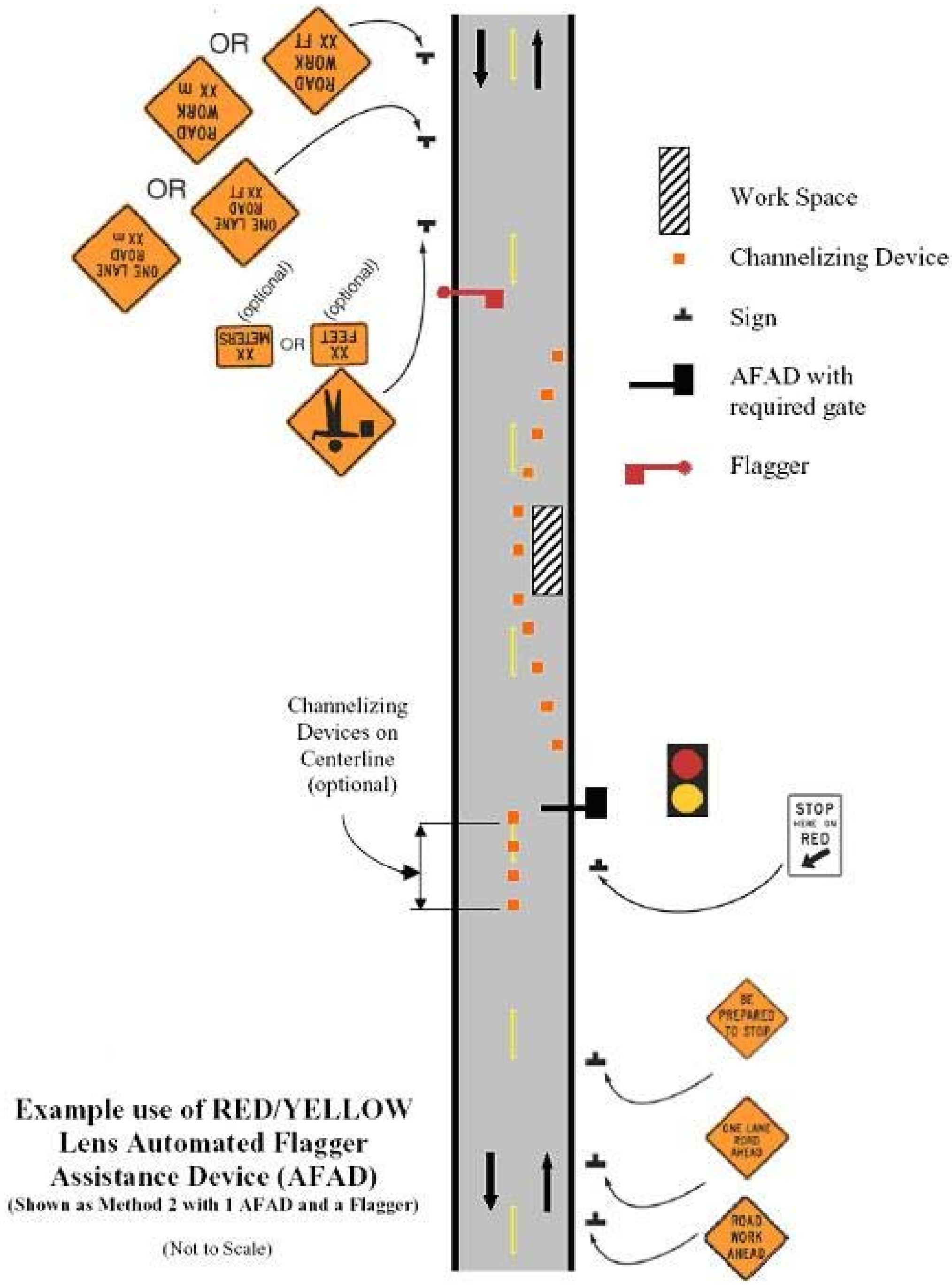
Figure 8 shows an example of a RED/YELLOW Lens AFAD (FHWA, 2003a). Experiments were conducted in several states (Ohio, Missouri, Wisconsin and Alaska) to test the devices. No crashes were recorded during those experiments. The Ohio study found that using such devices can be a cost-effective way to provide for a one-lane closure; the Missouri study showed a benefit/cost ratio ranging from 1.15–2.25 (FHWA, 2003a).

AFADs may be considered for use when all of the following conditions exist: 1) one lane of traffic is closed on two-lane, two-way roadways; 2) ADT is less than 1,500 vehicles per day; 3) distance of lane closure is 800 feet or less; and 4) the operator has an unobstructed view of the AFAD and approaching traffic in both directions. AFADs have also been used in several other states such as Kansas, Washington, and Virginia (WSDOT, 2009; Cottrell, 2006).



(Source: FHWA, 2003a)

Figure 7 Example Use of Stop/Slow AFAD



(Source: FHWA, 2003a)

Figure 8 Example Use of RED/YELLOW Lens AFAD

2.1.12 Other ITS Systems

As mentioned above, work zone ITS systems are often deployed to serve a combination of purposes. A work zone ITS system may use different technologies as described in the previous subsections. Table 5 shows site characteristics of some work zone ITS applications that served multiple purposes (FHWA, 2002b).

Table 5 Site Characteristics of Work Zone ITS Applications

Site Characteristic	Illinois	Michigan	New Mexico	Arkansas
Location	I-55, Springfield	I-496, Lansing	I-40/I-25, Albuquerque	I-40, West Memphis
Primary Purpose	• Traffic monitoring and management • Traveler info.	• Traffic monitoring and management • Traveler info.	• Incident Management • Traffic monitoring and management	• Traffic monitoring and management • Traveler info.
Real-Time Info. on the Internet	Yes (map of congestion levels)	Yes (camera images and map of travel speeds)	Yes (camera images)	No
Real-Time Info. on CMS	Yes	Yes	For major incidents (manually activated)	Yes
Staffed Traffic Mgt. Center	No	Yes (5:00 am to 7:00 pm)	Yes (5:00 am to 8:00 pm)	No
Temporary or Permanent Deployment	Temporary	Temporary	Parts of system permanent	Temporary
Lease or Purchase	Lease	Lease/Purchase	Purchase	Lease

(Source: FHWA, 2002b)

Table 6 summarizes some recent best practices that used work zone ITS technologies to achieve multiple system objectives (Luttrell et al., 2008). These best practices generally found that work zone ITS systems were effective in reducing traffic queues, diverting mainline traffic to alternate routes, and improving traffic safety.

Table 6 Recent Best Practices

	Study Location	System Objectives	Key Findings
Washington, DC	DC-295 (7 miles)	• Reduce work-zone-related congestion • Provide delay and speed information • Provide info. to commuters via Internet	• Traffic queues much shorter where speeds dropped below 30 mph • Traffic volume significantly decreased when the system posted delay information: 3% to 90% lower observed mainline volumes)
Texas	I-35 in Waco	• Provide real-time information on downstream conditions • Provide alternate route guidance	• 1% to 28% reduction in mainline traffic volume (with an average of 10%)
Arkansas	I-30 Little Rock to Benton	• Improve the safety of travelers by providing warning of slowed traffic or congested downstream conditions	Survey results: • Reduced drivers' exposure to hazard • Enhanced safety performance of the highway • Improved traveler tolerance of work zone delays
North Carolina	I-40 in Winston Salem	• Reduce demand and congestion • Provide delay information • Provide pre-trip information via Internet	(Schedule and data issues hindered assessment of the system.)

2.2 Common Issues and Lessons Learned

A variety of issues and lessons have been learned from existing practices, case studies, and cross-cutting studies. There are site-specific lessons from each work zone ITS deployment. For instance, the travel time system using a light source to assist in reading license plates required public utility access for power, which was found challenging as the system was deployed in a remote mountainous location (FHWA, 2004c). Therefore, camera locations were limited by the availability of power.

While there are site-specific issues and lessons learned, this section intends to summarize those commonly identified issues and associated lessons learned, based on four cross-cutting studies and five best practices (FHWA 2002b; Luttrell, 2008). The common issues can be classified into institutional issues, systems engineering issues, and public issues. The lessons learned from these three issues are summarized in the following figure. The lessons learned from existing studies could be valuable for future work zone ITS implementation.

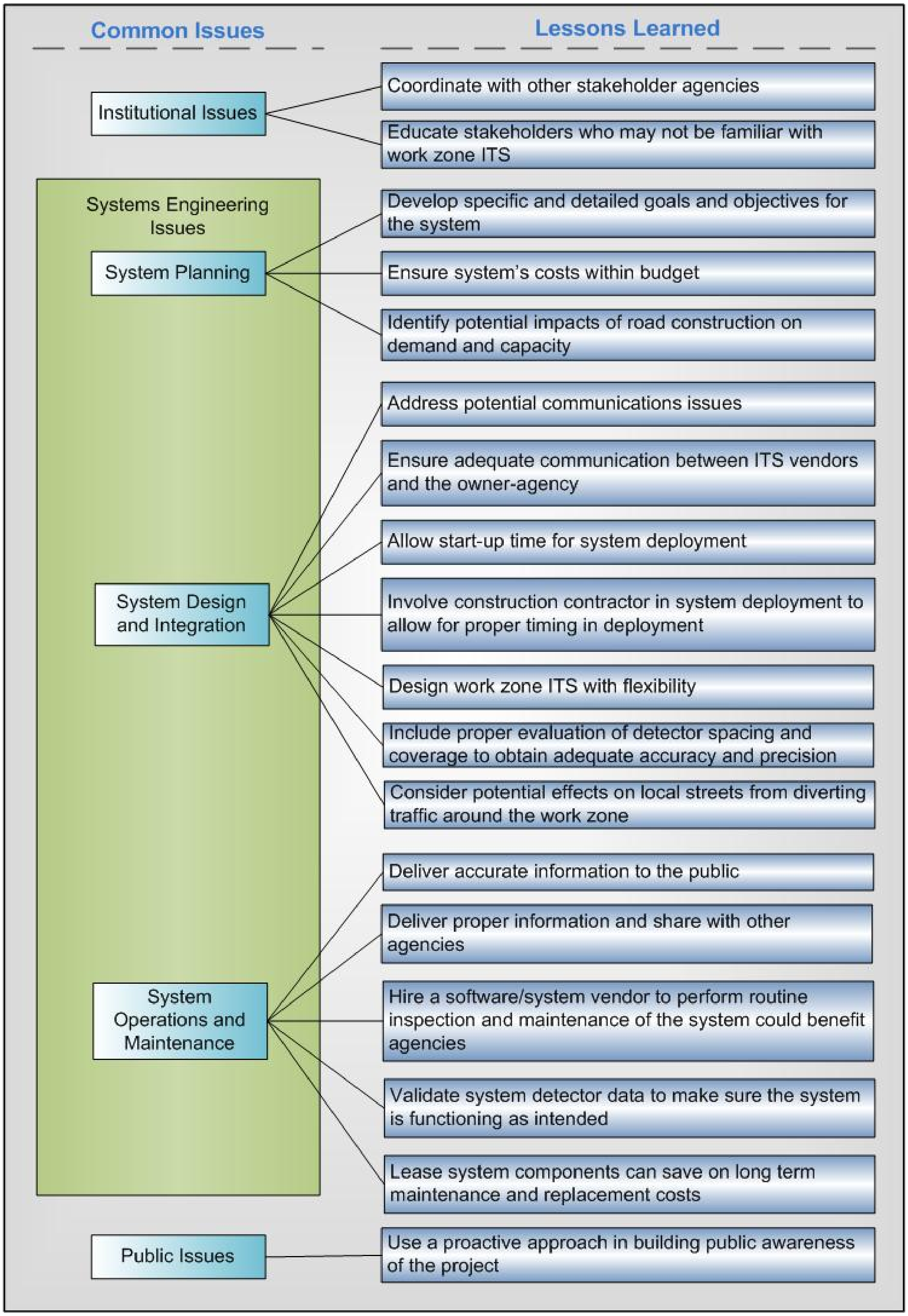


Figure 9 Summary of Common Issues and Lessons Learned

2.3 Summary

This technical memorandum has described the use of ITS technologies in work zones. The results from existing studies have collectively showed that ITS systems are useful for improving mobility and safety in work zones.

The synthesis of the bulk of studies will help interested agencies identify available work zone ITS systems, conditions for use, benefits, and lessons learned. Also, this memorandum will serve a fundamental role in identifying potential ITS technologies that can be applied to work zones on Federal lands.

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