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Criteria for Portable ATIS in Work Zones

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Abstract

The purpose of the study was to determine the best practice for the temporary deployment of advanced traveler information systems (ATIS) in highway work zones. ATISs can be as complex as devices that provide real-time information about delays or alternate routes or as simple as devices that activate radar detectors within vehicles. This study comprehensively compares and contrasts 16 different devices in 27 separate deployments throughout the United States. Particular attention is paid to system configuration, message content, media, information processing, and real-time data collection methods. Systems are compared for their effectiveness for warning drivers, promoting smother traffic flow, improving safety, calming traffic, and reducing delay. The study recommends an 11 step procedure whereby traffic engineers can choose the most appropriate ATIS configuration for any given work zone.

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1. Introduction

There have been several recent applications of real-time Advanced Traveler Information Systems (ATIS) specifically within work zones in order to improve both mobility and safety. Examples of real-time ATIS devices are variable message signs, highway advisory radio, CB citizen band broadcasts, and speed advisory displays. Many of these applications have been experimental, and there does not yet exist a consensus as to when, how and where the devices should be deployed.

A work zone is a segment of a highway with construction, maintenance, or utility work activities and is typically marked by signs, channelization devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign or high-intensity rotating, flashing, oscillating, or strobe lights on a vehicle to the END ROAD WORK sign or the last temporary traffic control (TTC) device[1].

A work zone may cause deviations from the normal range of transportation system safety and mobility, referred to as work zone impacts[2] by FHWA. Work zones pose an impedance to traffic flow and reduce the predictability of driving conditions. Thus, work zones tend to increase delays and crashes, involving significant monetary and human costs. The FHWA work zone safety and mobility policy requires all states to implement a policy for work zone impact management. ATIS devices have the potential to mitigate negative impacts of work zones and would likely be important elements in work zone traffic management plans.

Drivers' lack of compliance with speed restrictions has often been cited as one of the major contributing factors to work zone crashes. Coupled with unpredictability in the work zone, non-compliance compounds the likelihood of severe consequences. ATIS devices which help calm traffic within work zones can have major benefits.

It has been well established that Intelligent Transportation Systems (ITS) within urban freeway systems have helped reduce congestion. Given recent advances in wireless technology, new systems have been developed using the similar ITS devices for implementation on highway work zones[3]. The basic objective of employing an ATIS in work zones is to control traffic to improve the safety and efficiency of traffic operations and highway work[4]. ATISs can provide travelers with real-time information on changes in traffic patterns, nighttime closures and travel route availability, and they can even warn drivers about their own speeds, if excessive. A variety of ATISs are commercially available for implementation in work zones. The systems utilize different equipment and methodologies and serve different objectives. This report pulls together many reviews of these products.

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[1] Federal Highway Administration, "Manual on Uniform Traffic Control Devices", Part 6,: "Temporary Traffic Control", Chapter 6c, Section 6C.02 "Temporary Traffic Control Zones", 2003.

[2] Federal Highway Administration, 23 CFR Part 630 [FHWA Docket No. FHWA-2001-11130.

[3] Meyer, Eric, "Construction Area Late Merge System—KS", Midwest Smart Work Zone Deployment Initiative, Retrieved on August 22, 2005 from http://www.ctre.iastate.edu/smartwz/reports/MwSWZDI-2004-Meyer-CALM_System.pdf.

[4] Pant. P., "Smart Work Zone Systems. Workshops, Work Zones Information". Retrieved April 11, 2005 from http://www.ops.fhwa.dot.gov/wz/workshops/accessible/Pant_paper.htm.

A Portable Smart Work Zone System

A "Smart work zone" system or "work zone ITS" refers to use of technology to support effective work zone management and operations. Smart work zones that are outside areas with permanent ITS implementations must use portable equipment. Such equipment involves the integration of computers, communications, and sensor technologies. Its various components include input devices (such as traffic detectors), information processing devices (such as personal computers running control software), and output devices (such portable message signs)[5]. A smart work zone should be portable, automated, reliable, have the ability to analyze traffic flow in real-time, and provide updated information to drivers[6].

National Guidelines and Standards

Manual on Uniform Traffic Control Devices (MUTCD)

Chapter 6 of the Manual on Uniform Traffic Control Devices (2003), "Temporary Traffic Control" is largely dedicated to work zones. It mentions user safety, worker and responder safety, and the efficiency of road user flow as the integral elements of temporary traffic control (TTC). Chapter 6A states that TTC zones present constantly changing conditions to the road user, creating a high degree of vulnerability for the workers and incident management responders. Chapter 6B mentions that unexpected situations faced by the road users in the work zones can be compensated by TTC. It also states that "adequate warning, delineation, and channelization should be provided to assist in guiding road users in advance of and through the TTC zone" as a principle to guide drivers. MUTCD mentions that most TTC zones can be divided into four parts (Section 6C.03): the advance warning area, the transition area, the activity area, and the termination area. The different parts of the TTC will be discussed in detail in a later section in this report. Chapter 6F is devoted to "Temporary Traffic Control Zone Devices" and talks about design and application of these devices. Chapter 2A talks about functions and purpose of signs and also discusses the usage of Changeable Message Signs (section 2A.07).

Chapter 6F.55 covers portable changeable message signs (PCMS) and states "the primary purpose of portable changeable message signs in TTC zones is to advise the road user of unexpected situations." "Portable changeable message signs have a wide variety of applications in TTC zones including: roadway, lane, or ramp closures, crash or emergency incident management, width restriction information, speed control or reductions, advisories on work scheduling, road user management and diversion, warning of adverse conditions or special events, and other operational control."

Some of the situations in which PCMS can be used are (6F.55):

- Where the speed of vehicular traffic is expected to drop substantially;
- Where significant queuing and delays are expected;
- Where adverse environmental conditions are present;
- Where there are changes in alignment or surface conditions;

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[5] Scriba, T., "ITS and Work Zones", ARTBA Work Zone Conference, Workshop C: New Technologies for Smart Work Zones, November 2004, Retrieved on April 11, 2005 from http://wzsafety.tamu.edu/outreach/2004_wz_conference_presentations/its.pdf.

[6] Pant. Prahlad D., "Smart Work Zone Systems. Workshops, Work Zones Information. Retrieved on August 22, 2005 from http://ops.fhwa.dot.gov/wz/workshops/accessible/Prahlad_ppt.htm.

- Where advance notice of ramp, lane, or roadway closures is needed;
- Where crash or incident management is needed; and/or
- Where changes in the road user patterns occur.

The chapter also delineates standards and guidelines for PCMS deployment. These guidelines and standards will be discussed in detail in later sections in this report.

MUTCD promotes usage of PCMS in coordination with other technologies for information dissemination. "Support: Changeable message signs, with more sophisticated technologies, are gaining widespread use to inform road users of variable situations, particularly along congested traffic corridors. Highway and transportation organizations are encouraged to develop and experiment with changeable message signs and to carefully evaluate such installations so that experience is gained toward adoption of future standards."

MUTCD does not talk about smart work zones nor does it provide information about devices other than a PCMS that could be used for providing real-time information to drivers. The MUTCD does not give warrants for any ATIS devices within work zones. Incorporation of specifications for deployment of such systems would help planners and engineers determine appropriate locations for these devices.

Regulation on Work Zone Safety and Mobility

In September 2004, the Federal Highway Administration (FHWA) issued a regulation (23 CFR Part 630) pertaining to planning work zone safety and mobility, to become effective in October 2007. The regulations will require state DOTs to develop transportation management plans for highway projects with significant traffic impacts. Interstate highway projects lasting more than three days in transportation management areas (usually urban areas with population greater than 200,000) are categorically included; other projects may be included at the discretion of the state DOT and the FHWA.

The transportation management plans (TMP) should incorporate transportation operations (TO) and public information (PI) components. The regulation requires that "TO component shall include the identification of strategies that will be used to mitigate impacts of the work zone on the operation and management of the transportation system within the work zone impact area". Work zone traffic management has been listed as one of the TO strategies. The PI component is required to include communication strategies to inform affected road users of the expected work zone impacts. The regulation mentions that "this may include traveler information strategies".

The regulation recognizes that "work zones directly impact the safety and mobility of road users and highway workers" and that "these safety and mobility impacts are exacerbated by an aging highway infrastructure and growing congestion in many locations." It also mentions "each state shall work in partnership with the FHWA in the implementation of its policies and procedures to improve work zone safety and mobility. (Part 630.1014)"

Generic Goal and Objectives of ATISs in Work Zones

Generic Goal for ATIS in Work Zones

Wireless technology has allowed familiar ITS strategies to become portable and to be implemented with a wide variety of highway work zones[7]. The basic goals of employing an ATIS in work zones are straightforward.

- Control traffic to improve the safety of traffic operations and highway work.
- Control traffic to improve the efficiency of traffic operations and highway work[8].

The safety issue is dominated by the concern over excessive speeds in the work zones. Sudden slowing of vehicles are also causes of crashes. ATIS could well be used to warn speeding drivers and inform all other drivers about the slower speeds ahead in the work zones. ATIS can also be used to divert traffic to alternate routes, promote lane merging, and provide information about the delays.

Introduction to Generic Objectives

Objectives typically define the specific, often measurable, level of performance that would be required to progress toward a given goal. Defining objectives helps in setting up criteria that could be used to evaluate applicability of different systems. Well defined objectives also help identify the opportunities for system improvement after the system is installed and provide specific results to be attained. Four groups of objectives pertain to ATIS deployment in work zones: information dissemination; safety; mobility; and response by drivers.

This section lists several "generic" objectives that might be adopted when doing work zone planning. The generic objectives are a starting point. A planner may chose or reject or modify any of these objectives to meet local needs. Generic objectives are typically phrased so plans try to maximize, minimize or achieve a particular product. The list of generic objects contains redundancies, so it is appropriate to combine or eliminate some.

Information Dissemination

One of the most important goals of smart work zones is enabling the drivers to make informed choices. Effective information dissemination is equally important as accurate and reliable information.

- Maximize accurate and up-to-date information for drivers on the highway
- Maximize accurate and up-to-date information for trip planning
- Maximize accurate and up-to-date information for transportation monitoring agencies
- Maximize accurate and up-to-date information for incident management agencies

For each of the above, provide specific information about these items.

- Delays
- Causes of delay
- Driving conditions
- Potential hazards
- Location
- Available detours and alternate routes
- Speed violations
- Lane closures

[7] Meyer E., "Construction Area Late Merge (CALM) System".

Work Zone Safety

Work zone 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[9].

- Minimize number of crashes in the work zone
- Minimize severity of crashes in the work zone
- Minimize speed of vehicles in the work zone
- Minimize speed differentials upstream of the work zone
- Minimize the surprise element in the work zone
- Minimize sudden braking
- Maximize safety of the drivers
- Maximize safety of the workers
- Maximize driver alertness
- Maximize predictability of driving conditions

Work Zone Mobility

With reference to work zone, mobility pertains to moving road users efficiently through or around a work zone area with a minimum delay compared to baseline travel when no work is present.

- Achieve efficient flow of traffic
- Minimize congestion in the work zone
- Minimize traffic demand at the approach to the work zone
- Maximize diversion of traffic to alternate routes
- Maximize the capacity of the work zone by allowing late merging

Response by Drivers

It is helpful to recognize within the objectives that favorable responses by drivers are necessary to meet goals for the work zone.

- Minimize the level of frustration of the driver by providing information
- Achieve a reasonable time to respond to the message conveyed and take necessary action
- Maximize informed decision making

These generic objectives pertain to portable ATIS devices, but achieving the objectives requires a multifaceted strategy.

System Setup

A work zone can be divided into four parts[10]:

1. Advance Warning Area
2. Transition Area
3. Activity Area
4. Termination Area

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[9] Federal Highway Administration, 23 CFR Part 630 [FHWA Docket No. FHWA-2001-11130

[10] Zwahlen H., Russ A., "Evaluation of the Accuracy of a Real-Time Travel Time Prediction System in a Freeway Construction Work Zone",. Transportation Research Board 81st Annual Meeting, CD-ROM, 2002.

The layout of components of a portable ATIS relative to these work-zone areas is governed by the purpose the component is expected to serve. Scientex Corporation for its ADAPTIR system recommends placement of speed sensors at regular intervals from the advance warning area to the activity area for the collection of traffic data, Figure 1. One or more PCMSs must be placed upstream of the work zone to convey real-time traffic information to passing drivers.

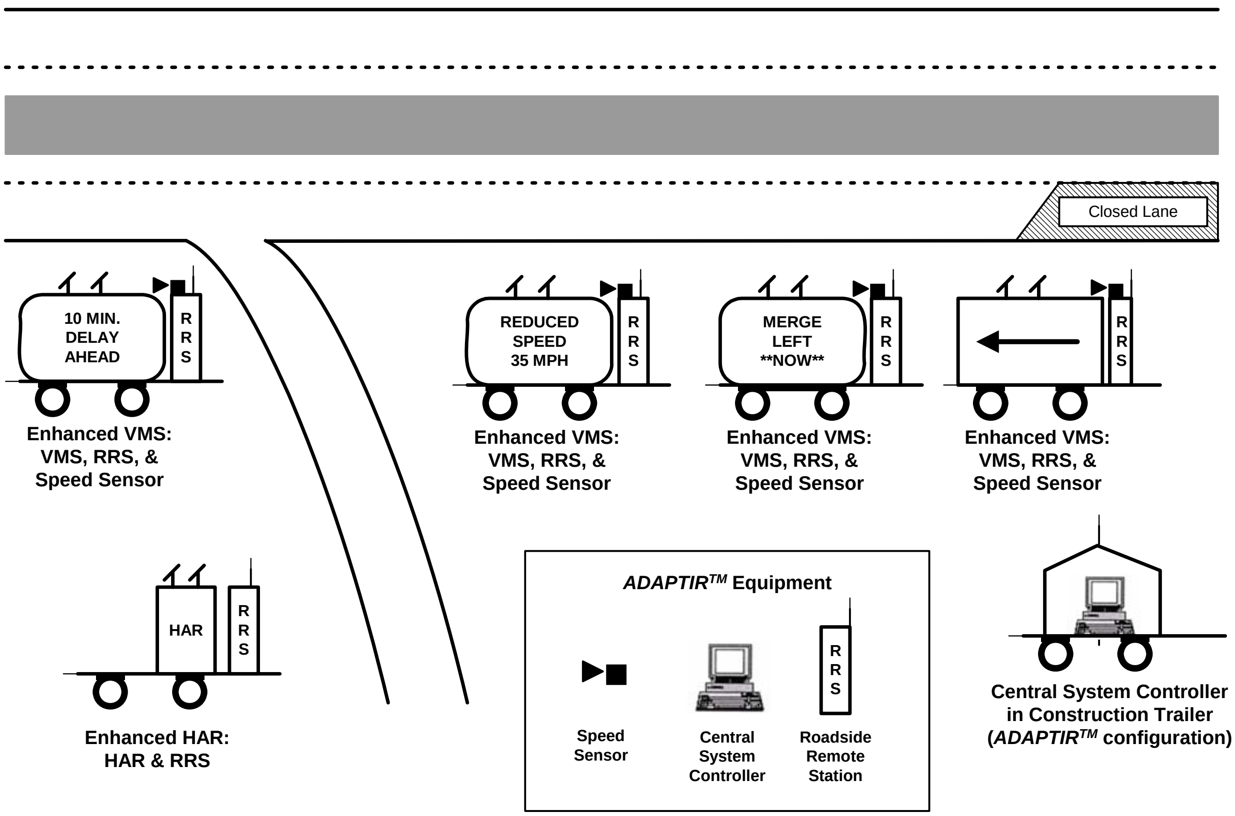

Figure 1. ADAPTIR Architecture
Source: ADAPTIR, Website of Scientix Corporation; Available online: http://pwaa002675.psiweb.com/10_pager.doc

The layout of PCMSs and sensors for the deployment of the CALM system in Kansas, and the TIPS system in Ohio and Wisconsin and the IntelliZone deployment in Missouri and Wisconsin all followed the same pattern as mentioned above.

Variations can be made, depending upon the technology. TIPS, because it needs to estimate total travel time through the work zone, required at least one detector well into the work zone to measure traffic flow conditions after the merge point. Since the CALM system guides the merging of vehicles, it has a slightly different configuration of signs. Some signs in the CALM system are placed in the transition zone.

Stand-alone speed monitoring systems can be placed at locations where the speed of the vehicles needs to be monitored usually in the advanced warning area just ahead of the transition area.

Messages

Different ATISs perform different tasks and therefore use different types of messaging devices to communicate with drivers. The particular message content conveyed also depends on the task of the ATIS, as well as the communication medium.

In the deployment of ADAPTIR in Nebraska, three types of messages were used, each having more than one phase: (1) speed advisory messages, (2) delay messages, and (3) diversion messages, as shown in Figure 2.

Speed Advisory Message	Phase 1	Phase 2
	I-80 (E)	REDUCED
	ADVISORY	SPD AHD
	XX:XX XM	XX MPH
Delay Message	**Phase 1**	**Phase 2**
	I-80 (E)	XX MIN
	ADVISORY	DELAY
	XX:XX XM	AHEAD
Diversion Message	**Phase 1**	**Phase 2**
	30 MIN	CONSIDER
	DELAY	ALT.
	AHEAD	ROUTE
The PCMS closest to the work zone just said:		
	RIGHT	
	LANE	
	CLOSED	

Figure 2. Complex PCMS Messages from ADAPTIR
Source: ADAPTIR, Nebraska. MwSWZDI

The same system when deployed in Arkansas had only the delay message in two phases, as shown in Figure 3.

Phase 1	Phase 2
REDUCE SPEED	YY MINUTE
TO XX MPH	DELAY

Figure 3. Simple PCMS Messages from ADAPTIR
Source: ADAPTIR, Arkansas. MwSWZDI

However, the Arkansas deployment also used Highway Advisory Radio (HAR) to disseminate a three-phase message, as shown in Figure 4.

Phase 1	Phase 2	Phase 3
Introductory message	Daily or weekly message	Message that fit the scenario in effect at the lane closure,
(General project information)	(Detailing the lane closures planned for that day or week)	(E.g., Currently there is a 15-minute delay through the work zone.)

Figure 4. HAR Messages from ADAPTIR
Source: ADAPTIR, Arkansas. MwSWZDI

The TIPS system in Ohio had one message in two phases, a shown in Figure 5.

Phase 1	Phase 2
XX MIN TO	WORKZONE
END OF	ENDS
WORKZONE	YY MILES

Figure 5. PCMS Messages from CHIPS
Source: TIPS, Ohio. MwSWZDI

The systems displaying vehicular speed simply indicate the approaching vehicle's speed and the speed limit, such as "Your Speed 37". In some cases such boards are mounted on moving vehicles such as maintenance crews and are used as "you-me" boards with the speed of the carrying vehicle as well as the oncoming vehicle being indicated on the board as indicated in Figure 6. Under most circumstance the "you" speed would be considerably higher than the "me" speed.

YOU	ME
XX	XX

Figure 6. Speed Display Message Format for You-Me Signs

ATIS Operation

Operations of all ATISs can be classified as having the three major components shown in Figure 7.

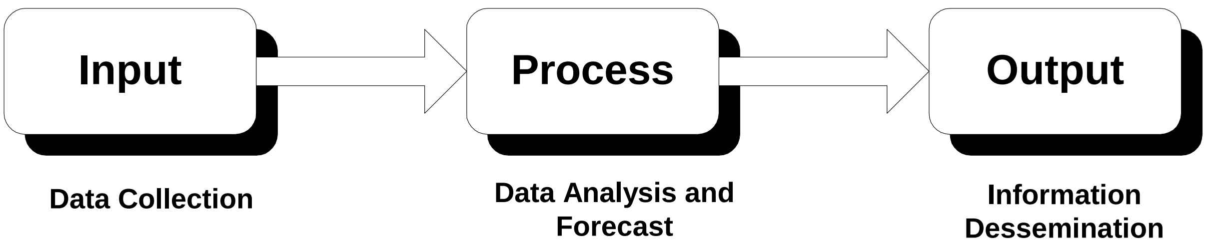

Figure 7. Fundamental Structure of Portable ATIS Devices

Input Devices

Advanced travel information systems require devices to collect real-time traffic data to be able to provide real-time information. A variety of devices are used as input devices for data collection including: microwave detectors, K-band radar and video detection systems. The input devices gather information about the traffic movement and in some cases about a particular driver. The data are then sent to a processing unit using wired or wireless communication.

Processing Units

The smartness of a smart work zone lies in the processing algorithms that analyze traffic data, produce estimates of delays and predict speeds, and send appropriate message to the output devices. Different manufacturers refer to processing units by different names. IntelliZone utilizes a mobile control unit (MCU) for processing, which is mounted on an easy to move trailer, positioned at the roadside. The MCU can be programmed with built-in logic to interpret the traffic data and automatically change the variable message signs upstream[11]. An on-site central system controller (CSC) runs software to control the ADAPTIR system. The two variants of ADAPTIR differ in the deployment of the CSC. In ADAPTIR/WZ, the CSC is located in a construction trailer at the work zone. The construction trailer provides a long-term source of electrical power, security from theft and vandalism, and a benign operating environment. In addition, construction trailers typically can supply a telephone connection enabling ADAPTIR to be monitored and controlled remotely. Furthermore, a telephone connection allows the system to alert off-site traffic operations personnel to trouble conditions (e.g., reduced traffic speeds and low equipment battery voltage). To minimize deployment time, the ADAPTIR/IM configuration

[11] Quixote Transportation Safety, "The Future Of Work Zone Safety Is The IntelliZone System", Retrieved April 12, 2005, http://www.quicktrans.com/intellizone.

relocates the CSC to an environmental and security enclosure mounted on the field equipment itself (typically an arrow panel). TIPS uses an onsite personal computer to run specific software for estimating travel times to be conveyed to variable message signs for display. Computerized Highway Information Processing System (CHIPS) is a software package developed by ASTI Transportation Systems for traffic management. CHIPS is hosted on a central systems controller located at a central location. It receives signals from the detectors, processes the data and sends signals to message signs[12].

Some systems only convey the detected speed and do not require a dedicated processing unit. Systems such as SpeedGuard, speed monitoring display, and safety warning system fall under this category.

Output Devices

Output devices are used to convey the desired message to the drivers. The messages could be *proactive* or *reactive*. Messages informing about the driving conditions ahead or an alternate route can be categorized as proactive messages. Messages such as those cautioning speeding vehicles to slow down can be categorized as reactive messages. Some of the most common output devices used in advanced traveler information systems are portable changeable message signs (PCMS), radio channels, in-vehicle radar detectors, and strobe flashes.

Portable Changeable Message Signs (PCMS)

A PCMS is a traffic control device that is capable of displaying a variety of messages to inform drivers. A PCMS displays messages through elements on the face of the sign that can be activated to form letters or symbols[13].

A PCMS can be used to alert and inform drivers during one of the following scenarios.

- Construction or maintenance
- Incident management
- Special event
- Notification of future construction or event
- Where the speed of vehicular traffic is expected to drop substantially
- Where significant queuing and delays are expected
- Where adverse environmental conditions are present
- Where there are changes in alignment or surface conditions
- Where advance notice of ramp, lane, or roadway closures is needed
- Where changes in the road user patterns occur

A PCMS can provide a unique message that alerts the driver and supports standard signing for these conditions.

- Speed reduction
- Advance notice of lane closures and shifts
- Diversion to a different route

[12] ASTI Transportation Systems, Inc, “CHIPS Overview”, 2002, Retrieved on April 12, 2005 from http://www.asti-trans.com/software.htm.

[13] Federal Highway Administration, “Portable Changeable Message Sign Handbook”, Turner Fairbank Highway Research Center, FHWA Report No. FHWA-RD-03-066, Retrieved August 22, 2005 from http://www.tfhrc.gov/pavement/ltpp/reports/03066/#intro.

- Advance notice of ramp closures
- Expected reopening of existing closed lane
- Roadway status for special events
- Crash or other incidents
- Changes in alignment or surface conditions

The standards for PCMS are given by the MUTCD.

- Each message shall consist of either one or two phases.
- A phase shall consist of up to three lines of eight characters per line.
- Each character module shall use at least a five wide and seven high pixel matrix.
- PCMS shall automatically adjust their brightness under varying light conditions, to maintain legibility.
- The control system shall include a display screen upon which messages can be reviewed before being displayed on the message sign.
- The control system shall be capable of maintaining memory when power is unavailable.
- PCMS shall be equipped with a power source and a battery back-up to provide continuous operation when failure of the primary power source occurs.
- The mounting of Portable Changeable Message signs on a trailer, a large truck, or a service patrol truck shall be such that the bottom of the message sign panel shall be a minimum of 2.1 m (7 ft) above the roadway in urban areas and 1.5 m (5 ft) above the roadway in rural areas when it is in the operating mode.
- The text of the messages shall not scroll or travel horizontally or vertically across the face of the sign.

Specific guidelines have been developed for selection of appropriate PCMS for particular tasks.[14]

- Establish the objectives of the use of the PCMS.
- Delineate the messages necessary to accomplish the objectives.
- Determine the legibility distance required to allow drivers to read and comprehend the messages.
- Determine the PCMS locations, which allow drivers ample distance to read, comprehend, and react to the messages.
- Identify type and extent of localized constraints that might affect the legibility of the PCMS.
- Identify the environmental conditions under which the PCMS will operate.
- Determine target value and legibility of candidate PCMSs.
- Determine costs of candidate PCMSs.
- Select the CMS that will allow the selected messages to be read under all environmental conditions within the cost constraints of the agency.

PCMS Message Design Process[15]

[14] Dudek, Conrad L., "Guidelines on the Use and Operation of Changeable Message Signs", Report No. FHWA/TX-92/1232-9, 1992. Referred by Garber. Nicholas J, Srinivasan Srivatsan, "Effectiveness of Changeable Message Signs in Controlling Vehicle Speeds in Work Zones", Phase II, 1998.

[15] "Portable Changeable Message Sign Handbook", Turner Fairbank Highway Research Center.

Message Selection. PCMS used on construction and maintenance projects should be treated as an integral part of the traffic control plan (TCP). Desired messages, locations, and general time periods of display should be listed for all known or anticipated PCMSs used during the project. Of course, additional opportunities to use the PCMS may come up during the life of the project, and the TCP should allow for these unanticipated messages. However, the governing agency should retain control over selection and display of the unanticipated messages.

Message Display. A PCMS message can use one, two, or, when absolutely necessary, three phases in which to relay its message. Below are message guidelines for the number of phases required to convey the message.

One-Phase PCMS:

Line 1—Describe problem.
Line 2—Identify location or distance ahead.
Line 3—Provide driver instruction.

Two-Phase PCMS:

Phase 1—Describe problem.
Phase 2—Provide driver instruction.

Three-Phase PCMS:

Phase 1—Describe problem.
Phase 2—Identify location or distance ahead.
Phase 3—Provide driver instruction.

Care must be given to ensure a short message length and to avoid repeating messages covered by static signing.

Default Message. A default message should be programmed into the PCMS in case the unit becomes disabled. Since the default message will act as a warning to field personnel that the PCMS has malfunctioned, a message should be chosen that will not alarm drivers and will not be used for any other purpose. Alternatively, to indicate that the PCMS is malfunctioning, a pattern such as solid bars may be used.

Changing a PCMS Message. It is desirable to have the PCMS display the most correct and appropriate information to the driver as possible. However, there are times when the PCMS will not have the desired message already stored as one of the standard messages in the database. In this case, the required message must be added to the database. The control system needs to include a display screen upon which messages can be reviewed before being displayed on the PCMS. It is recommended that an instruction manual be stored with the PCMS for in-field programming of the message.

Mobile HAR

Mobile Highway Advisory Radio (Mobile HAR) is a system of low-power radio transmitters licensed for state use[16]. It is essentially a radio transmitter that is mounted on a trailer, allowing it to be easily moved and set up for short time periods, with an accompanying sign instructing

[16] Wisconsin DOT, "HAR, Travel Information.", updated October 11, 2004. Retrieved from http://www.dot.wisconsin.gov/travel/smartways/har.htm.

drivers to tune their radios to the appropriate station for important information. HAR has been used by transportation agencies to disseminate information to the traveling public regarding work zones, detours, accidents, maintenance activities, local advisories, inclement weather, construction schedules and other information as authorized by the Federal Communications Commission (FCC) in its Rules and Regulations specified in 47 CFR §90.242.

CB Radio Channel

CB channel radio is available in a large number of trucks. Systems such as Wizard CB Alert System use CB radio channels to automatically broadcast alert messages. The radio channel is intended to alert the drivers about the work zone and help the traffic merge efficiently into one lane before the work zone starts, reduce the average speed and speed variance approaching the work zone.

Radar Detectors

Radar detectors are located inside the vehicles and are capable of detecting the presence of radar equipment located along roadside. Safety Warning System (SWS) and Drone Radar (DR) are two systems that are based on these devices. SWS requires a specialized SWS receiver to display the messages. However all K-band radar detectors sound an alarm on receiving signals from a SWS transmitter. Drone Radar works on a similar principle and triggers the radar detectors in the vehicles in case of speed violations.

Use of radar detectors in noncommercial vehicles is banned in Virginia and Washington D.C. Radar detector use in commercial vehicles has been prohibited in the U.S. since 1995[17] [18].

Speed Displays

Speed displays are similar to PCMS though much smaller in size and show only vehicle speeds. The Speed Monitoring Display[19] uses two 18-inch LED characters to display speed while the SpeedGuard System[20] uses 24-inch characters. Speed displays can also be mounted on moving vehicles such as maintenance vehicles. The speed of the maintenance vehicle can be measured using a link to the gearbox odometer while the speed of the oncoming vehicles can be measured using radar mounted on the display itself.

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[17] Code of Federal Regulations, Title 49, Volume 4[Revised as of October 1, 2001], CITE: 49CFR392.71, [Page 983-984]. As referred by Todd L. Sherman, Mobile Scanner & RADAR-Detector Laws In The U.S. (December 16, 2002). Retrieved on April 12, 2005 from http://www.afn.org/~afn09444/scanlaws/laws/radar/commercial.html.

[18] Beltronics USA. “Are radar detectors legal?”, 2004. Retrieved on April 12, 2005 from http://www.beltronics.com/detector-faq.html.

[19] As deployed in Iowa under the Midwest Smart Work Zone Development Initiative.

[20] As deployed in Nebraska the Midwest Smart Work Zone Development Initiative.

2. Work Zone ATISs

ADAPTIR

System Description[21]

ADAPTIR is a portable, automated, real-time, condition-responsive traffic control and congestion management system. It integrates conventional traffic management components such as variable message signs and arrow panels with speed sensors, roadside remote stations, wireless communications technology, and an on-site personal computer. ADAPTIR operates around-the-clock, in all weather conditions, and has low power requirements for virtually maintenance-free operation. Optionally, ADAPTIR can be integrated with highway advisory radio to provide up-to-the-minute diversion or alternate route information.

ADAPTIR has the following basic components:[22]

- One or more PCMSs deployed upstream of the work zone to display real-time traffic information to drivers;
- HAR to provide drivers with more detailed information than can be conveyed on the PCMSs;
- Central system controller (CSC), which is an off-the-shelf IBM-compatible personal computer, to run the control software;
- Radar sensors to continuously measure speeds at multiple locations upstream of the work zone; and
- Roadside remote stations (RRS) to receive data from the radar sensors and, under the control of the CSC, program the PCMSs and HAR to display and broadcast the appropriate messages.

Operation

ADAPTIR uses a central system controller (CSC) to perform operations using control software. Radar sensors are deployed to measure speeds at multiple locations upstream of the work zone. Roadside remote stations (RRS) receive data from the radar sensors and tell the PCMS to display appropriate messages. ADAPTIR also has the capability to broadcast the messages using HAR[23].

The system is deployed in or upstream of a work zone or congested area. It acquires speed data from multiple locations, analyzes the data to predict delay and identify hazardous conditions, and presents detailed, time-stamped advisory messages to drivers. The message library is customized to include speed, lane use, and alternate route information.[24]

Past Evaluations

Deployments in Nebraska and Arkansas have been critically evaluated.

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[21] Scientex Corporation, “ADAPTIR”,. Retrieved on April 12, 2005 from http://pwaa002675.psiweb.com/ad-main.htm.
[22] McCoy, Pat, “ADAPTIR”, Midwest Smart Work Zone Development Initiative, 2000, Retrieved on August 22, 2005 from http://www.ctre.iastate.edu/smartwz/reports/MwSWZDI-2000-McCoy-Adaptir.pdf.
[23] McCoy, Pat,. “ADAPTIR”.
[24] Scientex Corporation, “ADAPTIR”.

Nebraska

ADAPTIR was evaluated under the Midwest Smart Work Zone Development Initiative in Nebraska by Pat McCoy who was affiliated with the University of Nebraska, Lincoln.

Objective. The objective of the study was to evaluate the effect of the system on traffic and driver decisions.

Project Site. The project was conducted in a work zone on I-80 between Lincoln and Omaha in the vicinity of the Highway 63 interchange near Greenwood.[25] The work zone was an interstate reconstruction project involving closure of one roadway for reconstruction and head-to head operation on the other roadway. The AADT in 1998 for this section was 38,000 vehicles/day with 21% of the traffic being trucks. The speed limit in the work zone was reduced to 55 mph from the normal 75 mph.

System Setup. The system set up was similar to the explanation of system operation except that HAR was not employed in this study.

Messages. Three types of messages were displayed: speed advisory messages, delay messages, and diversion messages. The three PCMSs farthest upstream of the work zone were blank when traffic conditions did not warrant the display of speed advisory, delay, or diversion messages. The PCMS closest to the work zone displayed the lane closure message when none of the other messages were displayed. Messages are shown in Figure 8.

Speed Advisory Message	Phase 1	Phase 2
	I-80 (E)	REDUCED
	ADVISORY	SPD AHD
	XX:XX XM	XX MPH
Delay Message	**Phase 1**	**Phase 2**
	I-80 (E)	XX MIN
	ADVISORY	DELAY
	XX:XX XM	AHEAD
Diversion Message	**Phase 1**	**Phase 2**
	30 MIN	CONSIDER
	DELAY	ALT.
	AHEAD	ROUTE

[25] McCoy, Pat, "ADAPTIR".

The message displayed by PCMS closest to the work zone while other PCMSs did not display any message		
	RIGHT	
	LANE	
	CLOSED	

Figure 8. PCMS Messages.
Source: ADAPTIR, Nebraska, MwSWZDI

Logic. The logic used by the CSC for displaying messages is shown in Figure 9.

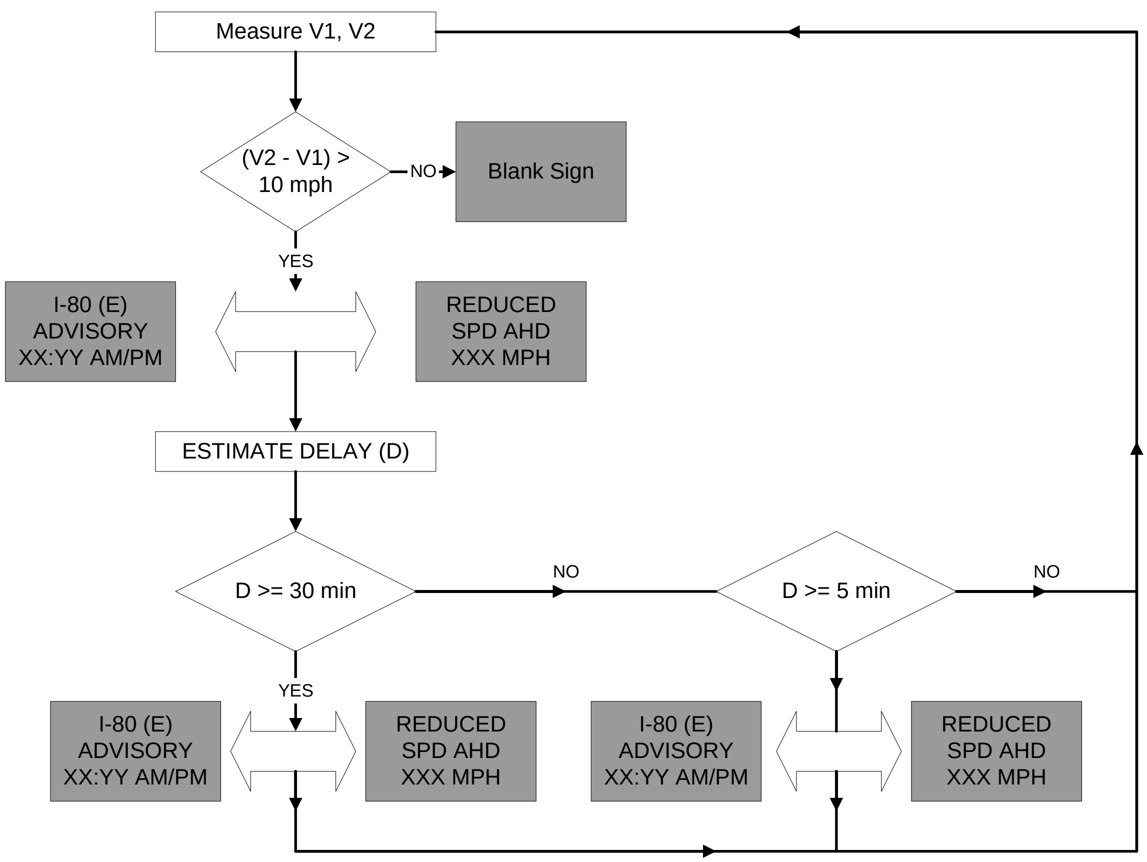

Figure 9. PCMS Messages. ADAPTIR, Nebraska, MwSWZDI
Source: ADAPTIR, Nebraska, MwSWZDI

Data Collection. Five types of data collection were conducted to evaluate the effectiveness of ADAPTIR.

- Traffic speed and lane distribution in advance of the lane closure taper
- Number of forced merges in advance of the lane closure taper
- Driver compliance with the advisory speed messages

- Mainline and ramp volumes at the diversion point
- Driver survey

The data for speed, lane distribution, forced merges, and driver compliance were collected using video cameras. The diversion point volumes were measured using portable, recording traffic counter/classifier units.

Data Analysis. The videotapes recorded during before and after studies were analyzed using the Autoscope video processing system for speed and lane distribution to identify the periods of congested flow. The following speed parameters were compared: mean speed, standard deviation, 85th percentile speed, 10 mph pace, percentage of speeds within the pace, percentage complying with the speed limit, and mean of highest 15 percent of speeds. Rate of forced merges was computed for before and after conditions. The statistical tests used to evaluate the difference in the before and after values were the t-test, covariance analysis, and the binomial test. There were no periods of congested flow during the before and after studies. The driver surveys were compiled to evaluate the visibility and legibility of the display.

Results. ADAPTIR did not seem to affect the vehicle speeds in advance of the lane closure taper. Also, it did not affect the lane distributions or forced merges in advance of the lane closure taper. This result was expected as the data were collected during periods of uncongested flow when the speed advisory messages were seldom displayed. ADAPTIR did not seem to affect the rate of forced merges in advance of the lane closure taper. The system had mixed results for vehicle diversion. Those speed advisory messages displayed during periods of uncongested flow were not effective in reducing speeds. It was apparent the spacing between the PCMSs influenced the effectiveness of the speed advisory messages. Further research is needed to determine the optimum spacing of the ADAPTIR PCMSs, which may vary with traffic and roadway conditions.

Only about 24 percent of those seeing a blank PCMS understood what it meant. The remaining drivers thought the PCMS was not working or simply didn't know what it meant. Further research would be needed to examine the trade-offs between leaving PCMSs blank when there is no real-time, condition-responsive message to display versus displaying a general message.

Arkansas

Objective. The project was aimed at development of a queue detection system that would prevent/reduce rear-end collisions and also provide real-time information to the drivers regarding potential backups caused by lanes closures.

Site Description. The installation occurred on Interstate 40 in Lonoke County, where about 6.3 miles of surface were being rehabilitated. Average daily traffic was 36,350 vehicles per day with 43% of the traffic being trucks. Lane closures were frequently relocated within this highway segment.

Cost. The equipment cost $750 per day for a period of 350 days plus $60,000 for the highway advisory radio system for a total cost of $322,500.

System Design. The ADAPTIR system deployed consisted of a central system controller and two highway advisory radios (HARs). It also included five traffic sensors (TS), five changeable message signs (CMSs), and two supplemental speed stations per lane closure.

The system displayed downstream traffic speed information followed by delay information. Forty different scenarios were preset for the delay information. The messages displayed were based on the speed differential between traffic sensors. If the speed differential was below 10 mph the CMS displayed the delay information. In case of speed differential exceeding the 10 mph threshold, a two phased message was displayed on the upstream variable message sign saying “REDUCE SPEED TO XX MPH”, followed by the message “YY MINUTE DELAY”. The central system controller was located in the construction contractor’s office and was programmed for a 600 second (10 minute) cycle time.

The messages broadcast on HAR composed of three separate phases. The first phase provided general project information. The second phase displayed a daily or weekly message with information about the lane closures planned for that day or week. The third phase carried a message in case of a lane closure.

Problems Encountered. The radar traffic microwave sensors (RTMS) were found difficult to calibrate on-site due to high percentage of trucks and frequent relocation of the lane closures. The RTMS units were replaced with Doppler radar units to resolve the issue.

The cycle length of 600 seconds was found to be too long for optimum accuracy in dynamic work zone conditions.

Delay estimations were not accurate enough for public approval as several complaints were filed even if the delay estimate was almost within five minutes of the actual delay. To address the issue, the delay messages were replaced with generic messages.

In some instances there were problems with the communication between the central system controller and the HARs via landline telephone. Pagers were not used as they did not function consistently in this rural site.

System Accuracy. The projected and actual travel times were compared to determine the system accuracy. The acceptable range of error was defined as less than or equal to five minutes. However, in all cases, the error was beyond the acceptable limits. The system overestimated as well as underestimated the delay. The difference in predicted and actual travel times ranged from 2 hours 11 minutes 10 seconds to 5 minutes 14 seconds.

IntelliZone

System Description[26]

The standard IntelliZone system consists of microwave sensor, a mobile control unit (MCU) and variable message signs. The variable message signs inform the drivers about the driving conditions ahead and are intended to prevent sudden braking. The IntelliZone system can be configured to address the specific requirements of each work zone. The standard system can be upgraded to include equipment such as weather stations, highway advisory radio (HAR), video cameras and other features. The IntelliZone system has been designed as a portable and flexible system to be able to adapt to requirements of different work zones.

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[26] Quixote Corporation, “Intellizone”, 2002, Retrieve on August 22, 2005 from http://www.quixtrans.com/intellizone.htm.

Operation

The microwave sensor measures traffic volume and speed non-intrusively. As vehicles pass through the work zone, this real-time data are transmitted to a the MCU mounted on an easy-to-move trailer, which is positioned at the roadside. The MCU can be programmed with built-in logic to interpret the traffic data and automatically change the variable message signs upstream[27].

Past Evaluations

Deployments in Missouri and Wisconsin were evaluated by the MwSWZDI.

Missouri

Objective. The objectives of the study were to evaluate the performance of the IntelliZone system with respect to its effect on the speed pattern, traffic conflicts and acceptance by the drivers.

System Setup. Three mobile count units (which can measure flow, speed, and density) were placed in each lane where queues could form due to the construction zone. Two variable message signs (PCMS units) were placed approximately two miles and five miles upstream from the detectors. One mobile command unit was placed between the detectors and the PCMS units.

Project Site. The study was conducted along I-70 northwest of St. Louis in the city of Wentzville. The work zone involved the reconstruction of the freeway interchange. This segment of freeway does not experience a severely congested morning or evening rush. The AADT for the count station closest to the work zone in the year 2000 was 48,901 vehicles per day. The arrangement of the work zone included concrete barriers directly next to travel lanes, creating a very narrow corridor.

Data. Three types of data were collected:

- Speed and headway data;
- Driver survey; and
- Conflict data.

Temporary traffic data recorders were placed on the roadway in order to collect the volume, average speed, and surface conditions. Data were grouped into intervals of fifteen minutes due to limited memory available in the detectors. The detectors were located at 7, 4.5, and 1.5 miles upstream from the work zone. Data were also collected using digital camcorders on tripods and portable video surveillance trailers. The speed, headway, and volume data were obtained using video processing unit from *Iteris* called Vantage Edge. Surveys were conducted to determine driver response. Conflict data were recorded on 7 separate days, 3 in the before condition and 4 in the after condition. Cameras were used in leapfrogging manner to keep up with the backward moving queue.

The data were tabulated for analysis. The conflict data, however, were not consistent and hence unsuitable for analysis. T-tests were conducted to determine if the average speeds were significantly different at a confidence level of 95%.

Results. The vehicles in the right lane did not slow down until 2 miles before the work zone probably because the work zone was not visible until that point. T*here was not a definite trend*

[27] Quixote Corporation, “Intellizone”.

between any of the locations for the left lane. Essentially, speeds remained the same for vehicles in the left lane, showing that there was little, if any, reaction to static VMS. Regarding headways in the uncongested after condition, there was no pattern in the right lane as headways remained about constant. In the left lane, however, there was a slight increase in time headway.

An interesting observation of the survey answers was that the percentage of drivers who could read the entire message was less than the percentage who could understand the entire message. Almost all drivers could understand the message, but 22.4% could not read the entire message. This could be due to vehicles in the right lane interfering with left lane vehicles or it could be due to the VMS display not changing fast enough to read the entire message. A large number of drivers (66.3%) said the signs caused them to slow down, while only 16.9% said they did not affect the driver's behavior.

Wisconsin

Objective. The objectives of the Wisconsin test of IntelliZone were to determine the relevance of information to drivers, the accuracy of the information and the potential of the signs to encourage diversion.[28]

System Setup. Three microwave detectors and three variable message signs (PCMSs) were deployed ahead of a work zone on the northbound lanes of US 41 in and near Green Bay. The detectors were capable of measuring speed, flow, and density. One detector was located just ahead of the taper. The two other detectors were located upstream about 1.5 and 3.5 miles ahead of the work zone. Because of lighter than expected traffic, data from the two detectors farthest upstream were not used at any time during the test period. Signs were placed about 1.5 mile, 3.5 miles and 7 miles upstream of the work zone. IntelliZone calculated a "decision speed" which was the volume-weighted average of speeds in the two lanes. Additionally, it was necessary to eliminate any display of messages when occupancies were very low, to avoid spurious messages when traffic was light. Signs had two phases. One phase said "ACTUAL SPEEDS AHEAD" and the second phase gave the speed in 10 mph ranges (e.g., 10 – 20 MPH) or said that traffic was stopped.

Project Site. US 41 is a four-lane freeway at this location. The work zone eliminated the rightmost of the two northbound lanes. The work zone was also slightly downstream of an on-ramp from STH 172, which merges into the right lane of US 41. Data were taken on two Friday afternoons (one just ahead of Memorial Day) and on Thursday, July 3 in order to capture a large number of vacation travelers passing through the work zone. Queuing was moderate during times of data collection. Many drivers could opt to take alternate routes to bypass the work zone. In particular, many long distance drivers could take I-43 from Milwaukee or points further south.

Data. Data principally consisted of information from drivers stopping for gasoline at the first off-ramp on US 41 beyond the work zone. Data from the IntelliZone detectors were also analyzed. A questionnaire was administered to 308 drivers; of these 186 drivers had passed through the work zone.

Results. Only 12 of 186 drivers passing through the work zone rated the signs as being inaccurate. Most drivers who could rate the signs indicated they were satisfied. Only eight

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[28] Horowitz, Alan J. and Thomas Notbohm, "Evaluation of Intellizone: "A System for Providing Speed Advisories to Drivers Entering Work Zones", Midwest Smart Work Zone Deployment Initiative, November 5, 2003, http://www.ctre.iastate.edu/smartwz/reports/MwSWZDI-2003-Horowitz-Intellizone.pdf.

drivers indicated they were dissatisfied (moderately or very) with the signs. The average reported delay for drivers passing through the work zone was the same (11 minutes) as the average amount of extra travel for drivers who were discouraged from passing through the work zone. Only three drivers reported that they diverted because of the signs.

There was a low correlation between the "decision speed" and the drivers reported delay. An analysis of data at the detector closest to the work zone revealed that the two lanes were operating in two distinct regimes. The left lane contained a queue during much of time drivers were being interviewed, but the right-lane remained free flowing. Thus, the "decision speed" was not correct for either lane. The free-flowing vehicles had come from STH 172, who entered US 41 well beyond the back end of the queue.

TIPS

System Description

TIPS is a portable, automated, real-time smart work zone system for predicting and displaying travel time or delay information to drivers in advance of and through freeway work zones. The system collects real-time traffic flow data using roadside non-contact sensors, calculates travel time between different points on the freeway, and displays the travel time information on several portable changeable message signs at pre-determined locations along the freeway.

TIPS can be used on any freeway that experiences congestion – with or without work zones. The real-time speed information could be displayed on large, permanent overhead variable message signs[29].

Past Evaluations

Ohio

Objective. The objective of the project was to find the accuracy of the travel times displayed by TIPS in a work zone.

System Design. The system deployed consisted of:

- Microwave radar sensors for vehicle detection on each lane of the freeway;
- Microcontroller with a specially written program for calculating traffic volume and occupancy for each lane and responding to polling requests;
- 220 MHz radios for transmitting traffic flow data from each microcontroller to the on-site personal computer;
- Intelligent traffic algorithm and travel-time estimation model residing in the specially-developed TIPS software in Windows NT environment;
- 220 MHz radios for transmitting travel time information from the personal computer to the portable changeable message signs;
- Portable changeable message signs for displaying travel time information to drivers; and
- Trailers for mounting sensors and radios, and solar panels.

Project Site. The system was deployed on I-75 (north bound) in the Dayton area.

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[29] PDP Associates, "Traffic Information & Prediction System (TIPS)", Retrieved on August 22, 2005 from http://www.pdpassociates.com/tips_introduction.htm.

Data Collection. Three crews, consisting of one driver and a data recorder, recorded a total of 119 runs during a three-day period. The system predicts travel times in rounded multiples of 4 minutes.

Messages. The message was displayed in two phases.

- XX MIN TO THE END OF WORKZONE
  Displayed for 4 seconds
- WORK ZONE ENDS YY MILES
  Displayed for 1.5 seconds.

Data Analysis. A regression analysis was performed between predicted and actual travel times. The intercept value and slope were tested for a 0.05 level of significance.

Results. Analysis of the data indicated that 88% of the readings were accurate within ± 4 minutes.

Wisconsin

Objective. The objective of the study to was evaluate the performance of TIPS within a rural freeway work zone by judging the accuracy of the system, determining if there was a measurable reductions in crashes, and measuring the diversion owing to the information on the signs.[30]

System Setup. The system used similar technology to the Ohio test. It involved five microwave detectors and four signs (PCMS). In an effort to encourage diversion, two of the signs were deployed well ahead of two off-ramps upstream of the work zone and the other two signs were deployed outside of two on-ramps at the same interchanges. One detectors was placed about 3 miles into the work zone, one detector was placed just ahead of the taper, and three other detectors were spaced well upstream of the work zone where long queues might form.

Project Site. The project site was a rural section of southbound I-94 between Milwaukee and Racine. This is a 6-lane facility. During the tests the work zone closed two lanes, allowing traffic to use the one remaining lane and a shoulder. The study was divided into a "before" period and an "after" period. During the before period the TIPS detectors and processing unit were active, but the signs were blanked. TIPS was fully operational during the after period. Queues of more than two miles regularly formed ahead of the works zone during peak periods.

Data Collection. Data were collected for about four hours on Thursday, Friday and Sunday afternoons. Peak traffic flow was observed to occur on Sundays because of the large number of vacation travelers. Floating car runs were made about every 20 minutes over four weeks before and four weeks after the signs were turned on. Volume data were collected from the TIPS detectors on I-94 and from tube counters that were placed at various points along alternate routes.

Messages. The message format and content were the same as in the Ohio test.

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[30] Notbohm, Thomas, Alex Drakopoulos, Alan J. Horowitz, "Travel Time Prediction System (TIPS)", Midwest Smart Work Zone Deployment Initiative, Summer 2001, Retrieved on August 22, 2005 from http://www.ctre.iastate.edu/smartwz/reports/MwSWZDI-2001-Drakopoulos-TIPS.pdf.

Data Analysis. Floating car travel times were compared with TIPS predicted travel times. Volume data across three cutlines were analyzed to determine whether significant diversion occurred because of the signs.

Results. TIPS was found to be accurate. More than 70% of TIPS predicted times were within 5 minutes of floating car times, and more than 85% of TIPS predicted times were within 30% of floating car times. Injury crash frequency was lower after TIPS began operation compared to the same work zone but measured for the northbound direction; however statistical significance could not be established. Diversion of up to 10% from I-94 attributed exclusively to TIPS during peak traffic periods.

CALM

System Description

The Construction Area Late Merge (CALM) system from The Scientex Corporation is a dynamic merge system configured to operate as an early merge system under light traffic loads and as a late merge system under heavier traffic loads.

CALM comprises three essential components. The core of the system is the central system controller (CSC), connected to the field components via some means of serial communication. Radio could be used for communication between CSC and the field components.

Past Evaluations

Kansas

Goal. The project was aimed at comparing the effectiveness of the CALM system (late merge) with that of conventional work zone traffic control (early merge) and to collect data that might be used later to improve the modeling of late merge systems. It also studied the effects of displaying real-time downstream speeds and examined system deployment and operation considerations.

Project Site. The site selected for the study was a segment of I-70 Eastbound in Kansas City, Kansas. A major reconstruction of the interchange between I-70 and I-635 required the closure of one lane eastbound throughout the construction period. Ramps between the interstates were closed. Standard work zone traffic control was present, in addition to the CALM components. The AADT ranged from 45,400 vehicle per day with 14% trucks at the western end of the segment to 71,300 vehicles per day with 11% trucks at the eastern end of the segment.

System Setup. The field components in this configuration was comprised of five trailer-mounted variable message signs (PCMS) and two trailer-mounted Remote Traffic Microwave Sensors (RTMS). Four of the five PCMS trailers also housed a radar speed sensor. The radar sensors provided overall (i.e., not lane specific) speeds and volumes, which were used in system operation as well as for data analysis.

Equipment Operation. RTMS sensors were operated in a sidefire orientation, reporting lane-specific speeds and volumes. Sidefire RTMS can report exaggerated volumes and invalid speeds under very congested conditions, but according to the authors this was the most effective means of obtaining lane specific data in this case.

The system was configured to operate in one of three modes—Early Merge, Late Merge, or Incident—switching automatically from one mode to another based on current traffic conditions as indicated by prevailing speeds. Based on both the system mode and the speeds near each PCMS, the system will operate each PCMS in one of five PCMS states—Early Merge, Late Merge-A, Late Merge-B, Incident-A, or Incident-B. Transitions between modes are based on average operating speeds. Speeds are categorized as Level 1, Level 2, or Level 3. Speed categories and PCMS modes are associated with a specific location, while system modes are associated with the system as a whole.

State	Description Criteria
Early Merge	All sensors report speed level 1.
Late Merge-A	Next Sensor (i.e., sensor immediately downstream of VMS) reports speed level 1; at least one other sensor reports speed Level 2; no sensors report speed Level 3
Late Merge-B	Next sensor reports speed Level 2; no sensors report speed Level 3
Incident-A	Next sensor reports speed Level 1; at least one other sensor reports speed Level 3
Incident-B	Next sensor reports speed Level 2 or 3; at least one other sensor reports speed Level 3

Figure 10. System Operating Mode Definitions[31]
Source: CALM System, Kansas, MwSWZDI

Study Type. The study was a before and after analysis with data being collected for one week before and two weeks after the installation of the system. The data were collected for four days during each week and only the data in congested conditions were considered.

Message. The Kansas DOT only displays messages on PCMSs when there is information to present that does not duplicate the static signing. Each sign can be one of 5 states. The late merge instructs drivers to use all available lanes all the way to the taper, and then take turns in the merge process.

System Effectiveness. System effectiveness was examined from two perspectives: change in driver behavior and improvement in flow.

Conclusion. Driver compliance decreased slightly during the first week of deployment, but the difference was not statistically significant. From the second week of deployment on, the percentage of drivers in Lane 1 at RTMS5 was greater than the before data. These numbers suggest both that drivers did change their behavior and that the behavior change required some "training" period to be fully realized. The lane distribution was significantly affected by the entrance ramp, prompting drivers to merge early. There did not appear to be an effect of the capacity on the work zone.

DELMTCS

System Overview

Dynamic Early Lane Merge Traffic Control System (DELMTCS) was jointly developed by Michigan DOT and Wayne State University. This system consists of dynamic "Do Not Pass/When Flashing" sign trailers that are equipped with detectors to capture speed, volume and lane occupancy data at the detection zone. A series of five signs dynamically communicate, with

[31] Meyer, Eric, "Construction Area Late Merge System".

one another to create a variable length of no passing zone, by activating the signs in an on-and-off flashing mode based on the detected traffic volume and occupancies[32].

The purpose of the DELMTCS is to reduce the number of aggressive driving maneuvers, improve safety and improve traffic flow by encouraging drivers to merge 'early' in the traffic stream. The sensors on the dynamic sign trailers detect traffic flow, speed, and occupancy, in order to create a dynamic no passing zone. Under high traffic volume conditions, the no passing zone will encourage drivers to merge well in advance of the lane taper where larger gaps are available in the traffic stream, and will provide safe and smooth merging of traffic. This system also induces a lower differential in vehicle speeds between the lanes, which also contributes to safety benefits. Thus, the total benefits of the DELMTCS include both tangible measures such as reduced travel time, reduced vehicular fuel consumption due to smoother traffic flow, reduced number of stops and delay, as well as intangible measures, such as benefits due to reduced air pollution from vehicle emissions, safety benefits related to a reduction in aggressive driver maneuvers, potential traffic crashes and associated risk due to road rage.

Past Evaluations

Michigan

Objectives. The objective of the project was to evaluate the effectiveness of DELMTCS in terms of reducing delay, aggressive driver behavior and increasing average travel speed.

Site Description. The project was conducted on I-94 between 23 Mile Road and 8 Mile Road in Macomb County, just north of Detroit. DELMTCS was installed in the advance warning area.

Data Collection. The studies were performed during the 2002 and 2003 construction seasons. The studies involved analysis of delay and travel times during the morning and evening peak periods. *These studies were conducted using the floating car method where a two-person survey team was used with one person driving through the study zone and the second person recording the travel time and delay data at specific locations.* The travel time data were recorded through the work zone. *Traffic volume data and driver behavioral characteristics, including aggressive driving maneuvers at the lane merge area were also recorded.*

Data Analysis. The before-and-after analysis indicated that DELMTCS was effective in reducing travel time delays, number of stops and aggressive driving maneuvers. T-tests was used to determine if there were significant differences (at the 95% confidence level) in the travel times before and after the installation of the DELMTCS on the selected work zone. A comparison was made between the travel times through the work zone during the morning and evening peak periods, before and after the implementation of the system. The results indicated significant reductions in delay after the installation of the DELMTCS system.

Benefit Cost Analysis. An economic analysis considered the benefits of DELMTCS in terms of travel time savings and fuel consumption savings. Travel time savings were calculated as the difference between the delays recorded from the travel time runs for before and after periods. The travel time savings are then converted to monetary values using various values of time. It

[32] Datta, Tapan, Kerrie Schattler, Puskar Kar, Arpita Guha, , "Development and Evaluation of an Advanced Dynamic Late Merge Traffic Control System for 3 to 2 Lane Transition Areas in Work Zones", Wayne State University, Research Report RC-1451, January 2004, Retrieved on August 22, 2005 from http://www.michigan.gov/documents/mdot_RC-1451_97846_7.pdf.

was found that when a value of time was greater than $3.33, the benefit-to-cost ratio would be greater than one, indicating that the monetary benefits of DELMTCS outweigh the cost of the system.

Fuel consumed (in gallons) by vehicles was calculated. The same length of time was used for the each of the before and after periods. An average cost of fuel of $1.50 per gallon was used to quantify the benefits due to the fuel savings.

Other intangible benefits such as reduction in pollution, reduced number of stops and associated acceleration and deceleration cycles, delay, and congestion were not considered in this study.

Conclusion. DELMTCS was found to be effective in reducing aggressive driver behavior, increasing safety and reducing delay in the work zone.

Dynamic Late Merge System (DLMS)

System Description

DLMS is an ATIS for work zones that was developed by Minnesota Department of Transportation. A similar system was also developed in Maryland. DLMS's purpose is to promote orderly merges when queues develop ahead of a lane closure. Its configuration is similar to DELMTCS and CALM, consisting of traffic sensors with a queuing area and upstream variable message signs to alert drivers of the desired lane changing behavior.[33]

Past Evaluations

Minnesota

Objectives. Between 2003 and 2004 Minnesota performed five tests of DLMS. These deployments had five objectives: shorten queue lengths; increase capacity; reduce aggressive driving; reduce incidents; and reduce travel time. This section describes results from the last four deployments of DLMS in 2004.

Site Descriptions. The configurations of all tests were similar. One RTMS detector was used to determine if queuing was present and three PCMSs provided information to drivers. When a queue developed, upstream signs said "USE BOTH LANES/MERGE X.X MILES AHEAD" or "USE BOTH LANES/PREPARE TO STOP". Near the taper a sign would say "MERGE HERE/TAKE TURNS". All of the tests involved closing one of two lanes. The tests were at these locations.

- I-494 northbound in Plymouth, MN, left lane closed
- I-494 southbound in Plymouth, MN, left lane closed
- US 52 northbound in St. Paul, MN, left lane closed
- I-35 southbound, south of the Twin Cities metropolitan area, right lane closed, ahead of a crossover

Data on incidents were not obtained. Baseline (before) volume data were taken only at the I-35 site at only one detector; therefore, conclusions were largely limited to what could be ascertained

[33] URS, "Evaluation of 2004 Dynamic Late Merge System", Report for Minnesota Department of Transportation, December 2004.

from conditions during deployment of the system. Minnesota's conclusions are based primarily on data on lane distribution after deployment and on visual observations.

Conclusions. Some drivers were confused by the signs or did not exhibit cooperative behavior, thereby reducing the effectiveness of the system. Minnesota concluded that signs should be placed on the median or shoulder nearest the lane to be closed. The PCMS nearest the taper should be positioned adjacent to the last static sign in order to avoid seemingly contradictory information and to provide sufficient space for merging. DLMSs are not needed when volumes are consistently less than 1500 vehicle per hour for a work zone with one open lane. When volumes are greater, as benefit cost study should be performed.

Maryland

Objectives. A detailed summary of the Maryland deployment is found in the Minnesota report.[34] The objective of Maryland's test was similar to Minnesota's.

Site Description. The system was deployed on I-83 southbound at Cold Bottom Road. The right lane was closed. The system was configured with four PCMSs and three RTMSs. Flashers were also placed on three static signs reading "USE BOTH LANES WHEN FLASHING". A typical message upstream was, "USE BOTH LANES TO MERGE POINT". The last sign before the taper read, "TAKE YOUR TURN/MERGE HERE". The system became active when the occupancy at all three RTMSs exceed 15% (queued conditions) and remained active until the occupancy dropped below 5% (free flow conditions).

Data collection. Volume and speed data were obtained by RTMSs. Data on queue length and merging behavior were obtained by camcorder. Data were collected one day before and four days after deployment.

Conclusions. Maryland measured increased capacity through the taper by about 15% when the system was deployed. Queue lengths were reduced because of a more even distribution between lanes. There was an increase in "stop-and-go" maneuvers and there were more locations where merging occurred.

Brown: Real-Time CMS Control[35]

System Description

Real-Time CMS Control (RTCMSC) is an en route traveler information system whereby real-time traffic-responsive information is provided to drivers by means of a changeable message sign (CMS) strategically placed in advance of a diversion point upstream of the work zone. The objective of the system is to advise drivers of a work zone ahead and encourage them to divert to an alternate route when there is congestion in the work zone.

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[34] Chang, Gang Len, Kyeong-Pyo Kang, Petru Horvath, "Evaluation of a Dynamic Late Merge System for Work Zone Operations", University of Maryland, College Park, Retrieved on August 22, 2005 from http://attap.umd.edu/Project_Slides.asp?ID=5&curPage=1

[35] Pesti, G, "Brown Real-Time CMS Control and Iteris Wireless Detection", 2002, Midwest Smart Work Zone Deployment Initiative, Retrieved on August 22, 2005 from http://www.ctre.iastate.edu/smartwz/reports/MwSWZDI-2002-Pesti-Brown-Iteris_System.pdf.

Past Evaluations

Nebraska

Geza Pesti affiliated with University of Nebraska, Lincoln, evaluated RTCMSC in Nebraska.

Objectives. The primary objective of RTCMSC was to encourage drivers to divert to an alternate route during congestion in the work zone. It was not expected to affect vehicle speeds, lane distribution or other traffic characteristics. Therefore RTCMSC was evaluated based on its effectiveness in diverting traffic. The percentage of diverted traffic was used as the measure of effectiveness.

Project Site. The project was conducted at a 2.7-mile section of eastbound I-80 within two work zones near Lincoln, Nebraska. The section operated as a 4-lane divided interstate highway. It was located between two relatively long sections of the interstate with head-to-head operation. The AADT at the section was approximately 38,000 vehicles per day, including 21% trucks. The speed limit in the study area was reduced from 75 to 55 mph as it was located between two work zones.

System Setup. The RTCMSC system was comprised of a video detection system and a portable CMS. The communication between the video detection system and the CMS was provided by radio signal. Video detection was used to determine the speed of vehicles entering the work zone. The video camera of the RTCMSC was mounted on the mast arm of a pole located on the roadside.

Placement. Traffic counts on the entry and exit ramps were taken using two traffic counter/classifier units deployed and operated by the Nebraska Department of Roads. Traffic on I-80 eastbound was monitored using the video camera of the RTCMSC at the beginning of the lane closure taper, approximately one mile downstream of the diversion point at the Highway 6 interchange. Volume data at this location were determined by Brown Traffic's video image processing system, and then stored in a log file.

Data Collection. Traffic counts at the entry and exit ramps were taken using two traffic counter units. The traffic on the highway was monitored using a video camera at the beginning of the lane closure taper.

Data Analysis. The time intervals for display of normal and diversion messages were determined. The 20-minute percentages of existing traffic were determined separately for the time periods of normal and diversion messages. An analysis of covariance was conducted to determine the statistical significance of the effect of CMS message and traffic volume on the 20-minute percentages of traffic on the mainline and the exit ramp. The t test was used to determine the statistical significance of the differences between the mean mainline and exit ramp percentages across the two messages.

Message. During uncongested periods 2-phase messages shown in Figure 11 were displayed.

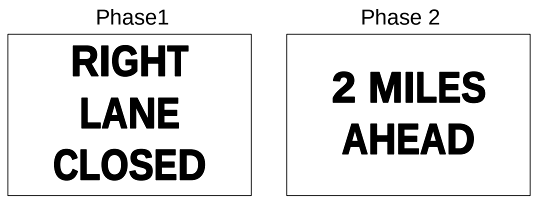

Figure 11. PCMS Messages
Source: Brown Real-Time CMS Control and Iteris Wireless Detection, MwSWZDI

However, during congestion in the work zone, a single phase message in Figure 12 was displayed.

Figure 12. PCMS Messages
Source: Brown Real-Time CMS Control and Iteris Wireless Detection, MwSWZDI

Conclusion. The RTCMSC was effective in encouraging some drivers to divert to an alternate route when congestion was detected in the work zone. Although its effectiveness was limited to about 4.5 percent diversion, the effect of diversion message displayed on the percentage of traffic on the exit ramp was statistically significant with 95% confidence. The effect on traffic volumes during the study period was not statistically significant.

Travel Messenger

North Carolina

Travel Messenger, a product of International Road Dynamics, Inc., is a traffic-responsive messaging system that displays travel conditions on PCMSs upstream of a work zone. Travel Messenger also provides information on a Web site. The only documented application of Travel Messenger was in North Carolina.[36]

Objective. The objective of the ATIS was to alert drivers to delays and encourage use of alternate routes.

Project Site and Configuration. Travel Messenger was deployed on I-95 near Smithfield and Rocky Mount. AADT was in excess of 35,000 vehicles per day on two lanes, one of which is closed for road work. Most drivers were from outside North Carolina. The configuration consisted of three sensors, one near the beginning of the taper and two further upstream, and three signs. One sign was located about two miles before the taper, another sign was located about two miles before the last off-ramp before the work zone, and the last sign was located four miles farther upstream.

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[36] Bushman, Rob and Curtis Berhelot, "Response of North Carolina to a Smart Work Zone System", Transportation Research Board 84th Annual Meeting CD-ROM, Washington, DC, 2005.

Messages. Messages were organized into three categories, generic, short-delay, and long-delay. Generic messages alerted drivers of the work zone, but offered no specifics or advice. A short-delay message told drivers about the expected length of the delay. A long-delay message was three phased, such as “Traffic Stopped Ahead / 20 Minute Delay / Use Exit 141 As Alt”.

Data Collection and Results. The system was evaluated primarily by asking local drivers about the signs. A survey was mailed to a random sample of drivers. There was a 23% response rate. Of those drivers having seen the signs, 43% felt the signs were always accurate and 54% felt the signs were sometimes accurate. Frequent drivers used the signs in their route choice decision making, with 40% indicating they were often influenced and 46% saying they were sometimes influenced by the signs. Only 12% of drivers with Internet access was aware of the Web site. Congestion on alternate routes was a problem only in the one incident where I-95 was closed completely.

CHIPS

System Description

CHIPS is a “traffic management package” and can be programmed to adjust to specific needs. Users can define the messages to be displayed on the PCMSs for different traffic conditions as detected by RTMSs. The CHIPS software is installed in the control computer at the command center, controls the operations of the system and maintains communication between the devices. The communication between CHIPS and field devices can be maintained through a radio network.

If CHIPS detects a change in the status of RTMS, it identifies the predefined traffic scenario and displays the corresponding message on the PCMS. It also maintains a log that records the state of each RTMS.

Past Evaluations

Arkansas[37]

Objective. The main goal of this project by the Arkansas State Highway and Transportation Department was to provide a queue detection system for preventing or reducing rear-end collisions and provide real-time information to motorists regarding potential backups caused by lane closures.

The main objectives of the AHTD were as follows.

- Prevent/reduce rear-end and other crashes
- Improve work-site safety
- Provide real-time information to the motorist regarding potential backups caused by lane closures
- Improve incident management
- Improve congestion management

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[37] Tudor, Lorie H., Alan Meadors, Robert Plant, “Deployment of Smart Work Zone Technology in Arkansas”, Transportation Research Board 82nd Annual Meeting CD-ROM, 2003.

Project Site. The site was named North Little Rock (NRL) and was classified as urban. The project was conducted in Pulaski County, which involved the rehabilitation of an 8.6 mile urban segment of Interstate 40 from Highway 67 to the Lonoke County Line. This section had an AADT of 44,000 vehicles per day with 35% trucks.

System Setup. The CHIPS system developed by ASTI Transportation Systems consisted of a Central System Controller (CSC), a host computer in the Engineer's office, one CMS and six traffic sensors for westbound traffic. For eastbound traffic, nine traffic sensors and one CMS were installed. Landline telephone was used for communication between the system and a highway advisory radio system. The system provided motorists with real-time traffic, delay and diversion advisories. It also provided pager alerts and e-mail transmission to selected personnel in the event of traffic queues.

The sensors were located along the entire length of the project. The CMSs were located to provide information about alternate routes in case of congestion. The CSC was located in the contractor's office and was programmed for a 5.8-minute cycle. The system had 80 preset scenarios that included:

XX Mile Backup YY Miles Ahead - Be Prepared to Stop

Slow Traffic Ahead – Be Prepared To Stop

Drive Safely – Buckle Up

Cost. The bid for the system was placed for 1,000 days operation at $390 per day plus $100,000 for the highway advisory radio system, totaling $490,000.

Problems Encountered. Phone lines for the Internet and software support were lost and could not be accessed.

Cell phone communicating with the HARs experienced cell carrier drops in service due to backups generated by excessive cell phone usage by motorists using their cell phones during a queue. The contractor changed to standard phone lines to communicate with the HAR devices with good results.

Touch tone pagers did not convey accurate enough information, therefore the contractor switched to Arch wireless pagers. These pagers send text messages to the appropriate personnel with more accurate real-time information.

A second computer had been added to the Central System Controller computer. This "utility" computer handled tasks such as e-mailing, sending pages and updating web pages, while the "master" computer continued to communicate with the traffic sensors and the CMSs.

System Accuracy. In order to determine the accuracy of the system, the messages on the CMS and HAR were compared with the actual traffic conditions. The data was collected from the first visible changeable message sign. The data was collected until the end of the work zone. It was found that 90% of the messages matched the actual conditions.

System Effectiveness. A direct correlation was found between the message displayed on the changeable message signs and highway traffic. The number of vehicles taking the alternate route increased by a factor of two for all vehicles and a factor of nine for truck traffic on Highway 70 when the CMS reported messages ranging from "Slow Traffic Ahead – Be Prepared to Stop" to "Five Mile Backup Ahead – Be Prepared to Stop".

California[38]

Objectives. The objectives of the system were to display real-time traveler information to drivers approaching work zones, to slow down the traffic upstream of queues, to promote orderly lane changes, and to encourage drivers to take alternate routes during congested periods.

The objectives of the study included these items.[39]

- Evaluate the performance of CHIPS in the areas of system functionality, traffic data acquisition, motorist information messages, and system communications.
- Evaluate the reliability of CHIPS in conveying accurate information and the ability to collect accurate traffic speeds and estimate delays.
- Evaluate the effectiveness of CHIPS in reducing traffic delays and in reducing crashes.
- Evaluate the system cost.

Site. CHIPS was tested at a work zone site on I-5 between Magic Mountain Parkway and Rye Canyon Road in Santa Clarita, California. I-5 is a major north-south route used for international, interstate, interregional and intra-regional travel and shipping.

The study site for the evaluation was located on the southbound approach to the work zone. Caltrans had placed several static signs along the route for traffic control. The traffic on southbound lanes was much heavier than the traffic on Northbound lanes and therefore only southbound lanes were chosen for the study.

System Setup. The system was composed of field devices and hardware and software in the command center. The facilities in the field included quick queue trailers, EZ cam mobile video trailers, and portable changeable message signs (PCMS). The quick queue trailer detected the changes in traffic flow. PCMSs displayed real-time traffic information to travelers. The EZ cam is a trailer mounted closed circuit TV (CCTV) camera used to monitor the traffic conditions in the field. Each of these three devices communicated with the command center.

"The command center had the following hardware and software: communication systems (including a 450 MHz radio and 5.9 GHz wireless video antennas and receiver), AXIS 2400 video server, e-mail and page PC, and the control computer running the core CHIPS software. The command center communicated with quick queue trailers and PCMSs through a 450 MHz radio network and the EZ Cams through a 5.9 GHz wireless video transmission system. The AXIS 2400 video server at the command center published surveillance video data received from the EZ Cams to the Internet."

Users could also remotely access CHIPS (i.e., the control computer) using software called PCAnywhere.

Messages. The PCMS used for the study had 24 characters. The table below indicates the messages displayed at each PCMS for different scenarios.

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[38] Chu L. et al., "Evaluation of Effectiveness of Automated Workzone Information Systems", Transportation Research Board 84th Annual Meeting CD-ROM, 2005.
[39] Chu, Lianyu "Evaluation of Automatic Work Zone Information Systems", project description, Retrieved on August 22, 2005 from http://www.its.uci.edu/~lchu/workzone.html.

Table 1. CHIPS Message Numbers under Different Detector Conditions

	Queue Detector			CMS Combo Message				
Scenario	RTMS-1	RTMS-2	RTMS-3	PCMS-1	PCMS-2	PCMS-3	Caltrans CMS	Caltrans PCMS
S1	F	F	F	1	1	1		
S2	T	F	F	2	3	5		
S3	T	T	F	6	7	3	10	
S4	T	T	T	6	7	8	9	11

T=Queue being detected, F=No queue detected

Message Number	Phase 1	Phase 2
1	BLANK BLANK	BLANK BLANK
2	TRAFFIC/JAMMED	SOUTH 5/AT RYE/CANYON
3	SLOW/TRAFFIC/AHEAD	PREPARE/TO/STOP
4	TRAFFIC/JAMMED/NXT 2 MI	EXECT/5MIN/DELAY
5	TRAFFIC/JAMMED/AHEAD	126 FWY/TO MAGIC/MOUNTAIN
6	SOUTH 5/TRAFFIC/JAMMED	AUTOS/USE NEXT/EXIT
7	JAMMED/TO MAGIC/MOUNTAIN	EXPECT/10 MIN/DELAY
8	JAMMED/TO MAGIC/MOUNTAIN	EXPECT/15 MIN/DELAY
9	TRAFFIC JAMMED TO MAGIC MTN	AVOID DELAY USE NEXT EXIT
10	TRAFFIC JAMMED ROUTE 126 TO MAGIC MTN	
11	SOUTH 5 ALTERNAT ROUTE	AUTOS USE NEXT 2 EXITS

Figure 13. CHIPS Messages for Each Message Number

Data Collection and Analysis. A before and after study was conducted and on-ramp and off-ramp traffic volumes were collected for two different time periods. Travel times and diversion rates were analyzed using this data. An analysis of safety effects of CHIPS was also sought, but a direct analysis of crash data was difficult to conduct due to uncontrollable factors. The following traffic flow parameters were used as measures of effectiveness of safety effects:

1. Traffic throughput
2. Traffic throughput (or volume) variance based on one-minute throughput data
3. Sample speed mean
4. Variance of speed samples

For this analysis traffic count and speed data were collected using counters and speed guns at two locations. Traffic counts and speed data were collected at the same time for a length of 30 minutes under queued conditions. *The collected traffic count data were used for the analysis of traffic throughput and traffic volume variance. The collected speed samples were used for speed mean and speed variance analysis.*

A postcard-based driver survey was also conducted to obtain travelers' comments on CHIPS. Two off ramps were selected to distribute the survey postcards. About 400 postcards were distributed and a total of 100 post cards were returned. The questions in the survey included:

1. *Why did you get off the I-5 south?*
2. *Did you see any electronic traffic signs regarding construction and/or traffic delays?*
3. *Did the traffic signs influence your choice of route?*
4. *Did you find these signs useful?*

In response to the first question, 78 respondents selected "avoid traffic", 24 respondents selected "buy gas and foods" and 5 respondents picked "arrived at destination". Almost all (99%) respondents saw messages on the PCMSs. This could be attributed to the congested conditions during the time when postcards were distributed. A majority (78%) of respondents who saw the messages changed their route based on the information on the PCMSs. A majority felt that PCMSs messages were useful.

Conclusion. The study of CHIPS found these conclusions.

- Obvious diversion was observed on two evaluation dates because the travel time along the diversion route was shorter than freeway mainline during traffic congestion.
- Based on the study of the effects of traffic flow, the driving environment after the use of CHIPS seemed safer.
- Positive responses about the system were obtained based on driver surveys. Most survey respondents thought the system was useful for dispensing information, providing alternate routes, and avoiding delay.

SpeedGuard

System Description

The SpeedGuard radar speed reporting system is a speed monitoring display, which informs drivers of their speeds and thereby encourages them to slow down if they are traveling above the speed limit. The objective of the system is to calm traffic and increase speed limit compliance. The SpeedGuard radar speed reporting system is a portable, self-contained trailer unit. It is equipped with radar to measure the speeds of approaching vehicles. The vehicle speeds are displayed on a panel with 24-inch LED numerals. The unit is equipped with a photocell for automatically controlling the brightness of the display. The system is powered by three12-volt heavy-duty marine batteries rated for 168 hours (one week) of use. The message YOUR SPEED is mounted on the trailer beneath the variable speed display. A speed limit sign can be mounted on a rack above the display. The rack can be lowered for transport.[40]

[40] McCoy, P, "SpeedGuard Radar Speed Reporting System, Nebraska", Midwest Smart Work Zone Deployment Initiative, 2000, Retrieved on August 22, 2005 from http://www.ctre.iastate.edu/smartwz/reports/MwSWZDI-2000-McCoy-Speed_Display.pdf.

Past Evaluations

Nebraska

Objective. The objective of the application was to reduce the speed of traffic and increase speed compliance by informing their drivers of their current speed.

Project Site. The site was located on the westbound approach to a work zone on I-80 between Lincoln and Omaha in the vicinity of the Highway 63 interchange near Greenwood. The work zone involved closing of the left lane and reducing the speed on the right lane from 75 mph to 55 mph.

Data Collection. Traffic speed was to be measured for at least 24 hours before and after the deployment of the SpeedGuard system. NuMetrics NC-97 traffic counter/classifiers were installed to measure the speed, at six positions on the two lanes at distances of 500 feet, 1000 feet, and 1500 feet in advance of the taper.

Data Analysis. The project encountered equipment malfunctioning and limitations.

- The SpeedGuard System malfunctioned, and thus only seven hours of after study data were collected, compared to 58 hours of before study data.
- The Speeds were stored in 14 speed bins in the Nu-Metrics NC-97 traffic counter/classifier because of limitations in its storage capacity.
- The two units located at 1000 feet in advance of the lane enclosure taper malfunctioned.

The speeds recorded during congested flow conditions were not included in the analysis. The data were divided into four sets: daytime passenger cars; nighttime passenger cars; daytime non-passenger vehicles; and nighttime non-passenger vehicles.

The following speed parameters were compared: mean speed, standard deviation, 85^{th} percentile speed, 10 mph pace, percentage of speeds within the pace, percentage complying with the speed limit, and mean of highest 15 percent of speeds.

Results. There was a statistically significant reduction in speed at 500 feet before the taper. An improvement in the uniformity of speeds was also noticed in passenger as well as non-passenger vehicles. The results at 500 feet before taper were found to be similar for daytime and nighttime conditions. However, at 1500 feet more statistically significant differences were observed in the nighttime. This increased effectiveness was attributed to the greater visibility of the SpeedGaurd display at night.

Conclusion. The data analysis showed that the system was effective. However, the analysis was based on only seven hours of data.

Kansas

Objective. The objective of this deployment was to reduce speed and speed variance.

Study site. The evaluation was conducted in a five mile long work zone on I-70 approximately 30 miles west of Topeka. *The test was conducted during the second phase of a reconstruction project in which the eastbound lanes were closed, and two-way traffic was being carried on the westbound lanes.* Originally, data were to be collected at ten locations on the site. However, due to equipment failure, usable data were obtained from only four collection points, during times when the system was in operation.

Data Collection. The performance measures used in this study were speed and speed distribution. Vehicle speeds were recorded using pneumatic tubes and automatic traffic recorders. The study was conducted as a before and after study, and the data were collected 24 hours per day for one week each before and after the deployment of the system.

Data Analysis. Multiple speed characteristics for a week each in before and after conditions were compared for analysis. *The week following the deployment of the speed display, the Kansas Highway Patrol (KHP) provided active speed enforcement for a total of 8 hrs, recording the times during which an officer was present so that the corresponding data could later be identified.* The data comprising the hour immediately following the departure of KHP was also included in the analysis.

Results. The speed display resulted in a significant reduction in mean speeds, 85th percentile speeds, percentage of drivers exceeding the posted limit, and speed variation (standard deviations). Law enforcement produced similar results upstream, but downstream, the values *increased* relative to the baseline. Interestingly, data during the hour following the KHP's departure from the test site (i.e., "Post-Law Enforcement") showed that speeds at upstream data points closest to the speed display not only increased to normal, but exceeded baseline speeds.

Conclusions. The radar-triggered speed display was easily deployed and very mobile. The setup time was less than 10 minutes once the site was identified. The display was quite effective, reducing mean speeds, 85th percentile speeds, percent of drivers exceeding the posted limit, and standard deviations for both cars and trucks. The effects were less pronounced, but still significant, at approximately 0.8 km (0.5 mile) downstream of the speed display. In contrast, law enforcement appears to cause an increase in speeds downstream from the patrol car. Additionally, speeds continue to increase after the patrol car is no longer in the area. The reason for this phenomenon is unknown.

Wizard CB Alert System

System Description

CB channel radio is available in a large number of trucks. Wizard CB Alert System uses CB channel radio to automatically broadcast alert messages. The Wizard CB Alert System is intended to alert the drivers about the work zone, to help the traffic merge efficiently into one lane before the work zone starts, and to reduce the average speed and speed variance approaching the work zone.

Operation

Wizard CB system is automatically broadcasts recorded messages over the CB channel radio. It can be used in conjunction with a variety of input devices.

Past Deployments

Missouri

Goal. The primary goal of this evaluation was to determine the effectiveness of the Wizard CB alert system (CB message) as located in the approach to a highway work zone.

Objective Measures. The effectiveness of the system was mainly determined by the mean speed, speed variance, and lane distribution upstream of the work zone. In addition, a variety of speed parameters were analyzed to evaluate the traffic control devices in detail.

Project Site. The project was conducted at a stationary, long-term work zone on eastbound I-70 near Columbia, Missouri. Posted speed limit approaching the work zone was reduced from 70 mph to 60 mph and then to 50 mph. The messages were broadcast from a location approximately six miles upstream of the lane closure. The messages were broadcast on channel 19.

Message. The following message was displayed when the right lane was closed: "This is the Missouri Department of Transportation. The right lane of Eastbound I-70 is closed ahead. Watch for slow or stopped traffic." A similar message was transmitted when the left lane was closed. The AADT in the eastbound direction was approximately 14,600 vehicles, with 25.6 % trucks. The right lane was closed during the study.

Data Collection. Data were collected at four locations along the approach to the work zone both before and after the deployment of the system. The data were collected in 15-minute intervals. Due to breaks in the pneumatic tubes, data at all four locations during all time periods could not be collected, but approximately 24 hours of data were collected for both the before and after cases. Crash data were collected from one mile upstream through the end of the work zone. Driver surveys were conducted to determine the reach and effect of the messages.

Data Analysis. The differences in statistics before and after the installation of the system were ascertained. A two-tailed t-test with a 95% confidence limit was conducted to find differences in average speeds.

Results. Problems were reported at one of the four data collection locations. Therefore, data were only reported for three functional locations. The percentage of the vehicles in the closed lane declined after the deployment of the system with higher reductions in trucks compared to passenger cars. Changes in the mean speed varied from location to location. The compliance with the speed limit improved at night.

Driver Response and Ease of Use. Driver interviews were conducted between the transmitter and the lane closure. Most of the drivers came to know of the work zone from a conversation or a recorded message on the CB channel radio and a majority of them understood the message completely or partially. 97.3% of the drivers felt that the information provided was at least somewhat useful and many of them wanted to be warned about three to five miles before the work zone.

Safety. The time period during which the system was in operation was too short for a conclusive response on reduction in crashes.

Conclusions. The CB message was associated with improved lane distributions in most cases, for all passenger cars and trucks. The improvement was more pronounced in the case of trucks.

Iowa

Project Site. The Wizard CB Alert System was used in conjunction with a work project performed by an Iowa Department of Transportation (DOT) striping crew on I-35.

Message. The effectiveness of the system was greatly influenced by the message content. Based on truckers' suggestion, the message was changed several times. In order to give an indication of the location of the paint crew, milepost ranges were added to the message. To reduce the time required for recording and changing CB messages, relative location of the paint crew was provided instead of the exact location. This message format was found to be very successful. However, over doubts that on hearing *"Iowa DOT"* the drivers may think that the message might be from commercial vehicle enforcement officers, the message was changed again. *This final message presented all pertinent information clearly and concisely. Also, the message would only need to be changed when and if the roadwork changed direction or changed roadways.*

First Variation	**This is the Iowa DOT. Slow-moving painting operation in the right lane of northbound Interstate 35. Please use caution.**
Second Variation	**This is the Iowa DOT. Slow-moving painting trucks in the right lane of northbound Interstate 35, milepost 160 to milepost 170. Please use caution.**
Third Variation	**This is the Iowa DOT. Northbound drivers on Interstate 35, you are approaching a slow-moving paint crew in the right lane. Please use caution.**
Final Variation	**This is an Iowa DOT road work alert. Northbound drivers on Interstate 35, you are approaching a slow-moving paint crew in the right lane. Please use caution.**

Figure 14. Wizard CB Messages
Source: CB Wizard Alert System, Iowa, MwSWZDI

Evaluation. A survey was conducted to evaluate the effectiveness of the system. A total of 94 surveys were filled out by truck drivers, 88 of which had a CB radio in their truck. Of those, 70 drivers had their radios tuned to channel 19 during the preceding hours, while 59 drivers had their radios tuned as they passed the paint crew.

A majority of the truck drivers heard the Wizard CB messages, although it may not have been their first indication that they were approaching the paint crew. Most of the drivers who heard the messages felt that the message was effective at warning them of the paint crew. All the drivers indicated that a continued use of the system in future would be helpful.

Conclusion. The Wizard CB alert system was found to be very effective at warning the drivers about upcoming road conditions. The information was conveyed to a large percentage of commercial vehicles. A large number of drivers approved of the system and showed their support for its continued use in the future.

Kansas

Objective. The objective of the application was to provide advance warning to the drivers about the traffic situation ahead. The parameters for measurement of performance were lane distribution of trucks upstream of the project and truck speeds upstream of the project.

Project Site. The site was located on I-35, from in Harvey County.

Data Collected. Lane distributions of trucks at 500, 1000 and 1500 feet upstream of taper were recorded and the speed of vehicles, upstream of taper was noted. Pneumatic tube counters were used to collect the data.

Data Analysis. Before and after comparisons were made of the 85th percentile speed, average speed, and pace speeds. The project encountered equipment difficulties. Only one tube per counter could be utilized. Data corruption was another issue encountered during this project. It was found out later that the CB receivers had not been functioning properly during the study.

Results. The trailer mounted system had high degree of portability. *Use of CB frequencies does not require an FCC permit unlike the HAR that restricts the mobility of HAR due to legal constraints.* Some of the CB receivers used for testing did not operate properly.

Conclusion. The traffic volumes experienced at the test site at night were low. The terrain was level and the visibility was excellent. Therefore not much improvement was sought in the traffic control measures. The project also encountered problems in the equipment. Due to these reasons the effectiveness of the data collected could not be verified.

Texas

Objective. The objective of the project was to determine the level of compliance with messages sent through the Wizard CB Alert System to truck drivers and to determine if the system reduced speeds and improved safety. The project also sought to determine whether Spanish-speaking drivers would be equally influenced by the system.

Test Sites. The Wizard CB Alert was tested at four sites.

- I-35 near Hillsboro, where soil stability problems prompted TxDOT to remove trucks from the right-most lane.
- I-410 southeast of San Antonio, where lanes were closed due to an asphalt overlay project.
- I-35 south of Cotulla, where lanes were closed for a total reconstruction of the pavement.
- Loop 20 (an arterial) in Laredo, which was undergoing a widening to five lanes.

Messages. Different messages were used at each site, with the I-35 Hillsboro site having two separate messages.

- I-35 Hillsboro Message 1. "This is the Texas Department of Transportation. All Northbound trucks on Interstate 35 should use the left lane through the next work zone. The speed limit through the work zone is 45 miles per hour. Thank you."
- I-35 Message 2. "This is the Texas Department of Transportation. All Northbound trucks on Interstate 35 should use the left lane through the next work zone. We are performing an analysis of the soil strength below the right lane. The speed limit through the work zone is 45 miles per hour. Thank you."
- I-410 Message. "This is the Texas Department of Transportation. Southbound Interstate 410 traffic is entering a work zone. All vehicles must use the left lane. Thank you."
- I-35 Cotulla Message. "This is the Texas Department of Transportation. All northbound traffic on Interstate Highway 35 should use the right lane through the next work zone. The advisory speed limit through the work zone is 55 miles per hour. Thank you."
- Loop 20 Message. "This is the Texas Department of Transportation. Southbound traffic on Loop 20 is approaching a construction work zone. Construction in progress, please use caution. The advisory speed limit is 45 miles per hour. Thank you."

The Loop 20 message was broadcast in English for one week and in Spanish for another week.

Data Collection. Speeds were measured at several points before and within each work zone. Lane choice was measured at the I-35 Hillsboro site. A survey of drivers was conducted at the Loop 20 site. Data before and after the deployment of the system were taken at each site; however, the number of days of data collection varied according to the site.

Results. An implementation in Texas of CB Wizard Alert system found that average speeds of trucks dropped by 2 mph and the lane distribution of trucks changed significantly compared to another work zone with the CB alert system.[41] The study recommended that Texas use the CB alert system in rural areas with large truck volumes. Spanish language drivers tended not to listen to channel 19, so they were less affected by the system.

Speed Monitoring Display

System Description

Speed displays use a radar device to detect and display the speeds of approaching vehicles. It consists of a large box which houses K-band radar and two 18-inch LED characters, which are visible in direct sunlight from up to 1000 feet away. The system may use solar power panels and the excess power is stored in a car-type battery[42].

Operation

The K-band radar used in the system broadcasts a directional radar beam over approximately one mile. The radar detects the approaching vehicles and shows their speeds on the LED display. The display box also has an "overspeed" option, which flashes drivers' speeds when they exceed the speed limit. Further, the speed measuring radar sets off the radar alarms in vehicles equipped with these devices.

Past Evaluations

Iowa

Objective. The objective of the project was to evaluate the impact of the speed display on reducing vehicles' speed and increasing speed uniformity at work zones.

Site Organization. The project was conducted at a work zone on I-35, as a part of the Midwest States Smart Work Zone Deployment Initiative (MwSWZDI). Speed monitoring display was deployed in a work zone consisting of a left lane closure with a crossover. *The speed display was mounted atop a stationary pole located 2,250 feet upstream of the lane closure taper.*

Data Collection. The study was conducted as a before and after study. Data were collected for two days prior to and four days after the system installation for five hours each day. The data were collected under two modes: active radar only and active radar and display to determine the impact of radar signal and the impact of the radar signal combined with the display board informing the drivers of their speed.

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[41] Ullman, Gerald, et al, "Improving Work Zone Safety Using Traffic Management and Enforcement Tools", Project Summary Report 2137-S, Texas Transportation Institute, FHWA/TX-03/2137-3, September 2002.

[42] Maze, Tom, "Speed Monitoring Display", Midwest Smart Work Zone Deployment Initiative, 2000, Retrieved on August 22, 2005 from http://www.ctre.iastate.edu/smartwz/reports/MwSWZDI-2000-Maze-Speed_Display.pdf.

Data Analysis. Speed data at two locations 1500 feet and 500 feet upstream of the taper were collected before and after the installation of the system for the passenger as well as non-passenger vehicles.

Results. A modest decrease in mean speed was observed when the display was deployed. They also indicate increases in vehicle percentages complying with the posted speed limit, an increase in vehicles traveling in the 10-mph pace, and a reduction in the 10-mph speed interval. A moderate decrease in 85th percentile speed was noted in passenger cars. However, a similar trend was not detected for trucks.

The reduction in speeds due to the speed monitoring display were clearly pronounced at the location closest to the work zone with a reduction of more than 3 mph in the mean speed and 5 mph in the 85th percentile speed. An increase in the percentage of vehicles complying with the speed limit was noted along with an increase in percentage of vehicles traveling in the 10 mph pace. However, t-tests (95% confidence level) could not determime that the changes in mean speed were statistically significant.

Conclusions. Although, after the deployment of the speed monitor, the percentage of vehicles in the traffic stream complying with the speed limit increased, the reduction in mean speeds were not found to be statistically significant. A low number of vehicles equipped with radar detectors could be the possible reason for the lack of statistically significant speed reductions.

Safety Warning System

System Description

The Safety Warning System (SWS) is vehicle-mounted or semi-portable stationary radar detector alert system that transmits a fixed message to all SWS compatible detectors, notifying them of up-coming road or traffic conditions. SWS primarily consists of a transmitter. *The transmitter can be mounted on the outside of a vehicle.* The signals from SWS transmitter can be detected by any K-band radar detector sounding an alarm. However, some detectors are capable of reading and displaying SWS messages.

Operation

The SWS transmitter features a narrow, bidirectional beam that focuses the transmission so it only affects drivers along the roadway where the construction is taking place, up to two miles.

Past Deployments

Kansas

Objective. The objective of this project is to provide advance-warning messages concerning road hazards to drivers of vehicles equipped with SWS detectors.

Study Site. The study site is located on I-135 in Harvey County.

Performance Measures. The effectiveness of the advanced warning provided to the visitors was assessed by determining the lane distribution upstream of the project and vehicle speeds upstream of the project.

Data Collected. Data for lane distribution was collected at locations 500 feet, 1000 feet, and 1500 feet upstream of the taper with the help of pneumatic tubes counters for one day before and after the installation. Data for speed of vehicles, upstream of the taper and in the cross-over were also collected.

Data Analysis. The speed data were analyzed by comparing the 85th percentile speeds, average speeds, and percentage of vehicles exceeding the posted speed limit before and after installation.

Results. The SWS resulted in no significant change in the lane distributions 500 ft upstream of the taper. Speeds in the crossover showed statistically significant reductions with the activation of the SWS for passenger cars at night and for both cars and trucks during the day. The reduction in mean and 85th percentile speed though statistically significant was less than 1 mph and therefore had little practical significance. There was a greater reduction in the percentage of drivers exceeding the speed limit for passenger cars than for trucks.

Conclusions. The effectiveness of SWS can be determined only after a set of technical and political issues are resolved. The number of vehicles equipped with SWS compatible detectors is not known. Moreover, most SWS compatible devices are radar detectors, which make them illegal in commercial vehicles. Some SWS compatible receivers are not radar detectors, but they have not yet achieved significant market penetration. A large number of cars are equipped with radar detectors that are not SWS compatible. SWS triggers a standard radar detector, although the warning message cannot be decoded by these devices. *Though the speed reductions were small, they were statistically significant, indicating that the system was effective at drawing drivers' attention to the driving task.*

Iowa

Objective. The objective of this project is to provide advance warning messages concerning road hazards to drivers of vehicles equipped with SWS compatible detectors.

Site Organization. The case study work zone consisted of a left lane closure with a crossover leading into two-way traffic. The SWS transmitter was mounted atop a stationary pole located 2,250 feet upstream of the lane closure taper.

Traffic data were collected at 1500 feet and 500 feet upstream of the taper using two traffic data collection trailers equipped with video cameras that were mounted 30 feet above the ground. Traffic flow performance data were derived from the video using *Autoscope* image processing technology.

Data Collection. Traffic flow performance data were recorded for five hours for two days prior to and two days after the SWS transmitter installation. The recorded video tapes were analyzed to determine the types, arrival times, and speeds of approaching vehicles. More than 2500 data points were recorded during each day of data collection.

Data from only the free-flowing vehicles (headways >= 5 seconds) were retained, resulting in elimination of more than half of data points. However, a reduction in the quantity of data did not pose any problems.

Evaluation Parameters. The analysis of the speed data included the following evaluation parameters: time mean speed, 85th percentile speed, 10-mph pace, percentage of observations in the 10 mph pace, standard deviation of the time speed, percentage of observations complying with speed limits, time mean speed of the highest 15 percent of speeds.

All statistics except mean speeds and standard deviations were determined from graphical analysis.

Results. For graphical analysis, each data set was first grouped into intervals of two miles per hour (mph). Cumulative percentages of vehicles traveling at each interval were calculated and plotted.

The differences between the mean speeds recorded before and after the transmitter installation were not found to be statistically significant for all data sets. The reason for similar mean speed before and after the use of the SWS is probably small number of vehicles equipped with radar detectors able to receive the transmitted SWS signals. There was a slight increase in the number of vehicle observing the speed limit during the implementation of SWS. However, other measures of effectiveness similarly resulted in no discernable trend.

Conclusion. The effectiveness of SWS cannot be correctly evaluated until a substantial number of vehicles are equipped with SWS compatible detectors.

Drone Radar

System Description

Radar drones are used to inhibit drivers from speeding. Radar drones trigger radar detectors installed in approaching vehicles, prompting drivers to slow down. Radar drones are expected to reduce the speed in work zones and reduce the speed variance in work zones.

Use of radar detectors in non-commercial vehicles is banned in Virginia and Washington D.C. Radar detector use in commercial vehicles has been prohibited in the U.S. since 1995[43] [44].

Past Deployments

Drone Radar was evaluated in Kansas for the MwSWZDI.

Kansas

System Setup. The project utilized two radar drone units deployed at either end of a 1 mile segment of an Interstate work zone (the entire work zone was approximately five miles long).

Project Site. The project was conducted on a segment on I-70 in Wabaunsee County. The ADT for the section was 18,000 vehicles per day. The speed limit in the section was reduced to 60 mph from the normal 70 mph.

Data Collection. Speed data were collected with the help of pneumatic tubes and automatic traffic counters. Data were collected for four days (24 hours per day) each with and without the radar being deployed.

Results. Speeds were measured at 10 locations. The data were downloaded twice from the counters. In both the inspections, power supplies for both the drones were found to be exhausted. *It was later determined the batteries could be expected to power the drones for at least 24 hours. Consequently, only the 24 hours following those two inspections were used in the analysis.*

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[43] Code of Federal Regulations, Title 49, Volume 4[Revised as of October 1, 2001], CITE: 49CFR392.71 [Page 983-984]. As referred by Todd L. Sherman, Mobile Scanner & RADAR-Detector Laws In The U.S. (December 16, 2002). Retrieved on April 12, 2005 from http://www.afn.org/~afn09444/scanlaws/laws/radar/commercial.html.

[44] Beltronics USA. "Are radar detectors legal?".

Some changes in the mean and 85th percentile speeds were observed, but no consistent pattern was seen.

Conclusions. The data suggests that drones may cause a small decrease in the 85th percentile speed near the unit, but that speeds increase farther downstream. The use of a radar drone does not seem to be an effective device for reducing speeds in highway work zones.

Real Time Traffic Control System (RTTCS)

System Description

RTTCS consisted of portable dynamic message signs (DMSs), portable traffic sensors, and portable closed-circuit television (CCTV) cameras linked via wireless communications to a central workstation. The RTTCS uses a wireless modem system, suggesting that the RTTCS system would be good candidate for rural or other applications where utilities are not available or in large work zones characterized by frequent changes in roadway alignments.

Operation

The system's traffic sensors provide congestion information by detecting the speed and presence of vehicles as they pass the sensor stations. The central processor automatically generates predefined messages that are displayed on PCMSs upstream from the sensor location and updates the traffic condition map on the project website.

Past Deployments

Illinois[45]

System Setup. The system deployed consisted of 17 remotely controlled portable PCMSs, eight portable traffic sensors, and four portable CCTV cameras. All components were electronically linked to a central base station using wireless communications. The roadside systems operated from batteries that could be recharged using small solar panels.

The RTTCS consisted of data collection devices electronically linked via wireless communications to a central base station server. The base station server processed data collected by system sensors and calculated delay at each sensor station. The system then disseminated appropriate information to travelers and IDOT staff. The system's eight portable traffic detectors used X-Band radar to automatically collect vehicle speed and presence data. The system used four portable CCTV cameras to identify possible incidents detected by the traffic detectors (e.g., if the system detected traffic stopped for long periods of time) or to confirm traffic conditions "when system data were ambiguous."

[45] Federal Highway Administration, "Intelligent Transportation Systems in Work Zones: A Case Study. Real-Time Work Zone Traffic Control. Using an Automated Traffic Information System to Reduce Congestion and Improve Safety During Reconstruction of the I-55 Lake Springfield Bridge in Illinois", 2004, Retrieved on August 22, 2005 from http://ops.fhwa.dot.gov/wz/technologies/springfield/springfield.pdf.

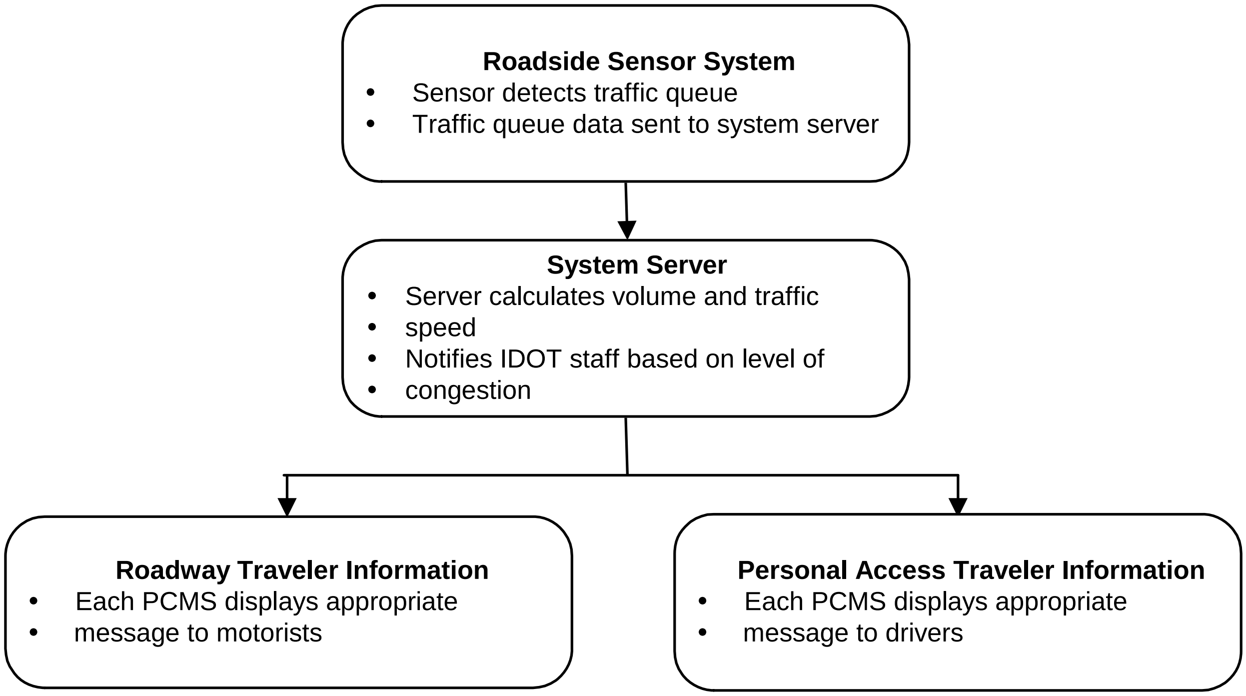

Figure 15. System Operation
Source: Intelligent Transportation Systems in Work Zones: A Cross-Cutting Study

Project Site. The construction project entailed reconstructing the Lake Springfield Bridge on I-55, improving I-55 south of Springfield, and improving the Toronto Road and Southwind Road overpasses. Reconstruction of the Lake Springfield Bridge involved first closing the southbound span and diverting southbound traffic onto the northbound span, and then reversing the process once work on the southbound span was complete. IDOT required the vehicles to reduce their speed to 45 mph from 55 mph.

Evaluation. IDOT officials expressed satisfaction over system performance though the system was not formally evaluated.

Arizona DOT System[46]

The Arizona DOT System has characteristics similar to other portable ATISs, but it was used primarily to enforce maximum-delay provisions in the construction contract. The information obtained was not communicated directly to drivers.

System Setup. The system consisted of two monitoring stations and a central processor. Each monitoring station included an inductive loop embedded in the roadway, a control cabinet with a communications system, and two digital cameras (one for each direction of traffic) linked to the cabinet via fiber-optic cable. In addition, each camera was equipped with a light source to assist in reading license plates with plastic covers. The system required access to public utilities for a

[46] Federal Highway Administration, "Intelligent Transportation Systems in Work Zones, A Case Study, Reducing Congestion with the Use of a Traffic Management Contract, Incentive During the Reconstruction of Arizona State Route 68", October 2004, FHWA-HOP-04-032, Retrieved on August 22, 2005 from http://www.ops.fhwa.dot.gov/wz/technologies/arizona/.

power source since power requirements for the lighting system made the use of solar power prohibitively expensive.

The system used point-to-point microwave communication technology that was already available at the project location. This communication system provided substantial data throughput (as much as 800 MB per second). The only drawback to this method of communication was the need for line-of-sight, which necessitated the installation of repeaters to relay signals from the roadside sites to the main transmitter.

System Operations. The system captured, immediately encrypted, and then stored images of license plate numbers as vehicles entered and left the work zone. Vehicles passing over the inductive loops triggered the digital imaging process. The monitoring stations captured digital images of the vehicles' rear tag numbers and stored them locally. The system would then send the encrypted images to the central processing station every 10 minutes. The central processor compared the encrypted images to match vehicles entering the work zone with vehicles leaving the work zone. The processor then compared the time a vehicle tag was detected entering the work zone with the time it was detected leaving the work zone to determine total travel time.

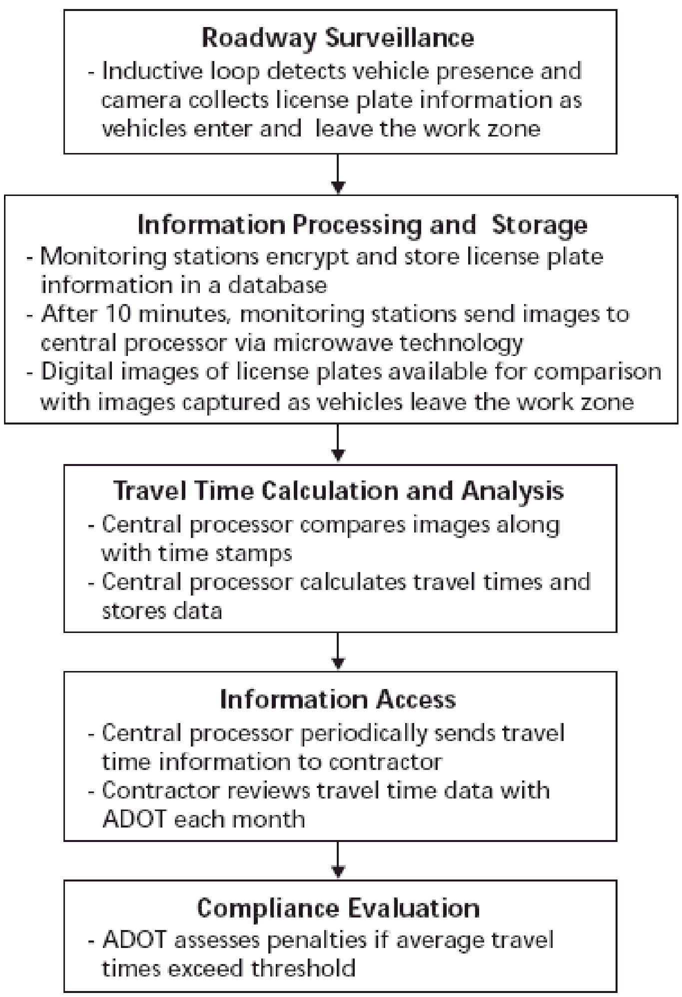

Figure 16. System Operation
Source: Intelligent Transportation Systems in Work Zones: A Case Study

System Performance. The system functioned as intended. It was able to read approximately 60 percent and match approximately 11 percent of the license plates photographed during the operation. ADOT considered this level of performance to be adequate.

System Evaluation. Overall, both ADOT project managers and the contractor were satisfied with the performance of the system and with the concept of the travel time incentive/disincentive clause, though no formal system evaluation was performed.

Issues and Impacts. Drivers initially voiced concern about privacy issues due to the use of cameras to photograph license plates. This issue was addressed by informing the public, through the use of newsletters and other public outreach methods, that the system immediately encrypts all license plate numbers before archiving them so that no actual license plate information is retrievable. This action ultimately eased any privacy concerns of the public.

Although the contractor mounted the light and camera system behind construction signs to avoid causing distraction to drivers, some drivers complained that the light was distracting at night. These complaints diminished after the contractor adjusted the angle of the lights and ADOT educated the public about the purpose of the lights.

3. Criteria for Installation and Selection of an ATIS

The use of ATISs in work zones is relatively new, and extensive research has not been done on its effect or on its traffic characteristics[47]. ATISs are expensive to install and operate and need solid justification for the expenditure. The systems are designed for performing specific operations; therefore, it is essential to classify the systems based on the situations in which they can be used, type of information they provide, and the media for information dissemination. Major user and nonuser benefits can be forecasted for ATISs, so it is possible to perform an abbreviated cost-benefit analysis which would provide that justification. Convenient warrants for deployment are not available.

User benefits are principally travel time savings, safety improvements and operating costs. Nonuser benefits include air pollution emission reductions. Traffic simulation software can be applied to estimate some of these benefits. QuickZone and QUEWZ have been specifically designed for work zone applications. There are several microscopic simulation packages that can also be applied to work zones, including CORSIM (developed by FHWA) and many commercial software packages. In addition, there are dynamic traffic assignment packages that have provisions for estimating the impact of ITS deployment, including Dynasmart-P and DynaMIT-P sponsored by FHWA, as well as other products.

Benefits heavily depend on what the system is intended to accomplish. Based on their functionality, ATISs can be classified into following categories:

- Real-time integrated systems;
- Stand-alone warning systems;
- Other systems.

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[47] Bushman, R, C. Berthelot, "Estimating The Benefits Of Deploying Intelligent Transportation Systems In Work Zones", Transportation Research Board 83rd Annual Meeting CD-ROM, 2004.

Costs of deploying these systems vary considerably across categories, so it is unlikely that extensive analysis would be needed for anything other than real-time systems, which are the most expensive.

Below is the list of systems evaluated in this report, organized by the three categories. Beyond costs and benefits, the selection of the system depends upon the intended message, media for the message and the setting.

Category	Product
Real Time Systems	ADAPTIR
	IntelliZone
	TIPS
	Brown Real-time CMS control
	CALM/DLMS
	DELMTCS
	Work Zone Speed Advisory System
	Real Time Traffic Control System
	Arizona DOT System
	CHIPS (a software product)
Stand-alone Systems	SpeedGuard
	Speed Monitoring Display
	Mobile/Stationary Speed Boards
	D-25 Speed Advisory
Other Systems	Wizard CB Alert System
	Mobile HAR
	Safety Warning System

Figure 17. ATIS Products by Category

Messages and Media

Different traffic situations require different modes of information dissemination. Under certain circumstances, a written message might be more preferable than a voice message and vice versa. Different ATISs have different information dissemination capabilities and compatibility with other media. The systems have been listed below with the types of information they provide. A logical relationship exists between media and messages, as indicated in Figure 18.

System	Message Format	Media
IntelliZone	Written messages	PCMS
ADAPTIR	Written, voice messages	PCMS, HAR
CALM/DLMS	Written messages	PCMS
TIPS	Written messages, website	PCMS, Internet
Brown Real-Time CMS Control	Written messages	PCMS
Work Zone Speed Advisory System	Written messages, website	PCMS, Internet
SpeedGuard	Written messages	Speed Display
Speed Monitoring Display	Written messages	Speed Display
Mobile/Stationary Speed Boards	Written messages, warning flash	Speed Display, Strobe Flash
D-25 Speed Advisory	Written messages, warning flash	Speed Display, Strobe Flash
Wizard CB Alert system	Voice messages	CB channel radio
Mobile HAR	Voice messages	HAR
Safety Warning System	Voice messages, warning sounds	Radar detectors
Real Time Traffic Control System	Written messages	PCMS, Internet

Figure 18. The Message Formats and Media for Work Zone ATISs

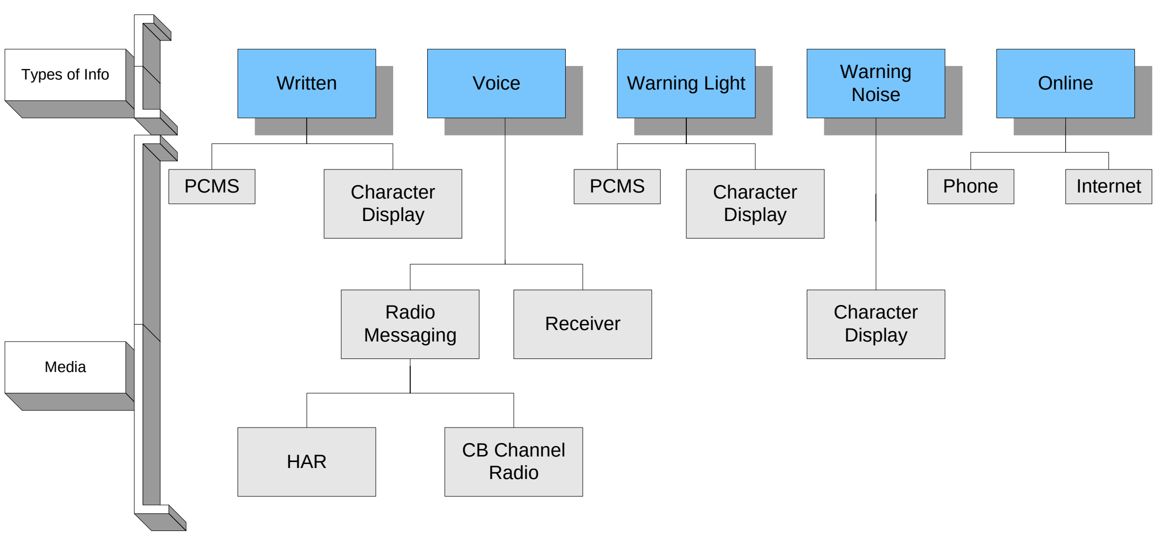

Figure 19. Relationship between Message Format and Media in a Work Zone ATIS

Message Content

Although the exact wording of messages can vary greatly depending upon the goals of the deployment and local variations in drivers, there is only a small set of advisories that have been communicated effectively using dynamic information.

- Information about delays or slow speeds ahead
- Warnings about stopped traffic ahead
- Advice on lane selection
- Advice on alternative route selection
- Warnings about excessive driving speeds
- Warnings about potential hazards ahead

The limited display capabilities of some devices greatly constrain the amount of detail that can be provided. Other warnings that are appropriate for static signs can also be communicated through the ATIS when convenient.

Setting

The setting of the work zone is important when selecting the ideal ATIS for a particular task and location. Figure 20 illustrates how settings might be classified for ATIS deployment in work zones. The setting depends upon the intensity, duration, congestion levels, driver decision opportunities, and existence of other media and driver experience (roughly classified as urban or rural).

- *Intensity.* The extent of the capacity reduction, usually measured in number of lanes closed or percent of capacity removed.
- *Duration.* The length of time (week, months) that the work zone is active.
- *Congestion Levels Expected.* The expected level of inconvenience to drivers, usually measured in delay or queue length (miles or minutes), both of which depend upon work zone capacity and approaching volumes.
- *Opportunity for Driver Decisions.* The availability of alternative routes and off-ramps.
- *Urban or Rural.* A rough measure of the amount of pre-trip or en route information already available to drivers, either through media other than the ATIS or through experience. Urban drivers are assumed to be more experienced and have greater access to a variety of information sources.

ATIS deployment in work zones makes the greatest sense when intensity is high, duration is long, congestion levels are expected to be high, driver decision opportunities exist, and the surrounding land use is rural.

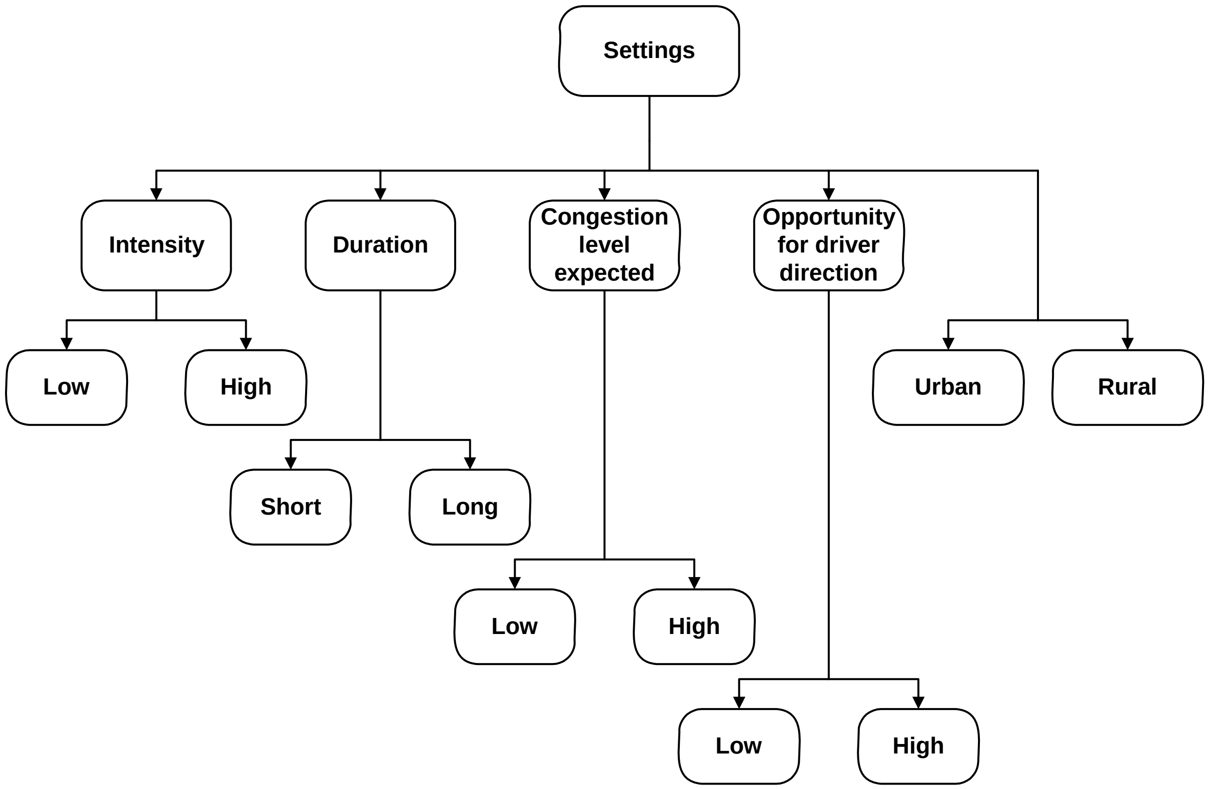

Figure 20. Variables Describing the Work Zone Setting for ATIS Deployment

Generic Systems

Ideally, the decision to deploy an ATIS should be made independently of the unique aspects of a particular product. Experience has shown that many products have a variety of hardware configurations and messaging capabilities. Within the sequence of decisions, just as with any project, the need for any ATIS should be established ahead of the choice of a vendor to supply the system. ATISs can be organized as to the components they use. Below is a list of eight generic systems that can be considered while making deployment decisions.

Real-time Systems

Detector(s) + Processing unit + VMS(s)

Detector(s) + Processing unit + VMS(s) + Radio Messaging

Detector(s) + Processing unit + VMS(s) + Radio Messaging + Website

Stand Alone Systems

Radar + Speed display(s)

Radar + Speed displays + Strobe flash

Radar + Speed displays + Messaging Device

Radio Messaging Systems

Radar Detectors

Work Zone Traffic Analysis Software

Several software packages are available to estimate the delay in work zone under different conditions. These software packages differ considerably in their assumptions, input requirements, and capabilities. Software should be selected on the basis of both its realism and its usability. The major questions to ask about the realism of software are listed below.

- Is driver behavior and traffic flow relationships adequately represented?
- Is it possible for the software to set its own diversion rates or allow users to create diversion due to specific events within the work zone? Is the method of creating diversion realistic?
- Is there an ability to establish traffic equilibrium or some appropriate approximation?
- Is the software sufficiently dynamic to handle short-term effects of messages, incidents, or other changes in capacity?
- Does the software calculate delays, operating costs, air pollution emissions, or safety indices?
- Does the software require at most the information normally available when planning work zones?
- Has the software been subjected to sufficient testing in work zone applications?

We are unaware of any software packages for which all the answers are yes. Since software capabilities rapidly evolve, it is not appropriate in this report to try to answer these questions for any particular package at this time.

A practical constraint on the selection of software is its ease of use. Software products with long and steep learning curves or software products with unreasonable data entry requirements are not acceptable for planning most work zones.

Work Zone Specific Software

QuickZone

QuickZone, implemented within Excel, was developed by FHWA for quick and flexible estimation of work zone delay. The ease-of-use goal for QuickZone is less than three hours to complete an analysis. It is being distributed as open-source software, available for modification and customization as per requirements.

QuickZone requires four critical data components:

- A network that describes the mainline facility under construction as well as adjacent alternatives in the travel corridor;
- Data that describes the plan for work zone phasing, including capacity reductions;
- Patterns of pre-construction corridor traffic patterns; and
- Descriptions of various mitigation strategies to be implemented in each phase, including estimates of capacity changes from these mitigation strategies.

QuickZone compares expected travel demand against proposed capacity by facility on an hour-by-hour basis for the life of the project to estimate delay and mainline queue growth. Traffic demand is varied by hour and by season across all project phases.

Delay is calculated at each bottleneck within the system by tracking the number of queued vehicles. Total system delay without any behavioral response may then be compared with system delay assuming a behavioral response from en route information provided to drivers.

QUEWZ-98[48]

QUEWZ-98 is a microcomputer analysis tool for planning and scheduling use in freeway work zone lane closures. It analyzes traffic conditions on a freeway segment with and without a lane closure in place and provides estimates of the additional road user costs and of the queuing resulting from a work zone lane closure. It calculates speed from a speed/flow curve. It uses cumulative arrival/departure diagram to find queue length.[49] The road user costs calculated include travel time, vehicle operating costs, and excess emissions.

Microscopic Traffic Simulation

Microscopic traffic simulation packages, such as CORSIM, offer a highly flexible method of analysis of a large variety of work zones. These packages are principally designed for operational studies of complex traffic systems, but can be adapted to work zone planning.

Microscopic traffic simulation packages create synthetic vehicles with synthetic drivers who have stochastically varying behaviors. Such models are calibrated to local conditions, and have the capability of analyzing many different geometries and traffic control devices. Microscopic simulation models need very accurate descriptions of the highway itself and traffic controls, which requires considerable expertise and staff time. Some commercial packages are expensive. Models can mix multiple classes of vehicles, but do not usually exhibit equilibrium conditions following Wardrop's first principle. Simply put, Wardrop's first principle requires consistency between delays and route choice on a network.

Dynamic Traffic Assignment

Dynamic traffic assignment (DTA) software packages have recently emerged as a practical tool for analyzing a variety of traffic situations, including work zones. DTA has been described as mesoscopic or macroscopic, depending upon the sophistication of the delay estimation routines. Similarly to microscopic traffic models, DTA tracks vehicles in both space and time. Unlike microscopic models, DTA is deterministic and tracks packets of vehicles, each packet starting at the roughly the same time and place and going to roughly the same destination. DTA models are capable of satisfying Wardrop's first principle. FHWA has sponsored the development of two DTA software packages, specifically for ITS purposes. DTA is also a feature of several travel forecasting software packages, although their applicability to ITS applications is more restricted.

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[48] Texas Transportation Institute, "QUEWZ-98", Retrieved on August 22, 2005 from http://tti.tamu.edu/product/software/quewz.stm.

[49] Chitturi, Madhav V., Rahim F. Benekohal, "Comparison of Queue Length Estimates from QUEWZ, FRESIM and Quick Zone with Field Data",University of Illinois at Urbana-Champaign, Retrieved on August 22, 2005 from http://www.ite.org/Conference/Presentations/Session27-Benekohal.ppt.

For example, the way in which Dynasmart-P handles ATIS has been briefly described in a report on ITS deployment strategies:[50]

There are three different types of messages: speed advisory, route advisory and congestion warning. Each message has it own starting and ending time input for the user.

- *For the speed advisory messages there is a threshold speed that is specified by the user. This threshold can be positive or negative. Dynasmart-P will increase or decrease the speed on the link by that percent.*
- *For route advisory messages a path number (among K shortest paths) is specified by the user that indicates where vehicles will divert. In addition, it is necessary to indicate which vehicles are affected by the message: vehicles bound for all destinations or just one destination.*
- *For congestion warning messages the percent of VMS responsive vehicles on a specific link is specified. They will be rerouted to another path, either the current best path or a random path among the K-shortest paths.*

Although Dynasmart-P can divert drivers due to VMSs, it requires user input as to the behavioral response of drivers to signs.

Selecting an ATIS

Step 1. Establish objectives for the ATIS. These objectives may be stated succinctly in just a few sentences. Examples are provided in earlier chapters of this report.

Step 2. Based on the objectives, vehicle mix, expected road conditions, and driver population, select the general category of message content. Select from the six categories listed earlier in this chapter. Also select general warning messages that may supplement the dynamic messages or be displayed when there is no need for dynamic messages.

Step 3. Assemble data about the work zone. Data need to be collected that will allow a complete analysis of intensity, duration, congestion, driver decision opportunities, and the quality of other information (urban/rural). Critical pieces of information are work zone capacity and the availability of alternative routes. It is also necessary to obtain a value for drivers' time savings and an average value for each eliminated crash.

Step 4. Analyze data for delay and queuing, safety, vehicle operating costs, and emissions. Software is helpful for this step but not necessary for simple work zones. A cumulative flow diagram (see next section) might be a sufficient amount of analysis for estimating delays and queuing under normal work zone operations and probable incidents. It is very important to estimate the amount of diversion that is expected in the absence of ATIS so that a valid forecast of approaching volume can be made. This diversion would be related to the amount of pertinent information already available to drivers.

Step 5. Estimate the cost of each generic system, properly configured to accomplish the information dissemination task for the work zone.

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[50] Horowitz, Alan J., Juan Duarte, Andrew Cross, "Long Range Deployment of ITS Strategies: Concept Definition", Midwest Regional University Transportation Center, Project 02 – 04, February 2003, Retrieved on August 22, 2005 from http://www.mrutc.org/research/0204/ITSLongRangeDeployment1.pdf.

Step 6. Estimate the low-end user benefits associated with delay reduction and safety improvements that can be specifically associated with each ATIS. A very conservative estimate should be made. In order to see delay reduction benefits, there must be an opportunity for drivers to divert given the information provided. The largest measured diversion to date due to an ATIS in a work zone is about 10%. In order to see safety improvements, there must be an expectation of fewer rear-end crashes due to increases in driver alertness and smoother traffic flow or fewer crashes involving work zone equipment or personnel due to reductions in speed.

Step 7. Selecting a category of ATIS, either real-time or stand-alone systems.

- Real-time systems that predict delays and provide detour information. Such systems should be selected in situations where excessive queuing is predicted. Any rural location where recurring queue lengths are expected to be greater than 15 minutes is a candidate for a real-time system. Any rural or urban location with infrequent queues greater than 30 minutes and where en route information is sparse is a candidate for a real-time system. Alternate routes must exist. There is little reason for real-time systems where traffic volumes are consistently below 1500 vehicles per hour per lane (remaining open).
- Real-time systems that provide lane choice instructions. Such systems can reduce physical queue length and should be selected in situations where long queues might result in an unduly hazardous situation (e.g., poor sight distance to the rear of a queue) or block other traffic flow (e.g., upstream off-ramps or at-grade intersections).
- Stand-alone systems that warn the drivers of excessive speeds. Such systems are cost effective and should be used for controlling the speeds of vehicles in situations of low congestion or where real-time systems are not warranted.
- Any system or combination of systems that may correct a potentially hazardous situation that cannot be fully corrected by static signing.

“Other” systems have not yet demonstrated sufficient merit by themselves and should only be considered in special cases or in combination with a real-time system or a stand-alone system.

A variety of components can be selected based on type of information to be disseminated, the intensity of the work zone, duration, opportunity for driver decision and the budget. If the low-end, conservative estimate of benefits exceeds the costs for at least one generic configuration, then the category has merit.

Step 8. Select the generic system within the category that has the highest ratio of low-end benefits to costs. Determine whether there are substantial differences in benefits not already included in the analysis that might affect the decision. Intangible benefits, such as driver satisfaction and reduction of road rage, should be considered only if the decision is not otherwise clear. If an assumption of diversion has been made in the estimate of benefits, then the generic system must have sufficient number and placement of media to achieve that diversion.

Step 9. Define standards of accuracy for the information provided by the system. Define standards of reliability for the system.

Step 10. Select the vendor that can meet the capabilities of the chosen generic system.

Step 11. In consultation with the vendor, develop a plan of action to assure that the system meets accuracy and reliability standards. Write message content and define the specific traffic conditions under which each message is displayed. Coordinate static signing with the ATIS.

Coordinate other information sources, such as Web pages and 511 information services, with the ATIS.

Estimating Queuing with Cumulative Flow Diagrams

For many work zones, the amount of delay can be easily estimated using cumulative flow diagrams. There are three major cases to consider: normal flow, work zone flow without en-route diversion, and work zone flow with en-route diversion. Cumulative flow diagrams can also be used to analyze numerous special cases, such as incidents. The normal flow case is a classical bottleneck problem, which is illustrated in Figure 21. This situation is typical of a short-term work zone or other work zones within the first few days of construction activity in an urban area, if there is little publicity. The total delay is the area between the arrival curve, A(t), and the departure curve, D(t), which is shaded. The arrival curve is the cumulative number of vehicles that arrive just upstream of the taper and join whatever queue might exist. The slope of the arrival curve is equal to the upstream flow rate approaching the work zone. The departure curve is of constant slope, equal to the work zone capacity, when a queue is present. The arrival curve and the departure curve coincide when there is no queue.

Figure 22 illustrates the same work zone after several days or when there is considerable publicity given to the construction activities. Capacity of the work zones is the same as in Figure 22, but the upstream arrival rate is less. The amount of diversion from the work zone would depend upon the availability of alternate routes and would tend toward equilibrium conditions. The reduction in upstream traffic flow would be less in rural areas, where many drivers have only a limited amount of information about possible delays.

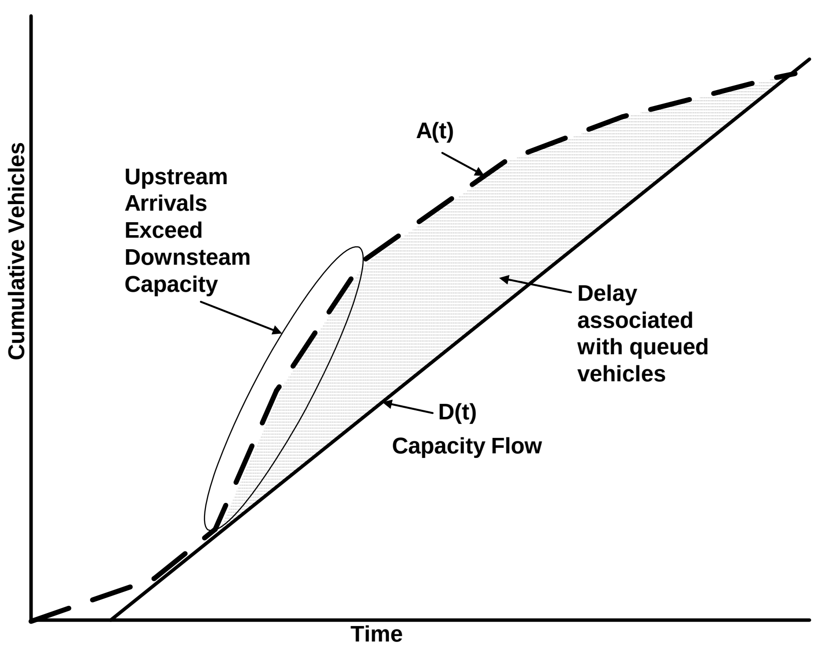

Figure 21. Cumulative Flow Diagram of a Work Zone without Pre-trip Planning or Diversion

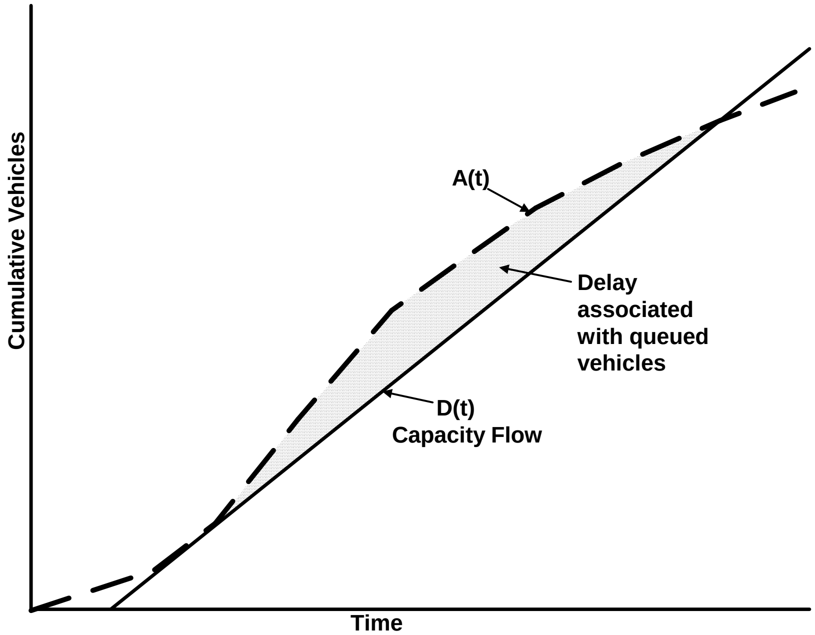

Figure 22. Cumulative Flow Diagram of a Work Zone with Pre-trip Planning

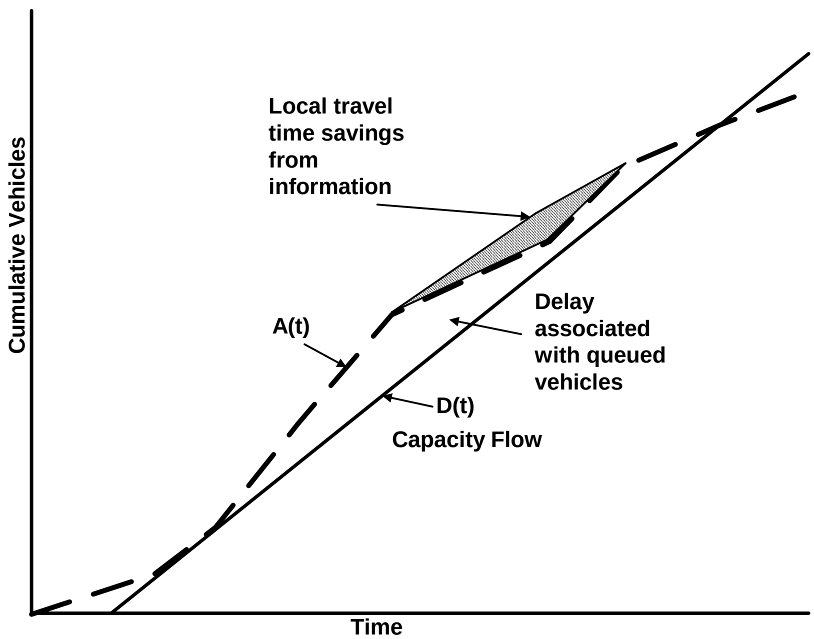

Figure 23. Cumulative Flow Diagram of a Work Zone, with Pre-trip Planning and En Route Diversion

Figure 23 illustrates the effect on en route information about delays, which causes some drivers, who intended to pass through the work zone, to alter their routes. Figure 23 is almost identical to Figure 22, except that vehicles reaching an upstream location well head of the work zone are alerted to the possibility of long delays. Some of these drivers take alternate routes. The travel time savings, shown in the shaded area, are the local benefits to drivers passing through the work zone. Diverted drivers may or may not incur delays on their alternate route. Any such delays would reduce the benefits of the information.

An Example of Calculation of Diversion Benefits of an ATIS

Data from the TIPS deployment in Wisconsin can be used to demonstrate a quick procedure for forecasting benefits of diversion within rural work zones. As described earlier, TIPS was deployed southbound on I-94 in Racine County. One of three lanes was closed. Because of heavy vacation traffic in summer months, traffic volumes on Sunday exceeded those on weekdays.

TIPS was found to encourage diversion of between 7% to 10% from I-94. Multiple diversion routes existed on nearby arterials and all of those arterials operated at essentially free-flow conditions, except at traffic controls, which were sparse. Table 2 contains hour-by-hour volumes for I-94 during construction but before TIPS was deployed. Separate data is given for weekdays and weekends. By analysis of detectors just inside the work zone, a capacity of almost 2900 vehicles per hour could be established. Table 2 also shows the calculated queue lengths for each hour.

Table 2. Volumes Approaching Work Zone Before Deployment and Calculated Queue Lengths

	Weekdays		Weekends	
Hour	Volume	Queue Length	Volume	Queue
12-1 am	521	0	760	0
1-2 am	394	0	553	0
2-3 am	361	0	520	0
3-4 am	427	0	321	0
4-5 am	755	0	359	0
5-6 am	1502	0	532	0
6-7 am	2253	0	777	0
7-8 am	2321	0	1027	0
8-9 am	2031	0	1365	0
9-10 am	1982	0	1952	0
10-11 am	2078	0	2425	0
11-12 am	2288	0	2915	15
12-1 pm	2450	0	3165	280
1-2 pm	2654	0	3279	659
2-3 pm	2966	66	3355	1114
3-4 pm	3165	331	3295	1509
4-5 pm	3365	796	3215	1824
5-6 pm	3152	1048	2886	1810
6-7 pm	2428	576	2489	1399
7-8 pm	1869	0	2112	611
8-9 pm	1657	0	1796	0
9-10 pm	1511	0	1441	0
10-11 pm	1240	0	1048	0
11-12 pm	915	0	668	0

This benefit analysis is done with a temporal resolution of 1 hour. “Weekends” volumes are from Sundays, and “Weekdays” volumes are averages from Thursdays and Fridays. Queue lengths are found by simply subtracting the capacity from the approaching volume and accumulating the excess. Total vehicle hours of queuing delay may be found by summing the queue lengths over all hours.

Data in Table 3 are the approaching volumes assuming a 7% diversion rate on weekends and a 5% diversion rate on weekdays. These diversion percentages were applied only to hours in which a queue existed in Table 2. It can be seen that these small diversion percentages can have a large impact on queue length.

US DOT recommends a value of time in travel equal to 70% of the prevailing wage rate for intercity travel[51]. For southeast Wisconsin, the value of time would translate to about $14 per hour. For this example, passengers are ignored.

In the TIPS deployment, diverting drivers almost invariably reached their destinations sooner, as indicated by floating car runs made at the time. The average queued vehicle on weekends before deployment was delayed about 23 minutes and the average queued vehicle on weekdays was delayed about 10 minutes. The volume weighted delay was about 16 minutes. It is conservatively assumed that ½ of this delay was actually saved by diverting.

The total benefit of this deployment was therefore estimated to be $324,000 per week.[52] This estimate ignores any congestion impacts on surrounding streets, which is appropriate in this case.

It is important to observe that the "before" volumes in this analysis are with the work zone, but without TIPS. Work zones are known to discourage traffic by themselves, so it is incorrect to use unmodified traffic counts taken before construction is started.

In this example the diversion percentages were uniformly applied to all vehicles during hours in which a queue was present in the before period. A better method would have been to assume a greater amount of diversion during times when queues were particularly long. Unfortunately, there is little available data to suggest how the diversion percentages could be varied over time.

The cost of a system similar to TIPS would likely be between $200,000 and $400,000 for a full construction season. Thus, it is fairly easy to conclude that TIPS's benefit-cost ratio is much greater than 1 for this deployment, even without considering safety, fuel or emissions impacts.

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[51] Kruesi, Frank E., "The Value of Saving Travel Time: Departmental Guidance for Conducting Economic Evaluations", April 9, 1997, Retrieved on August 22, 2005 from http://ostpxweb.dot.gov/policy/Data/VOT97guid.pdf.

[52] Delay from queuing is the sum of the queue lengths times the time interval over which the queue are measured (1 hour in this case). For example, weekday delay before is 1*(66+331+796+1048+576) = 2817 vehicle hours. For weekdays after, there are only three hours with queues having lengths of 107, 404, and 498 vehicles between 3 pm and 6 pm. Thus, the total delay is just 1009 hours. The time savings across all 5 week days is then 5*(2817-1009) or 9040 hours. The calculation for week ends is similar, giving 13764 vehicle hours of time savings across two days. Total benefits from queue reduction alone is then $14*(9040+13764) or $319,256. The remaining, smaller part of the benefits comes from time savings of the diverted vehicles because of a faster alternative route.

Table 3. Volumes Approaching Work Zone After Deployment and Calculated Queue Lengths, Assuming a 7% Diversion Rate on Weekends and 5% Diversion Rate on Weekdays

	Weekdays		Weekends	
Hour	Volume	Queue Length	Volume	Queue
12-1 am	521	0	760	0
1-2 am	394	0	553	0
2-3 am	361	0	520	0
3-4 am	427	0	321	0
4-5 am	755	0	359	0
5-6 am	1502	0	532	0
6-7 am	2253	0	777	0
7-8 am	2321	0	1027	0
8-9 am	2031	0	1365	0
9-10 am	1982	0	1952	0
10-11 am	2078	0	2425	0
11-12 am	2288	0	2711	0
12-1 pm	2450	0	2943	43
1-2 pm	2654	0	3049	192
2-3 pm	2818	0	3120	412
3-4 pm	3007	107	3064	576
4-5 pm	3197	404	2990	666
5-6 pm	2994	498	2684	450
6-7 pm	2307	0	2315	0
7-8 pm	1869	0	1964	0
8-9 pm	1657	0	1796	0
9-10 pm	1511	0	1441	0
10-11 pm	1240	0	1048	0
11-12 pm	915	0	668	0

4. Conclusions

Devices for portable ATISs are commercially available in essentially three categories:

- Real-time systems
- Stand-alone systems
- Other systems

Although there have been extensive evaluations of products in each category, there are still many unanswered questions about their effectiveness in a variety of environments. There is a need for additional experience using them within a variety of work zones.

Real-time systems have the greatest potential benefits, but also have the greatest potential costs. Real-time systems collect and process traffic data and then inform drivers of conditions ahead using variable messages signs or other media. The quality of the information provided by these systems has improved from the earliest applications. Real-time systems have the potential of alerting drivers to intermittent hazards, reducing driver frustration, improving merging, and encouraging diversion. If connected to a Web site or a 511 service, the systems can also aid pre-trip planning. Since there are no stock configurations of these systems, careful planning is required to properly match the equipment to the work zone. Real-time systems offer little advantage over static signing or stand-alone systems when traffic is light.

Stand-alone systems also provide instantaneous information, but are limited to simple tasks such a displaying a single vehicle's speed. Stand-alone systems are less flexible and less costly than real-time systems. Tests of these systems have demonstrated their effectiveness in calming traffic in and near work zones. These systems are effective in all traffic conditions. They should be deployed anytime speeding might be a problem and static signing might be insufficient to control that speeding.

Other systems attempt to communicate with drivers through receiving equipment already present in vehicles, such as CB radios or radar detectors. Because the availability of receivers in any given vehicle is unknown or illegal, the information must be duplicated by static signing or static highway advisory radio or both. Studies of these systems did not find a strong impact on driver behavior. If there is a need to communicate with trucks only, CB radio can reach a high percentage of truck drivers. However, not every truck driver is tuned to a channel 19, so CB radio can only serve as a secondary means of communication.

Real-time systems have provided messages in these categories.

- General information about work zone activity.
- Speed of traffic further downstream, including whether traffic is stopped.
- Instructions or advice on lane choice.
- Information about the amount of delay might be expected.

It is possible for a single system to provide different messages, depending upon traffic conditions, construction activities, lane closures, and time of day.

Safety benefits of any of these systems are largely inferred. Study periods have been too short to provide statistically significant samples of crashes. Nonetheless, many of these systems have been shown to reduce driver frustration, reduce speeding, and otherwise calm traffic. Some systems can also reduce the amount of traffic through the work zone. These effects would suggest that work zones would be safer when the systems are deployed.

The largest source of benefits from these systems comes from reductions in traffic flow, which can reduce queuing, delay, and crashes. In order for traffic reductions to occur, the system must convince some drivers to divert. Diversion percentages between 4.5% and 10% have been reported in the literature. Even these small percentages can have substantial time-savings benefits over the life of the construction project.

One of the most prevalent design issues with ATISs is the message content. With only 24 characters in each of two phases, there is very little room on a portable changeable message sign. Messages from highway advisory radio and CB broadcasts also need to be succinct. In regions of the US with large Spanish-speaking populations, bilingual messages are necessary.

Portable ATISs should be considered during the planning of traffic management for any work zone. States should develop comprehensive guidelines for the deployment of portable ATISs. Warrants, standards, or guidance for the deployment of portable ATISs should be added to Chapter 6 of the MUTCD.

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