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Identification of Traffic Control Devices for Mobile and Short Duration Work Operations

FINAL REPORT

July 2006

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16. Abstract

This report documents and summarizes the study "Identification of Traffic Control Devices for Mobile and Short Duration Work Operations," for the New Jersey Department of Transportation. The study was conducted in three tasks: 1. Literature Search, 2. Evaluation Criteria and Analysis, and 3. Identify Guidelines to Eliminate Driver Inattentiveness, and Design Alternative Strategies and Techniques for Traffic Control. The study was conducted by two groups: the Region 2, University Transportation Research Center, City College of New York and the Institute for Transportation Research and Education, North Carolina State University. Working papers were completed for each of those tasks.

The objective of this research project is to study mobile and short duration work zone safety with particular attention to the identification of work zone safety devices, information systems for the reduction of safety and congestion, and implementation of innovative techniques to reduce delays and crashes due to work zones. The research approach includes a literature search to identify the potential technologies and information systems for mobile and short duration work operations. Potential technologies and information systems were identified from the Transportation Research Board and National Cooperative Highway Research Program reports, international sources, Strategic Highway Research Program reports, other State DOT correspondence, and manufacturers and vendors. Recommendations are made to fabricate and implement the Balsi Beam with the assistance of Caltrans and the FHWA on selected short duration work zones and implement "Bright Zone Signs and Beacon Wear Safety Vests" to improve work safety and visibility in work zones.

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EXECUTIVE SUMMARY

Introduction

This report documents and summarizes the study “Identification of Traffic Control Devices for Mobile and Short Duration Work Operations,” for the New Jersey Department of Transportation. The study was conducted in three tasks: 1. Literature Search, 2. Evaluation Criteria and Analysis, and 3. Identify Guidelines to Eliminate Driver Inattentiveness, and Design Alternative Strategies and Techniques for Traffic Control. The study was conducted by two groups: the Region 2, University Transportation Research Center, City College of New York and the Institute for Transportation Research and Education, North Carolina State University. Working papers were completed for each of those tasks.

The objective of this research project is to study mobile and short duration work zone safety with particular attention to the identification of work zone safety devices, information systems for the reduction of safety and congestion, and implementation of innovative techniques to reduce delays and crashes due to work zones. The specific objectives are to:

- Identify state-of-the art work zone safety technologies to improve worker safety in mobile work zone and short term maintenance operations,
- Identify information systems for work zone traffic control to reduce delays and crashes,
- Identify “best practices” for the use of law enforcement to improve work zone safety,
- Identify key issues to be considered from public outreach and information systems.
- The identified work zone safety items will provide improvements for maximum protection of the motoring public, protection of exposed workers in the work zone and of workers in the set up of the work zone, and will meet the current standards established by internal policies of the NJDOT.

Research Approach

The research approach includes a literature search to identify the potential technologies and information systems for mobile and short duration work operations. Potential technologies and information systems were identified from the Transportation Research Board and National Cooperative Highway Research Program reports, international sources, Strategic Highway Research Program reports, other State DOT correspondence, and manufacturers and vendors. The identified technologies and information systems were researched to obtain users and technical information on their effectiveness.

For this study, mobile and short duration work zones are defined as work operations that move along the pavement or shoulder intermittently or continuously, with frequent stops or one fixed area where the work operations require a short time to complete. In all of these situations, extensive protection systems would not be practicable for the completion of the work or traffic disruption.

The Manual on Uniform Traffic Control Devices provides uniform standards for safety protection of workers and traffic control during work operations. The manual suggests signs, light boards, arrow panels, and truck mounted attenuators in a caravan of vehicles to provide state-of-the art protection for exposed works, warn and alert motorists, and provide traffic control around the work area.

Work Zone Safety Technologies

TRB, NCHRP and State DOT Sources

This literature search focused on safety technologies for mobile and short duration work zone safety technologies from Transportation Research Board and National Cooperative Research Program publications, FHWA, State DOT and other agency publications which include web sites of most national safety organizations. The search identified nine devices which are used by State agencies or have the potential for use in mobile and short duration work zones. The devices are:

- Fluorescent/Bright Signs
- Reflectorized/Bright Suits and Vests
- Drone Radar and Speed Indicator/Displays
- Remotely Operated Autoflagger
- Truck Mounted Attenuators and Message Boards
- CB Wizard Alert System
- Rumble Strips
- Intrusion Alarm
- Lane Merger System

The TRB and NCHRP literature indicates that State DOTs use the MUTCD and caravan approach to mobile and short duration work zone safety situations. Texas DOT noted operational problems that included the improper use of arrow-boards, the lack of uniform procedures for freeway entry and exit, large spacing between caravan vehicles, and unnecessary lane blockage by the caravan. The recommended solutions to the problems are improved communications, effective advance signing, controlled caravan length, caravan positioning procedures observed during certain operation:, and modifications to procedures observed in others. Missouri DOT tested three traffic control devices: white lane drop arrows, orange rumble strips, and the CB wizard alert system-were tested for their effectiveness in improving merging and reducing speed and speed variance at an interstate highway work zone. All three devices appear to be effective for improving safety in work zones.

The States DOTS of Kansas, Nebraska, Iowa, and Missouri conducted a pooled-fund study of innovative devices designed to improve the safety and efficiency with which highway maintenance is conducted. In the state of Kansas, a total of nine devices were evaluated, including lighted raised pavement markers, CB-radio warning systems, and radar-triggered speed displays. All of the products showed potential for improving work zone safety and operations.

An NCHRP study focused on human response to warning lights which varied by the type of light both in closed field and operational tests. It was found during research that no one light is maximally effective in both transmitting information and gaining attention. Therefore several of the lighting recommendations combine the two types of light in order to ensure optimum information transmission and conspicuity. Some of the devices like shadow vehicles were found to be very effective in producing desired results but involved substantial costs as well.

The Caltrans Worker Safety program includes construction and maintenance worker safety orientation and instruction, the use of protective vehicles – shadow vehicles, barrier vehicles and advance warning vehicles for all work zones and a District Driver Training Program to eliminate employee preventable vehicle accidents.

The New York Sate Department of Transportation(5, 7) has initiated Highway Work Zone Safety Awareness bulletins, partnered with the New York State Police and identified specific features for improved mobile and short duration work zones. The agency identified six intrusion countermeasures: increased police enforcement, reduced channelization spacing, enhanced flagger stations, rumble strips, reduced speed limits, dynamic message signs, and drone radar.

Strategic Highway Research Program

The Strategic Highway Research Program (SHRP) was initiated to improve the safety of workers, improve efficiency of work operations and improve traffic control. The primary emphasize of SHRP was work zone safety concepts and research of applicable devices.

Of the ten initial devices researched, tested, and developed by SHRP, the Flashing Stop/Slow Paddles is the only device with a potential for short duration and mobile work zone traffic control, and therefore worker safety. The NJDOT has approved this device for use by maintenance forces. However, the device is clumsy, heavy and requires frequent battery changes. An initial evaluation indicates that the device is somewhat effective for traffic control and worker safety.

Recently, SHRP researched five devices that have the potential for increased work efficiency, and improved worker safety by eliminating direct worker exposure to traffic and mitigating errand vehicles. The five devices which are discussed the report are:

- Cone Shooter
- Automated Pavement Crack Sealers
- Automated Debris Removal Vehicle
- Balsi Beam
- Robotic Highway Safety Markers.

All of the above five devices appear to have some practical application. However, the Balsi Beam has the greatest potential for protecting exposed workers in short duration work operations. The beam provides a positive protection from errand vehicles and is crash worthy as tested by NCHRP criteria. Unlike portable concrete median barrier which is time consuming and labor/equipment intensive to set up, and requires a 42 inch clear zone between the barrier and the worker, the Balsi Beam can be set up in less than 10 minutes and requires no clear zone between the beam and workers. The California Department of Transportation is presently implementing the barrier for specialized concrete construction and bridge repair operations on high speed interstate highways. The beam can be used in maintenance operations wherever workers are exposed to traffic in a limited area for several hours. No workers have been killed or injured while working behind the beam.

California Balsi Beam and Presentation

The researchers met with California Department of Transportation engineers to observe the operation of the Balsi Beam and talk to Caltrans maintenance workers. The Caltrans is implementing the second generation prototype beam with a bridge and concrete repair crew on Route I-80 between Marysville and Reno, NV.

Caltrans uses the beam for medina barrier repairs, bridge deck patching and repairs, slab replacement and joint repairs, installation of bridge sealers and guiderail and parapet repairs. The beam is used in conjunction with other safety equipment - - TMAs, trucks, signs and safety set up . The bridge maintenance crew and foreman were very enthusiastic about using the beam. The crew is able to use air compressors, bobcats and other equipment in the work area of the beam. Suggestions have been made to incorporate some of the equipment on the beam-tractor to make the beam a multi-functional piece of equipment.

Essentially, Caltrans, Division of Equipment, designed the beam with some assistance from TTI and funding from the FHWA. Caltrans fabricates and builds their own trucks and large equipment for maintenance, so they have extensive equipment design and fabricating experience. Caltrans and the FHWA would like to implement the beam in the east coast DOTs. At this time, Caltrans does not have the resources to demonstrate the beam throughout the country, and would like other State DOTs to be involved in implementation. The researchers believe this is an opportunity for NJDOT to improve worker safety, be a showcase and assist the FHWA for the implementation of the beam in the eastern states.

The researchers presented the information on the Balsi Beam and a PowerPoint presentation to Region South and Region North Maintenance workers and engineers. Both regions were interested in the potential for the beam to protect workers. However, Region North has the best application for the beam on bridge and concrete repair projects along Route I-80 in Northern New Jersey.

Law Enforcement

In the report, "The Use of Uniformed Police Officers", the FHWA recommends the presence of uniformed police officers on Federal-aid highway work zones. It further recommends the use of automated enforcement and intrusions alarms as well as uniformed police officers to improve traffic safety at highway work zones. Our literatures search indicates that most State DOT s have programs and policy regarding the use of uniformed police officers at highway work zones.

Motorist Information, Education and Outreach Systems

Motorist Information, Education and Outreach Systems are important tools for State DOTs. Most DOTs and the FHWA have specific programs to inform the public and train workers.

Review of Work Operations

The researchers conducted five field observations of mobile and short duration work operations to analysis and compare current maintenance work zone operations with the MUTCD and other agencies, as well as interviews with work zone safety personnel. The safety for mobile operations of pothole patching, sweeping, spraying and mobile patching was in accordance with MUTCD requirements. Workers requested improved devices such as strobe lights and improved reflective materials for signs to get driver's attention.

Conclusions

The objective of the research project was to study mobile and short duration work zone safety. The objective was achieved successfully by suggesting existing and new measures, techniques and devices to better catch the driver's attention, improve traffic control within work zones, and recommendations to reduce delays and crashes due to work zones.

Devices and technologies were identified from information from TRB, NCHRP and other State DOT resources sources. These devices and technologies are being used or tested by State DOTs, and have the potential to improve the safety of exposed workers and the motoring public. The Safe Lites company produces “Bright Zone Signs and Beacon Wear Safety Vests” with a patented “GlowSkin” technology. This technology will improve worker visibility and safety in short duration work operations.

Five new SHRP products for the improved safety of workers and the motoring public were identified for potential implementation by the NJDOT. These devices and vehicles remove or enclose exposed workers in the work area by placing them in vehicles or behind fixed barriers. The Balsi Beam as developed and implemented by the California Department of Transportation and the FHWA, has the potential to improve safety of workers in short duration work operation in New Jersey.

The FHWA recommends the presence of uniform police officers in highway work zones. Many State DOTs have programs to train and coordinate police efforts for highway work zones. Motorist Information, Education and Outreach Systems are important tools for State DOTs. Most DOTs and the FHWA have specific programs to inform the public and train workers.

Based on the literature search and field inspections of mobile and short duration work zones, interviews with NJDOT personnel and the literature search of the cause of work zone accidents, the following conclusions and recommendations are presented:

- Most NJDOT work zone crashes are caused by careless driving, speeding and motorist inattention cause accidents, which are similar causes to crashes in work zones from the literature and other agencies. The most significant cause is motorist inattention to the work zone system and traffic conditions.

- NJDOT mobile and short duration work zones meet the safety standards for design and application specifications for traffic control during highway maintenance by *Manual on Uniform Traffic Control Devices (*MUTCD).
- Safety devices should be selected to reduce traffic speed through work zones, improve motorists' recognition of work zone hazards, and improve motorists' attention to signs and the work zone.
- Any new safety devices for mobile and short duration work zones should be implemented in conjunction with worker safety training, and public safety and education programs.

Recommendations

The NJDOT should fabricate and implement the Balsi Beam with the assistance of Caltrans and the FHWA on selected short duration work zones.

The NJDOT should implement "Bright Zone Signs" to improve work safety and visibility in work zones.

The researchers propose to develop a work plan to prepare a licensing agreement with Caltrans, prepare plans and specifications for bidding, investigate bidding and fabrication schemes such as fabrication at a facility in California, inspection and engineering expertise during fabrication, delivery of the beam, operation training and implementation studies with NJDOT engineers.

INTRODUCTION

Work zones are a necessary part of meeting the needs of our nation's aging transportation infrastructure. With the highway infrastructure getting older and requiring consistent maintenance, it is believed that there will be more work zones in the future. These work zones coupled with traffic on highways are a major source of future and present congestion. Due to this congestion, there are more chances of crashes expected, which is a major cause of concern to both workers and the traveling public. This increased frequency of work in the work zones makes it necessary to work at day and nighttime, requiring special precautionary measures to avoid hazards. It is estimated that work zones contribute to about 24% of highway delay making people more frustrated due to loss of time.

The final report documents and summarizes the study: "Identification of Traffic Control Devices for Mobile and Short Duration Work Operations", for the New Jersey Department of Transportation. The study was conducted by two groups: Institute for Transportation Research and Education, North Carolina State University and the Region 2, University Transportation Research Center, City College of New York. The study investigated new technologies and information systems to improve safety of workers in mobile and short duration maintenance work zones.

Objective

The objective of this research project was to study mobile and short duration work zone safety with particular attention to the identification of work zone safety devices, information systems for the reduction of safety and congestion, and implementation of innovative techniques to reduce delays and crashes due to work zones. The specific objectives were to:

- Identify state-of-the art work zone safety technologies to improve worker safety in mobile work zone and short term maintenance operations,

- Identify information systems for work zone traffic control to reduce delays and crashes,
- Identify “best practices” for the use of law enforcement to improve work zone safety,
- Identify key issues to be considered from public outreach and information systems.

Research Approach

This study was conducted in three tasks: 1. The literature research focused on the identification, evaluation and recommendations for the implementation of technologies and safety devices for highway maintenance workers and motoring public, 2. The development a proposed methodology and criteria for measuring and evaluating the selected new technologies and Information systems, and the analysis of the current NJDOT practices for short duration and mobile work zone operations, and 3. The identification of guidelines to eliminate driver inattentiveness, design alternative strategies and techniques for traffic control. The three tasks are documented in three Working Papers which were prepared during the first year of the study. This document summarizes the three working papers. The reader should refer to the working papers for source references.

The literature research focused on safety technologies, motorist information systems, law enforcement, and outreach and education systems for the motoring public. A concentrated effort was made to search for mobile and short duration work zone safety technologies which would be used in field evaluation tasks. The research team searched extensively through many sources of information to gather the relevant material. Among the considerations were the websites of State DOT’s, Transportation Research Board (TRB), Strategic Highway Research Program (SHRP), Federal Highway Authority (FHWA) and Texas Transportation Institute (TTI). Several of publications such as Better Roads, Roads & Bridges and Public Works Magazine were searched for relative articles.

The methodology and criteria for measuring and evaluating the selected new technologies and Information systems was developed from existing methods and criteria which were researched in the literature. The method of evaluation consists of using the selected device on appropriate work zones and includes feedback regarding the ease of use and any problems with its use by maintenance workers. The guidelines to eliminate driver inattentiveness, and the alternative strategies and techniques for traffic control were identified from the literature. The guidelines were developed from other state DOT sources and practices.

Short Duration and Mobile Work Zone

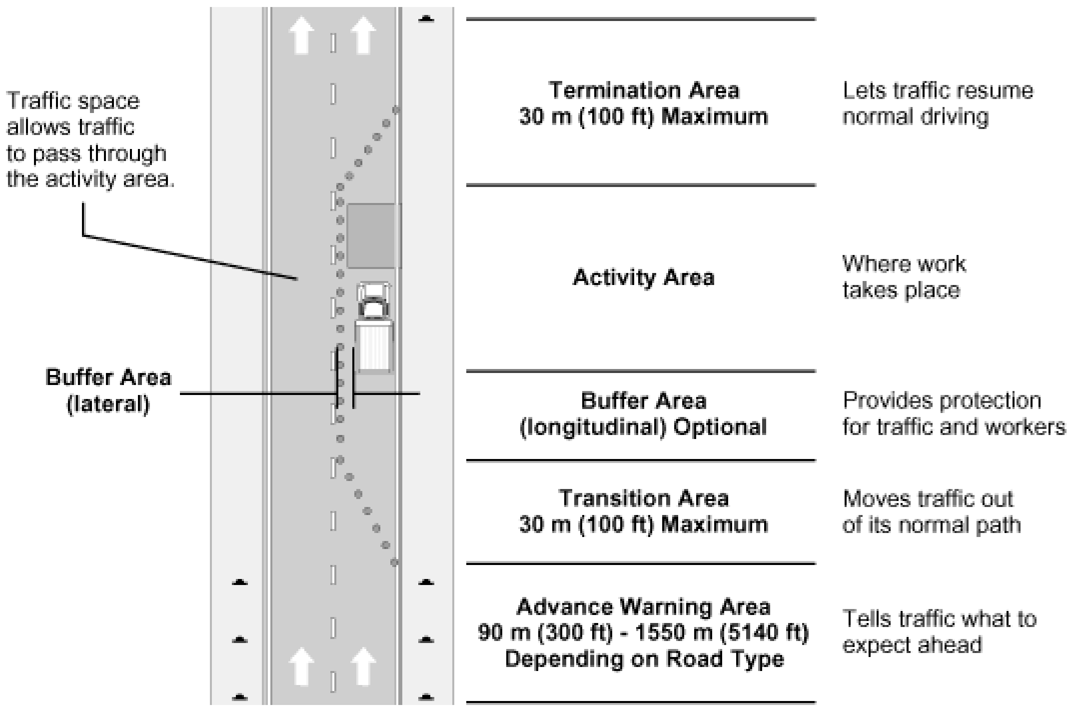
A work zone is an area of the traveled way where highway construction, maintenance, or utility-work activities are occurring. A work zone is generally marked by signs, channelizing devices, barriers, pavement markings, and construction/maintenance work vehicles. It extends from the first warning sign or flashing lights on a vehicle to the end of roadwork sign or the last traffic control device. A work zone may be for short or long durations and may include stationary or moving activities. A typical work zone is shown in Figure 1. The work zone activities can be categorized into the following:

- Long-term stationary activities: It consists of highway construction such as building a new bridge, adding travel lanes to the roadway and extending an existing roadway.
- Mobile highway maintenance activities: It consists of highway repair work such as crack sealing and pothole repair etc.
- Short-term stationary activities: It consists of utility work such as repairing of electric, gas, or water lines on the highway.

Mobile work zones can be further categorized as:

- Intermittent Mobile Operations: These operations like litter cleanup, pothole patching, or utility operations, involves frequent stops and is similar to stationary operations.

- Continuous Moving Mobile Operations: These operations include work activities in which workers and equipment move along the road without stopping (mowing, pavement striping, street sweeping, or herbicide spraying), usually at slow speeds.



The Five Defined Areas of the Common Work Zone

Figure 1: Typical Work Zone

Manual on Uniform Traffic Control Devices

Part VI of the *Manual on Uniform Traffic Control Devices (*MUTCD) provides the design and application specifications to meet the special demand for uniform standards for traffic control during construction and maintenance operations on streets and highways in the United States. Temporary traffic control devices (cones and other channelization devices) and advanced warning signs (flagger ahead and lane closure) are used to direct traffic around construction zones. The criteria for design will vary based on environmental conditions such as illumination, weather, traffic speed and other factors of consideration. Although each work zone will have individual traffic control plans based on the type and location of worksite, all traffic control plans will have similarities that are inherent to every work zone.

There are four typical applications of short duration/mobile operations described by the MUTCD. These are listed below, and illustrated in the attached diagrams.

1. Mobile operations on the shoulder (TA-4) Shown in Figure 2
2. Mobile Operations on a two-lane road (TA-17) Shown in Figure 3
3. Mobile operations on a two-lane road using flaggers (TA-13) Shown in Figure 4
4. Mobile operations on a multilane road (TA-35) Shown in Figure 5

Typical Applications for Temporary and Mobile Operations (MUTCD Part VI)

<u>Mobile operations on the shoulder (TA-4)</u>

This operation requires the following equipment:

- Adequate traffic control signs describing Road work ahead.
- Optional arrow panel
- Optional Truck mounted attenuator (TMA)
- Shadow vehicle with “shoulder work” sign

<u>Mobile Operations on a two-lane road (TA-17)</u>

This operation requires the following equipments.

- Shadow vehicle with optional arrow panel
- Sign with appropriate work type
- Optional Truck mounted attenuator

Mobile operations or Temporary Road closure on a two-lane road using flaggers (TA-13)

This applies to road closures not exceeding 20 minutes during the daytime. This operation requires the following equipments.

- Flagger
- Signs
- Optional Truck mounted attenuator
- Provide adequate buffer space depending on the speed limit.

Mobile operations on a multilane road (TA-35)

This operation requires the following equipments.

- Arrow panels
- Adequate traffic control signs.
- Shadow vehicles with “lane closed” sign

The typical applications figures are provided in the following pages. The figures show the position and type of equipments to be used in temporary and mobile operation. All work zones should strictly adhere to the MUTCD requirements regarding signs and equipment during a work zone operation.

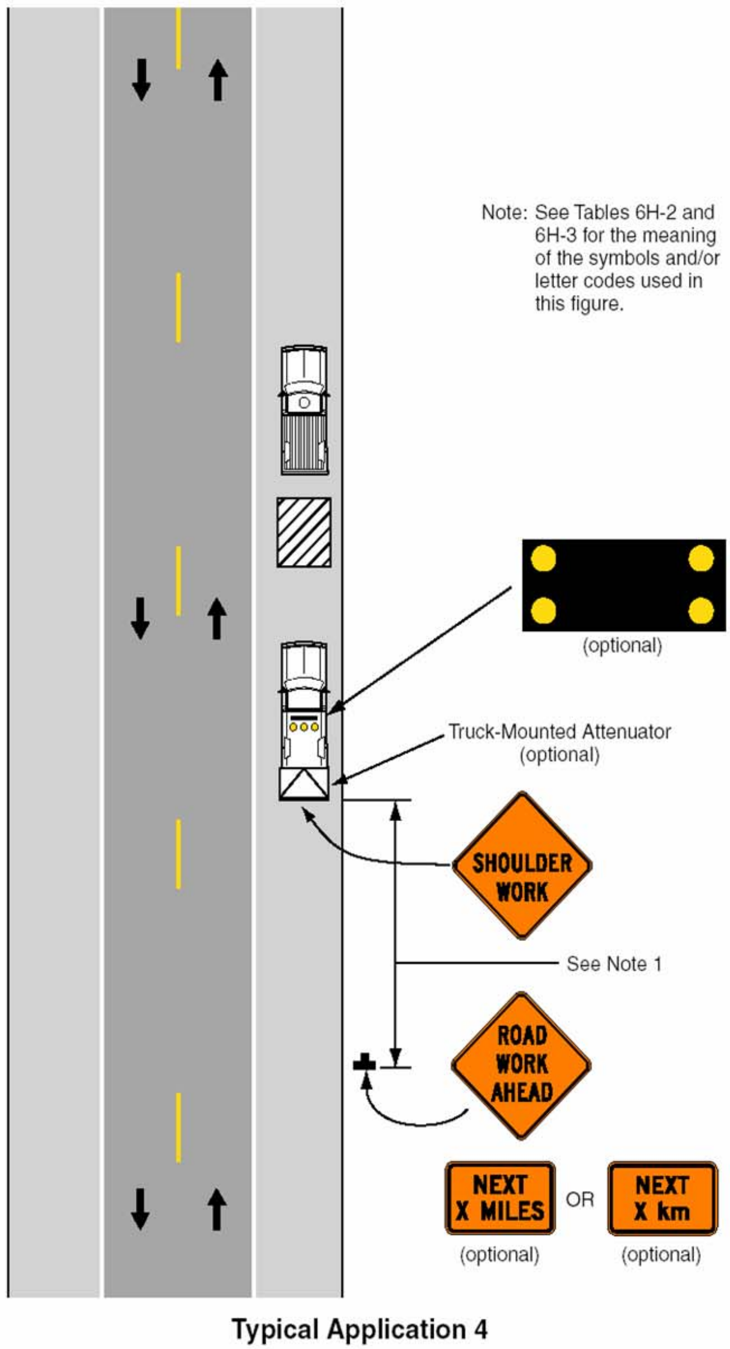


Figure 2: Mobile operations on the shoulder

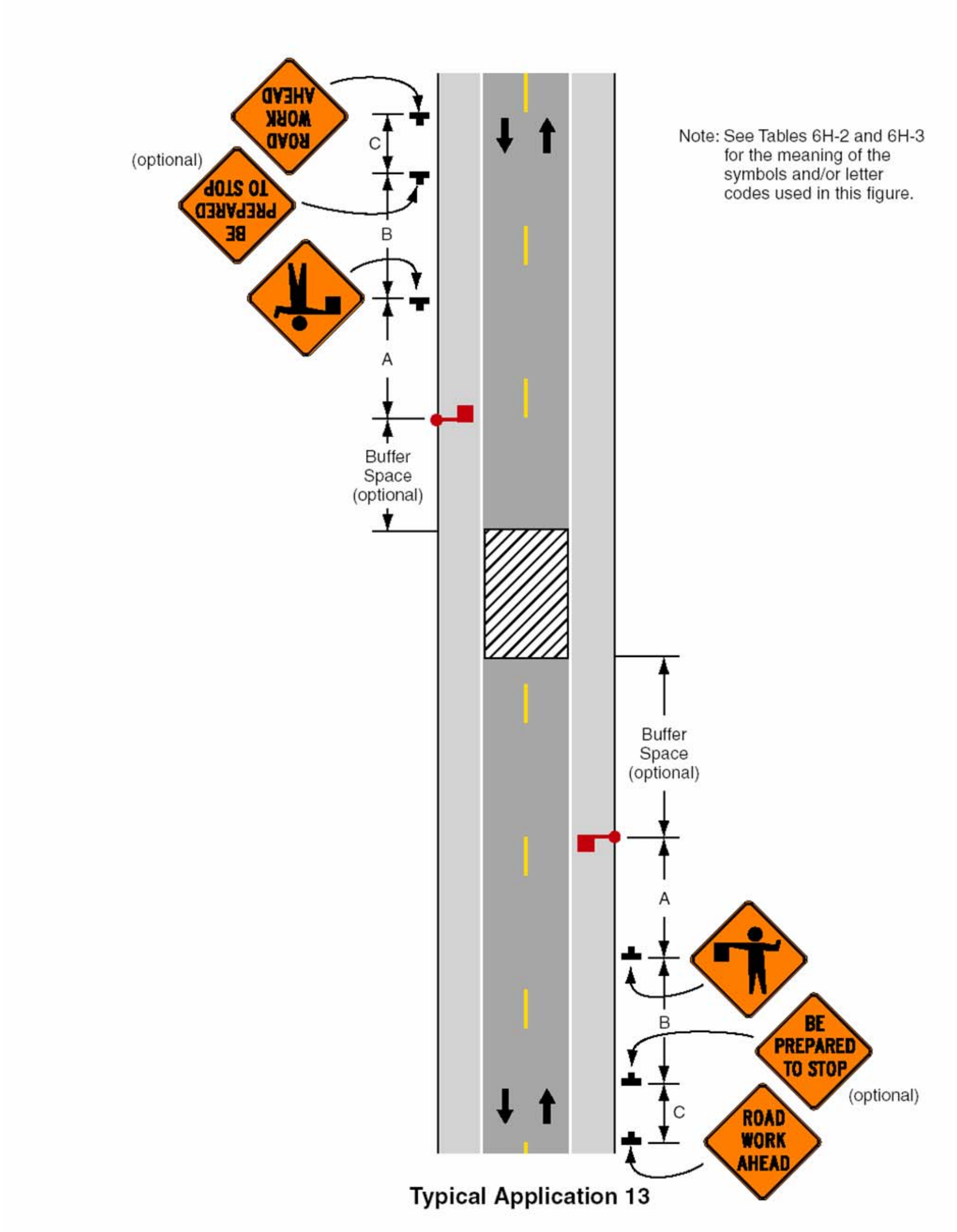


Figure 3: Mobile Operations on a two-lane road (TA-17)

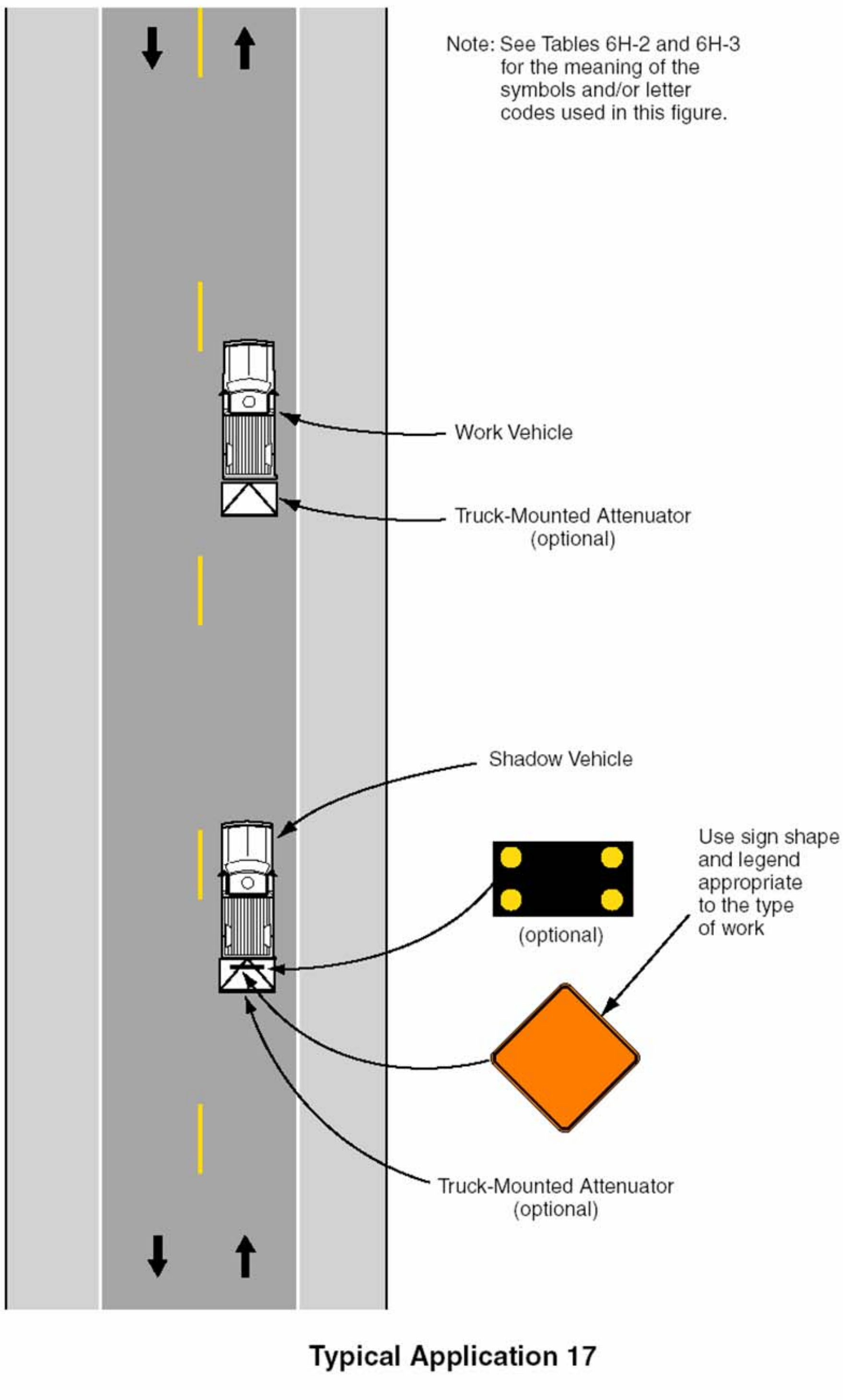


Figure 4: Mobile operations on a two-lane road using flaggers

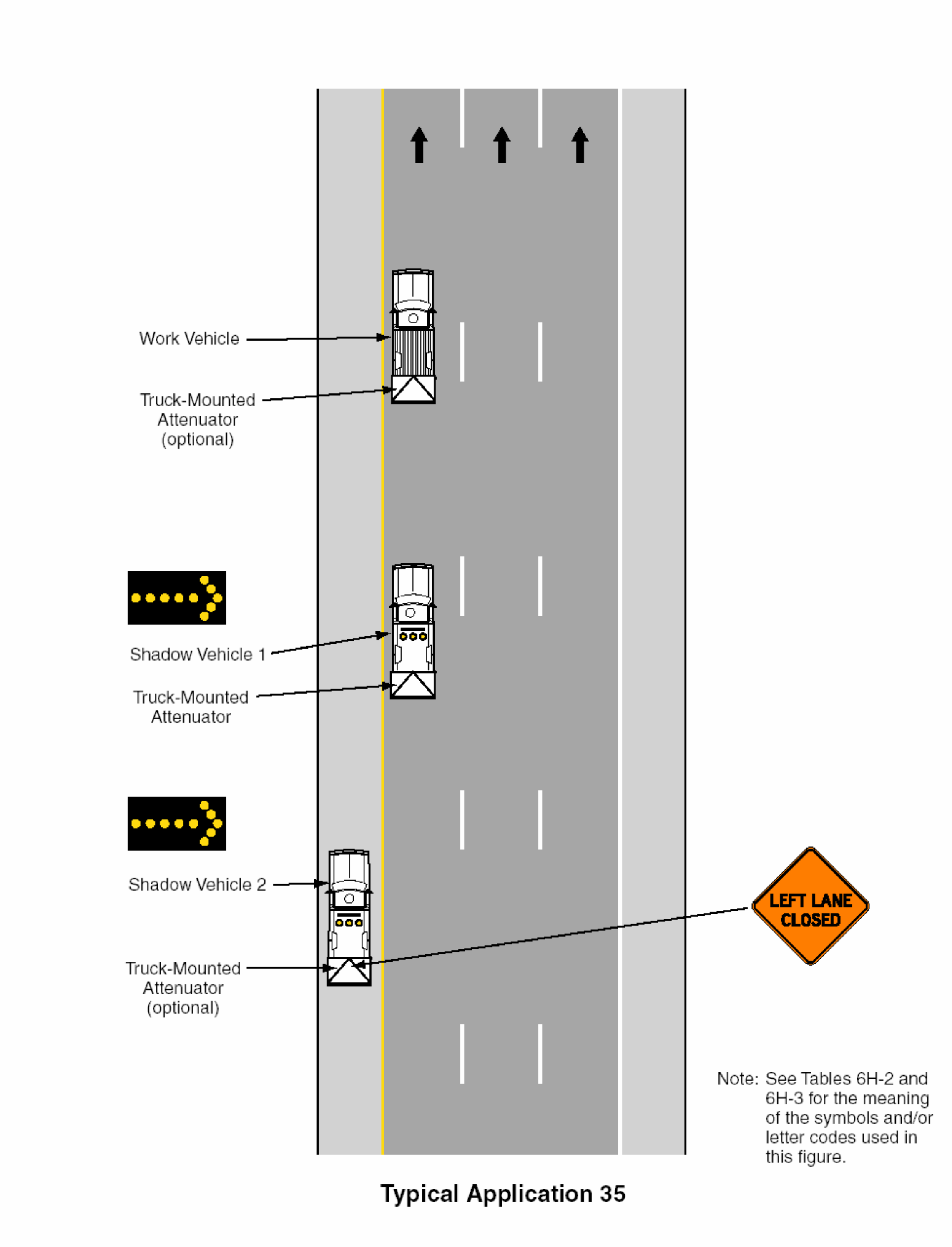


Figure 5: Mobile operations on a multilane road (TA-35)

LITERATURE SEARCH

The literature research focused on safety technologies, motorist information systems, law enforcement, and outreach and education systems for the motoring public. A concentrated effort was made to search for mobile and short duration work zone safety technologies which would be used in field evaluation tasks. A list of researched organizations, agencies and web sites is shown in the bibliography.

TRB, NCHRP and Proceedings Literature

During 1999, the Departments of Transportation from the states of Kansas, Nebraska, Iowa, and Missouri conducted a pooled-fund study of innovative devices designed to improve the safety and efficiency for highway maintenance work zones. In the state of Kansas, a total of nine devices were evaluated, including lighted raised pavement markers, CB-radio warning systems, and radar-triggered speed displays, among others. All of the products showed potential for improving work zone safety and operations. Some of the products require further development before they can be recommended for widespread deployment. The four products which appear to show the most promise were orange removable rumble strips; the Vertical SafetyCade -- designed to replace the reflectorized drum, radar – triggered speed display, and an experimental configuration of Lightguard lighted raised pavement markers used to delineate a crossover in an interstate work zone. In all cases, pneumatic hoses were used to collect the data. In most cases, one to two days of data were collected before and after device installation.

The University of Kansas evaluated three traffic control devices: white lane drop arrows, orange rumble strips, and the CB wizard alert system. The devices were tested for their effectiveness in improving vehicle merging and speed reduction and speed variance at an interstate highway work zone in

Missouri. Results of implementing the white lane drop arrows and the CB wizard alert system indicate decreases in the percentage of vehicles in the closed lane, mean speed, and speed variance. It also appears that the CB wizard alert system may be more effective than the white lane drop arrows. The CB wizard alert system in conjunction with the orange rumble strips did show similar reductions, but they were much smaller in comparison to the CB wizard alert system alone.

Problem areas identified during the observation of five moving maintenance operations on Texas urban freeways are discussed in a TRB by Faulkner. The operations included striping and the installation of raised pavement markers. The identified problem areas were grouped into two categories: problems related to freeway design and operational problems. Problems related to freeway design occur at entrance and exit ramps and major interchanges or result from horizontal and vertical curvature. Operational problems include the improper use of arrowboards, the lack of uniform procedures for freeway entry and exit, large spacing between caravan vehicles, and unnecessary lane blockage by the caravan. The recommended solutions to the problems are improved communications, effective advance signing, controlled caravan length, caravan positioning procedures observed during certain operation:, and modifications to procedures observed in others.

This comprehensive research report published by TRB was developed due to the growing concern of increasing frequency of hazards during moving and short-term work zone operations. The research was very thorough and effective in a way that it encompassed different possible formations of mobile maintenance operations. Eleven categories of short-term and moving work zones contained corresponding traffic control devices, vehicle warning light systems and driver actions respectively. Though studies supported traffic control devices (TCD) applications and guideline development, it was also found that accident reduction was the ultimate measure of device effectiveness.

This research mainly focused on human response to warning lights varied by the type of light both in closed field and operational tests. It was found during research that no one light is maximally effective in both transmitting information and gaining attention. The reason for this was that rotating and strobe lights, which were effective in getting driver's attention, were not as useful in providing speed and closure rate information especially when the service vehicle was stopped. Conversely flashing lights, which worked really well for giving speed info, were not effective in providing clear clue of working zone to drivers from long distances. Therefore several of the lighting recommendations combine the two types of light in order to ensure optimum information transmission and conspicuity.

Apart from the findings related to different types of lights functioning's, cost benefit analysis was developed to aid in making some of the decisions. Some of the devices like shadow vehicles were found to be very effective in producing desired results but involved substantial costs as well. Therefore separate cost-effectiveness criteria were included as a basis for agency-specific decisions regarding its use.

In a research study by the Texas Transportation Institute, potential hazards associated with mobile and short duration work zones, as well as the probable underlying causational factors were identified by focus groups and field observations. In addition, a survey of state transportation agencies was conducted to determine current practices. The research study identified four primary hazards: motorist behavior, motorists' comprehension, and worker exposure and vehicle conflicts.

State Transportation Agencies

The goals of the California Department of Transportation (Caltrans) Highway Worker Safety Program are to: Improve worker safety, reduce accidents, minimize night work, increase public awareness and use protective vehicles, equipment and safety apparel. In addition, In 1998 Caltrans initiated a California Highway Worker Campaign to increase public awareness of work zone safety. The Caltrans Worker Safety program includes construction and maintenance worker safety orientation and instruction, the use of protective vehicles – shadow vehicles, barrier vehicles and advance warning vehicles for all work zones and a District Driver Training Program to eliminate employee preventable vehicle accidents.

The objective of the District Driver Training Program is to eliminate preventable vehicle accidents. To meet this objective, two programs are undertaken - one of prevention and one of cure. The prevention consists of screening the driving record of each potential employee who could be expected to drive a vehicle as part of the employee's work and providing Defensive Driving Training. The cure program is a refresher driver training (a minimum of three hours) every four years for employees who drive on state business and appropriate disciplinary action for problem drivers of state equipment. Caltrans is also working with the California Association of Safety Educators to develop a curriculum, including a video tape, for use in more than 900 driver education classes statewide. This ongoing program educates new generations of drivers in how to drive safely near work zones.

Caltrans initiated improved safety equipment such as orange signs and cones with improved reflectorized sheeting, and change message signs to provide additional awareness to the public. Improved safety apparel was also initiated for workers. To reduce worker exposure, specialty equipment such as liter machines, cone trucks crack sealing vehicles and spray outrigger vehicles are being used.

California Highway Patrol officers are used on specific work zones to reduce speed of the traffic. This program has been very effective in enhancing highway worker safety.

The New York Sate Department of Transportation has initiated Highway Work Zone Safety awareness bulletins, partnered with the New York State Police and identified specific features for improved mobile and short duration work zones. The NYSDOT initiated six intrusion countermeasures: increased police enforcement, reduced channelization spacing, enhanced flagger stations, rumble strips, reduced speed limits, dynamic message signs, and drone radar.

WORK ZONE TECHNOLOGIES

Workers in short-term maintenance work zones are placed in a particularly hazardous position. Short-term and mobile maintenance work zones are typically located on high-speed roads; with traffic control installed each day in the morning and removed by dusk. Since these work zones are in place only for a short time, drivers do not expect to encounter them. Regulatory speed limits cannot be lowered at the sites, and it is difficult to get law enforcement agencies to regularly patrol temporary work zone sites.

Fluorescent Signs for Work Zones

The Iowa DOT is using fluorescent signs for their mobile work zone operations. These illuminated signs (fluorescent being the background) were developed to get the driver's attention approaching the work zones. The illuminated part may be yellow or green and gives a clear visibility to motorists. These signs are mounted on the back of trucks. The DOT claims that they are producing good results.

Advanced Warning Signs

The Virginia Department of Transportation (VDOT) is continuously striving to improve the flow of traffic as well as to protect workers and motorists in work zones. By using an advanced warning sign that is easily understood by motorists, both motorists and workers benefit. VDOT and several other state departments of transportation have expressed interest in modifying the advanced warning signs for work zone operations. The advanced warning sign is intended to alert drivers and to prepare drivers to stop (if necessary) prior to reaching work zone operations. For example the construction vehicle sign warns drivers that the truck they are following is a construction vehicle and may leave the lane to enter an active work area.

Flashing arrow boards warn drivers that the lane they are traveling in is closing ahead and a lane change is required. The arrow direction will indicate which lane is open for travel. Similarly, when only the four corners of the board are flashing, drivers must use caution, but do not change lanes. This light pattern is also used when work is on the shoulder of the roadway.

Variable Message Signs

Variable message signs (VMS) are traffic control devices used to provide motorists en-route traveler information. They are commonly installed on full-span overhead sign bridges, post-mounted on roadway shoulders, trailer mounted for work zones and overhead cantilever structures. For work zones, the objective of providing the information is to allow the motorist time to avoid an incident, prepare for unavoidable conditions, or to give travel directions. For all information displayed the goal is to have a positive impact on the motorist's travel behavior. VMS are designed to affect motorist behavior to improve traffic flow, safety and operations. Changeable messages signs (CMS) or portable VMS are intended to operate in a location for a short period of time and then be moved to a new location or stored until needed again. Variable message sign technology includes: flip disk, light emitting diode, fiber optic and hybrid of several technologies.

Several manufacturers are working to solve the problem of driver inattentiveness to variable message signs by developing systems that use the signs to display messages based on real-time measurements of traffic conditions. One such system is *Adaptir (Automated Data Acquisition and Processing of Traffic Information in Real-Time)*, a technology developed by the Scientex Corp. with support from the Federal Highway Administration (FHWA) and the Maryland State Highway Administration.

The Adaptir system measures traffic speeds using Doppler radar, the same technology used by police to detect speeders. Traffic speeds are measured at several points within and upstream of a work zone. The data are then sent to a central control system, which analyzes the data to pinpoint patches of traffic congestion and delay and then selects the appropriate prerecorded message to post on a variable message sign- -or series of signs--just upstream of the site. The messages prepare motorists for actual traffic conditions ahead. For example, if traffic is extremely slow in the work zone, a variable message sign upstream of the work zone might warn of a 10-minute delay ahead; a second sign might then warn drivers to slow to 55 km/h (35 mi/h). If traffic speeds decrease further, indicating worsening congestion, the system would automatically change the signs to indicate an even longer delay and advise of slower speeds ahead. The signs can also be used to suggest alternate routes or tell drivers to tune in to a highway advisory radio station. To emphasize the timeliness of the messages, each sign can also display the time the message was posted. Drivers armed with information on traffic ahead are better prepared for changing traffic conditions and thus more likely to have a safe trip. The economic benefits of reducing delays and improving safety at a work zone can outweigh the cost of the Adaptir system by a factor of six or more, according to an economic analysis conducted by Scientex.

Truck Mounted Attenuators and Message Boards

Trucks / trailers can carry different devices to inform motorists of work zone presence. Texas Transportation Institute tested a speed control device placed on the back of a trailer and found it very effective as the drivers slowed by an average of 5 mph while passing through work zones.

Portable Changeable Message Signs (PCMS) can also be fixed on the top at the back of trucks or trailers. The message changes with the progress of work going on in the construction zone to provide real-time information. The message can be varying speed limit or some warning message like change of lane, congestion ahead etc. alerting the drivers to slow down, because of highway maintenance going ahead. Energy Absorption Systems tested the first truck-mounted impact absorption device that can withstand the force of up to 4,410lbs, traveling at up to 62 miles/hr, meeting both mandatory and optional National Cooperative Highway Research Standards.

Drone Radar and Speed Display Trailer

The purpose of Drone Radar is to reduce speed in work zones resulting safer work areas. Drone radar is generally placed on portable changeable message sign/signs (PCMS) and since PCMS has the power, it activates Drone Radar. Radar alerts the inattentive drivers before approaching the transition area. A study by Dr. Patrick McCoy showed that radar speed displays have been effective, although their working depended on their proximity to work zone area. The Ohio DOT and Massachusetts DOT are employing this device and have found it to be satisfactory. The Virginia DOT is also using Unmanned (Drone) Radar detectors to inform drivers approaching the work zone.

Speed display trailer studied by TxDOT features a 24-inch LED display and uses Ka-band radar to detect oncoming vehicles. The display has a strobe lamp that flashes when a vehicle is detected traveling over a preset speed threshold. This feature is intended to simulate the operation of photo radar, possibly decreasing speeds through the threat of automated enforcement. During this evaluation, the speed threshold for the strobe light was set at 75 mph. The display also has a 130 dB siren that can be activated by vehicles traveling over a preset speed. This option is intended to warn workers when an extremely high-speed vehicle is approaching.

This device proved to be effective in short term/mobile operation as the display could be set up in under 10 minutes. The controls were easy to operate, and TxDOT crews that have used the device have reported no maintenance problems.

Flashing Lights

Research sponsored by the Texas Department of Transportation (TxDOT) and conducted by the Texas Transportation Institute (TTI) has revealed helpful techniques that improve safety for workers and increase visibility of work zones for motorists. In a general scenario, the indication of a work zone ahead is given to the drivers by flashing yellow warning signals or a sign telling to move from one lane to the other. A new method of warning drivers of approaching work zones is proving to be safer and easier to understand from greater distances. The approach was developed as a part of a TTI research project that was sponsored and implemented by TxDOT. It utilizes a series of synchronized flashing lights attached to the drums that form a lane closure taper. The flashing lights illuminate in a sequence from the beginning to the end of the taper. According to closed-course studies at TTI's Riverside Campus in College Station and roadway tests in Houston, drivers responded more positively to the synchronized flashing light system than to the normal traffic control setup used at construction sites in Texas. It was also found that as the synchronized flashing warning light system was activated, there was a one-fourth reduction in the number of passenger vehicles 1,000 feet before the lane closure taper.

Dancing diamonds (lights)

The Oregon Department of Transportation (ODOT) uses dancing diamond panel displays as an advance caution device for mobile and short duration maintenance operations. The panel is a sign with a matrix of light elements capable of either flashing and/or sequential displays. Non-directional arrow panel displays are intended as caution displays. Before 2001, literature lacked significant statistical support for any one type of caution display. A 2001 Oregon Department of Transportation (ODOT) study suggested that the + ACI-dancing diamonds are better than the other caution displays like flashing box. ODOT also found that local citizens preferred the dancing diamonds to other caution displays. However, additional research was needed to confirm these findings.

To evaluate the effectiveness of the dancing diamonds and +ACI- flashing box+ACI- displays, a field experiment was conducted. The results of this experiment showed that the dancing diamond was associated with a statistically significant 3 km/h (2 mph) reduction in mean speeds, whereas the flashing box display was associated with no statistically significant reduction in mean speeds, indicating that the dancing diamonds prompt safety near highway work better than the flashing box.

Rotating lights / Strobe Lights

This comprehensive research report published by TRB was developed due to the growing concern of increasing frequency of hazards during moving and short-term work zone operations. The research was very thorough and effective in a way that it encompassed different possible formations of mobile maintenance operations. Eleven categories of short-term and moving work zones contained corresponding traffic control devices, vehicle warning light systems and driver actions respectively. Though studies supported traffic control devices (TCD) applications and guideline development, it was also found that accident reduction was the ultimate measure of device effectiveness.

This research mainly focused on human response to warning lights varied by the type of light both in closed field and operational tests. It was found during research that no one light is maximally effective in both transmitting information and gaining attention. The reason for this was that rotating and strobe lights, which were effective in getting driver’s attention, were not as useful in providing speed and closure rate information especially when the service vehicle was stopped. Conversely flashing lights, which worked really well for giving speed info, were not effective in providing clear clue of working zone to drivers from long distances. Therefore several of the lighting recommendations combine the two types of light in order to ensure optimum information transmission and conspicuity.

Apart from the findings related to different types of lights functioning's, cost benefit analysis was developed to aid in making some of the decisions. Some of the devices like shadow vehicles were found to be very effective in producing desired results but involved substantial costs as well. Therefore separate cost-effectiveness criteria were included as a basis for agency-specific decisions regarding its use.

Rumble Strips

In an effort to promote safer conditions in work zones, the Kentucky Transportation Center, in conjunction with the State of Kentucky and the Federal Highway Administration (FHWA), sponsored a project to demonstrate the use of the portable rumble strip at maintenance work zones across the State. When drivers feel the vibration and hear the sound caused by the portable rumble strip, they are given a final reminder that they are about to enter a temporary work area.

Developed by the Strategic Highway Research Program (SHRP), the portable rumble strip is placed across the road about 100 m (250 ft) in advance of the work zone. The device causes a vibration in the steering wheel and a rumble as vehicles pass over it, warning drivers that conditions on the road will soon become dangerous. The portable rumble strip is best suited for low-speed roads that carry few heavy trucks. The portable rumble strip is also easy to use. The device weighs about 34 kg (75 lb), and one or two workers can deploy it from the back of a pickup truck.

A number of studies have demonstrated the benefits of shoulder rumble strips in reducing death and serious injury caused by inattentive drivers in Run-off-road (ROR) crashes. The methodologies used in these effectiveness studies and their results vary from state to state, but all show some measure of crash reduction attributed to the presence of shoulder rumble strips.

Intrusion Alarms

Drivers sometimes fail to notice the signs, cones, and other warnings that they are approaching a highway work zone. Intrusion alarm developed under the SHRP provides safety to workers in the work zone either by audio or visual means, when a motorist intrudes into the work zone. State of Vermont is using these alarms to inform the workers well before the danger. Example of audio intrusion alarm is a flashing strobe light, which activates as soon as a driver by mistake enters in the danger part of a work zone. The biggest benefit is that the workers get few seconds to clear out of danger way.

After testing two models of the work zone intrusion alarm, Vermont AOT's research unit purchased a model that uses an infrared beam sent from a transmitter unit to a receiver unit that also houses the siren. When a vehicle breaks this beam, the siren goes off. The research unit picked this model because it was the fastest and easiest to set up.

STRATEGIC HIGHWAY RESEARCH PROGRAM (SHRP)

The SHRP was started in 1987 by the U.S Congress in response to a growing national concern over the condition of the highway system. It established a 5-year, large-scale, applied research program aimed at improving the performance, durability, safety, and efficiency of the Nation's highway system.

The Strategic Highway Research Program (SHRP) was initiated to improve the safety of workers, improve efficiency of work operations and improve traffic control. The primary emphasize of SHRP was work zone safety concepts and research of applicable devices. Tthe Strategic Highway Research Program (SHRP) identified 10 work zone safety device concepts that are applicable in work zones; especially for maintenance activities. There are currently eight manufactured devices available:

1. Salt Spreader Truck-Mounted Attenuator (TMA).
2. Vehicle Intrusion Alarm (discussed above).
3. Queue Detector.
4. Portable Rumble Strip (discussed above)
5. Direction Indicator Barricade.
6. Opposing Traffic Lane Divider.
7. Flashing STOP/SLOW Paddle.
8. All-Terrain Sign & Stand.

The Salt Spreader Truck-Mounted Attenuator is commercially produced and is marketed exclusively by private industry. The seven other devices, representing the basic SHRP-developed concepts, are commercially available and are ready for field use. These include Opposing Traffic Lane Dividers, Portable Rumble Strip, Flashing STOP/SLOW Paddle, Direction Indicator Barricades, Vehicle Intrusion Alarms, Queue Detector, and the All-Terrain Sign Stand with Signs. The other two devices are the Remotely Driven Vehicle (RDV) and the Portable Crash Cushion trailer (PCT). The Remotely Driven Vehicle (RDV) is being evaluated by the Minnesota DOT and is under development. Shorter-length

Portable Crash Cushion trailer (PCT) have been built for FHWA and are being tested in Alabama, New York, California, and Minnesota.

Cone Shooter

The Advanced Highway Maintenance and Construction Technology (AHMCT) Center has developed a machine that can automatically place and retrieve traffic cones. This new device can safely and quickly opens and close busy lanes. Typical lane configuration uses 80 traffic cones for each 1.5 miles of lane closure. Usually cones come in size of 36 inches. Caltrans uses a 28-inch cone weighing 10 pounds. Manually only three cones can only be carried by a worker at a time. Also it is difficult for place cones during mobile operations. It is slow and dangerous in busy roads. The cone shooter is meant to reduce injury and cost.

Automated Pavement Crack Sealers

One of the frequent maintenance operations involves crack sealing of the pavements. Sealing of cracks along the pavement is done by mobile operation. Crack sealing is performed for longitudinal cracks or sealing of joints between concrete lanes and also random cracks along the pavement. Hand sealing of longitudinal as well as random cracks consume more time, involve workers, safety concerns and also lanes closure. The AHMCT has developed two automated pavement crack sealers: a. Longitudinal Crack Sealer, and b. Random Crack Sealer. The devices perform the same operation with greater efficiency and less time. A typical sealing operation involves a large crew sealing 1.5 to 3 km per day, while the crew is exposed to moving traffic in adjacent lanes.

Debris Removal Vehicle

Roadway litter removal is labor intensive, may expose workers to traffic, and costs the nation over half a billion dollars a year. To help make litter removal safer and more efficient, AHMCT has developed the new litter removal and debris vacuum system. The two vehicles developed are: a. Automated Litter Bag/Debris Collection Vehicle, and b. Debris Vacuum System.

Manual retrieving of litter bags and debris can be greatly improved in terms of efficiency and safety with the introduction of the Automated Litter Bag/Debris Collection Vehicle developed by the AHMCT Center. The main goal of the machine is to reduce the number of personnel required for the operation and keep the worker safely within the vehicle while still allowing efficient performance.

Robotic Highway Safety Markers

All work zone maintenance operation uses traffic control devices such as cones, signs, safety barrels and barricades. Proper traffic control is critical in highway work zone safety. Deployment of these devices in work zone involves labor, consumes time, and poses hazards to workers. Also for mobile work operations, placement of the devices could be impossible. In order to efficiently use the devices for work zones, the department of Mechanical engineering in University of Nebraska Lincoln has developed a mobile safety barrel robot. The robotic safety barrels can self-deploy and self-retrieve, removing workers from this dangerous task. The robots move independently so they can be deployed in parallel and can quickly reconfigure as the work zone changes. These devices would be of great advantage in mobile work zones, where the cones or barrels could move along with the working crew, saving time and increasing safety to workers.

Balsi Beam

The Balsi Beam is a truck mounted, moveable, expandable beam that will provide positive work zone protection comparable to a fixed concrete barrier. It is specifically intended to enhance worker safety when carrying out shoulder repair in work zones adjacent to guardrails, inlet repair, bridge rails, bridge deck repair, sound walls and other work where workers are normally exposed to traffic or behind cones in short work areas for several hours. Usually the shadow vehicle

or the truck mounted attenuator provides protection from rear end collisions; the new device provides protection from adjacent lane traffic.
Each side of the trailer consists of high-strength steel box and I-beams section that are capable of extending an additional 15 feet for a total of 30 feet of secure working area. Using hydraulic power, each beam can rotate to either side (left or right), depending on which side of the road a protective barrier is needed. The trailer beams act as a rigid obstacle to deflect traffic away from maintenance workers.

The Balsi Beam was initiated by the California Department of Transportation and the Federal Highway Administration to address the high rate of highway maintenance workers that are killed each year. The Laborer's Health and Safety Fund indicates that 120 to 130 highway workers are killed each year in work zones by errand vehicles. The American Road & Transportation Builders Association indicate that the fatality rate for highway maintenance and construction workers is 32 people killed for every 100,000 workers. By comparison, the rate for all construction workers is 13 people killed per 100,000 workers and the general industry rate is 4 people killed per 100,000 workers. These terrible statistics indicate the need for a highly mobile device to protect exposed work zone personnel. Indeed, no such device can be all encompassing, but any device that reduces highway worker fatalities such as the Balsi Beam is an important asset to highway workers and the people who want to protect them. As a result of a serious accident, Caltrans' Division of Maintenance investigated various means to protect exposed workers. The Caltrans' Division of Research and Innovation researched concepts for a protection system and the Division of Equipment designed and built a mobile work zone protection device (Balsi Beam) with the assistance of a trailer manufacturer. The Balsi Beam has its own dedicated tractor truck to transport it to the worksite at normal highway speeds without the need for any permits.

Figure 6 The Balsi Beam being rotated from side to side

The Balsi Beam system is highly mobile, highly maneuverable, easily deployed and is capable of redirecting a ¾ ton pick truck at near NCHRP TL-3 impact performance levels. Crash tests at TL-2 and near TL-3 indicate that the beam showed no deflections. (Caltrans tests for TL-3 were performed at an angle of 20 degrees and speed of 60 mph.) The Texas Transportation Institute reviewed and categorized a large number of highly mobile work zone operations for the functional requirements of the Balsi Beam. These operations included about two thirds of the total operations that maintenance workers normally perform.
The device is being implemented in Caltrans' District 4, which serves the San Francisco Bay area. Caltrans plans to deploy it for more testing elsewhere in the State. The prototype device cost approximately $217,000 to build, but it is expected that cost would drop significantly when other models are produced. A patent for the Balsi Beam system is pending.

Review of Caltrans Balsi Beam

The California Department of Transportation demonstrated the Balsi Beam at their Marysville Maintenance yard and conducted a meeting with the researchers to discuss the development and implementation of the beam. The beam is being implemented by a bridge repair crew on Route I-80 from Marysville to Reno, Nevada. This section of the route has many structures and has mountainous terrain. In good weather, typical traffic speeds exceed 80 mph. Before implementation of the beam, the crew had experienced many work zone intrusions by high speed errand vehicles.

The crew uses the beam to protect workers repairing bridge decks, joints, parapets, concrete approaches and median barrier. Essentially, any work in a limited area where workers and equipment are concentrated for a specific task for several hours or one work day. Using improvised work techniques and small equipment such as a Bobcat to replace a larger front end loader, the crew is able to provide safe protected work areas which include a truck with tools, an air compressor and concrete mixer. Other work techniques provide space for a dump truck to unload material for patching and repairs. Future modification to the beam trailer will include tool storage and mounting for a compressor or other such equipment. Caltrans workers feel secure behind the beam.

The Balsi Beam trailer is driven to the work site; the beam is rotated to provide protection for the appropriate side and locked into place. The beam requires about 10 minutes to set-up. The set up of other safety equipment is typical to the set up time for any lane or shoulder closure. The beam is accompanied by several dump trucks with TMAs, signs, light boards, tool storage vehicles and appropriate devices for closing a lane or shoulder. In special case cones are used in conjunction with warning signs ahead of the work area. Since traffic speeds are very high and vehicle intrusion likely, work zone safety is carefully planed to provide the maximum protection for works and the safety of the traveling public. The advantage of the beam in such a work zone is the positive protection of workers in a concentrated area for a specific task. Indeed, barrels or cones, even behind a dump truck with a TMA would not afford the secure enclosed wok area.

Presentations to NJDOT Engineers

The researchers presented the results of the Caltrans beam demonstration to maintenance engineers in the Trenton Headquarters, Region North and Region South. The PowerPoint presentation provided a background of the beam development, crash test information and pictures showing the functions of the beam. The researchers provided answers to the engineers' questions. Most engineers were enthusiastic about the implementation and safety prospects of the beam for NJDOT operations.

METHODOLOGY AND CRITERIA FOR MEASURING AND EVALUATING THE NEW TECHNOLOGIES AND INFORMATION SYSTEMS

State Agencies

The Texas Transportation Institute conducted a survey of all state transportation agencies to obtain data on safety operations for mobile and short duration maintenance. Information, supporting materials and data were obtained from eighteen agencies. In addition to the survey responses, focus groups of Texas Department of Transportation field and supervisory personnel were assembled to identify hazards and to simulate new ideas and creative concepts that could improve worker and motorist safety through such work zones. The TTI investigators conducted field observations of eleven mobile and eighteen short duration maintenance operations in five districts of Texas.

The TTI survey results indicated the most significant hazards for all responding agencies were high speed traffic, and inattentive motorists which resulted in rear end crashes of safety vehicles and errant vehicles entering the shadow vehicle convey or the work area. Some state agencies approach the solution to these issues by incorporating advance warning devices in addition to the standard MUTCD safety. Such devices and solutions are:

- brighter or fluorescent signs on shadow vehicles,
- trail vehicles with speed display boards below the arrow panel,
- the use of better or additional lighting on shadow vehicles, such as solid light bars, blue lights, or light emitting diode(LED) lights,
- dynamic message boards in advance of the work area, and
- police to enforce traffic laws.

All of these devices provide the motorist with the optimum warning to reduce or eliminate crashes and improve worker safety.

The New York State Department of Transportation maintains a work zone accident data base to track the causes of crashes in such areas. The annual analysis of these data indicate that rear end accidents of construction and maintenance vehicles and rear end crashes of motorists by other motorists is the most common crash. Such crashes are indicative of speeding and inattentiveness by motorists. The New York Sate DOT has identified seven intrusion countermeasures for stationary, mobile and short duration work zones:

- reduced channelization spacing,
- enhanced flagger station,
- rumble strips,
- reduced speed limits
- police enforcement,
- dynamic message signs, and
- drone radar.

The Center for Transportation Studies at the University of Virginia studied the characteristics of work zones crashes for all types of work zones. The results indicate that rear end crashes are the predominate type of crash. Although no solutions were proposed in the scope of the study, it clearly indicated that speed and inattentiveness are contributing factors for such crashes.

Analyses of the Current NJDOT Practices for Short Duration and Mobile Work Zone Operations

The researchers conducted field observations of mobile and short duration work operations to analysis and compare current maintenance work zone operations with the MUTCD and other agencies, as well as interviews with work zone safety personnel. The first group of field observations was conducted in Region South with personnel from the Bureau of Employee Safety.

The mobile pothole patching operation consisted of the automated pothole patching truck, two dump trucks with Truck Mounted Attenuators behind the patching truck, and the foreman’s pickup truck ahead of the patching truck. The operation occurred on inside northbound lane of U.S. Route 130 in Haddon

Township. The operation is shown in Figure 7. A flashing arrow board, “Road Work Ahead” sign and a Scorpion TMA were mounted on the rear of both dump trucks.   The dump trucks maintained proper distance between the potholing patching and traffic as the operation rounded curves and advanced in the straight roadway. A single warning sign was placed off the right should some distance prior to the operation.

A sweeping operation consisted of the sweeper and a single dump truck on NJ Route 38 in Mount Laurel. The operation was in the right shoulder. The flashing light board and sign were similar to the previous operation. The sweeping operation is sown in Figure 8

During the inspection of the above mobile operations, the NJDOT inspectors observed an electrical crew preparing for repair work at a traffic intersection. The electrical crew had not placed warning signs ahead of their parked vehicle, and failed to wear safety vests. The NJDOT inspectors discussed safety rules with the crew.

The second group of field observations was conducted in Region North with personnel from the Bureau of Employee Safety.   The observations consisted of a liter pick up operation which consisted of a dump truck and dump truck with small TMA, and a landscape spraying operation with the truck mounted sprayer and a dump truck with a Scorpion TMA on Route I-280 in West Orange. Both operations were being conducted on the shoulder. This operation is shown in Figure 9.

A second landscape spraying operation was observed on Route I-78, Scotch Plains in the insider shoulder. The operation consisted of the sprayer and two dump trucks each with a Scorpion TMA. The Shadow vehicles rode in the inside lane to protect the spraying vehicle with straddled the shoulder and lane. This is shown in Figure 10.

Figure 7 Pothole Patching Operation.

Figure 8 Shoulder Sweeping Operation

Figure 9. Landscape spraying operation on outside shoulder

Figure 10. Landscape spraying operation on the inside shoulder.

A short duration work zone was observed on Route I-287, Basking Ridge. The operation consisted of a pothole patching crew that was filling a pothole with hot mixed asphalt. Three dump trucks with the Scorpion TMA were located behind two workers who were shoveling the material from a dump truck. A foreman's pick up truck was in front of the dump truck. The two workers were exposed to traffic for a distance of 30 feet between the attenuator truck and material truck. Traffic was backed up for a mile or more behind the operation and was moving slowing past the operation, which precluded taking pictures.

In interviews with the NJDOT personnel from the Bureau of Employee Support, it was noted that most work zone accidents in New Jersey are caused by errant motor vehicles. Few work zone intrusions or crashes are caused by trucks. In their opinion, these accidents at NJDOT work zones were caused by careless driving, speeding, and inattentiveness of the motorists to the work zone, other vehicles and signs. Driver inattentiveness was the most significant cause. The personnel emphasized the importance of police for all work zone operation because police encourage motorist to reduce their speed.

The NJDOT personnel emphasized the importance of public education – outreach and safety programs – to inform the public on the importance of work zone safety, and the need to show that workers have families and need their considerations. Safety programs should include work zone safe driving instructions in driver's manuals, posters and education for truck drivers at rest stops, and CB notification for truckers and in-car notification for motorists in the event of a work zone. Such items will be discussed in subsequent working papers and tasks for this project.

NJDOT personnel suggested improved advanced warning such as signing ahead of the work zone, improved lighting such as LED, variable strobes, and arrow boards that "follow" traffic, and improved work zone planning to reduce conflicts between various maintenance operations.

Criteria for Device Functionality in Mobile Operations

These evaluation criteria for certain devices will provide assistance in selecting appropriate traffic control devices for worker safety, and the safe and efficient movement of traffic through mobile and short duration work zones. From the devices and equipments identified in the literature report and, depending on the utility and effectiveness, the device functionality can be classified into five categories as follows:

Reduce exposure to the motorists/crew

Along work zones, the changing driver habits and traffic patterns cause safety concerns. The device should keep the road users and workers safe, while at the same time inhibiting traffic flow as little as possible. The ultimate goal of this criterion is to prevent worker injuries, motor vehicle accidents, and personal injury to motorists and/or pedestrians.

Warn motorists/crew to minimize likelihood of crash

Maintenance crews in short-term work zones have a frightening job. Short-term/mobile work zones present special challenges in providing safe conditions for work crews. In short duration or mobile work zones, which are only in one place for a short period of time, motorists have very little chance to develop any expectations about the presence or layout of the work zone. Workers must perform their repair work while on constant alert for drivers who disregard or fail to notice the warning signs to slow down. This study is attempting to identify devices that would effectively alert drivers to work zone conditions and motivate them to change the way they drive within the work zone. The traffic control devices should be able to warn as well as minimize the likelihood of crash in order to improve worker and driver safety.

Minimize severity of crashes once they occur

An effective traffic control device in a short-term work zone must be easy to set up and remove without compromising the safety of the workers. Even though no one device can eliminate all, crash severity can be minimized by using devices that could absorb the major impact and reduce exposure to workers. Truck mounted attenuators, crash cushions and Balsi Beam can serve as devices which satisfy this criterion. The devices should also provide sufficient visibility to gain driver attention.

Provide separation between work crew and traffic

Separating traffic from work activities by the use of temporary traffic barriers, shadow vehicles with truck-mounted attenuators, or similar devices minimizes risk for both workers and travelers. The need for positive separation should be based on work zone factors including:

- Traffic speed and volume
- Distance between workers and traffic
- Duration and type of work operations
- Physical hazards present

Improve work zone visibility/presence

Visibility issues for motorists approaching and driving through highway work zones is a major concern. Ninety percent of a driver's reaction depends on vision, and vision is severely limited at night or in inclement weather conditions. Depth perception, color recognition, and peripheral vision are all compromised after sundown. Conditions such as fog, rain, snow and dusk also hinder visibility to drivers, therefore decreasing worker safety. Therefore it is important to provide good visible traffic control devices and sufficient lighting to the work zones.

Traffic control devices and delineation treatments need to be effective in meeting the needs of motorists on various types of highway facilities under various traffic and lighting condition. Lighting should be used on traffic control devices such as flashing lights or arrow panels. Glare must be controlled so as not to interfere with the visibility of the work zone by drivers and workers.

The work area and its approaches should also be lighted to provide better visibility for drivers to safely travel through the work zone. Illumination should be provided wherever workers are present to make them visible.

The summary of the criteria and initial device performance are shown in Table 1.

Table 1 Criteria satisfied by selected work zone devices/equipment

WORK ZONE DEVICE	CRITERION				
	1	2	3	4	5
Truck Mounted Attenuator	Partly Satisfy	Fully Satisfy	Partly Satisfy	Partly Satisfy	Fully Satisfy
Vehicle Intrusion Alarm	Does not satisfy	Fully Satisfy	Partly Satisfy	Does not satisfy	Does not satisfy
Rumble Strips	Does not satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Does not satisfy
All Terrain Sign and Stand	Does not satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Partly Satisfy
Directional Indicator Barricade	Does not satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Fully Satisfy
Flashing Stop/Slow Paddle	Does not satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Fully Satisfy
Opposing Traffic Lane Divider	Does not satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Partly Satisfy
Queue Detector	Partly Satisfy	Fully Satisfy	Does not satisfy	Does not satisfy	Partly Satisfy
Remotely Driven Vehicle	Partly Satisfy	Fully Satisfy	Partly Satisfy	Partly Satisfy	Fully Satisfy
Portable Crash Cushion	Partly Satisfy	Does not satisfy	Fully Satisfy	Partly Satisfy	Does not satisfy
Cone Shooter	Fully Satisfy	Does not satisfy	Partly Satisfy	Does not satisfy	Partly Satisfy
Pavement sealers	Fully Satisfy	Does not satisfy	Partly Satisfy	Partly Satisfy	Partly Satisfy
Debris Removal Vehicle	Fully Satisfy	Does not satisfy	Does not satisfy	Fully Satisfy	Partly Satisfy
Balsi Beam	Fully Satisfy	Partly Satisfy	Fully Satisfy	Fully Satisfy	Partly Satisfy
Robotic Highway Safety Marker	Fully Satisfy	Does not satisfy	Does not satisfy	Partly Satisfy	Does not satisfy

Does not satisfy Partly Satisfy Fully Satisfy

From the above table it is seen that none of the devices fully satisfies the entire five criteria. But devices such as Truck mounted attenuator, remotely driven vehicle, and Balsi beam at least partly satisfies all the criteria.

GUIDELINES TO ELIMINATE DRIVER INATTENTIVENESS

General Nature of Work Zone Crashes

Past accident-based analyses have provided some knowledge of the general nature of work zone crashes. However, there is a continuing need for additional analyses of well-defined and more detailed accident data. Through better identification of the specifics of the work zone problem, it is hoped that, ultimately, work zone safety will be enhanced considerably. There is a continuing need for information on the number of vehicles involved, the type of crash and the manner of collision, vehicle maneuvers before the crash, and the first and most harmful events. If these general crash descriptors could be analyzed by zone type, such information would provide a better understanding of the extent to which a crash can be attributed to vehicle flow and the path provided to an individual vehicle. This analysis would be an initial step in setting priorities for treatment development and direction.

Analysis Of Work Zone Crashes

Work zone related crashes continue to increase every year across the nation, thus the safety of road users and workers has become a top priority for transportation agencies. Work zones tend to cause hazardous conditions for drivers and construction workers since they generate conflicts between construction activities and traffic. Numerous innovations in temporary traffic control materials and techniques have been developed and deployed in recent years.

Many studies seem to indicate that the introduction of work zones lead to an increase in accident rates, although that pattern is dependent on traffic and geometric conditions, traffic control devices, length of work zone, weather, lane closure strategy and other aspects of the work zone environment. The increase in crash rate at work zones may be due to several reasons including disruption of traffic due to closed lanes, improper lane merging maneuvers by drivers, and inappropriate use of traffic control devices

Crash Frequency

Studies related to work zones revealed that crash rates at work zones were higher than at non–work zone locations. They also indicated that crash rates depend on the type of traffic control device used. In a construction zone crash study conducted by Hall and Lorenz, crashes during construction increased by 26 percent compared with crashes in the same period in the previous year when no construction. In another study involving short term and long term work zones on freeways, Rouphail and others showed that the crash rates during construction increased by 88 percent compared to the “before” period at long-term work zones and the crash rates for short-term work zones were not affected by the road work. Garber and Woo found that on average the crash rates at work zones on multilane highways in Virginia increased about 57 percent; on two-lane urban highways the increase was about 168 percent when compared with crash rates prior to the installation of the work zones. In a study conducted on all type of roads, Pigman and Agent showed that crash rates during construction exceeded those in the before period at 14 of 19 sites. In another study conducted along rural interstates, Nemeth and Migletz also showed that crash rates during construction increased significantly compared to the before period.

In several studies involving work zones along two-lane highways, the use of a combination of cones, flashing arrows, and flaggers on multilane highway work zones and a combination of cones, flaggers, or 4 static signs and flaggers resulted in the fewest crashes whereas the use of flaggers at urban work zones resulted in the fewest crashes.

Crash Severity

Studies concluded that work zone crashes were more severe than other crashes, involving a high number of worker fatalities. The average work zone crash was more severe than the average crash in terms of the number of vehicles involved and average property damage.

Crash Location

The location of crashes is an important aspect in analyzing for suitable countermeasures and devices to be adopted for the type of crash. Several studies addressed the locations of crashes in work zones. Two studies found that most crashes occurred in the work area (combining the longitudinal buffer and activity areas). Nemeth and Migletz found that 39.1 and 16.6 percent of accidents occurred in the longitudinal buffer area and in the activity area, respectively at single-lane, crossover, and bi-directional zones (two-lane two-way operation).

From studies conducted related to work zone crashes, it is concluded that the activity area was the predominant crash location, followed by the transition area, the advance warning area, the longitudinal buffer area, and the termination area. The Typical work zone is shown in Figure 11. Figure 12 shows a graphical representation of results obtained based on crash location on work zones.

Figure 3 shows a pie chart that represents the distribution of work zone crashes by road type. Although the highest percentage of work zone crashes occurred on urban interstate highways, it cannot be concluded that these highways are more susceptible to work zone crashes, as these crashes were not normalized for traffic volumes or for the number of work zones on each type of road. The data that would be required for such an analysis was not reported in the literature.

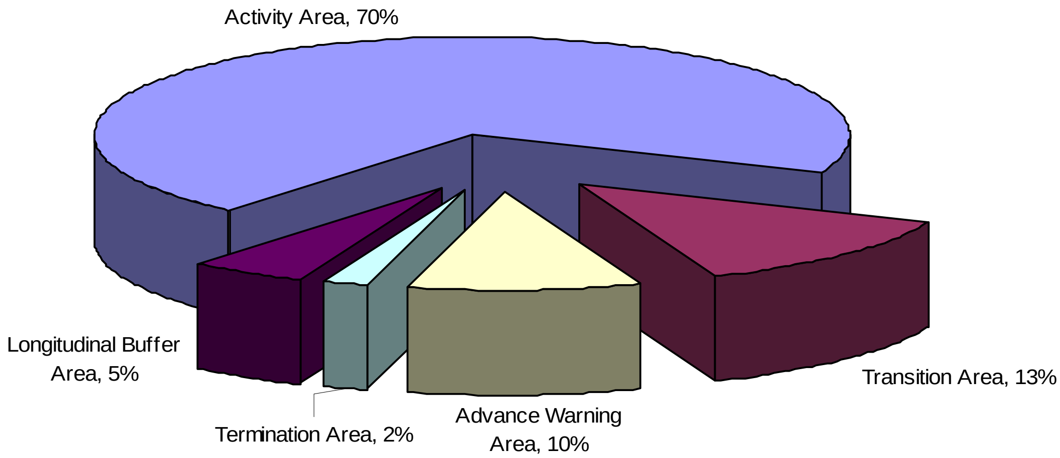


Figure 11: Location distributions of Work Zone Crashes

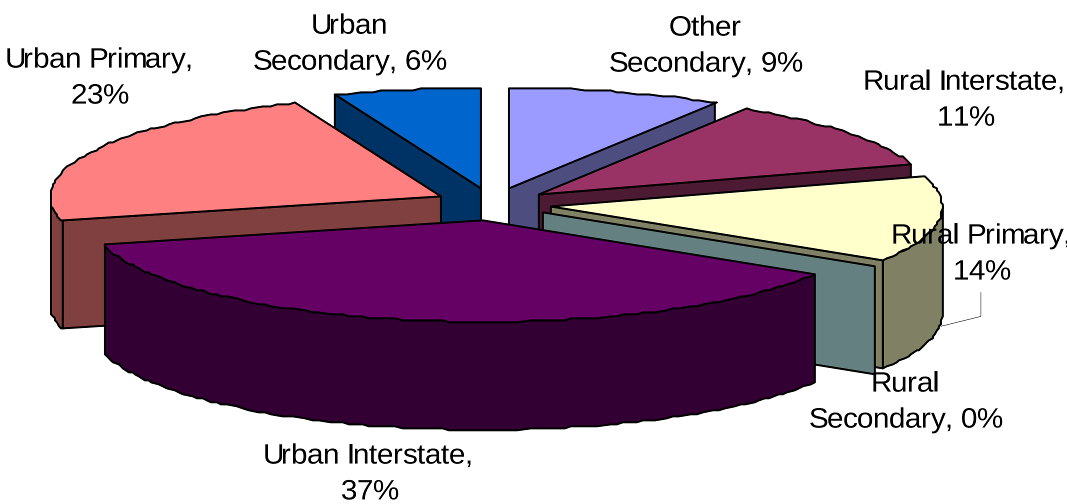


Figure 12: Road type distributions for all work zones

In a recent study conducted by Garber and Ming, the results indicate that the activity area was the predominant location for work zone crashes regardless of highway type and that rear-end crashes were the predominant type of crash. The results also indicated that the proportion of sideswipe same direction crashes in the transition area was significantly higher than in the advance warning area and that work zone crashes involved a higher proportion of multi-vehicle crashes and fatal crashes.

Crash Type

The results of several studies indicated that rear end crashes were the predominant collision type in work zones. Richards and Faulkner found that rear-end accidents account for 40 percent of accidents reported in work zones. They attributed this to slowing among preceding vehicles. Single-vehicle, fixed object accidents were the second highest, representing over 15 percent of all accidents reported in work zones. Pigman and Agent found that, as suspected, work zone crashes involving heavy vehicles were more severe than those in which heavy vehicles were not involved. Pigman and Agent also found that crashes during darkness were more severe, whereas Nemeth and Migletz found that crashes during daylight hours were more severe than those at night or at dawn and dusk and that single-vehicle crashes were predominant at night. Two studies concluded that nighttime crashes were especially concentrated in the transition area.

A summary of major studies conducted on crash characteristics and coverage of crash characteristics are tabulated in Table 2 and Table 3 respectively.

Table 2. Major Studies Concerning Crash Characteristics

Ref	Year	Duration	Length or Number of sites	Number of Crashes	State	Road Type
5	1982-85	Average 255 days	168 projects, 172 sections, 1045 mi	631	New Mexico	Rural section of interstate and federal-aid primary
6	1980-85	N/A	4 long-term,25 intermittent or	N/A	Illinois	Chicago area expressway system
7	1982-85	Generally longer than	26 sites	N/A	Virginia	Urban 2-lane, 3-lane highway with 4 or more lanes
8	1983-86	4 yr	N/A	2013	Kentucy	All
9	1973	Mostly within 1 yr	21 sites,384 mi	151	Ohio	Rural Interstates
10	1984-85	2 years	N/A	N/A	Virginia	All
11	1982-86	N/A	All,then 60,then 9 projects	N/A	Ohio	All
12	1977	1yr	N/A	1847 of 2127 selected	Virginia	All

Table 3 Coverage of Crash Characteristics in Various Studies

Subject	Ref. Results	Remarks
Crash Rates	5,6,7,8,9 increase after before period	Crash rates increase in work zones
	7,10 higher at work zones	
Crash Location	5,13,15 most occurred at activity area or combined longitudinal buffer and activity	Activity area is the predominant location of crashes
Rear End Crashes	4-15 : predominant collision type	Rear end crashes are the frequent type
Multiple Vehicle crashes	4-15: overrepresented at work zones	
Crash Severity	8,11 more severe at work zones	
Crash Severity at night time	8: more severe than daytime	
Severity of crashes involving heavy vehicles	8 more severe	
Collision type distribution	12: fixed object crashes	

Technologies to Reduce Crashes in Work Zones

A1998 report by the Federal Highway Administration, noted that the two leading causes of work zone crashes are excessive speed and driver inattention. Further, it noted that there is universal agreement that the most effective way of controlling speed in the work zone is to have a staffed police car with flashing lights at the onset of the work zone. Drivers detect the presence of police either visually or via radar detectors and reduce their speed to comply with the posted work zone speed limit. The reduced speeds and reduced variation in speeds result in fewer accidents or less severe accidents and minimize dangerous interactions between vehicles and workers and equipment.

Traffic control devices used in work zones should strictly follow the MUTCD requirements. Shielding the activity area in a work zones can be done using devices such as Balsi beam, traffic cones, and portable barriers. Additional protection of work zones can be done using intrusion alarms, rumble strips, truck mounted attenuators and effective advance warning signs such as –“Be Prepared to Stop”, - “Shoulder work Ahead”, -“Work Zone Approaching” which would draw driver attention. Warning drivers of queues ahead is another method of preventing crashes caused by vehicles following too closely. Devices such as queue detectors combined with changeable message signs could warn drivers well in advance.

A thorough literature search was conducted using all the available resources for identifying devices and technologies, which are effective in catching driver’s attention. Among various techniques that are being employed by various DOTs, intrusion alarms and portable rumble strips which are the most widely used devices.

<u>Rumble Strips</u>

In an effort to promote safer conditions in work zones, the Kentucky Transportation Center, in conjunction with the State of Kentucky and the Federal

Highway Administration (FHWA), sponsored a project to demonstrate the use of the portable rumble strip at maintenance work zones across the State. When drivers feel the vibration and hear the sound caused by the portable rumble strip, they are given a final reminder that they are about to enter a temporary work area.

Developed by the Strategic Highway Research Program (SHRP), the portable rumble strip is placed across the road about 100 m (250 ft) in advance of the work zone. The device causes a vibration in the steering wheel and a rumble as vehicles pass over it, warning drivers that conditions on the road will soon become dangerous. The portable rumble strip is best suited for low-speed roads that carry few heavy trucks. The portable rumble strip is also easy to use. The device weighs about 34 kg (75 lb), and one or two workers can deploy it from the back of a pickup truck.

A number of studies have demonstrated the benefits of shoulder rumble strips in reducing death and serious injury caused by inattentive drivers in Run-off-road (ROR) crashes. The methodologies used in these effectiveness studies and their results vary from state to state, but all show some measure of crash reduction attributed to the presence of shoulder rumble strips.

Intrusion Alarms

Drivers sometimes fail to notice the signs, cones, and other warnings that they are approaching a highway work zone. Intrusion alarm developed under the SHRP provides safety to workers in the work zone either by audio or visual means, when a motorist intrudes into the work zone. State of Vermont is using these alarms to inform the workers well before the danger. Example of audio intrusion alarm is a flashing strobe light, which activates as soon as a driver by mistake enters in the danger part of a work zone. The biggest benefit is that the workers get few seconds to clear out of danger way.

After testing two models of the work zone intrusion alarm, Vermont AOT's research unit purchased a model that uses an infrared beam sent from a transmitter unit to a receiver unit that also houses the siren. When a vehicle breaks this beam, the siren goes off. The research unit picked this model because it was the fastest and easiest to set up.

ALTERNATIVE STRATEGIES AND TECHNIQUES FOR TRAFFIC CONTROL

Technologies

Workers in rural short-term maintenance work zones are placed in a particularly hazardous position. Short-term and mobile maintenance work zones are typically located on high-speed roads; with traffic control installed each day in the morning and removed by dusk. Since these work zones are in place only for a short time, drivers do not expect to encounter them. Regulatory speed limits cannot be lowered at the sites, and it is difficult to get law enforcement agencies to regularly patrol temporary work zone sites in rural areas. Studies conducted at work zones evaluated a large number of innovative traffic control devices that had the potential to improve safety in short-term work zones. Researchers examined countermeasures that would increase driver awareness of the upcoming work zone, make workers more visible, or slow down traffic. Since these work zones were in place only for a short time, it was also essential that each device be easily set up and removed.

Flashing Lights

Research sponsored by the Texas Department of Transportation (TxDOT) and conducted by the Texas Transportation Institute (TTI) has revealed helpful techniques that improve safety for workers and increase visibility of work zones for motorists. The researched techniques is shown in Figure 13.   In a general scenario, the indication of a work zone ahead is given to the drivers by flashing yellow warning signals or a sign telling to move from one lane to the other. A new method of warning drivers of approaching work zones is proving to be safer and easier to understand from greater distances. The approach was developed as a part of a TTI research project that was sponsored and implemented by TxDOT. It utilizes a series of synchronized flashing lights attached to the drums that form a lane closure taper. The flashing lights illuminate in a sequence from the beginning to the end of the taper. According to closed-course studies at TTI's

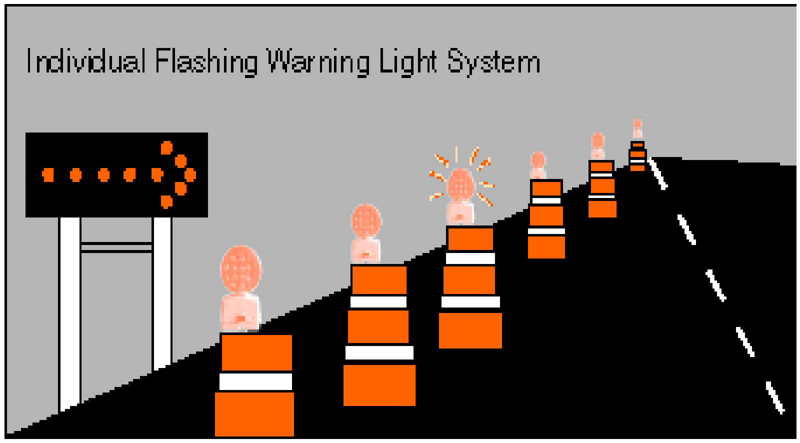


Figure 13 Texas DOT Flashing Lights

Riverside Campus in College Station and roadway tests in Houston, drivers responded more positively to the synchronized flashing light system than to the normal traffic control setup used at construction sites in Texas. It was also found that as the synchronized flashing warning light system was activated, there was a one-fourth reduction in the number of passenger vehicles 1,000 feet before the lane closure taper.

Dancing diamonds (lights)

In this context, it is also pertinent to discuss here arrow panels consisting of a matrix of lights. Non-directional arrow panel displays are designated as caution displays. Before 2001, literature lacked significant statistical support for any one type of caution display. A 2001 Oregon Department of Transportation (ODOT) study suggested that the + ACI-dancing diamonds are better than the other caution displays like flashing box. ODOT also found that local citizens preferred the dancing diamonds to other caution displays. However, additional research was needed to confirm these findings. The lights are shown in figure 14.

To evaluate the effectiveness of the dancing diamonds and +ACI- flashing box+ACI- displays, a field experiment was conducted. The results of this experiment showed that the dancing diamond was associated with a statistically significant 3 km/h (2 mph) reduction in mean speeds, whereas the flashing box display was associated with no statistically significant reduction in mean speeds, indicating that the dancing diamonds prompt safety near highway work better than the flashing box.

Rotating lights / Strobe Lights

This comprehensive research report published by TRB was developed due to the growing concern of increasing frequency of hazards during moving and short-term work zone operations. The research was very thorough and effective in a way that it encompassed different possible formations of mobile maintenance operations. Eleven categories of short-term and moving work zones contained corresponding traffic control devices, vehicle warning light systems and driver

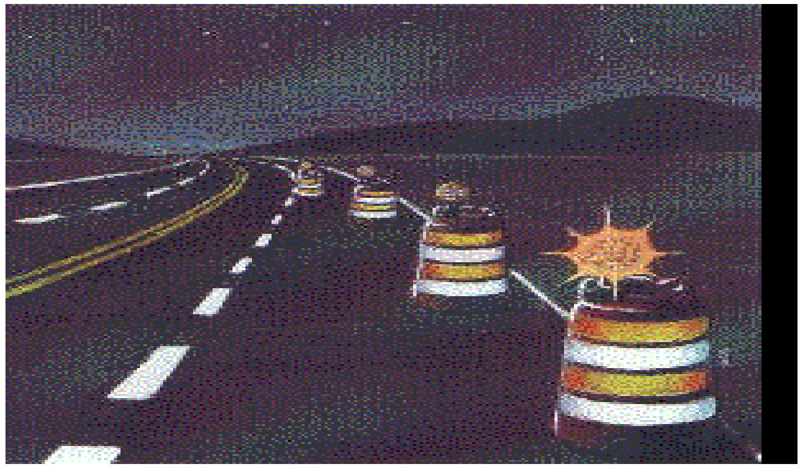


Figure 14 Dancing diamonds (lights)

actions respectively. Though studies supported traffic control devices (TCD) applications and guideline development, it was also found that accident reduction was the ultimate measure of device effectiveness.

This research mainly focused on human response to warning lights varied by the type of light both in closed field and operational tests. It was found during research that no one light is maximally effective in both transmitting information and gaining attention. The reason for this was that rotating and strobe lights, which were effective in getting driver's attention, were not as useful in providing speed and closure rate information especially when the service vehicle was stopped. Conversely flashing lights, which worked really well for giving speed info, were not effective in providing clear clue of working zone to drivers from long distances. Therefore several of the lighting recommendations combine the two types of light in order to ensure optimum information transmission and conspicuity.

Apart from the findings related to different types of lights functioning's, cost benefit analysis was developed to aid in making some of the decisions. Some of the devices like shadow vehicles were found to be very effective in producing desired results but involved substantial costs as well. Therefore separate cost-effectiveness criteria were included as a basis for agency-specific decisions regarding its use.

Advanced Warning Signs

The Virginia Department of Transportation (VDOT) is continuously striving to improve the flow of traffic as well as to protect workers and motorists in work zones. By using an advanced warning sign that is easily understood by motorists, both motorists and workers benefit. VDOT and several other state departments of transportation have expressed interest in modifying the advanced warning signs for work zone operations. The advanced warning sign is intended to alert drivers and to prepare drivers to stop (if necessary) prior to reaching work zone operations. Typical advanced warning signs are shown in figure 15.

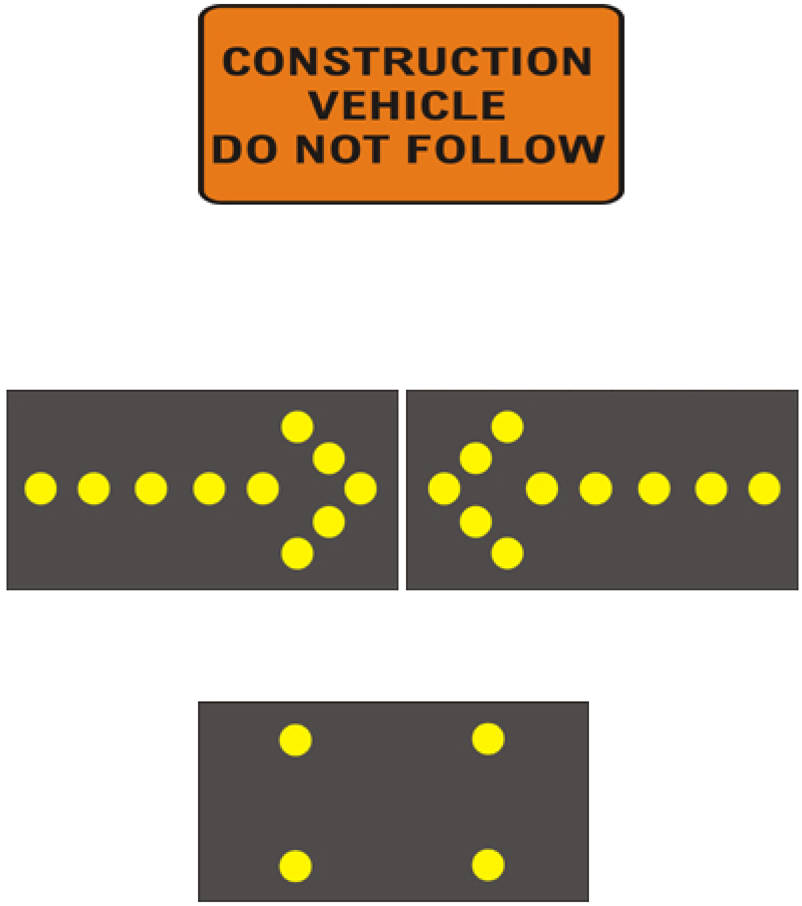


Figure 15   Typical Advanced Warning Signs

For example the construction vehicle sign warns drivers that the truck they are following is a construction vehicle and may leave the lane to enter an active work area.

Flashing arrow boards warn drivers that the lane they are traveling in is closing ahead and a lane change is required. The arrow direction will indicate which lane is open for travel.

Similarly, when only the four corners of the board are flashing, drivers must use caution, but do not change lanes. This light pattern is also used when work is on the shoulder of the roadway.

Variable Message Signs

Highway maintenance projects create difficulties for highway workers and motorists alike. Project crews work just steps away from passing traffic, usually separated by only a line of plastic barrels or cones. Motorists must navigate changing traffic patterns, which can cause delays and frustration. They also face an increased risk of rear-end collisions caused by sudden changes in travel speed. Typical variable message sign is shown in figure 16.

It's not that motorists haven't been warned to slow down as they approach the work zone; rather, many motorists fail to heed the warnings because they find the signs unreliable. They've seen too many "Slow" and "Work Zone Ahead" signs that are still in place after the crews have gone home, or variable message signs whose messages do not reflect current traffic conditions.

Several manufacturers are working to solve this problem by developing systems that use variable message signs to display messages based on real-time measurements of traffic conditions. One such system is *Adaptir (Automated Data Acquisition and Processing of Traffic Information in Real-Time)*, a technology developed by the Scientex Corp. with support from the Federal Highway Administration (FHWA) and the Maryland State Highway Administration.

The Adaptir system measures traffic speeds using Doppler radar, the same technology used by police to detect speeders. Traffic speeds are measured at several points within and upstream of a work zone. The data are then sent to a central control system, which analyzes the data to pinpoint patches of traffic congestion and delay and then selects the appropriate prerecorded message to post on a variable message sign- -or series of signs--just upstream of the site. The messages prepare motorists for actual traffic conditions ahead. For example, if traffic is extremely slow in the work zone, a variable message sign upstream of the work zone might warn of a 10-minute delay ahead; a second sign might then warn drivers to slow to 55 km/h (35 mi/h). If traffic speeds decrease further, indicating worsening congestion, the system would automatically change the signs to indicate an even longer delay and advice of slower speeds ahead. The signs can also be used to suggest alternate routes or tell drivers to tune in to a highway advisory radio station. To emphasize the timeliness of the messages, each sign can also display the time the message was posted. Drivers armed with information on traffic ahead are better prepared for changing traffic conditions and thus more likely to have a safe trip. The economic benefits of reducing delays and improving safety at a work zone can outweigh the cost of the Adaptir system by a factor of six or more, according to an economic analysis conducted by Scientex.

Speed Display Trailer

This evaluation utilized a trailer-mounted speed display provided by TxDOT. The unit, figure 17, features a 24-inch LED display and uses Ka-band radar to detect oncoming vehicles. The display has a strobe lamp that flashes when a vehicle is detected traveling over a preset speed threshold. This feature is intended to simulate the operation of photo radar, possibly decreasing speeds through the

Figure 16 Variable Message Signs

Figure 17   Speed Display Trailer

threat of automated enforcement. During this evaluation, the speed threshold for the strobe light was set at 75 mph. The display also has a 130 dB siren that can be activated by vehicles traveling over a preset speed. This option is intended to warn workers when an extremely high-speed vehicle is approaching.
This device proved to be effective in short term/mobile operation as the display could be set up in under 10 minutes. The controls were easy to operate, and TxDOT crews that have used the device have reported no maintenance problems.

New Dynamic Message Systems Technology

The 3M Company produces a “Scotchlite LED-1 Pixel” technology with fluorescent reflective material and high output InGaAIP light emitting diodes. The LEDs are embedded in the fluorescent reflective panel for improved reflectivity. This new technology is used in the 3M Variable Speed Limit Sign to improve sign visibility and alert drivers. The technology is shown in figure 18.

Glowing Safety Lights

The Safe Lites Company produces “Bright Zone Signs”. The technology incorporates small glow lamps which are composed of phosphors that are ignited by small electrical charges. The lamps can be hardwired into a vehicles electrical system or to rechargeable Lithium batteries for vests and wearing apparel. The glowing lamps can be seen from a farther distance than standard illuminated signs and reflective materials, and significantly improve the visibility of works at night.

Figure 18 “Scotchlite LED-1 Pixel” technology with fluorescent reflective material

Effectiveness of Police Presence and Enforcement Measures

The use of police enforcement in work zones is a common practice among State DOTs especially during short term/mobile operations. Since inattention and irresponsible behavior by drivers are suspected to contribute to the frequency of work zone crashes, a program featuring presence of and enforcement by law officers has been implemented by many states to alleviate the effect of crashes in work zones. Several studies found that the use of extra enforcement in work zones is a common practice in many states and that these practices appear to be increasing. There are several benefits of increased law enforcement police presence and activity in work zones indicated in literature, survey responses and worker interviews. Limited congestion increase has been reported from these efforts. Enforcement activities in work zones has proven beneficial in reducing speeds, ensuring compliance with traffic regulations, and improving safety for workers and motorists.

A study concerning the use of uniformed police officers on federal-aid highway construction projects was prepared pursuant to Section 1213(c) of the Transportation Equity Act for the 21st Century (TEA-21). It concluded that the majority of states use uniformed police officers in at least some work zones where there are particular traffic safety concerns. Officers are commonly deployed both day and night and in a variety of locations within and in advance of actual work activities. The states' survey responses stated an overwhelming opinion that extra enforcement has benefits in both lowering speeds and improving safety in work zones.

The FHWA engineers work closely with state highway engineers and law enforcement officials to identify appropriate engineering safety countermeasures for high-risk locations and for new roads. FHWA also works with the enforcement community, such as the International Association of Chiefs of Police (IACP), regarding the effective use of uniformed police officers on federal-aid highways. FHWA additionally works with emergency medical services, police and fire organizations to ensure that public safety is maintained at high levels and access for emergency vehicles is possible during work zone operations.

Work Zone Enforcement Technology

Police enforcement relies on personal presence supplemented with technology tools such as radars and laser guns. Jones and Lacey (1997) conducted a study in Iowa to determine the effectiveness of laser-based speed enforcement programs compared with radar during 1994–1995. Radar and laser speed measurement devices were used extensively in the cities of Dubuque and Council Bluffs, respectively. Both cities increased speed enforcement activities during the study period and raised public awareness of the risk for being cited for speeding violations. Speed data were collected once each week at 10 locations in each city before and after the enforcement program implementation. The study found that the radar-based speed enforcement program decreased the percentage of vehicles traveling more than 5mph over the posted speed limit by about 20 percent. This observation may be partially explained by the prior existence of a higher level of speed compliance in that community. The researchers concluded that laser-based speed measuring devices should supplement rather than replace existing radar measuring technology.

Remote Speed Enforcement

Another technology and strategy currently considered in work zones is real-time remote speed enforcement. A study conducted in several work zones in Europe conclude that due to high speeds and traffic volumes in many work zones, stopping drivers for traffic violations may be dangerous for both motorists and officers. A remote speed enforcement program uses automated speed enforcement (ASE) system to detect violators and alert an officer located beyond the work zone of the violation. ASE can use a variety of technologies (e.g., radar, LIDAR, elapsed travel measurements, and in-pavement sensors) to detect vehicle speeds. When a violation is detected, a photograph of the vehicle license plate is taken and transmitted to officers stationed outside of the work area. After the violating vehicle has passed through the work area the motorist can be stopped safely. ASE programs can also mail tickets to the owner after a vehicle has been identified. In most states criminal citations cannot be issued using only ASE evidence.

ASE systems have also been employed in the United States. Several communities have used or are currently using ASE. It is common for communities using ASE to experience a decline in both speeding violations and crashes[22]. For example, in Paradise Valley, Arizona, noted a decrease in crashes from 460 in 1986 to 224 in 1992 after implementing an ASE program. Similarly, West Valley, Utah, observed a decline from 2,130 to 1,710 crashes annually after using ASE for two years. A Texas Transportation Institute study examined whether a remote enforcement system was technically feasible and whether vehicles could be correctly identified downstream, and surveyed the attitudes of law enforcement agencies regarding the system. The study found that a downstream observer could correctly match about 84 to 88 percent of the offending vehicles. One problem observed was in the transmission of photographs to an officer downstream. Speed thresholds may need to be established to ensure hardware/software processing capabilities are not overloaded. The law enforcement community expressed concerns with the legal aspects of the system. Some officers and officials believe that modifications would need to be made to the system and/or to state codes to permit enforcement using only photographic evidence.

South Dakota completed a study during 1998 using three deterrents to reduce speeds in work zones: video/LIDAR, a Highway Patrol car, and a decoy car. The study found the most effective option was a decoy car parked on the shoulder. A problem found with the active Highway Patrol car was that when the officer left in pursuit of a violator, he/she was absent from his/her position at the beginning of the work zone for 15 minutes or more. The South Dakota DOT is currently collecting data using an ASE system in work zones. South Dakota DOT is planning to present the findings at a future legislative session in support of legislation to permit direct mailing of citations. All violators cannot be detected with ASE, especially on high speed and high volume roadways, but it is believed that an ASE system can identify many more violators than a single police officer.

Work Zone Law Enforcement Functions

Police officers can be utilized in work zones in many different applications, such as:

- keeping travel lanes free of illegally parked or stalled vehicles on detour routes and major traffic arteries by arranging for removal
- controlling illegal turning movements that may restrict capacity at intersections directing traffic in congested situations
- providing advance warning of heavily congested or stopped traffic in advance of a problem area, such as a lane closure
- assisting in traffic control for special construction events, such as bridge beam erection and changes in traffic patterns
- observing and reporting traffic problems on state highways or detour routes to the appropriate engineering staff
- enforcing speed and any other restrictions in or near the work zone area
- aiding in traffic control during the daily signing setup and takedown activities
- preventing intrusions into closed lanes, exits

A study conducted by Virginia DOT surveyed several work zone crews, and that the officer be stationed in the lane closure 500 to 1,000 feet in advance of the first work crew. If traffic backs up, then the officer should be in advance of the backup. Sixty percent of the respondents reported that the officer was most typically located at the beginning or in advance of the lane closure, and 50 percent reported the location as inside the work area, either near the workers or away from the workers. Only 4 percent of the respondents noted the location as at the end of or following the work area. There were also comments suggesting that VDOT or VMS personnel assign the location, that the officer position should depend on the location of the work zone, and that officers be mobile and patrol the entire work zone and thus are not located at any one place.

However, the benefits of enforcement appear to have not been intensively quantified. In addition, procedures for the use of law officers in work zones are quite inconsistent across the nation, and so is the general implementation of specific legislation addressing work zone traffic violations. Variation can also be found in funding levels and sources for enforcement activities in work zones among the states. Training of law officers prior to work zone duty is not mandatory, but it would be better to provide them with adequate training for their work zone duty.

As crashes and deaths continue to rise annually in work zones, it is imperative that beneficial enforcement programs such as the use of law officers in work zone be continued, refined, and expanded. Future studies are needed to supplement the knowledge base and provide guidance to agencies when considering the use of law enforcement to calm traffic, ensure compliance with traffic laws, and thus provide for safer work zones.

Guidelines for Use of Extra Enforcement

Studies have been undertaken to establish guidelines for assigning law enforcement officers to work zones. In 1995, the FHWA developed guidelines for use of uniformed police officers on federal aid projects in Massachusetts. The FHWA conducted interviews with Massachusetts Highway Department personnel from Construction, Traffic, and Design Divisions. Interviews were also conducted with personnel from the Massachusetts Turnpike Authority, the Massachusetts State Police, and the Boston Police Department. Considering information gathered from the interviews (and after consulting the national MUTCD, the state of Massachusetts and local training manuals, and current nationwide practices) the FHWA recommended guidelines to determine when uniformed police officers or civilian flaggers should be used for traffic control on federal-aid projects in Massachusetts. It was recommended that flaggers and uniformed traffic officers should be used only when standard temporary traffic control measures do not adequately guide traffic and provide safety for motorists and workers. The guidelines also state that use of flaggers may be necessary to control traffic on alternating one-way operations or other situations where supplemental information must be provided. Flaggers may be replaced with police officers when high traffic speeds, high traffic volumes, or other extenuating circumstances occur. The guidelines suggest that a uniformed traffic officer with a marked patrol car and flashing, lights should be assigned to nighttime operations. A summary of the guidelines is provided in Table 3.

Table 3. Guidelines for Flaggers and Uniformed police

Work Activity	Low Speed & Low Volume	High Speed & High Volume
Work in the median or roadside area (no infringement on the roadway)	Neither flaggers nor uniformed officers are required	Neither flaggers nor uniformed officers are required
Shoulder closed with concrete barrier	Neither flaggers nor uniformed officers are required	Neither flaggers nor uniformed officers are required
Shoulder closed without concrete barrier (work adjacent to traffic)	Neither flaggers nor uniformed officers are required	1 uniformed officer suggested
Setting up or removing lane closures, lane shift, or other changes in traffic pattern	1 flagger per traffic approach suggested	1 uniformed officer per traffic approach suggested
Lane closed on multi-lane roadway with concrete barrier	Neither flaggers nor uniformed officers are required	Neither flaggers nor uniformed officers are required
Lane closed on multi-lane roadway without concrete barrier (active work adjacent to traffic)	Neither flaggers nor uniformed officers are required	1 uniformed officer per traffic approach suggested
Survey crew—roadway centerline	1 flagger per traffic approach suggested	1 uniformed officer per traffic approach suggested
Temporary Road closure (15–20 minutes)	1 flagger per traffic approach suggested	1 uniformed officer per traffic approach suggested
Ramp work	1 flagger suggested	1 flagger suggested
Moving operation in travel lane	1 flagger suggested	1 uniformed officer suggested
One lane, alternating traffic (no signal)	1 flagger at each end and at each cross street suggested	1 uniformed officer at each end and 1 flagger at each cross street suggested
Work within intersection	Flagger(s) suggested (number dependent upon field conditions)	Flagger(s) suggested (number dependent upon field conditions)

In 2002, NCHRP Report 476 proposed traffic control guidelines for nighttime maintenance and construction projects. The report states that for all nighttime work activities, the need for and extent of police services should be considered. It was concluded that visible police enforcement is highly desirable in nighttime operations to encourage driver adherence to traffic regulations and to manage incidents such as crashes, breakdowns, and major congestion. Criteria suggested police services might be advisable for nighttime operations as follows:

- construction activities closely adjacent to traffic without positive protection
- restrictions to traffic flow based on work zone features (e.g., no shoulder, reduced shoulder width, reduced lane width, or reduced number of travel lanes)
- locations where incidents are expected to produce substantial congestion and delays
- special operations that require traffic control or shifts of the traffic pattern
- locations where traffic conditions and crash history indicate that substantial problems may be encountered during construction
- projects with heightened public concern regarding the impacts of the traffic control plan

Other factors that should be considered include traffic speed and volume through the construction site. Engineers may also wish to refer to these criteria when deciding whether or not to use extra enforcement during daytime activities.

Work Zone Enforcement Legislation

The Texas Transportation Institute (TTI) conducted a survey regarding work zone legislation in 1997 and provided updated related information on the National Work Zone Safety Information Clearinghouse (NWZSIC) website in 2002. The survey found that 47 states have implemented higher fines for traffic violations in work zones. Enhanced enforcement penalties in most states are applicable to all types of work zones: construction, maintenance, and utility. However, some states limit application to construction areas only.

Of the 47 states with increased fines in work zones, 32 apply the higher penalties only to speed violations, while increased fines can be issued for all traffic violations in 11 of the responding states. Four states describe specific traffic violations where higher fines can be applied, such as reckless driving, driving under the influence, improper passing/overtaking, and following too closely.

Some states actively enforce more than just moving violations in work zones. Michigan, Montana, Oregon, and Washington have enacted legislation allowing a driver to be charged with reckless endangerment of highway workers in a work zone. The state of Oregon also permits drivers to be cited for refusing to obey a flagger. Similarly, Utah allows tickets to be issued for failure to obey a peace officer or other traffic controllers in construction or maintenance zones.

Increased fine amounts vary from state to state; most commonly, standard fine rates are doubled for work zone violations. Midwestern states that apply double fines include Iowa, Kansas, Nebraska, and South Dakota. Fifteen states with increased fines in work zones use fixed amounts for violations. In Missouri, for example, moving violations in work zones are assessed the standard fine amount plus 35 dollars.

The TTI survey found that about one-half of responding states with higher work zone fines require appropriate signing to notify motorists of this fact. Furthermore, approximately half of the states apply increased fines only if workers are present in the work zone. In addition to requiring workers to be present for higher fine application, Illinois has a policy and Tennessee a code provision requiring flashing lights to indicate workers are present.

South Dakota is the only state that authorizes agents or employees of the State department of transportation to issue citations within work zones for speeding and other violations. Despite the commonality of increased penalties for violations among the states, analyses of fatal crashes in work zones between 1984 and 1995 indicated no consistently measurable effect on fatal work zone crash frequency due to higher fines. According to NWZSIC, six states have adopted legislation allowing a speed limit reduction within a work zone without a traffic engineering investigation.

Education and Awareness Programs

Engineers and planners have the responsibility to make sure the work zone is designed and operating properly with safety in mind. Drivers and pedestrians have the responsibility to always be alert and obey the traffic laws. Passengers should always buckle up and act responsibly. The police and the courts have the responsibility to make sure that the traffic and work zone laws are enforced. Public safety agencies have the responsibility of responding to and securing crash locations and enforcing traffic laws. Local communities and county and state governments need to allocate funding for safe roads and increase public awareness about work zone safety. Everyone should take some responsibility for work zone safety.

Several public awareness and technical training is conducted through wide range of activities such as: training courses for federal, state and local highway engineers, worker and drivers; conferences, CDs, brochures for the general public and work zone employees; clearinghouse website; bilingual safety public outreach materials; national work zone awareness week where national, state and local public activities seeks to raise public consciousness about the need for driving safely in work zones.

The National Work Zone Safety Information Clearinghouse started in 1998 by FHWA and the American Road and Transportation Builders Association (ARTBA), provides excellent educational resource reaches the public and the highway community.

Young drivers are prone to create more crashes. In order to educate young drivers, FHWA has produced Moving Safely across America, an interactive CD that is being distributed to 15000 driver education teachers. FHWA is also producing innovative tolls and materials for increasing work zone safety awareness and safe driving to teen drivers.

Good work zone practices of state transportation agencies all over United States, strictly following MUTCD requirements is compiled into a Best Practices Guidebook (available at http://www.ops.fhwa.dot.gov/wz/workzone.htm or on a CD). In the Fall of 2003, FHWA published a Traffic Control Handbook for Mobile Operation at Night that describes detailed guidance for night time construction, maintenance and utility operation.

FHWA maintains good database on recent work zone related research, developments, safety statistics, and technology transfer. These resources are updated regularly and made available to researchers and engineers.

Worker Education Programs

Many state agencies provide periodic worker education programs to inform and encourage safe work practices when workers are exposed to traffic and entering the work zone. These programs include the proper personal attire, use of safety equipment, safety set-up rules and procedures, and conduct. Periodic programs are held monthly, quarterly and semi-annually in a central location or in regional headquarters. Courses are given by agency safety personal and in some instances by professional teaching staff to discuss and inform the worker of new procedures as well as standard procedures. In addition to the worker education programs, agencies provide safety inspectors to regularly check agency work zone safety procedures and correct deficiencies as they occur.   Although it may be difficult to measure the effectiveness of such programs, these programs intuitively suggest a concern for safety on the part of the management and an awareness of safety on the part of the workers.

Program Implementation

Many state DOT sponsors work zone-oriented public information programs to reduce the number of crashes in work zones. In Iowa, the current program, "Expect the Unexpected in the Work Zone”, is a by-product of the popular television series, "The Twilight Zone”. The major components of the program are: an educational curriculum for grades K-12 (this includes a six-minute video tape and a classroom instructor's guide that includes student activities to increase awareness of the need for safe driving in work zones), public service announcements and paid advertising for television, radio, newspapers and magazines to get information about safe driving in work zones directly to the motoring public, brochures, stickers, and posters. Several DOTs’ and FHWA propagate tips for driving safely in work zones.

Like drivers, workers need to be guided by educating them to make sure the existence of a work zone with all its parameters in place, i.e. all the devices should be in right place and working properly. Secondly if it’s the night operation then all devices should be reflectorized or illuminated. It should be ensured that all the maintenance vehicles should be within the vicinity of a work zone. In addition, workers with specific traffic control responsibilities should be trained in traffic control techniques, device usage and placement. Don’t assign untrained workers the responsibility for setting up and maintaining the system. Workers should be given true information and training and all devices and signs should be removed that are not in use, meaning that there should be minimum hindrance to the free flow of normal traffic. Drivers should not be made to think, respond, brake rapidly by awkward placement of devices and usage of signs. Another important thing to note is that safety features may provide adequate warning for a vigilant driver, but may be inadequate for an inattentive driver. It means that drivers should be guided in a clear and obvious manner throughout the work zone.

CB Wizard Alert System and Program

The device is a portable radio that broadcasts real-time work zone information and safety tips to citizens through radio channels. This device is especially good for truckers by letting them know about the traffic patterns through latest updated news. It is designed to give drivers monitoring the CB radio advanced warning of upcoming delays at construction sites or incidents. The advanced warning will allow drivers the opportunity to moderate their speed and become observant of the need to slow, stop, or maneuver before they reach the work zone or encounter queues of halted vehicles. Since truck operators most commonly monitor CB radios, it was assumed that the CB Wizard would have the most impact on truck drivers. With Certificate of Approval issued in January 1998, Penn DOT is using the device.[41]

Work Zone Evaluation Methods

There has been a dedicated effort over the past five years to minimize impacts to the public as they travel through work zones. While national data on the cost of work zone delays is not readily available, daily road-user delay costs on many urban freeway reconstruction projects have been calculated to be over $50,000 per day. Because of the significant impacts to the public in terms of delay and user costs, the Federal Highway Administration (FHWA) established the Strategic Work-Zone Analysis Tools (SWAT) program [29, 32]. It addresses work-zone factors and stresses the importance of accounting for work-zone influences when making transportation improvement decisions. Three tools are being developed as part of the SWAT program**:**

a. “Expert System” software program;

b. “Quick Zone” software program

c. A Detailed simulation model.

a. Expert System

With the Expert System, a user would enter data on the characteristics of the work zone, such as the type of highway improvement or repair work being done and the duration of the work. The program would then provide a list of possible mitigation strategies for reducing work zone delays and costs. The software is still being developed by FHWA and its expected release date is 2004. More information can be found on the FHWA Turner-Fairbank Research Center web site at http://www.tfhrc.gov/its/swat.htm.

b. Quick Zone

A prototype version of Quick-Zone, new work zone delay estimation software developed by FHWA in cooperation with Mitretek Systems, is now available on the web for use and assessment. A user need only have Microsoft Excel 97 or higher running on a Windows-based PC to use the Quick-Zone application. The software allows the user to compare the traffic impacts for work zone mitigation strategies and estimate the costs associated with these impacts. The costs can be estimated for both an average day of work and for the entire life cycle of construction. Version 0.99 of Quick-Zone was released in April 2001.

Specifically, the program provides the following functions:

1. Quantification of corridor delay resulting from capacity decreases in work zones.
2. Identification of delay impacts of alternative project phasing plans.
3. Supporting tradeoff analyses between construction costs and delay costs.
4. Examination of impacts of construction staging, by:
   - location along mainline;
   - time-of-day (peak vs. off-peak); and
   - season (summer vs. winter).
5. Assessment of travel demand measures and other delay mitigation strategies.
6. Allowing the establishment of work completion incentives.

The software is available for download at FHWA's Turner-Fairbank Research Center website at: http://www.tfhrc.gov/its/quickzon.htm.

c. Simulation Model

FHWA's simulation model, planned for release in 2004, is designed to be used in conjunction with Quick Zone to more precisely estimate the impacts of specific work zone strategies and the effectiveness of mitigation techniques. More information about the model can be found at the Turner-Fairbank Research Center website: http://www.tfhrc.gov/pubrds/nov00/strategic.htm.

Using a software tool like Quick-Zone, work zone traffic impact analysis could be performed, by selecting appropriate traffic control recommendations for the safe and efficient movement of traffic through construction work zones. The Expert System and Simulation Model, planned for release in 2004, would help in better estimation of work zone impacts, costs, and delays.

CONCLUSIONS

This report documents and summarizes the study “Identification of Traffic Control Devices for Mobile and Short Duration Work Operations,” for the New Jersey Department of Transportation. The study was conducted in three tasks: 1. Literature Search, 2. Evaluation Criteria and Analysis, and 3. Identify Guidelines to Eliminate Driver Inattentiveness, and Design Alternative Strategies and Techniques for Traffic Control. The study was conducted by two groups: the Region 2, University Transportation Research Center, City College of New York and the Institute for Transportation Research and Education, North Carolina State University. Working papers were completed for each of those tasks.

The objective of this research project is to study mobile and short duration work zone safety with particular attention to the identification of work zone safety devices, information systems for the reduction of safety and congestion, and implementation of innovative techniques to reduce delays and crashes due to work zones. The specific objectives are to:

- Identify state-of-the art work zone safety technologies to improve worker safety in mobile work zone and short term maintenance operations,
- Identify information systems for work zone traffic control to reduce delays and crashes,
- Identify “best practices” for the use of law enforcement to improve work zone safety,
- Identify key issues to be considered from public outreach and information systems.
- The identified work zone safety items will provide improvements for maximum protection of the motoring public, protection of exposed workers in the work zone and of workers in the set up of the work zone, and will meet the current standards established by internal policies of the NJDOT.

The literature search focused on safety technologies for mobile and short duration work zone safety technologies from Transportation Research Board and National Cooperative Research Program publications, FHWA, State DOT and other agency publications which include web sites of most national safety organizations. The search identified nine devices which are used by State agencies or have the potential for use in mobile and short duration work zones. The devices are:

- Fluorescent/Bright Signs
- Reflectorized/Bright Suits and Vests
- Drone Radar and Speed Indicator/Displays
- Remotely Operated Autoflagger
- Truck Mounted Attenuators and Message Boards
- CB Wizard Alert System
- Rumble Strips
- Intrusion Alarm
- Lane Merger System

The literature from most sources indicates that State agencies use the MUTCD work zone standards and the caravan approach to mobile and short duration work zone safety situations.

Texas Transportation Institute survey results indicate the most significant hazards for all responding agencies were high speed traffic, and inattentive motorists which resulted in rear end crashes of safety vehicles and errant vehicles entering the shadow vehicle convey or the work area. Some state agencies approach the solution to these issues by incorporating advance warning devices in addition to the standard MUTCD safety. Such devices and solutions are:

- brighter or fluorescent signs on shadow vehicles,
- trail vehicles with speed display boards below the arrow panel,

- the use of better or additional lighting on shadow vehicles, such as solid light bars, blue lights, or light emitting diode(LED) lights,
- dynamic message boards in advance of the work area, and
- police to enforce traffic laws.

All of these devices provide the motorist with the optimum warning to reduce or eliminate crashes and improve worker safety.

The Strategic Highway Research Program researched five devices that have the potential for increased work efficiency, and improved worker safety by eliminating direct worker exposure to traffic and mitigating errand vehicles. The five devices which are discussed the report are:

- Cone Shooter
- Automated Pavement Crack Sealers
- Automated Debris Removal Vehicle
- Balsi Beam
- Robotic Highway Safety Markers.

The Balsi Beam has the greatest potential for protecting exposed workers in short duration work operations. The beam provides a positive protection from errand vehicles and is crash worthy as tested by NCHRP testing. Unlike portable concrete median barrier which is time consuming and labor/equipment intensive to set up, and requires a 42 inch clear zone between the barrier and the worker, the Balsi Beam can be set up in less than 10 minutes and requires no clear zone between the beam and workers. The California Department of Transportation is presently implementing the barrier for specialized concrete construction and bridge repair operations on high speed interstate highways. The beam can be used in maintenance operations wherever workers are exposed to traffic in a limited area for several hours. No workers have been killed or injured while working behind the beam.

The FHWA recommends the presence of uniformed police officers on Federal-aid highway work zones. It further recommends the use of automated enforcement and intrusions alarms as well as uniformed police officers to improve traffic safety at highway work zones. The literature indicates that most State DOT s have programs and policy regarding these of uniformed police officers at highway work zones.

Motorist Information, Education and Outreach Systems are important tools for State DOTs. Most DOTs and the FHWA have specific programs to inform the public and train workers.

The researchers conducted five field observations of mobile and short duration work operations to analysis and compare current maintenance work zone operations with the MUTCD and other agencies, as well as interviews with work zone safety personnel. The safety for mobile operations of pothole patching, sweeping, spraying and mobile patching was in accordance with MUTCD requirements. Workers requested improved devices such as strobe lights and improved reflective materials for signs to get driver's attention.

The researchers met with California Department of Transportation engineers to observe the operation of the Balsi Beam and talk to Caltrans maintenance workers. The Caltrans is implementing the second generation prototype beam with a bridge and concrete repair crew on Route I-80 between Marysville and Reno, NV.

Caltrans uses the beam for medina barrier repairs, bridge deck patching and repairs, slab replacement and joint repairs, installation of bridge sealers and guiderail and parapet repairs. The beam is used in conjunction with other safety equipment - - TMAs, trucks, signs and safety set up .   The bridge maintenance crew and foreman were very enthusiastic about using the beam. The crew is able to use air compressors, bobcats and other equipment in the work area of the beam. Suggestions have been made to incorporate some of the equipment on the beam-tractor to make the beam a multi-functional piece of equipment.

Essentially, Caltrans, Division of Equipment, designed the beam with some assistance from TTI and funding from the FHWA. Caltrans fabricates and builds their own trucks and large equipment for maintenance, so they have extensive equipment design and fabricating experience. Caltrans and the FHWA would like to implement the beam in the east coast DOTs. At this time, Caltrans does not have the resources to demonstrate the beam throughout the country, and would like other State DOTs to be involved in implementation. The researchers believe this is an opportunity for NJDOT to improve worker safety, be a showcase and assist the FHWA for the implementation of the beam in the eastern states.

The researchers presented the information on the Balsi Beam and a PowerPoint presentation to Region South and Region North Maintenance workers and engineers. Both regions were interested in the potential for the beam to protect workers. However, Region North has the best application for the beam on bridge and concrete repair projects along Route I-80 in Northern New Jersey.

RECOMMENDATIONS

The NJDOT should fabricate and implement the Balsi Beam with the assistance of Caltrans and the FHWA on selected short duration work zones.

The NJDOT should implement “Bright Zone Signs to improve work safety and visibility of workers in work zones.

The researchers propose to develop a work plan to prepare a licensing agreement with Caltrans, prepare plans and specifications for bidding, investigate bidding and fabrication schemes such as fabrication at a facility in California, inspection and engineering expertise during fabrication, delivery of the beam, operation training and implementation studies with NJDOT engineers.