Improving the Safety of Mobile Lane Closures

DETAILS

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IMPROVING THE SAFETY OF MOBILE LANE CLOSURES

This digest contains excerpts from a study conducted for NCHRP Project 20-05, "Synthesis of Information Related to Highway Problems." The study was conducted by Alireza Hadayeghi and Brian Malone, Synectics Transportation Consultants, Inc., St. Catherines, Ontario, Canada. Gail R. Staba is the Senior Program Officer for this study.

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SUMMARY

The aging of the United States and Canada's road infrastructure, coupled with an increase in traffic volumes, has taken a toll on the existing road network. For this reason, there is an ever increasing need for maintenance and rehabilitation operations on the roadways. Although traffic control techniques for road construction and maintenance vary widely, one of the methods experiencing increased use, because of its ability to increase efficiency and minimize operational impacts, is mobile lane closures. The objective of this report is to synthesize practices employed by transportation agencies during mobile lane closures and to summarize research carried out on different components of mobile lane closure.

There are two components to this report. The first is a literature review that includes an overview of the terms applicable to mobile lane closures and their definitions, as used by different agencies; an overview of existing guidelines, handbooks, and manuals; current experiences and notable practices employed by various agencies; and an overview of existing research that evaluates the effectiveness of different practices and technologies. The second component is a survey questionnaire that addresses the state of the practices employed by (U.S.) state and (Canadian) provincial transportation agencies.

The results of the literature review indicate that, in the United States, numerous states rely on regulations, policies, standards, and/or documented practices that are either complementary or supplementary to the *Manual of Uniform Traffic Control Devices* (*MUTCD*), as published by the FHWA. In Canada, each provincial agency complements and/or supplements the Canadian *MUTCD,* as published by the Transportation Association of Canada (TAC), with its own published requirements. Accordingly, there is some disparity and overlap between the definitions and interpretations relating mobile lane closures between jurisdictions.

The typical set-up configurations for mobile lane closures found in the FHWA's *MUTCD* were compared with the *Ontario Traffic Manual* (*OTM*)—*Temporary Conditions* (*Book 7*), as published by the Ministry of Transportation, Ontario (MTO). The major difference found between the FHWA's *MUTCD* and *OTM—Book 7* involved the requirement under specific circumstances for one or more shadow vehicles to protect the rear of the mobile closure operation.

There are a number of successful mobile lane closure traffic control devices and techniques currently being used by transportation agencies to ensure the safety of workers and motorists. A review of

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innovative and experimental devices and technologies revealed that none of the devices evaluated were capable of simultaneously meeting all of the most desirable criteria for mobile operations protection. These criteria are as follows:

- Reduce exposure of workers to vehicles,
- Warn motorists and work crew to minimize the likelihood of a crash,
- Minimize the severity of crashes once they occur,
- Provide separation between work crew and traffic, and
- Improve work zone visibility and presence.

According to the findings of the literature review, even remotely driven vehicles, which remain experimental as of this writing, only partially satisfy these criteria.

Research papers discussing innovative safety devices, and assessing the effectiveness of the existing safety devices and practices, were reviewed. Other emphasis areas in the research were as follows:

- Identification of hazards associated with mobile operations,
- Provision of improved road-user guidance in the presence of mobile operations (advance warning; work vehicle identification; and the provision of information supporting rapid, error-free, and appropriate behaviors), and
- A review of the current mobile lane closure definition.

The survey consisted of 74 questions that were designed to gather information on regulatory and guidance documents, policies, practices, equipment and technology used; field experiences; and further technology and research needs. Twenty-eight U.S. recipients responded to the questionnaire, a 54% response rate. Responses from three Canadian provinces were also received. Because of the differences between the U.S. *MUTCD* and the Canadian *MUTCD,* the survey results reflect only the responses provided by the U.S. states.

The survey results revealed the following:

- About 85% of the respondents do not believe that either misinterpretation of the mobile lane closure definition by maintenance personnel is occurring or that it is problematic.
- Wide variations were observed in the types of temporary traffic control (TTC) operations used by the respondents for different activities.
- The majority of the respondents do not use any quick reference tables or computerized decision-making tools to ensure proper selection and applications of TTC.
- For 61% of the respondent departments of transportation (DOTs), truck-mounted attenuators (TMAs) are mandatory on shadow vehicles.
- Most of the participating DOTs in the survey do not use signs mounted on the first shadow vehicle to indicate the number of vehicles in a work convoy.
- More than 64% of the responding DOTs do not use equipment to reduce exposure of workers or completely eliminate workers on foot in the mobile lane closure work zones, such as automatic crack sealing, patching, debris collection vehicles, etc.
- The great majority of respondents were not regularly using work zone safety intrusion alarms.
- Flaggers are used by 62% of respondents for mobile lane closure work zones on two-lane roads.
- In terms of the use of signs, most participating DOTs use temporary signs installed in advance to warn motorists about mobile lane closures.
- Traffic is prohibited by 65% of DOTs from passing the work convoy in case of two-way, two-lane roadways with unimproved shoulders and 77% of DOTs do not use any special devices to explain passing arrangements on two-lane roadways with improved shoulders.
- Some DOTs do not analyze the crash data associated with mobile operations because of the difficulty in isolating relevant crashes in their crash database.
- Results showed that only 20% of the respondent states were aware of any technology/device developments or research projects in progress that could increase the safety of mobile lane closures.

Although extensive research has been done on the different aspects of mobile lane closures, such as the effectiveness of specific traffic control devices in such operations, there are still a number of other issues upon which research information is either limited or unavailable. For example, there is a need for additional research information on optimal vehicle spacing (i.e., between buffer vehicles and work vehicles), placement of workers within the mobile

lane closure work area, and training of workers on mobile lane closure procedures.

INTRODUCTION

Background

The aging of the United States and Canada's road infrastructure, coupled with an increase in traffic volumes, has taken a toll on the existing road network. For this reason, the need for maintenance and rehabilitation operations on the roadways is ever increasing.

Whenever there is construction or maintenance work being done on the roadway, not only does it impact traffic flow, but it also has the potential to negatively affect the safety of the roadway for both road users and workers (*1*). Data show that more than 1,000 fatalities and 40,000 injury crashes per year in the United States are related to work zone crashes (*2*).

Although traffic control techniques for road construction and maintenance vary widely, one of the methods experiencing increased use, because of its ability to increase efficiency and minimize operational impacts, is mobile (moving and intermittent) lane closures, which are defined in the next section. Although mobile closures have demonstrated operational benefits, they also exhibit unique safety risks. Many traditional TTC methods associated with static closures, which are used to warn and guide road users and to protect workers, are unsuited to mobile operations. Further complicating the task of providing adequate road-user guidance and worker protection is the dynamic nature of the closure and of the traffic conditions in which it must function.

Definition of Mobile Lane Closures or Mobile Operations

For the purposes of this report, a mobile lane or shoulder closure is defined as any activity associated with short-duration work that moves continuously or intermittently along a road segment. Some agencies call this type of closure a mobile operation. The work might be done directly from the moving vehicle or equipment, or it may involve workers on foot (*3*).

Objectives

The objective of this report is to synthesize the practices employed by transportation agencies during mobile lane closures. This document may be used for improving the overall safety of work zones by identifying notable practices relating to mobile lane closures. Mobile (moving and intermittent) lane closures are common TTC measures and are used for many short-duration construction, maintenance, and engineering activities performed on roads open to traffic. As opposed to stationary, longer duration road closures, mobile lane closures employ a traffic control set up that moves with the work and does not channel and separate moving traffic away from work crews through the use of physical barriers, such as a temporary concrete barrier, delineators, etc. Typically, the procedure is best applied in situations where the work being undertaken is of a very short duration or is indeed moving along the road. Examples of work for which moving lane closures may be used include, but are not limited to the following:

- Sweeping,
- Pothole patching,
- Line painting,
- Installing raised pavement markings,
- Vegetation spraying,
- Storm water catch basin cleaning, and
- Installation and removal of static work zone traffic controls.

Methodology

The two components to this report are a literature review, which included an overview of definitions of mobile lane closures used by different agencies; an overview of existing guidelines, handbooks, and manuals; present experiences and notable practices employed by various agencies; and an overview of the existing research evaluating the effectiveness of different practices and technologies, and a survey questionnaire that addressed (U.S.) state and (Canadian) provincial transportation agencies state of the practice.

Organization of the Report

This report is divided into four sections. The following (second) section provides an overview of relevant literature, including a review of the definitions of mobile lane closures used by different agencies as contained in existing guidelines, handbooks, and manuals. It also discusses the existing regulatory base, consisting of the *MUTCD,* standard specifications, and TTC plans, and presents a number of

devices that are currently either being used or have the potential to be used in mobile lane closures. This section concludes with an overview of existing research evaluating the effectiveness of different practices and technologies.

The third section summarizes the state of the practice among transportation agencies with respect to mobile lane closures by presenting the survey results.

The final section provides a summary of the key findings of the project, including the state of the practice, candidate "notable practices," comments on the state of research and technology, and highlights the need for additional research and technology development.

LITERATURE REVIEW

Existing State and Provincial Regulations and Guidelines

In the United States, standards and recommendations for mobile lane closures are included in the FHWA *MUTCD—Part 6—Temporary Traffic Control* (*4*). In addition to FHWA's *MUTCD* some states have their own *MUTCD,* which is generally based on the FHWA's *MUTCD,* with some additional guidance or interpretation applicable to each state.

In Canada, guidance for traffic control is provided in the Canadian *MUTCD* (*5*). In addition to the Canadian *MUTCD,* each province has its own regulations. The approach varies by province, with some having a separate provincial *MUTCD* and others having corresponding documents. Ontario, for example, has a series of manuals titled the *Ontario Traffic Manual* (*OTM*), which is similar to the *MUTCD* and is divided into individual "books," each covering a specific subject. *OTM—Temporary Conditions* (*Book 7*) (*6*) covers work zones.

The FHWA has also published the *Traffic Control Handbook for Mobile Operations at Night* (*3*), which contains a synthesis of current practices for performing mobile lane closures at night.

There is some disparity and overlap between the definitions and interpretations of mobile lane closures between jurisdictions. In some cases, mobile lane closures are included with short-duration operations. In other cases, it is a stand-alone topic with a discrete definition. Table 1 presents the definitions of mobile lane closures found for some of the different transportation organizations. Most states generally follow the *MUTCD* definition; however, the definition used by some states differs from the *MUTCD,* and these are highlighted in Table 1. Additional definitions obtained from the survey results are provided in Table 4.

The sections that follow focus on the following three reference regulations/guidelines and how they relate or differ from each other:

- FHWA's *MUTCD* (*4*),
- *Ontario Traffic Manual (OTM)—Temporary Conditions (Book 7) (6),* and
- FHWA's *Traffic Control Handbook for Mobile Operations at Night* (*3*).

These sections are organized such that each section summarizes the key components of mobile lane closures for each of the three documents.

The following is a summary of key aspects of mobile lane closure and should not be used as the

Table 1 Mobile lane closures definitions

Regulation	Definition
FHWA *MUTCD* (*4*)	Work that moves continuously or intermittently
Texas *MUTCD* (*7*)	Work that moves continuously or intermittently stopping up to approximately 15 min
Minnesota *MUTCD* (*8*)	Operation that is continuously moving or stopped in one location for periods of 15 min or less. The traffic control devices are typically vehicle mounted.
Virginia *MUTCD* (*9*)	Work that moves intermittently (1–15 min) or continuously
OTM Book 7 (*6*)	Work that is done while moving continuously, usually at low speeds (typically 25 km/h), or intermittently, with periodic brief stops related to the mobile activity, which do not exceed a few minutes in duration.

sole source of information for implementing these types of operations. It is important that each state or province review the full range of documentation referenced and also ensure that local regulations and guidelines have been considered

FHWA's *MUTCD* (*4*) classifies work duration in the following five categories:

1. *Long-term stationary* is work that occupies a location for more than 3 days.
2. *Intermediate-term stationary* is work that occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 h.
3. *Short-term stationary* is daytime work that occupies a location for more than 1 h within a single daylight period.
4. *Short duration* is work that occupies a location for up to 1 h.
5. *Mobile* is work that moves intermittently or continuously.

Temporary Traffic Control Zone

According to FHWA's *MUTCD* (*4*), the primary function of TTC is to provide for the reasonably safe and efficient movement of road users through or around work zones while reasonably protecting workers, responders to traffic incidents, and equipment.

Figure 1 shows the typical components of a TTC zone. Although this figure shows a typical stationary lane closure, the components are also applicable to mobile lane closures. The TTC zone is typically divided into the following four components:

- *Advance Warning Area*—section of highway where road users are warned about the upcoming work zone or incident area. This typically involves the use of static signs. (Note that, in mobile lane closures, the advance warning area generally moves with the closure, as the devices are vehicle-mounted. If static advance warning signs are used, the distance between the advance warning area and the transition area increases as the work proceeds along the road.)
- *Transition Area*—section of the roadway where drivers are redirected out of their normal travel path. This typically involves the use of cones or other types of delineators to form tapers. (Note that, in mobile lane closures, the transition area moves with the work area.)
- *Activity Area*—section of the roadway where the work is taking place. It includes the work space, traffic space, and buffer space. This area is typically separated from the portion of the roadway that remains open to traffic by cones, delineators, or temporary traffic barriers. (Note that, in mobile lane closures, the provision of guidance devices or a physical separation by means of a barrier is generally impractical.)
- *Termination Area*—section of the roadway that is used to return drivers to their normal travel path.

Mobile Lane Closure Procedures

The following procedures and guidelines are included in the *MUTCD* and are specifically related to mobile lane closures.

- Sign Placement
  - For mobile operations, a sign may be mounted on a work vehicle, a shadow vehicle, or a trailer stationed in advance of the TTC zone or moving along with it. The work vehicle, the shadow vehicle, or the trailer may or may not have an impact attenuator.
- Signs and Lighting Devices
  - The SLOW TRAFFIC AHEAD sign may be used on a shadow vehicle, usually mounted on the rear of the most upstream shadow vehicle, along with other appropriate signs for mobile operations to warn of slow moving work vehicles. A ROAD WORK sign may also be used with the SLOW TRAFFIC AHEAD sign.
  - For mobile operations that move at speeds less than 5 km/h (3 mph), mobile signs or stationary signing that is periodically retrieved and repositioned in the advance warning area may be used.
  - Warning signs; high-intensity rotating, flashing, oscillating, or strobe lights on a vehicle; flags; and/or channelizing devices might be used and moved periodically to keep them near the mobile work area.
- Arrow Panels
  - Type B [1500 × 750 mm (60 × 30 in.)] arrow panels are appropriate for intermediate-speed

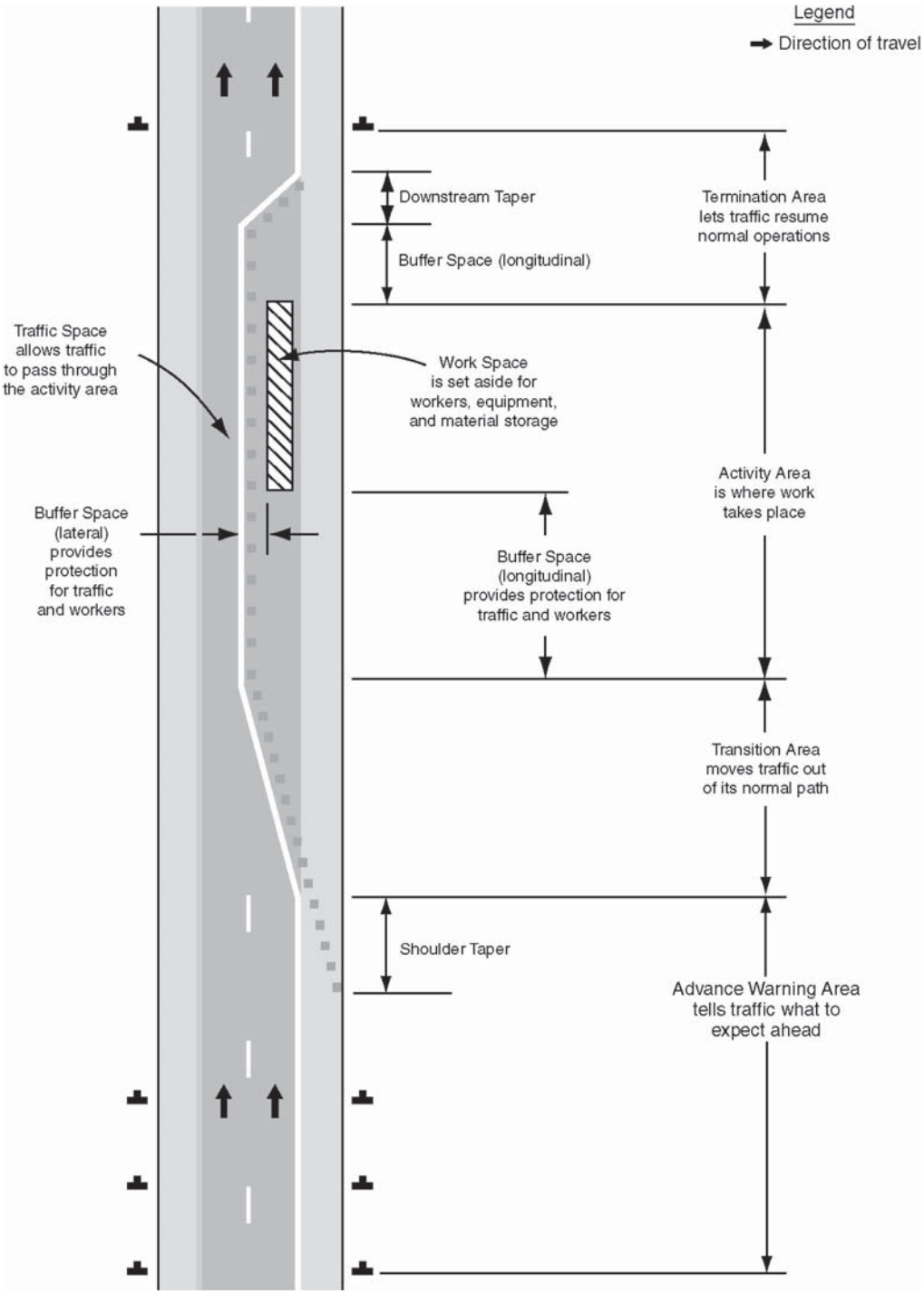

Figure 1 Component parts of a temporary traffic control zone (*4*).

facilities and for maintenance or mobile operations on high-speed roadways.

– For mobile operations where a lane is closed, the arrow panel should be located to provide adequate separation from the work operation so as to allow for appropriate reaction by approaching drivers.
– If there are mobile operations on a high-speed travel lane of a multi-lane divided highway, arrow panels should be used.

- Vehicles
  - Appropriately colored or marked vehicles with high-intensity rotating, flashing, oscillating, or strobe lights may be used in place of signs and channelizing devices for short-duration or mobile operations. These vehicles may be augmented with signs or arrow panels.
  - When mobile operations are being performed, a shadow vehicle equipped with an arrow panel or a sign should follow the work vehicle, especially when vehicular traffic speeds or volumes are high. Where feasible, warning signs should be placed along the roadway and moved periodically as work progresses.
  - At higher speeds, vehicles may be used as components of the TTC zones for mobile operations. Appropriately colored and marked vehicles with signs; flags; high-intensity rotating, flashing, oscillating, or strobe lights; truck-mounted attenuators; and arrow panels or portable changeable message signs (PCMSs) may follow a train of moving work vehicles.
  - For some continuously moving operations, such as street sweeping and snow removal, a single work vehicle with appropriate warning devices on the vehicle may be used to provide warning to approaching road users.
- Flaggers
  - Flaggers may be used for mobile operations that often involve frequent short stops.
- General Guidelines
  - Maintaining reasonably safe work and road-user conditions is a paramount goal in carrying out mobile operations.
  - Safety in short-duration or mobile operations should not be compromised by using fewer devices simply because the operation will frequently change its location.
  - Mobile operations also include work activities where workers and equipment move along the road without stopping, usually at slow speeds. The advance warning area moves with the work area.
  - Under high-volume conditions, consideration should be given to scheduling mobile operations work during off-peak hours.
- Standard
  - Mobile operations that move at speeds greater than 30 km/h (20 mph), such as pavement marking operations, shall have appropriate devices on the equipment (i.e., high-intensity rotating, flashing, oscillating, or strobe lights; signs; or special lighting) or shall use a separate vehicle with appropriate warning devices.

Typical Set-Up Configurations

The three typical applications of mobile lane closures contained in the *MUTCD* are described here.

Mobile lane closures on shoulder (Figure 2)

Guidance:

1. In those situations where multiple work locations within a limited distance make it practical to place stationary signs, the distance between the advance warning sign and the work should not exceed 8 km (5 mi).
2. In those situations where the distance between the advance signs and the work is 3.2 km (2 mi) to 8 km (5 mi), a Supplemental Distance plaque should be used with the ROAD WORK AHEAD sign.

Option:

3. The ROAD WORK NEXT XX km (MILES) sign may be used instead of the ROAD WORK AHEAD sign if the work locations occur over a distance of more than 3.2 km (2 mi).
4. Warning signs may be omitted when the work vehicle displays high-intensity rotating, flashing, oscillating, or strobe lights, if the distance between work locations is 1.6 km (1 mi) or more and if the work vehicle travels at vehicular traffic speeds between locations.
5. Vehicle hazard warning signals may be used to supplement high-intensity rotating, flashing, oscillating, or strobe lights.

Standard:

6. Vehicle hazard warning signals shall not be used instead of the vehicle's high-intensity rotating, flashing, oscillating, or strobe lights.
7. If an arrow panel is used for an operation on the shoulder, the caution mode shall be used.

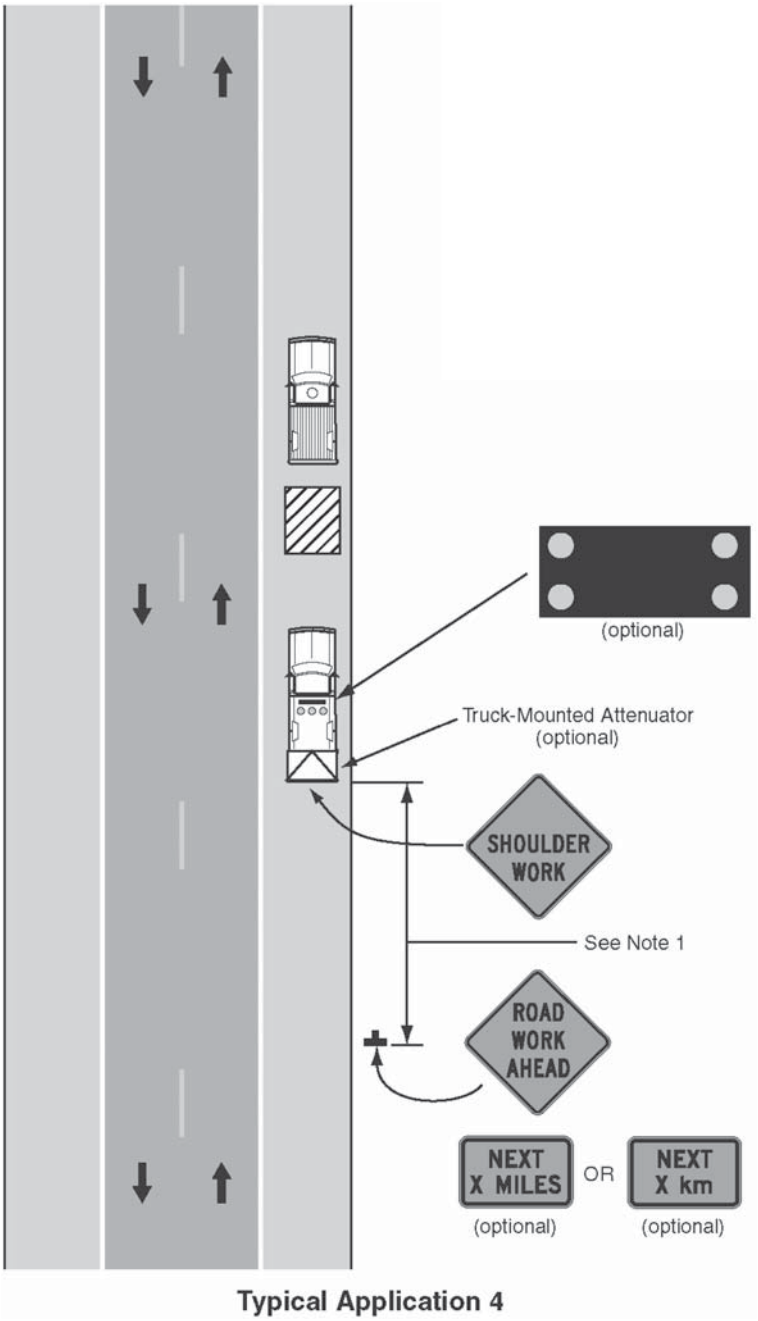

Figure 2 Mobile lane closure on shoulder (*4*).

Mobile lane closures on a two-lane road (Figure 3)

Standard:

1. Vehicle-mounted signs shall be mounted in a manner such that they are not obscured by equipment or supplies. Sign legends on vehicle-mounted signs shall be covered or turned from view when work is not in progress.
2. Shadow and work vehicles shall display high-intensity rotating, flashing, oscillating, or strobe lights.
3. If an arrow panel is used, it shall be used in the caution mode.

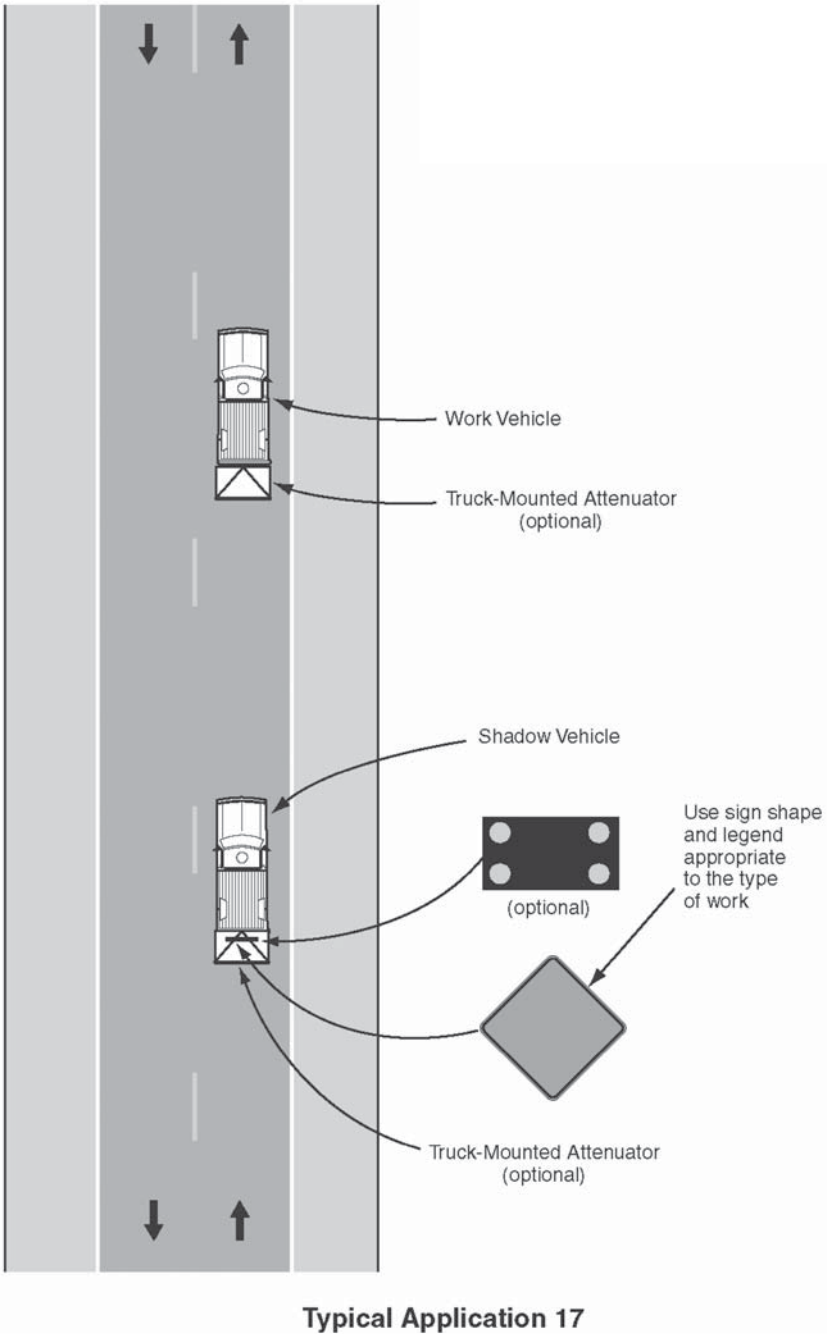

Figure 3 Mobile lane closures on two-lane road (*4*).

Guidance:

4. Where practical and when needed, the work and shadow vehicles should pull over periodically to allow vehicular traffic to pass.
5. Whenever adequate stopping sight distance exists to the rear, the shadow vehicle should maintain the minimum distance from the work vehicle and proceed at the same speed. The shadow vehicle should slow down in advance of vertical or horizontal curves that restrict sight distance.
6. The shadow vehicles should also be equipped with two high-intensity flashing

lights mounted on the rear, adjacent to the sign.

Option:

7. The distance between the work and shadow vehicles may vary according to terrain, paint drying time, and other factors.
8. Additional shadow vehicles to warn and reduce the speed of oncoming or opposing vehicular traffic may be used. Law enforcement vehicles may be used for this purpose.
9. A truck-mounted attenuator may be used on the shadow vehicle or on the work vehicle.
10. If the work and shadow vehicles cannot pull over to allow vehicular traffic to pass frequently, a DO NOT PASS sign may be placed on the rear of the vehicle blocking the lane.

Support:

11. Shadow vehicles are used to warn motor vehicle traffic of the operation ahead.

Standard:

12. Vehicle hazard warning signals shall not be used instead of the vehicle's high-intensity rotating, flashing, oscillating, or strobe lights.

Mobile lane closures on a multi-lane road (Figure 4)

Standard:

1. Arrow panels shall, as a minimum, be Type B, with a size of 1500 × 750 mm (60 × 30 in.).

Guidance:

2. Vehicles used for these operations should be made highly visible with appropriate equipment, such as high-intensity rotating, flashing, oscillating, or strobe lights; flags; signs; or arrow panels.
3. Shadow Vehicle 1 should be equipped with an arrow panel and truck-mounted attenuator.
4. Shadow Vehicle 2 should be equipped with an arrow panel. An appropriate lane closure sign should be placed on Shadow Vehicle 2 so as not to obscure the arrow panel.
5. Shadow Vehicle 2 should travel at a varying distance from the work operation so as to provide adequate sight distance for vehicular traffic approaching from the rear.
6. The spacing between the work vehicles and the shadow vehicles and between each shadow vehicle should be minimized to deter road users from driving in between.
7. Work should normally be accomplished during off-peak hours.
8. When the work vehicle occupies an interior lane (a lane other than the far right or far left) of a directional roadway having a right shoulder 3 m (10 ft) or more in width, Shadow Vehicle 2 should drive the left shoulder with a sign indicating that work is taking place in the interior lane.

Option:

9. A truck-mounted attenuator may be used on Shadow Vehicle 2.
10. On high-speed roadways, a third shadow vehicle (not shown) may be used with Shadow Vehicle 1 in the closed lane, Shadow Vehicle 2 straddling the edge line, and Shadow Vehicle 3 on the shoulder.
11. Where adequate shoulder width is not available, Shadow Vehicle 3 may drive partially in the lane.

The presence of at least one shadow vehicle is mandatory in all three configurations, whereas the use of a TMA on either the work vehicle or shadow vehicle is optional.

Ontario Traffic Manual—Temporary Conditions—Book 7 (*6*) classifies work duration into the following four categories:

1. *Long Duration Work* refers to stationary maintenance, construction, or utility activities that require a separate work space for longer than 24 h.
2. *Short Duration Work* refers to stationary maintenance, construction, or utility activities that require a separate work space, which is continuously occupied by workers and/or equipment and that are more than 30 min and less than one 24-h period in duration.
3. *Very Short Duration Work* occupies a fixed location for up to 30 min, including set-up and take-down time.

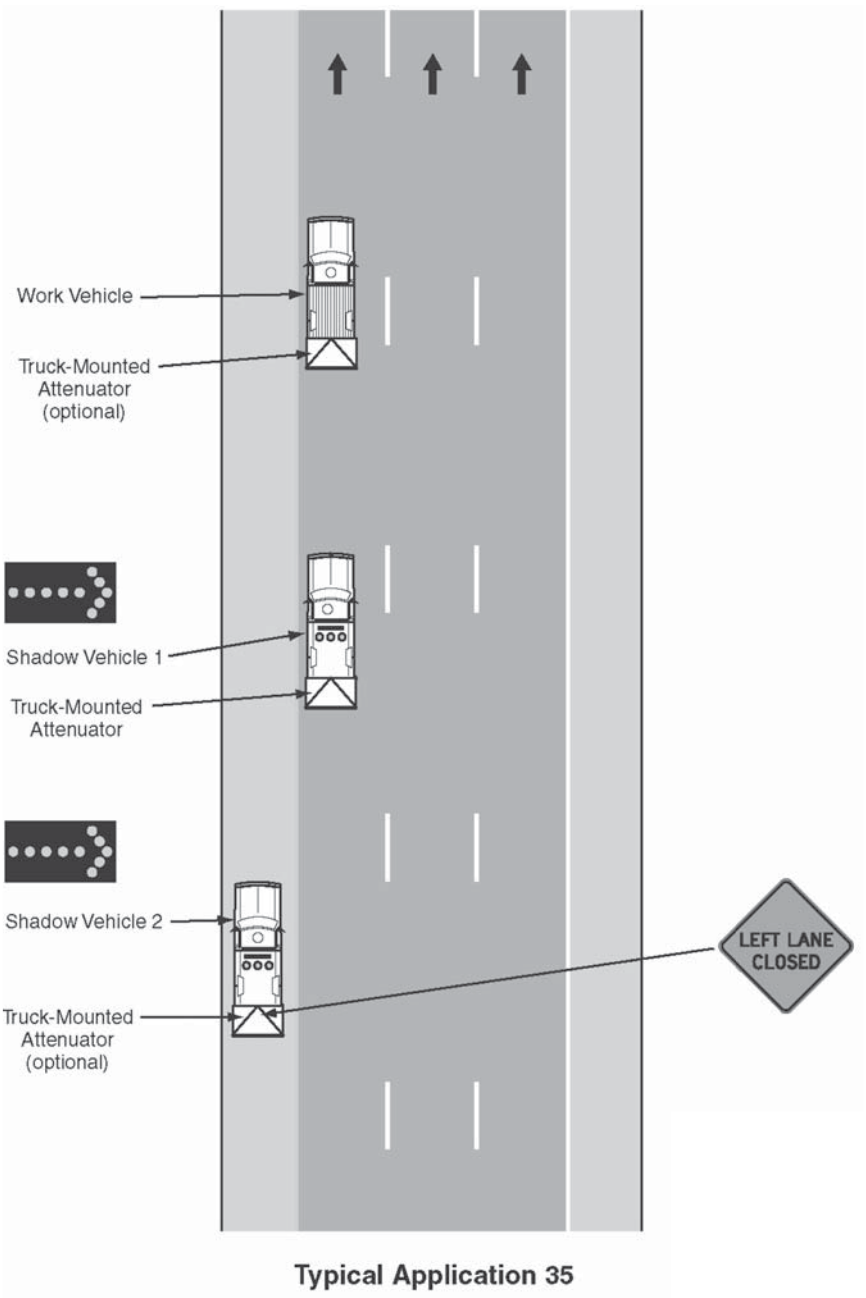

Figure 4 Mobile lane closure on multi-lane road (*4*).

4. *Mobile Operations* involve work that is done while moving continuously, usually at low speeds (typically 25 km/h), or intermittently, with periodic brief stops related to the mobile activity that do not exceed a few minutes in duration.

The main difference between the FHWA's *MUTCD* and *OTM Book 7* is that the latter groups long-term stationary and intermediate-term stationary into one category, the "Long Duration Work" category.

The components of a TTC zone in the *OTM Book 7* are very similar to *MUTCD*. A diagram illustrating the different components is shown in Figure 5.

OTM Book 7 contains a decision matrix for choosing which type of layout configuration applies for the different types of operations. This

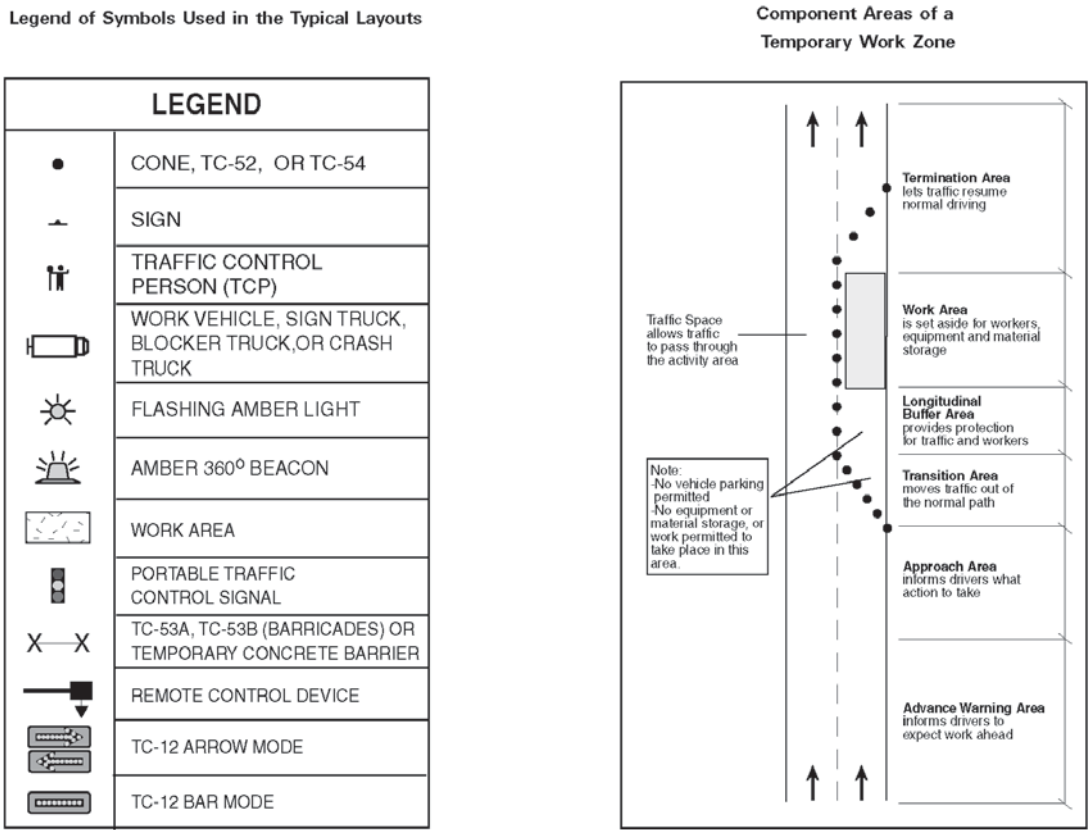

Figure 5 Component areas of a TTC work zone (*6*).

matrix is only applicable for operations done in Ontario and cannot be applied directly in the United States, because it differs from the FHWA *MUTCD* procedures. The concept, and the guidance it provides however, is noteworthy. Figure 6 shows an example of how this matrix works. For example, for an activity being performed on the right shoulder of a two-lane road but which encroaches in the right lane (Activity 3 in Figure 6), a mobile lane closure is used and typical layout 7 (TL-7) is applied (Figure 7). This figure is an excerpt of the full decision matrix and does not show all of the typical layouts for mobile lane closures. This report does not show all typical drawings from the matrix, and *OTM Book 7* should be referenced for further information.

OTM Book 7 has a greater number of layout configurations for mobile lane closures than the FHWA *MUTCD*. The following figures show the equivalent set up for the following three *MUTCD* set up configurations examined previously.

Mobile Lane Closures on Shoulder

OTM Book 7 has two different configurations for mobile lane closures on the shoulder, one applies to two-lane roads and multi-lane roads (non-freeway), shown in Figure 8, and the other applies to freeways, shown in Figure 9. The main difference between the two configurations is the presence of a shadow vehicle (buffer vehicle) for mobile shoulder closures on freeways. A major difference between *OTM Book 7* and the FHWA *MUTCD* is that the *MUTCD* configuration requires the presence of a shadow vehicle independently of the road type.

Lateral intrusion deterrence gap (LIDG) distances for Figure 9 are shown in Table 2. *OTM Book 7* uses the metric system, with conversion to the imperial system also provided in Table 2.

The LIDG is an Ontario-developed concept that attempts to provide optimal spacing between the shadow vehicle and the work vehicle or work

Type of Activity	Type of Work							
	Mobile Operations (continuously moving)		**Very Short Duration** (30 minutes or less, including set up/take down time)		**Short Duration** (more than 30 minutes, up to 24 hours)[1]		**Long Duration** (more than 24 hours)	
	Undivided	Divided	Undivided	Divided	Undivided	Divided	Undivided	Divided
1. Construction zone advisory signing							TL-1 2-lane and ML non-Fwy	TL-2 (non-Fwy & Fwy)
2. Speed zone signing							TL-3 2-lane and ML non-Fwy	TL-4 (non-Fwy & Fwy)
3. Shoulder and roadway edge work on a two-lane road								
Right shoulder work	TL-5		TL-5		TL-6		TL-6	
Encroachment in right lane (remaining lane 3 m wide or more)	TL-7		TL-7		TL-8		TL-8	
Partial lane shift (remaining lane less than 3 m wide) No parking lanes present			TL-9		TL-9			
Partial lane shift (remaining lane less than 3 m wide) Parking lane present			TL-10		TL-10			
4. Shoulder and roadway edge work on a multi-lane road								
Right shoulder work (non-freeway undivided) Right or left shoulder work (non-freeway divided)	TL-5	TL-5	TL-5	TL-5	TL-6	TL-6	TL-6	TL-6
Right or left shoulder work (freeway) (left lane is mirror image of right)		TL-11		TL-11		TL-12		TL-12
Work in median (non-freeway)		TL-5		TL-5		TL-6		TL-6
Work in median (freeway)		TL-11		TL-11		TL-12		TL-12

Figure 6 *OTM—Book 7* decision matrix (*6*).

area under typical applications. Provision of an LIDG is applicable to both in-lane and shoulder operations, which are either mobile or involve intermittent stops, where a shadow vehicle is used. The length of the LIDG is dependent on, and increases with, the posted speed limit of the roadway. Selection of an appropriate LIDG is critical to worker safety. If the shadow vehicle is too close to the work vehicle or work area, it may be propelled into the work vehicle or work area if struck, potentially injuring workers. If the shadow vehicle is situated too far upstream of the work vehicle or work area, a vehicle from an adjacent lane may be permitted to intrude between the shadow vehicle and the work vehicle or work area, negating the benefit of providing a shadow vehicle, and increasing the risk of collision. For operations such as line-painting, where required convoy length is dictated by drying time, an additional shadow vehicle is generally added to the rear of the convoy, and the shadow vehicle immediately behind the work vehicle focuses solely on maintaining the LIDG separation.

Mobile Lane Closures on a Two-Lane Road

Figure 10 shows the mobile lane closure set-up configuration for a two-lane road. In this set up the

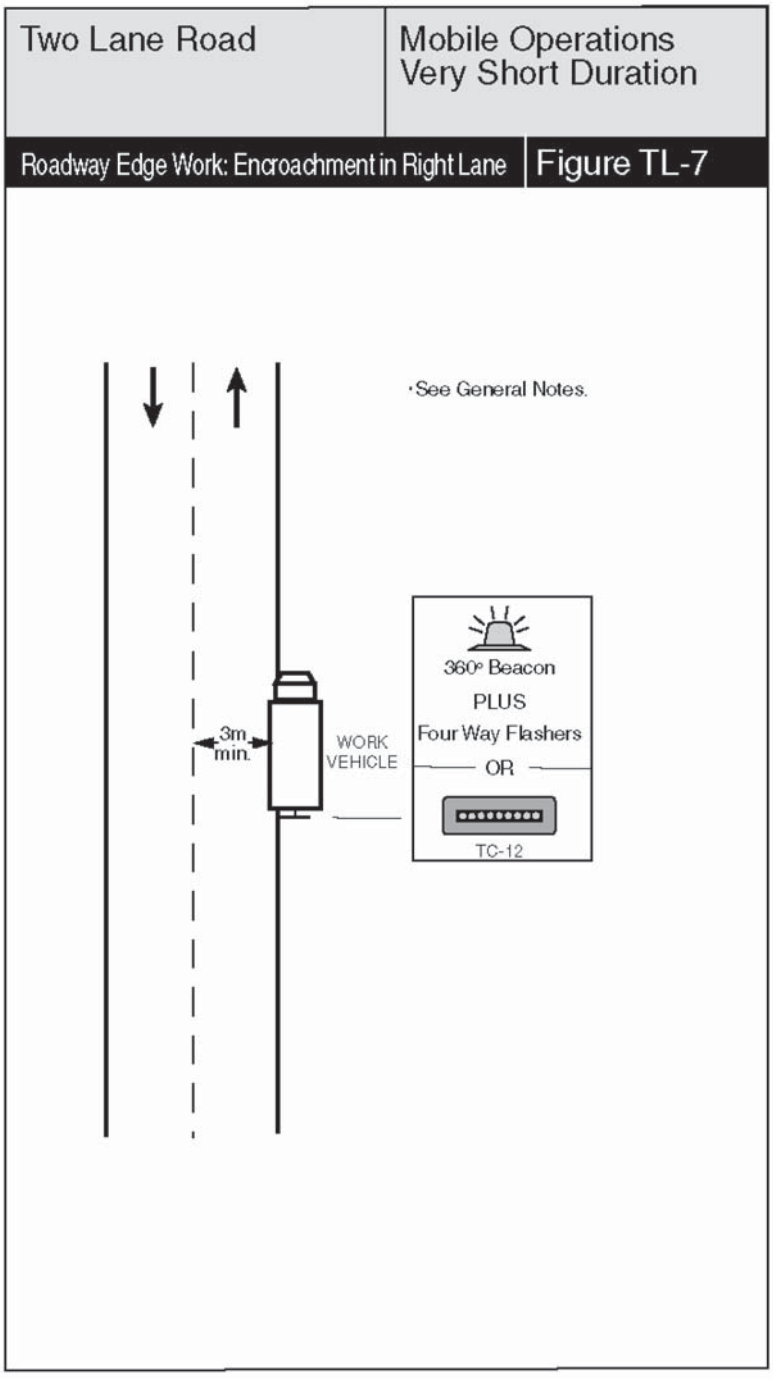

Figure 7 Two-lane road—roadway edge work: encroachment in right lane (*6*).

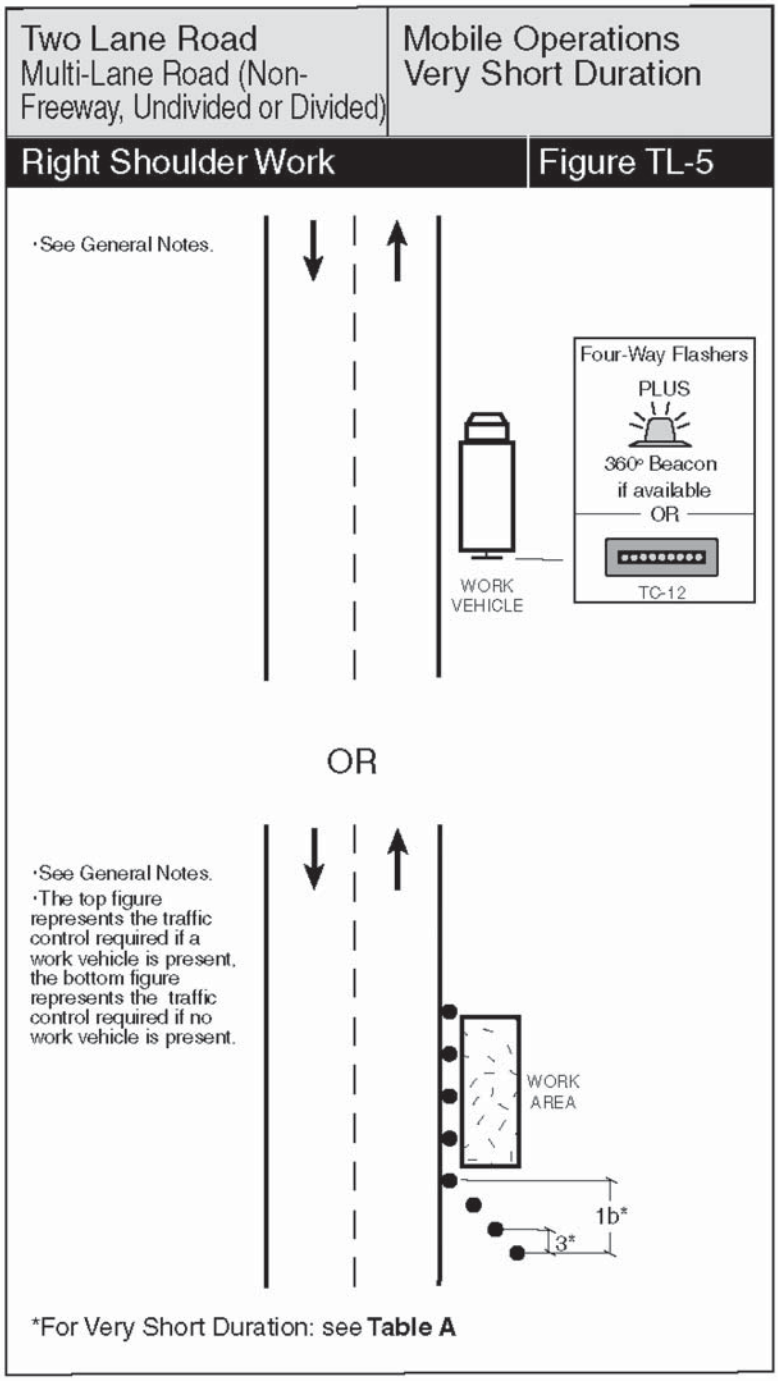

Figure 8 Right shoulder work [two-lane road and multi-lane road (non-freeway)] (*6*).

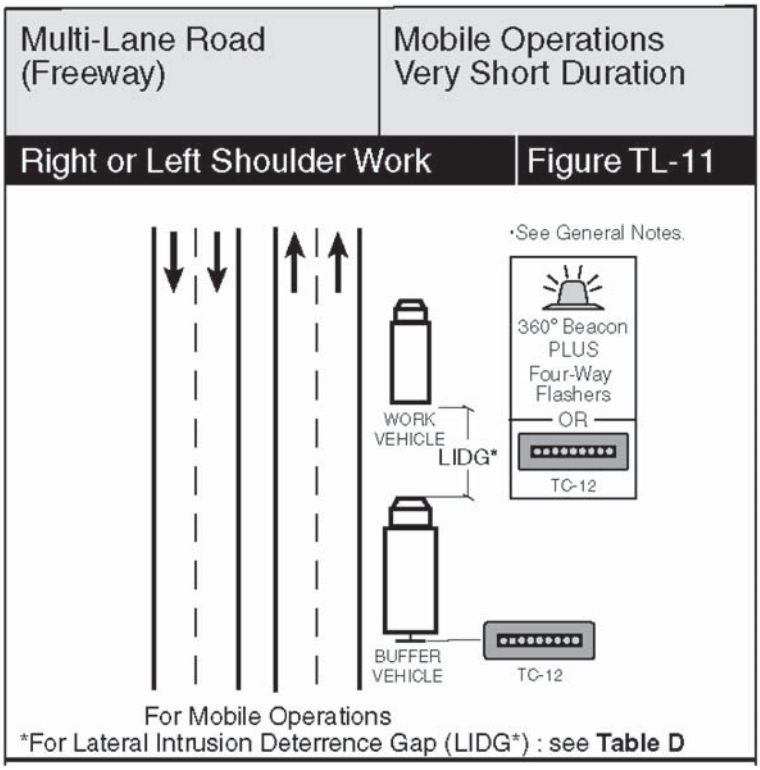

Figure 9 Right or left shoulder work [multi-lane road (freeway)] (*6*).

use of a shadow vehicle is not required, which differs significantly from the FHWA *MUTCD* configuration (see Figure 3).

Mobile Lane Closures on a Multi-Lane Road

The set-up configuration for a multi-lane road is divided into two categories, non-freeways and freeways. Non-freeways are further separated into undivided and divided roads. The following figures show the configuration for each of these categories.

For divided multi-lane (non-freeway) roads, the set-up configuration for left lane closures is the mirror image of the right lane closure configuration, as shown in Figure 11.

For left lane closure on undivided multi-lane (non-freeway) roads, the configuration shown in Figure 12 applies.

Figure 13 shows the configuration for right or left lane closures on freeways, where the left lane is the mirror image of the right.

The main difference between *OTM Book 7* and FHWA *MUTCD* is the use of two shadow vehicles, regardless of the road configuration (i.e., divided or undivided, non-freeway or freeway). This is intended to permit the buffer vehicle to maintain the LIDG under all circumstances.

Table 2 Lateral Intrusion Deterrence Gap (LIDG): mobile work operations

Normal Regulatory Speed Limit	LIDG
70 km/h (44 mph)	35 m (115 ft)
80 km/h (50 mph)	45 m (148 ft)
90 km/h (56 mph)	50 m (164 ft)
100 km/h (62 mph)	55 m (180 ft)

Source: *OTM—Book 7*, Table D—Application of Longitudinal Buffer Area and Buffer Vehicles (*6*).

FHWA Traffic Control Handbook for Mobile Operation at Night

Some mobile lane closures can be done at night, when traffic flows are lower and the impact of dis-

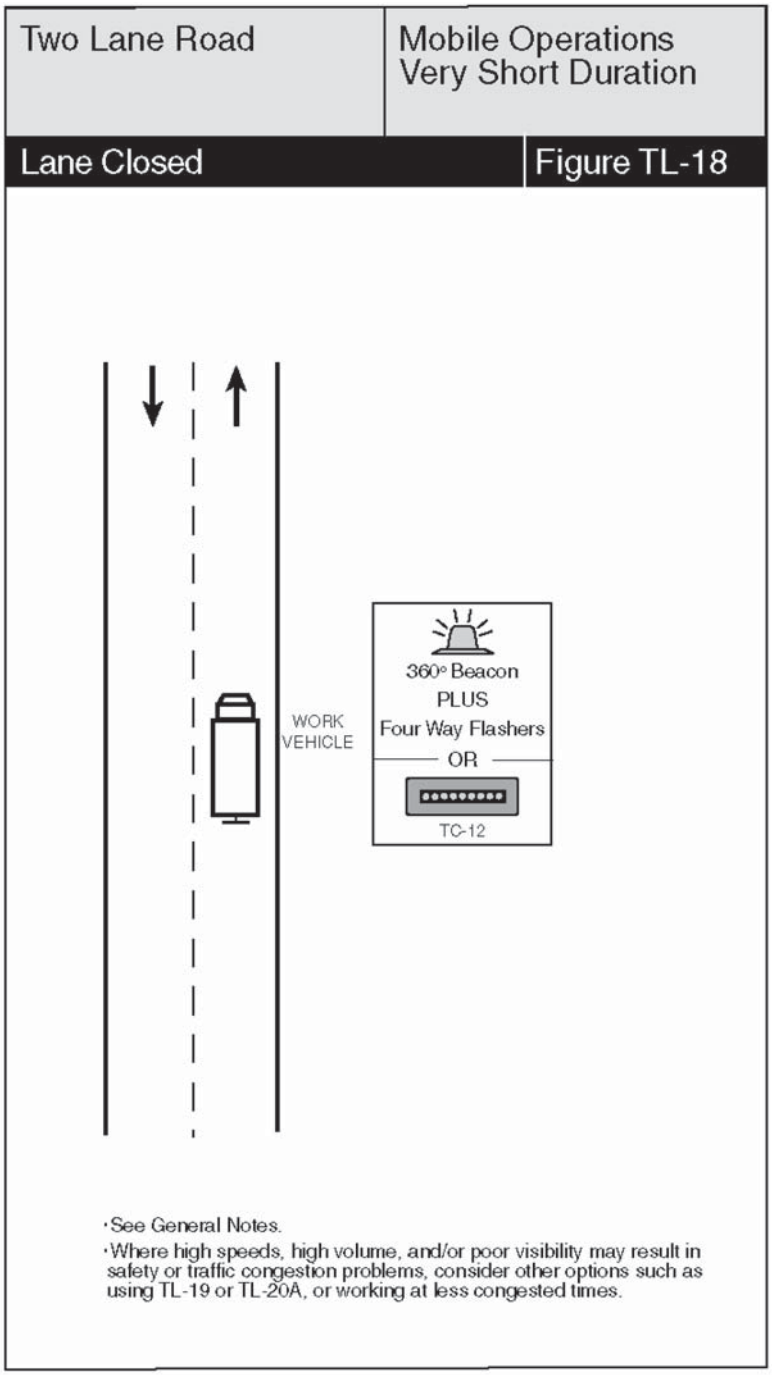

Figure 10 Two-lane road—mobile lane closure (*6*).

rupting traffic is not as significant. However, there are some additional risks to operating at night, such as reduced visibility, the potential for higher travel speeds resulting from lighter traffic volumes, and differences in both drivers' and workers' behavior (*3*).

The following are some of the typical mobile lane closure operations found in the FHWA *Handbook* (*3*) that are commonly done at night.

- Pavement marking installation;
- Pavement marking removal;
- Raised pavement markers—new installations and lens replacement;
- Shoulder rumble strips—installation;
- Pavement sweeping;
- Pavement sampling—coring, pavement soundings, skid tests, etc.;

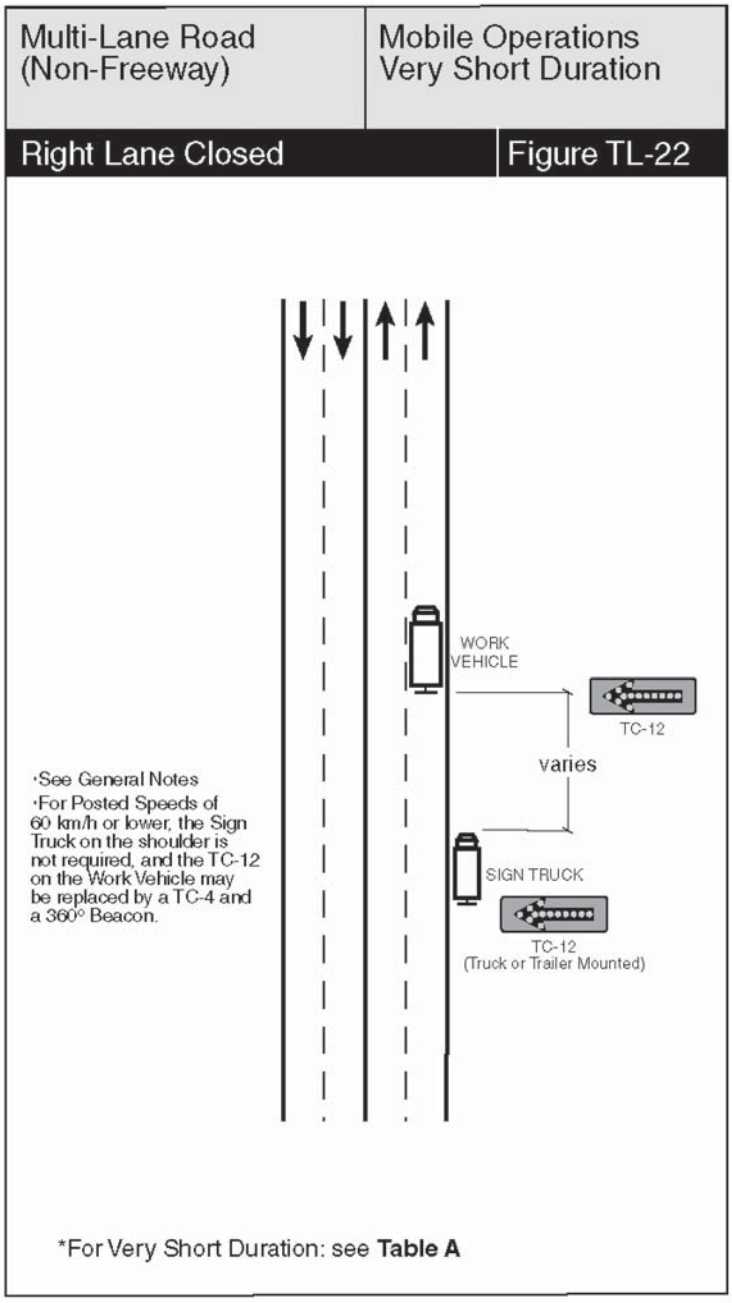

Figure 11 Multi-lane road (non-freeway)—right lane closure (*6*).

- Pavement repairs—limited in scope, such as pothole patching and other small repairs;
- Debris cleanup—both routine cleanup and removal of debris, and emergency removal of storm debris and spilled material;
- Vegetation control—application of herbicides adjacent to shoulders;
- Post mounted delineators—repair, replacement, installation;
- Small roadside signs—repair, replacement, installation;
- Cleaning drainage facilities—catch basins, drop inlets, etc.;
- Emergency repairs—miscellaneous operation necessary to restore safe highway operation that can be completed within a few minutes. Operations requiring longer exposure of work crews should use stationary traffic control set ups; and

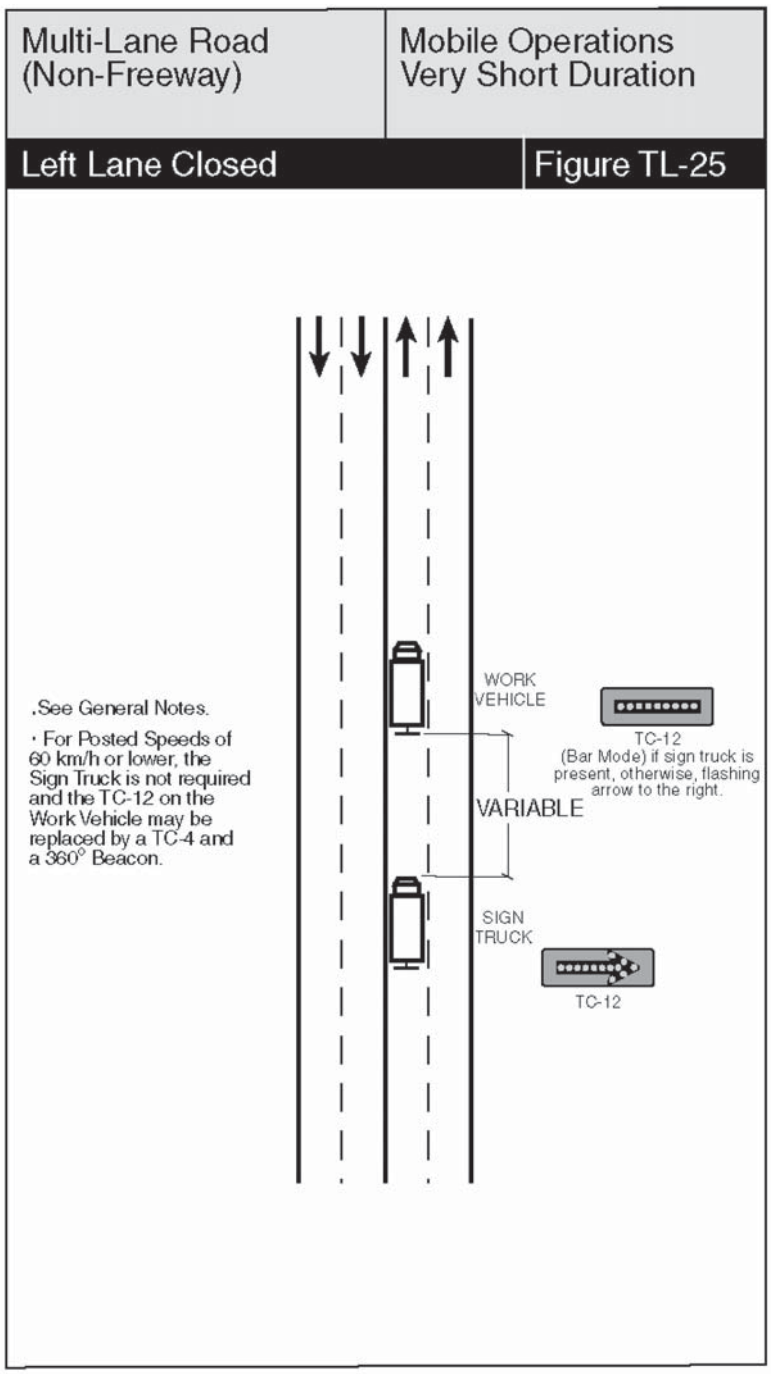

Figure 12 Multi-lane road (non-freeway)—left lane closure (*6*).

- Incident management—unplanned incidents may require the set up of detours, road closures, diversions, etc., to control traffic through or around the incident area. Although the established traffic controls may need to remain in place for an extended period, the operation to set them up may be handled as a mobile lane closure during night hours. Likewise, planned incidents such as movement of oversize loads may occur at night, and fall into the category of mobile lane closure.

Work Zone Illumination

When mobile lane closures are done at night, lighting becomes an essential component of these

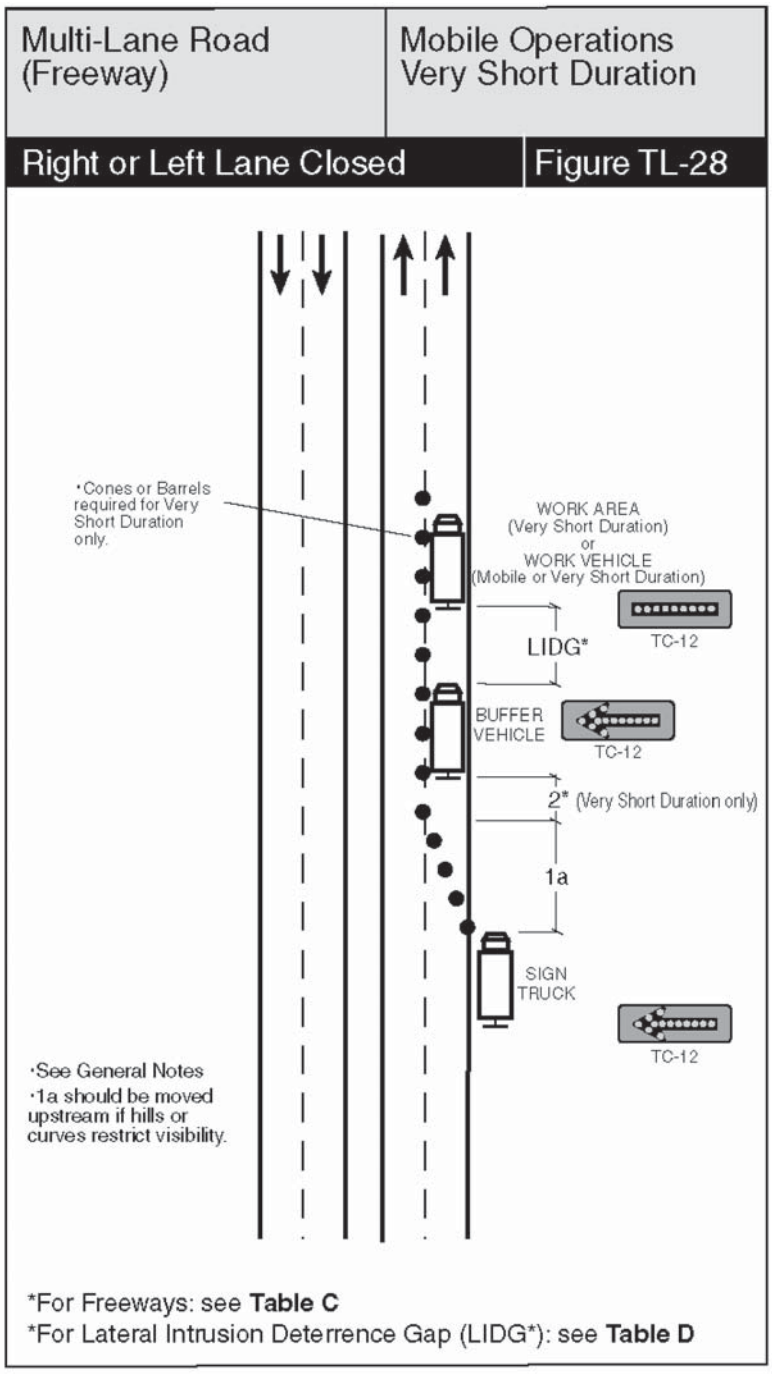

Figure 13 Multi-lane road (freeway)—right or left lane closure (*6*).

operations; by allowing for efficient completion of work task and also enhancing worker safety. It is important that lighting devices provide adequate illumination and not cause glare that interferes with working or driving tasks (*3*).

The FHWA's *Handbook* (*3*) provides guidance on recommended levels of illumination and procedures to control glare, these guidelines are summarized here:

- Illumination levels—recommended minimum level of horizontal illumination is 59 lux (5 footcandles). More complex tasks may require higher illumination levels.

- Glare control—positioning and aiming light sources such that they are not directly aimed at drivers and workers.
- Luminarie position
  - For illumination of the work area, elevating the light source as high as possible and aiming it downward reduce glare and improve illumination of the work area.
  - For illuminating the roadway surface, positioning the lights low on the vehicle helps eliminate glare and increases the level of illumination on the pavement.
- Types of work lights
  - Automotive floodlights (requires 12-volt vehicle electrical system)—can be conveniently mounted where needed to provide illumination for work tasks. They can also be used to illuminate signs mounted on the rear of the work vehicle. These lamps may not provide adequate illumination for large work areas.
  - Halogen floodlights (requires a 120-volt power source)—provides sufficient light to illuminate a larger area of pavement around work vehicles.
  - Trailer-mounted luminaries (typically generator-powered)—light plants—effective for very large work areas. However, they are not always practical to use in mobile lane closures because of the effort involved in moving and adjusting the lights as the work moves.
  - Trailer-mounted light plants positioned on truck beds—allows easy transport and provides a high level of light output. However, these luminaries can be difficult to position without creating glare.

FHWA's *Handbook* (*3*) has 10 typical application diagrams for mobile lane closures at night, some of which are illustrated in this report. These figures show the equivalent nighttime set-up configurations from the *MUTCD* for shoulder and multi-lane highway closures. These examples illustrate the principles and guidance provided in both the *Handbook* and the *MUTCD*; however, they should not be directly applied for any operation without careful consideration of the actual characteristics of the highway, traffic, and work operation.

Mobile Lane Closures on Shoulder

The *Handbook* contains the following two configurations for mobile lane closures on the shoulder. The first is applicable to two-lane roads, and the second is applicable to high-speed, multi-lane highways.

- NMTA-1 Night Mobile Operation on Shoulder of Two-Lane Two-Way Roadway. In addition to the *MUTCD* guidelines, the following apply to nighttime mobile lane closures (Figure 14).
  1. This plan is appropriate for intermittent moving operations positioned on the shoulder, completely free of or with only minimal intrusion into the travel lane. Such operations stop briefly, typically for 15 min or less, at various locations along a highway.
  2. The distance between the work vehicle and the shadow vehicle should be based on traffic conditions.
  3. Vehicle #1 may be omitted when the size of the work crew does not require two vehicles. If only one vehicle is used, the workspace should be positioned immediately in front of the vehicle.
  4. Work lights should be provided on Vehicles 1, 2, or both, depending on the nature of the work operation. Both vehicles should be equipped with warning lights with 360° visibility.
  5. When multiple work locations within a limited distance make it practical to place stationary signs, the ROAD WORK AHEAD sign may be placed on the shoulder. The distance from the sign to the work should be kept as short as possible, not to exceed 2 mi.
  6. Where sight distance is good and traffic speed and volume are not high, this plan may be adapted to continuously moving operations such as sweeping. Vehicle 1 performs the work and Vehicle 2 serves as the shadow vehicle and advance warning vehicle. Except for work on very-short highway segments, it is not normally practical to use stationary signs for continuously moving operations.
  7. When shoulder width does not permit both vehicles to be positioned completely beyond the travel lane, refer to NMTA-3A, -3B, and -7 in the *Handbook* for guidance.

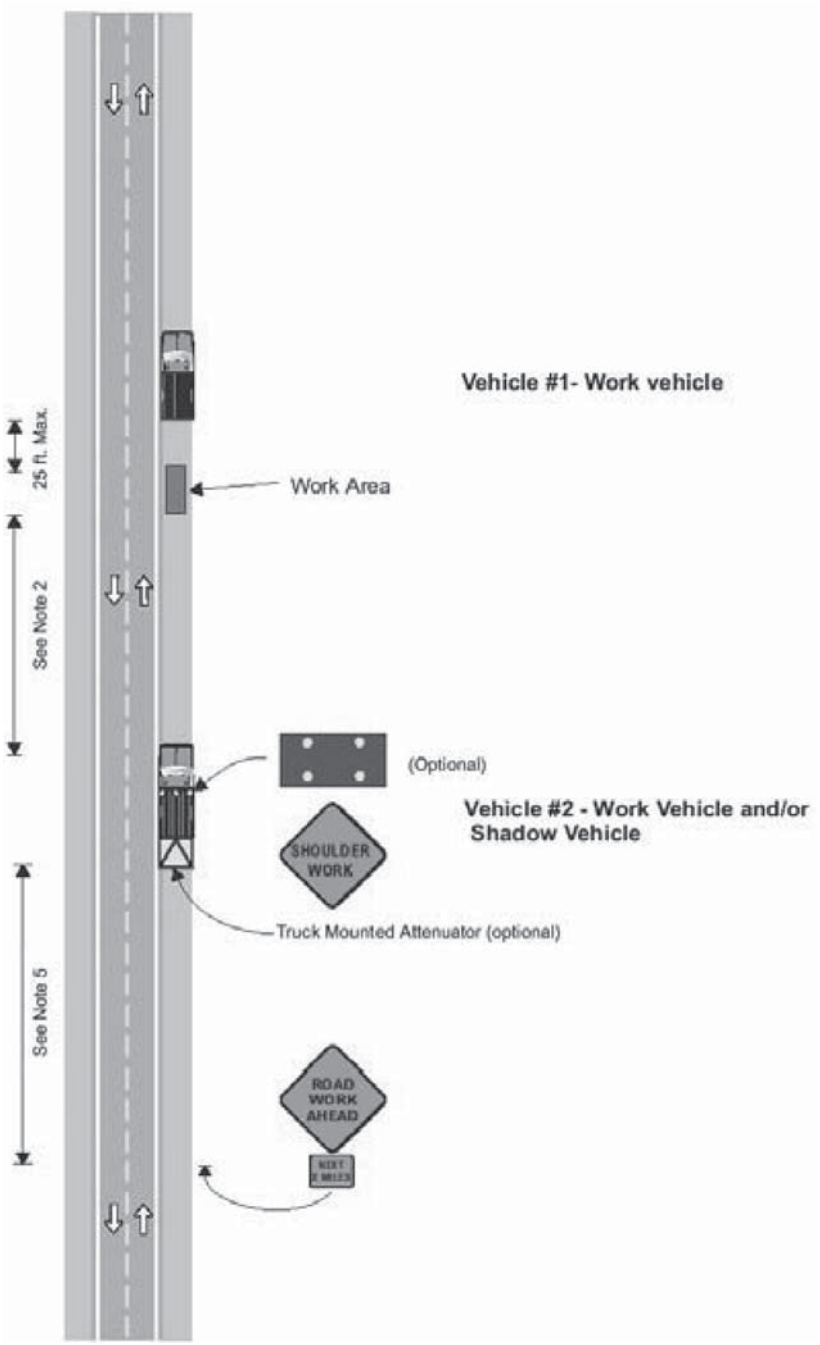

Figure 14 Night mobile operation on shoulder of two-lane, two-way roadway (*3*).

- NMTA-2 Night Mobile Operation on Shoulder of High Speed Multi-Lane Highway (Figure 15).
  1. This plan is appropriate for continuously moving operations such as sweeping or herbicide application, especially where sight distance is not good or higher traffic speed and volume may be encountered.
  2. The distance between the work vehicle and the shadow vehicle should be based on traffic conditions.
  3. Where the operation must stop briefly at intermittent locations, a stationary ROAD WORK AHEAD sign may be placed on the shoulder. It should be kept as close as possible to the operation, not to exceed 2 mi.

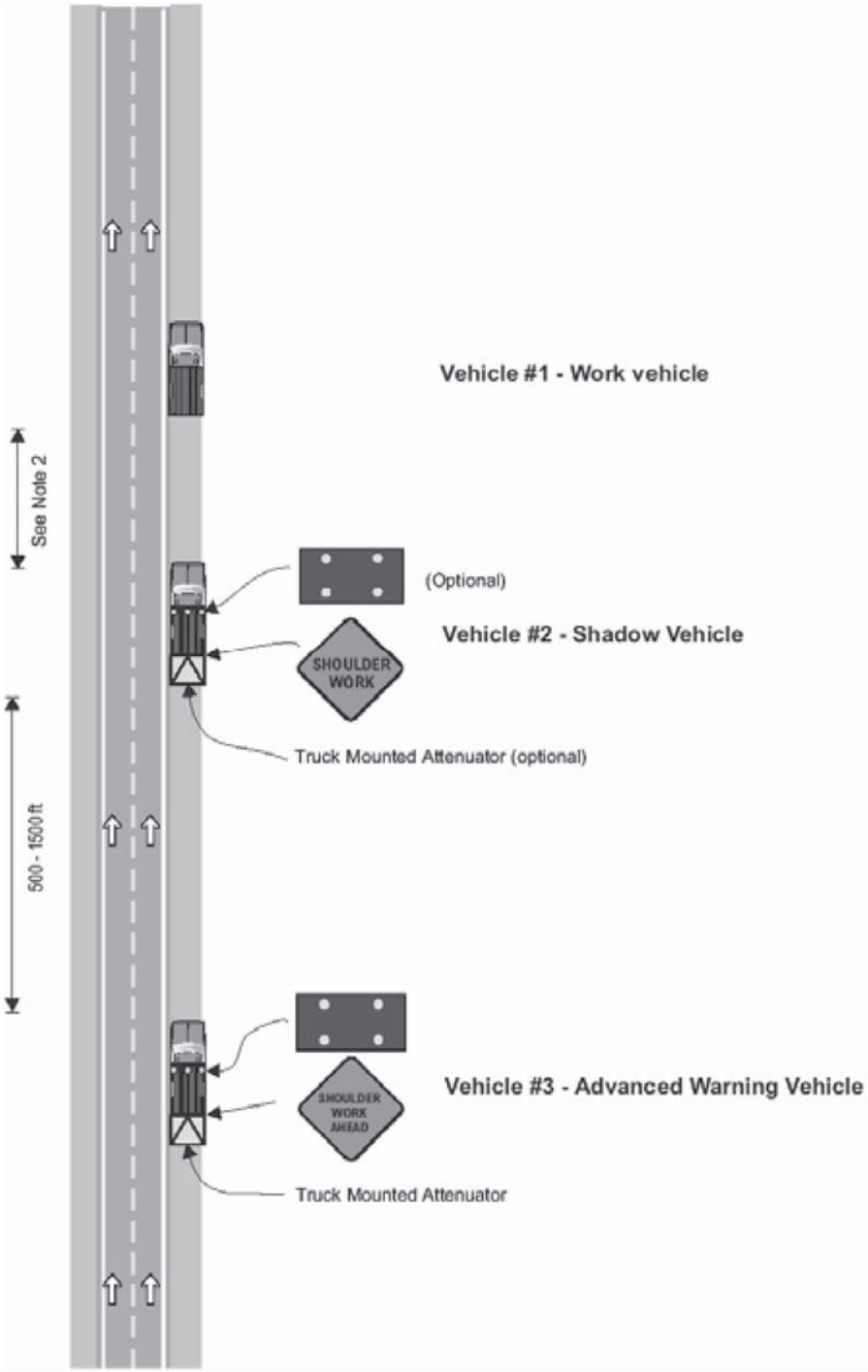

Figure 15 Night mobile operation on shoulder of high-speed, multi-lane highway (*3*).

4. For continuously moving operations all work is performed from Vehicle 1, with no workers on foot. When intermittent stops require workers to be on the pavement, the work space should be located immediately behind or ahead of Vehicle 1.
5. Work lights should be provided on Vehicle 1 to light the work operation, and may be provided on Vehicles 2 and 3 as needed, depending on the nature of the operation. All vehicles should be equipped with warning lights with 360° visibility.

6. When shoulder width does not permit all vehicles to be positioned completely beyond the travel lane, refer to NMTA-5 and -6 in the *Handbook* for guidance.
7. The position of Vehicle 3 should vary based on sight distance, ramps, intersections, shoulder obstructions, etc. A minimum of 500 ft in advance of Vehicle 2 is desirable; with a maximum of 1,500 ft. Shorter distances may be used for low speeds.
8. Vehicle 3 may be deleted where speeds are less than 55 mph and sight distance is adequate to provide at least 1,500 ft visibility to Vehicle 2 (1,000 ft visibility for speeds of 40 mph or less).
9. Refer to TA-4 of Part 6, *MUTCD* for additional guidance.

Mobile Lane Closures on a Multi-Lane Road

- NMTA-8 Night Mobile Operation on Interior Lane of Multi-Lane Highway (Figure 16).
  1. This plan is appropriate for mobile operations in the interior lane of a multi-lane highway. It may be used for continuously moving operations or for operations that stop briefly, such as pothole patching.
  2. For pavement marking operations, additional vehicles may be needed to place and retrieve cones or to protect the fresh line from tracking—refer to NMTA-5, -6, and -7.
  3. Work lights should be provided on the work vehicle as needed to illuminate the work operation, and may be provided on other vehicles. All vehicles should be equipped with warning lights with 360° visibility.
  4. The distances between the shadow vehicle and the work vehicle should be based on traffic conditions. (See page 20 of this handbook for guidance.)
  5. The length of the taper (L) formed by the moving vehicles should be based on guidance in Table 6C-2, Part 6 of the *MUTCD*. For speeds of 45 mph or greater, the distance in feet is the product of the lane width (W) in feet and the speed (S) in mph ($L = W \times S$).
  6. Where traffic speed and volume are not high and sight distance is good, Vehicle 3 may be deleted.
  7. When traffic speed and volumes are high, added vehicles may be necessary to provide extra distance between the two merge tapers.
  8. Where narrow shoulders or brief obstructions do not permit Vehicle 5 to be positioned fully on the shoulder, refer to NMTA-5, -6, and -7 for additional guidance. Under all circumstances, a minimum of four vehicles should be included in this plan.
  9. Work access to the center lane may also be provided by closing the left and center lanes. The decision of whether to close the right or left lane should be based on the available shoulder widths and sight distances, and the frequency of on/off ramps requiring traffic to cross the right lane.

Traffic Control Devices Used During Mobile Lane Closure

The *MUTCD* treats some aspects of mobile lane closure and short-duration operations similarly in terms of traffic control device requirements.

Paaswell et al. (*10*) identified traffic control devices used during mobile lane closure and short duration operations to improve safety in the work zone. The following devices were described as being used by different state DOTs in the United States during the mobile lane closures:

- Advanced Warning Signs—Mounted on a work vehicle, these signs alert drivers to be prepared to slow down or stop; they may include fluorescent signs.
  - Fluorescent signs for work zones—currently being used by the Iowa DOT. Mounted on the back of trucks, these signs have fluorescent backgrounds and are used to get the driver's attention as they approach the work zone.
  - Flashing arrow panels indicate in which direction the driver should relocate. When only the corners of the panels are flashing, drivers must use caution but are not required to change lanes.
  - Dancing diamonds lights—currently being used by the Oregon DOT. Dancing panel displays are used as an advanced caution device for mobile lane closures. The sign is a panel with a matrix of light elements that

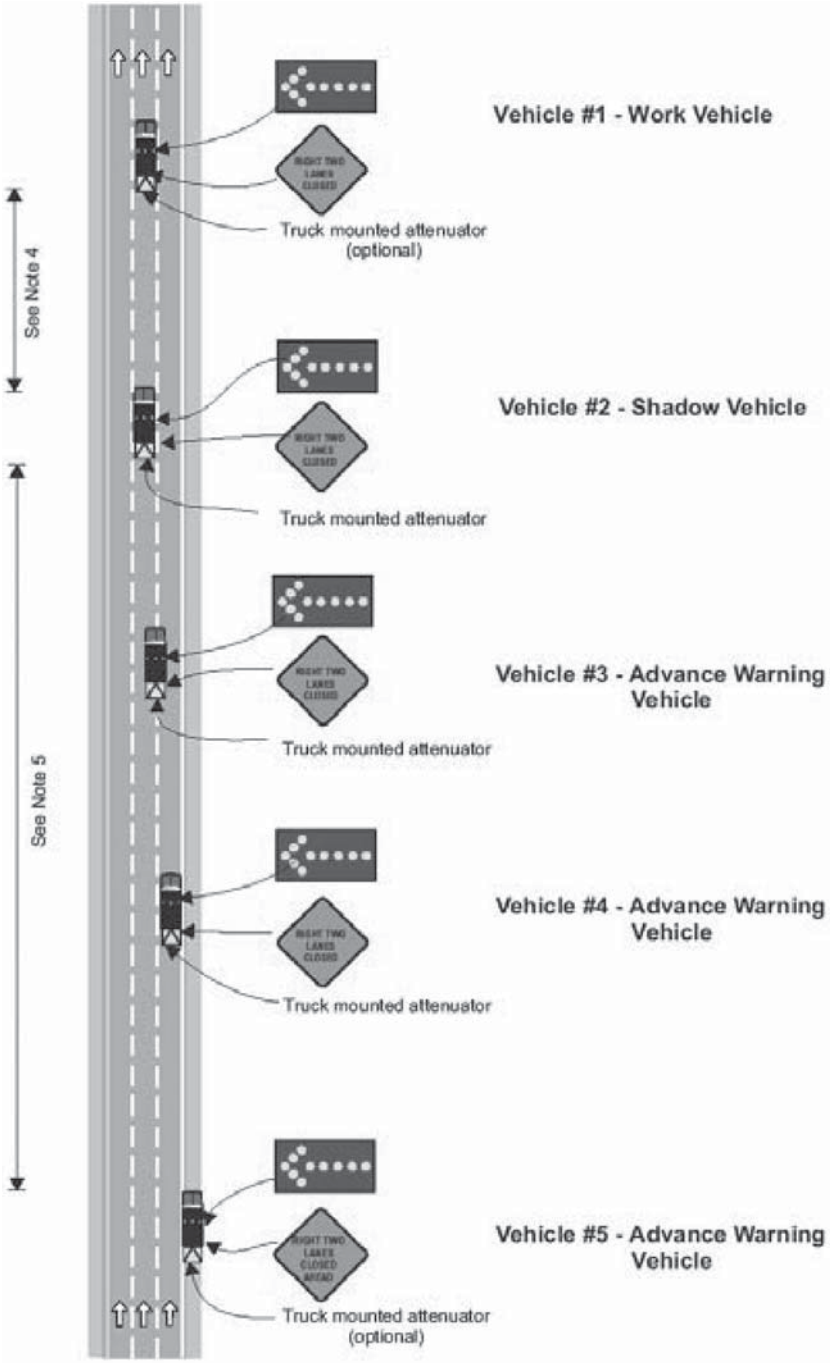

Figure 16 Night mobile operation on interior lane of multi-lane highway (*3*).

can flash and/or display lights in a sequential pattern.

– PCMSs (Figure 17)—traffic control devices that provide drivers with en-route traveler information. They can be mounted on work vehicles used during mobile lane closures. In mobile lane closures, the purpose of the PCMSs is to provide information to drivers so that they avoid incidents and prepare for unavoidable conditions.

– Truck-mounted message boards—can carry a variety of devices that can warn driver of the work zone ahead.

- TMAs—These are energy-absorbing devices mounted on the rear of a truck to deform on impact in a controlled manner. Some of the

Figure 17 Portable changeable message sign (*Source:* Washington State DOT).

current truck-mounted impact absorption devices can withstand a force of up to 4,410 lb (2,000 kg), traveling up to 62 mi/h (100 km/h). *NCHRP Report 350* (*11*) contains standards for different types of road conditions. Guidelines on the use of TMAs in work zones are addressed in a research paper by Humphreys and Sullivan (*12*).

- Drone Radar—currently being used by Ohio and Virginia DOTs. Drone radar may be used to help reduce speed in the work zones. It warns the driver of their speed before approaching the transition area. It is generally placed on PCMSs.

The following device is also used in mobile lane closures:

- Citizens Band (CB) Wizard Alarm System—unmanned CB radio transmitter designed to automatically broadcast work zone safety messages prior to motorists entering a work zone. The device monitors the CB radio transmissions and when it detects a lull a safety message is broadcast. These messages can be prerecorded or recorded on site. The device is mainly used to warn truck operators of work zones (including mobile) and/or unusual traffic conditions (*13*).

Innovative and Experimental Technologies

State DOTs and other national research programs are constantly looking for or developing innovative technologies that will improve the safety of mobile lane closures.

One of these programs is the Strategic Highway Research Program (SHRP), a five-year, applied research initiative, authorized by the U.S. Congress in 1987 to develop and evaluate techniques and technologies to combat the deteriorating conditions of the nation's highways and to improve their performance, durability, safety, and efficiency (*14*).

A number of safety device concepts were identified by SHRP to be applicable in work zone maintenance activities. The following are commercially available and can be used in mobile lane closures (*10*).

- Vehicle Intrusion Alarm—provides safety to the workers by alerting them, either by audio or visual means, that a driver has entered the work zone. The alarms can provide sufficient warning for the workers to clear out of the vehicle's path.
- Flashing STOP/SLOW Paddle—similar to the conventional stop/slow paddles used by flaggers at work zones, but equipped with high-intensity flashing lights that are visible even during the day. When a driver fails to heed the flagger's instructions, the flagger can activate the flashing lights to get the driver's attention.

The following two SHRP devices are experimental and were under evaluation.

- Portable Crash Cushion Trailer—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 the installation and removal of the barrels (*15*).
- Remotely Driven Vehicles—large dump trucks that follow workers as they move along the highway, serving as moving barriers between work crews and oncoming vehicles. The shadow vehicles lessen the risk for highway workers, but put the driver of the vehicle in a problematic position should the vehicle be hit (*16*).

Paaswell et al. (*10*) also identified devices developed by the Advanced Highway and Construction Technology (AHMCT) Center. The AHMCT is a research center located on the campus of the University of California–Davis that develops concept vehicles and equipment for the California DOT (Caltrans) (*17*). AHMCT has developed a number of automated devices that would assist in reducing

Figure 18 Automatic cone setting device (*Source:* Advanced Highway and Construction Technology).

worker exposure to traffic in mobile lane closures. These devices are described here:

- Automatic Cone Setting Device (Figure 18)—these devices can automatically place and retrieve cones in the work area, replacing the need for workers to do that job, which can be difficult and hazardous in mobile lane closures.
- Automated Pavement Crack Sealers—two types of automated pavement crack sealers were developed: a longitudinal crack sealer and a random crack sealer. They can increase worker safety by removing the need for workers to hand seal pavement cracks.
- Debris Removal Vehicle—two types of vehicles were developed: an automated litter bag/debris collector vehicle and a debris vacuum system. These devices can greatly improve the safety of workers by keeping the workers inside the vehicle, thus decreasing exposure to moving traffic.

These devices were evaluated by Paaswell et al. (*10*) on their functionality in mobile lane closures and short duration operations based on the following five criteria:

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

Paaswell et al. (*10*) evaluation is shown in Table 3.

The research concluded that none of these innovative or experimental devices fully satisfy all the criteria. However, remotely driven vehicles at least partially satisfy all of the criteria (*10*). Unfortunately,

Table 3 Criteria satisfied by selected work zone devices/equipment (*10*)

Work Zone Device	Criterion				
	1	2	3	4	5
Vehicle Intrusion Alarm					
Flashing Stop/Slow Paddle					
Portable Crash Cushion Trailer					
Remotely Driven Vehicle					
Automatic Cone Setting Device					
Pavement Sealers					
Debris Removal Vehicle					

Does not satisfy **Partially satisfy** **Fully satisfy**

Source: Paaswell, R.E., et al., *Identification of Traffic Control Devices for Mobile and Short Duration Work Operations*, July 2006 (*10*).

at this writing, remotely driven vehicles remain in the experimental stages and are not commercially available for use.

There are other automated devices that perform activities similar to the ones mentioned previously, and also help reduce worker exposure to traffic in mobile lane closures, such as grass cutting devices, etc. These devices were not evaluated in the Paaswell et al. research (*10*), but are believed to perform similarly to those included in the research.

Other innovative devices include a mobile barrier trailer, which is an integrated, rigid wall trailer that can be used in conjunction with standard semitractors to provide mobile, improved, safety and work environments for personnel at applicable maintenance sites (*18*).

Although the mobile barrier trailer was not included in the Paaswell et al. research paper, it would likely satisfy some levels of the criteria cited previously.

Work Zone Crashes

As mentioned previously, there are more than 1,000 fatalities and 40,000 injury crashes related to work zone crashes in the United States every year.

New York crash data from 1993 to 1998 showed that intrusion accidents accounted for approximately 10% of all work zone crashes and about 8% of serious injury crashes. Approximately 20% of intrusion type crashes involved mobile lane closures (*19*).

Traffic control devices are often involved in these work zone crashes. Bryden (*20*) examined 461 work zone crashes, occurring between 2001 and 2005, involving Category 3 (i.e., crash attenuators and temporary traffic barriers) and Category 4 (trailer-mounted arrow panels, changeable message signs, and light towers) devices. Research found that both work zone attenuators and temporary barriers (Category 3) were involved in a significant number of crashes and injuries. It showed the importance of following correct procedures for different types of operations.

Although data on work zone crashes are available in the United States every year, specific data related to mobile lane closures are not available.

Safety of Workers

Chapter 8 of the *Caltrans Maintenance Manual* (*21*) is dedicated to the protection of workers. Section 8.22 of that chapter addresses mobile lane closures. It highlights that the following procedures should be followed in a mobile lane closure operation.

- Before employees work in a moving lane closure, a discussion shall be held so that all involved employees will know what their role in the operation is and how to proceed safely.
- In any slow moving operation the first vehicle in the lane approached by motorists shall be a shadow vehicle.
- For information on vehicle spacing, vehicle positioning, and signing, refer to the Traffic Control System for Moving Lane Closure on Multilane Highways and on Two Lane Highways.
- All vehicles used as shadow trucks shall be equipped as defined in Section 8.11 of the *Manual,* "Protective Vehicles." Radio communication in all vehicles is required.
- Other requirements for moving lane closures and shadowing moving operations, found in the Maintenance Code of Safe Operating Practices, shall be followed.
- Exceptions to this rule are tow trucks and snow removal/de-icing equipment.

The National Work Zone Safety Information Clearinghouse (*22*) provides information to improve motorists, workers, and pedestrians' safety in roadway work zones. The Clearinghouse's website, www.workzonesafety.org, has information on crash data, latest technologies and equipment, best practices, online training and conferences, etc. For example, there are references to training materials such as videotapes that can be obtained through the different organizations. The following are references found for videos relating to mobile lane closures:

- Mobile Work Zone Operation (*23*)—shows how protection vehicles are used to safeguard mobile lane closure operations.
- "Highway Work Zone Safety—Moving Operations/Maintenance Safety" (*24*)—discusses the importance of recognizing personal responsibility for safety in the highway work zone.

Information is constantly being added or updated in the Clearinghouse's website, making it a valuable resource for work zone information in general.

There is, however, inadequate research information on the training of workers performing mobile lane closures in general and more specifically, how

effective certain training practices are, such as formal versus informal training.

Notable Research and Practices

Advance Warning Signs

Schrock et al. (*25*) have assessed the effectiveness of different arrow type displays used in short-term and mobile lane closure work zones. The assessment was based on interviewing four focus groups. Participants' opinions and understanding were explored on the following three different arrow display alternatives:

- Individual arrow displays when mounted on a single vehicle;
- Multiple arrow displays when mounted on several work vehicles; and
- Individual caution displays when mounted on a single work vehicle.

Images of these alternatives were shown to the participants to determine their understanding of them. Both flashing and sequential arrow and chevron displays were used in the first two cases. In the first case, 78% of participants rated the sequential displays more effective in conveying the information about a lane closure than the flashing displays. A few pointed out that the sequential chevron display seemed to be indicating the presence of a sharp curve instead a lane closure warning.

In the second case, participants agreed that presence of more than one work vehicle was effective in providing them with the information that they were approaching a larger or more extensive work zone operation. With multiple arrow displays in a moving convoy, 88% of the motorists were able to correctly interpret that one lane is closed. Participants preferred staggering the work vehicles into the closed lane as this would provide positive reinforcement to the lane closure message. Participants were in favor of having additional information about the work zone in the form of static signs on the back of the shadow vehicles. Some participants preferred specific directions such as "MOVE OVER," "RIGHT LANE CLOSED," or "MOVE LEFT" on the static sign.

In the third case, participants commented on whether caution displays are needed if other devices such as flashing amber lights are present.

Researchers have recommended additional field research on these displays to improve their usage and enhance motorist understanding.

Vehicle Warning Lights

Kamyab and McDonald (*26*) presented notable practices for increasing protection and visibility of highway maintenance vehicles. It was found that most of the United States use amber warning lights on vehicles, and also apply some type of retro-reflective material to enhance the visibility at night. In addition, the use of mounted warning signs with rotating or strobe lights was common for routine operations. For snow removal equipment, the use of retro-reflective tape, warning flags, and rotating and strobe lights was more common.

A review of available research on emergency vehicle lights by Solomon (*27*) has found two important issues:

1. An increase in the number of flashing light signals decreases the ability of drivers to quickly respond to the emergency message.
2. An emergency flashing light is more quickly detected when there are no other flashing lights present in the field of view.

Based on these studies, he commented that "there is a limit to the number of flashing lights mounted on an emergency vehicle and exceeding that number will make the vehicle less safe." The following are the recommendations from the report:

- "When an emergency vehicle is responding in an emergency mode, it should be equipped with fewer warning lights of lower power and less motion and flash duration should be longer."
- "When the emergency vehicle is parked on the shoulder or at the curb it should display non-strobe, amber beacons or incandescent, simultaneous flashers with relatively long illuminated intervals that are exposed toward the direction of on coming traffic; they should not be used in conjunction with any other flashing lights or sequencing displays."

Although this research was focused specifically on emergency vehicle lighting, the findings as they relate to the ability of drivers to respond to flashing lights on the road could be useful in mobile lane operations.

Ullman et al. (*28*) have developed recommendations for improving the vehicle and equipment warning light policy for the Texas DOT and potential safety improvements in the department's pavement

data collection activities. Recommendations on vehicle warning lights were provided on the basis of findings of a nationwide survey, motorist's survey, and field studies. The national survey revealed that 86% of the states that provided responses to the survey, use at least one other color besides yellow on some of their equipment. The results of the motorists' survey indicated that the combination of blue and yellow lights provides a slightly greater sense of hazard to motorists than the yellow light alone, but that there was no statistically significant difference in the responses of the motorists in these two conditions. A yellow and red light combination was preferred by the motorists as it was more indicative of a higher hazard condition to them and they believed a greater need to respond by applying their brakes. The field study was done to determine whether motorists' perceptions of different warning light color configurations make them behave differently in terms of vehicle speed, lane choice, and braking activities. The results were more consistent with the findings from the survey results. An increase in motorists' response frequency was evident as colors were added to the basic yellow light used on most working vehicles and a further increase in this response was seen when a law enforcement vehicle was present. On the basis of these findings researchers have recommended changes to the Texas DOT current warning light policy.

Mobile Barrier Protection

Ullman et al. (*29*) developed a set of functional requirements for highly portable positive protection technologies that may protect highway workers. Researchers have identified and assessed a large number of construction and maintenance work activities that are highly mobile and the specific roadway design features that have the most significant impact on these functional requirements. The roadway features identified included lane and shoulder width, traffic speed, vehicle type, number of travel lanes, vertical curvature, and horizontal curvature. They have discussed the requirement of lateral encroachment into the adjacent lane and the impact angles for different separation distance. The functional requirements were developed on the basis of the following five roadways and environmental dimensions:

- Spatial requirements,
- Access requirements,
- Mobility needs,
- Transportability, and
- Traffic control and illumination.

The research suggested both essential and desirable requirements, and also provided some cross references to show which activities do and do not meet the functional requirements. It was concluded that although it is desirable to have a protection device that can accommodate a wide possibility of work zone conditions, the study showed a number of practical limits to activities that can be accommodated by a single type of highly portable positive protection system and a system meeting the stated functional requirements could accommodate about two-thirds of the construction and maintenance activities considered in the study. The system must be highly portable, highly maneuverable, easily deployed, should be adjustable for various lane widths, and be capable of reducing ¾ ton pickups at angles and speeds up to 25 degrees and 60 mph if the selected performance level is 3.

Speed Control in Mobile Lane Closures

Pigman et al. research (*30*) was focused on evaluation of the measures and procedures that will alter or control the speed of motorists in work zones, investigation of the feasibility of using automated equipment to replace flaggers in the work zone, the development of policy and guidelines for the use of elevated platforms near traffic, and evaluation of the safety issues associated with mobile lane closures and short-term work activities. To determine the effectiveness of various speed control measures in work zones, speed data were collected at 23 locations across the state of Kentucky for different strategies that included signs, radar display, and police enforcement. The 50th and 85th percentile speeds were calculated for each site.

The results demonstrated that a police presence was associated with the largest reduction in speed. The investigation on the use of four automated flagger devices has revealed that there is inadequate widespread use of these devices because of the cost and time and convenience factors of placing the devices in the work zone. It was determined by the researchers that these devices have the potential for application in long-term lane closures at work zone locations such as bridge deck repairs. A guideline was developed by the researcher for use of aerial lifts and elevated platforms in conjunction with a typical application drawing for aerial work within an intersection.

The recommended guidelines were focused on the hazard associated with working over an open lane or traffic. On the basis of the comments provided by the maintenance personnel on the practicability and durability of the flashing STOP/SLOW paddles, researchers have suggested the use of a light-emitting diode-type flasher. A handbook was developed by the researchers to provide guidelines for traffic control in short duration and mobile lane closure work zones, which include typical application diagrams developed for various types of short duration and mobile lane closures. The handbook emphasized work duration, major traffic control considerations, fundamental principles, guidance, options, support for short duration operations or mobile lane closures, component parts of a TTC zone, tapers, flaggers, arrow panels, warning lights, nighttime operations, signs, and typical operation diagrams.

Other Safety Issues in Mobile Lane Closure

Ullman et al. (*31*) identified potential hazards associated with mobile lane closures and short duration maintenance operations, which may be indicative of the underlying causal factors. Hazards were identified based on observed motorist reactions, roadway characteristics, and work activity. For mobile lane closure maintenance operations hazards were found to be associated with the motorists' inability to recognize the speed differential between the convoy and their vehicle, reentering the convoy after passing the trail vehicle, visibility of work vehicles, and motorist failure to undertake the appropriate passing maneuver for different roadway characteristics. The work activities performed adjacent to the roadway or on the shoulder were found to have very little influence on traffic behavior. Researchers have concluded that if more specific information about the upcoming roadway condition and the appropriate action to be taken in such cases were provided, many of these hazards could be addressed.

Finley and Ullman's research (*32*) was focused on examining the terminology used to define mobile lane closure and short-duration operations and determine if changes would help distinguish between these types of operations, assist in developing maintenance traffic control plans tailored to select mobile lane closure and short-duration operations, and support the development of more specific guidance in determining whether protection vehicles are needed based on roadway volume (average daily traffic) and posted speed limit. The research team conducted a survey to determine the current practices employed by the states during mobile lane closure and short duration operations. It was revealed from the survey that the definitions of mobile lane closure and short-duration operations used by the transportation agencies were not always consistent with the *MUTCD* definitions which, in turn, may make it difficult for the field personnel to select the proper traffic control devices. It was concluded by the researchers that a clearer distinction between the definitions of the two operations is needed. Researchers have recommended that the two operations be distinguished by the duration of the operations associated with "temporary traffic control zone," instead of by the "work" being performed. Thus, an operation may be considered mobile if the temporary traffic control zone moves intermittently or continuously. If the temporary traffic control zone is stationary, then the operation is no longer considered to be mobile. To this end, the researchers recommended changes to the work duration definitions, including the replacement of the word work by temporary traffic control zone, and the addition of an amount of time a mobile operation (mobile lane closure) can be stopped before it is considered to be a short-duration operation. Researchers have developed mobile maintenance traffic control plans for different operations on divided and undivided highways and short-duration maintenance traffic control plans for sign, delineator, and lighting maintenance operations. They have developed guidance for choosing whether protection vehicles are needed based on the roadway traffic volume (average daily traffic) and posted speed limit.

Finley et al. (*33*) identified and evaluated traffic control devices that could be used for mobile lane closures and short duration maintenance operations, and assessed motorists' understanding of these devices. Motorist comprehension was examined with regard to a device's ability to inform a motorist of a roadway situation. Three different situations were used:

- The number of vehicles in a work convoy;
- Speed differential between the work convoy and the normal traffic stream; and
- Passing a work convoy operating on the centerline of a two-lane, two-way roadway with improved shoulders.

Researchers identified current signs in use, and appended additional words and text messages to them to determine how well they inform the motorists about how to pass the work vehicles. Participant's

responses were combined and the percentage of correct responses was computed for each treatment. Treatments were considered to be understood by the participants when 85% of them correctly interpreted the treatment. In the case of comprehension levels less than 85%, statistical procedures were used to determine if the result was significantly different from the 85% criteria. Researchers have found that placing the number of working vehicles on the sign "Work Convoy" (currently in use in Texas to inform motorists that they are approaching multiple working vehicles); that is, "3 Vehicle Convoy," improved motorists' comprehension from 53% to 79% (not statistically different from the 85% criterion). Therefore, they have recommended the use of "# Vehicle Convoy" sign instead of the current "Work Convoy" sign on the back of the trail vehicle. In addition, the result of the evaluation of a "Your Speed" sign for mobile speed display showed that although this display was understood by more than 85% of participants, it did not provide information to the motorists regarding the speed of the working vehicles, and thus a large speed differential remained between the work convoy and the approaching traffic.

Researchers did not recommend the use of a "My Speed" or a "Your Speed/My Speed" display as there was sufficient evidence of misinterpretation of the displays by the participants, and the result was judged to be too much information for participants to correctly interpret in the time available to them. Researchers have suggested future study on mobile speed display signs.

To inform motorists that it is permissible to pass the work vehicles, text messages were appended to the existing, "Work Convoy" sign, along with a right flashing arrow display. Among the text messages, a "Pass on Shoulder" message alternating with the right flashing arrow was found to improve the performance of the participants from 66% to 97%. However, the researchers have recommended evaluating this sign in the field before it is adopted.

Although research has been conducted on various aspects of mobile lane closures, such as the effectiveness of specific traffic control devices on such operations, there are still a number of other issues where research information is limited or not available; for example, vehicle spacing (buffer vehicles and work vehicles), placement of workers within the mobile lane closure work area, and training of workers on mobile lane closure procedures, all require further study.

SURVEY RESULTS

Scope and Methodology

To assess the state of the practice among transportation agencies with respect to mobile lane closures, a survey was e-mailed in the spring of 2008 to DOTs in each of the 50 states in the United States as well as the District of Columbia and Puerto Rico, along with 7 provinces in Canada. The purpose of this survey was to identify notable practices employed by transportation agencies during mobile lane closures under various road and traffic conditions. The range of technologies in use, challenges faced, and solutions to problems found were also investigated. The survey also assessed the perceived effectiveness of the identified practices and the motivations behind their use, from the agencies' prospective.

The survey consisted of 74 questions that were designed to gather information on regulatory and guiding documents; practices, equipment, and technology used; field experiences; and technology and research needs. The survey was sent to both the maintenance and the traffic engineering departments of each state and provincial DOT. A total of 59 jurisdictions were sent the survey (see Appendix A for survey).

The survey was originally sent on April 28, 2008; over the next two months, two follow-up e-mails were sent and follow-up phone calls were made to the DOTs that had not yet responded to the survey. A total of 29 surveys were received after this first attempt (26 states and 3 provinces).

A second attempt was made in January 2009 to improve the survey response rate. This included telephone calls to all U.S. DOTs that had not participated in the survey and e-mailing the survey after the phone calls. Multiple attempts were made to achieve direct contact by phone. Two additional surveys were received as a result of this second attempt. Therefore, the total number of U.S. respondents, including the District of Columbia and Puerto Rico, is 28, a 54% response rate.

Although the response rate of 54% was not as high as desired for a NCHRP synthesis report, the results of the survey gathered valuable information on the state of practice of mobile lane closures in North America.

Because of the differences between the U.S. *MUTCD* and the Canadian *MUTCD,* the survey results reflect only the responses provided by the U.S. state DOTs.

The survey was divided into five main sections and concluded with a final comment section. The results of each section are summarized here. The percentages shown are representative of the number of DOTs that responded to the survey and do not represent all DOTs.

Section I—Contact Information and Overall Knowledge of Mobile Lane Closures

The first section contained a request for contact information and inquired about the DOTs' familiarity with mobile lane closures. All of the respondents were at the very least somewhat familiar with the subject, and 35% were very familiar with it.

The survey asked for the definition of mobile lane closure used in each DOT. Table 4 summarizes the responses by U.S. state DOTs. Although the definitions are somewhat similar, some have more specific information, such as how long the operation can be stopped at one location and the speed at which the operation moves.

Section II—Regulatory and Guiding Documents: Temporary Traffic Control

The following characteristics, shown in Table 5, are taken into account by the TTC plans in mobile lane closures of the respondents.

The majority of the respondents (85%) do not believe that the mobile lane closure definition used by their organization is being misinterpreted by maintenance personnel. However, the following comments were given as examples of how the definition may be misinterpreted by those who believe that the mobile lane closure definition is being misinterpreted.

- A variety of interpretations exist on how far back it is necessary to have advanced warning [*MUTCD* recommends that advance warning sign and the work should not exceed 8 km (5 mi)] and the number of shadow vehicles.
- Mobile lane closures are sometimes used when stationary closures should be, because crews find that setting up a stationary work zone often takes longer than the actual work.
- Maintenance crews perform activities that are defined as mobile lane closures with flaggers to increase the safety of the public and work crew. However, this may create conflicts between maintenance and traffic engineers on issues such as the distance from flagger signs to the work area, relative to what may be indicated in *MUTCD* and what may be appropriate to safety of these operations.
- Some users misinterpret paving operations as mobile because they continually move, and other short duration operations that move often may be confused as mobile.

Table 6 summarizes the types of TTC operations used for the different activities. From this table it can be seen that the results are quite varied, with a wide variation as to the type of TTC that is used for some activities, such as installation and removal of raised pavement markings, pothole patching, snow plowing, etc. It is notable that none of the activities indicated a 100% consistent standardization of the use of a specific TTC operation.

For instances where short duration lane closures were used for any of the previously mentioned activities, DOT staff were asked to specify whether specific or special conditions were used to justify a short duration closure as opposed to a mobile closure, such as workers on foot, duration of stops, etc. The results are summarized in Table 7. One of the primary conditions stated by the respondents was the presence of workers on foot.

State Regulations

In addition to the FHWA *MUTCD* and state *MUTCD,* more than 18% of respondents reported using the FHWA *Traffic Control Handbook* (*3*) for mobile operations at night, and 13% reported using *NCHRP Report 476: Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction* (*34*), whereas more than 30% do not use any additional documents to provide further guidance on mobile lanes closures.

Results indicated that other documents used for guidance included the FHWA Utility Work Zone Safety Guidelines and Training, the FHWA Traffic Control Devices and Practices to Improve the Safety of Mobile and Short Duration Maintenance Operations (*35*), and the FHWA Positive Protection Brochure.

The majority of DOTs that responded to the survey (73%) do *not* use quick reference tables or computerized decision-making tools to ensure the proper selection and applications of TTC plans for mobile

Table 4 Mobile lane closure definitions

State	Definition
Alaska	*MUTCD* definition (Mobile is work that moves intermittently or continuously)
Arizona	*MUTCD* definition (Mobile is work that moves intermittently or continuously)
Connecticut	*MUTCD* definition (Mobile is work that moves intermittently or continuously)
Florida	Mobile operations would be called a rolling road block, performed by Florida patrol officers. It is used to slow traffic for a specified distance to allow road work to occur ahead of the officers, or crash attenuator vehicles accompanying line/striping crews.
Georgia	*MUTCD* definition (Mobile is work that moves intermittently or continuously)
Illinois	Mobile lane closure is a moving operation that requires a lane closure. Example: pavement marking operation that would last longer than 15 min and no longer than 1 h. The speed of this operation would be greater than 1 mi/h.
Indiana	Mobile operations are work activities that move along the road either intermittently or continuously. Intermittent mobile operations often involve frequent short stops that are similar to stationary operations. Continuous mobile operations include work activities in which workers and equipment, move along the road without stopping, usually at low speeds.
Maryland	According to the Maryland State Highway Administration, mobile operations involve work that is performed at all speeds, whether continuously or intermittently, with stops that do not exceed 15 min in duration and slow moving operations (excepting paving operations, which use stationary lane closures).
Michigan	*MUTCD* definition (Mobile is work that moves intermittently or continuously)
Minnesota	Mobile operation is an operation that is continuously moving or stopped in one location for periods of 15 min or less. The traffic control devices are typically vehicle mounted.
Mississippi	*MUTCD* definition (Mobile is work that moves intermittently or continuously)
Missouri	Mobile operations include planned work that moves intermittently or continuously. These operations often involve frequent, short stops for activities where workers are on foot. The stops can only last up to 15 min.
Montana	Montana Department of Transportation does not have specific definition for mobile lane closures. The *MUTCD* short duration is used.
Nebraska	*MUTCD* definition (Mobile is work that moves intermittently or continuously)
New Hampshire	It is not defined, but by practice, concurred with survey definition [i.e., work that is done while moving continuously at low speeds (typically, around 25 km/h)] or intermittently with periodic brief stops, related to the mobile activity, which do not exceed a few minutes in duration. Operations that move at very low speed (5 km/h) are virtually short-duration lane closures. For the New Hampshire DOT that includes pavement marking operations only as the lane remains closed while paint dries. Other mobile operations, such as winter maintenance operations, do not necessarily close a lane.
New York	Currently anything that occupies the same spot for 15 min or less is considered mobile. Owing to New Yorks recent adoption of the national *MUTCD* 'Short duration' is a new term and New York is considering redefining its terms. One possibility may be that workers on foot in the roadway will be considered short duration and work done primarily from vehicles (stripping, sweeping) will be considered mobile.
North Dakota	*MUTCD* definition (Mobile is work that moves intermittently or continuously)
Oregon	Continuous moving operation that moves along the road at an average speed of 3 mph or more.
Pennsylvania	Operations that move intermittently or continuously at an average speed of 1 mph or more.
Texas	Work that moves continuously or intermittently (stopping up to approximately 15 min)
Virginia	Work that moves intermittently (1–15 min) or continuously.
Washington	*MUTCD* definition (Mobile is work that moves intermittently or continuously and the signs move with the operation rather than being placed in a stationary position as in a sign standard or post).
West Virginia	An operation that moves steadily or intermittently over a significant length of highway.
Wisconsin	Lane closed by work that moves intermittently or continuously. The work may involve short stops up to a few minutes in duration. Channelizing devices are not used to close the lane.

Note: Definitions are included as provided in the survey.

lane closures. Some states have their own work zone safety guidelines that are used for this purpose.

Safety and Training

More than 53% of respondents do not have a defined set of safety rules established to be used by crews specifically for the mobile lane closures. However, more than 51% have guidelines for placing workers within mobile work zones, including spacing from shadow vehicles.

Approximately 82% of the respondents have their workers undergo traffic control and safety training, either formal (50%) or informal (47%), for mobile lane closures. Informal training is mostly administered as on-the-job training (82%).

Table 5 Characteristics taken into account in TTC plans

Characteristics	Percentage
Roadway Type	12
Location of Work (shoulder vs. traffic lane)	13
Roadway Geometry	9
Topography	7
Traffic Volumes	10
Posted Speed Limit	9
Lighting Conditions (day/night)	7
Weather	5
Equipment	8
Staffing	6
Type of Work Performed	14
Total	100

Table 8 shows the components used in the safety training for mobile lane closures. In addition to these components, other components mentioned were:

- Crew meetings to review the operation and responsibilities prior to work. The Oregon DOT requires traffic control certification to be renewed every 5 years.
- The Pennsylvania DOT maintenance crew is trained every year in work zone traffic control.
- The Texas DOT requires construction and maintenance crew with work zone duties to attend work zone traffic control and traffic control refresher classes every two years.

The typical preparation for workers who perform mobile lane closures on a day-to-day basis includes tailgate meeting (43%), communications (27%), and chain-of-command (25%), with the remainder consisting of safety plan discussion.

More than 93% of respondents did not have any concerns with the use of personal protective equipment (PPE), such as compliance with standards, garment maintenance/disposal, etc., as they relate to mobile lane closures.

Section III—Equipment and Technology

Service Vehicles The following tables show which service vehicles are used for warning motorists and protecting workers in mobile lane closures for different road classifications. For example, Table 9 shows that for freeways, sign vehicles and shadow vehicles are mandatory under all conditions for the majority of DOTs that responded to the survey (71% and 76%, respectively, on freeways, and 66% and 76% for divided multi-lane highways). Table 10 shows that for undivided multi-lane highways and two-lane highways sign vehicle and shadow vehicle are mandatory for 62% and 71%, respectively, under all conditions, and 70% and 45% for two-lane highways. The use of additional shadow vehicles, on the other hand, shows greater variance among the different states.

Vehicle Lights Table 11 shows the type of lights that are typically used on service vehicles for mobile lane closures. More than half of the responding

Table 6 Temporary traffic control operation

Activity	Temporary Traffic Control (TTC) Operation				
	None	Mobile Lane Closure	Short Duration Lane Closure (stationary TTC)	Mobile or Short Duration (depending on conditions)	Total
Line Painting	0%	80%	3%	17%	100%
Installing/Removing Raised Pavement Markings	4%	39%	25%	32%	100%
Shoulder Texture (rumble strips)	0%	21%	51%	28%	100%
Pothole Patching	3%	29%	32%	36%	100%
Spot Edge Repair	4%	14%	39%	43%	100%
Sweeping	0%	73%	10%	17%	100%
Snow Plowing	43%	53%	0%	4%	100%
Mowing	46%	18%	7%	29%	100%
Herbicide Spraying	15%	66%	4%	15%	100%
Core Sampling	0%	0%	57%	43%	100%
Storm Water Catch Basin Cleanup	10%	14%	34%	42%	100%
Installation and Removal of TTC	14%	48%	17%	21%	100%
In-line (lateral) Rumble Strips	7%	10%	52%	31%	100%

Table 7 Conditions for short-duration closures

State	Conditions
Alaska	Workers on foot
California	Pavement marking and re-lamping operations have a 20 min rule; if the operation takes longer than 20 min, a static lane closure is required.
Connecticut	Workers on foot, duration of stops, and time to complete the work
Florida	Very short-term closures are accomplished by the use of a crash attenuator truck.
Illinois	If work is within 2 ft of the edge of pavement and the operation is 60 min or longer; if sight distance of the workforce is a problem and conditions are unsafe; if the operation is not moving at the speed of 1 mi/h as specified in our traffic standards; and if workforce protection is in question.
Maryland	Special conditions may exist on all of the work where short duration lane closures may be used instead of mobile lane closures. These would certainly include workers on foot and/or duration of stops.
Michigan	Short duration lane closures are used when the work operation is in the traffic lane. If it moves slowly, has staff outside their vehicle, and the operation is not capable of leaving the roadway to evade an errant vehicle.
Minnesota	If the operation will generally take more than 15 min in a section of roadway, the length of the "sight distance," the short-duration lane closure will be used.
Missouri	Type of work determines the type of closure needed.
Nebraska	Most of the work done under the short duration lane closures requires more time than a mobile lane closure will allow.
North Dakota	Additional layouts have been implemented that exceed the minimum for a low speed of 5 mph or less during operations for added safety.
Oregon	It depends on where the work is relative to the lanes. Mowing away from the shoulder there is no traffic control, next to the road there may be a mobile or a short-term closure depending on the geometrics, etc.
Texas	Long line painting is usually mobile, short line (crosswalks, etc.) depends on location, duration of stops, and whether the work is in a lane, on a shoulder, or off the pavement is a factor. Mowing is typically off the pavement and done with warning signs and flashing or strobe lights.
Utah	Workers on foot for a short duration
Washington	Short duration stationary lane closures would typically be used in operations that may last up to 60 min in duration and may include operations such as pot-hole repair, re-lamping, surveying, bridge inspections, etc. Very short-duration operations may include debris removal, work zone sign installation or removal, retrieval of lost cargo, and motorist assistance.
West Virginia	Workers on foot and complexity of tasks.

DOTs use both rotating incandescent amber lights and strobe lights. Another type mentioned was LED lights.

Table 12 shows the results of the survey for using four-way emergency flashers in work zones with mobile lane closure. The results indicate that four-way emergency flashers are not used by most responding agencies in addition to rotating and incandescent light and strobe lights.

Table 8 Components included in the safety training for mobile lane closures program

Components	Percentage
New Employee Orientation	23
Detailed Technical Training for Responsibilities Assigned	21
Jobsite Refresher Training	25
Meeting to Analyze Jobsite Occurrences and Incidents	22
Other	9
Total	100

Conditions mentioned in the survey for the use of four-way emergency flashers are:

- Used for night work.
- The use of flashers while travelling on the roadway is a violation of the state of Florida statues.
- If the four-way flashers are identified as interfering with motorists expectation or causing motorist confusion with other TTC devices (flashing arrow panels, truck-mounted portable variable message signs), they are not to be used during these operations.
- Depends on the positioning of other vehicles.
- Depends on the vehicle and the operation being performed. Washington State DOT vehicles follow the guidelines shown in the Vehicle and Equipment Lighting Standards.
- Depends on the amount of other lighting used on the vehicle.

Table 9 Service vehicles used (freeway and divided multi-lane highways)

	Freeways				Divided Multi-Lane Highways		
	Sign Vehicle (advance warning vehicle)	Shadow Vehicle	Additional Shadow Vehicle	Ramp Vehicle	Sign Vehicle (advance warning vehicle)	Shadow Vehicle	Additional Shadow Vehicle
Mandatory under all conditions	71%	76%	25%	0%	66%	76%	26%
Use depends on traffic volume	0%	4%	11%	20%	4%	4%	8%
Use depends on posted speed limit	4%	0%	4%	0%	4%	0%	0%
Use depends on work	8%	4%	26%	50%	17%	8%	33%
Use depends on traffic volume and posted speed limit	0%	0%	4%	0%	0%	0%	4%
Use depends on traffic volume and work	4%	0%	4%	0%	0%	0%	4%
Use depends on posted speed limit and work	0%	0%	0%	0%	0%	0%	0%
Use depends on traffic volume, posted speed limit, and work	13%	12%	22%	15%	9%	8%	21%
Never used	0%	4%	4%	15%	0%	4%	4%
Total	100%	100%	100%	100%	100%	100%	100%

Table 10 Service vehicles used (undivided multi-lane highways and two-lane highways)

	Undivided Multi-Lane Highways				Two-Lane Highways			
	Sign Vehicle (advance warning vehicle)	Shadow Vehicle	Additional Shadow Vehicle	Pilot Vehicle	Sign Vehicle (advance warning vehicle)	Shadow Vehicle	Additional Shadow Vehicle	Pilot Vehicle
Mandatory under all conditions	62%	71%	14%	0%	70%	45%	4%	15%
Use depends on traffic volume	0%	0%	14%	7%	0%	15%	20%	0%
Use depends on posted speed limit	5%	5%	0%	0%	0%	0%	4%	0%
Use depends on work	24%	10%	38%	40%	17%	12%	40%	40%
Use depends on traffic volume and posted speed limit	0%	0%	0%	0%	0%	0%	0%	0%
Use depends on traffic volume and work	0%	0%	5%	0%	0%	4%	8%	5%
Use depends on posted speed limit and work	0%	0%	0%	0%	4%	4%	0%	0%
Use depends on traffic volume, posted speed limit, and work	9%	9%	24%	13%	9%	12%	16%	15%
Never used	0%	5%	5%	40%	0%	8%	8%	25%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 11 Light type

Type of Lights	Percentage
Rotating Incandescent Amber Lights	17
Strobe Lights	17
Both Rotating Incandescent Amber Lights and Strobe Lights	53
Other	13
Total	100

Truck-Mounted Attenuator

TMAs are mandatory for most of the respondent DOTs (61%) on shadow vehicles. TMAs are mandatory on sign vehicles and work vehicles under certain conditions for some DOTs. Table 13 summarizes how TMAs are used.

Conditions mentioned in the survey for the use of TMAs are:

- If the advance warning vehicle encroaches on a traveled lane (on narrow shoulders) TMAs are used;
- For striping and pothole patching TMAs are not used;
- When work vehicles cannot support a TMA, a protection vehicle is used with a TMA;
- Mandatory on multi-lane divided highways;
- Attenuators are typically mounted on older dump trucks;
- When a shadow vehicle is not used, TMAs are used;
- When an advanced warning vehicle cannot travel completely off the travel way, TMAs are used;
- The use of TMAs is not a strict requirement in Washington; and
- On freeways, divided highways, and undivided multi-lane facilities all of the zone stripers are required to have TMAs.

Communication

In terms of communications between service vehicles, the majority of respondents (61%) use both two-way radios and cell phones, whereas 36% exclusively use two-way radios.

Safety Protection Devices

Besides seat belts, Table 14 shows the additional safety protection devices used for the driver and occupants of service vehicles. Another type of device mentioned was a 5-point racing harness, which is used in Florida.

The great majority (85%) of respondents do not use signs mounted on the first shadow vehicle to indicate the number of vehicles in a work convoy.

The survey results indicate that most of the participating DOTs in the survey (72%) do not use channelizing devices for delineating the work space or to provide positive protection (including innovative devices) if workers are on foot in mobile work zones. For the ones that do, the devices most commonly used are traffic cones, traffic barrels, and vertical panels.

More than 64% of the responding DOTs do not use devices to reduce the exposure of workers or completely eliminate the presence of workers on foot in conducting work activities within the mobile work zones [through means such as automated equipment to perform crack sealing, patching, installing raised pavement markers (RPMs), debris collection, etc.]. For the DOTs that do use automated equipment, the equipment most often used are litter debris removal vehicles, pothole patching trucks, magnet trucks, and truck decks for set up and removal of channelizing devices.

The great majority of the DOTs that responded to the survey (93%) do not use work zone safety intrusion alarms (such as infrared, microwave, pneumatic, etc.) regularly for mobile work zone operations.

Work platforms (aerial lift or elevated platforms used for work on hardware located at a height inaccessible for normal work operations) are used on work vehicles by 20% of the responding DOTs for jobs or tasks requiring workers on foot in a work zone during mobile lane closures.

Table 12 Use of four-way emergency flashers

	Sign Vehicle (advance warning vehicle)	Shadow Vehicle	Work Vehicle	Pilot Vehicle
Used Under All Conditions	20%	19%	19%	17%
Used Under Certain Conditions	24%	23%	27%	13%
Never Used	56%	58%	54%	70%
Total	100%	100%	100%	100%

Table 13 Truck-mounted attenuator use

	Sign Vehicle (advance warning vehicle)	Shadow Vehicle	Work Vehicle	Pilot Vehicle
Mandatory Under All Conditions	24%	61%	10%	0%
Mandatory Under Certain Conditions	47%	31%	45%	5%
Never in Use	29%	8%	45%	95%
Total	100%	100%	100%	100%

Flaggers are used by 62% of respondents for mobile work zones on two-lane roads. However, automatic flaggers, automated flagger assistance devices (AFAD), or flashing stop/slow paddles are used for mobile work zones on two-lane roads by only 15% of respondents.

It is important to note that even though AFADs are mentioned in the survey, some states do not allow the use of AFADs in mobile lane closures.

Work Lights (Task Lights)

The survey asked what types of work lights (task lights) are used to light the work zone or flagger stations in mobile lane closures at night, and what was the level of satisfaction with the use. The results are listed here:

- Halogen spotlights (high satisfaction)
- On-board halogen lights (high satisfaction)
- Halogen floodlights (high satisfaction)
- Balloon lighting (high satisfaction)
- Mobile light plants (high satisfaction)
- Vehicle headlights (medium satisfaction).

Signs

Most participating DOTs (89%) install temporary signs (e.g., "Road Work Ahead" with "Next X Miles") on the ground to warn motorists about mobile lane closures. Speed displays mounted on a shadow vehicle are used by only 20% of DOTs.

Table 14 Additional safety devices

Safety Device	Percentage
Shoulder Harnesses	7%
Head Restraints	3%
High-Back Seats	17%
Shoulder Harnesses and Head Restraint	13%
Shoulder Harnesses and High-Back Seats	33%
None	20%
Other	7%
Total	100%

For mobile lane closures conducted on two-way, two-lane roadways with unimproved shoulders, 65% of responding DOTs prohibit traffic from passing the work convoy. The majority of these DOTs (67%) use vehicle-mounted signage to inform motorists about the prohibition; other DOTs rely on state traffic rules (33%). When passing is allowed and mobile lane closures are conducted on centerline or on the traffic lane on two-lane roadways with improved shoulders, the most common passing arrangement is passing allowed to the left and prohibited to the right (on shoulder). However, 77% of DOTs do not use any special devices to explain passing arrangements on two-lane roadways with improved shoulders.

Public Information

Real-time Advanced Traveler Information Systems (ATIS) and/or Highway Advisory Radio (HAR) are used by 44% of respondents to improve safety and mobility of mobile lane closures. When it comes to informing the public about mobile lane closures using mass media (within ATIS or otherwise), 58% of responding DOTs inform the public and 42% do not.

Section IV—Field Experience with Mobile Lane Closure

For the majority of participating DOTs (81%) there is a high level of compliance with TTC plans and procedures for mobile lane closures.

Non-Compliances Issues

The following are some of the typical non-compliances issues found by the responding DOTs relating to mobile lane closures:

- Insufficient shadow vehicle (sometimes is a resource issue);

- Running shadow vehicles, particularly in a travel lane without a TMA;
- Improper spacing of vehicles;
- No shadow vehicle; and
- Wrong arrow/caution mode.

The following are some of the measures taken to increase compliance:

- A fine will be issued per day if contractor is not in compliance,
- DOT staff will be reprimanded by supervisor,
- Disciplinary action will be taken against the supervisor,
- Inspectors and supervisors will shut down operation, and/or
- Training and monitoring.

Safety Analysis

Figure 19 shows the methods used to analyze the safety of mobile lane closures by the DOTs surveyed.

Table 15 shows some of the main reasons why some DOTs do not analyze the crash data associated with mobile operations. Other reasons mentioned were the difficulty of isolating the mobile lane closure crash from the balance of the crash database.

The survey asked about typical safety issues with mobile lane closures, and the measures taken to increase safety and their effectiveness (see Table 16 for the answers).

Table 17 shows the responses received from different DOTs when asked what technology and/or devices should be developed, further improved, or more widely adopted to increase the safety of mobile lane closures.

The following are some of the aspects of the mobile lane closures that respondents thought should be further researched or addressed to increase safety:

- Motorists education and awareness;
- Improvement of safety devices for workers;
- Improvement of traffic protection standards for the workers;
- Workers' visibility;
- Glare at night from non-project source;
- More advance warning on high-speed roadways;
- Vehicle-mounted equipment that may be deployed to warn motorists that a shadow vehicle is stopped or moving slowly;
- Effectiveness of static signs mounted on the back of work, sign, and shadow vehicles;
- Safety of mobile lane closure using limited resources, equipment, and people;

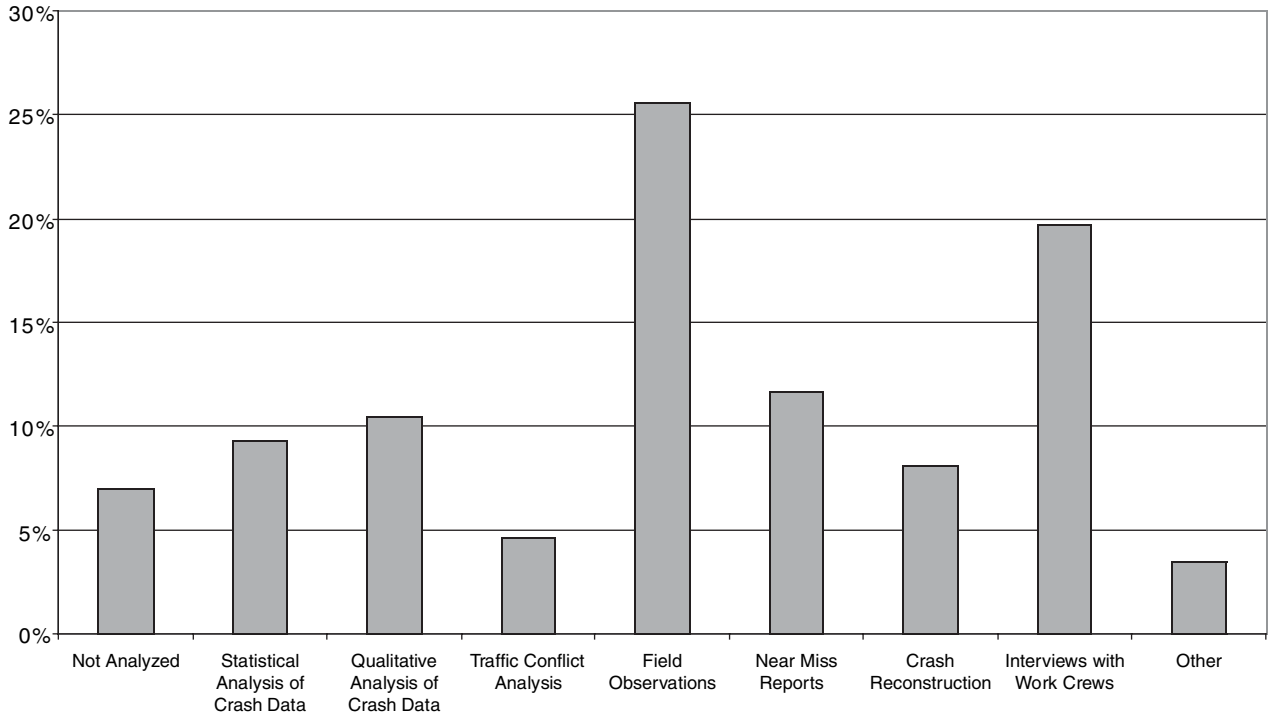

Figure 19 Safety analysis methods.

Table 15 Main reasons for not analyzing crash data

Reasons	Percentage
Analysis Is Not Incorporated in the Agency's Routine Practice	31
Inadequate Staff Resources	39
Insufficiency or Low Quality of Crash Data	26
No Access to Crash Data	4
Total	100

- Research on human response to mobile lane closures or spot hazard;
- Mobile flagging; and
- Use of PCMS versus arrow panels only, in mobile lane closures.

Section V—Technology and Research Needs

Lastly, the survey asked if the participants were aware of any technology/device developments or research projects in progress that could increase the safety of mobile lane closures. Only four of the respondents (20%) were aware of any such initiatives; their responses were:

- Look to research and development within the automotive racing industry to improve operator restraint devices,
- Worker visibility research at Purdue University, and
- Mobile barrier protection.

Summary of Key Findings

The following are some of the key survey findings:

- Approximately 85% of the respondents do not believe in misinterpretation of the mobile lane closure definition by maintenance personnel.
- Wide variation was observed in the type of TTC operations that are used by the respondents for different activities.
- Majority of the respondents do not use any quick reference tables or computerized decision-making tools to ensure proper selection and applications of TTC.
- Approximately 82% of the respondents have their workers undergo traffic control and safety training, either formal (50%) or informal (47%).

Table 16 Safety issues and measures taken

Safety Issues	Measures
Reduced sight distance	Requires additional advance warning/shadow vehicle
Unsafe traffic queues	Requires suspension of the activity
Passing cars	Requires the use of law enforcement to assist
Traffic speed and distracted drivers	Requires using more police in clearly marked vehicles
Traffic passing shadow vehicle and re-entering closed lane at work site	Added shadow vehicle closer to work site (within roll ahead distance) Maintain appropriate spacing
Visibility at night	Requires lighting packages
Mobile lane closure on hills	Requires increased shadow vehicle distance
Stationary signs get too far from the work	Requires the use of multiple signs along the work area
Other issues include: • Reducing traffic delay through work zone • Intersections and interchanges can be very problematic for mobile lane closure operations	Other measures include: • Additional red flashing lights • Addition of PCMS to shadow vehicle • Avoid peak hours of traffic

PCMS = portable changeable message sign.

Table 17 Recommended technologies by DOTs for improving safety in mobile lane closures

Priority	Technology
High	• Improve advance warning devices • Additional/different warning light packages • Additional equipment to eliminate on foot exposure • A navigational system that can inform that construction operation is near and give alternative route to avoid it • Improve truck-mounted attenuators • Intrusion warning devices • Positive protection • Better advance information to drivers • Vehicle infrastructure integration (traveler notification using automatic vehicle locating) • Channelizing devices that can be towed or attached to vehicle to warn motorist and move along with work zone • Soft targets that can be towed or mounted on truck or impact attenuator • Recommendations for truck-mounted PCMS messages and full matrix symbol displays
Medium	• Integration with GPS technology • Visibility at night (reflectorization) • Portable barrier devices
Low	• Radar emitters

PCMS = portable changeable message sign; GPS = global positioning system.

- The majority of the respondents have made sign vehicles and shadow vehicles mandatory for warning motorists and protecting workers under all conditions.
- More than half of the respondents use both rotating incandescent amber lights and strobe lights on mobile lane closures. Four-way emergency flashers are not used most of the time.
- For 61% of the respondent DOTs, TMAs are mandatory on shadow vehicles.
- Most of the participating DOTs in the survey do not use signs mounted on the first shadow vehicle to indicate the number of vehicles in a work convoy.
- More than 64% of the responding DOTs do not use equipment to reduce exposure of workers or completely eliminate workers on foot in the mobile lane closure work zones, such as automatic crack sealing, patching, installing RPMs, debris collection vehicles, etc.
- The great majority of respondents were not regularly using work zone safety intrusion alarms.
- Flaggers are used by 62% of respondents for mobile lane closure work zones on two-lane roads.
- In terms of use of signage, most participating DOTs use temporary signs installed on the ground to warn motorists about a mobile lane closure.
- Sixty-five percent of DOTs prohibit traffic from passing the work convoy in instances of two-way, two-lane roadways with unimproved shoulder, and 77% of DOTs do not use any special devices to explain passing arrangements on two-lane roadways with improved shoulders. None advocate permitting passing on the right, even in the presence of an improved shoulder.
- The respondents' answers were split; 58% said yes and 42% no, in case of the use of mass media to inform the public about the mobile lane closure.
- Eighty-one percent of the participating DOTs have a high level of compliance with TTC plans and procedures for mobile lane closure. Some typical non-compliance issues

included no shadow vehicle, insufficient shadow vehicles, improper spacing of vehicles, etc.
- Some DOTs do not analyze the crash data because of the difficulty of isolating the relevant crash from the crash database.
- Result showed that only 20% of the respondent states were aware of any technology/device developments or research projects in progress that could increase the safety of mobile lane closures.

CONCLUSIONS AND FUTURE RESEARCH NEEDS

Mobile lane closures are used frequently in North America in roadway maintenance and rehabilitation operations. However, when and how this type of operation is carried out may vary significantly.

The following conclusions were derived from the literature review on mobile lane closures.

- Although both the United States and Canada have their own *Manual on Uniform Traffic Control Devices* (*MUTCD*), which address procedures for mobile lane closures, some states and provinces follow their own manual. Therefore, there are no standardized practices used across each country.
- A review of innovative and experimental devices and technologies revealed that none of the devices evaluated were capable of simultaneously meeting all of the most desirable criteria for mobile operations protection. These criteria are as follows:
  - Reduce exposure of workers to vehicles,
  - Warn motorists/crew to minimize likelihood of crash,
  - Minimize the severity of crashes once they occur,
  - Provide separation between work crew and traffic, and
  - Improve work zone visibility/presence.
- Research has shown that an increase in motorists' appropriate response frequency to vehicle warning lights was evident when colors were added to the basic yellow light used on most work vehicles, and a further increase in this response frequency was seen when law enforcement vehicles were present.
- Current research shows that the presence of more than one work vehicle was effective in providing motorists with the information that they were approaching a larger work zone operation. In addition, multiple arrow displays in a moving lane closure helped motorists correctly interpret that one lane was closed on multi-lane roadways.
- Research has shown that by providing more information about the upcoming road conditions and the appropriate action to be taken in these conditions potential hazards could be avoided. This finding is tempered however by the recognition that too much information or information presentations that are overly complex or potentially subject to misinterpretation can also lead to driver error.
- Researchers found that a more clear distinction between the definitions of mobile lane closure and short-term operations could be helpful.
- Research has also shown that including the number of working vehicles present (i.e., # Vehicle Convoy) on the "Work Convoy" sign improved motorists comprehension.

The following are some of the gaps in information found while conducting the literature review:

- Although data on work zone crashes are available in the United States every year, specific data related to mobile lane closures are not available.
- There is inadequate research information on training of workers performing mobile lane closures in general and, more specifically, how effective certain training practices are, such as formal training versus informal.
- Lack of research information on appropriate vehicle spacing (buffer vehicles and work vehicles), and placement of workers within the mobile lane closure work area.

The survey results revealed the following:

- About 85% of the respondents do not believe in misinterpretation of the mobile lane closure definition by the maintenance personnel.
- Wide variation was observed in the type of TTC operations that are used by the respondents for different activities.
- A majority of the respondents do not use any quick reference tables or computerized decision-making tools to ensure proper selection and applications of TTC.
- For 61% of the respondent DOTs, TMAs are mandatory on shadow vehicles.

- Most of the participating DOTs in the survey do not use signs mounted on the first shadow vehicle to indicate the number of vehicles in a work convoy.
- More than 64% of the responding DOTs do not use equipment to reduce exposure of workers or completely eliminate workers on foot in the mobile lane closure work zones, such as automatic crack sealing, patching, debris collection vehicles, etc.
- The great majority of respondents were not regularly using work zone safety intrusion alarms.
- Flaggers are used by 62% of respondents for mobile lane closure work zones on two-lane roads.
- In terms of use of signage, most participating DOTs use temporary signs installed on the ground to warn motorists about mobile lane closures.
- Sixty-five percent of DOTs prohibit traffic from passing the work convoy in case of two-way, two-lane roadways with unimproved shoulders, and 77% of DOTs do not use any special devices to explain passing arrangements on two-lane roadways with improved shoulders.
- Some DOTs do not analyze the crash data because of the difficulty of isolating the relevant crash from the crash database.
- Results showed that only 20% of the respondent states were aware of any technology/device developments or research projects in progress that could increase the safety of mobile lane closure.

It is interesting to note that although research has shown that by including the number of working vehicles present on the "Work Convoy" sign it improved motorists' comprehension, the majority of the responding DOTs indicated that the number of vehicles in a convoy was not shown.

Research has shown that by providing information to motorists about upcoming road conditions and the appropriate actions to be taken could avoid potential hazards. At the same time, survey results showed that most respondent DOTs do use a temporary sign installed on the ground to warn motorists of upcoming mobile lane closures.

In addition, the reason some of the responding DOTs do not analyze crash data is the result of the difficulty of isolating mobile lane closure crashes, which is also one of the issues encountered during the literature search task.

Based on the literature review and survey results, the following are suggestions for future research on mobile lane closure.

Although various research projects have examined different aspects of mobile lane closure, such as the effectiveness of specific traffic control devices on such operations, there remain a number of other issues where research information is limited or not available. The following are some of the issues that could be looked at in future research:

- How innovative traffic control devices and equipment affect roadway safety;
- Incidents of crashes occurring specifically as a result of mobile lane closures;
- The placement of workers within the mobile lane closure work zone; and
- Spacing of vehicles; examining the difference between state and provincial standards or guidelines.

The following are some of the aspects of the mobile lane closures that respondents thought should be further researched or addressed to increase safety.

- Motorists education and awareness;
- Improvement of safety devices for workers;
- Improvement of traffic protection standards for the workers;
- Workers' visibility;
- Glare at night from non-project sources;
- More advance warning on high-speed roadways;
- Vehicle-mounted equipment that can be deployed to warn motorists that a shadow vehicle is stopped or moving slowly;
- Effectiveness of static signs mounted on the back of work, sign, and shadow vehicles;
- Safety of mobile lane closures using limited resources, equipment, and people;
- Human response to mobile lane closures or spot hazards;
- Mobile flagging; and
- Use of PCMS versus arrow panels only, in mobile lane closures.

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APPENDICES A THROUGH D

To find Appendices A through D for this report, go to www.trb.org and search for "NCHRP Research Results Digest 339."

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