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

CUNY Project 2003-27

Phase I- Task 1
Review of Technical Literature

By

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INTRODUCTION

Work zone safety traffic control is an area that has been gaining a lot of attention during the past few years. Travelers come across several types of work zones on a regular basis due to increased maintenance and reconstruction along the nation's highways. Work zones pose a hazard to the regular traveler in terms of safety. Evidence suggests an increasing number of fatalities, injuries, and costs due to work zone-related accidents. According to the National Work Zone Safety Information Clearinghouse[1], in one year, work zones are associated with more than 700 fatalities, 24,000 injury crashes, and 52,000 property damage-only crashes and the estimated cost of these crashes exceed $ 4 billion per year. Therefore it is vital that efforts be made to enhance the safety and reduce fatalities in work zones.

OBJECTIVES

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 of the study are to[1]:

- Provide improvements for maximum protection of the motoring public and workers in the work zone and in the set up of the work zone,
- Identify state-of-the art work zone 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,
- Meet the current standards established by internal policies of the NJDOT,
- 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.

CONTENTS OF THIS REPORT

The literature search report is organized as follows

- Identification of generic components describing Temporary Traffic Control
- Review of the most recent MUTCD standards for mobile work zones
- Typical MUTCD applications of Mobile Work Zones.
- Nighttime Mobile Operations and typical applications.
- Review of the Strategic Highway Research Program (SHRP)
- Review of SHRP safety devices and new SHRP Devices
- Recent Work Zone products
- Devices Identified based on their functionality
- Plan of Work for next quarter
- References-The hyperlinks in the reference directly opens the respective online document.

Components of a Temporary Traffic Control Zone

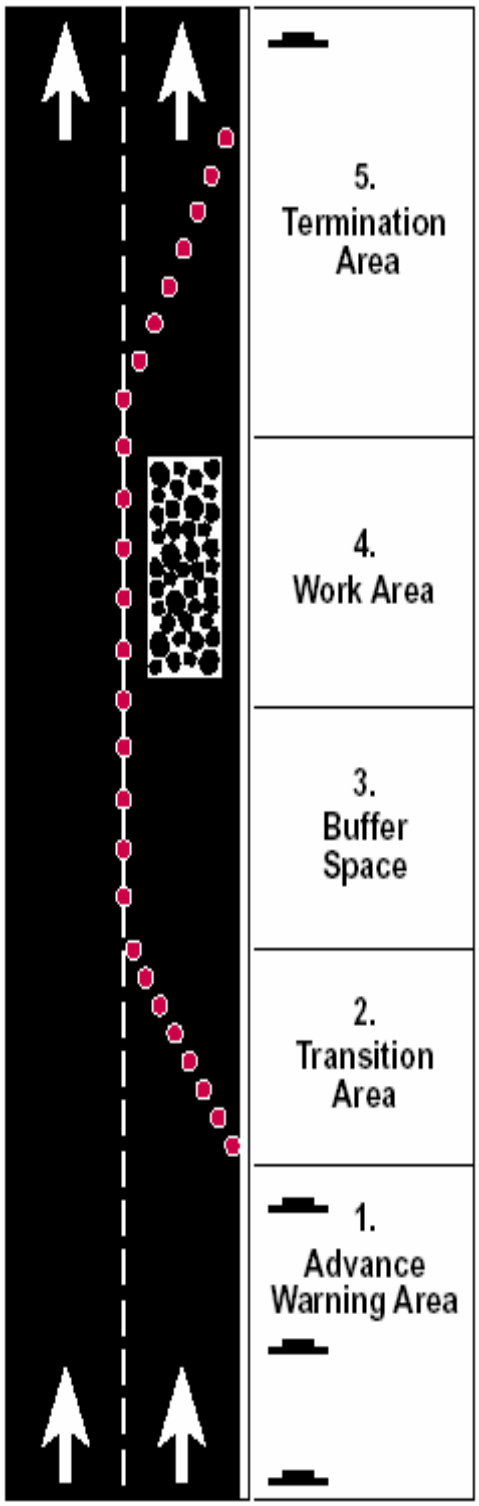
Termination Zone
The **termination area** is used at worksites to allow traffic to clear the activity area and return to normal traffic operations. It is the final portion of the traffic control zone that extends from the end of the activity area to the sign denoting the end of the work zone

Work Area
The **work area** is where the maintenance or construction work is taking place, including space for equipment and materials.

Buffer Area
It provides an additional element of safety before the actual workspace. It provides a recovery space for errant vehicles and separates traffic flow from the work activity. Work activities should not take place and equipment and materials should not be stored within the buffer area.

Transition area
A **transition area** is required when lanes are to be closed, the travel path shifted, or both, to accommodate the workspace.

Advance warning area
All traffic control zones should have an **advance warning area**. The advance warning area is important to alert drivers to potentially unusual or hazardous conditions so that driving speeds and driving practices can be adjusted in preparation for such conditions. The advance warning area contains the warning signs.



(Source: Reference No: 2)

SHORT DURATION / MOBILE WORK ZONE

Short-term roadwork is defined as an activity that requires traffic control[1], takes less than one period of daylight, and is not performed at night. Mobile operations move along the road either intermittently or continuously. Safety is a major concern during such operations.

Mobile operations are classified into two:

1. Intermittent Mobile Operations-These operations like litter cleanup, pothole patching, or utility operations, involves frequent stops and is similar to stationary operations.
2. 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.

Review of 2003 MUTCD[3]

Part VI of the *Manual on Uniform Traffic Control Devices* 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)
2. Mobile Operations on a two-lane road (TA-17)
3. Mobile operations on a two-lane road using flaggers (TA-13)
4. Mobile operations on a multilane road (TA-35)

Typical Applications for Temporary and Mobile Operations mentioned in the MUTCD Part VI

1. Mobile operations on the shoulder (TA-4)

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

2. Mobile Operations on a two-lane road (TA-17)

This operation requires the following equipments.

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

3. 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
- Shadow vehicle with optional arrow panel
- Signs
- Optional Truck mounted attenuator
- Provide adequate buffer space depending on the speed limit.

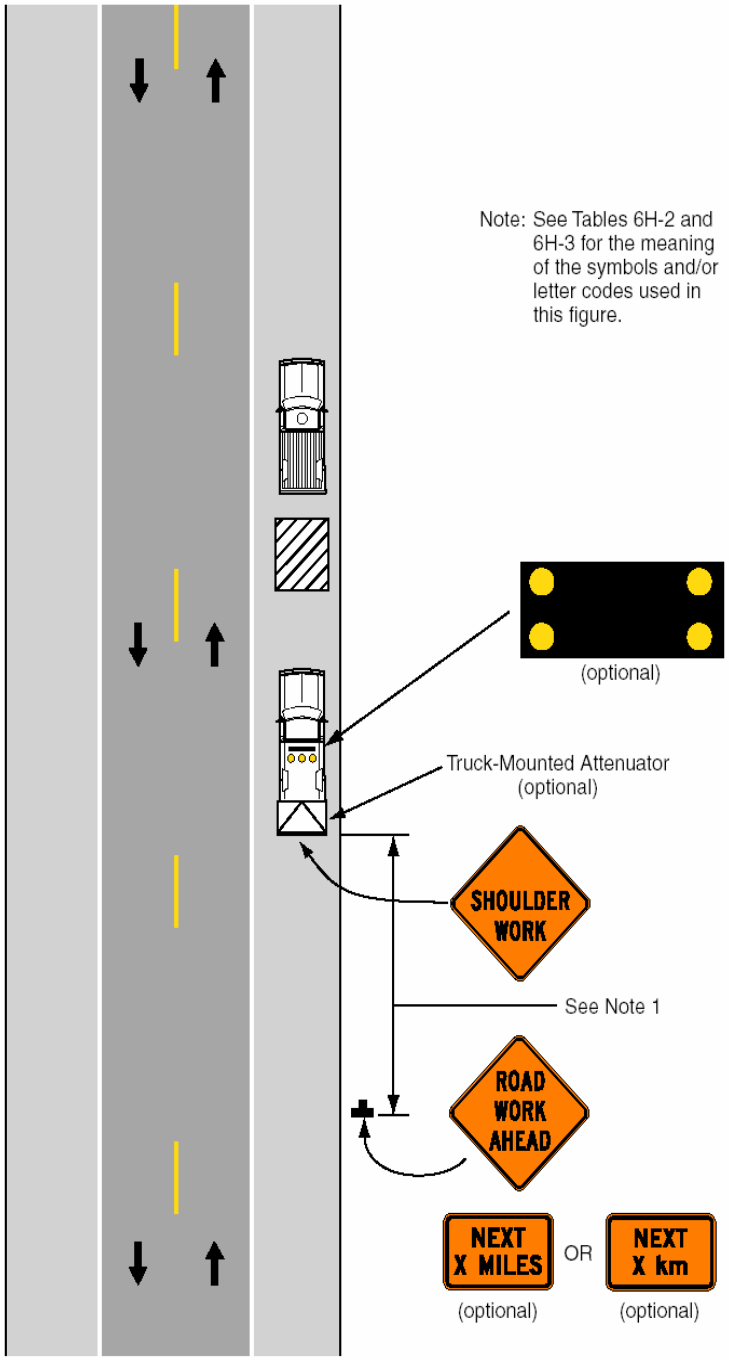
4. Mobile operations on a multilane road (TA-35)

This operation requires the following equipments.

- Arrow panels
- Adequate traffic control signs.
- Optional Truck mounted attenuator
- 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 6H-4. Short-Duration or Mobile Operation on Shoulder (TA-4)



Typical Application 4

(Source: Reference No: 3)

Figure 6H-13. Temporary Road Closure (TA-13)

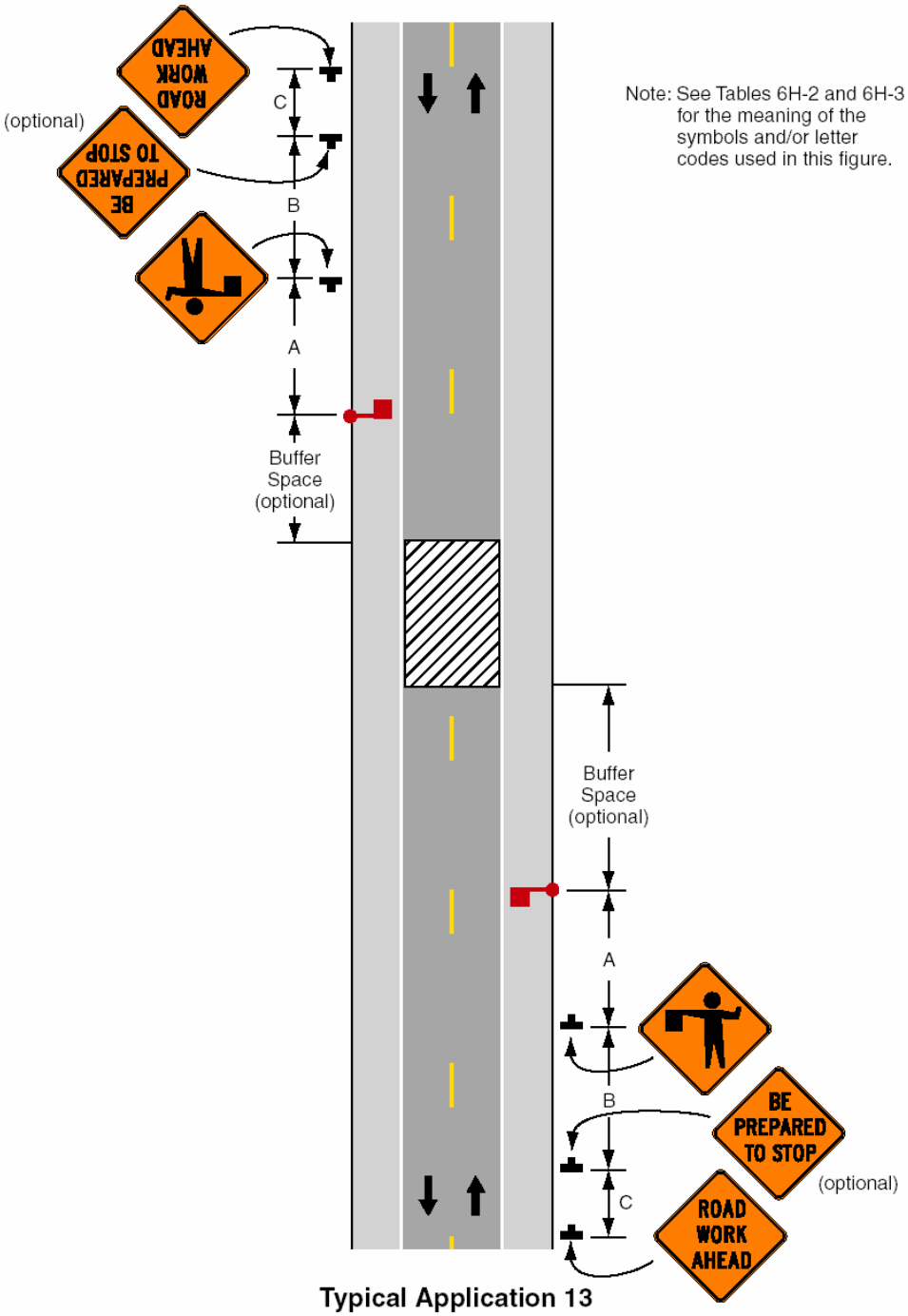


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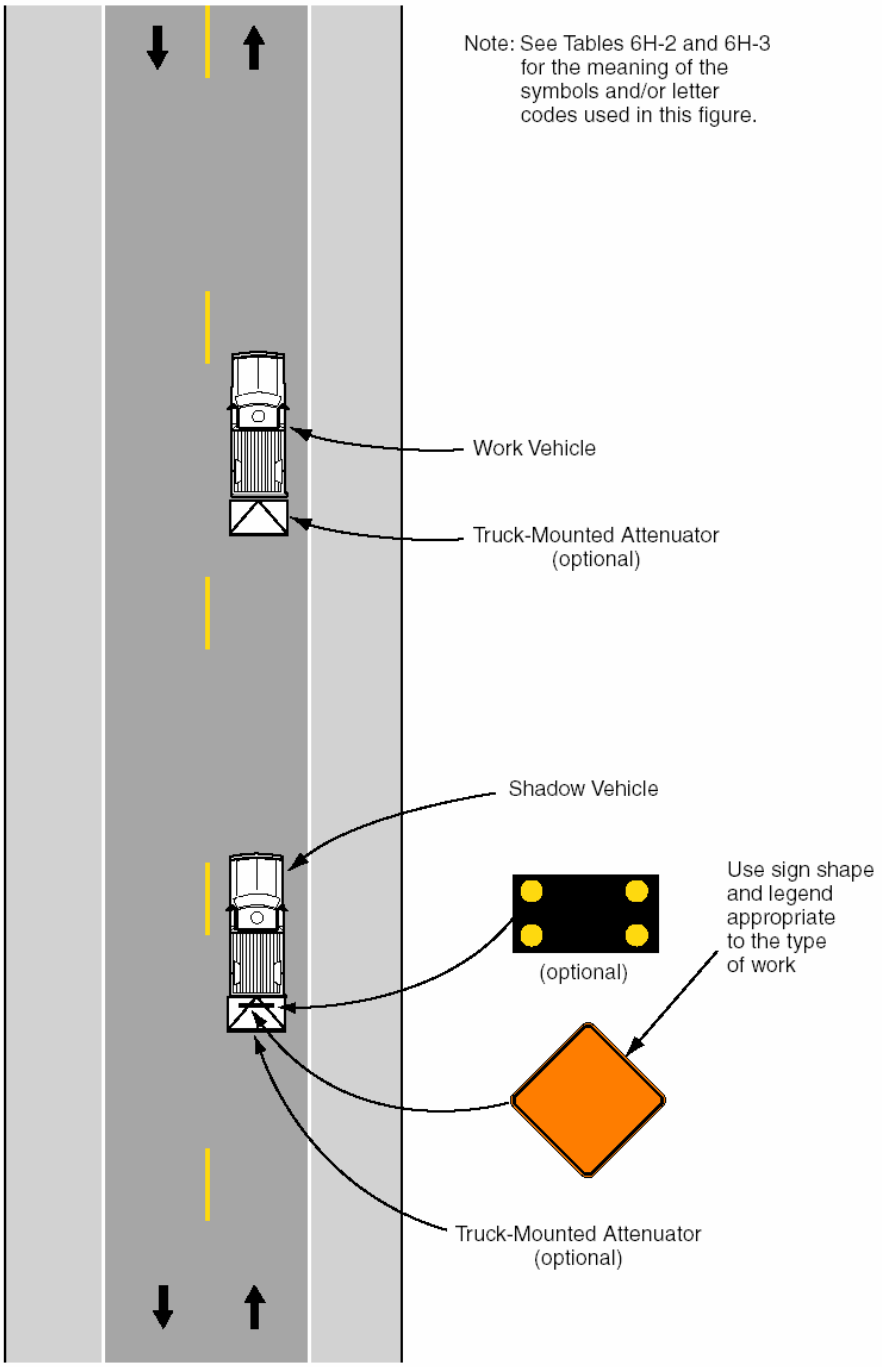
Figure 6H-17. Mobile Operations on Two-Lane Road (TA-17)



Typical Application 17

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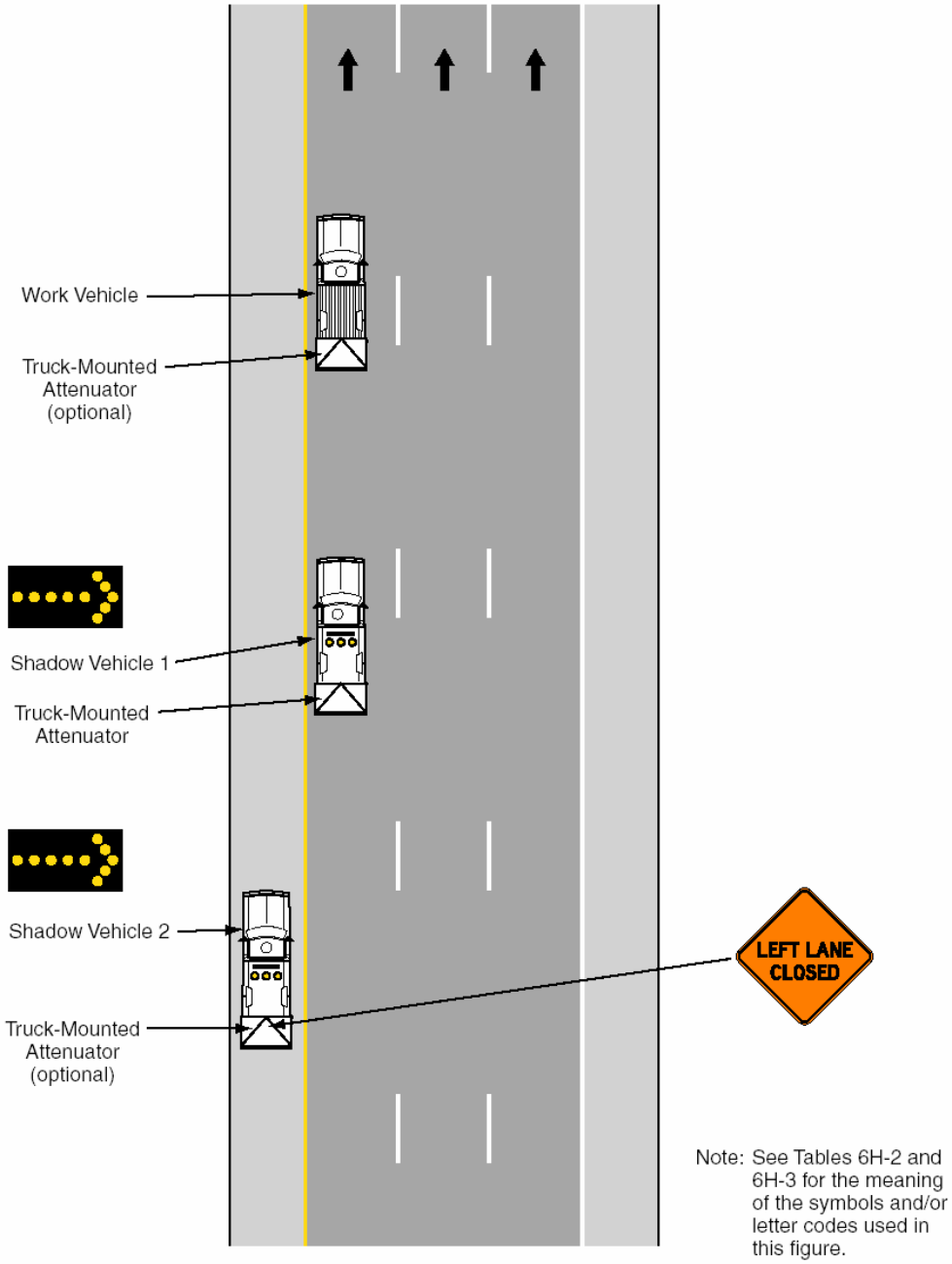
Figure 6H-35. Mobile Operation on Multi-lane Road (TA-35)



Typical Application 35

(Source: Reference No: 3)

Mobile Operations at Night[4]

Higher traffic volumes on many highways make it difficult to perform work operations during daytime hours. Disruption of traffic causes congestion and delays for the traveling public. Certain maintenance operations like applying pavement markings, pavement sweeping, pothole patching, and repairs to small signs and delineators can be effectively done at night, thus avoiding disruption of traffic flow. Night operations could prove to be effective in highways with heavy traffic and also in urban areas. Night operation may reduce traffic impacts, but it adds risks associated with reduced visibility, higher speeds, and behavior and expectancy issues for drivers and workers alike.

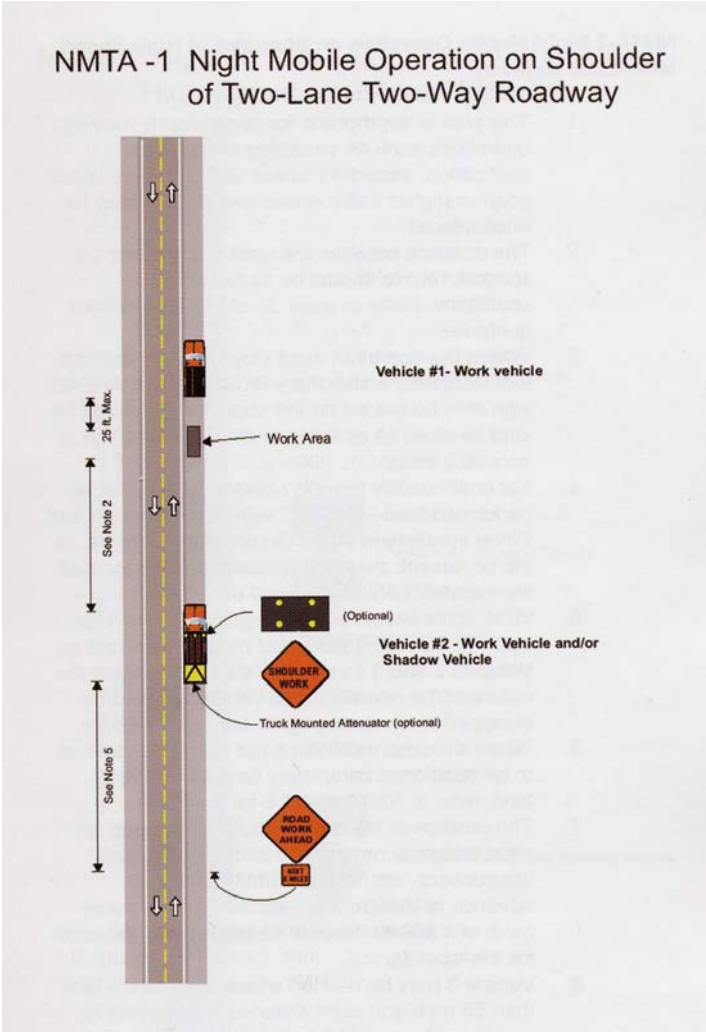
Typical Applications Diagrams (TDAs) for Night Mobile Operations[4]

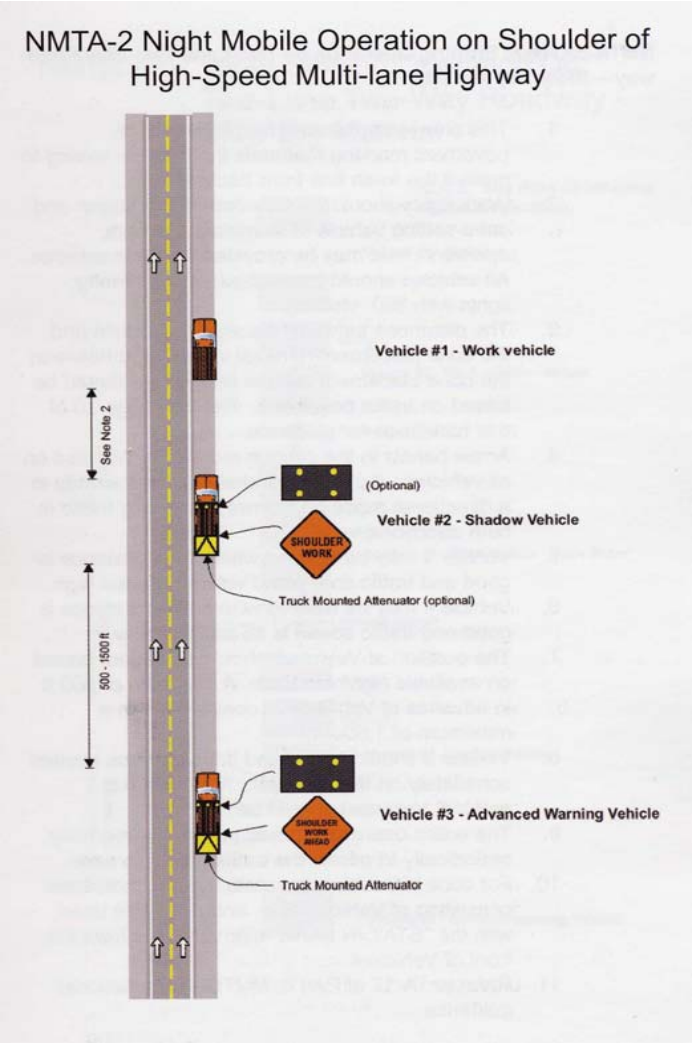
Typical Applications and current practices are provided in the handbook "Traffic Control Handbook for mobile operations at night-Guidelines for Construction, Maintenance, and Utility Operations" developed for FHWA.

Apart from the applications provided in the MUTCD, these typical applications provide appropriate traffic control plan specifically for nighttime operations. The examples mentioned include both two-lane and multilane highways. Some diagrams illustrate examples of pavement marking applications, which is one of the most common mobile night work operations. Pavement marking applications are categorized as slow dry and rapid dry. Rapid dry materials are those can be protected by a moving vehicle. Cones are used for protection during slow drying pavement marking applications. All the operations employ the basic devices mentioned above in the MUTCD Typical applications.

Following are ten Typical Application Diagrams

1. **NMTA-1** Night Mobile Operation on Shoulder of Two-Lane Two Way Roadway
2. **NMTA-2** Night Mobile Operation on Shoulder of High Speed Multi-Lane Highway
3. **NMTA-3A** Night Striping Operation on Two-Lane Two Way Roadway-Slow Drying Material
4. **NMTA-3B** Night Striping Operation on Two-Lane Two Way Roadway –Rapid Drying Material
5. **NMTA-4** Night Striping Operation in Turn Lane of Multi-Lane Highway
6. **NMTA-5A** Night Striping Operation on Multi-Lane Highway-Coning Required-Striping Operation
7. **NMTA-5B** Night Striping Operation on Multi-Lane Highway-Coning Required-Cone Retrieval.
8. **NMTA-6** Night Striping Operation on Multi-Lane Highway-Coning Not Required
9. **NMTA-7** Night Striping Operation on Multi-Lane Highway-Narrow Shoulder and Restricted Sight Distance.
10. **NMTA-8** Night Striping Operation on Interior Lane of Multi-Lane Highway





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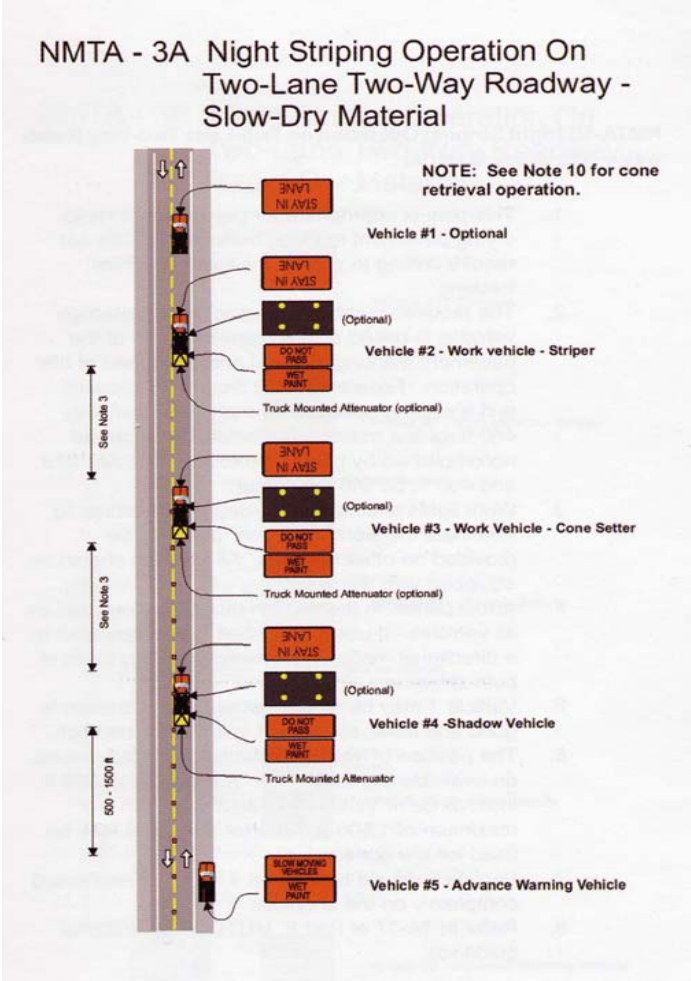

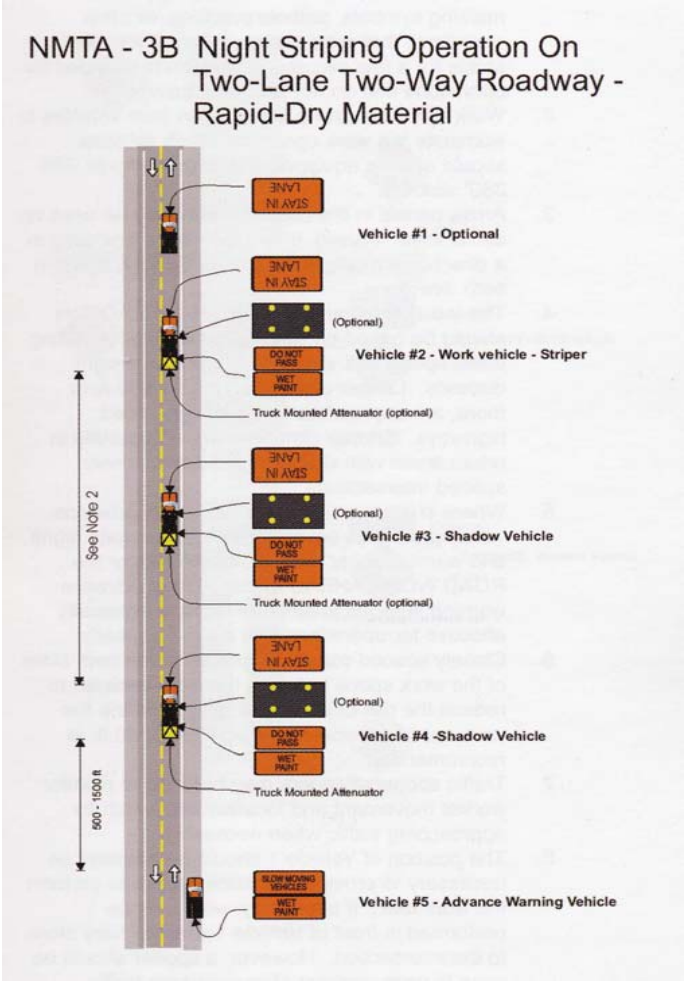

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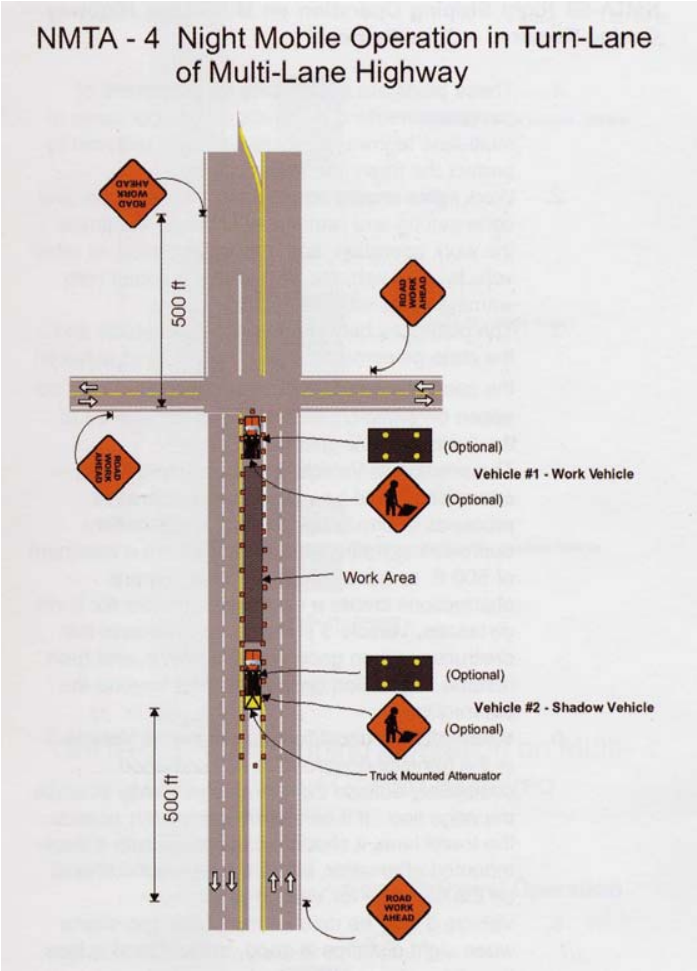

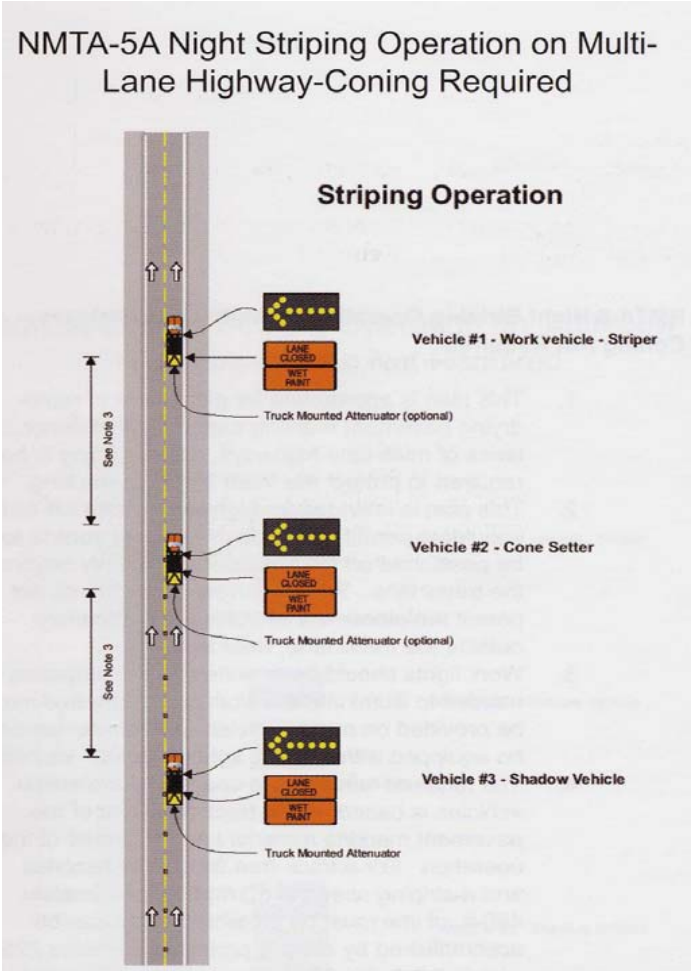

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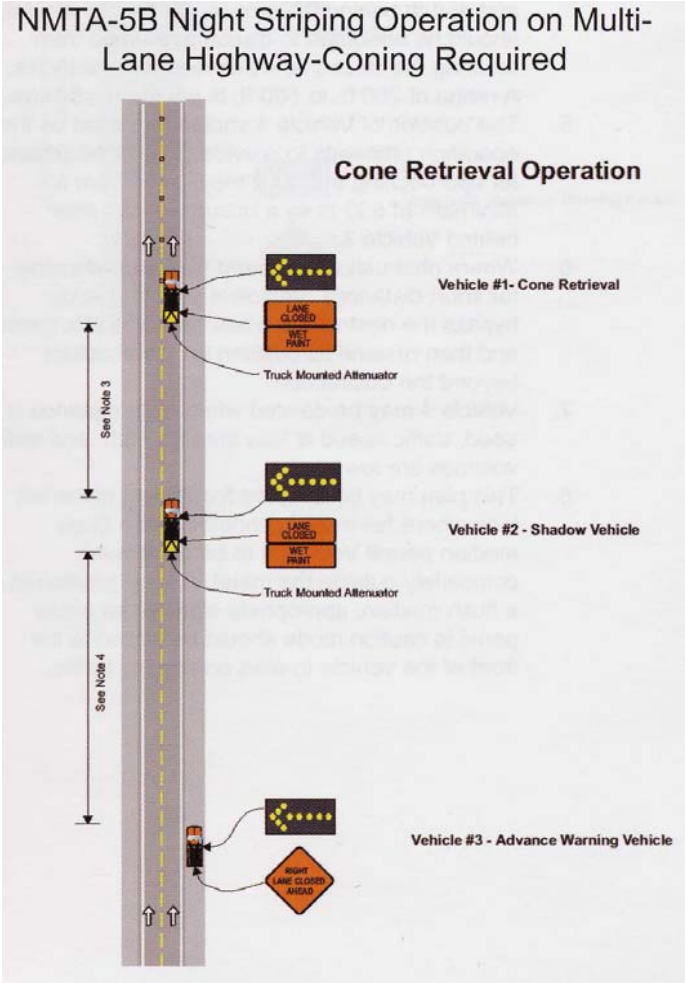

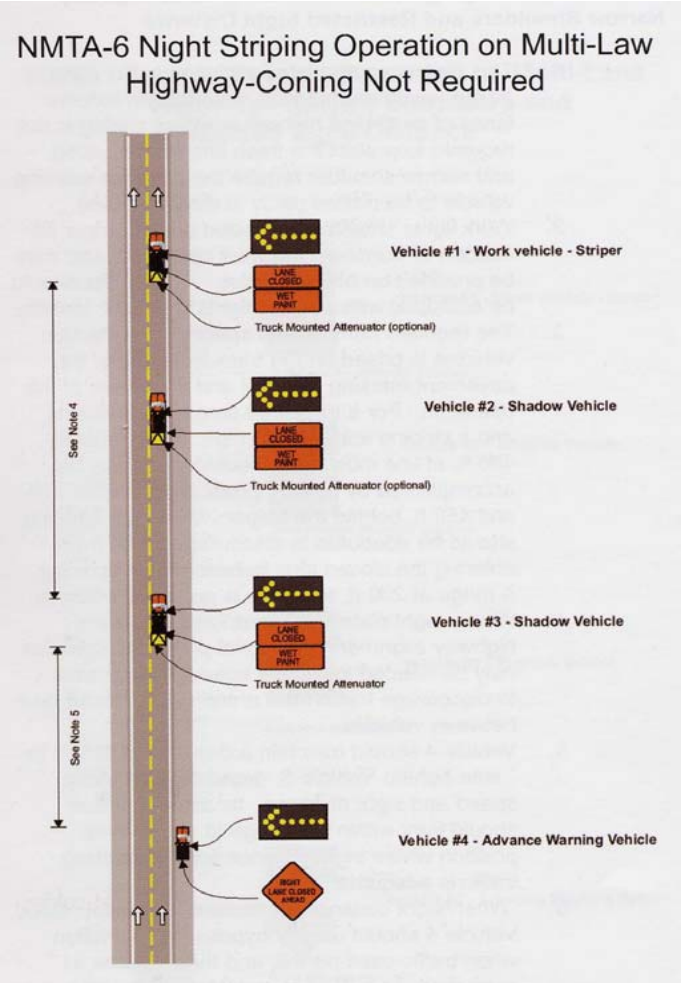

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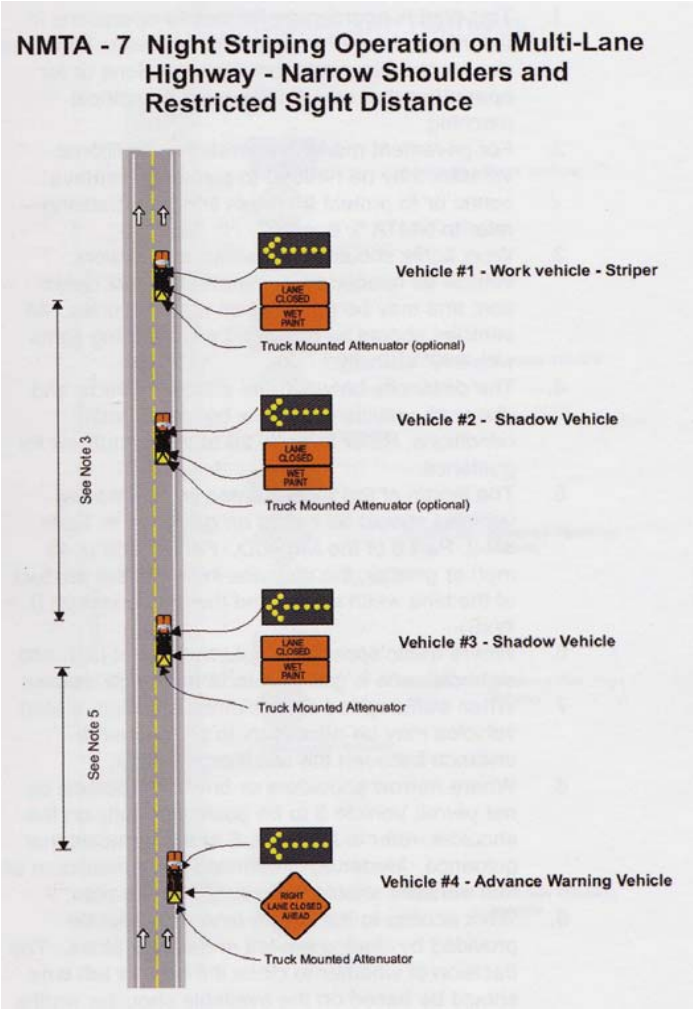

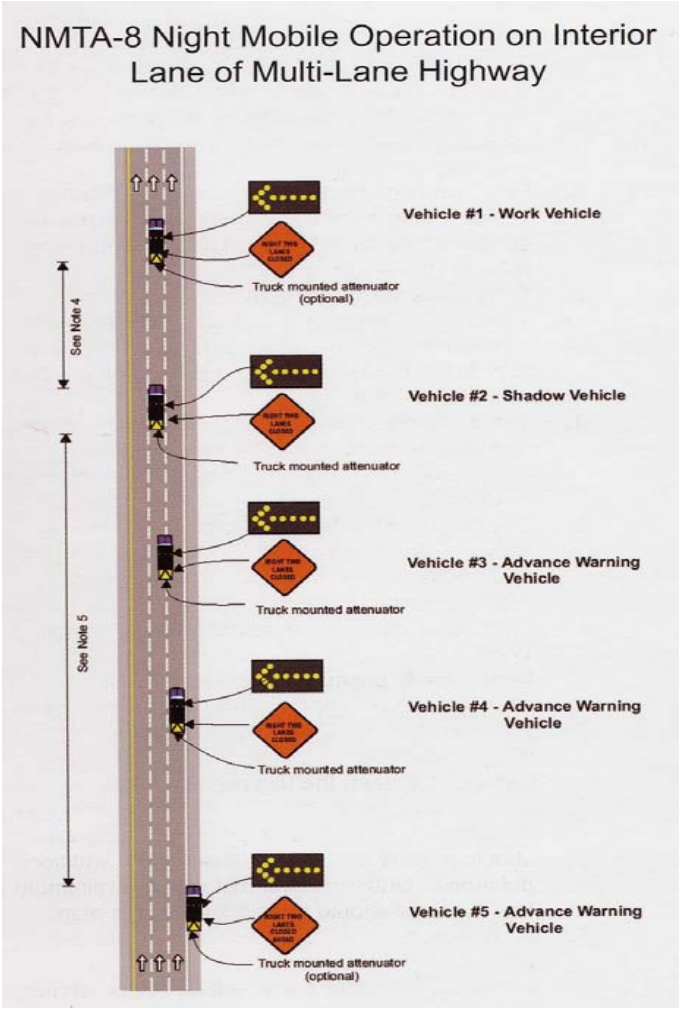

(Source: Reference No: 4)

STRATEGIC HIGHWAY RESEARCH PROGRAM (SHRP)

The SHRP was started in 1987 by the U.S Congress[5], 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 research was conducted by private organizations and universities and was concentrated in four areas:

- Asphalt,
- Concrete and structures,
- Highway operations (maintenance and work zone safety), and
- Pavement performance (the long-term pavement performance study).

The research phase ended in 1992. Several devices were developed and tested by DOT's and finally implemented in the work zone operations and maintenance. The Federal Highway Administration (FHWA) is requiring all states to have all traffic control devices in a work zone be crashworthy and to qualify as such according to the testing and acceptance guidelines of the National Cooperative Highway Research Program (NCHRP) Report 350[6].

Strategic Highway Research Program (SHRP) Safety Devices[7]

In order to improve the safety and efficiency of day-to-day construction, maintenance and traffic operations in work zones, the 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.
3. Queue Detector.
4. Portable Rumble Strip.
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. The case studies conducted by state DOT's are listed in the table below.

SHRP Devices Test Studies conducted by State DOT's

State	Case Study Title
Alabama	Alabama DOT: Pointed in the Right Direction
	A Better Way to Control Traffic
Arkansas	New Barricade Sign Proves Eye Catching
Georgia	Opposing Traffic Lane Divider Shows the Way During Georgia Floods
	Georgia Finds Better Alternative for Directing Traffic Through Taper Lanes
Idaho	Alarm Provides Life-Saving Warning
Illinois	Less Confusion in Work Zones
Indiana	Sign Improves Motorist Safety in Highway Work Zone
Iowa	Flashing Sign Grabs Drivers' Attention
Kansas	Lighted Paddle Improves School Safety
Kentucky	New Device Gives Audible Warning of Upcoming Work Zones
	Lane Divider Eases Redirecting Traffic
	Flaggers Won't Give Up New Safety Device
Maine	Flashing Sign Protects Workers on Back Roads
Minnesota	Robot Shadow Vehicle Protects Maintenance Crew
Mississippi	Mississippi Helps Drivers Find the Right Lane
Missouri	Lighted Paddle Improves Road Work Safety
New Mexico	Lighted Paddle Increases Flagger Safety
	Rumble Strip Gets Drivers' Attention
New York	New York State Finds Intrusion Alarm a Potential Lifesaver
North Dakota	New Warning Device Makes Work Zones Safer
Ohio	Lighted Paddle Makes Flaggers More Visible
Oklahoma	New Device Improves Safety in Work Zones
Pennsylvania	Flashing Paddle Creates Safer Highway Work Zones
Puerto Rico	New Device Keeps Traffic Under Control at Elementary School
South Dakota	Lighted Paddle Improves Flagger Visibility
	New Direction Indicator Improves Motorist and Worker Safety
Tennessee	Rugged Terrain No Problem for New Warning Sign
Texas	A Better Way to Channel Traffic
Vermont	Alarm System Improves Safety on Work Zones
Washington	Intrusion Alarms Offer Workers Peace of Mind

(Source: Reference No: 8)

Preliminary Findings from Testing of SHRP devices[7]

The SHRP prototype devices were evaluated by different state DOT's during several projects. Various advantages and limitations were identified from the study. According to a panel of safety experts at Texas Transportation Institute (TTI), adoption of just two of the more widely used SHRP work zone safety devices—the flashing stop/slow paddle and the opposing traffic lane divider—could cut the number of accidents by approximately 5 percent. The National Highway Traffic Safety Administration estimates that 14 percent of work zone fatalities involve construction workers and pedestrians and 86 percent involve motorists.

Requirements for Crash Testing of Work Zone Devices[6] **(NCHRP 350)**

The work zone traffic control devices have been classified into four (4) categories, each having its own testing requirements and compliance date. The following is a list of the categories, examples of devices in each category (not inclusive), and the date the category must be in compliance:

Category 1 includes those items that are small and lightweight, such as channelizing and delineating devices. Included are items that have been in common use for many years and are known to be crashworthy by crash testing of similar devices or years of demonstrable, safe performance. These include cones, tubular posts, flexible delineator posts, and plastic drums with no attachments. These devices may be allowed for use on the NHS based on the developer's self-certification. **October 1, 1998**

Category 2 includes devices that are not expected to produce significant vehicular velocity change but may otherwise be hazardous. Examples of items in this class are barricades, portable sign supports, intrusion alarms, and plastic drums, vertical panels, or cones with lights. Testing of devices in this category will be required. However, some devices may qualify for reduced testing requirements. **October 1, 2000**

Category 3 includes hardware that is expected to cause significant velocity changes or other potentially harmful reactions to impacting vehicles. Hardware in this category must be tested to the full requirement of NCHRP 350. Concrete protection barriers, fixed sign supports, crash cushions, and other work zone devices not meeting the definitions of Category 1 or 2 are examples from this category. **October 1, 2002**

Category 4 includes portable or trailer-mounted devices such as flashing arrow panels, temporary traffic signals, area lighting supports, and portable changeable message signs. After compliance date of October 1, 2002, this class of devices may not be used unless they are placed behind crashworthy barriers or shielded with TMAs or crash cushions.

SHRP SAFETY DEVICES

1. Salt Spreader Truck-Mounted Attenuator (TMAs) [4].

TMAs are portable crash cushions mounted on the rear end of shadow vehicle and other service vehicles. They reduce the risk of injuries in rear end crashes by absorbing part of the energy impact. They are highly effective in reducing injuries for motorists as well as provide a safety barrier for the working crew.

Energy Absorption Systems, Inc. produces a variety of crash cushions and truck-mounted attenuators used in work zone operations. All the products comply with NCHRP 350 test requirements and have been extensively tested for different speeds (ranging from 62mph-30mph) for use in highways and urban roads.

The attenuators are lightweight and portable and can be attached and removed within 10 minutes and can be efficiently used in mobile operations. Also when an impact occurs, it induces the vehicle to automatically apply air brakes.

2. SHRP Work Zone Safety Intrusion Alarms

This device, developed under SHRP was tested by Vermont Agency of Transportation and the New York State DOT[8]. The intrusion alarm transmitter is placed in front of the work area near the first point where an errant driver would enter the work area. The receiver and siren are placed next to the workers—about 500 to 1,000 feet apart. Once a vehicle enters this area, the alarm is set off, giving a warning sound of approximately 125dB, giving time for the crew time to get out of the way of errant vehicle.

The intrusion alarm is a portable, easy-to-use warning device that makes highway work zones safer. All of the devices on the commercial market consist of two units:

- One device houses the transmitter.
- The other device houses the receiver and siren

There are seven intrusion alarms in the market. The devices range in price depending on their features.

a). <u>Infrared Intrusion Alarm</u> manufactured by *ASTI Transportation Systems of Newark, DE*

The two components are aimed at each other to establish an infrared triangular line of detection.

- Self-seeking alignment
- Optional strobe light
- Optional solar panels to charge battery

Cost: $3,600

b). Microwave Intrusion Alarm (*Traffic Management Systems Corporation of St. Louis, MO)*

Using a microwave beam, the two components are aimed to detect an intruder. When the beam is broken the siren sounds.

Features

- It has a high-intensity, high frequency strobe light

Cost: $4,000

c). Pneumatic Tube & Radio Signal Alarm *(Safe-Lite Systems of Newton, PA.)*

Transmitter uses radios to send two high frequency signals. The two signals virtually eliminate the chance of a stray signal causing a false alarm.
Cost: $4,000

d). Pneumatic Tube Intrusion Alarm *CSE Manufacturing (Central Security and Electronic Inc. of Rolla, MO)*

Transmitter is stationed at beginning of work zone. Receiver/siren is placed near workers. When a vehicle drives over tube a signal is sent to the receiver sounding alarm.

Features

- supervisory signal every 10 minutes

Cost: $1,250

e). Pneumatic Tube Intrusion Alarm *(Columbia Safety Corporation of Woodland, WA)*
Uses a pneumatic tube and switch that sends a signal to the siren positioned 500 feet from traffic near the workers.

Features

- does not use detector beams or radio

Cost: $1,500

f). Pneumatic Tube Intrusion Alarm *(Action West of Keslo, WA)*
Uses a pneumatic tube and switch as a detector that sends a signal to the siren positioned near the workers

Features

- does not use a detector beams or radio

Cost: $880

g). Watch Dog Perimeter Work Zone Intrusion Alarm (*Kenco International of Loigonier Valley, PA)*

A 300-500 feet sensing line stretches from the beginning of the work area to a 120 dB alarm.

Features

- industrial strength steel reel for storage of sensing line
- additional sensing line modules can be easily added

Cost: $2,295

Limitations of the intrusion Alarms

Although the intrusion alarm adds safety to the work crew, it may also prove to give false alarms at times, thereby causing interruption of work. These equipments may be cumbersome for mobile operations as setting time is more. Also the high cost of these devices has made it unpopular among state DOT's.

3. Queue Detector

The detector was developed to monitor traffic backups in work zones. If traffic slows to the preset level or stops, however, the detector activates a message board or other device to warn approaching drivers of the changing travel conditions ahead.

The portable detectors project an infrared beam across the traffic lanes and measure how long it takes vehicles to cross through the beam. If this measurement exceeds a preset limit, it indicates that traffic has slowed down or stopped. The detectors send this information to the CHIPS central computer located in a nearby DOT field office, which then activates the appropriate message on the variable message signs in less than 30 seconds. The system uses radio signals rather than cellular telephone connections to ensure reliable high-speed communication. The queue length detectors and variable message signs give drivers ample time to slow down before encountering a traffic backup.

The queue detector uses integration of variable message signs, which may be clumsy for mobile operations, but can be used for temporary work zones in urban areas.

4. Portable Rumble Strips

In temporary road maintenance work zones, work crews rely on motorists to notice the work area and drive carefully to avoid an accident. Unfortunately, drivers often do not pay attention to the signs warning them of the upcoming work zone.

Developed by the Strategic Highway Research Program (SHRP), the portable rumble strip was used to caution drivers about an approaching work zone. The portable rumble strip is 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. It 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. Kentucky Transportation Center, in conjunction with the State of Kentucky and the Federal Highway Administration (FHWA), tested the use of the portable rumble strip at maintenance work zones across the State[8].

The portable rumble strip was found to be very useful at work zones in Lexington, according to reports from the Lexington Streets and Roads Department. It was particularly effective when placed on the road in advance of a flagger. This combination gives drivers two warnings of the approaching work zone. First, the driver feels a vibration and hears a rumble, alerting him or her to potentially dangerous conditions ahead. When the driver sees the flagger, he or she will be prepared to stop or slow down.

The NYDOT uses rumble strips in their work zones. The strips work well on low-volume streets and in cities. On high-volume/high-speed roads, the rumble strips may subject to swerving. They are particularly effective when a work zone is around a corner and workers can't see oncoming traffic.

Benefits

The portable rumble strip has several advantages:

- The vibration effects makes drivers aware of the approaching work zone and are better prepared for changing conditions.
- It works well on low-volume roadways and in the urban areas.

Limitations

- Installation of the rumble strips may be too lengthy for the rumble strips to be applied at short-term maintenance work zones.
- It cannot be used for a mobile work zone operation.
- It should be avoided in neighborhoods where noise is a concern

Rumble strip installation (Source: Reference No: 9)

5. Direction Indicator Barricade

The direction indicator barricade[10] is used to direct motorists through areas where highway maintenance requires lane closures. The direction indicator barricade is a replacement for the conventional barrels. This device, developed under the Strategic Highway Research Program (SHRP), is a conventional barricade with a 60- by 30-cm (24- by 12- in) horizontal arrow panel and a 60- by 20-cm (24- by 8-in) chevron panel. The panels can be reversed to allow the same device to be used in outside or inside lanes. The barricade's orange-and-white bias-striped pattern and black directional arrow make it easy for drivers to see and track the appropriate path.

Direction indicator barricade (Source: Reference No: 8)

Georgia, Alabama, South Dakota, and Arkansas DOT[8] tested the direction indicator barricade in several projects. The conventional barrels are bulky and do not always provide clear instructions to motorists as they pass through a taper area into a temporary travel lane. But the new direction indicator barricade proved useful and effective for night operations.

Benefits

The direction indicator barricades offer several advantages over the traditional solution, barrels. The benefits are:

- Easier and faster to set up and remove and uses only minimum amount of space
- The device is also sturdy and durable, with no significant maintenance problems
- The flexible barricade is easy to set up and move, unlike the traditional sawhorse barricades.
- The direction indicator barricade successfully attracted motorists' attention and improved traffic flow than traffic cones or other barricade devices
- Although the direction indicator barricade costs more than traditional barricades, the shorter set-up time its maintenance-free operation promises long-term savings.

6. Opposing Traffic Lane Divider

Developed under the Strategic Highway Research Program (SHRP), the opposing traffic lane divider is an orange sign that features two-way arrow which clearly shows motorists that traffic on both sides of the sign is moving in opposite directions.

The opposing traffic lane divider is used to denote the new centerline on roads that have been changed from one-way to two-way traffic as a result of maintenance work or other situations. The divider is a small, portable sign with two-way arrows on its face. Signs are placed in sequence to indicate the temporary centerline of the road, which separates the opposing traffic flows. The divider is easy to install and remove, and cannot be blown over by high winds or gusts from passing vehicles. If struck by a vehicle, the divider is designed to either spring back to an upright position or be easily restored by a maintenance crew member.

Opposing traffic lane divider (Source: Reference No: 11)

Indiana and Georgia DOT[8] have used opposing traffic lane dividers for several years in temporary work zones. Texas DOT[8] traditionally used concrete barriers to separate the traffic flows, but installing these barriers is time-consuming and costly for temporary work zones.

After testing the opposing traffic lane divider on roads across the State, Texas DOT found that the combination of clear instructions for drivers and easy installation procedures make the device an excellent alternative to concrete barriers.

The massive size and weight of concrete barriers were installed and removed using cranes—a time-consuming, labor-intensive, and costly process. But the new device can be easily set up and removal by one person and requires no special equipment to transport. The device has been adopted as standard equipment for Texas DOT maintenance operations statewide.

The device has several key advantages:

- Significant financial savings from low installation costs.
- Speedy conversion of roads from one-way to two-way use.
- Shorter disruptions to traffic while the dividers are installed and removed.
- Clearer instructions for safely navigating drivers through areas where traffic patterns have been temporarily modified.
- The lane dividers' ease of installation and removal helps to reduce the risk of injury to workers.
- Better traffic flow.

7. Flashing STOP/SLOW Paddle

Temporary work zones on highways or on city streets are extremely dangerous, and the worker most exposed to traffic is the flagger. Flaggers are responsible for alerting drivers to the need to stop or slow down as they approach a temporary work area and directing vehicles through the work zone. But drivers often fail to notice these instructions, creating the risk of accidents.

The flashing stop/slow paddle features a flashing high-intensity light incorporated into the stop side of the paddle. If a motorist does not appear to be heeding the flagger's instructions, the flagger activates the light, which is bright enough to be seen on even the sunniest days. Also the signs were especially effective when in poor visibility, such as dawn and dusk and during foggy conditions.

The new device was tested by different state DOT's and it was used in urban as well as rural areas. This new device was tested by Alabama, Kentucky, Iowa, Maine, North Dakota, South Dakota, Ohio, Okalahoma, Pennsylvania DOT, and Puerto Rico[8]. After extensive testing, the device has been approved for use in temporary work zones.

Benefits

- Improved motorist response to warning signals.
- Improved safety for workers and motorists.
- Drivers are more aware of work zones.
- Flaggers feel better protected from traffic.
- Drivers pay more attention to flaggers and their instructions.
- An increased level of security for work crews.

Limitations

- The paddles can be too heavy for a long day on the job.
- It has a short battery life.

8. Portable all-terrain sign and stand.

During highway maintenance or repair, the signs are setup on the shoulder or slope at the side of the road, warning motorists of the work zone ahead. Major highways generally have wide, flat shoulders with plenty of room for signs, but many roads have narrow shoulders or no shoulders at all especially in mountainous states. So it is not easy to setup the signs along the shoulder on these roads.

This problem is overcome by the use of the portable all-terrain sign and stand. The device features adjustable legs that can be placed on any slope. Stakes driven through the legs secure the sign to the ground. It can be used on roads with a narrow shoulder or where ditches, embankments, or other features leave no space for a conventional sign.

The all-terrain sign stand is also useful in areas with high winds or on roads that carry a great deal of truck traffic, as it remains stable in gusty, windy situations. This device is being widely used by the Tennessee Department of Transportation (DOT) [8].

Benefits

The all-terrain sign are useful for the following.

- Place warning signs on the side of any road, whether the site is windy, has little or no shoulder, or abuts a steep slope.
- Drivers are warned of work zones ahead even in roads where there is no room on the shoulder for a traditional sign.

NEW SHRP PRODUCTS

1. Remotely Driven Vehicle (RDV)

The remotely driven shadow vehicle is one of the best devices, which can be used for mobile or short duration work zone. For short duration, installing concrete barriers and other measures would be difficult. A shadow vehicle is the one that follows the work crew at a distance, serving as a moving barrier between the workers and the oncoming traffic. The vehicle provides safety to workers, but the driver himself is at risk from crashes.

Minnesota DOT[8] in conjunction with SHRP built a prototype remote-control shadow vehicle. The truck is controlled by remote control operation from roadside. The radio-control system controls the truck's steering, brakes, and accelerator, as well as the headlights, horn, turn signals, and emergency flashers. The truck follows about 200 to 300 feet [60 to 90 meters] from the work crew.

The remote-control shadow vehicle protects the driver and also protects motorists who run into it. The back end of the truck is equipped with an energy-absorbing cushion that softens the impact in case a vehicle crashes into the back of the truck.

The cost to convert Minnesota DOT's truck to remote-control operation was about $75,000. The remotely driven vehicle is now nearing commercial production. Once the production of the vehicle begins, the kit to convert a truck to remote-control operation will be available for about $35,000. Though the cost of vehicle is high, it may be well below the compensation amount and life of a person.

Benefits

- The driver of the vehicle is almost at no risk.
- This equipment could be effectively used in mobile work zones.
- The crash cushion at the rear reduces the impact in case of a crash.

2. Portable Crash Cushion

Barrels are used at work sites to protect highway workers and cushion the impact of a crash. Setting up crash barrels is a time consuming process and its infeasible for mobile work zone operations and also exposes workers to considerable danger. By making the process easier and faster, the risk to workers is lessened because the barrels are likely to be used more often. This would be a boon to the safety of workers and motorists alike. It is being tested in five states; Alabama, California, Iowa, Minnesota, and New York[12].

The portable crash cushion trailer is a tilt-bed trailer equipped with a pallet of hinged steel plates. Sand-filled barrels are secured to the pallet, and a winch is provided to assist in installation and removal of the barrels. Rollers on the trailer bed allow the pallet to easily slide on and off the trailer.

Another type of crushable cushion manufactured by Energy Absorption Systems is made of energy-absorbing cartridges surrounded by a framework of steel beam panels. Its compact and modular design (3 to 9 bays) accommodates speeds from 70 km/h (43 mph) to 115 km/h (71 mph). The monorail base eliminates the need for anchoring chains and tension cable, therefore easy installation. The equipment is relatively lightweight and the entire system can be moved as a single unit using lifting brackets on diaphragms.

Portable Crash Cushion for Work Zones (Source: Reference No: 12)

RECENT WORK ZONE PRODUCTS

New work zone devices have increased the efficiency and safety of work zone operations and are being widely used in construction and maintenance operations. The following five products are discussed below.

1. Cone Shooter
2. Automated Pavement Crack Sealers
3. Automated Debris Removal Vehicle
4. Balsi Beam
5. Robotic Highway Safety Markers

1. Cone Shooter[13]

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 open 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.

AHMCT Cone Shooter (Source: Reference No: 13)

Features

- By default, the Cone Shooter handles generic 28 inch highway cone. It can be readily modified to handle other sizes of cones.
- The Cone Shooter is controlled using simple switches by the driver.
- The automated equipment occupies minimal space on standard trucks. A standard vehicle envelope is maintained when not handling cones

- By default, 80 cones can be stored in stacks laying on side. The carrying capacity can be readily modified.
- Cones can be placed in the forward direction, on either the left or right side.
- In the default configuration, you can automatically space cones every 25, 50 or 100 feet and while traveling at a speed of 10 MPH. Spacing choices are readily modified.
- Easy retrieval of upright or knocked-over up cones on either the left or right side while traveling either in a forward or reverse direction.

2. Automated Pavement Crack Sealers[13]

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. AHMCT has developed a couple of automated pavement crack sealers, which could 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.

The two devices developed by AHMCT are:

a. Longitudinal Crack Sealer
b. Random Crack Sealer.

a. Longitudinal Crack-Sealing Machine (LCSM)

The Longitudinal Crack Sealing Machine (LCSM) was developed to automate the sealing of relatively continuous longitudinal cracks, such as those that occur between a concrete lane and asphalt shoulders.

The LCSM enables a highway worker to seal longitudinal pavement cracks and joints with hot applied sealant from inside the relative safety of the truck cab. The workers no longer are exposed to direct traffic in longitudinal sealing operations as in the traditional manual application procedure. The driver controls the entire sealing process from within the truck cab while a support worker is typically utilized to load the sealant blocks into the kettle. Use of the LCSM also dramatically increases seal production rate, primarily by eliminating the strenuous nature of the operation. A comparison of hand application and LCSM application is shown below.

Table showing Longitudinal Crack Sealing Machine vs. Hand Application

	LCSM	Hand
Employees	3	4
Average miles per day	3.5	0.8
Work days	9	40
Bare rate cost	$4,017	$23,820
Closures	NO	YES
Employees on foot	NO	YES

(Source Reference No: 13)

The LCSM driver remotely deploys the application head to the pavement, steers the truck along the crack, controls sealing speed with the accelerator petal, and remotely controls the sealant flow with a hand controller. The shoe pulls along a reservoir of sealant that overcomes the random change in crack size. A display screen in the cab relays machine status information to the driver.

Conventional Hand sealing Operation (Source: Reference No: 13)

Sealing using LCSM (Source: Reference No: 13)

The LCSM has been operated in four different Caltrans maintenance districts, but has primarily been operated in District 11 in California.

Transfer Tank Longitudinal Sealer (2TLS)

The Transfer Tank Longitudinal Sealer (2TLS) machine is the third generation longitudinal sealing machine developed by AHMCT and Caltrans is midway through the task of fabrication. The Transfer Tank Longitudinal Sealer (2TLS) is scheduled to be field tested with Caltrans in summer 2004. This machine is highly anticipated by Caltrans maintenance department.

The new Transfer Tank Longitudinal Sealer includes features for faster and continuous operation (almost 8 times faster than the present LCSM). Also the 2TLS is a green machine. Propane fuel will replace diesel fuel to allow this machine to meet the air quality standards required to be operated anywhere in California. These features will allow the 2TLS to dramatically increase highway seal production and safety compared to the current LCSM.

b. *Random Crack Sealer*

The Random Crack Sealer uses an Operator Controlled Crack Sealing computer interface for sealing of the pavement. The machine reduces worker exposure to traffic and makes pavement-sealing process into a simple computer point and click process. The goal of this project was to build a fully functioning self-contained truck mounted automated sealing system that could a seal full lane-width of in-lane cracks.

The vehicle features a long reach robot that automates the sealing of in-lane pavement cracks. A video camera is mounted on an overhead boom. As the vehicle drives along the road, the pavement under the robot is displayed on the computer screen in the cab.

Random Crack Sealer (Source: Reference No: 13)

Display Screen of the crack on a computer screen in the vehicle
(Source: Reference No: 13)

The asphalt crack is displayed on the screen as seen in the figure. The area bounded by the red box is 12 ft by 13 ft. If the crack needs to be sealed, the truck is stopped and it is clicked on both ends of the crack. The controller automatically recognizes and traces each crack on the screen then plans and displays an optimal sealing path. On clicking an <OK> button, the sealing robot seals each crack with hot applied sealant.

The sealing robot works independently from the controller, so other cracks can be pointed out while sealant is applied, thereby maximizing the machine's production rate. When sealing is complete on a particular patch of pavement, then the arm is retracted and drives on, locating for more cracks.

The machine is a prototype and is being road-tested by Caltrans. The sealant head has also been tested.

3. Debris Removal Vehicle[13]

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 new litter removal and debris vacuum system. The two vehicles developed are:

a. Automated Litter Bag/Debris Collection Vehicle
b. Debris Vacuum System

a. Automated Litter Bag/Debris Collection Vehicle

Frequent mobile maintenance operation involves litterbag and debris removal. They operate in low efficiency, moderate costs, and high risk of injury. Some operations require one worker to drive along the roadside, periodically stopping and getting out collecting the bags from the roadside into the truck. Other operations allow the driver to stay in the vehicle while additional crewpersons remove litter bags and large debris from the roadside and place them in the truck.

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.

Automated Litter Bag/Debris Collection Vehicle (Source: Reference No: 13)

A prototype was tested and evaluated and changes were made in the design of the second-generation machine. The second generation machine has the multi-terrain ability to pick up litter bags and large debris from either side of the standard 7.6 cubic meter (10 cubic yard) slightly modified compacting conventional cab truck at levels within 4 feet above or below road surface. The hydraulic clamshell-type manipulator mounted between the cab and the compactor of a truck has several preset locations, corresponding to typical areas of pickup. The driver can direct from the pickup location within the cab. Once the operator has grabbed the desired object and indicated so with the push of one button, the manipulator will retract itself to a position above the opening of the trash compactor, the lid will open; the pinch will release its contents into the trash compactor and return to a position ready for traveling or further use. The pinch bucket can grip objects such as multiple or single

litter bags, tires, mufflers, and lumber. The maximum payload of the bucket is approximately 45.4 kilograms (100 pounds).

Recent field testing of the machine demonstrated that it has the ability to pick up several tires or up to 8 bags at one time. Development has been supported by the Federal Highway Administration, Caltrans and a private contractor.

b. Debris Vacuum System

The Automated Roadway Debris VACuum or "ARDVAC" equipment integrates a commercial vacuum system in the vehicle. It is designed to be an add-on feature for existing, commercially available sewer and ditch cleaning trucks, which makes rapid commercialization of this concept very likely.

Using a "vacuum cleaner" of sufficient size can readily collect most litter. The traditional problem has been how to position the vacuum in tight places while working from a cab. The dexterity achieved with the ARDVAC system allows easy access to roadway edges and collection of the litter that tends to blow up against fence lines, vegetation, and other objects. Using a joystick control from within a cab, an operator can quickly vacuum behind guard rails, down into depressions, and under bushes.

Implementing the ARDVAC system into a maintenance operation will allow for more regular collections of litter and greatly reduce the hazardous manual labor involved in this task. The vehicle is currently developed by the Clean Earth Environmental Group, Alabama.

Debris Vacuum System (Source: Reference No: 13)

4. Robotic Highway Safety Markers[13]

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.

Robotic Highway Safety Marker (Source: Reference No: 13)

5. Balsi Beam[15]

Balsi Beam is a truck mounted, expandable beam that will provide work zone protection comparable to a concrete barrier. It is specifically intended to enhance worker safety when carrying out shoulder repair in work zones adjacent to guardrails, bridge rails, and sound walls. Usually the shadow vehicle or the truck mounted attenuator provides protection from rear end collisions; the new device would provide protection from adjacent lane traffic.

Balsi Beam (Source: Reference No: 15)

Each side of the trailer consists of high-strength steel box section beams that are capable of extending an additional 4.6 m (15 ft). 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 then extends to provide a 9.1-m (30-ft) secure work zone. The trailer beams act as a rigid obstacle to deflect traffic away from maintenance workers.

The device is being used 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.

CRITERIA FOR DEVICE FUNCTIONALITY IN MOBILE OPERATIONS

From the devices and equipments identified, depending on the utility and effectiveness, the device functionality can be classified into five categories as follows:

1. Reduce exposure to the motorists/crew
2. Warn motorists/crew to minimize likelihood of crash
3. Minimize severity of crashes once they occur
4. Provide separation between work crew and traffic
5. Improve work zone visibility/presence

The devices classified based on the criteria above are tabulated in the table below.

Table Showing Criteria satisfied by work zone devices/equipments

WORK ZONE DEVICE	CRITERION				
	1	2	3	4	5
Truck Mounted Attenuator					
Vehicle Intrusion Alarm					
Rumble Strips					
All Terrain Sign and Stand					
Directional Indicator Barricade					
Flashing Stop/Slow Paddle					
Opposing Traffic Lane Divider					
Queue Detector					
Remotely Driven Vehicle					
Portable Crash Cushion					
Cone Shooter					
Pavement sealers					
Debris Removal Vehicle					
Balsi Beam					
Robotic Highway Safety Marker					

Does not satisfy Partly Satisfy Fully Satisfy

COST OF DEVICES IDENTIFIED

The costs of the devices are obtained from product manufacturers and research centers. Remotely driven vehicle and Balsi beam involved huge cost during their development, but as the vehicle enters commercial production prices are expected to come down. Pavement sealers, cone shooter and debris removal vehicles are currently prototypes. Their prices are expected to be declared as they enter into commercial production by the next quarter of 2004. Robotic highway safety markers are currently being evaluated in University of Nebraska Lincoln.

Cost for Devices used in Mobile Work Zones

Device	Unit	Cost Range
Truck Mounted Attenuator	Each	$12,000-$18,000
Intrusion Alarm	Each	$1000-$4000
Portable Rumble Strip	Per mile	$4500
All terrain Sign& Stand	Each	$150-$200
Directional barricade indicator	Each	$50-$200
Opposing traffic lane divider	Each	$40-$100
Flashing stop-slow paddle	Each	$100-$400
Remotely Driven Shadow Vehicle	Each	$75,000
Portable Crash Cushion	Each	$10,000
Cone Shooter	Each	$80,000-$100,000
Balsi Beam	Each	$217000
Debris Removal Vehicle	-	Not Available*
Pavement Sealers	-	Not Available*
Robotic Highway Safety Marker	-	Not Available*

Source Reference No: 8, 13, 14, 15, and 16

* Prototype devices, cost currently unavailable

PLAN OF WORK FOR NEXT QUARTER

Every year large sums of money are being expended by state agencies for compensation for fatalities/injuries of workers in work-zone related crashes. Many of the devices developed for work zones also involve substantial R&D costs. Almost all the devices reviewed in this task are aimed at reducing worker exposure to traffic thus providing safer work zones. By reducing work zone related crashes, these devices could also have a positive impact on the amount of compensation to be paid for fatalities or injuries to workers. In the second quarter of the project, we will focus on the analysis of the benefits and cost associated with many of the devices used in mobile work zones. Also long term savings accrued by using certain devices need to be investigated.

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