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| 16. Abstract<br>Very short duration maintenance operations (VSDOs) last for 15 minutes or less and usually involve operations such as removing an object from the roadway (either on the pavement or adjacent shoulder) or pothole patching. These activities have the potential to interrupt traffic flow and can pose a safety risk for both workers and drivers. Specific guidance for VSDOs is undocumented and workers tend to use their own judgment in making critical time sensitive decisions. Identifying risk factors in VSDOs helps maintenance workers better judge the immediate conditions and make more informed decisions on whether to conduct an operation as a VSDO or not. This study sought to define a VSDO and identify typical VSDOs. In addition, this study identified risk factors that maintenance workers may face during VSDOs. Moreover, this study prepared a list of technologies and methods for minimizing risk to workers in VSDOs. This study also presented a risk management process that enables maintenance workers to identify work zone hazards for VSDOs and improve their judgment about work zone conditions and hazards. Multiple scenarios illustrating the risks were presented, and related safety recommendations were also discussed. | | |
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# Worker Safety in Very Short Duration Work Zone Operations: State of Practice and Risk Management Process

Li Wang
Sami Kolahdoozan
Dan Seedah
Fernanda Leite
Randy B. Machemehl

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Center for Transportation Research
The University of Texas at Austin
1616 Guadalupe St, Suite 4.202
Austin, TX 78701

www.utexas.edu/research/ctr

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Project Engineer: Dr. Randy Machemehl
Professional Engineer License State and Number: Texas No. 41921
P. E. Designation: Dr. Randy Machemehl

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# Products

Accompanying this report is an Educational Module and a Safety Guidebook (0-6640-P2).

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# Executive Summary

Very short duration maintenance operations (VSDOs) last for 15 minutes or less and usually involve operations such as removing an object from the roadway (either on the pavement or adjacent shoulder) or pothole patching. These activities have the potential to interrupt traffic flow and can pose safety risks for both workers and drivers. Specific guidance for VSDOs is undocumented and workers tend to use their own judgment in making critical time-sensitive decisions. Identifying VSDO risk factors helps maintenance workers better judge work zone conditions and make more informed decisions on whether to conduct an operation as a VSDO. This study sought to identify the definition of a VSDO as well as describe typical VSDOs. In addition, this study identified risk factors that maintenance workers may face during these types of operations. Moreover, this study prepared a list of technologies and methods for minimizing risk to workers in VSDO work zones as well as a risk management process. Multiple scenarios illustrating the risks were presented, and related safety recommendations were also discussed.

# 1. Introduction

Texas has the most roadway mileage of any state in the nation, and maintenance is a major function of the Texas Department of Transportation (TxDOT). The safety of workers and motorists is a major concern and the Federal Highway Administration recognizes this challenge and makes provisions for work zone safety in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) (FHWA 2007). Setting up sufficient traffic control devices without severely interrupting traffic and sacrificing safety is a challenging task for traffic engineers, researchers, and maintenance workers.

Very short duration maintenance operations (VSDO) typically last for a few minutes and the major challenge involved is workers setting up adequate traffic control treatment quickly enough so that installing and disassembling the traffic control devices does not take longer than the work activity to be performed. Previous studies (Ullman et al., 2003) observed that workers are reluctant to utilize extensive traffic control for activities that only take a few minutes to complete. In addition, the setup and removal of traffic control devices increases the workers' exposure to traffic. Adequate safety is therefore a concern for both workers and motorists in VSDOs.

Activities that can be categorized as VSDOs include debris removal, pothole patching, edge patching, delineator maintenance, warning sign placement, supervisor markings for future work, photography, data collection/surveys, and signal light replacement. Some of these activities are performed daily and others weekly or monthly depending on the setting (rural or urban). These activities have the potential to interrupt traffic flow and can pose a safety risk for both workers and drivers. Activities not classified within this new category of maintenance operations include short duration and mobile maintenance operations such as crack sealing, herbicide application, mowing/brush cutting, raised pavement marker replacement, snow and ice control, striping, sweeping, guardrail work, lighting maintenance, paving operations, signal work, and sign repair and installation. These activities may take more than 15 minutes and thus cannot be considered VSDOs.

Current provisions of the Manual on Uniform Traffic Control Devices (MUTCD) and the Texas MUTCD support the need for a simplified control procedure for mobile and short duration operations but do not fully address the technical and practical aspects of very short duration roadway maintenance activities. In addition, inconsistency among the definitions and classification of mobile and short duration maintenance operations make it difficult for personnel to determine the traffic control setup to use (Ullman et al., 2003). As such, a simple, flexible, and appropriate set of traffic control setups applicable for all VSDO scenarios is needed.

Some of the primary VSDO hazards and concerns identified by studies (Tsyganov et al., 2005; Ullman et al., 2003; Finley et al., 2004) include the following:

- high speed traffic,
- high traffic volumes,
- motorists ignoring or not understanding traffic control devices,

- inattentive motorists not noticing the work area or not taking precautions such as reducing speeds,
- effectiveness of current traffic control devices,
- visibility of work zone,
- proper setup and location of short term traffic control devices,
- maintenance vehicles being rear-ended by traffic,
- erratic vehicles entering the convoy or work area,
- last-ditch lane changing,
- lack of adequate training for new employees,
- roadway geometry, and
- environmental conditions.

These hazards and concerns are applicable for VSDOs as well.

## 1.1 Accidents in Work Zones

As shown in Table 1, work zone-related accidents in Texas steadily decreased from 197 fatalities in 2002 to 126 fatalities in 2007, but increased again to 134 fatalities in 2008. However, the number of work zone accidents related to VSDOs is undocumented. Recent eyewitness accounts shared by maintenance supervisors from California and Texas represent some of dangers resulting from workers trying to perform VSDOs. In California, a maintenance worker was killed while trying to remove a dead dog on a freeway ramp. Despite the worker having a spotter to watch for oncoming traffic, the worker ran in the same direction as the vehicle when the spotter yelled at the worker. The eyewitness account in Texas describes a maintenance worker patching some pavement failures on an urban roadway. The worker allegedly parked on the shoulder and would dart out into a travel lane with a shovel when no traffic was oncoming, dump patching material in the affected area, and dash back to the shoulder. These incidents are typical of the hazards maintenance workers face each day because of either negligence or inexperience. Compounding the problem are inattentive drivers who do not respond to temporary traffic control devices.

**Table 1: Construction/Maintenance Zone Fatalities in Texas**

Source: 2008 Fatality Analysis Reporting System (FARS)—ARF, NHTSA

| *Year* | *Number of Fatalities* |
|---|---|
| 2008 | 134 |
| 2007 | 126 |
| 2006 | 146 |
| 2005 | 159 |
| 2004 | 162 |
| 2003 | 171 |
| 2002 | 197 |
| 2001 | 141 |
| 2000 | 155 |

These two incidents illustrate the need for effective worker training and guidelines on performing VSDOs. This study seeks to develop interactive training modules for maintenance workers that will both educate and test workers on responding to work zone hazards. In addition to proper worker training, appropriate traffic control devices will be selected based on how quickly they can be set up and dismantled, and still provide the adequate protection needed during maintenance operations.

## 1.2 Who Is Impacted?

Both the traveling public and the workers are impacted by these types of operation. Using law enforcement and follow vehicles reduces the available lanes for the traveling public during the operation. Maintenance workers that utilize the run-and-grab method for debris removal subject themselves to potential injury or death.

## 1.3 Overview of the Report

This report is organized as follows: the next section details provisions from the various publications applicable to VSDOs. Then, research approaches applied in this study will be discussed, followed by research findings. In the research findings section, findings from shadowing activities, Expert Panel meetings, and the risk management process as well as validation step for this research study will be explained. Finally, final remarks and recommendations for future studies will be discussed.

# 2. Background Review

The following section details provisions from the various publications applicable to VSDOs. Provisions include those from the national *Manual on Uniform Traffic Control Devices* (MUTCD), the Texas MUTCD, and other state DOT guidelines.

## 2.1 Current Provisions of MUTCD pertaining to VSDOs

The MUTCD defines the standards used by road managers nationwide to install and maintain traffic control devices on all public streets, highways, bikeways, and private roads open to public traffic. The Manual is published by the Federal Highway Administration (FHWA) under 23 Code of Federal Regulations (CFR), Part 655, Subpart F (FHWA, 2011).

The Manual is a compilation of standards to be adopted by all states and serves as their legal document for all traffic control devices, including road markings, highways signs, and traffic signals. It has been administered by the FHWA since 1971 and is updated periodically to accommodate the changing transportation needs of the nation and address new safety technologies, traffic control tools and traffic management techniques. The most recent version of the Manual is the 2009 edition (FHWA, 2011).

Part 6 of the manual covers temporary traffic control (TTC), which includes the following topics:

- Chapter 6A - General
- Chapter 6B - Fundamental Principles
- Chapter 6C - Temporary Traffic Control Elements
- Chapter 6D - Pedestrian and Worker Safety
- Chapter 6E - Flagger Control
- Chapter 6F - Temporary Traffic Control Zone Devices
- Chapter 6G - Type of Temporary Traffic Control Zone Activities
- Chapter 6H - Typical Applications
- Chapter 6I - Control of Traffic Through Traffic Incident Management Areas

Topics from the Manual discussed in this section include the fundamental principle of TTC, work durations, and location of work.

### 2.1.1 Fundamental Principles

The Manual recognizes the need for traffic continuity and worker safety during TTC operations as stated in Sections 6A.01 (03-05) under the Fundamental Principles chapter: "TTC planning provides for continuity of the movement of motor vehicle, bicycle, and pedestrian traffic…transit operations, and access…to property and utilities," when the normal function of the roadway, or a private road open to public travel, is suspended. The primary function of a "TTC is to provide for the reasonably safe and effective movement of road users through or around TTC zones while reasonably protecting road users, workers, responders to traffic incidents, and equipment. Of

equal importance to the public traveling through the TTC zone is the safety of workers performing the many varied tasks within the work space" (MUTCD Section 6A.01 [03-05], 2009).

Section 6A.01 (07) of the Manual also points out that "no one set of TTC devices can satisfy all conditions for a given project or incident."

Part 6 of the Manual therefore provides only typical applications that depict the use of TTC devices and advises that for each situation, the TTC selected must be relevant to the type of highway, road user condition, duration of operation, physical constraint, and the nearness of the work space or incident management activity to road users (MUTCD Section 6A.01 [07], 2009).

Following are the seven fundamental principles of a TTC as outlined by the Manual in Section 6B[1]:

1. General plans or guidelines should be developed to provide safety for motorists, bicyclists, pedestrians, workers, enforcement/emergency officials, and equipment.
2. Road user movement should be inhibited as little as practical
3. Motorists, bicyclists, and pedestrians should be guided in a clear and positive manner while approaching and traversing TTC zones and incident sites.
4. To provide acceptable levels of operations, routine day and night inspections of TTC elements should be performed.
5. Attention should be given to the maintenance of roadside safety during the life of the TTC zone.
6. Each person whose actions affect TTC zone safety, from the upper-level management through the field workers, should receive training appropriate to the job decisions each individual is required to make. Only those individuals who are trained in proper TTC practices and have a basic understanding of the principles (established by applicable standards and guidelines, including those of this Manual) should supervise the selection, placement, and maintenance of TTC devices used for TTC zones and for incident management.
7. Good public relations should be maintained.

VSDOs generally fall under the TTC category and must therefore adhere to these principles.

**Work Duration**

According to Section 6G.02 (01-02) of the Manual, work duration is a major factor in determining the number and types of devices used in TTC zones, and the duration of a TTC zone is defined relative to the length of time a work operation occupies a spot location. Following are the five categories of work duration as defined in the MUTCD:

1. **Long-term stationary:** work that occupies a location more than 3 days.

[1] Detailed information for each principle can be found in Section 6B of the Manual.

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

VSDOs are not independently classified by the MUTCD but are similar to Short Duration operations in that "it often takes longer to set up and remove the TTC zone than to perform the work." The Manual further states that "workers face hazards in setting up and taking down the TTC zone [and]…since the work time is short, delays affecting road users are significantly increased when additional devices are installed and removed" (MUTCD Section 6G.02 [12], 2009).

The Manual also states that "as compared to stationary operations, mobile and short-duration are activities that might involve different treatments. Devices having greater mobility might be necessary such as signs mounted on trucks [and] devices that are larger, more imposing, or more visible can be used effectively and economically" (MUTCD Section 6G.02 [09], 2009).

The Manual advises that *"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 [and]…augmented with signs or arrow boards*" (MUTCD Section 6G.02 [11), 2009). Further, "simplified control procedures may be warranted for short-duration work [and] a reduction in the number of devices may be offset by the use of other more dominant devices such as high-intensity rotating, flashing, oscillating, or strobe lights on work vehicles" (MUTCD Section 6G.02 [13], 2009).

VSDOs may sometimes involve mobile operations such as litter pickup and pothole patching. The Manual suggests that "*flags and/or channelizing devices may additionally be used and moved periodically to keep them near the mobile work area, and flaggers may be used for mobile operations that often involve frequent short stops"* (MUTCD Section 6G.02 [13], 2009).

The Manual further provides guidance for mobile operations, suggesting that shadow vehicles be equipped with an arrow board or a sign, especially when vehicular traffic speeds and volumes are high. In addition, the Manual suggests that, "where feasible, warning signs should be placed along the roadway and moved periodically as work progresses" (MUTCD Section 6G.02 [19], 2009).

Section 6G.02 (20-21) of the Manual also states that "under high-volume conditions, consideration should be given to scheduling mobile operations work during off-peak hour, and if there are mobile operations on a high-speed travel lane of a multi-lane divided highway, arrow boards should be used" (MUTCD Section 6G.02 [20-21], 2009).

**Location of Work**

According to the Manual, the choice of TTC depends upon the work zone's location. As a general rule, the closer the work is to road users (including bicyclists and pedestrians), the

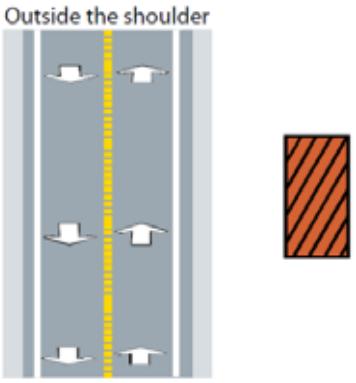
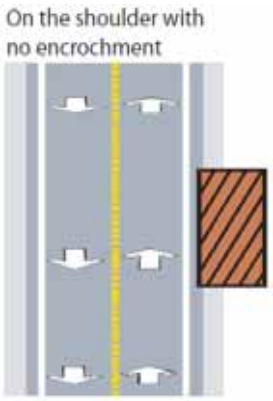
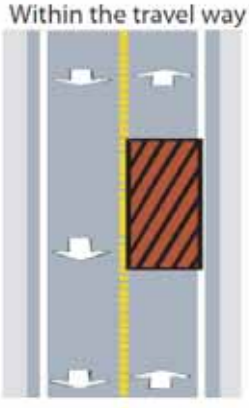
greater the number of TTC devices that are needed (MUTCD Section 6G.03, 2009). Procedures are described later in this memo for establishing TTC zones in the following locations:

A. Outside the shoulder,
B. On the shoulder with no encroachment,
C. On the shoulder with minor encroachment,
D. Within the median, and
E. Within the traveled way.

Table 2 is derived from the Missouri Department of Transportation's (MoDOT) *Technician Training Manual* and it summarizes the definitions and special requirements of the various work zone locations.

**Table 2: Summary of Work Locations**

Source: MoDOT Work Zone Technicians

| Location of Work | Definition | Special Requirements | Legend |
|---|---|---|---|
| **Work beyond shoulder** | Any work performed between the edge of the shoulder, the edge of the traveled way where no shoulder exists, to the right-of-way line or within any unimproved median. | Work performed in this area typically requires a minimal amount of temporary traffic control, such as signs and fleet lighting, or even none at all.<br><br>The amount and type of TTC depends on the lateral displacement of the work activity and the location and movement of any work vehicle or equipment relative to the edge of the shoulder, or traveled way where no shoulder exists. |  |
| **Work on shoulder** | Any work performed on the shoulder that does not significantly encroach upon the adjacent driving lane. | |  |
| **Work within the traveled way** | Any operation requiring a lane closure. | a) More TTC devices are required to ensure the safety of both the motorist and the worker.<br><br>b) Mobile operations typically require a vehicle-mounted sign, flashing arrow panel, fleet lighting, protective vehicle, and truck-mounted attenuator.<br><br>c) Stationary operations usually require the substitution of multiple stationary signs for the single vehicle-mounted sign and the addition of channelizing devices and flaggers. |  |

The *Manual* also provides typical example applications of TTC that can be modified, combined, or customized for a particular work zone environment. Examples of TTC applications applicable to VSDOs include[2] those shown in Table 3:

**Table 3: Applicable Typical Applications from the MUTCD**

| Typical Application Description | Typical Application Number |
|---|---|
| **Work Outside of the Shoulder (see Section 6G.06)** | |
| Work Beyond the Shoulder | TA-1 |
| **Work on the Shoulder (see Sections 6G.07 and 6G.08)** | |
| Work on the Shoulders | TA-3 |
| Short Duration or Mobile Operation on a Shoulder | TA-4 |
| Shoulder Work with Minor Encroachment | TA-6 |

Additional provisions of the MUTCD applicable to VSDOs include the following:

> Section 6B.01 (09) - *All TTC devices shall be removed as soon as practical when they are no longer needed. When work is suspended for short periods of time, TTC devices that are no longer appropriate shall be removed or covered.*
>
> Section 6C.01 (12) - *Reduced speed limits should be used only in the specific portion of the TTC zone where conditions or restrictive features are present. However, frequent changes in the speed limit should be avoided. A TTC plan should be designed so that vehicles can travel through the TTC zone with a speed limit reduction of no more than 10 mph.*
>
> Section 6C.01 (13) - *A reduction of more than 10 mph in the speed limit should be used only when required by restrictive features in the TTC zone. Where restrictive features justify a speed reduction of more than 10 mph, additional driver notification should be provided. The speed limit should be stepped down in advance of the location requiring the lowest speed, and additional TTC warning devices should be used.*
>
> Section 6C.01 (14) - *Reduced speed zoning (lowering the regulatory speed limit) should be avoided as much as practical because drivers will reduce their speeds only if they clearly perceive a need to do so.*
>
> Section 6C.01 (15) - *Support: Research has demonstrated that large reductions in the speed limit, such as a 30 mph reduction, increase speed variance and the potential for crashes. Smaller reductions in the speed limit of up to 10 mph cause smaller changes in speed variance and lessen the potential for increased crashes. A reduction in the regulatory speed limit of only up to 10 mph from the normal speed limit has been shown to be more effective.*

## 2.2 Current Provisions of the Texas MUTCD pertaining to VSDOs

The 2006 Texas MUTCD is the most recent version of the Texas MUTCD and contains standards in accordance with provisions of the 2003 National MUTCD. A review of the document did not identify any significant changes to Part 6 of the national MUTCD, which

[2] Examples with diagrams of the typical applications can be found in Appendices D and E.

pertains to TTC. Note: The 2011 TMUTCD is now in effect based on the 2009 National MUTCD.

According to the National Work Zone Safety Information Clearinghouse, TxDOT typically utilizes truck-mounted arrow panels when travel lanes are blocked for very short periods of time during operations such as pavement patching or litter pickup on rural roads.

> In some cases, TxDOT also uses a special "Lane Blocked" sign on a vehicle running behind the caravan on the shoulder that shows a row of numbers corresponding to the number of lanes on the roadway, and an "X" below which of those lanes are closed (similar in concept to an overhead lane control signal array that might be used on an arterial or freeway)(National Work Zone Safety Information Clearinghouse, n.d.).

## 2.3 Current Provisions of Other State DOTS pertaining to VSDOs

A comprehensive literature review of state DOTs did not identify any specific provisions for VSDOs. The followings paragraphs, however, summarize guidelines from other DOTs that pertain either directly or indirectly to VSDOs.

### 2.3.1 Indiana DOT Work Zone Safety Guidelines

In InDOT Guidelines, VSDO is not specified as a separate type of operation but is included in "Short Duration Operation" and "Mobile Operation."

### 2.3.2 Missouri DOT Work Zone Technicians

MoDOT has six categories of work duration. These categories differ from other DOTs' in the provision of a 30-minute short term operation category and an additional emergency category. MoDOT classifies *short-term stationary operations* as planned daytime work occupying a location for more than 30 minutes, but less than 12 hours, and *short duration operations* as planned daytime or nighttime work occupying a location up to 30 minutes. An *emergency operation* is defined as work involving the initial response to and repair/removal of Response Priority 1 items (according to the MoDOT's *Incident Response Plan Manual*). Table 4 summarizes the MoDOT definitions for short duration and mobile operations.

**Table 4: MODOT Definitions for Short Duration and Mobile Operations**

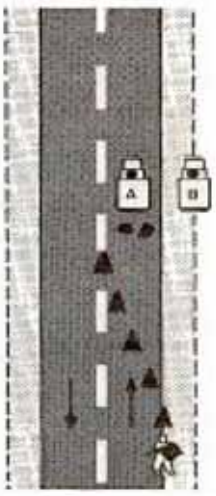
Source: MoDOT Work Zone Technicians

| Duration of Work | Definition | Typical Activities | Typical Devices |
|---|---|---|---|
| **Short duration operations** | Daytime or nighttime work occupying a location up to 30 minutes. | Crack sealing, raised pavement marker replacement, guardrail work, lighting maintenance, paving operations, signal work, and sign repair and installation | Vehicle-mounted signs, truck-mounted flashing arrow panels, fleet lighting, protective vehicles, channelizer cones, and truck-mounted attenuators |
| **Mobile operations** | These include planned work that moves intermittently or continuously. These operations often involve frequent, short stops for activities where workers are on foot. These stops can last **up to 15 minutes in duration**. | Litter cleanup, pothole patching, mowing, snow removal, spraying, sweeping | a) In some continuously moving operations, a work vehicle equipped with fleet lighting may be sufficient.<br>b) In others, a protective vehicle equipped with fleet lighting, a truck-mounted attenuator, a flashing arrow panel, and a sign may be needed.<br>c) Where work proceeds at less than 5 miles per hour, place warning signs along the roadway and move them periodically as work progresses. |

### 2.3.3 Arkansas State Highway Transportation Department's Safety Manual

The Arkansas State Highway Transportation Department's *Safety Manual* contains special provisions for two-lane highway potholing and edge patching as stated here:

> Two-lane highway potholing and edge patching
> When shoulders do not exist, place patch truck at location "A". When shoulder is available, place patch truck at location "B". When potholes are small and require very little time to repair, the following are minimum requirements:
> 1. Revolving flashing amber light
> 2. Truck emergency flashers
> 3. Properly attired flagger
> 4. Traffic cones as shown
> 5. Fifty- to 100-foot long two-way traffic tapers with channeling devices spaced 10 to 20 feet to provide clear delineation of the taper
>
> (Source: Chapter 6, Page 31)

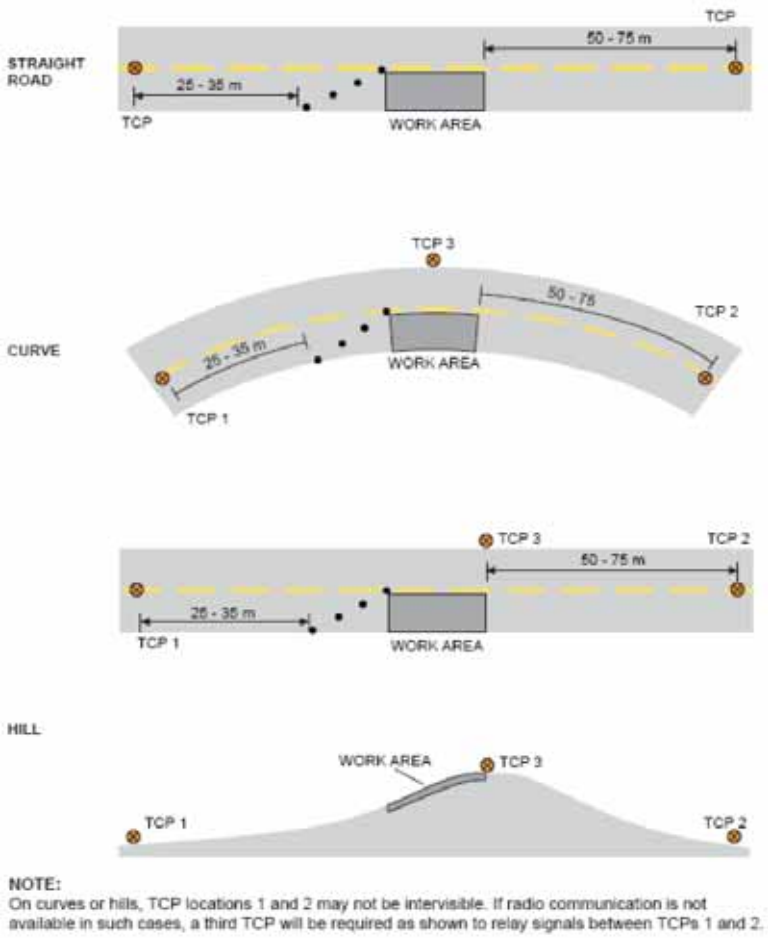


### 2.3.4 British Columbia Ministry of Transportation and Infrastructure, Canada

British Columbia Ministry of Transportation and Infrastructure's *Traffic Control Manual for Work on Roadways* (similar to the MUTCD) did not contain any information pertaining to VSDOs but sections of the manual such as the "installation and removal of devices" and recommended locations of traffic control persons (flaggers) are presented here:

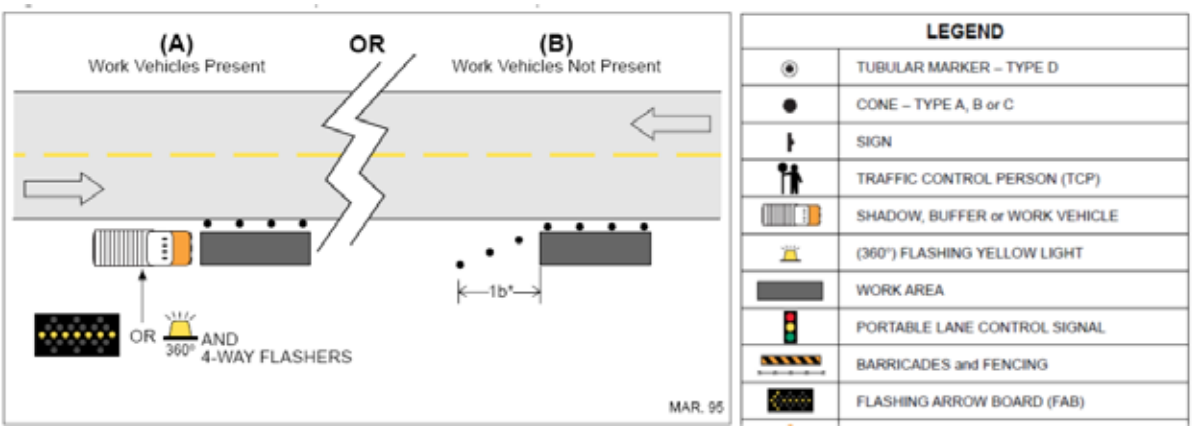
> Installation and Removal of Devices
> Motorists do not expect to encounter workers in the roadway setting up a traffic control zone. Since the goal is to make the entire operation safe, high level warning devices, traffic control persons, or flashing vehicle lights should be used to warn the drivers of the presence of workers. Flashing arrow boards are valuable to assist the workers during placement or removal of channelizing devices for lane closures.
>
> As soon as the work is completed and traffic control devices are no longer needed, they should be removed. Any cones and channelizing devices on the travelled roadway should be removed first, followed by the signs. Flashing arrow boards, high level warning devices, traffic control persons and/or flashing vehicle lights should be used in the removal process. No workers shall ride on the rear outside of a vehicle while it is reversing. On low volume roadways, devices should be removed in the opposite order of installation by first removing those closest to the work area and continuing progressively upstream away from the area. On high volume roadways, devices may be removed as for low volume or they may be removed with the flow of traffic provided there is a buffer vehicle, which may be equipped with a rear-mounted impact attenuator.
>
> Traffic Control Persons (TCPs) (Flaggers)
> It is the responsibility of the traffic control person to effectively communicate with the travelling public by using traffic control motions and signals that are precise and deliberate so that the meaning of signals can be clearly understood.
>
> Typical Traffic Control Layouts for Short Duration Work Zones (Exception for Emergency and Brief Duration Work)
> If the work being carried out is of an emergency or brief duration nature, as defined, and is within a speed limit of 60 km/h or less, it may not be practicable to provide the TCPs or advance signing called for in Chapters 3 and 4 of the Traffic Control Manual.
>
> (Source: http://www.th.gov.bc.ca/publications/eng_publications/TCM/Traffic_Control_Manual.htm)

Figures 1–4 are also from this manual.



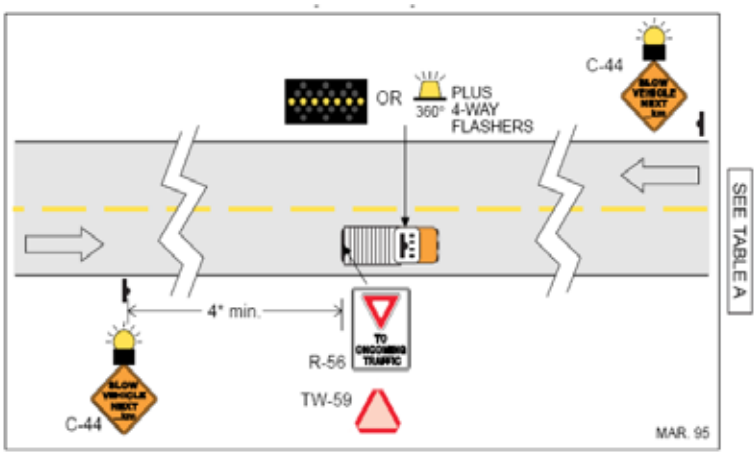

Source: British Columbia Ministry of Transportation and Infrastructure pp. 2.3.8, 1999

*Figure 1: Location of Traffic Control Persons*




Source: http://www.th.gov.bc.ca/publications/eng_publications/TCM/Traffic_Control_Manual.htm

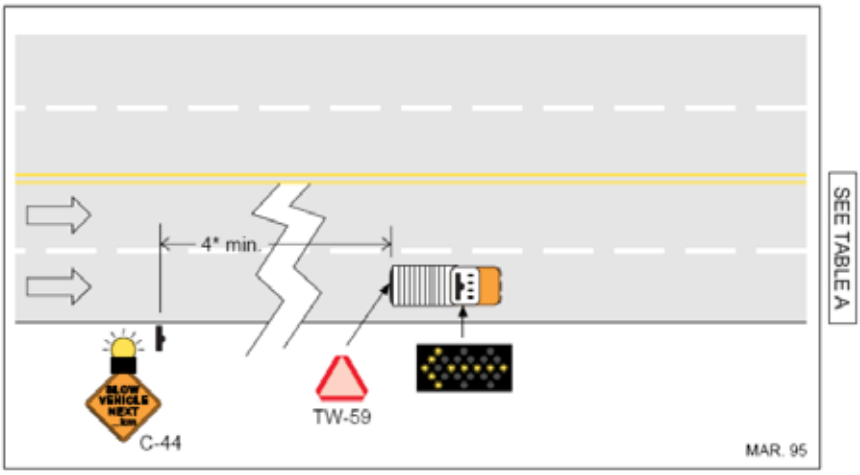
*Figure 2: Work on Shoulder (Less than 30 Minutes)*




- For pavement striping see Appendix B of the Traffic Control Manual.
- Typical applications are hydroseeding, grading, sweeping and flushing, etc.
- Maximum distance on C-44 signs should not exceed 8 km.
- A Type B flashing yellow light or flags shall be used with C-44 signs. Addition of a HLWD is optional.
- If speed limit is 60 km or less, the C-44 sign and its accessories may be omitted.
- All signs should be removed or covered when work is not underway and work vehicles can travel at posted speeds.
- A shadow vehicle with a C-45 or other appropriate sign on the rear may be required by the road authority.
- R-56 may be omitted from large line-type utility vehicles if it is impractical to mount the sign.

Source: http://www.th.gov.bc.ca/publications/eng_publications/TCM/Traffic_Control_Manual.htm

*Figure 3: Continuously Slow Moving Work – Two-Lane Two-way Roadway*




- For pavement striping, see Appendix B of the Traffic Control Manual.
- Typical applications are hydroseeding, grading, flushing and sweeping etc.
- Maximum distance on C-44 sign should not exceed 8 km.
- A Type B flashing yellow light or flags shall be used with the C-44 sign. Addition of a HLWD is optional.
- If speed limit is 60 km or less, the C-44 sign and its accessories may be omitted .
- If speed limit is 60 km/h or less, the FAB can be replaced by a 360° plus 4-way flashers.
- All signs should be covered or removed when work vehicles can proceed at posted speeds.
- A shadow vehicle with a C-45 or other appropriate sign on the rear may be required by the road authority.

Source: http://www.th.gov.bc.ca/publications/eng_publications/TCM/Traffic_Control_Manual.htm

*Figure 4: Continuously Slow Moving Work – Multilane Roadway*

## 2.4 Summary of Literature

Despite the recognition of VSDOs, MUTCD and other state Department of Transportation manuals on traffic control devices do not independently classify VSDOs as a type of work zone operation. The review of current literature identified very few specific references to VSDOs and those references provided very little specific guidance.

However, based on the literature, the researchers inferred that VSDOs are a form of temporary traffic control (TTC) and must adhere to the stated principles of a TTC. Work duration is a major factor in determining the number and types of devices used in TTC zones. Similar to short duration operations, "it often takes longer to set up and remove the TTC zone than to perform the work" as stated by the MUTCD.

Workers face hazards in setting up and taking down the TTC zone, and in the case of VSDOs, workers may be reluctant to set up these devices. In summary, devices that are applicable to operations within the scope of VSDOs must have greater mobility and be larger, more imposing, or more visible to the traveling public. In addition, 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.

# 3. Research Methods

The research approaches applied in this study include field observations made by shadowing maintenance operations, Expert Panel discussions, and scenario-based risk assessments. The research team originally envisioned a decision matrix describing VSDO work zone conditions and safety recommendations as a primary component of this research effort, but findings from the shadowing and Expert Panels indicated that such a matrix would be impractical and inefficient to implement. A scenario-based risk assessment approach is instead proposed to streamline the risk assessment process and enhance judgments of the maintenance workers during VSDOs. These approaches are discussed in this chapter.

## 3.1 Concept of the Decision Matrix

The objective of this research effort was to provide specific guidance to the maintenance workers for most cases of VSDOs. The recommended safety guidance was one dimension in the decision matrix; other dimensions were used to describe specific situations (e.g., weather condition, type of work, location of work, and traffic condition). The researchers envisioned a matrix that would be exhaustive, inclusive of all beneficial guidance, but not redundant. The attributes for describing a specific VSDO were identified based on the literature, shadowing observations, and Expert Panel recommendations. Providing safety guidance for all possible cases with numerous combinations of condition features proved to be impractical and less beneficial to the maintenance workers. As shown in Figure 5, if we generate all possible scenarios, using limited numbers of categories of each factor, thousands of combinations would result, leading to thousands of scenarios—which is neither manageable nor beneficial for the maintenance crews. If we develop a decision tree ordered by the level of importance of each factor, a section of the tree structure would be similar to the one shown in Figure 5. The number of scenarios omitted from this tree structure is presented under each branch and the total number of scenarios generated is 11,664. Attempting to describe and provide safety recommendations for all possible scenarios is neither practical nor beneficial for implementation. Based on the shadowing observations and Expert Panel recommendations, a scenario-based risk assessment approach is proposed instead. This approach circumvents the challenges of decision matrix development and implementation by explicitly streamlining the risk assessment process in order to enhance the judgments of the maintenance workers during VSDOs.

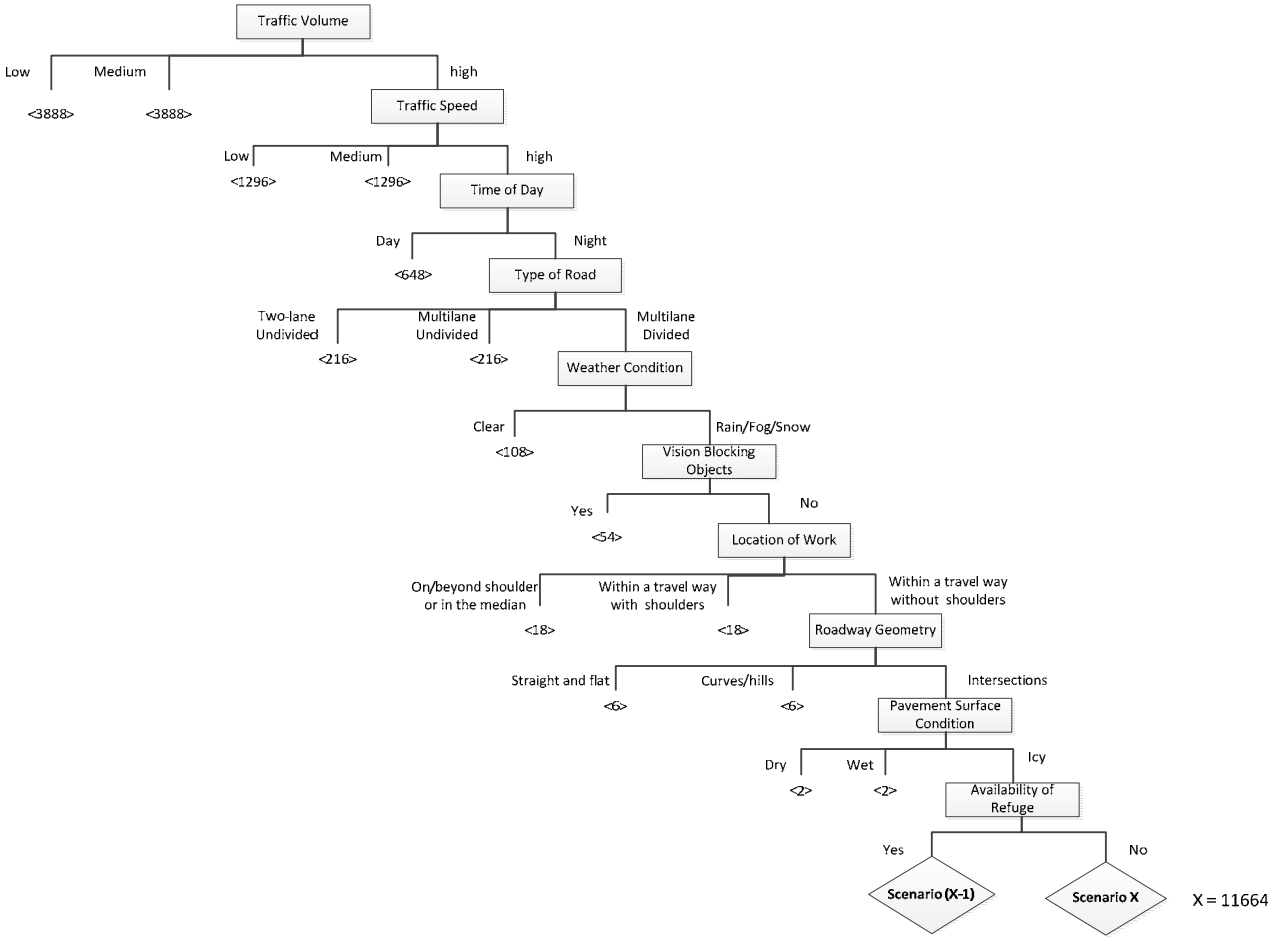



*Figure 5: An Example of the Scenario Enumeration*

## 3.2 Shadowing

Shadowing activities were conducted to help the research team learn about TxDOT's current VSDO practice so as to provide more applicable and practical guidance to the maintenance crews. The authors rode with TxDOT maintenance crews on separate days in February, June, and July, 2011, in both urban and rural areas. Fifteen VSDOs were observed and documented in three districts—one urban and two rural. For each observation, the work duration, illustration of the scenario, actions taken, roadway geometry, work location, location of the parking vehicles, traffic control procedures, and safety precautions were recorded. Typically, VSDOs are not differentiated from other maintenance operations; thus, no particular crew is assigned to perform only this kind of operation. Maintenance crews at TxDOT usually perform a variety of tasks during a typical day; only some of the observations could be considered VSDOs. Detailed description of the scenarios and important findings from the shadowing are relayed in Section 4.1. Findings from the shadowing provide the basis for subsequent Expert Panel discussions and the scenario-based risk assessment.

## 3.3 Expert Panel

In addition to the shadowing activities, two Expert Panel meetings were held on April 27, 2011 and March 9, 2012. The Expert Panel was composed of nine road maintenance experts, including

experienced maintenance workers, supervisors, and traffic engineers in Texas and was convened to provide expert opinions on the current practice of VSDOs and suggestions for safety improvements. The average number of years of experience of the panel members was 22 years, thus providing a wealth of knowledge and experience.

In the first Expert Panel meeting, two surveys were conducted for knowledge elicitation. The first survey, shown in Appendix A, was conducted at the beginning of the Expert Panel meeting using a recall-based method designed to retrieve expert knowledge without providing predefined options or outside intervention. The second survey, shown in Appendix B, was conducted at the end of the meeting after interactive discussions using a recognition-based method designed to promote consensus in a standardized setting. Through this Expert Panel, VSDO was defined, the minimum safety requirements and important influencing factors of VSDOs were derived, and a decision-making process of whether to proceed with the work as a VSDO was developed. This process was further refined by the research team and presented in a decision flowchart (shown in Section 4.2.4).

In the second Expert Panel meeting, a modified Delphi Process was used to guide the deliberations of the panel with two sets of surveys. The first survey, shown in Appendix C, was conducted at the beginning of the meeting without discussion and the second survey, shown in Appendix D, was conducted at the end of the meeting to draw converging opinions. Through the surveys and discussions, the important influencing factors to be considered when developing strategies for VSDOs were identified and prioritized and were further used to simulate typical VSDO scenarios.

In addition, safety recommendations for the developed scenarios were updated based on the panel members' opinions (shown in Section 4.2.3).

## 3.4 Scenario-Based Risk Assessment

Through the shadowing and Expert Panels, the research team identified the factors influencing the level of risk to maintenance workers and motorists during VSDOs. A scenario-based risk management process was designed to elicit risk mitigation strategies. *Risk* refers here to the potential for an accident that harms workers or drivers during a VSDO. S*cenario* is used here to describe a possible set of conditions under which accidents are likely to occur. The objective of scenario-based hazard analysis is to stimulate thinking about possible dangerous conditions and accidents, assumptions relating to these occurrences, potential opportunities and risks, and courses of action. The results introduce the risky scenarios under which accidents are likely to occur and provide recommendations of additional safety precautions to the maintenance workers performing VSDOs in a limited set of scenarios. As mentioned previously, many different factors influence VSDO conditions. Therefore, a decision tree or decision-making matrix would become large and complicated and is neither applicable nor practical for maintenance workers. As a result, different scenarios representing the most common and the worst VSDO cases were developed. For each scenario, the influencing factors such as traffic volume, traffic speed, time of day, type of road, weather condition, emergency/severity of danger, vision blocking, location of work, roadway geometry, pavement condition, and availability of refuge are described. In addition, safety recommendations for each scenario are provided.

The risk management process, illustrated in Figure 6, includes five steps: 1) risk identification, 2) risk assessment, 3) risk analysis, 4) mitigation strategies, and 5) evaluation. First, the types and sources of safety risks in VSDOs are identified. Then, the identified risks are assessed and prioritized. Only the risks that are most likely to occur and have serious consequences are considered in the subsequent analysis. The causes of those risks are analyzed and mitigation strategies are proposed, which will be evaluated and refined in a new cycle. The results are presented in Sections 4.3 and 4.4.

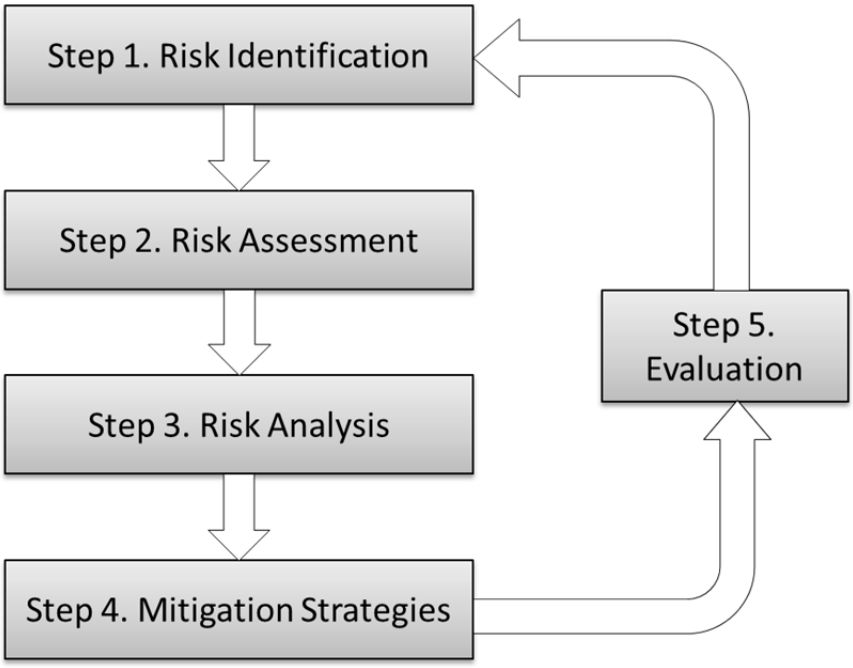



*Figure 6: The Risk Management Process*

# 4. Research Findings

This section includes research findings based on research methods described in the previous section. This section shows details and findings of shadowing activities. Also, findings from two Expert Panel meetings will be discussed. Then, five different steps of the proposed risk management process will be fully explained. Moreover, multiple scenarios illustrating the risks are presented, and related safety recommendations are also discussed. Finally, the validation step for proposed scenario-based risk management will be explained.

## 4.1 Shadowing Activities

Shadowing activities were conducted to help the research team learn about the current common practices of VSDOs and provide more applicable and practical guidance to the maintenance crews (Wang et al., 2012). Findings from the shadowing activities provided an important basis for subsequent Expert Panel discussions and the scenario-based risk assessment. Thirty VSDO observations were conducted and 15 unique samples, shown in Table 5, were documented during the shadowing activities in three TXDOT districts—one urban and two rural (Wang et al., 2012). For each observation, the researchers recorded work duration and location, scenario description, actions taken, roadway geometry, location of the parking vehicles, traffic control procedures, and safety precautions.

Based on shadowing observations, VSDOs can be characterized into three different groups, each defined by the location of the operation:

1. Operations on or beyond the shoulder
2. Operations within a traveled way with a shoulder
3. Operations within a traveled way without a shoulder, e.g., bridges

**Table 5: A Summary of 15 Unique Observations**

| Observation | Work Duration | District Area | Number of Workers and Trucks | Traffic Control Devices |
|---|---|---|---|---|
| **Operations on or beyond the shoulder** | | | | |
| Observation 1: Picking up a dead wild pig in the median | 5 minutes | Urban | Two workers and two trucks | Truck-mounted flashing light bars |
| Observation 2: Picking up a dead deer in the median | 2 minutes | Rural | Two workers and one truck | Truck-mounted flashing light bars |
| Observation 3: Setting up warning sign at a high way entrance | 10 minutes | Urban | Two workers and two trucks | Truck-mounted flashing light bars, portable message sign |
| Observation 4: Picking up a trash bag on three-lane divided highway | 5 minutes | Urban | One worker and one truck | Truck-mounted arrow boards and flashing lights |
| Observation 5: Removing tire scraps from the shoulder | Less than 1 minute | Rural | One worker and one truck | Truck-mounted flashing light bars |
| Observation 6: Removing pallets from the road | Less than 1 minute | Rural | One worker and one truck | Truck-mounted flashing light bars |
| Observation 7: Removing Plant Growing on the Shoulder | 5 minutes | Rural | One worker and one truck | Truck-mounted flashing light bars |
| Observation 8: Removing dead cow from the Shoulder | Less than 5 minutes | Rural | Four workers and two trucks | Truck-mounted flashing light bars, truck-mounted message board, backhoe and a flagger-person |
| Observation 9: helping other vehicles | 3 minutes | Rural | One worker and one truck | Truck-mounted flashing light bars |
| **Operations within a traveled way with a shoulder** | | | | |
| Observation 10: pothole patching | 3 minutes | Rural | One worker and one truck | Truck-mounted flashing light bars |
| Observation 11: Removing dead animal from middle of the roadway | Less than 1 minute | Rural | Two workers and one truck | Truck-mounted flashing light bars |
| Observation 12: Removing tire scraps from the roadway | Less than 1 minute | Rural | One worker and one truck | Truck-mounted flashing light bars |

| Observation | Work Duration | District Area | Number of Workers and Trucks | Traffic Control Devices |
|---|---|---|---|---|
| **Operations within a traveled way without a shoulder** | | | | |
| Observation 13: Picking up debris along the shoulder of a bridge | 2 minutes | Urban | Three workers and two trucks | Truck-mounted flashing light bars |
| Observation 14: Picking up debris along the bridge | Less than 1 minute | Rural | Three workers and two trucks | Truck-mounted flashing light bars |
| Observation 15: Picking up multiple objects on exit ramp | 5 minutes | Urban | Four workers and three trucks | Truck-mounted arrow boards and flashing lights, two trucks with attenuators |

In general, operations on or beyond the shoulder pose fewer hazards to maintenance workers and the traveling public. If operations are conducted within a traveled way and the road has a shoulder, the maintenance vehicles are usually parked on the shoulder and the workers step out of the vehicles and walk into the traveled way to perform tasks without any extra safety protection. Operations within a traveled way without a shoulder often involve temporary lane closure.

Typically, VSDOs are not differentiated from other maintenance operations; no particular crew is assigned to perform only this kind of operation. Maintenance crews at TxDOT usually perform a variety of tasks during a typical day; therefore, only some of the observations recorded could be considered VSDOs. Typical scenarios and important findings from the shadowing are described in the following subsections.

### 4.1.1 Shadowing Details

TxDOT maintenance workers use a variety of vehicles and equipment. Figure 7 shows a typical pickup truck that is equipped with traffic control devices: arrow boards, flashing light bar, bumper, portable message sings, fire extinguisher, first aid kit, and traffic cones. Figure 8 shows the internal radio system the maintenance crews use to communicate with the service center and the other vehicles.


*Figure 7: Maintenance Pickup Truck*

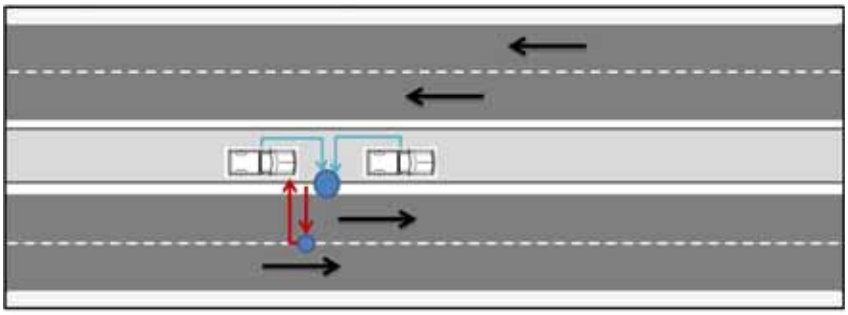

*Figure 8: Internal Radio System*

## Operations on or beyond the Shoulder

### Observation 1: Picking up a dead wild pig in the median

Observation 1 involved picking up a dead animal along the shoulder adjacent to the median, which is a common operation performed by TxDOT maintenance workers (see Table 6). The operation took 5 minutes. Two trucks (one work truck and the shadow vehicle) and two workers were used in this operation. As shown in Figure 9, two maintenance workers walked from the truck into the roadway and shoveled the dead pig into a plastic bag. The crew leader noticed some leftover parts in the middle of the roadway. During gaps in the traffic, he walked out into the travel lane to perform the necessary task (see Figure 10). This action was identified as a risky behavior because the worker walked directly into the travel way to pick up remains without any extra protection. The only traffic control device used in this operation was the truck-mounted flashing light bars.

**Table 6: Summary of Observation 1**

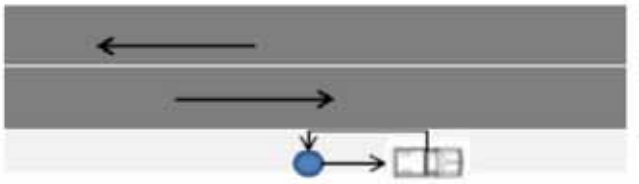
| **Observation 1: Picking up a dead wild pig in the median** | |
|---|---|
| Observation classification | Operations on or beyond the shoulder |
| Duration | 5 minutes |
| Illustration |  |
| Roadway geometry | Four-lane divided, level and straight |
| Location of work | On the shoulder and in the travel way |
| Risk level | Risk level is moderate due to medium traffic volume and medium traffic speed and the location of work. |
| Work vehicle location | In the median area attaching the shoulder |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | 1. Two maintenance workers walked from the truck into the roadway and shoveled the dead pig into a plastic bag.<br>2. The crew leader noticed some leftover parts in the middle of the roadway. He looked for a gap in the oncoming traffic stream and walked out into the travel lane to conduct the necessary task. |
| Safety precautions | N/A |

| | |
|---|---|
| Pictures |  <br>*Figure 9: Work Procedures of Observation 1*<br>  <br>*Figure 10: Picking Leftover Parts within the Travel Way* |

### Observation 2: Picking up a dead deer on the shoulder

Observation 2 involved picking up a dead deer on the shoulder (see Table 7). The operation took 2 minutes. One truck and two workers were used in this operation. As shown in Figure 11, two maintenance workers walked out of the truck and moved the dead deer onto the truck. The only traffic control device used in this operation was the truck-mounted flashing light bars.

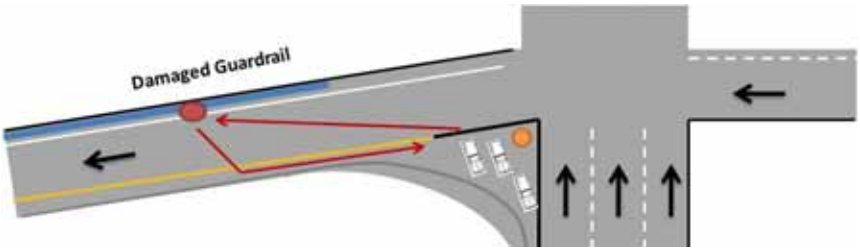
**Table 7: Summary of Observation 2**

| **Observation 2: Picking up a dead deer in the median** | |
|---|---|
| Observation classification | Operations on or beyond the shoulder |
| Duration | 2 minutes |
| Illustration |  |
| Roadway geometry | Two-lane rural road, level and straight |
| Location of work | Outside of the shoulder |
| Risk level | Risk level is low due to low traffic volume and roadway geometry. |
| Work vehicle location | Outside of the shoulder |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | Two maintenance workers walked out of the truck, walked to the dead deer, picked it up, and placed it in the back of the truck. |
| Safety precautions | N/A |
| Pictures |  *Figure 11: Work Procedures of Observation 2* |

### Observation 3: Setting up a warning sign at high way entrance

Observation 3 involved placing a cone at the location of a damaged guardrail and setting up an associated warning sign, which took 10 minutes to perform (see Table 8). Three trucks and three workers were used in this operation. However, none of the trucks were used as a shadow vehicle and the worker walked across the entrance ramp without any extra protection. As illustrated in Figure 12, one worker took a picture, walked across the roadway, and put a cone next to the damaged guardrail, and then walked back across the road. Finally, two workers set up a portable warning sign beside the entrance. The research team found that although the traffic volume could be conditionally controlled by the adjacent traffic signals, the worker still faced a hazard as the worker walked towards the damaged guardrail with his back facing the direction of oncoming traffic.

**Table 8: Summary of Observation 3**

| **Observation 3: Setting up warning sign at a highway entrance** | |
|---|---|
| Observation classification | Operations on or beyond the shoulder |
| Duration | 10 minutes |
| Illustration |  |
| Roadway geometry | Entrance ramp |
| Location of work | Outside of the shoulder |
| Risk level | Risk level is high due to medium traffic volume, high traffic speed and roadway geometry. |
| Work vehicle location | In the median area attaching the shoulder |
| Traffic control devices | Truck-mounted flashing light bars, portable message sign |
| Traffic control procedures | 1. One worker took a picture, walked directly across the road, and put a cone at the damaged place<br>2. The worker walked back from across the road.<br>3. He then set up a portable warning sign beside the entrance. |
| Safety precautions | N/A |

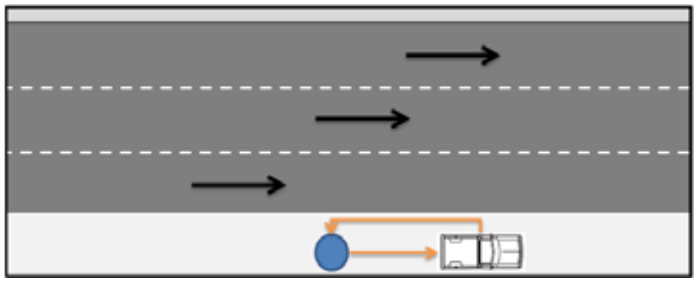
| | |
|---|---|
| **Pictures** |  |

*Figure 12: Work Procedures of Observation 3*

### Observation 4: Picking up a trash bag on three-lane divided highway

Observation 4 involved one maintenance worker picking up a trash can on a six-lane divided high speed roadway. The worker received notification from the service center concerning a trash can found on the right shoulder of the three-lane divided roadway. After initially driving past the object, the worker parked a few feet away from object (on the shoulder), turned on his flashing lights, and walked back to pick up the bag. The only form of protection was the flashing lights. Drivers did not slow down as they drove past the maintenance vehicle.

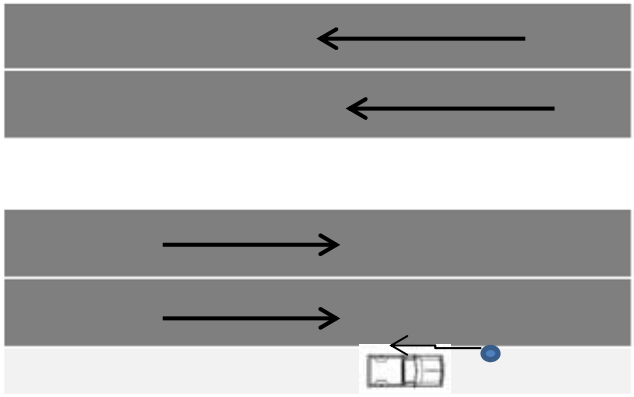
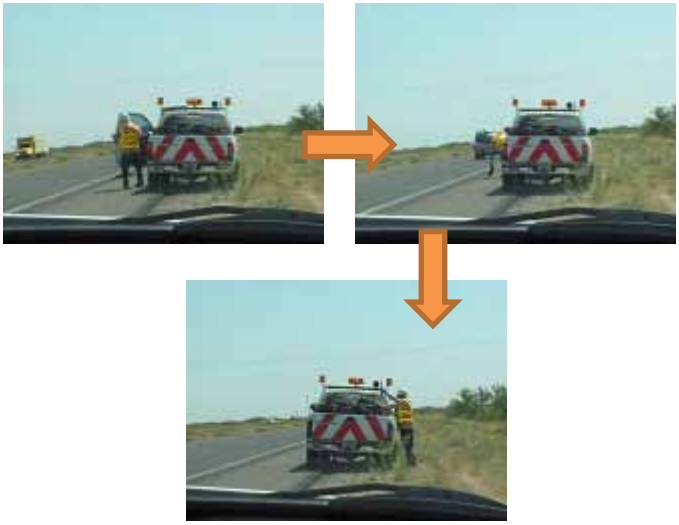
**Table 9: Summary of Observation 4**

| **Observation 4: Picking up a trash bag on three lane divided highway** | |
|---|---|
| Observation Classification | Operations on or beyond the shoulder |
| Duration | 5 minutes |
| Illustration |  |
| Roadway geometry | Three-lane divided highway |
| Location of work | On the shoulder |
| Risk level | Risk level is low due to low traffic volume and the location of work. |
| Work vehicle location | On the shoulder |
| Traffic control devices | Truck-mounted arrow boards and flashing lights |
| Traffic control procedures | One maintenance worker walked out of the truck, walked to the trash item (trash bin), picked it up, and placed it in the back of the truck. |
| Safety precautions | N/A |
| Pictures | N/A |

### Observation 5: Removing tire scraps from the shoulder

Observation 5 involved removing tire scraps from the roadway (see Table 10). The operation took less than 1 minute. One truck and one worker were used in this operation. As shown in Figure 13, one maintenance worker walked on the traveled way and removed tire scraps from the shoulder. The only traffic control device used in this operation is truck-mounted flashing light bars.

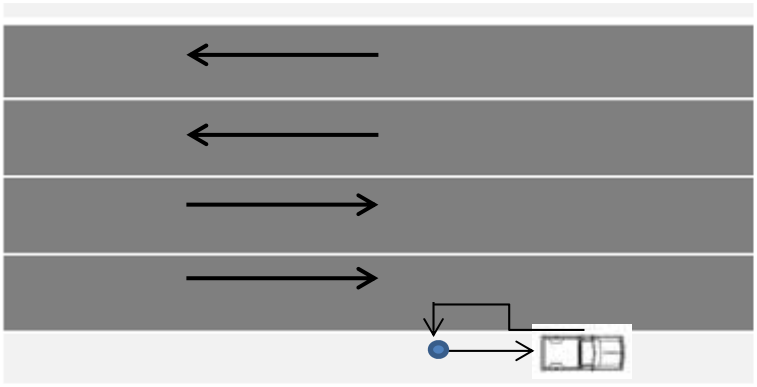
**Table 10: Summary of Observation 5**

| **Observation 5: Removing tire scraps from the shoulder** | |
|---|---|
| Observation classification | Operations on or beyond the shoulder |
| Duration | Less than 1 minute |
| Illustration |  |
| Roadway geometry | Four-lane divided, level and straight |
| Location of work | On the shoulder and in the travel way |
| Risk level | Risk level is low due to low traffic volume and roadway geometry. |
| Work vehicle location | On the shoulder |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | A maintenance worker walked out of the truck and removed tire scraps from the shoulder. |
| Safety precautions | N/A |
| Pictures |  *Figure 13: Removing Tire Scraps from the Shoulder* |

### Observation 6: Removing pallets from the shoulder

Observation 6 is removing pallets from the shoulder (see Table 11). The operation took less than 1 minute. One truck and one worker were used in this operation. As shown in Figure 14, one maintenance worker moved pallets to his truck. The only traffic control device used in this operation was truck-mounted flashing light bars.

**Table 11: Summary of Observation 6**

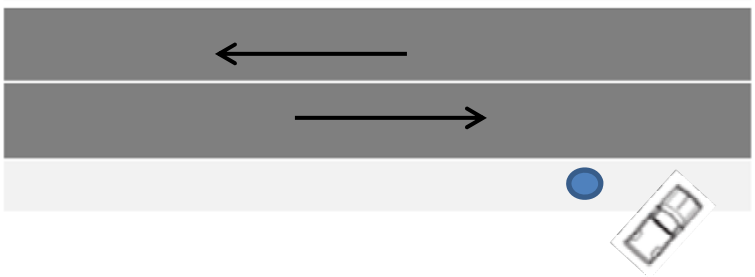
| **Observation 6: Removing Pallets from the Road** | |
|---|---|
| Observation Classification | Operations on or beyond the shoulder |
| Duration | Less than 1 minute |
| Illustration |  |
| Roadway geometry | Four-lane road, level and straight |
| Location of work | On the shoulder |
| Risk level | Risk level is low due to low traffic volume and roadway geometry. |
| Work vehicle location | On the shoulder |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | A maintenance worker walked from the truck to the pallets and picked them up from shoulder. |
| Safety precautions | N/A |

| | |
|---|---|
| Pictures |  *Figure 14: Removing Pallets from the Road* |

### Observation 7: Removing plant growing on the shoulder

Table 12 shows Observation 7, removing plant growth on the shoulder. The operation took 5 minutes. One truck and one worker were used in this operation. As shown in Figure 15, one maintenance worker parked his car in front of the plant. This behavior is identified as a risky action as the worker does not have any protection while he was working on a shoulder. The only traffic control device used in this operation was truck-mounted flashing light bars.

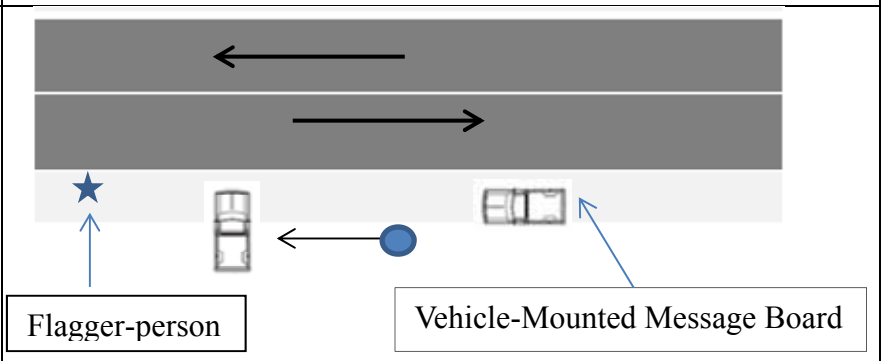
**Table 12: Summary of Observation 7**

| **Observation 7: Removing Green Plant Growing on the Shoulder** | |
|---|---|
| Observation classification | Operations on or beyond the shoulder |
| Duration | 5 minutes |
| Illustration |  |
| Roadway geometry | Two-lane road, level and straight |
| Location of work | On the shoulder |
| Risk level | Risk level is low due to low traffic volume and roadway geometry. |
| Work vehicle location | On the shoulder |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | A maintenance worker walked out of the truck and removed a green plant growing on the shoulder. |
| Safety precautions | N/A |
| Pictures |  *Figure 15: Removing a Plant Growing on the Shoulder* |

### Observation 8: Removing a dead cow from the shoulder

Table 13 shows Observation 8, removing a dead cow from the shoulder. Once the cow was located, Tthe operation took less than 5 minutes. Two trucks and a back-hoe were used in this activity. As shown in Figure 16, a maintenance worker lifted the dead cow into/onto the truck using a back-hoe. The traffic control devices used in this operation were truck-mounted flashing light bars and a flagger. In addition, Figure 17 shows traffic control devices used in this activity.

**Table 13: Summary of Observation 8**

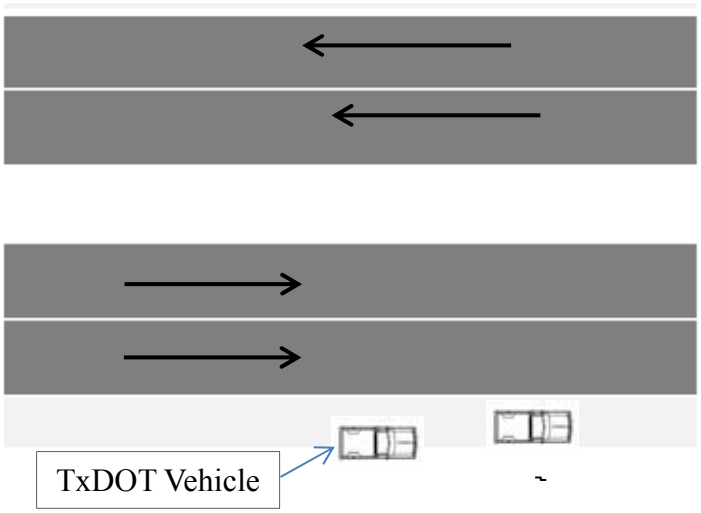
| **Observation 8: Removing a Dead Cow from the Shoulder** | |
|---|---|
| Observation classification | Operations on or beyond the shoulder |
| Duration | Less than 5 minutes |
| Illustration |  |
| Roadway geometry | Two-lane rural road, level and straight |
| Location of work | On the shoulder |
| Risk level | Risk level is moderate due to size of the cow |
| Work vehicle location | On the shoulder |
| Traffic control devices | Truck-mounted flashing light bars, truck-mounted message board, and a flagger-person |
| Traffic control procedures | Maintenance workers put a dead cow in a truck using a back-hoe. |
| Safety precautions | Flagger-person |

| | |
|---|---|
| Pictures |  <br>*Figure 16: Removing a Dead Cow from the Shoulder*<br>  <br>*Figure 17: Traffic Control Devices Used in This Operation* |

### Observation 9: Helping other vehicles

Table 14 shows Observation 9, helping other vehicles. In this activity, a maintenance worker walked out of the truck and approached a disabled vehicle's driver to ask him about his problem. Then, a maintenance worker asked for a help via cell phone (Figure 18).

**Table 14: Summary of Observation 9**

| **Observation 9: Helping Other Vehicles** | |
|---|---|
| Observation classification | Operations on or beyond the shoulder |
| Duration | 3 minutes |
| Illustration |  |
| Roadway geometry | Four-lane divided, level and straight |
| Location of work | On the shoulder |
| Risk level | Risk level is low due to low traffic volume and roadway geometry. |
| Work vehicle location | On the shoulder |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | A maintenance worker walked out of the truck and approached another vehicle driver to ask him about a problem. Then, a maintenance worker asked for a help via cell phone. |
| Safety precautions | N/A |
| Pictures |  *Figure 18: Helping Other Vehicles* |

## Operations within a Traveled Way with a Shoulder

### Observation 10: Pothole patching

Observation 10 involved patching a pothole in the middle of the roadway and on the shoulder (see Table 15). The operation took 3 minutes and one truck and one worker were used. As shown in Figure 19, the maintenance worker walked from the truck into the roadway and deposited patching materials in the pothole. To do this, the maintenance worker looked for a gap in the oncoming traffic stream to walk out into the travel lane and complete the necessary task. This action was identified as a risky behavior because the worker walked directly into the traveled way to do the job without any extra protection. After completing the pothole patching, the maintenance worker backed over the patch with his truck to compact it. This activity is also identified as a hazardous action because backing up on roads is dangerous. The only traffic control device used in this operation was truck-mounted flashing light bars.

**Table 15: Summary of Observation 10**

| **Observation 10: Pothole Patching** | |
|---|---|
| Observation classification | Operations within a traveled way with a shoulder |
| Duration | 3 minutes |
| Illustration |  |
| Roadway geometry | Two-lane rural road, level and straight |
| Location of work | In the middle of the roadway |
| Risk level | Risk level is moderate due to location of the maintenance work. |
| Work vehicle location | On the shoulder |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | One maintenance worker walked out of the truck and placed material in the pothole. Then, he backed over the patch with his truck to compact it. |
| Safety precautions | N/A |
| Pictures |  |

*Figure 19: Work Procedures of Observation 10*

### Observation 11: Removing dead animals from the middle of a roadway

Observation 11 involved removing dead animals from the middle of the roadway (see Table 16). The operation took less than 1 minute. One truck and one worker were used in this operation. As shown in Figure 20, one maintenance worker walked on the traveled way and removed the animal from the middle of the roadway. To do this, the maintenance worker looked for an opening in the oncoming traffic stream to walk out into the travel lane and do the necessary task. This action was identified as risky behavior as the worker walked directly into the travel way to do the job without any extra protection. The only traffic control device used in this operation is truck-mounted flashing light bars.

**Table 16: Summary of Observation 11**

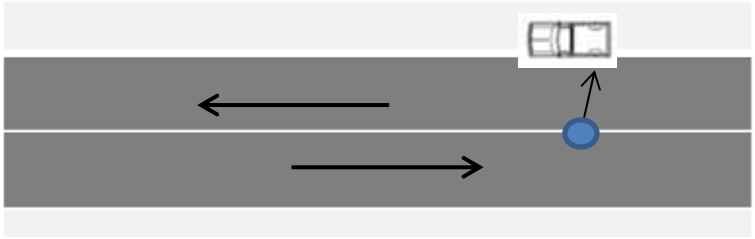
| **Observation 11: Removing dead animal from middle of the roadway** | |
|---|---|
| Observation Classification | Operations within a traveled way with a shoulder |
| Duration | Less than 1 minute |
| Illustration |  |
| Roadway geometry | Two-lane rural road, level and straight |
| Location of work | In the middle of the roadway |
| Risk level | Risk level is low due to low traffic volume and straight roadway geometry. |
| Work vehicle location | On the shoulder |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | One maintenance worker walked from the truck into the roadway, and removed the dead animal from the middle of the roadway. |
| Safety precautions | N/A |

| | |
|---|---|
| **Pictures** |  *Figure 20: Work Procedures of Observation 11* |

### Observation 12: Removing tire scraps from the roadway

Observation 12 involved removing tire scraps from the roadway (see Table 17). The operation took less than 1 minute. One truck and one worker were used in this operation. As shown in Figure 21, one maintenance worker walked on the traveled way and removed tire scraps from the middle of the roadway. To do this, the maintenance worker looked for gaps in the traffic stream to walk out into the travel lane and perform the necessary task. This action was identified as a risky behavior as the worker walked directly into the travel way to do the job without any extra protection. The only traffic control device used in this operation was truck-mounted flashing light bars.

**Table 17: Summary of Observation 12**

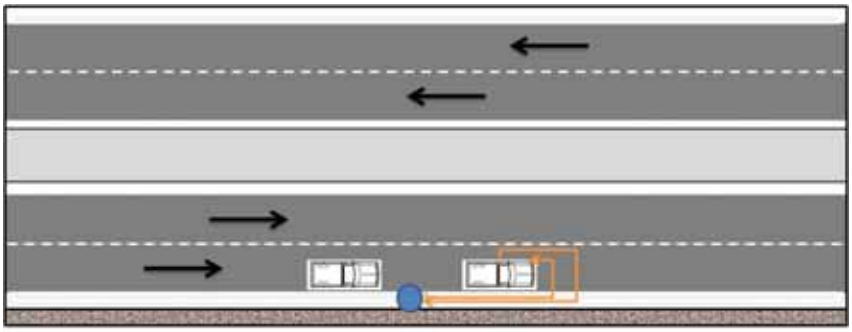
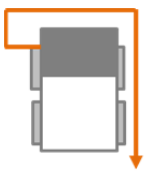
| **Observation 12: Removing tire scraps from the roadway** | |
|---|---|
| Observation classification | Operations within a traveled way with a shoulder |
| Duration | Less than 1 minute |
| Illustration |  |
| Roadway geometry | Two-lane rural road, level and straight |
| Location of work | On the travel way |
| Risk level | Risk level is moderate due to location of the maintenance work. |
| Work vehicle location | On the shoulder |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | A maintenance worker walked from the truck into the roadway and removed tire scraps from a road way. |
| Safety precautions | N/A |
| Pictures |  *Figure 21: Removing Tire Scraps from the Road* |

## Operations within a Traveled Way without a Shoulder (e.g., Bridges)

### Observation 13: Picking up debris along the bridge over the roadway

Observation 13 involved picking up debris along the shoulder (see Table 18). The operation took 5 minutes. Two trucks (a work pickup truck and a shadow vehicle) and two workers were used in this operation. Some safety precautions were taken, but hazardous situations still existed. Because the work location is on a concrete bridge, the worker was in the narrow space between the trucks and the concrete barrier (shown in Figure 22). In this situation, if the shadow truck were struck by an oncoming vehicle, the worker could be trapped.

**Table 18: Summary of Observation 13**

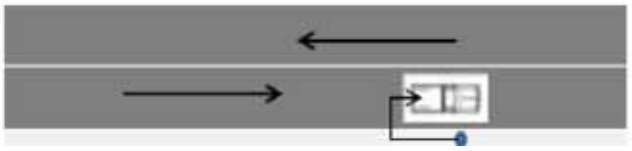
| **Observation 13: Picking up debris along the shoulder** | |
|---|---|
| Observation classification | Operations within a traveled way without a shoulder |
| Duration | 2 minutes |
| Illustration |  |
| Roadway geometry | Four-lane divided (on the bridge), level and straight |
| Location of work | On the right shoulder |
| Risk level | Risk level is high due to roadway geometry and no place for refuge. |
| Work vehicle location | In the travel way (on a bridge with solid barrier rail and a narrow shoulder, approximately 3 ft) |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | The cage truck operator exited the truck into the adjacent travel lane, walked around the front of his truck, then walked back toward the rear of his truck to pick up the debris.  |
| Safety precautions | • The shadow truck stopped approximately 50 ft behind the cage truck and the arrow board was raised.<br>• The shadow truck operator turned the steering wheel to the left (so that if the shadow truck was hit from the rear, it would |

| | |
|---|---|
| | travel into the adjacent travel lane and not impact the cage truck or cage truck operator).<br><br>**Note:** during the second litter pickup on the bridge, the maintenance crew leader in the shadow truck parked much closer to the cage truck and did not turn the steering wheel to the left. However, he was talking with the researchers, which likely distracted him from his normal mode of operations. |
| Pictures |  <br>*Figure 22: Work Procedures of Observation 13* |

### Observation 14: Picking up debris along the bridge over a river

Observation 14 involved picking up debris along a bridge (see Table 19). The operation took less than 1 minute, and one truck and two workers were used. In this operation, the truck stopped when the maintenance worker saw debris on the bridge. After stopping the truck, the other worker left the truck and picked up the debris (Figure 23). Because the operation was conducted on a concrete bridge, the worker was in the narrow space between the trucks and the concrete barrier. As a result, the worker faced a dangerous situation because the passing traffic did not pay attention to the flashing light bars and did not slow down.

**Table 19: Summary of Observation 14**

| **Observation 14: Picking up debris along the bridge** | |
|---|---|
| Observation classification | Operations within a traveled way without a shoulder |
| Duration | Less than 1 minute |
| Illustration |  |
| Roadway geometry | Two-lane road (on the bridge), level and straight |
| Location of work | On the right side |
| Risk level | Risk level is moderate due to narrow shoulder. |
| Work vehicle location | In the travel way (on a bridge with solid barrier rail and a narrow shoulder) |
| Traffic control devices | Truck-mounted flashing light bars |
| Traffic control procedures | The maintenance worker left the truck into the adjacent travel lane, picked up debris, and put it in the truck. |
| Safety precautions | N/A |

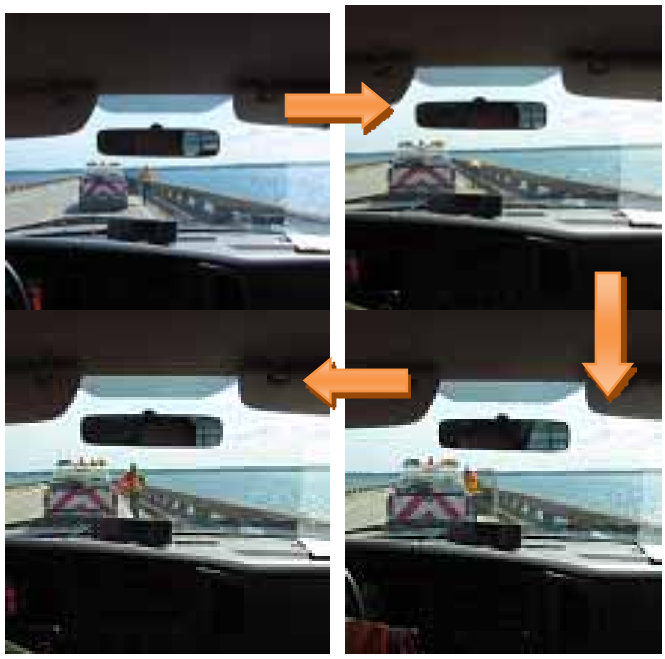
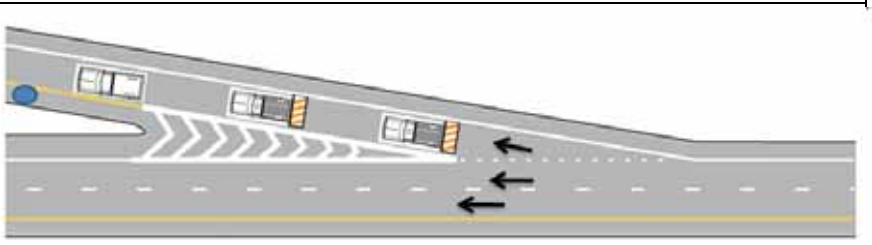
| | |
|---|---|
| **Pictures** |  |

***Figure 23: Work Procedures of Observation 14***

### Observation 15: Picking up multiple objects on exit ramp

Observation 15 was a more organized and planned operation because of the location of the objects (Table 20). The crew chief received a message from the service center concerning multiple objects found on an exit ramp. Due to the nature of the location and traffic speeds, the crew chief called for two truck-mounted attenuators (TMA) to assist him with the operation. The crew chief and the TMA drivers first gathered in a safe location to discuss the plan of action before proceeding with the operation. The plan involved the crew chief taking the lead with his truck with the other two attenuators following. After driving to the exit ramp, the lead vehicle turned on his flashing lights and the TMA trucks lowered both attenuators, and also turned on their flashing lights. All the trucks then drove slowly toward the ramp, notifying drivers of the operation with their flashers. The two TMAs both stopped at the ramp entrance, and the lead vehicle drove on the ramp to remove all the objects. After picking up the objects, the crew chief riding in the lead vehicle notified the other workers and all three vehicles safely exited the ramp. The geometry of the roadway (exit ramp) and the vehicle speeds required workers to take extra precaution and planning before performing this task.

**Table 20: Summary of Observation 15**

| **Observation 15: Picking up multiple objects on an exit ramp** | |
|---|---|
| Observation classification | Operations within a traveled way without a shoulder |
| Duration | 5 minutes |
| Illustration |  |
| Roadway geometry | Exit ramp |
| Location of work | On the shoulder and on travel way |
| Risk level | Risk level is high due to high traffic volume and roadway geometry. |
| Work vehicle location | On travel way |
| Traffic control devices | Truck-mounted arrow boards and flashing lights, two trucks with attenuators |
| Traffic control procedures | 1. Experienced team member with TMAs meet with crew chief at safe zone to discuss plan of action.<br>2. TMAs drive behind crew chief as they reach the exit ramp. Team waits on roadway shoulder for low traffic volumes before taking ramp.<br>3. TMAs stops on exit ramp to block traffic.<br>4. Crew chief drives on ramp to find object.<br>5. Crew chief ends up finding multiple objects at different locations on the ramp and picks them up.<br>6. Crew chief informs TMA drivers when task is completed.<br>7. Crew chief reports back to dispatcher after returning to safe zone. |
| Safety precautions | Use of TMA |
| Pictures | N/A |

### 4.1.2 Shadowing Findings

The shadowing observations revealed the current state of practice in VSDOs and provided insights into the need for specific guidance to the maintenance workers conducting VSDOs. The main findings from the shadowing are summarized and described in this section (Wang et al., 2012).

#### i) Duration of work

All operations recognized as VSDOs were conducted within 15 minutes, and 93% of all these operations took no more than 5 minutes. VSDOs often take only a few minutes (usually less than 5 minutes) and workers are usually reluctant to utilize extensive traffic control that will take longer to set up and remove than to perform the work.

#### ii) Crew and equipment

Most of the VSDOs were conducted with one truck and one worker. Only a few operations used one truck and two workers. Especially in rural areas, VSDOs often involved just one worker and one truck and limited traffic control devices were used during the operations. The most commonly used traffic control device was a truck-mounted flashing light bar, which may not be bright enough during daytime. Only in specific situations would supplemental traffic control devices be used. For instance, when removing a dead cow from the shoulder in a rural area, two trucks mounted with flashing light bars and a flagger were used as attention grabbers, and a back-hoe was used to lift the animal. As limited traffic control devices are used by maintenance crews, the motorists usually pass by without paying much attention to the work zone and the maintenance crews. As a result, more or better traffic control devices are needed to draw the attention of the traveling public.

#### iii) Location for parking maintenance vehicle

Maintenance crew vehicles are usually parked near the work location. However, in some cases, much safer places were available for maintenance workers to park their vehicles. Maintenance workers should be advised to park their vehicles in the safest available place. In addition, while shadowing, the researchers observed workers sometimes backing up to pick up objects after they drove past the objects. According to TxDOT policy, drivers are not supposed to back up in situations like these as it poses a danger to both workers and other road users. The policy requires that drivers turn around at a safe location, drive back to the location of the object, and perform the task.

#### iv) Request for assistance

Information such as location of an object (within the traveled way, on or beyond the shoulder, or in the median) may not be known until the crew arrives at the work zone, and the reported object type may not be known or described properly before dispatch. Hence, at times the crew and equipment on the scene are not adequate to perform the work. For urban high-volume high-speed roadways, if no crew members or TMAs are available, and the object is deemed dangerous to the traveling public, the crew may call 911 or a related public agency for assistance. On rural low-volume high-speed roadways,

workers usually pick up objects without any other assistance except for flashing lights on their trucks.

**v) Communication systems**

The research team found the communication system to be inadequate and unsafe for workers. In addition to communicating with the vehicle-mounted internal radio system, workers typically used one or more cell phones to talk to other crew members while driving. Workers also used cell phones while on foot at the work zone.

The shadowing findings suggest that more practical guidelines should be developed and more efficient and effective devices, which are easy to apply or adapt to current practice, should be used. Safety precautions and guidance need to be provided and stressed in the risky scenarios in which accidents are likely to happen and the consequent severity is high.

## 4.2 Expert Panels' Findings

As mentioned in the research methodology section, two Expert Panel meetings were held on April 27, 2011 and March 9, 2012. The Expert Panel was composed of road maintenance experts, including experienced maintenance workers, supervisors, and traffic engineers in Texas, and was convened to provide expert opinions on the current practice of VSDOs and suggestions for safety improvements.

In the first Expert Panel meeting, a definition of a VSDO was discussed as well as VSDO types and minimum requirements for performing them. In addition, influencing factors that should be considered during VSDOs were discussed. In the second Expert Panel meeting, influencing factors having impact on the condition of VSDOs were discussed. Also, safety recommendations for different scenarios, which will be explained in Section 4.4, were discussed. For knowing experts' opinion, different surveys, shown in Appendices A to C, were developed by the research team.

The following subsections are a summary of the meeting's proceedings and catalog findings as well as discussions resulting from the Expert Panel meetings.

### 4.2.1 Definition of VSDO

Based on the discussions with the Expert Panel, this definition of a very short duration operation (VSDO) was generated:

> **A planned or urgent activity, to be executed in 15 minutes or less by a crew of at least one worker and one truck, in which the hazard of *not* executing the work as a very short duration operation is greater than executing it.**

Activities identified by panel members that fall in this category of work zone operations include temporary pothole patching, debris removal, signal light replacement in rural areas, edge patching (edge of travel lane at short length), delineator maintenance on the side of the road, warning sign placement, supervisor markings for future work, taking photographs, setting up traffic counters and data collection/surveys. Normally, these activities can be completed within 15 minutes. The consensus of setting the time determinant as 15 minutes is also consistent with

the finding from the shadowing activities. Another important determinant in this definition is that the hazard of not executing the work as a VSDO should be greater than executing it. If suspending the work will not cause much hazard to the traveling public, and executing it will endanger the maintenance workers, then the guidelines suggest not proceeding with the work as a VSDO. A better option would be to perform the work later in a safer condition or wait for assistance. These determinants are also reflected in the decision flowchart presented in Section 4.2.4.

### 4.2.2 Minimum Requirements for Crew and Equipment

Should conditions be favorable for performing a VSDO, workers must ensure the following minimum safety requirements are met:

- At least one crew member and one truck, no upper threshold.
- Truck-mounted reflectors and flashing lights (current ones are not bright enough)
- Truck-mounted message board (multi-lane, crew oriented)
- Truck-mounted arrow board or arrow stick
- Amber and blue lights (minimum requirements with switch for different activities)
- TMA (for planned activities)
- Improved local (crew-level) communication devices
- Truck-mounted sweeper/rake

No ground-mounted traffic control devices were recommended by the panel. In addition, the panel recommended that the normal desirable condition would be for the maintenance vehicle to stop on the side of the road, unless the hazard of not parking the vehicle on the road is greater than parking it on the road. Each scenario is different so the minimum requirements may differ based on the operation. Workers should therefore proceed with the appropriate VSDO response for that particular scenario. Other safety precautions that can be taken by workers include having a spotter or using visually appealing devices such as arrow sticks, intrusion alarms, half-sleeve vests, and traffic flares.

### 4.2.3 Important Influencing Factors and Rankings

The Expert Panel agreed that should the risk involved in undertaking a VSDO be greater than the risk of nothing, workers should either reschedule the task or request assistance. Assistance may include TMAs, additional workers, and law enforcement involvement. Of the concerning factors that need to be considered when developing strategies for VSDOs, panel members identified traffic volume, traffic speed, time of day, and type of road as the four most important factors. A list of the influence factors that should be considered for VSDOs is listed and ranked by order of importance:

1. Traffic volume (high, medium, low)
2. Traffic speed (high, medium, low)
3. Time of day (day, night)
4. Type of road (two-lane undivided, multilane undivided, multilane divided)

5. Weather condition (clear, rain, fog, snow)
6. Emergency/severity of danger (to the public and workers)
7. Vision blocking objects (level of obstruction)
8. Location of work (beyond shoulder, on shoulder, within the traveled way, within the median (only applicable to divided roads))
9. Roadway geometry (straight and flat road, hills, curves, intersections)
10. Type of work
11. Pavement surface condition (dry, wet, icy)/condition of road
12. Availability of refuge

Traffic volume, traffic speed, time of day, and type of road are considered the most important factors for VSDOs because the variability of these four factors could be high and changes in condition will lead to major changes in solutions. For example, if the traffic volume and traffic speeds are low, then the worker will be comparatively safe and fewer safety precautions will be required. On the other hand, if the traffic volume is high, then it might lead to a lane closure, which requires shadow vehicles and more attention grabbers, because the workers could face significant safety risks under this condition. In order to provide helpful guidance to the workers, these influence factors needed to be further refined and prioritized, which was done during the second Expert Panel meeting.

To determine the worst combinations of traffic speed and volume, the graph shown in the Figure 24 was initially developed in the March 2012 Expert Panel meeting. As illustrated in Figure 24, the worst case in terms of a worker's misjudgment about VSDO conditions happens when traffic speed is high and traffic volume is medium/low. This case is common primarily in rural and farm-to-market (FM) roads. Also, as Figure 24 depicts, the probability of misjudgment by a maintenance worker decreases drastically when the traffic speed is low and traffic volume is low. In addition, Figure 24 shows that a maintenance worker can appropriately judge the work zone condition when the speed is low and traffic volume is high, but there is not enough time to safely execute the maintenance work as a VSDO. Moreover, the panel members believed that no VSDO is allowed when traffic speed and volume are high.

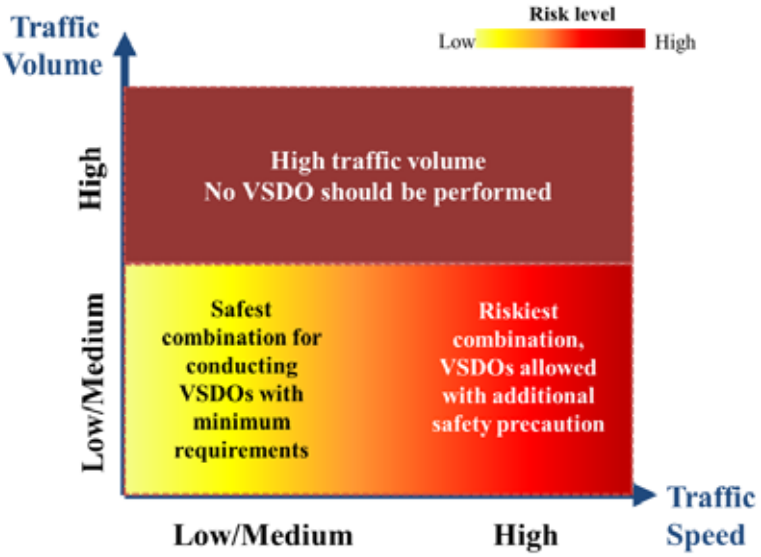



*Figure 24: Traffic Speed and Volume Graph*

In order to determine other main influencing factors of the risk occurrence during VSDOs, a questionnaire, shown in Appendix C, was developed within the research team. The objective of the questionnaire was identifying the main influencing factors of a work zone accident occurrence. The questionnaire was tested internally by the research team for refinement.

During the second Expert Panel meeting, the experts completed the questionnaire at the beginning of the meeting. The purpose of the first round of distributing the questionnaire was to assess panel members' opinions about risk factors, in general. As shown in Table 21, panel members answered that the likelihood of maintenance workers properly judging traffic speed in rainy and foggy weather are unlikely. Panel members also believed that the drivers are unlikely to control their vehicles to prevent a work zone accident in foggy weather and on icy pavement.

After a group discussion about the results of the first round, panel members were asked again to answer the same questionnaire a second time. The purpose of the second round was to consolidate the experts' opinions on VSDO risk factors. The results of the second round, also shown in Table 21, showed that experts downgraded their opinion when visibility is limited. The panel members believed that the likelihood of workers properly judging traffic volume decreased when visibility is limited due to foggy weather and other sight distance restrictions such as curves. Also, panel members determined the likelihood of maintenance workers properly judging traffic speed in rainy weather, foggy weather, and other sight distance restrictions such as curves are unlikely, very unlikely, and unlikely, respectively. In addition, panel members believed that drivers are unlikely to control their vehicle in rainy and foggy weather or on icy pavement.

**Table 21. Expert Panel Responses to Questionnaire**

| | **Results of 1st questionnaire distribution in the Expert Panel meeting** | **Results of 2nd questionnaire distribution in the Expert Panel meeting** |
|---|---|---|
| What is the likelihood of workers properly judging **traffic volume** under the following conditions: | | |
| Day | Likely | Likely |
| There is limited visibility due to | | |
| Night | Likely | Likely |
| Rainy weather | Neutral | Neutral |
| Foggy weather | Neutral | Unlikely |
| Other sight distance restrictions such as curves | Neutral | Unlikely |
| What is the likelihood of workers properly judging **traffic speed** under following conditions: | | |
| Day | Likely | Likely |
| There is limited visibility due to one of these factors: | | |
| Night | Neutral | Neutral |
| Rainy weather | Unlikely | Unlikely |
| Foggy weather | Unlikely | Very Unlikely |
| Other sight distance restrictions such as curves | Neutral | Unlikely |
| Rate the following conditions in terms of the driver's ability to control his/her vehicle to prevent a work zone accident: | | |
| Traffic volume is high | Neutral | Neutral |
| Traffic volume is medium | Likely | Likely |
| Traffic volume is low | Likely | Likely |
| Day | Likely | Likely |
| There is limited visibility due to one of these factors: | | |
| Night | Neutral | Neutral |
| Rainy weather | Neutral | Unlikely |
| Foggy weather | Unlikely | Unlikely |
| Driving on a straight roadway | Likely | Likely |
| Driving on a curve | Neutral | Neutral |
| Driving through an intersection | Neutral | Neutral |
| Operation is undertaken in travel lane | Neutral | Neutral |
| Operation is undertaken on a shoulder | Likely | Likely |
| The pavement surface is dry | Likely | Likely |
| The pavement surface is wet | Neutral | Neutral |
| The pavement surface is icy | Unlikely | Unlikely |

In general, the panel members believed that the following factors adversely impact workers' judgment and drivers' ability to control their vehicles:

1. Visibility is limited, such as foggy weather.
2. Traffic volume is medium and traffic speed is high.
3. Traffic volume is low and traffic speed is high.
4. The pavement surface is icy.

In addition to defining VSDOs and identifying and prioritizing influencing factors, a decision-making process for whether to proceed with the work as a VSDO was developed in the first Expert Panel meeting. The decision-making process was further refined by the research team and presented in a decision flowchart. The refined decision flowchart is discussed in the next subsection.

### 4.2.4 Decision Flowchart

The authors proposed a decision-making process that the maintenance personnel should go through when asked to perform a VSDO (Wang et al., 2012). The flowchart representing the decision-making process initially developed during the Expert Panel meeting was refined by the research team and is illustrated in Figure 25.

After the crew arrives at the work site, a quick judgment on whether to proceed with the work as a VSDO should be made based on the situation at that moment. In order to make a wise judgment, three questions must be answered successively. The answers will be reached by considering the important factors, such as traffic volume, traffic speed, time of day, type of roadway, weather condition, location of work, and pavement surface condition (see Section 4.2.3). Details of those three questions are described subsequently.

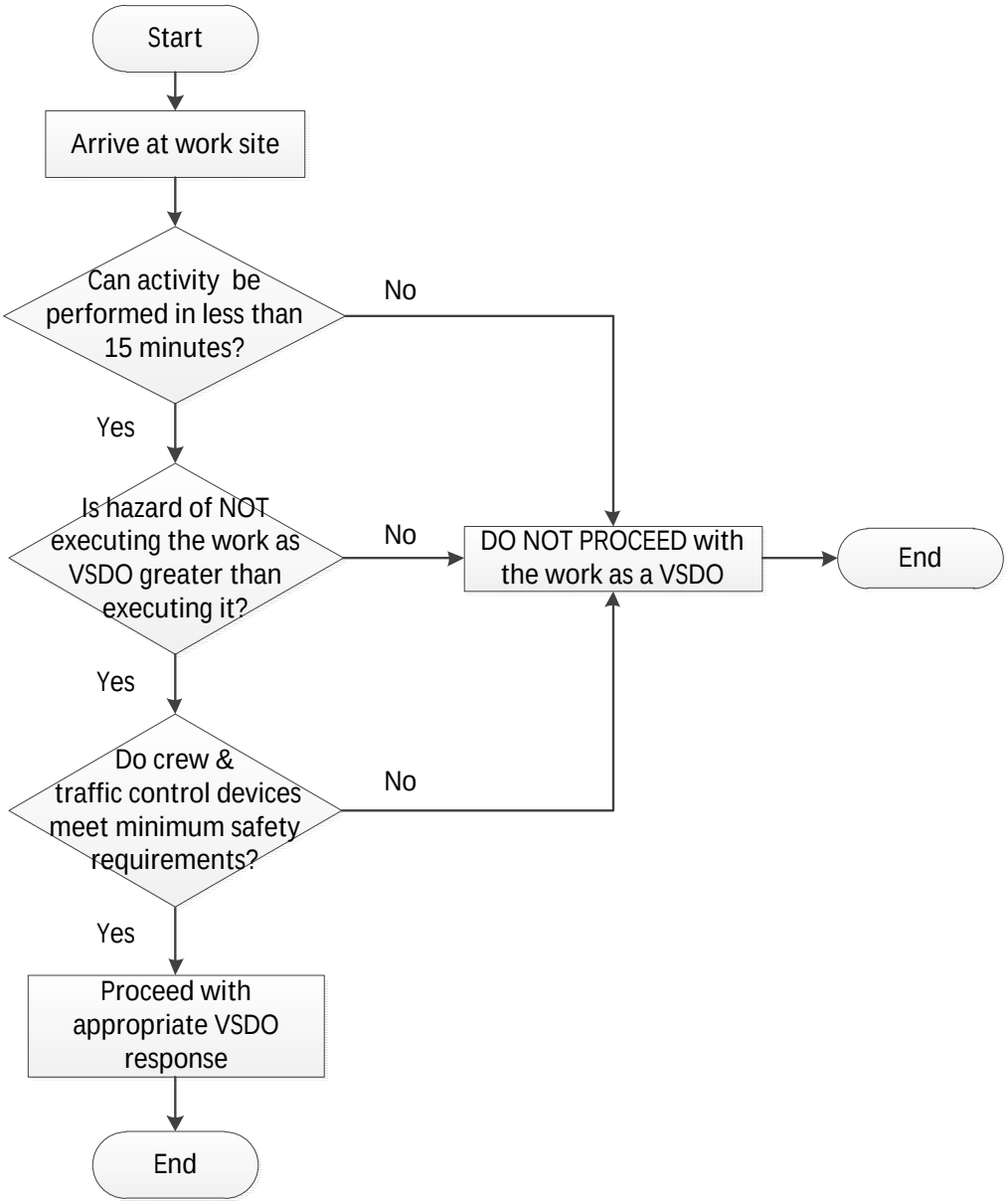



*Figure 25: Decision Flowchart for Proceeding with Work as a VSDO*

**Question 1: Can the activity be performed in less than 15 minutes?**
As explained in Section 4.2.1, VSDOs are usually performed within 15 minutes. If the task will take longer than 15 minutes to complete, then the crew should not proceed with the work as a VSDO. The workers should follow the instructions for that specific type of maintenance operation described in MUTCD. If the answer to this question is "yes," then continue with the next question.

**Question 2: Is the hazard of NOT executing the work as a VSDO greater than executing it?**
According to the definition of VSDOs, the hazard of *not* executing the work as a VSDO should be greater than executing it. If immediate execution of the work as a VSDO is hazardous to the

maintenance workers, then the recommendations suggest that work as a VSDO not proceed. A better option would be to perform the work later in a safer condition or after adequate assistance is obtained. The following situations are considered good reasons for not performing the task as a VSDO.

**1) The current situation is not dangerous to motorists.**
If temporarily leaving the situation as it is will not cause any danger to the traveling public, then the task could be suspended. For example, if a flat tire is located far beyond the shoulder, then suspending the work is fine if other unfavorable factors are in play (e.g., inadequate devices). However, if not executing the work leads to a hazard to the traveling public, then the work should be performed as soon as possible. For instance, previous interviews with traffic control center operators indicated that they consider an ordinary ladder dropped in the traveled way to be one of the most dangerous objects due to the potential effects of small cars hitting or driving over the ladder.

**2) The sight distance is inadequate for the worker.**
For example, picking up a dead animal at a sharp curve on a low volume high speed rural highway is highly dangerous, because it is difficult for the worker to observe the oncoming traffic and for the motorists to react appropriately upon sighting the maintenance crew.

**3) The traffic volume or traffic speed is high.**
If the traffic volume or speed is high, performing the task without enhanced safety equipment will be dangerous. Special devices or law enforcement involvement might be needed in this situation.

**4) Workers have no point of refuge.**
Observation 14 (picking up debris on a bridge) is a good example of this situation. Since the work location was on a concrete bridge, the worker was in the narrow space between the trucks and the concrete barrier. If the shadow truck were struck by an oncoming vehicle, the worker could have been trapped and killed.

**5) Weather condition is terrible for maintenance work.**
Examples include snowy or icy weather, or heavy fog.

**6) The light intensity is insufficient.**
Poor visibility poses safety hazards to both maintenance workers and the traveling public and thus the guidelines recommend that the crew not perform the work.

**Question 3: Do crew and traffic control devices meet minimum requirements?**
If the task can be completed within 15 minutes and the hazard of not executing it is greater than executing it, then the worker should determine whether the crew and traffic control devices meet the minimum safety requirements. A suggested list of minimum safety requirements developed with the Expert Panel is presented in Section 4.2.2. If crew and traffic control devices are insufficient for the task to be performed, then we recommend that they do not proceed. Each scenario is different, so minimum requirements may differ based on the operation. Workers should therefore proceed with the appropriate VSDO response for that particular scenario. For example, two workers and one truck mounted with a flashing light bar with high intensity might

be adequate for picking up a dead animal from the middle of a straight road in rural area, while picking up a dead animal within a traveled way with high traffic volume in urban area may require law enforcement involvement.

If the answers to all three questions are "yes," then performing the task is comparatively safe with appropriate VSDO response. Otherwise, the work should not be performed as a VSDO. If assistance is provided or the set of crew and equipment is modified or the safety condition changes, the worker(s) can go through the decision-making process again. For example, if the traffic volume or speed is high, the crew can suspend the work until the condition is favorable to perform the task; if the size of the object is unmanageable (e.g., cow), the task can be performed when effective equipment such as a back-hoe has arrived. However, some tasks should never be performed as VSDOs, such as repairing the damaged guardrail (which takes more than 15 minutes) or conducting maintenance work on a busy urban freeway.

## 4.3 Risk Management

The experts noted that workers are reluctant to utilize extensive traffic control during VSDOs because setting up adequate traffic control treatment usually takes longer than the work activity to be performed. Adequate safety is therefore a concern for both workers and motorists in VSDOs, because these activities have the potential to interrupt traffic flow and can pose a safety risk for both workers and drivers. In previous sections, the research team identified influencing factors affecting risk levels for maintenance workers and motorists during VSDOs. In Section 3.4, a risk management process that was designed to elicit risk mitigation strategies was documented. The risk management process includes five steps: 1) risk identification, 2) risk assessment, 3) risk analysis, 4) mitigation strategies, and 5) evaluation. In the subsequent sections, the types and sources of safety risks in VSDOs are first identified. Then, the identified risks are assessed and prioritized. Only the risks that are most likely to occur and have great impacts are considered in the subsequent analysis. The causes of those risks are analyzed and mitigation strategies are proposed.

### 4.3.1 Risk Identification

The first step in risk management is to identify types and sources of risk. A fault tree diagram was used for risk identification. Fault tree analysis is a top-down, deductive failure analysis that uses a graphical model of events to facilitate detailed analysis of system or component failure (Veseley, 1981). Figure 26 shows the fault tree diagram for safety risk identification during VSDOs. As shown in the diagram, if a worker misjudges the conditions of the roadway at the same time a motorist fails to properly control his/her vehicle, then an accident is likely to occur. The worker may misjudge the traffic volume, traffic speed, duration of work, or a combination of these factors. The driver may also fail to avoid an accident due to not seeing the worker or being unable to avoid hitting the worker after seeing the worker. The severity level of accident increases with the traffic speed. When the traffic speed is low, there is less danger; when the traffic speed is high, the consequences of an accident can be severe.

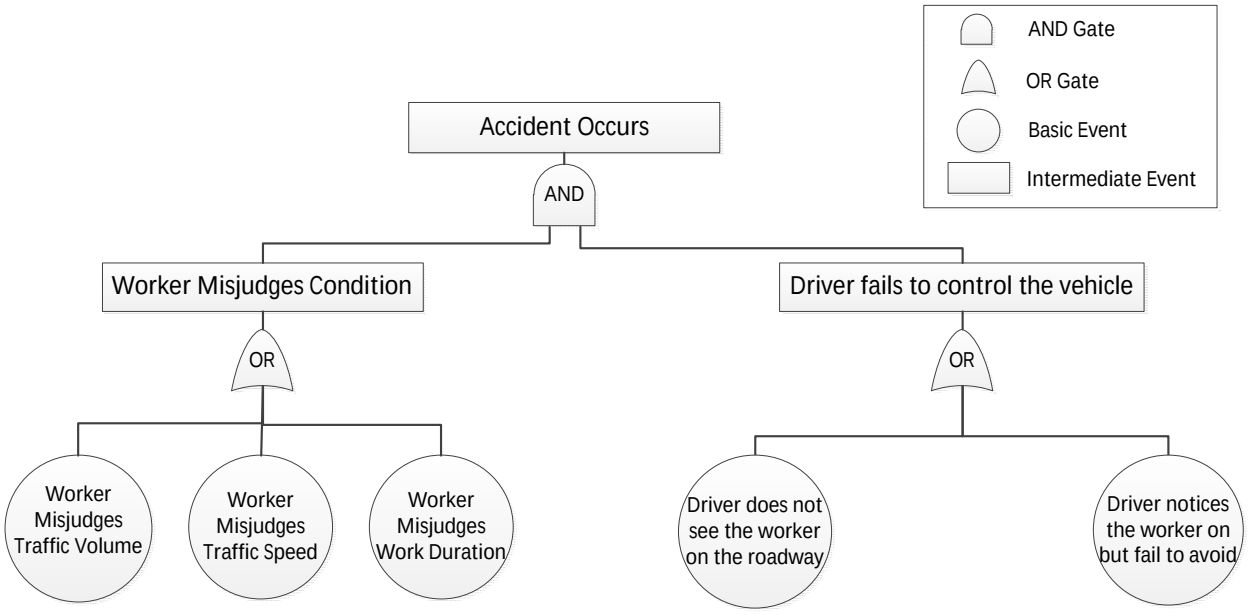



*Figure 26: A Fault Tree Diagram for VSDO Safety Risk Identification*

### 4.3.2 Risk Assessment

The second step is to assess and prioritize the identified risks. Risk assessment has two primary components: likelihood of occurrence and relative impact of the event. A risk matrix is used to illustrate the threat level, which is composed of the likelihood and impact of a risk (Figure 27). *Likelihood* is the chance that the risk will occur. *Impact* is the amount of damage that it would do were it to occur. The threat level increases as the likelihood and impact increases (represented by the x and y axes). The level of severity increases with the traffic speed. When the traffic speed is low, there is less danger; when the traffic speed is high, if an accident happens, the consequence can be severe. Among the risks identified above, the likelihood of workers misjudging work duration is comparatively low and the likelihood of the other risks happening is either medium or high, which needs further analysis. For the risk analysis, the research team focused on analyzing the probabilities of workers misjudging the traffic volume and speed and drivers failing to control the vehicle under medium or high traffic speeds.

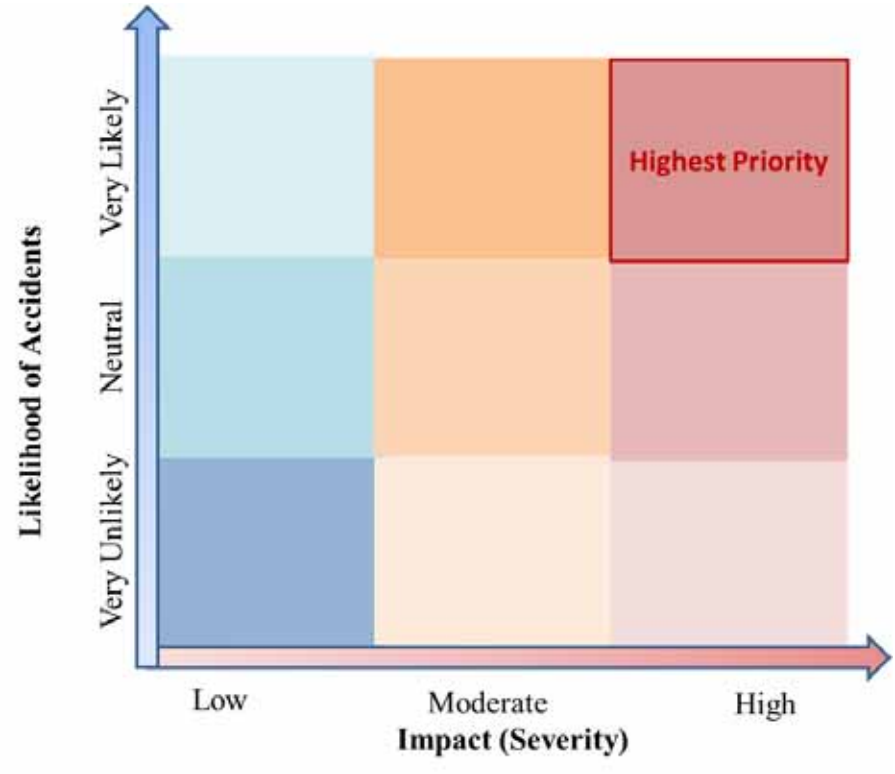



*Figure 27: Risk Matrix*

### 4.3.3 Risk Analysis

The third step is to analyze the prioritized risks in detail. As documented in Section 4.2.1, the Expert Panel agreed that if the risk involved in executing a task as a VSDO is greater than not executing it, workers should either reschedule the task or request additional help. Of the concerning factors that need to be considered when developing VSDO strategies, panel members identified traffic volume, traffic speed, time of day, and type of road as the four most important factors. A list of the factors that should be considered for VSDOs and their explanations were identified and ranked by order of importance, and this list was adopted for use in the decision matrix and is shown in Table 22.

**Table 22: Detailed Descriptions of the Influencing Factors**

| Ranking | Factor | Sub-dimension | Definition |
|---|---|---|---|
| 1 | Traffic Volume | High | Workers perceive that there is NOT enough time to walk to and from the work zone (between traffic) and finish the job safely |
| | | Medium | Workers perceive that there is enough time to walk to and from the work zone (between traffic) and finish the job safely, but with extra safety precautions |
| | | Low | Workers perceive that there is enough time to walk to and from the work zone (between traffic) and finish the job safely |
| 2 | Traffic Speed | High | Workers perceive that there is NOT enough time to walk to and from the work zone (between traffic) and finish the job safely |
| | | Medium | Workers perceive that there is enough time to walk to and from the work zone (between traffic) and finish the job safely, but with extra safety precautions |
| | | Low | Workers perceive that there is enough time to walk to and from the work zone (between traffic) and finish the job safely |
| 3 | Time of Day | Day | With sufficient visibility |
| | | Night | With limited visibility |
| 4 | Type of Road | Two-lane undivided | No median or other strip of land or divider separates the two directions of traffic |
| | | Multilane undivided | A multi-lane road with only striping (but no median) between the two directions of traffic flow |
| | | Multilane divided | A multi-lane road with a median or other type of divider between the two directions of traffic flow |
| 5 | Weather Condition | Clear | High visibility and good condition for outdoor maintenance work |
| | | Rain/fog/snow | Low visibility and poor condition for outdoor maintenance work |
| 6 | Vision-Blocking Objects | Yes | Curves, hills, or other objects that obstruct the view between workers in the work zone and the upcoming traffic |
| | | No | Nothing obstructs the view between workers in the work zone and the upcoming traffic |
| 7 | Location of Work | On or beyond the shoulder or in the median | Worker can perform the work without entering active travel lanes (e.g., picking up a dead pig on the shoulder) |

| Ranking | Factor | Sub-dimension | Definition |
|---|---|---|---|
| | | Within a traveled way with a shoulder | Worker has to perform the work by entering into the active travel lanes with a shoulder (e.g., removing tire scraps from the roadway with shoulders) |
| | | Within a traveled way without a shoulder | Worker has to perform the work by entering into the active travel lanes without a shoulder (e.g., picking up debris along the bridge without a shoulder) |
| 8 | Roadway Geometry | Straight and flat | Does not have vision-blocking objects; the speed of the upcoming traffic is predictable |
| | | Curves/hills | Has vision-blocking objects; the speed of the upcoming traffic is less predictable |
| | | Intersections | Has traffic coming from four different directions |
| 9 | Pavement Surface Condition | Dry | Maximum friction coefficient is available |
| | | Wet | Maximum friction coefficient is reduced |
| | | Icy | Maximum friction coefficient is greatly reduced |
| 10 | Availability of Refuge | Yes | Worker has a place to escape from potential traffic hazards |
| | | No | Worker does not have a place to escape from potential traffic hazards |

Traffic volume, traffic speed, time of day, and type of road are considered the most important factors for VSDOs because the variability of these four factors could be high and changes in any of these conditions will lead to major changes in solutions.

As mentioned in Section 4.2.3, workers may misjudge traffic conditions when traffic speeds are high and traffic volume is either low or medium (see Table 22 for description of traffic conditions). This scenario is mostly common in rural and FM roads.

Also, it was discussed in Section 4.2.3 that the probability of a maintenance worker misjudging a traffic condition decreases significantly when both traffic speed and volume are low. In addition, a maintenance worker can appropriately judge the work zone condition when the speed is low and traffic volume is high, but there is not enough time to safely execute the maintenance work as a VSDO.

Moreover, limited visibility (such as foggy weather) and icy pavement surface are other factors having an impact on a worker's judgment and the driver's ability to control their vehicles to prevent a work zone accident.

### 4.3.4 Mitigation Strategies

Safety precautions and guidance need to be provided and stressed in the risky scenarios in which accidents are likely to happen and the consequent severity is high. To be more applicable for

maintenance workers, the research team proposes a risk mitigation approach cen a scenario-based safety analysis, in compliance with the likelihood principle and therefore meeting the requirements of risk analysis. The proposed method helped the researchers to develop practical safety guidance for the most urgent cases and the results can easily be adjusted to efficiently deliver information to maintenance workers. This scenario-based safety analysis can provide useful guidance to the workers for proactive prevention of accidents in VSDOs. In the Expert Panel meeting, all scenarios were discussed with panel members to capture their opinion on safety recommendations. This scenario-based safety guidance can be included in a safety education program for TxDOT maintenance workers.

## 4.4 Scenario Development and Safety Recommendations

This section provides the results of scenario development and safety recommendations, which were refined in the second Expert Panel meeting. A scenario can be defined as a description of a possible set of conditions under which accidents are likely to occur. The objective of scenario-based hazard analysis is to stimulate thinking about possible dangerous conditions, possible accident occurrences, assumptions related to these occurrences, possible opportunities and risks, and courses of action. The results introduce the risky scenarios in which accidents are likely to occur and provide recommendations of additional safety precautions to the maintenance workers performing VSDOs in a limited set of scenarios. As mentioned in Section 4.2.3, many different factors influence VSDO conditions. If we blindly generate all possible scenarios using combinations of these factors, thousands of scenarios would result, which is neither manageable nor beneficial to the maintenance crews. Given 10 types of influencing factors, each with 2–3 subcategories, the total number of scenarios based on all possible combinations of factors is 11,664. The attempt to describe and provide safety recommendations for all possible scenarios is neither practical nor beneficial for implementation. In order to narrow the scope and still provide helpful guidance to the workers, these influencing factors need to be further refined and prioritized. As a result, different scenarios representing the most common and the worst-case VSDOs were developed. For each scenario, conditions of influencing factors such as traffic volume, traffic speed, time of day, type of road, weather condition, emergency/severity of danger, vision blocking, location of work, roadway geometry, pavement condition, and availability of refuge are described. In addition, safety recommendations for each scenario are provided.

In the following scenarios, traffic volume is defined according to these three levels:

a. *High*: There is not enough time to walk to and from the work zone and finish the job safely.
b. *Medium*: There is enough time to walk to and from the work zone and finish the job safely, but with safety precautions.
c. *Low*: There is enough time to walk to and from the work zone and finish the job safely.

### 4.4.1 Scenario I: Typical VSDOs on a Travel-Lane or Shoulder

#### Conditions

Researcher observations during shadowing activities indicate that a large portion of VSDOs are performed on straight roadways during clear days when traffic volume is medium or low and traffic speed is high. In this scenario, there is no vision-blocking issue (e.g., curve or hill) and a shoulder can be considered a refuge. See Table 23 and Figure 28.

#### Expert Panel Safety Recommendations

The minimum requirement for this scenario is one maintenance worker, with a truck equipped with a high-intensity light bar. Based on discussions in the Expert Panel meetings, the maintenance vehicle should be parked in a safe place. Experts believed that a shoulder is not a safe place and the vehicle should be parked as far away from traffic as is practical. Also, they mentioned that the vehicle should be parked before the work zone.

**Table 23: Summary of Scenario I**

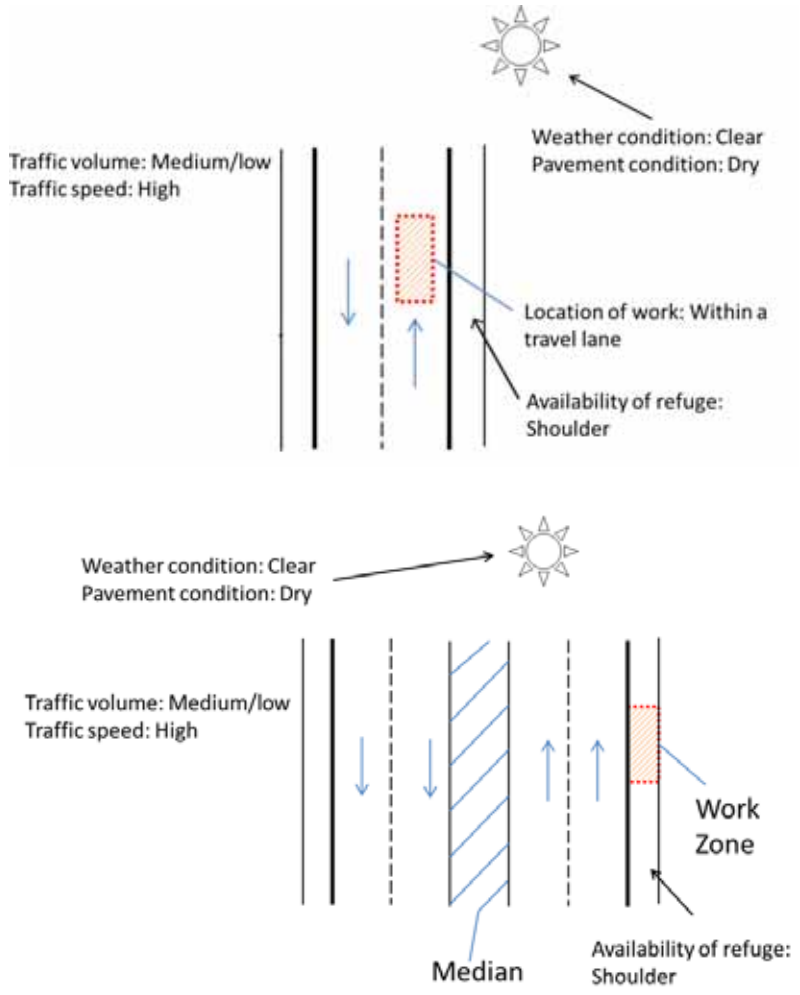
| | Description |
|---|---|
| Conditions |  |

*Figure 28: Scenario I Illustration*

| | |
|---|---|
| Safety Recommendations | • Minimum requirement<br>o One truck, one worker<br>o Truck should have a high-intensity light bar<br>• Where to park the maintenance vehicle?<br>o The closest possible parking space is favorable (in this situation, light bars would be more effective).<br>o A maintenance worker should park his vehicle on the same side where he wants to work.<br>• Minimum requirement<br>o One truck, one worker<br>▪ A worker should monitor oncoming traffic.<br>o Truck should have a high-intensity light bar.<br>• Where to park the maintenance vehicle?<br>o The maintenance vehicle should be parked in a safe place.<br>▪ The shoulder is not a safe place.<br>▪ Location should be as far away from traffic as is practical.<br>o The maintenance vehicle should be parked before the work zone. |

### 4.4.2 Scenario II: VSDOs with Vision-Blocking Geometry

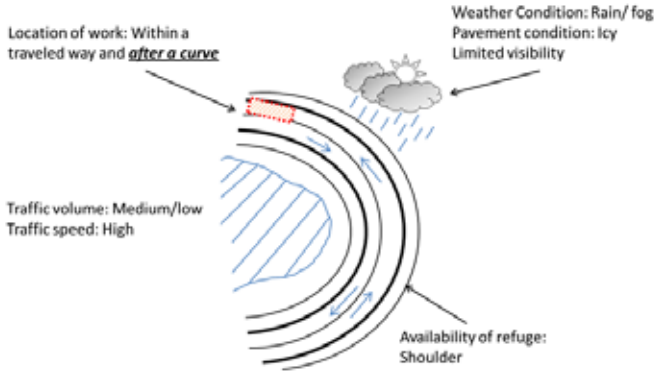
#### Conditions

This scenario presents a higher risk condition than Scenario I due to limited visibility because of vision-blocking geometry. Vision-blocking geometry alone significantly increases the risk of conducting VSDOs. This scenario also includes other risk factors such as icy pavement, high traffic volume and speed, and limited visibility because of weather conditions. See Table 24 and Figure 29.

#### Expert Panel Safety Recommendations

This scenario reflects an unsafe situation where extra precautions are required. In this situation, the risk of poor judgment on a worker's part is high. Also, a maintenance worker's judgment about conducting a VSDO is based on the gear and personnel available upon arrival at the work zone. For example, if a maintenance crew happens to consist of two workers, one worker can be used as a flagger. The flagger should have a view of the other worker, while remaining positioned before the curve/hill. Also, conducting the maintenance work as a VSDO depends on how much time a worker should spend doing the work and the work zone situation.

**Table 24: Summary of Scenario II**

| | Description |
|---|---|
| Conditions |  *Figure 29: Scenario II Illustration* |
| Safety Recommendations | • A flagger (if the crew has at least two workers)<br>o In this case, radio headset should be used for better communication between flagger and maintenance worker.<br>• Flare kits should be placed before the curve/hill.<br>• A flagger should use devices to increase his/her visibility, such as a safety baton and BlinkerStop flashing LED paddles.<br>• Special traffic sign<br>• Risk of making bad judgment is high.<br>• Could be done as a VSDO depending on the gear and personnel available upon arrival at the work zone |

### 4.4.3 Scenario III: VSDOs without Places of Refuge

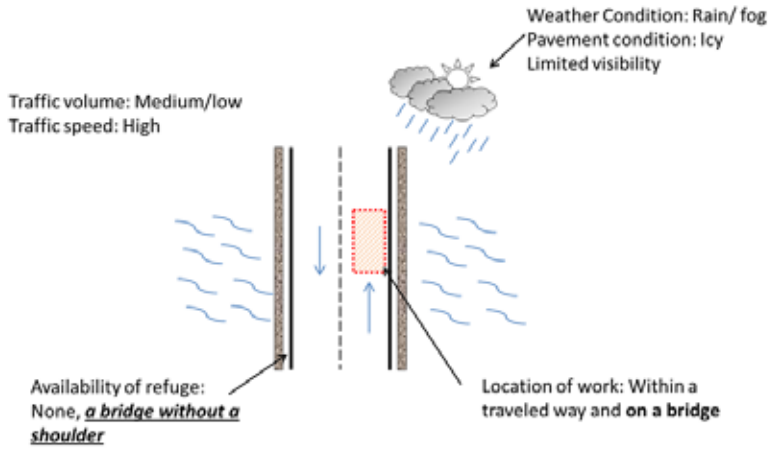
#### Conditions

This scenario reflects a higher risk condition than typical VSDOs (described in Scenario I) due to non-availability of refuge space. Non-availability of refuge alone significantly increases the risk of conducting a VSDO. This scenario also includes other risk factors such as icy pavement, high traffic volume and speed, and limited visibility due to weather conditions. See Table 25 and Figure 30.

#### Expert Panel Safety Recommendations

This scenario reflects an unsafe situation where extra precautions are required. In this situation, extra help is required because of unsafe conditions. If the traffic volume is low and visibility is not limited, the maintenance worker can conduct the maintenance work as a VSDO.

**Table 25: Summary of Scenario III**

| | Description |
|---|---|
| Conditions |  *Figure 30: Scenario III Illustration* |
| Safety Recommendations | • TMA<br>• Vehicle-mounted dynamic message signs<br>• In this situation, one additional worker should be used.<br>• Radio headset for communication<br>• This scenario represents a high-risk situation.<br>• Extra help is needed.<br>• If traffic volume is low and visibility is not limited, the work can be done as a VSDO. |

### 4.4.4 Scenario IV: VSDOs on Multilane Roadway without a Median

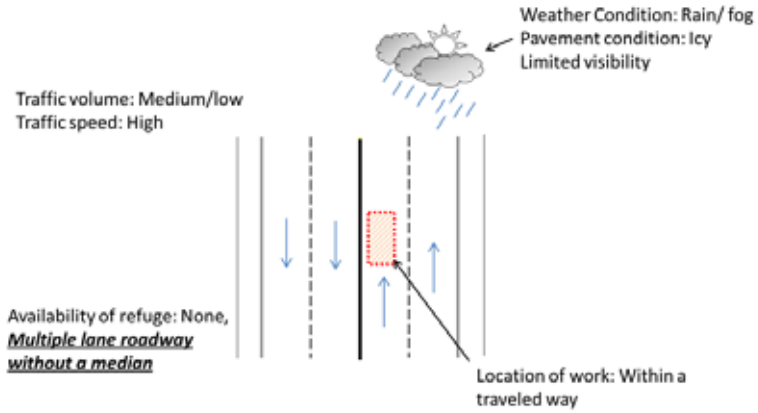
#### Conditions

This scenario reflects a higher risk condition than Scenario I due to location of work zone on a multilane roadway without a median. This scenario also reflects other risk factors such as icy pavement, high traffic volume and speed, and limited visibility due to weather conditions. See Table 26 and Figure 31.

#### Expert Panel Safety Recommendations

This scenario reflects a dangerous situation because the work zone is located on a travel-lane. If the traffic volume and speed is low, the task can be treated as a VSDO. In this case, the safety recommendations for Scenario I are applicable.

**Table 26: Summary of Scenario IV**

| | Description |
|---|---|
| Conditions |  *Figure 31: Scenario IV Illustration* |
| Safety Recommendations | • Two TMAs parked on both sides of the roadway<br>• Vehicle-mounted dynamic message signs<br>• This scenario represents a risky scenario because of work zone location.<br>• If traffic volume and speed are low, it can be done as a VSDO, applying the same safety recommendations as for Scenario I. |

### 4.4.5 Scenario V: VSDOs at an Intersection with Two-Way Roads

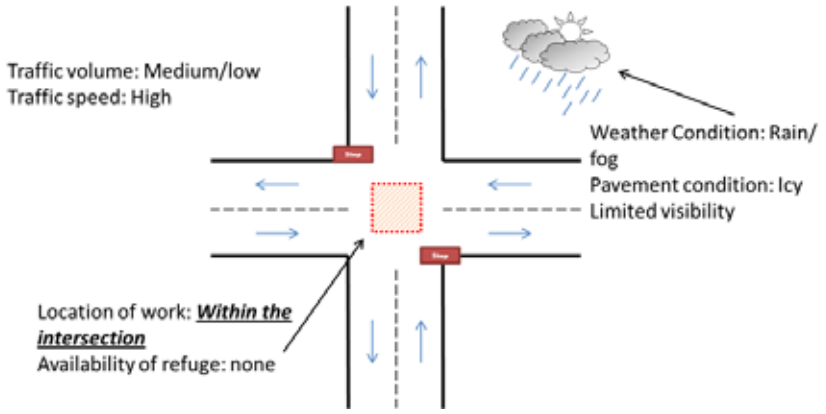
#### Conditions

This scenario reflects a higher risk condition than typical VSDOs (described in the Scenario I) due to work zone location at an intersection with two-way roads. This scenario also includes other risk factors such as icy pavement, high traffic volume and speed, and limited visibility because of weather conditions. See Table 27 and Figure 32.

#### Expert Panel Safety Recommendations

This scenario represents a risky situation. If traffic volume is low, this scenario can be treated as a VSDO. Also, if the particular work zone situation is judged to a low-risk situation, the work can be done as a VSDO. If a second worker is available, he can be used as a flagger. In this scenario, a maintenance vehicle should be parked in one of the intersection corners.

**Table 27: Summary of Scenario V**

| | Description |
|---|---|
| Conditions |  *Figure 32: Scenario V Illustration* |
| Safety Recommendations | • Two TMAs parked on both sides of the roadway<br>• Vehicle-mounted dynamic message signs<br>• Two flaggers<br>  ○ In this case, radio headset should be used for better communication between flagger and maintenance worker.<br>• Portable message signs to be installed before the intersection<br>• If traffic volume is low, it can be done as a VSDO.<br>• If the work zone condition represents a low-risk situation, it can be done as a VSDO.<br>• A maintenance vehicle can be parked in one of the intersection corners. |

## 4.5 Validation Step

To evaluate the proposed scenario-based risk management, a pilot workshop was held in the TxDOT offices in Austin, TX on July 17, 2012. The workshop was attended by 23 individuals from different districts specializing in different areas: safety, maintenance, and operations supervision. The average experience of participants was 17 years. The workshop comprised five different stages:

1. **Pre-workshop assessment to evaluate the current knowledge of participants about risk factors during VSDOs.** The assessment, shown in Appendix D, included questions on risk factors that participants would consider for provided scenarios.
2. **The definition of VSDOs and activities that should and should not be considered VSDOs.** The definition and activities were described in the introduction section.
3. **The importance of risk assessment during VSDOs.** Participants discussed how performing VSDOs can be very risky due to limited time for decision-making, negligence

of maintenance workers, limited traffic control devices, ambiguous scope of the work zone, and unpredictable conditions such as traffic speed, traffic volume, and weather condition. Also mentioned was that accidents are likely to occur in cases of poor judgment by both maintenance workers and drivers.

4. **Illustration of proper ways to assess risks and make better judgments during VSDOs.** Factors that will increase the probability of accidents during VSDOs are limited visibility due to foggy and rainy weather, icy pavement, and medium/low traffic volume and high traffic speed.
5. **Post-workshop assessment to evaluate the learning outcomes of the workshop.** The assessment, shown in Appendix E, included asking about risk factors for the same scenarios used in the pre-workshop assessment. The assessment also asked participants to provide comments about the workshop as well as evaluating the workshop's practicality.

*Figure 33: Pictures of the Workshop*

The results of pre- and post-workshop evaluation revealed that the workshop successfully highlighted risks of VSDOs. Participants mentioned more risk factors for each scenario in the post-workshop assessment than in the pre-workshop assessment. For example, results showed that the mean of risk factors listed for the pre-workshop assessment was 3.6, while participants listed 4.0 risk factors in the post-workshop assessment, on average.

In addition, Table 28 shows risk factors and number of occurrence for each risk factor based on the results of pre-workshop and post-workshop assessments. Table 28 indicates that in the pre-workshop assessment, the most mentioned risk factors are traffic volume, traffic speed, and weather condition, while work duration, roadway geometry, location of objects, and length of bridge are the least mentioned risk factors. In the post-workshop assessment, traffic volume, traffic speed, weather condition, size of objects to be removed, and escape route were the most mentioned risk factors. These factors were noted in the post-workshop assessment 32% more than in the pre-workshop assessment.

**Table 28: Risk Factors and the Number of Occurrence for Risk Factors based on Pre- and Post-Workshop Assessments**

| Risk Factors | Number of Occurrence | |
|---|---|---|
| | Pre-workshop Assessment | Post-workshop Assessment |
| Weather | 20 | 26 |
| Pavement Condition | 10 | 12 |
| Traffic Volume | 38 | 38 |
| Traffic Speed | 22 | 28 |
| Road Geometry | 3 | 3 |
| Shoulder Width | 10 | 6 |
| Parking Location | 14 | 14 |
| Sight Distance | 17 | 17 |
| Size of Objects | 10 | 20 |
| Location of Objects | 3 | 5 |
| Availability of Tools | 4 | 2 |
| Help | 4 | 10 |
| Hazard to Public | 10 | 6 |
| Work Duration | 2 | 6 |
| Escape Route | 13 | 18 |
| Time of Day | 8 | 6 |
| Length of the Bridge | 2 | 3 |

Moreover, participants strongly agreed that the workshop was the right length and speakers encouraged questions and comments. Participants also agreed that the workshop was well organized, clear, understandable, and worth their time. In addition, attendees agreed that

speakers were knowledgeable about the topic and the provided handouts during the workshop were useful. Furthermore, post-workshop evaluation comments indicated that, if a similar workshop were administered by TxDOT employees, it should be given by operation and maintenance supervisors. Also, supervisors should empower field workers in identifying risks during VSDOs and requesting additional help when activities are considered non-VSDOs, based on the proposed definition.

At the end of the workshop, the research team distributed a safety guidebook for VSDOs. The aim of developing the safety guidebook was to complement training modules that will educate maintenance workers on identifying work zone hazards. Identifying risk factors in VSDOs helps maintenance workers to better judge the condition of VSDOs and make more informed decisions on whether to conduct an operation as a VSDO or not. The safety guidebook provides details and findings of shadowing activities conducted to reveal the current practice of VSDOs at TxDOT. The guidebook also presents a risk management process that enables maintenance workers to identify work zone hazards for VSDOs and improve their judgment about work zone conditions. Multiple scenarios illustrating the risks are presented in the guidebook, and related safety recommendations are also discussed.

Furthermore, a VSDO pocket card designed by the research team was handed to participants in the workshop. The pocket card, shown in Figure 34, highlights the definition of VSDOs as well as risk factors that maintenance workers should consider during VSDOs.

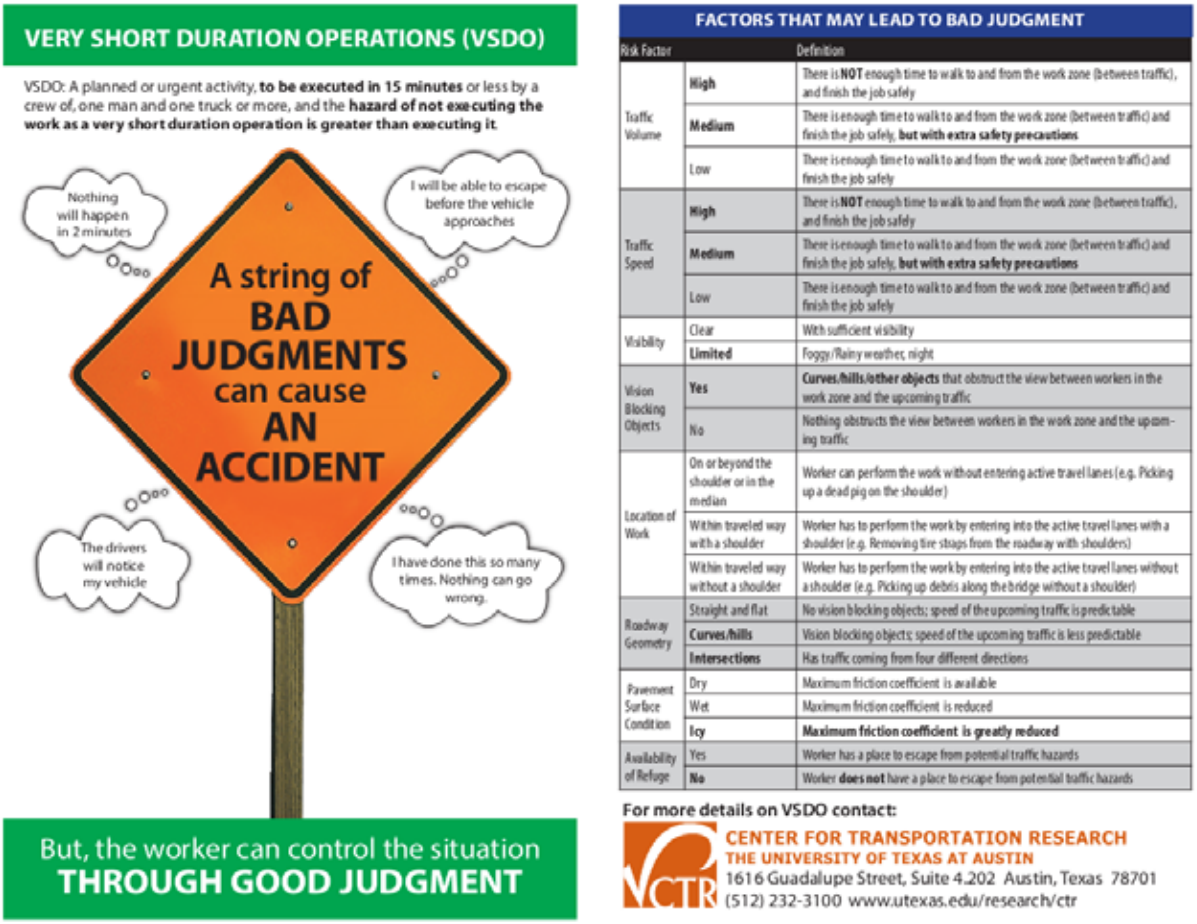



*Figure 34: The VSDO Pocket Card*

# 5. Final Remarks

This study has established a VSDO definition and described typical VSDOs. A VSDO is defined as a planned or urgent activity, to be executed in 15 minutes or less by a crew of at least one worker and one truck, in which the hazard of not executing the work as a VSDO is greater than executing it. This study has also refined the influencing factors affecting maintenance workers' judgment and drivers' ability to control their vehicle based on the Expert Panel meeting. In addition, this study proposed a scenario-based risk management process for safety analysis in work zones during VSDOs. The research team believed the scenarios-based safety guidance will provide efficient and effective training that ensure worker safety in VSDOs, especially when workers are inexperienced and their judgment skills are at an early stage of development.

In addition, this study provided safety recommendations for developed scenarios based on discussions in the Expert Panel meeting. Based on the Expert Panel meeting, the worst-case scenarios represent much higher risk than the most common scenarios. Also, panel members believe that if additional traffic devices or extra help is required, the operation can no longer be categorized as a VSDO. In addition, the cut-off line between executing the work as a VSDO or not depends on worker judgment. Hence, the Expert Panel recommended training workers to better identify risk factors in VSDOs.

As a validation step for the proposed risk management process, the feedback resulting from the discussions and assessments used in the workshop indicated that practitioners were generally supportive of the scenario-based risk management process described in Section 4.3. Also, participants mentioned that the training process must start from supervisors, in order to get full buy-in from their workers.

# 6. Recommendations and Future Work

The review of current literature identified very few specific references to VSDOs and those references provided very little specific guidance. The shadowing findings suggest that current guidance for VSDOs and temporary traffic control devices used in VSDOs are insufficient to protect workers and motorists. The need for recognizing VSDOs as a separate type of work zone maintenance operation was identified. Based on the recommendations from the literature and the Expert Panel, the authors devised a definition for VSDOs, proposed a flowchart for deciding when to proceed with the work as a VSDO, and suggested a list of minimum safety requirements for VSDOs. Future work includes further analysis of the factors that impact safety in VSDOs and the identification of effective traffic control devices.

## 6.1 Technologies and Methods for Minimizing Risk to Workers in VSDOs

Table 29 lists the devices identified by the research team for minimizing risk to workers in VSDOs. These devices are characterized into five different categories: Warning Devices, Making Trucks More Visible, Making Workers More Visible, Making Barriers More Visible, and Other Devices.

1. **Warning Devices**: These devices are used for warning the traveling public about an ongoing operation. For example, the Sonoblaster® Work Zone Intrusion Alarm, shown in Figure 35, warns errant vehicle drivers and worker crews to help prevent crashes and injuries in work zones when the vehicle hits safety signs. As another example, BlinkerStop Flashing LED Paddles, shown in Figure 36, allows the STOP sign to get easily noticed up to 2 miles away.

*Figure 35: Sonoblaster® Work Zone Intrusion Alarm*


*Figure 36: BlinkerStop Flashing LED Paddles*

2. **Making Trucks More Visible**: Right now, equipment installed on some TxDOT vehicles seems insufficient and, in some cases, cannot draw the attention of other drivers. For example, Figures 37 and 38 show TxDOT trucks used for installing and maintaining signs. As is shown in Figures 37 and 38, light bars and narrow fluorescent straps are the only safety equipment installed on this truck. This safety equipment is not visible enough for traveling vehicles and cannot work well as warning devices. Light bars, for example, cannot be seen from the back of the truck. Hence, more safety devices should be installed on TxDOT trucks to make them more visible.


*Figure 37: Backside of Truck Used for Installing Signs*

*Figure 38: The Other Side of Truck Used for Installing Signs*

In addition, during the researchers' shadowing activities, most maintenance workers expressed concern about the devices used to make their trucks more visible. In particular, they were concerned about the light bars installed on trucks. As shown in Figures 39–45, many different light bars are installed on TxDOT's vehicles. These light bars are not bright enough during daytime, and therefore need to be replaced. TxDOT is in the process of replacing them with new LED light bars (shown in Figure 46) that can draw the attention of drivers so they might be motivated to slow down and be more cautious when approaching workers performing VSDOs.

*Figure 39: Small Light Bar, Two Rotary Amber Lights, and Small Amber Lights in front of the Cabin*

*Figure 40: Small Light Bar and Two Rotary Amber Lights*

*Figure 41: Small Light Bar and Two Rotary Amber Lights*

*Figure 42: Small Light Bar, Two Rotary Amber Lights, and Arrow Lights*

*Figure 43: Large Light Bar*

*Figure 44: Another Type of Large Light Bar*

*Figure 45: Large Light Bar and Two Rotary Amber Lights*

*Figure 46: New LED Light Bars*

Moreover, maintenance workers suggested installing a red-and-blue light bar, similar to light bars used by DPS vehicles. In their opinion, the traveling public pays more attention to DPS light bars, responding by changing lanes and reducing their speed. Although TxDOT is not authorized to use red-and-blue light bars, the Oklahoma Department of Transportation (ODOT) has been authorized to use red-and-blue rear facing light bars (Pauls Valley Democrat, 2011).

In order to better understand the possible impact on maintenance workers' safety due to ODOT's use of red-and-blue light bars in maintenance vehicles, the research team contacted Brian Taylor, Division Two Traffic/Maintenance Engineer. According to Bryan Taylor's response, ODOT employees stated that red-and-blue light bars are the most important safety item they have. Employee testimonials noted drivers' slower speeds through and approaching work zones.

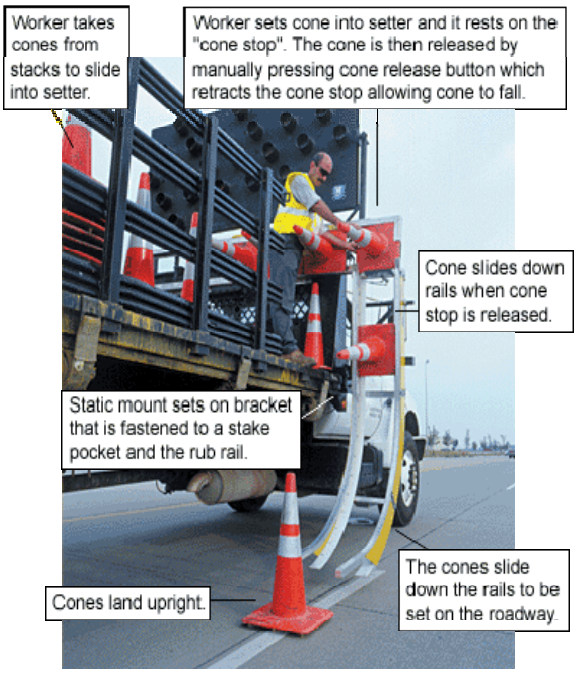
3. **Making Maintenance Workers More Visible**: Currently, some TxDOT maintenance workers wear only fluorescent safety vests and hard hats as safety clothing. However, the TxDOT warehouses stock full-length reflective trousers, as well as Class 3 vests that have more reflective material and background material than the standard Class 2 vests. Both are available for use. The pants, when added to a Class 2 vest, create a Class 3 ensemble.
   In order to increase the visibility of maintenance workers to travelling public, three items are included in Table 29. For instance, the gloves shown in Figure 47 can be seen up to ¼ mile away during both day and night; using this type of gloves can make maintenance workers and flagger-people more visible to the travelling public.


*Figure 47: A Flagger Wearing a GloGlove*

4. **Making Barriers More Visible**: The installation of signs and safety barriers is considered a VSDO. As a result, installing equipment on safety barriers to make them more visible for the travelling public may be a good way to increase the attention of moving traffic. Installing a Solar Strobe (Figure 48) on top of a traffic safety cone, for example, makes cones visible for up to 1640 ft.

*Figure 48: A Solar Strobe*

5. **Other Devices**: These devices can be used during VSDOs. For example, a Cone Setter and Cone Retriever can be used for automating the placement and retrieving of cones (Figures 49 and 50). As a result, a worker does not need to hang off the side of the truck and jump on and off to set and retrieve tipped cones. In another example, maintenance workers do not need to leave the work zone to use their radio system if they have radio headsets (Figure 51). In addition, these headsets provide noise reduction with use of NoisEzsm Ear Tips. As a result, these headsets can be used in both high and low noise environments. Another device that may be appropriate in some very high speed metropolitan environments is the use of a mobile barrier.




Source: Epic Solutions, 2011a

*Figure 49: Cone Setter*


Source: Epic Solutions, 2011b

*Figure 50: Cone Retriever*

*Figure 51: Radio Headset*

In general, for incorporating devices included in Table 29, two criteria should be considered: **applicability** and **cost/benefit ratio** of devices. Applicability and the cost/benefit ratio vary depending on the district and location where devices will be used. For example, although a Mobile Barrier Trailer may be an appropriate device for highways with high traffic volume, such as IH 35, it is not as useful for rural areas, such as the Lufkin and Odessa districts. Mobile Barrier Trailers block an entire lane, making them impractical for rural areas where most of the roads are two-lane undivided. Further, a Mobile Barrier Trailer is an expensive device, costing approximately $200,000, and thus might not be feasible due to budget constraints. In more rural districts, investing in equipping trucks with more cost-effective devices is a better approach. Table 29 lists such devices, such as the Super Arrowstik™ with Standard Control Module, Portable Arrow Light, and Remote Controlled LED Traffic Director and Warning Bar with Remote.

## Table 29: List of Devices

| | Category | Name | Manufacturer | Description | Properties | Applications | DOT & Traffic Safety Compliance | Reference | Image |
|---|---|---|---|---|---|---|---|---|---|
| **1** | Warning Devices | LED Road Flare Kit | Aervoe | An emergency flare that does not produce a flame, smoke, or harmful by-products and does not require batteries. Flares will be charged and ready for use when needed. | **1.** 16 super bright red LEDs are visible up to ½ mile<br>**2.** 9 flashing patterns including SOS Rescue<br>**3.** Powerful magnet to attach to metal surfaces<br>**4.** Made of durable materials, crush proof, corrosion proof | **1.** Identify road hazards<br>**2.** Signal for help<br>**3.** Mark detours, underwater scuba, or repair applications<br>**4.** Ideal for emergency responders | **1.** U.S. DOT (FMCSA) 49 CFR 392.25 & 393.95 (g)<br>**2.** MUTCD Type A (flashing) and Type C (solid on)<br>**3.** NFPA 1901 Standards for Traffic Safety, Section 6.7.3 Miscellaneous Equipment. | www.aervoe.com/paints_coatings/LED-Road-Flare-Kit-6-pack.html |  |
| **2** | Warning Devices | LED Barton Road Flare Kit | Aervoe | The emergency safety flares that replace standard safety wands and incendiary flares. Use of these safety flares reduces the risk of fires, ground water contamination, and batteries in our landfills. | **1.** 15 LEDs visible up to ½ mile<br>**2.** Crush proof<br>**3.** Corrosion proof<br>**4.** High strength magnets attach to metal surfaces<br>**5.** 5 Flash patterns including S.O.S. Morse Code | Emergency safety flare that can be held in hand or placed on the ground to identify road hazards, signal for help, mark detours, or direct traffic | - | www.aervoe.com/paints_coatings/LED-Baton-Road-Flare-Kit.html |  |

| | Category | Name | Manufacturer | Description | Properties | Applications | DOT & Traffic Safety Compliance | Reference | Image |
|---|---|---|---|---|---|---|---|---|---|
| **3** | Warning Devices | Safety Mirrors with Portable Stand | Roadtech Manufacturing Traffic Safety Consultants | For operation after or on curves, travelling traffic can be informed of operation. | **1.** 20% brighter than glass mirrors<br>**2.** Less distortion<br>**3.** Longer lasting | Moving traffic can be informed of operation after curve. | - | www.roadtech.com/ mirrors_new.html |  |
| **4** | Warning Devices | Traffic Guard Portable Speed Bumps | Astro Optics Corp. | The Traffic Guard is a portable speed bump system that is designed to temporarily control traffic flow. | **1.** All weather self-contained speed bump<br>**2.** Relocate from site to site<br>**3.** Eliminate maintenance problems associated with permanent speed bumps | Providing traffic control for temporary traffic patterns and emergency situations | - | www.astrooptics.com/ portablespeedbump.htm |  <br>  |
| **5** | Warning Devices | BlinkerStop Flashing LED Paddles | Astro Optics Corp. | It allows the STOP sign to get easily noticed. The LEDs match the STOP signs' color and shape so drivers will immediately recognize the red flashing octagonal message. | **1.** LEDs alert drivers up to 2 miles away<br>**2.** Lightweight and durable | It can be used during poor weather conditions or in areas of low light. | - | www.astrooptics.com/ paddle.html |  |

| | Category | Name | Manufacturer | Description | Properties | Applications | DOT & Traffic Safety Compliance | Reference | Image |
|---|---|---|---|---|---|---|---|---|---|
| **6** | Warning Devices | Portable Variable Message Board | Protection Services Inc. | It increases warning to moving traffic. | **1.** It utilizes LED technology<br>**2.** Easy programming<br>**3.** It utilizes solar power to extend the run time between charging<br>**4.** 18 inch letters | It increases warning to moving traffic. | NTCIP Compliant | www.protectionservices.com/TrailerProducts/SolarAssistVariableMessageBoards/SMC1000HE/tabid/162/Default.aspx |  |
| **7** | Warning Devices | Automated Flagger | Synergy Technology, LLC | It is a portable system for work zone traffic control to increase warning to passing traffic. | **1.** Signal lights<br>**2.** Warning horn<br>**3.** Solar and control panel<br>**4.** Gate arm | It increases warning to moving traffic. Also, it reduces labor cost and human errors. | Some types such as AF-100 meets the 2009 FHWA MUTCD Section 6E.04 specifications | www.noflaggers.com/Brochure00928/Default.html |  |

| | Category | Name | Manufacturer | Description | Properties | Applications | DOT & Traffic Safety Compliance | Reference | Image |
|---|---|---|---|---|---|---|---|---|---|
| **8** | Warning Devices | Sonoblaster® Work Zone Intrusion Alarm | Transpo Industries, Inc. | It is an impact-activated safety device that warns work crews and errant vehicle drivers simultaneously to help prevent crashes and injuries in work zones. Upon impact of an errant vehicle, the SonoBlaster's built-in $CO_2$-powered horn blasts at 125 dB to signal workers that their protective zone has been violated, giving them critical reaction time to move out of harm's way. | **1.** Built-in $CO_2$-powered horn<br>**2.** Ready to use with a simple keychain tool<br>**3.** It can be mounted on typical work zone barricades, cones, drums, delineators, etc. | **1.** Construction zones<br>**2.** Maintenance zones<br>**3.** Flagger protection<br>**4.** Stripping and marking<br>**5.** Patching/ pothole repair<br>**6.** Sweeping and cleaning | NCHRP 350 acceptance | www.transpo.com/ SonoBlaster.html |  |
| **9** | Warning Devices | W1-AG Automated Flagger Assistance Devices | IntelliStrobe Safety Systems | Highly visible device, stand-alone lane intrusion device | **1.** Siren alarm<br>**2.** High visibility LED signals<br>**3.** Hand-held remote transceiver | It increases warning to moving traffic. | **1.** FHWA & MUTCD 2009 approved<br>**2.** NCHRP 350 | www.flaggersafety.com/ AFAD_products.php |  |

| | Category | Name | Manufacturer | Description | Properties | Applications | DOT & Traffic Safety Compliance | Reference | Image |
|---|---|---|---|---|---|---|---|---|---|
| **10** | Warning Devices | Safety Baton | Roadtech Manufacturing Traffic Safety Consultants | It makes flagger more visible. | **1.** Batteries last up to 100 hours<br>**2.** LED lights are visible up to 3000 yards away<br>**3.** Flashing slow, fast, and steady | It increases visibility of maintenance workers. | - | www.roadtech.com/ batons.html |  |
| **11** | Making trucks more visible | Towman's Justice® LED Low Profile Lightbar | AWDirect | It increases visibility of trucks. | **1.** 10 amber LED modules<br>**2.** Two halogen work lights<br>**3.** Two LED stop/tail/turn lights<br>**4.** 52 patterns changing about every 10 seconds | It increases visibility of trucks. | - | www.awdirect.com/ towmans-justice-led -low-profile-lightbar- jf0baaaa/full-size- lightbars/ |  |
| **12** | Making trucks more visible | Portable Arrow Light | TRAFCON | Because of light weight, low cost, and portability, it can be used by maintenance workers to warn travelling vehicles when truck-mounted arrow boards are not available. | **1.** Light weight<br>**2.** Portability<br>**3.** Low cost | It can be used for all VSDO activities. | - | www.trafcon.com/ portable_arrow_ light.php |  |

| | Category | Name | Manufacturer | Description | Properties | Applications | DOT & Traffic Safety Compliance | Reference | Image |
|---|---|---|---|---|---|---|---|---|---|
| **13** | Making trucks more visible | Remote Controlled LED Traffic Director & Warning Bar With Remote | AWDirect | Flashing warning and traffic arrow directional signals in the same bar. | **1.** Wireless remote to control bar<br>**2.** Eight LED modules provide exceptional visibility day & night<br>**3.** Low profile design fits just about anywhere on trucks | It increases warning to moving traffic. | - | www.awdirect.com/remote-controlled-led-traffic-director-warning-bar-w-remote-aw-direct-awl1/arrow-directional-lights/ |  |
| **14** | Making trucks more visible | Super Arrowstik™ w/ Standard Control Module | AWDirect | It can flash patterns to direct motorist away from trucks. | **1.** An intense warning signal visible from over 1/2 mile away<br>**2.** LED lights<br>**3.** A low profile design that permit easy mounting | It increases warning to moving traffic. | - | www.awdirect.com/super-arrowstik-w-standard-control-module-as47lh/arrow-directional-lights/ |  |
| **15** | Making trucks more visible | Conspicuity Markings | 3M | It increases visibility of trucks to passing traffic. | **1.** Durable—resists weather, dirt, and aging<br>**2.** Aggressive adhesive<br>**3.** Non-corroding | It increases visibility of trucks. | DOT certified and guaranteed to meet and exceed NHTSA requirements | solutions.3m.com/wps/portal/3M/en_US/Traffic_Safety/TSS/Offerings/Products/Veh_Conspicuity_Markings/ |  |

| | Category | Name | Manufacturer | Description | Properties | Applications | DOT & Traffic Safety Compliance | Reference | Image |
|---|---|---|---|---|---|---|---|---|---|
| **16** | Making trucks more visible | Vehicle mount Arrow Panels | Traffic Control Service | It increases warning to moving traffic. | **1.** It utilizes LED technology<br>**2.** 15 or 26 lamps<br>**3.** Controller in truck cab | It increases warning to moving traffic. | - | www.tcsi.biz/pdf/Arrow%20Board,%20Roof%20Mounted/RoofMountedArrowBoard.pdf |  |
| **17** | Making trucks more visible | Vehicle mount Dynamic Message Signs | Traffic Control Service | It increases warning to moving traffic. | **1.** It utilizes LED technology<br>**2.** It displays one, two, three or four line messages<br>**3.** It displays symbols, moving arrows, graphics, and logos | It increases warning to moving traffic. | - | www.tcsi.biz/pdf/Arrow%20Board,%20Roof%20Mounted/RoofMountedArrowBoard.pdf |  |
| **18** | Making barriers more visible | Solar Strobe/Signal Light | Aervoe | Solar powered flare sits on top of a rubber traffic safety cone. Charge it all day in the sunlight and in low light it will automatically start to strobe and warn of potential danger. | **1.** 4 LED flashing light is visible up to 1640 ft<br>**2.** Large solar charging panel<br>**3.** Weatherproof | Mount to walls, barricades, rubber traffic cones, signs and poles | Meets MUTCD | www.aervoe.com/paints_coatings/Solar-Strobe-Signal-Light.html |  |
| **19** | Making barriers more visible | LED Safety Cone Light | Aervoe | It fits on top of the collapsible safety cone to make it more visible. | **1.** It can be seen up to 1000 feet away<br>**2.** A light beacon for the top of the cone for greater night visibility | It makes cones more visible | - | www.aervoe.com/paints_coatings/LED-Safety-Cone-Light.html |  |

| | Category | Name | Manufacturer | Description | Properties | Applications | DOT & Traffic Safety Compliance | Reference | Image |
|---|---|---|---|---|---|---|---|---|---|
| **20** | Making barriers more visible | Traffic Cone Flashing Light | emedco | Traffic cone yellow flashing light adds an extra alert in the dark. | **1.** Adds increased visibility to traffic cones in the dark<br>**2.** Mounts to any traffic cone 18"h or taller | Traffic cone yellow flashing light adds an extra alert in the dark. | - | www.emedco.com/ traffic-cone-flashing-light-fcl2.html |  |
| **21** | Making barriers more visible | Cylindrical Flashing Amber Light | emedco | Cylindrical flashing amber lights call extra attention to barricades and can be seen from any angle. | Cylindrical flashing amber light allows 360 degree visibility and includes mounting bolt and wrench<br>2. 5" dia. x 6"h | It calls extra attention to barricades and traffic safety. | - | www.emedco.com/ cylindrical-flashing-amber-light-tl2.html |  |
| **22** | Making barriers more visible | Circular Flashing Amber Light | emedco | It calls extra attention to barricades. | 7" diameter circular flashing amber light includes mounting bolt and wrench | It calls extra attention to your barricades and traffic safety. | - | www.emedco.com/ circular-flashing-amber-light-bl-s. html |  |
| **23** | Making maintenance worker more visible | Reflective Arm Bands | Stinson Equipment | It increases visibility of maintenance workers. | It can be used by all maintenance workers | It increases visibility of maintenance workers. | - | www.stinson.ca/ product_details.php? category_id=155& item_id=942&tab=desc |  |
| **24** | Making maintenance worker more visible | Guardianwear Safety Legging | Astro Optics Corp. | It allows maintenance workers to be seen better. | **1.** Made out of breathable 100% polyester-mesh fabric for extra comfort and coolness<br>**2.** One size fits all | It can be used to make workers more visible to passing traffic. | - | www.astrooptics.com/ guardian.htm |  |

| | Category | Name | Manufacturer | Description | Properties | Applications | DOT & Traffic Safety Compliance | Reference | Image |
|---|---|---|---|---|---|---|---|---|---|
| **25** | Making maintenance worker more visible | GloGlov | GloGlov USA | It increases visibility of maintenance workers. | Can be seen day or night, up to ¼ mile away | It is designed for traffic-directing and rescue-signaling professionals. | - | www.gloglov.com/ USA/index.html |  |
| **26** | Other | Mobile Barrier Trailer | Mobile Barriers | The Mobile Barrier Trailer allows the workers to be fully protected in all types of work zones. It also reduces setup and total time in work zones. | Equipment such as portable power/night lighting, on-board generator, message board, arrow board, and radar can be installed on the trailer | Can be used for all types of operations | Crash tested and accepted by FHWA for use on the National Highway System under both NCHRP350 & the new MASH Standards at both TL-2 and TL-3 Levels | www.mobilebarriers.com/ specs.htm |  |
| **27** | Other | Hurricane II Headset for Motorola Radios | HiTech Wireless | The Hurricane II headset is designed to provide the performance of a heavy duty headset. | **1.** It can be used in both high and low noise environment. **2.** It can be worn under helmet or cap | Can be used for all types of operations | - | www.hitechwireless.com/ products/Hurricane-II-Headset-for-Motorola.html |  |

| | Category | Name | Manufacturer | Description | Properties | Applications | DOT & Traffic Safety Compliance | Reference | Image |
|---|---|---|---|---|---|---|---|---|---|
| **28** | Other | Cone Setter | EPIC Solutions | It automates the placement of cones. Workers load cones from inside the truck bed. No one walks or hangs off the side of the truck. | It works with standard base 15″ cones up to 28″ tall as well as with 36″ tall cones. | It can be used for placing cones. It can save lives and labor (workers setting cones won't get hit by passing traffic). | - | www.epicsolutions.us/products/safety-equipment/cone-setter-cs3100/ |   |
| **29** | Other | Cone Retriever | EPIC Solutions | Cone retriever machines require only a driver and one person in back to unload the stacked cones from the unit. No one hangs off the side of the truck and no one jumps on and off to retrieve tipped cones. | The cone retrievers can pick up cones in any orientation, standing or lying down, at up to 15 mph. | It can be used for retrieving cones. It can save lives and labor (workers setting cones won't get hit by passing traffic) | - | www.epicsolutions.us/products/safety-equipment/cone-retriever-cr3200-series/ |   |

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# Appendix A: Expert Panel I - Survey (A)

0 – 6640 Work Zone Safety of Very Short Maintenance Operation

Name: _____
Position: _____
Agency/District: _____

1) How long have you worked in Highway Maintenance? ___years ___months

2) How long do you think is appropriate for defining a very short duration operation?

** This type of maintenance operation often takes the workers more time to set up the traffic control devices than actually performing the job; usually takes 2 crew members and a truck to do the work (e.g. debris removal).*

a. under 5min b. under 10min c. under 15min d. under 20min e. under 30min

3) What are some typical activities for very short duration operations?

_____

_____

_____

4) Usually, short duration operations require ____ crew member(s) and _____ truck(s).

5) What traffic control devices are normally used for these operations? Please check those that apply:

| Truck-Mounted Devices | Ground-Mounted Devices |
|---|---|
| ☐ Truck-Mounted Attenuator | ☐ Channelizing Devices (e.g. cones, barricades etc.) |
| ☐ Truck-Mounted Reflectors/Flashing Lights | ☐ Ground-Mounted Reflectors/Flashing Lights |
| ☐ Truck-Mounted Traffic Sign (Arrow Board) | ☐ Ground-Mounted Traffic Sign |
| ☐ Truck-Mounted Message Board | ☐ Ground-Mounted Message Board |
| ☐ Others<br>_____<br>_____ | ☐ Others<br>_____<br>_____ |

Do you think they are sufficient? _____ If not, what are your recommendations?

_____

_____

*Note: there are more questions on the other side.*

6) Does your district (agency) have specific guidelines on very short duration operations for the workers? If yes, please specify.

□ Yes _____ □ No

7) These are some important factors we have identified that might need to be considered during very short duration operations? Please check those that apply and rank the ones you have checked:

- □ ( ) Type of Road (Two-lane Undivided, Multilane Undivided, Multilane Divided)
- □ ( ) Traffic Speed (High, Medium, Low)
- □ ( ) Time of Day (Day, Night)
- □ ( ) Weather Condition (Clear, Rain, Fog, Snow)
- □ ( ) Location of Work (Beyond Shoulder, On Shoulder, Within the traveled way, Within the median (only applicable to divided roads))
- □ ( ) Roadway Geometry(Straight and flat road, Hills, Curves, Intersections)
- □ ( ) Vision Blocking Objects (level of obstruction)
- □ ( ) Pavement Surface Condition (Dry, Wet, Icy)
- □ Others:
  ( ) _____
  ( ) _____
  ( ) _____
  ( ) _____

8) Any other comments?

_____

_____

_____

_____

*Thank you!*

## Appendix B: Expert Panel I - Survey (B)

0 – 6640 Work Zone Safety of Very Short Maintenance Operation

Name: _____
Position: _____
Agency/District: _____

1) How long do you think is appropriate for defining a very short duration operation?
** This type of maintenance operation often takes the workers more time to set up the traffic control devices than actually performing the job; usually takes 2 crew members and a truck to do the work (e.g. debris removal).*
a. under 5min b. under 10min c. under 15min d. under 20min e. under 30min

2) What are the important factors that should be considered for very short duration operations? Please list them below and put the ranking under the factors:

_____, _____, _____, _____,
( ) ( ) ( ) ( )
_____, _____, _____, _____.
( ) ( ) ( ) ( )

3) What minimum traffic control devices do you think would be appropriate for very short duration operations?

- _____
- _____
- _____
- _____
- _____

4) Any other comments?

_____
_____
_____
_____

*Thank you!*

# Appendix C: Expert Panel II - Survey (A)

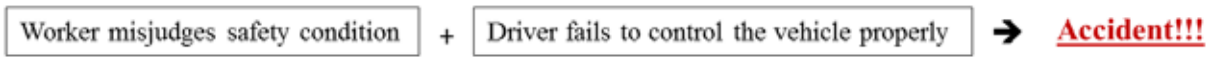
0 – 6640 Work Zone Safety of Very Short Maintenance Operation

Name: _____ Contact Phone Number: _____
Position: _____ Contact Email: _____
Agency/District: _____

How long have you worked in Highway Maintenance? _____

Very Short Duration Operations (VSDOs) last for 15 minutes or less and usually involve maintenance operations such as removing an object from the roadway (either on the pavement or adjacent shoulder) or patching a pothole or small hand level up areas. These activities have the potential to interrupt traffic flow and can pose a safety risk for both workers and drivers. This research aims to provide the maintenance workers a set of safety guidelines for the risky scenarios where accidents have high probabilities to occur.

During VSDOs, an accident will likely occur if a worker misjudges the safety condition and at the same time a driver of the upcoming traffic fails to properly control his/her vehicle to avoid the worker who is doing maintenance work. This survey is designed to identify the critical factors that increase the possibility of a worker misjudging the safety condition and a driver losing control of the vehicle.




1) Please rate the following conditions in terms of workers' judgment about the work zone conditions.

| What is the likelihood of maintenance workers properly judging ***traffic volume*** under the following conditions | |
|---|---|
| *Day* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *There is limited visibility due to* | |
| *Night* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *Rainy weather* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *Foggy weather* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *Other sight distance restrictions such as curves* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| What is the likelihood of workers properly judging ***traffic speed*** under the following conditions | |

| | |
|---|---|
| *Day* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *There is limited visibility due to* | |
| *Night* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *Rainy weather* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *Foggy weather* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *Other sight distance restrictions such as curves* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |

**2)** Please rate the following conditions in terms of the driver's ability to control his/her vehicle to prevent a work zone accident.

| | |
|---|---|
| Traffic volume is *high* (with medium/high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| Traffic volume is *medium* (with medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| Traffic volume is *low* (with medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *Day* (driving at medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| There is *limited visibility* due to | |
| *Night* (driving at medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *Rainy* weather (driving at medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| *Foggy* weather (driving at medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| Driving on *a straight roadway* (at medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| Driving on *a curve* (at medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| Driving *through an intersection* (at medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| Maintenance operation is undertaken *in a travel lane* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |

| | |
|---|---|
| Maintenance operation is undertaken *on a shoulder* | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| The pavement surface is *dry* (driving at medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| The pavement surface is *wet* (driving at medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |
| The pavement surface is *icy* (driving at medium to high speeds) | Very Unlikely ☐ Unlikely ☐ Neutral ☐ Likely ☐ Very Likely ☐ |

# Appendix D: Pre-Workshop Assessment

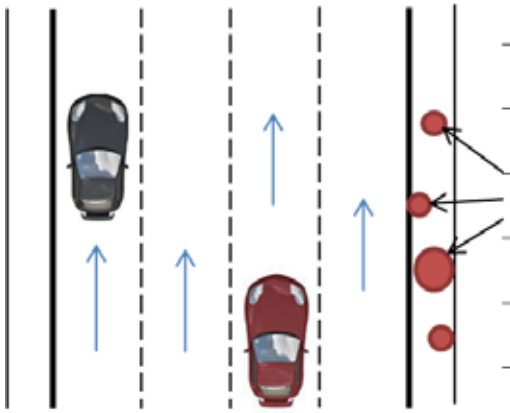
Position: _____
Agency/District: _____

1) How long have you worked in Highway Maintenance? _____years

2) You are working on road maintenance with a light bar mounted truck.
- Answer **YES** if you would proceed with the work on your own
- Answer **NO** if you would not proceed
- Give risk factors you would consider regardless of if you answered yes or no.

Scenario A: Removing multiple alligators (tire scraps) along a shoulder of a multilane divided highway

☐ YES ☐ NO

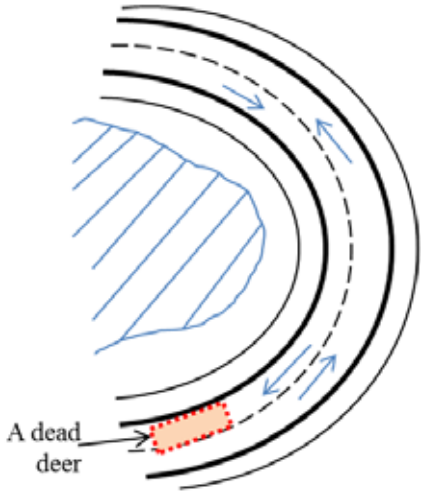


Risk factors you would watch out for or consider in your decision making:

_____
_____
_____
_____
_____
_____
_____
_____

Scenario B: Removing a dead deer from the middle of roadway in a rural area

☐ YES ☐ NO




Risk factors you would watch out for or consider in your decision making:

_____

_____

_____

_____

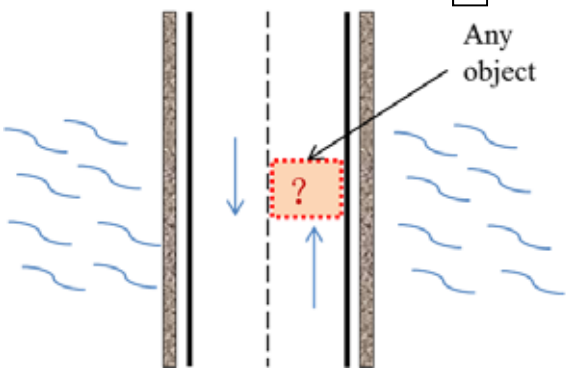
_____

_____

_____

_____

Scenario C: Picking up an object(s) on a bridge




☐ YES ☐ NO

Risk factors you would watch out for or consider in your decision making:

_____

_____

_____

_____

_____

_____

_____

_____

3) What do you expect to get out of this workshop?

*Thank you!*

# Appendix E: Post-Workshop Assessment

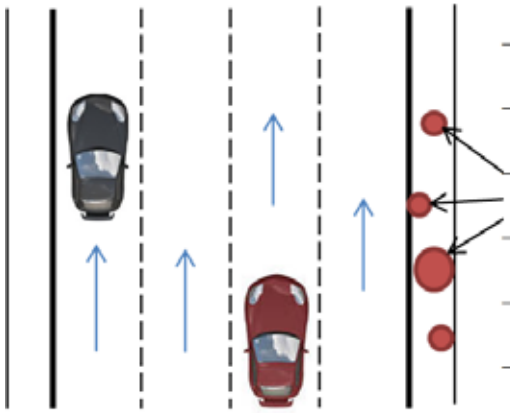
Position: _____
Agency/District: _____

1) How long have you worked in Highway Maintenance? _____years

2) You are working on road maintenance with a light bar mounted truck.
- Answer **YES** if you would proceed with the work on your own
- Answer **NO** if you would not proceed
- Give risk factors you would consider regardless of if you answered yes or no.

Scenario A: Removing multiple alligators (tire scraps) along a shoulder of a multilane divided highway

☐ YES ☐ NO

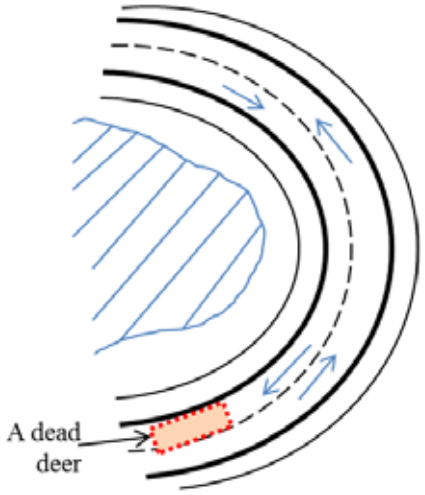


Risk factors you would watch out for or consider in your decision making:

_____
_____
_____
_____
_____
_____
_____
_____

Scenario B: Removing a dead deer from the middle of roadway in a rural area

☐ YES ☐ NO




Risk factors you would watch out for or consider in your decision making:

_____

_____

_____

_____

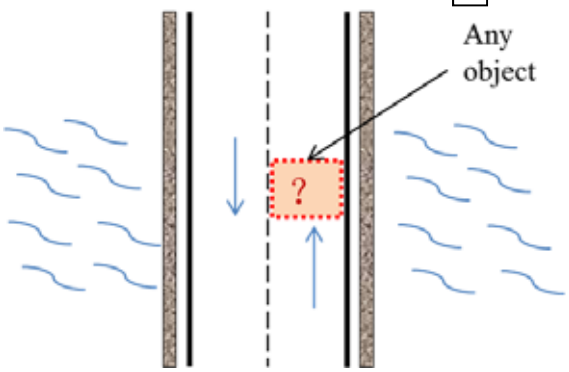
_____

_____

_____

_____

Scenario C: Picking up an object(s) on a bridge




☐ YES ☐ NO

Risk factors you would watch out for or consider in your decision making:

_____

_____

_____

_____

_____

_____

_____

_____

3) Please provide us with your comments regarding this Workshop. Your comments will help us improve future workshops. Please mark the box with an "X" that expresses your level of agreement with each statement.

| | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| The workshop was well organized | | | | | |
| The workshop was the right length | | | | | |
| The presentation(s) was clear and understandable | | | | | |
| The speaker(s) were knowledgeable | | | | | |
| The speaker(s) encouraged questions/comments | | | | | |
| The handout was useful | | | | | |
| I feel this workshop was worth my time | | | | | |

4) How can the workshop be improved?

_____

_____

_____

_____

5) Any other comments?

_____

_____

_____

*Thank you!*