AN ABSTRACT OF THE THESIS OF

Serey Raksa Moeung for the degree of Master of Science in Civil Engineering presented on August 29, 2022.

Title: Best Practices for Work Zone Safety during Traffic Control Placement, Removal, and Modification

Abstract approved:

____________________________________________________

John A. Gambatese

Previous research has shown that traveling in a work zone involves a higher risk of crashing compared to normal (non-work zone) driving conditions. Research further suggests that the severity of work zone crashes is greater on average than non-work zone crashes. The period of time in which the traffic control is being set up, removed, or modified for a work zone is also considered a critical situation where workers and motorists are exposed to risks, especially during the transition period. This study aimed to examine the safety hazards and risks associated with traffic control operations during the set-up, modification, and removal of temporary traffic control, and to develop guidance for enhancing safety as the temporary traffic control placement and removal takes place. To fulfill the research goal, the researchers established a research protocol involving four research methods: a comprehensive literature review on the study topics, a survey of state department of transportation
(DOT) and highway construction and contractor personnel, focus group interviews of contractors and DOT personnel, and on-site observations of traffic control placement and removal operations. The results from the literature review expose limited guidance and standard procedures for setting up and removing traffic control available to state DOTs and contractors. In addition, the survey results reveal hazardous steps in the traffic control operation that create life-threatening hazards to workers and motorists, such as in a situation where a traffic control device is being initially placed to form a lane closure. Results from both focus group interviews conducted revealed interesting findings that nighttime work zone traffic control operation is perceived to be more dangerous than daytime traffic control operation. Furthermore, the site observation results show other work elements associated with the traffic control process that were identified to be risky for workers and motorists during the traffic control operation. An example of those identified elements included: misleading arrow sign indication mounted on truck, wrong sequence order of sign installation, reading traffic control plan while driving to work zone, among others. To mitigate the risks identified in the operation, the researchers proposed several potential treatments, including placing a radar speed board with a portable changeable message sign (PCMS) in advance of the “Road work Ahead” signs, placing blue lights on cone devices, and implementing a rolling slowdown for initial sign set-up operation in a work zone, along with the given treatment analyses table for addressing high risk and moderate risk conditions to enhance safety during the traffic control operation in work zones. Further recommendations on best practices for state departments of transportation and roadway contractors are provided.
Best Practices for Work Zone Safety during Traffic Control Placement, Removal and Modification

by

Serey Raksa Moeung

A THESIS

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

__________________________________________
Serey Raksa Moeung, Author
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DEDICATION

This work is dedicated to my parents, Vannarom Moeung (Father) and Kalyan Chhay (Mother) for the source of love, support, and happiness that they provide in my life.
1. INTRODUCTION

1.1 Problem Statement

One of the top priorities for the Oregon Department of Transportation (ODOT) and other transportation agencies is to ensure safety during construction and maintenance in roadway work zones. According to the US Bureaus of Labor Statistics (BLS), the most recent data show that, in 2020, 1,008 workers, among a total of 4,764 workers in all industries, were fatally injured in the construction industry with more than two fatalities each work day due to construction operations (BLS 2020a). The transportation and warehousing industry was reported as experiencing the second-greatest number of fatalities among other industries (BLS 2020a). The BLS data indicates that the fatality rate that workers experience in construction and transportation is more significant than all other industries except the agriculture, forestry, fishing, and hunting industry.

BLS also provides evidence regarding to the rates of non-fatal occupational injuries and illness for construction and transportation in 2018 which were 3.0 and 4.5 injuries per 100,000 workers, respectively. Both rates are greater than the rates for all industries combined (2.8). These rates accumulated to approximately 200,000 injuries/illness in construction and 220,000 injuries/illnesses in transportation and warehousing.

Many of the fatalities and injuries recorded were caused by motor vehicle crashes. According to data received from the US department of Transportation (USDOT), the number of people who died due to motor vehicle crashes on roadways in the US in 2018 were 36,560 (USDOT, 2019). Many of the crashes that involved fatalities were reported in work zones. In 2018, work zone crashes consisted of 755 fatalities (workzonesafety.org 2019). Work zone
crashes involved with large trucks or busses consisted of 124, and 238 with some of them occurs in Oregon.

Due to the problem presented above, there is clear evidence that shows a demand in research focusing on this matter to enhance safety in construction and maintenance work zones. Therefore, addressing the current problem might reduce a significant number of crashes in work zones, improve travel times, and promote a high safety standard for motorists and workers across the country as well as boosting the overall country’s economy.

1.2 Research Goal/Objectives

In response to the need for improved safety in work zones, the research goal is to develop further knowledge and guidance that can contribute positive safety impacts for drivers and workers, particularly targeting work zone safety related to the period when traffic control is being set up, modified, and removed on high-speed roadways. This traffic control operation is typically performed by contractors and DOT personnel when road construction and maintenance are needed. The operation creates hazards which pose safety concerns for workers and motorists and has not been giving much attention in prior research. To resolve this matter, this research aims to investigate the nature of traffic control set-up, removal, and modification as well as introduce treatments which can mitigate the safety risks in the traffic control operations. The research objectives mainly focus on the following aspects:

- Explore existing guiding principles and common work practices used for traffic control placement and removal, and the risk exposure during these roadway transition periods
- Identify potential treatments to enhance safety during these transition periods
• Evaluate the level of safety risk and implementation feasibility involved with current and promising practices through both quantitative and qualitative measures

• Develop guidance to ensure high quality implementation and safety performance during the transition periods.

Once the guidance has been developed, the safe practices during traffic control set-up and removal will be available and ready to distribute to state DOTs and contractors for compliance as part of their traffic control operation to ensure the highest standards of safety protocol is in place during the transition periods.

1.3 Organization of Thesis

To ensure that this thesis is clear and easy to follow, the structure of the thesis is organized and classified as follows:

Chapter 1: Introduction

In this chapter, a brief introduction related to the research topic is introduced which includes the research problems addressed, the importance of the research, and research goal and objectives.

Chapter 2: Literature Review

This chapter presents a summary of previous studies related to the work zone traffic control including terminology, currently-used temporary traffic control devices, technologies used to place and remove traffic control devices, practices and procedures
for traffic control installation and removal, and safety risk associated with a work zone present and without a work zone present.

Chapter 3: Research Goal and Objectives

This chapter contains a summary of relevant literature including the gap in current knowledge, and the goal and objectives that the researchers aimed to address in the study.

Chapter 4: Research Design and Methods

This chapter presents the methodology that the researchers used to address the current problem in the study, which includes an industry survey, focus group interviews, and field observations.

Chapter 5: Results/Analysis

This chapter covers the analysis and results from survey, focus group interviews, and field observations.

Chapter 6: Discussion

This chapter discusses the interpretation of the results from the literature review, survey, focus group interviews, and site observations. The section also includes suggested alternative treatments for future implementation in the field.

Chapter 7: Limitations

This chapter describes the study limitations that researchers encountered during the research study, and their impact on the current study.
Chapter 8: Conclusions

This chapter summarizes the overall research goals and presents conclusions that can be drawn from the research findings based on the literature review, surveys, focus group interviews, and on-site observations.

Chapter 9: Recommendations

Recommendations for minimizing the limitations and enhancing future research quality are provided in this section. In addition, suggestions for future studies are presented, as well as safety guidance during traffic control operations for state DOTs and roadway construction and maintenance contractors.
2. LITERATURE REVIEW

This section of the thesis provides a thorough review of existing information on the work zone traffic control, including a glossary of terms used in the thesis. The contents included in the literature review section consist of in-depth descriptions of the purpose of traffic control devices, work zone classifications, common existing traffic control devices, and other information related to the processes used for placing, removing, and modifying the traffic control devices when road construction and maintenance operations occur. Furthermore, part of the comprehensive literature reviews also provides a description and comparison of the risk related to daytime and nighttime work zone operations, which helps to further understand the risk associated with the working conditions. The organization of the literature review consists of the following sections:

- Key definitions of terms
- Purpose of traffic control devices, and other previous studies related to work zone traffic control
- Work zone area and duration classifications
- Existing procedures used for traffic control setup and removal in work zones that are currently implementing in other states.
- Other characteristics of comparison for daytime and nighttime work zones such as crash severity, location of accident, root cause of work zone crash, and cost of traffic control.
- Strategies for mitigating the amount of time required for installing and removing work zone traffic control.
2.1 Glossary

**Clear zone:** An unobstructed area of roadway which is used to recover errant vehicles and generally extends beyond the edge of the travel lanes including any shoulders (ODOT, 2011).

**Edge of travel way:** The edge of the roadway which vehicles travel on and delineated by the fog line or edge of pavement, but not including the shoulders (ODOT, 2011).

**Exterior lane:** A lane that is adjacent to a shoulder along one edge of the roadway (Oregon Traffic Control Supervisor Certificate, 2020).

**Interior lane:** A lane located on a roadway with three or more lanes that is in-between other travel lanes on both sides (Oregon Traffic Control Supervisor Certificate, 2020).

**Sight distance:** The length of roadway that is clearly visible to drivers without any obstacle blocking the eye sight of the driver (ODOT, 2011).

**Temporary traffic control (TTC) zone:** A section of a roadway where road users experience a change in road condition because of any roadwork operation, incident, or unplanned special event taking place. A typical change in road condition mainly consists of the use of work zone traffic control devices, law enforcement, or other authorized personnel (OH, 2009; Ohio DOT, 2012).

**Traffic control device (TCD):** A traffic control device consists of signs, markings, signals, and other physical features that are used to command, warn, and regulate road users of a change in traffic patterns (ODOT, 2011).

**Work zone:** A section of a roadway where work operations such as road construction, utility work, and road maintenance temporarily occupy the roadway, and the roadway is closed to
public travel for a certain period of time. A work zone extends from the first ROAD WORK AHEAD warning sign to the last TTD (FHWA, 2009).

### 2.2 Work Zones and Temporary Traffic Control

A significant amount of the information related to work zones and temporary traffic control is provided in literature. This section of the thesis explains the purpose of temporary traffic control, work zone classifications, and provides definitions of each work zone component.

#### 2.2.1 Purpose of Temporary Traffic Control

The main purpose of temporary traffic control is to provide a safe travel route through a work zone. Temporary traffic control is used to provided effective movement of road users through or around a work zone without exposing road users, workers, responders to traffic accidents, and equipment to unsafe conditions (FHWA, 2009). According to Section 1A.02 of the Manual on Uniform Traffic Control Devices (MUTCD), to ensure traffic control devices are effective in work zones, the TCDs must meet the following five minimum requirements: 1) fulfill a need; 2) command attention; 3) convey a clear and simple meaning; 4) command respect from road user; and 5) give sufficient time for a road user to properly respond.

#### 2.2.2 Work Zone Classification

One of the factors used to determine the type and quantity of traffic control devices used in a roadway work zone is the work zone duration. The Federal Highway Administration (FHWA) organizes work zone operations into five different categories based on the length of time that the work operation occupies in work zone location (FHWA, 2009). The classifications of work zone operations defined by FHWA are as follows:
1. **Lone-Term Stationary:** Any type of work that occupies a location more than 3 days.

2. **Intermediate-Term Stationary:** Any type of work that occupies a location for one daylight period up to 3 days, or nighttime work lasting more than 1 hour.

3. **Short-Term Stationary:** Any type of work that occupies a location for more than 1 hour, but within a single of daylight period.

4. **Short Duration:** Any type of work that occupies a location up to 1 hour.

5. **Mobile:** Any type of work that involves continuous moving or intermittent movement along a roadway.

In addition, the definitions and descriptions related to the areas within a work zone are also contained in Section 6c.03 of the MUTCD and Section 2.1 of the Oregon Temporary Traffic Control Handbook (OTTCH) (ODOT, 2011). A work zone is generally divided into four main areas, which are defined as shown below and illustrated in Figure 2.1.

1. **Advance Warning Area:** An area that provides road users sufficient time to respond to changes in the upcoming road conditions in the downstream areas of the work zone (transition area, activity area, and termination area).

2. **Transition Area:** An area where the normal traffic condition is merged into a temporary path around the work area.

3. **Activity Area:** An area that consists of buffer space and the work space.
   - **Buffer space:** A section of a roadway upstream of the work space that is closed and used as a reserved space for increased safety.
- **Work space**: An area where road work activity is being conducted. This area is usually used for storing equipment and material, and is the work station for the workers.

4. **Termination Area**: An area that is located at the downstream end of a work zone where the merged traffic is released back to a normal condition. The length of the termination area is usually relatively short.

![Figure 2.1: Work Zone Areas (ODOT, 2011)]
2.3 Temporary Work Zone Traffic Control Devices

2.3.1 Types of Traffic Control Devices

Extensive research has been conducted on temporary traffic control devices that are currently used in work zones. To ensure all traffic control devices are captured during the literature review process, the researchers for the present study utilized different literature sources including publicly-available online sources, regulatory standards and guidance, journal and conference papers, the US Department of Transportation (USDOT) website, online periodicals, and traffic control device manuals. Table 2.1 provides a list of traffic control devices found during the literature review. Some of those devices available have been developed to fit a certain characteristic of a work zone.

Table 2.1: Current Existing Traffic Control Devices

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<td>Arrow board</td>
<td>A device that warns roadway users of traffic pattern changes in a work zone. Usually, this device shows flashing lights to indicate that extra caution is needed when traveling or merging in a work zone.</td>
<td>Datta et al., 2016</td>
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<td>Portable changeable message sign (PCMS)</td>
<td>A lighted, digital sign that integrates a programming function to display dynamic messages to road users of an upcoming change in the work zone. This device can be mounted on either a trailer or work vehicle.</td>
<td>Gambatese and Zhang, 2014</td>
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<td>Portable Temporary Signal (PTS)</td>
<td>A traffic signal that is used for navigating traffic through a small segment of a roadway or work zone. The signal is self-powered and illuminated using green-yellow-red lamps.</td>
<td>ODOT, 2011</td>
</tr>
<tr>
<td>Stationary sign</td>
<td>A sign deployed on a roadway to convey warnings, guidance, and regulatory messages to road users.</td>
<td>MUTCD, 2009</td>
</tr>
<tr>
<td>Temporary sign</td>
<td>A roadway sign that is situated in a work zone for a temporary use or purpose to regulate, warn, and</td>
<td>Gambatese and Zhang, 2014</td>
</tr>
</tbody>
</table>
guide road users during the roadway construction and maintenance.

<table>
<thead>
<tr>
<th>Lane Delineators</th>
<th>Channelizing device</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Channelizing device</strong></td>
<td>Channelizing devices consist of cones, drums/barrels, barricades, barriers, and mobile barriers. The devices are used to get driver attention to stay in a desired travel path, to separate opposing traffic flow, or to partially or totally restrict roadway use.</td>
<td>WisDOT, 2020</td>
<td></td>
</tr>
<tr>
<td>Plastic drum/barrel</td>
<td>A temporary roadway device primarily used for delineating a travel lane, identifying work areas, and constructing a lane closure taper. A plastic drum, also known as a barrel, is typically bigger than a traffic cone.</td>
<td>Gambatese and Zhang, 2014</td>
<td></td>
</tr>
<tr>
<td>Traffic cone</td>
<td>A device that is used to safely guide road users through a hazardous zone and notify drivers of upcoming roadway condition.</td>
<td>Nemire, 2012</td>
<td></td>
</tr>
<tr>
<td>Tubular and conical marker</td>
<td>A channelizing device that is used to delineate the roadway and direct traffic through a work zone. Multiple tubular or conical markers are usually placed in a line to guide traffic through a work zone and are used for short-term operations (less than three days).</td>
<td>Gambatese and Zhang, 2014</td>
<td></td>
</tr>
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<thead>
<tr>
<th>Barriers</th>
<th>Description</th>
<th>Source</th>
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<tbody>
<tr>
<td><strong>Barricade</strong></td>
<td>A device that can be portable or fixed, and usually consists of one to three rails with proper marking. This device is used to protect, delineate, and restrict all or a portion of the right of way to road users. There are three types of barricades: Type I, Type II, and Type III.</td>
<td>Infrastructure Training &amp; Safety Institute, 2011</td>
</tr>
<tr>
<td>Mobile barrier</td>
<td>One type of barrier that is portable, and can be towed by a semi-truck cab and used as protection to eliminate or reduce hazardous exposure of workers to errant vehicles.</td>
<td>Tymvios and Gambatese, 2014</td>
</tr>
<tr>
<td>Shadow vehicle</td>
<td>A vehicle that is used to protect workers or equipment from errant vehicles passing by the work zone and is positioned upstream of the worker and equipment. This vehicle is usually mounted with traffic control devices such as flashing lights, a changeable message sign, flashing arrow board, and/or oscillating, high intensity rotating lights to guide and provide attention to road users travelling through the work zone.</td>
<td>MUTCD, 2009</td>
</tr>
<tr>
<td>Device/Device</td>
<td>Description</td>
<td>Source</td>
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<tr>
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</tr>
<tr>
<td>Truck mounted attenuator (TMA)</td>
<td>A safety device that is used as a protection system for workers and reduce crash severity when vehicle intrusion occurs in work zone. This device is usually mounted on the rear of a work vehicle or protection vehicle. It protects workers by absorbing energy, thus, minimizing the level of severity of a crash.</td>
<td>ODOT, 2011</td>
</tr>
<tr>
<td><strong>Speed Detection and Enforcement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photo-radar speed enforcement system</td>
<td>A speed enforcement system integrates with radar that captures a vehicle’s speed, then sends a picture of the vehicle exceeding the speed limit in the work zone to the law enforcement agency for speed enforcement purposes.</td>
<td>Gambatese and Zhang, 2014</td>
</tr>
<tr>
<td>Police enforcement</td>
<td>A speed control and enforcement method that consists of a police officer in a vehicle stationed within or before a work zone, or patrolling through the work zone.</td>
<td>The Roadway Safety Consortium, n.d.</td>
</tr>
<tr>
<td>Radar speed monitoring display</td>
<td>A digital speed panel that shows feedback to road users of their vehicle speed along with the posted speed limit, and usually presents a message such as: “Your speed is XX mph”.</td>
<td>Gambatese and Zhang, 2014</td>
</tr>
<tr>
<td><strong>Site Access/Site Control</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated flagger assistance device (AFAD)</td>
<td>An automated flagging device that is placed in advance of the work area and is mounted with red/yellow/green signal heads, a movable traffic control arm, and high visibility signage. This device is controlled by using a remote control by a qualified person and its purpose is to limit vehicle travel within a work zone and allow for passage through a work zone when it is safe.</td>
<td>USDOT, 2017</td>
</tr>
<tr>
<td>Flagger</td>
<td>A worker (trained and certified as a flagger) who stand on roadway and holds a Stop/Slow paddle, lights, and/or red flag to navigate and control movement of road users through the work zone. A flagger typically is equipped with high-visibility safety apparel, and is located in advance of the work zone.</td>
<td>Li and Bai, 2009</td>
</tr>
<tr>
<td><strong>Lighting</strong></td>
<td></td>
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<tr>
<td>Floodlight</td>
<td>A type of light that is used to illuminate work areas during nighttime work zone operations and usually placed nearby equipment crossings, flagging</td>
<td>ODOT, 2011</td>
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stations, and other areas near where work is taking place.

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<thead>
<tr>
<th>Traffic Control Devices</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warning light</strong></td>
<td>A high-intensity, oscillating, rotating, flashing, or strobe warning light with 360° visibility that is mounted on a vehicle or other equipment to provide warning to motorists of an upcoming or nearby hazard.</td>
<td>ODOT, 2011</td>
</tr>
<tr>
<td><strong>Wearable lighting</strong></td>
<td>A personal light that is designed for workers to wear to enhance their safety and visibility within a work zone during nighttime work.</td>
<td>Nnaji et al., 2020</td>
</tr>
</tbody>
</table>

### Driving Behavior

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<tr>
<th>Name</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ghost police vehicle</strong></td>
<td>An empty police vehicle (no law enforcement officer present) that is parked before or within a work zone. This vehicle is used as a method to reduce vehicle speeds in a work zone.</td>
<td>Gambatese and Zhang, 2014</td>
</tr>
<tr>
<td><strong>Lane narrowing</strong></td>
<td>A method that is used to reduce vehicle speeds by narrowing the width of travel lane. The lane is commonly narrowed by using cones or barrels/drums.</td>
<td>Gambatese and Zhang, 2014</td>
</tr>
<tr>
<td><strong>Pilot car</strong></td>
<td>A vehicle that is generally used for guiding and leading traffic through or within a complex work zone area as well as maintaining the speed of traffic passing through a work zone.</td>
<td>OTTCH, 2011</td>
</tr>
<tr>
<td><strong>Portable rumble strip</strong></td>
<td>A movable device installed on a roadway surface that is used to maintain and control the speed of vehicles and to notify drivers of an upcoming roadway condition. Portable rumble strips are generally made of rubber and help to vibrate the vehicle when the vehicle travels over the rumble strip.</td>
<td>Wang et.al, 2013</td>
</tr>
</tbody>
</table>

All of the traffic control devices identified above must meet the list of ODOT requirements and be included on the ODOT Qualified Product List (QPL), which stated by the ODOT policy, in order to be used in ODOT right-of-way. To ensure the present study meets the research goals, the researchers assume that the investigation of the temporary traffic control devices used on the case study projects are on the ODOT QPL.
2.3.2 Technologies for Placing and Removing Traffic Control Devices

Many technologies have been developed for use while placing and removing traffic control devices in work zones. One safety technology is a platform where a worker can safely stand while deploying and removing temporary traffic control devices. The platforms have to be inspected and evaluated by the Occupational Safety Health Administration (OSHA) to verify that they meet the OSHA regulations for work platforms. The platforms that are currently available for installing and removing work zone traffic control devices are shown in Figures 2.2 to 2.5.

![Figure 2.2: Work Platform on Rear of Truck (ATSSA, n.d.)](image-url)
Figure 2.3: Guardrail System Platform on Rear of Truck (ATSSA, n.d.)

Figure 2.4: Lower-Level Platform on Side of Truck (ATSSA, n.d.)
Some technologies are available which do not require a worker on a work platform to deploy temporary traffic control devices. For example, Clint conducted a study of automated equipment for traffic control placement and removal (Clint, 1999). A prototype for an automated cone machine (ACM) for deploying and retrieving traffic cones was developed. Figure 2.6 shows an ACM. The ACM can transport a quantity of cones and be used for work zone closures that require 250 or more cones. Operation of an ACM requires only a single operator to place and remove cones for a lane closure operation.
2.4 Traffic Control Regulations and Guidance

This part of the thesis contains information related to traffic control specifications, guidance on the use of traffic control, and rules of thumb for installing and removing work zone traffic control devices. The information was obtained from documents published by ODOT and the Federal Highway Administration. Some of the documents share very similar titles and descriptions regarding traffic control with documents in many other states across the US.

2.4.1 Oregon Temporary Traffic Control Handbook (OTTCH)

The Oregon Temporary Traffic Control Handbook provides general standards and practices for work zone traffic control operations of three days or less on public roads in Oregon. Notably, the handbook adopts the principles contained in Part 6 of the MUTCD and the Oregon MUTCD supplements. As an example, with respect to temporary traffic control placement, Figure 4.1 in Section 4.3 of the handbook shows portable changeable message sign installation. The content
addresses the design of the PCMS, which includes information of the location where the PCMS should be placed, the visibility of signs, required height of the PCMS above the ground, and direction the sign needs to face. In addition, Section 2.5 of the handbook covers sign placement, but specifically focuses on the design of the sign. As stated in Section 2.5, the spacing distance of signs on non-freeways may be installed up to 2 times those shown on the Sign Spacing & Buffer Length Table (Table 2-4 in the OTTCH handbook).

Moreover, the handbook also contains descriptions of temporary pavement marker installation in Chapter 5. However, the information provided related to pavement installation in Chapter 5 is more related to the design of the temporary pavement markers, which specifically covers the spacing of markers and the number of markers used to simulate each type of line. Noticeably, information related to the work procedures to follow for temporary pavement marker placement and removal are not included in the OTTCH handbook.

2.4.2 Manual on Uniform Traffic Control Devices (MUTCD)

The MUTCD contains detailed information on traffic control devices and is currently used as a standard by state DOTs. The MUTCD provides information about the design of traffic control and the traffic control plan, and explains the standards for traffic control spacing, locations of signs, and the size and required mounting height of the signs. In addition, the manual also contains definitions of traffic control devices, indicates the purpose of the traffic control devices and their uses, and provides other standards that should be complied with to maintain safety in a work zone.

Nighttime work operation guidance for the temporary traffic control usage is provided in Section 6G.19 of the MUTCD as described below:
• Attention should be focused on improving the visibility of the traffic control device, driver guidance, and enhanced protection for workers.

• Improving brightness in the work zone by providing lights, additional markings, and retroreflective markings to workers, vehicles, and equipment.

• Deploying police enforcement in a work zone, especially when there is a likely chance of impairing driver eyesight or at common speeding zones, to reduce the speed of vehicles traveling through work zones during the nighttime.

Moreover, in Section 6G.02, the MUTCD provides guidance for not using temporary traffic control devices or unfeasible devices that are time-consuming or complicated to set up and remove for intermediate-term stationary work zones, or suitable for long-term stationary work zones. Utilizing these devices may increase the set-up and removal time, which could result in delaying the project time and increasing the time that workers are exposed to live traffic.

2.4.3 Blue Book (Oregon Technology Transfer Center, 2016)

The Oregon Technology Transfer Center’s Blue Book provides seven main safety topics related to traffic control work operations. The topics are:

1. Fundamental traffic control knowledge and standards;

2. Descriptions for personal protective equipment and equipment requirements for flaggers;

3. Descriptions of flagging positions and stations;

4. Guidance for using proper flagging signals;

5. Risks related to flagging operations and traffic control;

6. Process of installing traffic control on a two-way road using two flaggers; and
7. Details on how to deploy effective traffic control on a multi-lane roadway using one flagger.

This book adopts content contained in the MUTCD (2009 edition) and the OTTCH (2011 edition), in which some sections of the book explain topics related to the set-up and removal of temporary traffic control. As mentioned in the book, the location of the work must be identified prior to temporary signs being placed, and the sequence of sign and cone placement must be in the same order as the motorists will see them. In the situation where the particular work location is on a two-lane or two-way roadway with flaggers, installing the initial sign should be 1/2 mile away from the work activity area. The book also advises using either highway mile markers or the vehicle odometer to ensure sign spacing is precise and easy to install.

2.4.4 Oregon Standard Specifications for Construction (ODOT, 2021)

Section 00221.40 – General within the Oregon Standard Specification for Construction contains brief guidance on temporary traffic control device installation and removal. General guidance on movement, inspection, operations, and maintenance of the traffic control devices is included in the standard specs. As shown in Section 00221.40, any work activities that involve traffic control devices shall adhere to the project plans and specifications, and the following procedures:

- Install, maintain, and move all TCDs by operating with the direction of traffic.
- If necessary or directed, additional traffic control measures (TCMs) must be provided according to Section 00221.02.
- When existing TCDs are no longer needed or conflict with other TCDs, turn, cover, or take down the unnecessary TCDs.
• Remove traffic control devices from the downstream to the upstream direction, opposite of the set-up process.

Furthermore, Part (c) of the Standard Specifications provides information regarding to the discrepancy between temporary signs and work zone conditions, staging configuration, traffic pattern, and when signs are still needed. The specification provides the following instructions for this case:

• Cover sign to make it invisible to traffic
• Remove or cover sign flag boards if needed
• When covering signs and sign flag boards, follow the cover requirement in Section 00222.12.

2.4.5 Traffic Control Supervisor Certificate (ODOT, 2020)
Information related to the process of work zone traffic control installation and removal is available in the ODOT Traffic Control Supervisor Certificate documentation. The description briefly explains the steps for installing and removing traffic control devices in a work zone. Those explanations are mainly about preparation, the process of device installation, treatment of existing signs, and guidance on how to operate the protection vehicles (ODOT, 2020). The device installation process is performed according to the following standard:

When placing devices, the sequence of device installation should be deployed in the direction of the traffic flow. The installation of the first sign must be the first advance warning sign and the rest of the process should then proceed in following areas:

1. Advance warning area
2. Transition area
3. Activity area

4. Termination area

In the case where TCDs are needed on both sides of the roadway and might result in conflicting movement of traffic, the document advises installing devices in both directions at the same time, starting from each end farthest from the activity area. Alternately, one direction can be installed prior to setting up signs at one side of the roadway. The manual also recommends using flashing arrow displays and portable changeable message signs (PCMSs) to increase hazard awareness when workers are installing and removing traffic control devices in work zones.

2.5 Primary Variables to Consider for Traffic Control Set-up and Removal

Work zone traffic control device installation and removal demand significant attention and care. Due to roadway conditions, traffic, and work zone operations varying from one location to another, it is necessary to consider three main variables when selecting traffic control devices: (1) location of the work, (2) type of roadway, and (3) speed of traffic (MassDOT, 2017). A brief description of each variable is explained below (MassDOT, 2017):

**Location of the work:** Any work operations such as maintenance, short-term construction, and utility work are impacted by the area where the work operation is located. Generally, the closer the active work area to the roadway, the more quantity of traffic control devices are needed.

**Type of roadway:** As a roadway increases in complexity, the more there are hazards present in the roadway. Therefore, the work area can be dramatically impacted by roadway characteristics. To mitigate the safety risk in work zones, the maximum safety
protection should be in placed to prevent the worst hazard scenarios from happening on the work site.

**Speed of traffic:** Speed is one of the major factors to consider when determining the amount of traffic controls needed in a work zone. As a rule of thumb, as the speed approaching the work area increases, the size and number of traffic control devices needed are greater and their spacing should be smaller.

Other related factors, such as sight obstructions, should also be considered when planning traffic control devices. Extra precaution must be included to ensure minimal obstructions are present on roadways as well as to minimize the impacts on the driver’s view as much as possible when traveling through a work zone.

### 2.6 Procedures for Setting up and Removing Traffic Control in Work Zones

Workers experience more risk exposure during traffic control set-up and removal than during performance of the actual construction and maintenance work itself (Dudek et al, 1989). Inappropriate traffic control setup and removal in a work zone can mislead and confuse drivers which, in turn, can result in increasing driver perception reaction time to 4.5-5 seconds (Johnston et al., 2003). This dramatic change in reaction time from the 2.5 seconds that is commonly utilized for perception reaction time in roadway design creates a potential negative impact to safety. The following sections of the thesis describe procedures commonly followed for the set-up and removal of traffic control in work zones.
2.6.1 Procedures for Setting Up Traffic Control in Work Zones

A work zone traffic control placement procedure is extremely critical for enhancing not only public safety but also the safety of the workers who are involved in the set-up operation. Consistency in the traffic control set-up procedure will ensure safe passage on roadways for the public and provide for effective driver compliance with work zone traffic control regulations (ODOT, 2011). The findings of the literature review indicate a variety of suggested procedures for installing traffic control in work zones, which are explained in the subsections below.

2.6.1.1 General Guidelines for Traffic Control Set-up

The following guidance describes safety guidelines for traffic control device placement in a work zone (ConeZonebc.com, 2015):

- Ensure all traffic control devices are close by, clean, and in good condition.
- Install work zone traffic control devices starting with the farthest devices upstream of the work area, and in a way in which driver will see them. Worker should not turn their back to the traffic while installing temporary traffic control.
- Drive through a work zone to ensure proper set-up of the temporary traffic control without creating any confusion for drivers.
- Ensure all devices function according to their intended purpose throughout the day/night.
- Take down traffic control devices when the devices are no longer needed, and remove the devices in order starting from downstream to upstream.
2.6.1.2 Channelizing Device Placement

Channelizing devices are used when implementing a lane closure. A general process for installing channelizing devices in work zones is provided in the ODOT Traffic Control Supervisor Certificate documentation. As described in the manual, when installing the lane closure, the shoulder should be the area where the first channeling devices for the taper are laid out in a straight line. Then, the process of deploying each channelizing device should be proceed in a downstream direction. As the worker manually places devices starting from the shoulder to the inner lane, the worker must always be looking towards the oncoming traffic. Chapter 2 of the OTTCH also provides guidance on cone placement in a work zone, which is described below:

1. **Identify the taper length and spacing** by complying with the standard shown in the table “Taper Lengths and Device Quantities” in the OTTCH handbook.

2. **Placing first cone**: Beginning from the work space or buffer, measure off the taper length along the edge of the travel lanes or fog line. Then, place the first cone at the edge of the travel lane or fog to create the start of the merging or shifting taper.

3. **Placing second cone in taper**: Move along fog line toward the work space a distance equal to the posted speed, step one foot into the roadway, and place the second cone.

4. **Placing third cone**: Continue moving along the edge of the travel lane with a distance equal to the posted speed, then step two feet into the travel lane measured from the fog line. Place the third cone at that location.

5. **Placing remaining cones in the taper**: Continue moving toward the work area and place additional cones after stepping an additional one foot each time into the travel lane until the merging taper is formed.
6. **After the work zone is created:** Drive through the work zone to ensure the work zone is safe to travel through and well-guided for road users.

Specific procedures for different work zone operations and closures are also available in the literature. The sections below describe the installation processes for work zone traffic control with respected to specific types of work zone operations and closures.

### 2.6.1.3 Exterior Lane Closure on Freeway

As mentioned in the ODOT Traffic Control Supervisor Certificate documentation, in the case where it is not feasible to use the shoulder for worker access, the exterior lane can be terminated by positioning a protection vehicle with a TMA along the exterior lane. The process of the exterior lane closure is described as follows:

1. First, during installation of the first advance warning sign, the protection vehicle should be stationed in a blocking mode at least 100 feet upstream of the work zone. A repetitive operation should be applied for all warning sign installations. First, install signs on one side of the roadway followed by installing signs on the other side of the roadway. It is advisable to equip the vehicle used in the operation with a flashing arrow display and warning light.

2. After the advance warning signs are established, the channelizing devices are then installed. To enhance the safety for the workers placing the taper in front of the protection vehicle, the protection vehicle should gradually encroach on the exterior lane.

3. Lastly, place the protection vehicle in the closed lane while the channelizing devices in the activity area are installed.
2.6.1.4 Rolling Road Block on Freeway/Highway

In some work zone closure operations there may be a need for a rolling road block to ensure traffic control devices are safely placed in the work zone. Procedures for a rolling road block on a freeway or highway are described by the New York State Department of Transportation (NYSDOT) as follows:

**Step 1:** The starting point of the rolling road block needs to be determined ahead of time, and on-ramps shall be closed depending on how far the on-ramps are from the rolling road block operation.

**Step 2:** On-ramp traffic shall be controlled by a qualified flagger.

**Step 3:** A clearance vehicle must be used to verify that there are no vehicles blocking or distracting the operation. To ensure a safe operation, the clearance vehicle should be located downstream of the rolling slow down and follow the last vehicle traveling on the road so that it can ensure there are no moving or parked vehicles, open-on ramp traffic, and access entrances that will disrupt the rolling slow down operations. The clearance vehicle can then inform work crews that the roadway is free from traffic and it is clear to proceed with the operation.

**Step 4:** Work in roadway begins. When waiting for the road work to be completed, the clearance vehicle should stop and hold its position upstream of the work area. Once the work is completed, the work crews provide a visual indication to the approaching road block. The road block shall travel at a pre-planned speed and actively communicate with the work site. The speed of the road block can be adjusted accordingly to the pace of the
work. Optionally, a truck equipped with variable message sign (VMS) or towing a trailer-mounted VMS should be placed on the shoulder and maintain a distance of approximately 1,500-foot behind (upstream) of the end of the queue. As the road block passes the on-ramp, and the main road traffic queues disperse, ramp traffic can be released. All procedures and timing should be clearly defined at the pre-construction stage.

**Step 5:** After the completion of the lane closure operation, the work crew shall notify the rolling road block vehicles, and the clearance vehicle shall pass the site. Starting from the left lane, the blocking vehicle should speed up and pull over to the right side of the roadway. When police enforcement is present, the police should continue with the traffic flow to ensure the speed of traffic are well-maintained.

Figure 2.7 shows the process of conducting a rolling road block on a freeway or expressway.
Figure 2.7: Procedure for Rolling Road Block (NYSDOT, 2015)

2.6.1.5 Nighttime Highway Work Zone Closure

Work zone closures often occur during the nighttime when traffic volumes are reduced. When performing nighttime work, the sequence of installing temporary traffic control in a work zone plays a very important role in providing a high level of safety protection for the traffic and
workers while the work operation takes place (Bryden and Mace, 2002). According to National Cooperative Highway Research Highway Program (NCHRP) Report #476, the installation sequence for nighttime work zone traffic control operations should be as follows:

1. Turn on changeable messages signs to notify drivers of divisions, and other traffic condition changes in the work zone.
2. Uncover detour route signs and activate all other temporary traffic controls within detours.
3. Uncover other advance warning signs on detours, closure, and other temporary traffic paths.
4. Before establishing closures, install all portable lighting units at all critical locations such as intersections and other closure points, and ensure that the lights do not create any glare for drivers.
5. Restrict on-ramps from traffic by deploying barricades or other devices at closure points.
6. If off-ramps plan to terminate, place advance warning signs and install channelizing devices and barricades to delineate the travel path. When road closures are in place, if applicable, place a police patrol vehicle and a well-lit vehicle to block the road.
7. Install arrow boards on shoulders or at other places so that they will not distract drivers. During work break periods, light towers and other equipment shall be securely stored in the median beyond the roadside clear zone as shown in the example in Figure 2.7.
8. Install channelizing devices to indicate diversion, merge, or lane closure.
2.6.1.6 Stationary Lane Closure General Requirement (VDOT, 2019)

The Virginia Department of Transportation (VDOT) provides a practical guideline for installing stationary lane closures in the same direction of the traffic flow. The process described for terminating a lane are:

1. Install all advance warning signs
2. Install shoulder taper (Optional)
3. Activate arrow board on the shoulder at the start of the merging taper
4. Create a merging taper by installing channelizing devices
5. Begin installing channelizing devices along the buffer space
6. Continue placing channelizing device along the work area with the designated spacing
7. At the termination area, install channelizing devices
8. Install “END ROAD WORK” sign approximately 500 feet downstream of the last device in the lane closure.
9. Position a truck mounted with an attenuator (TMA) about 80 to 120 feet upstream of the first work crew or hazard approached by the motorists.

The sections below describe similar set-up approaches for a stationary lane closure on multi-lane highways.

2.6.1.7 Stationary Lane Closure on Multi-Lane Highway

The American Traffic Safety Services Association (ATSSA) published a field guide titled “Installation and Removal of Temporary Traffic Control for Safe Maintenance and Work Zone Operations,” which describes the procedures for installing and removing temporary traffic control in work zones. The guide includes the procedures for stationary lane closure installation on a multi-lane highway, which are as follows:

1. Mark the beginning of the work space. Use white or pink color paint only as other designated colors are used for different types of utilities.

2. Measure the buffer space distance starting from the beginning of the work space and mark the beginning of the taper.

3. Then, measure the taper length from the beginning of the buffer space and mark the beginning of the taper.

4. Measure the advance warning sign spacing starting from the start of the taper as shown in Figure 2.9, and mark the location of each sign.

5. Install advance warning signs beginning with right shoulder signs first, and then install signs on the left shoulder, if appropriate.

6. Place the arrow board on the shoulder prior to the taper and install it as close as possible to the beginning of the taper.
7. In the transition area, install the traffic control devices and arrow board with the flow of traffic. Using a truck mounted with an attenuator is advisable while installing the transition area.

8. Install the traffic control devices along the activity area, starting from the buffer space until reaching the end of the work space.

9. Begin installing traffic control devices in the termination area in the same direction as the flow of traffic.

10. Inspect the work zone by driving through the work zone and making notes of any changes that should be made, and correcting deficiencies, if necessary.

11. Identify any difficulties or inconvenience aspects of the setup by observing drivers driving through the work zone.

Figure 2.9: Advance Warning Sign Spacing Illustration (ATSSA, 2008)
2.6.1.8 Lane Closure for High Speed (≥ 45MPH) Roadway

The Massachusetts Department of Transportation (MassDOT) provides a description of lane closure installation procedures for both low-speed and high-speed roadways. High-speed roadways are defined as roadways that allow the traffic to travel at a minimum speed of 45 mph (MassDOT). MassDOT prescribes the following installation process for lane closures on high-speed roadways:

1. Begin installing advance warning signs starting from “ROAD WORK XXX” (W20-1) sign, and end with either the “END ROAD WORK” or “DOUBLE FINES END” signs.
2. Install all signs on the opposite side of the roadway from the intended closed lane. Then, install signs located tangent to the shoulder.
3. If needed, install shoulder taper.
4. Install arrow board on shoulder without leaving a big gap between the board and the start of the merging taper.
5. Install the merging taper by using the channelizing devices.
6. Create a buffer space accordingly to the pre-planned spacing.
7. Continue installing work area with pre-defined spacing.
8. Create termination area as necessary.
9. Position a TMA truck in advance of first crew or hazard approached by the motorists.

The need for deploying a shadow vehicle in the work zone depends on the number of lane and shoulder closures.
2.6.1.9 Detour Installation

The procedure of installing a detour is unique compared to other types of work zone closure installation operations. The process of installing a detour around a work zone described as follows (ATSSA, 2008):

1. Install the last sign that is clearly visible to drivers and guide them back to the route where they detoured from.
2. Install the remaining signs in backward order starting from the end of the detour toward the start of the detour. After all signs are in place, allow motorists to access the detour.

Figure 2.10 illustrates the process of installing and removing a detour with arrows indicating the direction of installation and removal. All detour signs can be installed simultaneously if the need for work crews is not a limitation. In the case where the labor force is limited, detour signs can be installed one by one and covered until ready for use.
2.6.2 Procedures for Removing Traffic Control in Work Zones

The MUTCD indicates that all temporary traffic control devices shall be removed from the work zone as soon as possible when the work is completed or suspended (FHWA, 2009). The TTC devices can be either removed or covered during the period of work suspension. If devices are not removed properly, safety hazards can exist during the removal process. The sections below explain the process of removing the TCC devices in different types of work zones.
2.6.2.1 Stationary Lane Closure Removal

ATSSA (2008) provides a recommended process for stationary lane closure removal. The recommended process is shown below:

1. Remove devices from the termination area backward, in the opposite direction of traffic flow. Utilize a shadow vehicle mounted with an attenuator if needed.
2. Continue to remove devices from the activity area in the opposite direction of the traffic flow.
3. Remove devices from the merging taper in the opposite direction of traffic flow.
4. Remove the advance warning signs proceeding from the taper to the first warning sign upstream of the work zone. Always remove the first warning sign last when removing signs in a work zone.

As noted above, the last step (step 4) involving the sign removal for stationary lane closures generated by ATSSA is slightly in conflict with both the procedure stated in the Guidelines for Temporary Traffic Control published by the Virginia Department of Transportation (VDOT, 2019) and those procedures suggested by some state DOTs. For instance, the VDOT guideline recommends initially removing the first advance warning signs when removing warning signs in the advance warning area, rather than removing the first warning sign in the work zone last.

2.6.2.2 Removal of Stationary Lane Closure on Multi-Lane Primary, Secondary, and Interstate Routes

The South Carolina Department of Transportation (SCDOT) publishes its own removal procedure for a stationary lane closure on multi-lane primary, secondary, and interstate routes (SCDOT, 2019). The removal process described by SCDOT is different from the standard
process described above. The standard process advises beginning removal of the traffic control devices starting from the termination area toward the advance warning area, whereas the SCDOT procedure recommends commencing removal of the devices from the activity area. The procedure for removal of TCDs from a stationary lane closure described by SCDOT is as follow:

1. Begin removing devices from the activity area in a reverse order of installation and proceed from the end of the downstream of the activity area toward the downstream of the taper area. The use of a worker vehicle is recommended and should only move and operate within the restricted travel lane. During the period of time when the work vehicle occupies the restricted travel lane, use of a shadow vehicle is not recommended due to the limited the space available for a shadow vehicle to occupy the lane. For safety purposes, during the nighttime it is advisable that the work vehicle be operated as far as possible from the adjacent open traffic lane.

2. After the TCDs are removed from the activity area, remove the TCDs in the transition area, which is composed of the taper. The removal process should be in the same direction as the traffic flow and should not progress against the direction of traffic at any time. The use of a shadow vehicle is recommended in the taper area and should be operated within no more than 100 feet in advance of a work vehicle as the work vehicle removes the devices.

3. When a trailer mounted changeable message sign is used in the work zone, remove the changeable message sign after removing the taper. Once the changeable message sign is removed, begin removing the static advance warning signs. As the removal operation is taking place, the work vehicle and shadow vehicle should operate in the same direction as
the traffic, and occupy the shoulder areas as much as they can to reduce encroachment into the adjacent travel lane.

4. Begin removing the advance warning area by operating the removal process in the same direction as the traffic flow. In the shoulder area, remove the advance warning signs that are next to the previous travel lane closure. While removing devices, it is recommended that the work vehicle use the shoulder area. In the meantime, the shadow vehicle should also operate within the same portion of the travel lane. While removing the advance warning signs, both vehicles should operate in the same direction through the advance warning area.

2.6.2.3 Lane Closure Removal on High-speed (≥ 45MPH) Roadways

As described by MassDOT (2017), the procedure for lane closure removal on a high-speed roadway is generally opposite to the direction of the traffic flow. The following is the lane closure removal procedure on high speed (≥ 45MPH) roadways published by MassDOT:

1. Withdraw devices starting from the far end of the activity area and work toward the downstream end of the merging taper.

2. Place the shadow vehicle in a blocking position to protect workers removing devices.

3. Position the work vehicle on the shoulder, and remove devices from the merging taper by hand and put them back in the work vehicle.

4. Once the roadway is clear, remove the arrow board.
5. Circle back to the start of work zone and begin removing the signs on the opposite side of the closed lane in the direction of traffic first, and then remove the advance warning sign on the side of the roadway.

6. At any time, workers should not cross multiple travel lanes to remove the advance warning signs on both sides of the roadway simultaneously.

7. Make a note of the time of each sign removal in the logbook.

2.6.2.4 Detour Sign Removal

When removing a detour, the first signs to be removed are those signs that motorists normally see at the beginning of the detour first (ODOT, 2020). The procedure for removing a detour is also described by ATSSA (ATSSA, 2008). The detour removal procedure is performed in an order that is reverse from the standard removal process of a normal stationary lane closure. The detour removal process is as follows:

1. Remove the sign at the start of the detour

2. Continue removing the remaining signs in the direction of the traffic flow as illustrated in Figure 2.10.

2.7 Work Zone Set-Up and Removal During the Daytime and Nighttime

Selecting the time of the day to perform construction and maintenance work can be a difficult decision given the advantages and disadvantages of working at nighttime and in the daytime. State DOTs often prefer to perform road construction and maintenance work at night to mitigate the impacts of the work operations on public during daylight hours. When planning and
conducting traffic control installation and removal, different factors associated with daytime and nighttime work, such as differences in traffic volumes and speeds, driver behavior, and site conditions, should be taken into account. Prior research has investigated various topics related to daytime and nighttime traffic control installation and removal, including work zone risk comparisons, crash severity, and locations of crashes. A summary of the literature is as follows:

2.7.1 Work Zone Risk Comparison between Daytime and Nighttime

The literature review exposed multiple research publications (journal articles, reports, etc.) related to safety risk during daytime and nighttime work. The results and recommendations contained within the publications are somewhat conflicting. There is statistical evidence showing that nighttime construction is approximately five times more dangerous than daytime construction (Arditi et.al 2007). This result was determined based on data on fatal accidents in highway work zones in the state of Illinois from the period between 1996 and 2001. However, the results contradict other research findings by Ha and Nemeth (1995), which claim that there is a noticeable increase in accidents during the daytime compared to the nighttime. Similarly, Ullman et al. (2004) conducted a study in Texas to evaluate the safety risk created by active nighttime work zones. The researchers concluded that the decrease in crash risk during the nighttime is greater than during daytime operations due, in part, to nighttime traffic volumes being 50% or lower than daytime off-peak period traffic volumes. This result is also supported by Zhang and Hassan (2019) who conducted a study comparing crash severity during nighttime and daytime work zone operations. The outcomes of the study indicate that, when comparing fatal crashes with a work zone present to those without a work zone present, fatal crashes
involving a passenger car in daytime work zones increase more dramatically than in nighttime work zones, with percentage increases of 549.4% and 58.7%, respectively.

Despite the findings mentioned above, other studies conclude that daytime and nighttime work zones are not significantly difference in term of risk comparison. NCHRP Report No.627 titled “Traffic Safety Evaluation of Nighttime and Daytime Work Zones” reports that, for an individual motorist traveling through a work zone, crash risk in the daytime and in the nighttime do not significantly vary (Ullman et al., 2008). Similarly, in another study, Zhao and Garber (2002) investigated crash characteristics in work zones and found that the severity of nighttime and daytime work zone crashes was not significantly different.

Moreover, Zhang and Hassan (2019) claimed that the fatality rate for nighttime work zones tends to increase during rainy conditions, while it decreases during rainy conditions in the daytime. As observed in the study, there is a positive relationship between vehicle speed and the level of injury severity. When speed increases, the level of injury severity also increases, especially for male drivers. The researchers also found that fatal crashes during the daytime tend to involve a passenger vehicle more often than during nighttime work. Lastly, the study also showed that the chance of an older driver being involved in a fatal crash is lower at night, whereas the rate of fatal crashes involving a younger driver is higher at night.

2.7.2 Distribution of Work Zone Crashes by Location

A study conducted by Garber and Zhao (2002) in Virginia investigated work zone crash characteristics and identified different aspects of work zone and non-work zone crashes. Part of the study was to determine the predominant locations where crashes occur in a work zone. Based on their investigation, 1,484 crashes were found in work zones and distributed throughout the
work zone areas. To identify daytime and nighttime crashes in work zones, the study defined daytime work as work that operates from 7:00AM to 7:00PM, and nighttime work as work from 7:00PM to 7:00AM. The study found that the activity area is a critical location where crashes commonly occur in work zones, followed by the transition area, advance warning area, longitudinal area, and termination area. In addition, work zone crash location distribution was compared for daytime and nighttime work. The results are shown in Figures 2.11 and 2.12 with respect to the daytime and nighttime crashes, respectively.

![Pie chart showing location distribution for work zone crashes during daytime work](image)

Figure 2.11: Location Distribution for Work Zone Crashes during Daytime Work (Garber and Zhao, 2002)
As can be seen in both figures (Figures 2.11 and 2.12), the probability of crashes in the activity area is higher in the nighttime than in the daytime. This result is opposite to the percentage of crashes identified in the transition area, where it is lower in the nighttime than in the daytime. The overall conclusion of the study states that both daytime and nighttime work zone crash rates were not significantly different.

Pitman et al. (1990) and Hargroves (1981) also conducted studies related to work zone crash location. The findings from both studies showed that the work area, combining the buffer and activity areas, was the location that contained the highest percentage of crashes, namely 44.7% and 54.1%, respectively, in each study. However, in contrast, Nemeth and Rath (1983) found that bi-directional travel sections where vehicles pass in opposite directions was the location where the majority of crashes happen in a work zone.
2.7.3 Work Zone Crashes related to Traffic Control Conditions

In a study by Ullman et al. (2008), the researchers investigated roadway and traffic conditions which potentially lead to a crash in work zone. The research primarily targeted daytime and nighttime crashes on freeways and expressways in five states: New York, Ohio, Washington, California, and North Carolina. The results of the study reveal that implementing different types of work zone traffic control measures could result in a significant difference in the crash rate in daytime and nighttime work zones. Table 2.2 indicates the percentage of work zone crashes related to the presence of different work zone traffic control measures for both nighttime and daytime crashes. As shown in Table 2.2, a lane closure was present in the highest percentage of crashes (57.6% of nighttime crashes and 50.4% of daytime crashes). The condition when minor traffic control was present but no work occurring was present to a greater extent in daytime crashes (17.2%) than nighttime crashes (7.6%). As stated by Shepard and Cottrel (1986), construction and maintenance work are mainly conducted at night because the traffic volume is lower than in the daytime. It is more feasible and convenient for workers to implement a lane closure at night and permit workers to work over a longer period of time than during the daytime off-peak period between the morning and afternoon rush hours.
Table 2.2: NYDOT Work Zone Crashes by Traffic Control Condition (Ullman et al., 2008)

<table>
<thead>
<tr>
<th>Type of Work Zone Traffic Control in Use</th>
<th>Percent of Daytime Crashes (n = 1757)</th>
<th>Percent of Nighttime Crashes (n = 316)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane Closure</td>
<td>50.4%</td>
<td>57.6%</td>
</tr>
<tr>
<td>Minor Traffic Control, Work Inactive</td>
<td>17.2%</td>
<td>7.6%</td>
</tr>
<tr>
<td>Minor Traffic Control, Work active</td>
<td>8.3%</td>
<td>9.5%</td>
</tr>
<tr>
<td>Flagging</td>
<td>8.0%</td>
<td>3.2%</td>
</tr>
<tr>
<td>Shoulder Closure</td>
<td>5.4%</td>
<td>0.9%</td>
</tr>
<tr>
<td>Median Crossover</td>
<td>3.3%</td>
<td>1.3%</td>
</tr>
<tr>
<td>Lane Shift</td>
<td>3.2%</td>
<td>0.9%</td>
</tr>
<tr>
<td>During Traffic Control Set-up and Takedown</td>
<td>3.1%</td>
<td>14.2%</td>
</tr>
<tr>
<td>Full Road or Bridge Closure</td>
<td>0.7%</td>
<td>3.8%</td>
</tr>
<tr>
<td>Other</td>
<td>0.4%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Chi-Square test results</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Daytime and nighttime distributions are significantly different from each other.

The study also revealed a higher percentage of nighttime crashes associated with traffic control set-up and removal compared to during the daytime. As presented in Table 2.2, traffic control set-up/removal was present in 14.2% of nighttime crashes, whereas in only 3.1% of daytime crashes. When performing a temporary lane closure, it is inevitable that the process will include setting up and removing temporary traffic control. Hence, removing temporary traffic devices each night is necessary to ensure all traffic lanes return back to normal operation for the peak travel period during the daytime.

2.7.4 Cost of Implementing Traffic Control in Work Zones

In 1990, Hinze and Carlisle examined a wide range of project variables impacted by nighttime construction work (Hinze and Carlisle, 1990). The investigation showed that state personnel and
some contractors claimed that the cost of adding traffic control on a nighttime project was 25% greater than during the daytime. However, this claim was not supported by some other contractors. Other contractors stated that the cost of implementing traffic control during the daytime and nighttime was not significantly different.

The results from a more recent study showed that nighttime operations are typically more expensive than daytime work because of the many additional cost factors associated with nighttime work, such as overtime payment, lighting expenses, and other costs related with enhanced traffic control (Mostafavi et al., 2012). A similar claim also made in the NYDOT Highway Design Manual (NYDOT, 2020). The manual mentions an increase in project cost and duration can result from nighttime operations which require enhanced traffic control for vehicles.

Agdas and Ellis (2010) conducted a study to evaluate the costs of implementing temporary traffic control on highway projects. The study findings show that the expenses associated with work zone traffic control on highways range somewhere from 6 to 10 percent of the total cost of the highway construction. Ullman et al. (2005) conducted a study to compare the cost of crashes occurring in nighttime work zones and the cost of placing traffic control to determine if the cost of placing the traffic control devices offset the cost of the crashes. Table 2.3 shows the results of the study. The table presents a comparison of the cost of nighttime work zone crashes and the cost of utilizing additional traffic control. As shown in Table 2.3, crash cost does not offset the cost of implementing traffic devices (drums/barrels) at a lower average annual daily traffic (AADT) level. However, at higher AADT levels, the amount of crash cost reduced is higher than the cost of placing traffic control devices in interstate freeways.
Table 2.3: Additional Crash Costs in Nighttime Work Zones Compared to Costs of Adding More Traffic Control Devices in the Traffic Control Plan (Ullman et al., 2005)

<table>
<thead>
<tr>
<th>AADT/Lane (Thousands)</th>
<th>Additional Crashes Expected due to Work Zone Per Night</th>
<th>Additional Crash Costs Expected due to Work Zone Per Night</th>
<th>Reduction in Additional Crash Costs Needed to Offset Cost of Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,500</td>
<td>0.000205</td>
<td>$26.12</td>
<td>NA</td>
</tr>
<tr>
<td>7,500</td>
<td>0.000732</td>
<td>$93.38</td>
<td>NA</td>
</tr>
<tr>
<td>12,500</td>
<td>0.001780</td>
<td>$227.08</td>
<td>NA</td>
</tr>
<tr>
<td>17,500</td>
<td>0.002976</td>
<td>$379.76</td>
<td>63%</td>
</tr>
<tr>
<td>22,500</td>
<td>0.005546</td>
<td>$707.72</td>
<td>34%</td>
</tr>
<tr>
<td>27,500</td>
<td>0.013558</td>
<td>$864.98</td>
<td>28%</td>
</tr>
<tr>
<td>32,500</td>
<td>0.016023</td>
<td>$1,022.26</td>
<td>24%</td>
</tr>
</tbody>
</table>

NA = result not applicable. Additional crash costs do not exceed cost of device implementation.

2.8 Risk Comparison Before and During Work Zone Construction

Research studies assessing the risk during the period before work zone establishment compared with the risk for the period during construction have gained interest from researchers. Pigman and Agent (1990) conducted case study evaluations of crash rates before and during the work. The study data was taken at 20 different site locations on highway construction and road maintenance projects. Their analysis reveals that the number of crashes during the construction period was greater than the period before the work zone was installed. Many other research studies claimed a similar result (e.g., Graham et al., 1978; Nemeth and Migletz, 1978). The three most common factors that lead to a crash were: following too close, driver inattention, and failure to yield right of way. The results further reveal that crashes that occur in work zones are more severe than crashes outside work zones. Crashes related to trucks was identified as the most severe type of crash during nighttime conditions, and the percentage of crashes involving trucks (25.7%) was greater than in non-work zone crashes (9.6%) (Pigman and Agent, 1990). Furthermore, the advance warning area was identified as an area where higher severity crashes usually occur compared to other areas in work zone.
Another study examined 79 construction projects in seven states to compare the risk before and during work zone take placement (Graham et al., 1978). The number of crashes before and during construction was recorded. Table 2.4 show a percentage of accident before and during construction in rural and urban area. The results of the study show that the crash rate on urban projects is slightly higher than on rural projects.

Table 2.4: Mean Accident Rate of Urban and Rural Projects (Graham et al., 1978)

<table>
<thead>
<tr>
<th>Setting</th>
<th>Mean Accident Rate*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Construction</td>
</tr>
<tr>
<td>Urban</td>
<td>170.96</td>
</tr>
<tr>
<td>Rural</td>
<td>87.78</td>
</tr>
</tbody>
</table>

Notes: *Number of accidents per 100,000,000 vehicle-km. 1 km = 0.6 mile.

2.9 Time Required for Traffic Control Set-up and Removal

Longer durations of work zone typically increase the frequency of injury and non-injury crashes (Khattak et al., 2002). Hence, it is important to shorten the work zone duration as much as possible to reduce worker risk exposure. As stated in Part 6 of Minnesota MUTCD (2019) and in the handbook titled “Guidelines for Traffic Control in Short Duration/Mobile Work Zones” published by the Kentucky Transportation Center (2008), that short term work zones often consume a significant amount of time to set-up and remove traffic control devices compared with the actual work operation itself. As work duration decreases, more attention should be given to the time of the traffic control set-up and removal (Datta et al., 2016). Datta et al. recommended the following tips to mitigate setup and removal time of the traffic control devices in work zones:

- Reduce the number of traffic control devices used in the work zone
• Eliminate the need to remove or cover permanent signs
• Replace ground-mounted devices with vehicle-mounted devices
• Use lightweight or smaller channelizing devices
• Use work vehicles to install channelizing devices
3. RESEARCH GOAL AND OBJECTIVES

To sum up, the literature review revealed guidance and manuals for traffic control set-up and removal operations are available for state DOTs and roadway contractors to abide by when performing work zone closure installations and removals. However, the information provided varies between states and insufficient detail of the setup and removal process is provided in many state DOT documents. A standard procedure is still needed to minimize conflicts and confusion amongst workers when following the processes for installing and removing work zone closures. Moreover, only few previous studies focused on safety issues during the transition period, such as the study by Ulman et al. (2008). The remaining research questions related to traffic control set-up, removal, and modification that still need to be addressed include:

1. What are the comprehensive principles and standard practices when planning and executing the temporary traffic control during the transition period?

2. What situations during traffic control set-up, removal, and modification lead to the most hazardous conditions for workers and motorists?

3. What are the best practices that should be followed by state DOTs and contractors in order to ensure a high level of safety performance during the traffic control transition period?

4. Are there technologies and equipment available for placing and removing traffic control devices that can help improve safety during the transition period?

5. Are there analytical tools that can be used to conduct real-time risk assessments for placing and removing traffic control in work zones?
6. How does safety risk during traffic control placement and removal in work zone differ between daytime and nighttime work operations?

7. What are the quantities of resources, such as the number of work crews, work vehicles, and temporary signs, that need to be utilized for each type of work zone operation in order to ensure a high level of safety for workers and motorists?

8. What are the criteria that need to be evaluated when planning and selecting the traffic control to implement in a work zone?

9. How does the number of crashes compare between the set-up and removal of traffic control?

As presented above, the research goal is to generate guidance that can promote and enhance the safety of workers and motorists during the transition period when traffic control is being set-up, removed, and modified. To achieve the research goal, two research questions are established for the present study: 1) “What are the hazardous situations that could potentially expose workers to high risk during traffic control placement, removal, and modification?” and 2) “What guidance can be given to state DOTs and roadway contractors to ensure workers and motorists have minimal risk exposure during work zone traffic control set-up and removal operations?” These research questions are the focus on this study. To the best of researchers' judgement, the preliminary answer (hypothesis) to the first research question is: the high-risk situation exists when workers are conducting the lane closure without sufficient protective equipment. However, the second research question still remains for judgement based on the outcomes of the study. Among the nine research questions listed above, the current study will address the first three questions, which are restated as:
1. What are the principles and rules of thumb for practice when planning and executing work zone traffic control?

2. Which roadway and work environment conditions put workers in life-threatening situations during traffic control operations?

3. What are the best practices for state DOTs and roadway contractors to follow when setting-up and removing temporary traffic control in work zones?

To answer the questions above and ultimately fulfill the research goal, four main objectives were established as follows:

1. Collect guiding principles, current standards of work operation, and risk exposures related to temporary traffic control operations. This objective will be accomplished by conducting a literature review and DOT/contractor survey.

2. Identify promising practices to improve safety during the transition period. This objective is fulfilled by conducting focused group interviews, a DOT/contractor survey, and site observations.

3. Evaluate differences in risk and implementation feasibility associated with current and promising practices through both quantitative and qualitative measures. The literature review, and DOT/contractor survey are used to achieve this objective.

4. Establish recommendations for ODOT and contractors to improve safety during traffic control transition periods. This objective is completed by utilizing statistical data analysis and receiving input from the ODOT Technical Advisory Committee (TAC) set up to oversee the research study.
Completion of the final stage of the study will ensure the developed guidance is disseminated to state DOTs and roadway contractors to comply with in their work operations.
4. RESEARCH DESIGN AND METHODS

As mentioned above, the goal of the research study is to provide supporting guidance for state DOTs and roadway contractors to improve work zone safety while temporary traffic control is being placed, modified, and removed for a work zone closure. To ensure the goal and objectives of the study are met, the research protocol shown in Figure 4.1 was established and followed. Following the research protocol, will address the first three research questions (Questions 1 to 3). The selected research methods were developed based on the results of the literature review, which is the initial task of Phase I. Four phases were established to define the completion and progress of the work and the objectives of the study. The initial task of Phase I (Literature review) has been presented up to this point in the thesis. The remaining tasks for Phase I that involves collecting data through a DOT/contractor survey will be presented in the next section of the thesis. The completion of Phase I results in the completion of Objective 1.

Phase II is related to hazard identification and risk assessment associated with traffic control operation activities, particularly during the setup, removal, and modification periods on high speed roadways. Phase III of the study involved identifying and developing recommendations that should be given to state DOTs and contractors to further enhance safety of workers and motorists during the temporary transition period. The completion of Phase II and Phase III generates the outcomes for Objectives 2, 3 and 4. Figure 4.1 shows the research tasks along with the data collection approaches (e.g. focus group interviews, DOT/Contractor survey, and site observations) that were conducted to accomplish each phase and achieve the research objectives. The researcher will prepare guidance and publish a document for public use based on the completed thesis.
### Phase 1: Current Knowledge and Practice (Objective 1)
- Document current standards for conducting temporary traffic control operations *(Literature review)*
- Document state of practice related to temporary traffic control operation *(DOT/contractor survey)*
- Collect examples of current practices *(DOT/contractor survey)*

### Phase 2: Hazard Identification and Risk Assessment (Objective 2 and 3)
- Identify common hazardous conditions and behaviors. *(Focus group interviews; Site observations)*
- Assess risk associated with hazardous conditions and behaviors *(Focus group interviews; Case studies)*

### Phase III: Recommendations and Guidance (Objective 2, 3, and 4)
- Identify potential recommended practices *(ODOT TAC review and input)*
- Evaluate one or more recommended practices *(Case studies)*
- Develop guidance for future practice *(Data analysis; ODOT TAC input)*

### Phase IV: Study Outputs and Dissemination
- Prepare guidance document

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**Figure 4.1: Research Methodology**
The following section contains in-depth descriptions and explanations of each research approach that the researchers used to achieve the research tasks and fulfill the objectives of the study.

4.1 Survey

The goal of the survey was to document knowledge and experience from industry and state DOT personnel regarding work zone traffic control set-up, removal, and modification that could not be obtained from the literature review and to supplement the literature review. The survey questions were developed based on the findings of the literature review as well as the intent to target the scope of the study in a way that the objectives of the study would be fulfilled. The survey questionnaire was organized into four sections to obtain the following information:

1. Personal demographic information related to respondent’s title, work location, work experience, and involvement with traffic control operations
2. Practical procedures associated with traffic control set-up, removal, and modification
3. Safety risk related to the temporary traffic control operations that workers and motorists typically encounter
4. Recommendations for safe practices during the set-up, removal, and modification of temporary traffic control in a work zone

As a first step, a list of questions was created and presented to ODOT Technical Advisory Committee (TAC) for review and feedback. After the feedback was received from the TAC, the quality of survey questions was enhanced based on the input provided. Then, the final version of the questions was established and submitted to the OSU Institutional Review Board (IRB), along with the recruitment emails, protocol, and a letter of research explanation, for IRB review and approval for research involving human subjects. The feedback received from the IRB was then
integrated into the survey, and the survey protocol was initiated after approval from the IRB. The survey questionnaire is provided in the Appendix.

The targeted survey population are those individuals who are employed in state DOTs and currently actively working for roadway construction contractors in the US. A purposive sample comprised of contacts at state DOTs and roadway contractors was used. The state DOT contacts consisted of personnel from the 50 US states who were on a contact list of state DOT research offices. In addition, contact lists from previous ODOT research studies, including both DOT and industry contacts, and from industry organization websites such as the Associate General Contractors (AGC) of Oregon and Washington, AGC of America, and the webpages of roadway construction firms in Pacific Northwest, were used. The contact lists were then combined and the contacts classified into two separated groups: one containing state department of transportation personnel and the other containing industry contacts (i.e., roadway contractors/subcontractors). The combined list of the DOT group consisted of 866 personnel, and the industry contact list contained 716 personnel. These contacts were included as additional contacts to those on the state DOT research office contact lists as stated above.

Emails containing the survey questionnaire were sent to the contacts which asked the recipients to complete the survey. If the recipients are not knowledgeable about the subject of the research, the recipients were then asked to forward the email to others within their organization or within/out of their state who they believed have familiarity with the research topic. Due to the snowball sampling, the final number of recipients who received the survey questionnaire is not known.
For survey distribution, the survey questions were initially uploaded to the Qualtrics web-based survey system that is operated by OSU. A link was then generated and incorporated in the emails sent to the contact lists. The researchers sent the email with the survey link to the TAC member to pilot the survey and review for feedback. Feedback received was then reviewed and incorporated into the survey questionnaire and recruitment information as advised.

The survey was distributed in two ways. The first approach was sent by the ODOT Research Office. The ODOT Research Office representative sent emails with the survey link and attachments to the Research Offices located in the DOTs in all of the different states across the US. Then, each individual state DOT Research Office distributed the email to personnel within the state DOT and to local contractors in the state requesting their participation in the survey. The second approach was sent by the researchers to the personnel on the other contact lists with similar research explanation documents attached to the email. To increase the response rate and ensure a significant number of responses was received, the researchers sent two follow-up emails to remind the recipients to fill out the survey before the expiration date.

4.2 Focus Group Interviews

The purpose of conducting the focus group interviews was to gain additional knowledge from ODOT and industry personnel of hazards related to traffic control operations, explore remedies to reduce risks in the traffic control operation, and identify focus areas of the study that the researchers should put more attention on to improve safety during traffic control set-up, removal, and modification. The targeted audiences of the focus group interviews were Oregon Department of Transportation personnel and Oregon roadway construction and roadway maintenance contractors. First, invitational emails which included Doodle poll links were created and sent to
both groups along with a sample of the focus group interview questions that was prepared in advance. The purpose of sending the interview questions to the participants in advance was to provide sufficient time for the participants to think about and prepare their answers. The Doodle poll link included in the invitational emails allowed the participants to indicate their availability for the interview. Then, to increase participation, follow-up emails were distributed to potential participants to remind them to indicate their availability on the poll.

To conduct the focus group interviews, the researchers split up the focus group interviews into two sessions, one for ODOT personnel and the other for roadway contractors that are based in Oregon. The chosen date of the interview for each group was made upon on the results received from the majority of participants who indicated their availability for an interview in the Doodle poll. Each group was interviewed separately on different dates via an online Zoom meeting. Due to time constraints, both groups were asked similar questions, approximately 7 to 9 questions including follow-up questions. The questions guided the discussion towards the following content:

- Safety issues associated with temporary traffic control operations that were identified in the previous research task.
- The perceived risk associated with each work zone traffic control activity.
- Ideas of how to change the traffic control operation in a way to mitigate the perceived risks associated with the traffic control.
- Traffic control set-up and removal safety improvement that the researchers should focus on for the research study.
To retain the information from the interview, the researchers sought permission from both groups to record the interview discussions. The researchers also took personal notes for future reference, and asked clarifying questions.

4.3 Field Observations

The purpose of the field observations was to capture the actual worksite setting during traffic control placement and removal as well as to record hazardous situations that pose safety concerns for workers and motorists. In accordance with the ODOT work plan, three projects based in Oregon were selected for the field observations.

The observation process was identical for all the three observed projects. First, the researchers reviewed the ODOT website to identify on-going roadway construction and maintenance projects that required a short-term traffic control operation and were possibly available for the observation. The review of the ODOT website revealed a list of 20 projects located in Oregon that were potential candidates for field observations. Among those 20 projects, only three projects were chosen for the observation. The selection of the projects was made based on input from the TAC members and were selected according to the following criteria: project involvement with a work zone traffic control set-up and removal operation, proximity of project work location, type of roadway (e.g., freeway or highway), and whether the project schedule was within the research study’s timeline. For the three selected projects, the researchers collaborated with the ODOT project representative and contacted the roadway contractor who was primarily responsible for the project tasks to discuss current work progress on the project, possible dates and times for a field visit, safety precautions needed for the visit, and expectations of the field
observations (e.g., purpose of the observation for the research study and how the observation process will be executed).

On the day of each field observation, the roadway construction field staff was asked to conduct their work operation according to their plan without any changes made or treatments applied. To retain the information from the observation, the researchers used several data collection methods such as in-person interviews, note-taking, photographing, and videotaping of the traffic control work activities from inside a work vehicle, inside a personal vehicle, and/or a safe location in the right of way.
5. RESULTS

5.1 Survey

The researchers received a total of 107 survey responses from both the state DOTs and construction contractors. Out of the 107 responses, 65 participants fully filled out the survey (62.6% of the total responses). The remaining responses were incomplete to varying degrees. However, the incomplete responses were included in the analysis to increase the data validity for some survey questions. Hence, any answers that were given sufficiently in the survey questionnaire were utilized in the analysis.

5.1.1 Respondent Personal Demographics

Regarding the respondents’ organizations, 84 respondents indicated the type of organization where they work. Figure 5.1 shows the percentage of responses received based on type of organization. The majority of respondents (60.7%) indicate that they work for a local, state, or federal transportation agency. Their job titles include safety manager/engineer, traffic control designer, roadway engineer, inspector, maintenance supervisor, and project engineer. The second-highest number of responses (34.5%) came from personnel who work on the industry side, either for a construction contractor or subcontractor firm, with titles of project manager and safety manager. Meanwhile, only 4.8% of the respondents represented other organizations, such as consulting firms and research organizations.
The next survey question asked respondents to indicate the location where they physically work. A total of 73 responses to this question were received with the majority of responses (22 responses) indicating they are located in Rhode Island. A high number of responses received from Rhode Island could be an indication of a significant passion of work zone safety involvement in Rhode Island. Among the 73 responses received for this question, only 2 responses were from Oregon. At least one response was received from 26 states. The accuracy of the survey results will improve if multiple responses are received from each state. Notably, all responses received were from organizations that identified as a local, state, or federal transportation agency, construction contractor/ subcontractor, and other research organization or consulting firm. Table 5.1 presents the total number of all responses received according to the state in which the respondents work.
Table 5.1: Distribution of Survey Responses based on Respondent Location

<table>
<thead>
<tr>
<th>State(s)</th>
<th>Number of responses</th>
<th>Percentage of responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL, AK, AR, FL, GA, IL, LA, ME, MS, NV, NE, ND, NJ, NM, NC, OK, PA, TX, UT, VA, SD, WV, WI, WY</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>AZ, DE, ID, IA, KY, MD, MN, MT, NH, NY, VT</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>CO, OR, KS, SC</td>
<td>2</td>
<td>3.4</td>
</tr>
<tr>
<td>CT, HI, TN, WA</td>
<td>3</td>
<td>5.2</td>
</tr>
<tr>
<td>OH, MI</td>
<td>4</td>
<td>6.9</td>
</tr>
<tr>
<td>CA, MO</td>
<td>6</td>
<td>10.3</td>
</tr>
<tr>
<td>IN</td>
<td>8</td>
<td>13.8</td>
</tr>
<tr>
<td>MA</td>
<td>12</td>
<td>20.7</td>
</tr>
<tr>
<td>RI</td>
<td>22</td>
<td>37.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>58</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

When examining the experience of the respondents in the transportation and construction industry, a total of 58 responses to this question were obtained. Figure 5.2 illustrates the respondent experience in the transportation and construction industry. Interestingly, the majority of respondents (52.6%) indicated they have more than 20 years of experience in the transportation and construction industry, whereas no responses were received from personnel who have less than a year of experience. A considerable number of respondents (43% of total respondents) indicated that they have experience ranging from 6 years to 20 years. For all respondents, the average experience is 13 years. The responses received from this question indicate that the respondents have a vast amount of experience in the transportation and construction industry.
Figure 5.2: Respondent Work Experience in Transportation and Construction Industry

5.1.2 Respondent Involvement with Traffic Control Set-up and Removal

The next section of the survey questionnaire aimed to gather information about the level of knowledge that respondents have regarding the topic of the traffic control set-up and removal. Involvement in planning and performing traffic control set-up and removal was one of the researchers’ interests to confirm respondent competency. The total number of responses received for the planning traffic control question was 74, and 72 for the question about performing traffic control operations.

Figure 5.3 illustrates the respondents’ job involvement with respect to planning and performing traffic control set-up and removal. As can be seen in Figure 5.3, large percentages of the respondents indicated that planning traffic control (43% of respondents) and performing traffic control operations (75% of respondents) is less than 20% of their job. Only a few respondents indicated that planning (8% of respondents) and performing (12% of respondents)
consisted of 81% or more of their job. The results from this question indicate that planning and performing the traffic control set-up and removal is not a common task that the respondents are involved in as part of their job. Notably, due to a variation in the number of years of experience within the respondents, the responses obtained for all other survey questions might be slightly biased. Respondents with extensive site experience might view safety risk during traffic control operations and safety in work zones differently than those respondents who have less experience in work zones or have never been involved with traffic control operations. A different perspective of risk could be attributed to risk normalization and/or risk discounting due to the duration of exposure to the work zone hazards.

Figure 5.3: Distribution of Respondents Involved in Planning and Performing Traffic Control Set-up and Removal
The next survey question asked participants to further verify their familiarity with planning and executing traffic control. Figure 5.4 shows their responses regarding familiarity with planning and performing traffic control set-up and removal operations. A significant number of respondents indicated that they are very and extremely familiar with planning (77% of respondents) and performing (59% of respondents) traffic control operations. Only a small percentage of respondents indicated they are not familiar, have minimal familiarity, or have low familiarity with planning (9% of respondents) and performing (21% of respondents) traffic control operations. Interestingly, this finding is contrary to the expectation from the previous question, which indicated that not many respondents are involved with planning and performing traffic control in their job. Based on these results, it can be inferred that although respondents are involved to a limited extent in planning and performing traffic control operations in their jobs, they do have a clear understanding of how to plan and perform the traffic control work.

Figure 5.4: Distribution of Respondents based on Familiarity with Traffic Control Planning and Execution
5.1.3 Safety Impact Associated with Traffic Control Set-up and Removal Activities/Task

In section 3 of the survey, topics such as challenges to, and safety risk assessment of, temporary traffic control set-up and removal activities/tasks were examined. To begin with, participants were asked to indicate the traffic control activities, such as cone placement and temporary lighting installation, that they have experience with in their job. Then, the subsequent question asked respondents to rank the safety issues related each traffic control activity that they have experience with. Table 5.2 shows the number of responses received regarding experience related to each traffic control placement activity. The most common activities were placement of cones/barrels for the lane closure, placement of temporary signage, and placement of variable message signs, all of which more than 90% of respondents have experience with. The next most common traffic control activities included: accessing the roadway and blocking/slowing traffic (89.4% of respondents), placement of temporary lighting (75.7%), placement of temporary striping (69.7%), and placement of temporary roadway markers/reflectors (68.1%).

Table 5.2: Experience of Respondent Related to Traffic Control Placement Activities (N = 66)

<table>
<thead>
<tr>
<th>Traffic Control Placement Activities</th>
<th>Number of responses</th>
<th>Percentage of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placement of cones/barrels for the lane closure</td>
<td>64</td>
<td>96.9%</td>
</tr>
<tr>
<td>Placement of temporary signage</td>
<td>63</td>
<td>95.4%</td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
<td>60</td>
<td>90.9%</td>
</tr>
<tr>
<td>Accessing the roadway and blocking/slowing traffic</td>
<td>59</td>
<td>89.4%</td>
</tr>
<tr>
<td>Placement of temporary lighting</td>
<td>50</td>
<td>75.7%</td>
</tr>
<tr>
<td>Placement of temporary striping</td>
<td>46</td>
<td>69.7%</td>
</tr>
<tr>
<td>Placement of temporary roadway markers/reflectors</td>
<td>45</td>
<td>68.1%</td>
</tr>
<tr>
<td>Placement/set-up of radar speed sign(s)</td>
<td>34</td>
<td>51.5%</td>
</tr>
<tr>
<td>Other activities: (Placement TMA, arrow board, portable traffic signal)</td>
<td>9</td>
<td>13.6%</td>
</tr>
</tbody>
</table>

Note: Each participant could select more than one activity that they had experience with.
The next set of questions intended to investigate the challenges that workers experience when performing temporary traffic control set-up and removal in a work zone, and assess the safety impact of the identified issues for each activity. Question #3.2 contained a list of potential work operation issues and instructed the participants to rank the issues for each of the activities in which they believed the issues have a safety impact on motorists and workers during the operation. The list of work operational issues provided were associated with resources, personnel, planning, and time constraints. The first review of the survey results for Question #3.2 revealed some invalid responses provided by the participants. The primary cause of the invalid responses could be that some respondents miscomprehended the instruction for the survey questions. For instance, a given question instruction guided the respondents to rank the work operational issues only from 1 to 5, and asked respondents to enter “0” if the impact to safety poses no concerns during traffic control operations. However, one respondent initially ranked the issue by putting a value of “8” although there were only five issues listed in the question. Since such responses violate the question instructions, the researchers did not incorporate these responses in the dataset for analysis. Table 5.3 presents the results from the question including the number of responses received and weighted ranking. The cleansing process was applied to the result shown in Table 5.3. Equation 5.1 was used to calculated the weighted ranking:

\[
\text{Weighted ranking} = \frac{(n_{(1)1} \times R_1 + \cdots + n_{(2)1} \times R_1 + \cdots + n_{(i)j} \times R_i)}{N_{total(ea,activity)}}
\]  
(Eqn. 5.1)

Where:

- \(n_{(i)j}\) = number of responses received for issue/risk \(i\), given each placement activity, \(j\)
- \(R_i\) = numerical scale of ranking for each issue (0, 1, 2, 3, 4, or 5)
\[ N_{\text{total}(\text{ea. activity})} = \text{total number of responses for each activity} \]

The weighted ranking values of each activity were derived using the number of responses from the ranking of each issue that is associated with each traffic control placement activity \((n_{(i)j})\), multiplying by the numerical scale \((R_i)\), and dividing by the total number of responses received for each traffic control activity. The calculated weighted ranking values are shown in Table 5.3. A lower weighted ranking value indicates greater negative impact to safety. Based on a preliminary analysis of the results shown in Table 5.3, it can be concluded that among all the five work operational issues given, “worker not following planned process” was ranked as having the greatest negative impact on motorist and worker safety (average ranking = 2.31), followed by lack of available equipment or equipment breakdown (2.70), planned process not applicable to field condition (2.88), time pressure to complete the set-up removal (2.99), and lack of available workers (3.29).
Table 5.3: Weighted Ranking of Impact of Work Operational Issues on Motorist and Worker Safety Risk (a lower value indicates a higher ranking)

<table>
<thead>
<tr>
<th>Activity/Task</th>
<th>Lack of available workers</th>
<th>N</th>
<th>Workers not following planned process</th>
<th>N</th>
<th>Lack of available equipment or equipment breakdown</th>
<th>N</th>
<th>Planned process not applicable to field conditions</th>
<th>N</th>
<th>Time pressure to complete the set-up/ removal</th>
<th>N</th>
<th>Average Weighted Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessing the roadway and blocking/slowing traffic</td>
<td>2.98</td>
<td>50</td>
<td>2.24</td>
<td>50</td>
<td>2.84</td>
<td>50</td>
<td>3.28</td>
<td>50</td>
<td>2.82</td>
<td>49</td>
<td>2.83</td>
</tr>
<tr>
<td>Placement of temporary signage</td>
<td>3.09</td>
<td>53</td>
<td>2.02</td>
<td>53</td>
<td>3.04</td>
<td>53</td>
<td>3.06</td>
<td>53</td>
<td>2.94</td>
<td>53</td>
<td>2.83</td>
</tr>
<tr>
<td>Placement of cones/barrels for the lane closure</td>
<td>3.02</td>
<td>54</td>
<td>2.17</td>
<td>53</td>
<td>2.94</td>
<td>54</td>
<td>3.02</td>
<td>54</td>
<td>2.93</td>
<td>54</td>
<td>2.82</td>
</tr>
<tr>
<td>Placement of temporary lighting</td>
<td>3.64</td>
<td>42</td>
<td>2.47</td>
<td>38</td>
<td>2.21</td>
<td>42</td>
<td>2.69</td>
<td>42</td>
<td>3.21</td>
<td>42</td>
<td>2.84</td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
<td>3.39</td>
<td>52</td>
<td>2.33</td>
<td>51</td>
<td>2.43</td>
<td>51</td>
<td>2.71</td>
<td>51</td>
<td>3.41</td>
<td>51</td>
<td>2.85</td>
</tr>
<tr>
<td>Placement of radar speed sign(s)</td>
<td>3.43</td>
<td>28</td>
<td>2.25</td>
<td>28</td>
<td>2.56</td>
<td>27</td>
<td>2.71</td>
<td>28</td>
<td>3.21</td>
<td>28</td>
<td>2.83</td>
</tr>
<tr>
<td>Placement of temporary striping</td>
<td>3.54</td>
<td>39</td>
<td>2.51</td>
<td>39</td>
<td>2.72</td>
<td>39</td>
<td>2.69</td>
<td>39</td>
<td>2.59</td>
<td>39</td>
<td>2.81</td>
</tr>
<tr>
<td>Placement of temporary roadway markers/reflectors</td>
<td>3.21</td>
<td>38</td>
<td>2.47</td>
<td>38</td>
<td>2.87</td>
<td>38</td>
<td>2.84</td>
<td>38</td>
<td>2.81</td>
<td>37</td>
<td>2.84</td>
</tr>
<tr>
<td>Average</td>
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<td>Maximum</td>
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</tbody>
</table>

Notes: Ranked from 1 – 5, where 1 = greatest impact to safety, 2 = second-highest impact to safety, and so forth. 0 = not an impact to safety. N = number of responses.
Similar to Question #3.2, the next question (Question #3.3) explored the safety impact on motorists and workers during the traffic control operations, but targeted roadway/jobsite issues. In this question, three roadway and jobsite issues were provided, which included lack of light, difficulty accessing lane or blocking traffic, and lack of space available for workers/equipment. The weighted ranking values, shown in Table 5.4, were also calculated using Equation 3.1. Weighted ranking values from other questions (e.g., Questions 3.4, 3.7, 4.3, and 4.4) shown later in the survey were also derived from the same equation with a calculation process similar to that for Question #3.2. When reviewing the results, a mistake similar to that for Question #3.2 was spotted in the responses to Question #3.3. Hence, the researchers cleansed the data by removing the incorrect responses to increase the accuracy of the results. Table 5.4 shows the results for Question #3.3. In terms of roadway/jobsite issues, the issue that causes the greatest safety concern for motorists and workers during traffic control set-up and removal was lack of space available for workers/equipment (average weighted ranking = 1.61), whereas lack of light issue was deemed as having the lowest impact on safety (average weighted ranking = 2.18).
Table 5.4: Weighted Ranking of Impact of Roadway/Jobsite Issues on Motorist and Worker Safety Risk (a lower value indicates a higher ranking)

<table>
<thead>
<tr>
<th>Activity/Task</th>
<th>Weighted Ranking of Impact of Roadway/Jobsite Issue on Motorist and Worker Safety</th>
<th>Lack of light (e.g., nighttime work)</th>
<th>N</th>
<th>Difficult accessing lane or blocking traffic</th>
<th>N</th>
<th>Lack of space available for workers/equipment</th>
<th>N</th>
<th>Average Weighted Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessing the roadway and blocking/slowing traffic</td>
<td>2.12 50</td>
<td>1.78 50</td>
<td>1.58 50</td>
<td>1.83</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of temporary signage</td>
<td>2.26 53</td>
<td>1.87 53</td>
<td>1.66 53</td>
<td>1.93</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of cones/barrels for the lane closure</td>
<td>2.24 54</td>
<td>1.72 54</td>
<td>1.65 54</td>
<td>1.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of temporary lighting</td>
<td>1.95 42</td>
<td>1.93 42</td>
<td>1.88 42</td>
<td>1.92</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
<td>2.27 51</td>
<td>1.96 51</td>
<td>1.51 51</td>
<td>1.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of radar speed sign(s)</td>
<td>2.25 28</td>
<td>1.67 27</td>
<td>1.32 28</td>
<td>1.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of temporary striping</td>
<td>2.15 39</td>
<td>1.64 39</td>
<td>1.59 39</td>
<td>1.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of temporary roadway markers/reflectors</td>
<td>2.18 38</td>
<td>1.66 38</td>
<td>1.71 38</td>
<td>1.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>2.18 38</td>
<td>1.78 38</td>
<td>1.61 38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>1.95 38</td>
<td>1.64 38</td>
<td>1.32 38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>2.27 38</td>
<td>1.96 38</td>
<td>1.88 38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: Ranked from 1 – 3, where 1 = greatest impact to safety, 2 = second-highest impact to safety, and 3 = least impact. 0 = not an impact to safety. N = number of responses.

The next question (Question #3.4) targeted traffic/motorist issues, such as high speed of passing vehicles, traffic congestion, and aggressive drivers, that have an impact on motorist and worker safety. Respondents were given five traffic/motorists issues and were asked to rank the issues from 1 to 5, where 1 is the greatest safety impact, 2 is the second-greatest safety impact, and 5 is the lowest safety impact. Respondents were instructed to enter “0” if the issue does not have any impact to safety. Table 5.5 shows the results for Question #3.4. The results show that “High speed of passing vehicles” was ranked as the most impactful issue on safety for all traffic
control placement activities/tasks (average weighted ranking = 1.50). The remaining four issues, in order from highest impact to lowest impact, are: aggressive drivers (2.06), high volume of traffic (2.64), high volume of trucks (3.39), and lastly, traffic congestion (3.82). It is comprehensible that traffic congestion was ranked as the least impactful issue among all five given issues since traffic is stationary or travelling at a low speed when congestion occurs.
Table 5.5: Weighted Ranking of Impact of Motorist/Traffic Issues on Motorist and Worker Safety Risk (a lower value indicates a higher ranking)

<table>
<thead>
<tr>
<th>Activity/Task</th>
<th>Weighted Ranking of Impact of Motorist/Traffic Issues on Motorist and Worker Safety</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>High speed of passing vehicles</td>
<td>N</td>
<td>2.68</td>
<td>N</td>
<td>3.38</td>
<td>N</td>
<td>3.88</td>
<td>N</td>
<td>1.84</td>
<td>N</td>
<td>2.69</td>
</tr>
<tr>
<td>Placement of temporary signage</td>
<td>N</td>
<td>2.72</td>
<td>N</td>
<td>3.42</td>
<td>N</td>
<td>3.79</td>
<td>N</td>
<td>2.13</td>
<td>N</td>
<td>2.70</td>
</tr>
<tr>
<td>Placement of cones/barrels for the lane closure</td>
<td>N</td>
<td>2.65</td>
<td>N</td>
<td>3.43</td>
<td>N</td>
<td>3.93</td>
<td>N</td>
<td>1.93</td>
<td>N</td>
<td>2.68</td>
</tr>
<tr>
<td>Placement of temporary lighting</td>
<td>N</td>
<td>2.69</td>
<td>N</td>
<td>3.60</td>
<td>N</td>
<td>3.95</td>
<td>N</td>
<td>2.17</td>
<td>N</td>
<td>2.79</td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
<td>N</td>
<td>2.75</td>
<td>N</td>
<td>3.47</td>
<td>N</td>
<td>3.76</td>
<td>N</td>
<td>2.29</td>
<td>N</td>
<td>2.77</td>
</tr>
<tr>
<td>Placement of radar speed sign(s)</td>
<td>N</td>
<td>2.43</td>
<td>N</td>
<td>3.11</td>
<td>N</td>
<td>3.61</td>
<td>N</td>
<td>2.21</td>
<td>N</td>
<td>2.59</td>
</tr>
<tr>
<td>Placement of temporary striping</td>
<td>N</td>
<td>2.59</td>
<td>N</td>
<td>3.31</td>
<td>N</td>
<td>3.77</td>
<td>N</td>
<td>1.95</td>
<td>N</td>
<td>2.60</td>
</tr>
<tr>
<td>Placement of temporary roadway markers/reflectors</td>
<td>N</td>
<td>2.61</td>
<td>N</td>
<td>3.39</td>
<td>N</td>
<td>3.89</td>
<td>N</td>
<td>1.95</td>
<td>N</td>
<td>2.64</td>
</tr>
<tr>
<td>Average</td>
<td>N</td>
<td>2.64</td>
<td>N</td>
<td>3.39</td>
<td>N</td>
<td>3.82</td>
<td>N</td>
<td>2.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>N</td>
<td>2.43</td>
<td>N</td>
<td>3.11</td>
<td>N</td>
<td>3.61</td>
<td>N</td>
<td>1.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>N</td>
<td>2.75</td>
<td>N</td>
<td>3.60</td>
<td>N</td>
<td>3.95</td>
<td>N</td>
<td>2.29</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: Ranked from 1 – 5, where 1 = greatest impact to safety, 2 = second-highest impact to safety, and so forth. 0 = not an impact to safety. N = number of responses.
5.1.4 Safety Impacts of Traffic Control Set-up Compared with Traffic Control Removal

Question #3.5 of the survey asked respondents to compare the safety risk during traffic control setup to that during the traffic control removal period. Four alternative options were provided to respondents to evaluate, as shown in the Figure 5.5 along with the results to the question. The majority of respondents (55.2\%) perceived the safety risk of installing the traffic control in the work zone is typically the same as that for removing the traffic control from the work zone. Only 19 out of 58 respondents (32.8\%) claimed that safety risk while installing the work zone traffic control is higher than while removing the traffic control. The reasons of claiming such as a statement are:

- Road users already have a comprehensive idea of what to expect for traffic control setup in place, such as roadway pattern changes, in a work zone during the removal operation. Therefore, it is less likely to cause a wrong maneuver while travelling in a work zone when the traffic control removal process takes place.

- When performing the traffic control removal, the process begins from downstream of the work zone. Therefore, workers are protected by existing traffic control devices upstream.

- The initial set-up of traffic control exposes workers to passing traffic, whereas removal usually takes place within the existing lane closure.

- For nighttime work, the installation of the traffic control operation usually takes place during the peak traffic period (evening) where people are travelling from work to their house. Therefore, work crews frequently deal with risks associated with passing traffic compared with removal in the early morning with less traffic.
The goals established for traffic control set-up and removal can impact safety and work performance of workers. To obtain a clear understanding of the goals of contractors for the planning and design of the traffic control set-up and removal operation, Question #3.7 asked respondents to rank given goals related to safety, mobility, amount of resources needed and time required, quality, and cost from the highest priority to the least priority for their work operation. Table 5.6 shows the ranking results based on the given goals. As can be observed from the table, the safety of motorists and workers was the top priority when planning and designing temporary traffic control operation (weighted ranking = 1.03). This interesting result indicates that the respondents are very concerned about safety and take it very seriously in their practices as
instructed by FHWA (2009) in which the main goal for temporary traffic control is to provide safe movement of traffic through the work zone by protecting road users and motorists from any accidents caused by traffic, equipment, or unexpected events. The remaining goals for traffic control planning and designing were ranked from highest to lowest as follows: quality of the traffic control placement (weighted ranking = 2.91), mobility of motorist through the work zone (3.06), number of workers required (3.91), coordination with construction/maintenance of work operation (4.00), amount of resource (4.21), amount of time required (4.24), and cost of the operation (6.46). The cost of operation was ranked as the least important goal for contractors which means there are no financial concerns for the companies when it comes to planning and designing the work zone traffic control. The respondents did not specify the other goals in detail, however one respondent indicated the availability of law enforcement officer assistance as being significantly least important among other goals.

Table 5.6: Ranking of Goals considered when Planning and Designing Temporary Traffic Control Operations (a lower value indicates a higher ranking)

<table>
<thead>
<tr>
<th>Goals</th>
<th>Number of Responses at each Ranking Level</th>
<th>Weighted Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorist and worker safety</td>
<td>34 1 0 0 0 0 0 0 0</td>
<td>1.03</td>
</tr>
<tr>
<td>Quality of the traffic control placement</td>
<td>8 8 8 5 2 4 0 0 0</td>
<td>2.91</td>
</tr>
<tr>
<td>Mobility of motorists through the work zone</td>
<td>5 12 8 4 2 1 2 1 0</td>
<td>3.06</td>
</tr>
<tr>
<td>Number of workers required</td>
<td>2 7 7 3 7 4 3 0 0</td>
<td>3.91</td>
</tr>
<tr>
<td>Coordination with the construction/maintenance work operations</td>
<td>6 6 2 5 6 3 4 2 0</td>
<td>4.00</td>
</tr>
<tr>
<td>Amount of resources (equipment and materials) required</td>
<td>2 8 3 5 3 9 1 2 0</td>
<td>4.21</td>
</tr>
<tr>
<td>Amount of time required</td>
<td>3 6 5 4 6 2 8 0 0</td>
<td>4.24</td>
</tr>
<tr>
<td>Cost of the operation</td>
<td>2 3 2 0 0 3 3 13 0</td>
<td>6.46</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>2 0 0 0 0 0 0 0 1</td>
<td>9</td>
</tr>
</tbody>
</table>
Notes: Ranking from 1 to 9, where 1 = highest priority, 2 = second-highest priority, and so forth. 0 = not a priority.

5.1.6 Safety Risk of Traffic Control Set-up and Removal by Location in Work Zone

To identify the level of safety risk in a specific work zone area, two questions were presented to the respondents with one targeted on worker safety (Question #4.1) and the other focused on motorist safety (Question #4.2). Both questions contained a similar format and asked respondents to rate the level of safety of the following work zone areas: advance warning area, transition area, activity area, and termination area. Rating scales of 0 to 5 were used where 0 = no risk, 1 = very low risk, and 5 = extremely high risk. Figure 5.6 shows results, based on the weighted average, regarding the work zone location with respect to Questions #4.1 and #4.2. Note that the trends for both questions (motorist safety and worker safety) are very similar to each other. The transition area was perceived as creating extremely high risk for both workers (weighted average = 4.34) and motorists (weighted average = 3.88) during traffic control set-up and removal. Whereas, the termination area was reported as the lowest risk area to both workers (2.61) and motorists (2.11). This finding is contrary to the findings from a previous research study by Garber and Zhao (2002) on the safety risk after the traffic control is set-up while the construction/maintenance work is being conducted which indicated that the activity area is the most hazardous area during daytime and nighttime operations.
5.1.7 Impact of Time of Work on Safety Risk

Roadway construction and maintenance work can influence worker and motorist safety differently in the daytime than in the nighttime. The time in which the work is performed can create hazards during the setup and removal of temporary traffic control. The researchers examined the daytime and nighttime safety impact of the traffic control operations on workers and motorists. Two questions were posed to evaluate the level of safety impact on workers (Question #4.3) and motorists (Question #4.4) based on time of work given six traffic conditions associated with traffic volume, speed, and congestion. Figure 5.7 and Figure 5.8 show the results in terms of the weighted ranking with respect to worker and motorist safety, respectively. Both
figures reveal that nighttime traffic control placement and removal generally introduces higher risk than daytime traffic control operations regardless of any traffic conditions, except for the daytime condition with high traffic volume and no congestion, which is perceived to pose greater risk for worker safety than the nighttime condition with high traffic volume and congestion for motorist safety. The work condition posing the least safety risk for workers is when the work is performed during the daytime with high traffic volume and congestion (weighted ranking = 4.25). However, for motorists, daytime with low traffic volume and free flow speeds was ranked as the lowest risk work condition (weighted ranking = 4.20).

Figure 5.7: Daytime and Nighttime Risk Comparison of Worker Safety
5.1.8 Safety Risk based on Specific Traffic Control Activity/Task being Performed

Two survey questions were designed to investigate the respondents’ risk assessment regarding to the level of safety risk associated with a specific activity/task performed during traffic control placement and removal. Question #4.7 guided respondents to rate the level of safety risk of the temporary traffic control activities to worker safety, whereas Question #4.8 focused on safety risk to motorists. An example of a traffic control placement activity could be the placement of a variable message sign on the roadway. Using a scale of 0 to 5, respondents were asked to rate what they think the risk would be, where 0 = no risk/I don’t know, 1 = very low risk, and 5 = extremely high risk. The results from Question #4.7 and Question #4.8 are shown in Table 5.7 based on calculations of the weighted average rating using Eqn. 5.1. The rating results for both motorist and worker safety are quite similar. Accessing the roadway and blocking/slowing traffic
was rated as the highest risk activity for both workers (weighted rating = 4.45) and motorists (3.76) among all of the traffic control activities. In addition, the second-highest risk activity for both motorists and workers was placement of cones/barrels (weighted average = 4.38 for workers, 3.55 for motorists). On the other hand, interestingly, placement of lights was identified as the least risky activity for both workers (2.98) and motorists (2.27).

Table 5.7: Weighted Average of Traffic Control Activities/Tasks in terms of Risk to Worker and Motorist Safety (A higher value indicates a higher rating)

<table>
<thead>
<tr>
<th>Activity/Task</th>
<th>Weighted Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placement of temporary lighting</td>
<td>Worker Safety (Q4.7)</td>
</tr>
<tr>
<td>Placement/set-up of radar speed sign(s)</td>
<td>2.98</td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
<td>3.11</td>
</tr>
<tr>
<td>Placement of temporary striping</td>
<td>3.22</td>
</tr>
<tr>
<td>Placement of temporary roadway markers/reflectors</td>
<td>3.55</td>
</tr>
<tr>
<td>Placement of temporary signage</td>
<td>3.57</td>
</tr>
<tr>
<td>Placement of cones/barrels for the lane closure</td>
<td>3.83</td>
</tr>
<tr>
<td>Accessing the roadway and blocking/slowing traffic</td>
<td>4.38</td>
</tr>
<tr>
<td>Other (please specify):</td>
<td>3.50</td>
</tr>
</tbody>
</table>

5.1.9 Temporary Traffic Control Set-up and Removal Practices and Technologies

The last part of the survey asked respondents open-end questions about safety advice and recommendations on technologies that could improve operational processes of traffic control set-up and removal on high speed roadways with multiples lane that require a short-term closure of one or more lanes.

Question #5.1 asked respondents to share their knowledge for improving safety in a work zone and efficiency of temporary traffic control operations. The responses received from the respondents included the following: using protective gear or equipment such as a truck with a
TMA, or seeking assistance from highway patrol vehicles while the traffic control set-up and removal operation takes place. These strategies have been utilized to mitigate crash frequency and severity as well as to stop over-speed vehicles travelling in the work zone. Other advice from respondents included: utilizing attention attracting devices such as flashing lights, arrow boards, and flashing blue lights to help alert drivers of road conditions ahead, encouraging early lane merging, and increasing awareness of road users while passing through the transition area. Other best practices provided were: having a clear traffic control plan for the set-up and removal, closely following the standard procedure and guideline of traffic control, for example, installing traffic control in the same direction as the traffic starting from upstream to downstream, and removing traffic control in a reverse direction from the installation process. Respondents also suggested having a competent person such as traffic control supervisor to oversee the whole traffic control placement and removal process, even while the traffic control was in place.

Moreover, to help reduce the overload stress of a single worker, such as in the situation where one worker runs across the traffic lanes to retrieve or place traffic control devices, employing multiple workers to help during the set-up and removal operation is recommended by the respondents. Doing so can mitigate the frequency of worker exposure to risk in a work zone.

Another survey question (Question #5.3) asked respondents about practices that are not recommended for the traffic control operation during set-up and removal. The feedback received from this question included: not having an exact, clear plan or standard of the traffic control operation, performing the traffic control operation without sufficient visibility in a work zone or poor visibility of PPE on workers, such as PPE covered with dirt, or not wearing high-reflective apparel. In addition, respondents recommended not implementing a lane closure when there are inadequate protection devices such as truck mounted with an attenuator, flashing lights, and a
dome light. Furthermore, other respondents mentioned not attempting to close a lane or remove a traffic control device from a restricted lane when workers are not well-trained or do not have proper training.

Lastly, a survey question asked respondents to provide their thoughts on innovative technologies and practices that they have experienced for enhancing the safe practice and effectiveness of the traffic control operation. Most suggestions were related to incorporating the use of an automated cone retrieval truck, which can automatically install and remove cones faster than doing the work manually. Other recommendations were: using an autonomous truck and a truck that utilized the front bumper equipped with a roller, which can shift barrels from an interior lane to a side lane without requiring workers on the roadway. One survey respondent advised using a Traffic Pro Bed truck which provides for safe traffic control set-up and removal operation in every circumstance, and has many convenient features such as equipment organization, safety restraint systems, a flexible height adjustment bucket, high grade visibility, light, and an automatic cone drive. Other general feedback not necessary related to technologies included: using police enforcement to control and maintain the speed of vehicles in a work zone, utilizing devices that can increase the level of comfort of workers in a work zone, such as radar speed signs, crash truck mounted with a TMA, and an audible alert system, and sufficient lighting in transition zones.

5.1.10 Risk Analysis Assessment and Summary

The survey results can be used to capture overall knowledge of traffic control set-up and removal safety risk. One of the targets of the study is to understand work conditions during traffic control set-up and removal that threaten worker and motorist safety the most. The findings from the
survey questions reveal which activities/tasks, and when activities/tasks, present the greatest risk, and what conditions intensify the risk. The hazardous conditions could exist as a result of the work process itself which typically involves workers, equipment, and other resources. The survey results also expose the locations within a work zone that contain the greatest risk, e.g., advance warning area, transition area, activity area, or termination area. This knowledge can be used to make a decision regarding a specific traffic control device to counter the risk.

Table 5.8 contains a summary of a risk assessment related to the conditions and steps in the set-up and removal process, with the location of the hazards present in the work zone. The table highlights situations that need to be focused on to reduce the greatest risk impact on worker and motorist safety. The values presented in Table 5.8 are the weighted average rankings from the survey response data shown in Tables 5.3, 5.4, and 5.5. As stated, the ranking scale ranged from 1 to 5, where 1 = greatest impact to safety and 5 = lowest impact to safety. A lower ranking value indicates a greater impact to safety.

To define the greatest risk conditions for the traffic control set-up and removal operation, three classifications of the risk were established. The following values were utilized to organize the three risk classifications:

- Low risk: Weighted average ranking > 3
- Moderate risk: Weighted average ranking from 2 to 3
- High risk Weighted average ranking < 2

The high-risk conditions are highlighted in dark grey shading and the moderate risk conditions are shown with light grey coloring in Table 5.8. The non-shaded areas indicate conditions that pose low risk to workers and motorist safety. Acronyms of the work zone areas are used to
indicate a location in which risk occurs in a work zone and are abbreviated as follows: advance warning area = AWA, transition area = TRA, activity area = AA, and termination area = TMA. As can be observed from the table, the high-risk conditions of the traffic control operation (mean weighted ranking < 2) occur when there is difficulty in accessing a lane or blocking traffic, lack of space available, and high speed of passing vehicles. Those conditions are considered as the high-risk conditions that generally introduce the most impact to all four major areas of the work zone. In addition, the analysis reveals moderate-to-high risk conditions (mean weighted ranking > 2, but close to 2) during the traffic control operation. Those conditions that cause moderate-to-high risk for the traffic control set-up and removal operation are: aggressive drivers, workers not following planned process, and lack of light. Those risks are also present everywhere in the work zone. It is interesting that the analysis from Table 5.8 indicates that all areas of the work zone could be possibly at high-risk, but the results from Questions #4.1 and #4.2 indicated only the transition area as the highest risk area among other major work zone areas. The in-depth analysis from the table indicates that a high volume of trucks, traffic congestion, and lack of available workers are perceived as low risk conditions (mean weighted ranking > 3), which do not highly threaten worker and motorist safety compared to the conditions that are previously identified above.
<table>
<thead>
<tr>
<th>Activities/Tasks</th>
<th>Location in work zone</th>
<th>Work Conditions</th>
<th>Roadway Conditions</th>
<th>Traffic Conditions</th>
<th>Mean weighted average ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lack of available workers</td>
<td>Workers not following planned process</td>
<td>Lack of light (e.g., nighttime work)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lack of equipment or equipment breakdown</td>
<td>Planned process not applicable to field conditions</td>
<td>Difficult accessing lane or blocking traffic</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lack of pressure to complete set-up and removal</td>
<td></td>
<td>Lack of space available for workers or equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High speed of passing vehicles</td>
<td>High volume of traffic</td>
</tr>
<tr>
<td>Accessing the roadway and blocking or slowing traffic</td>
<td>AWA, TRA, AA, TMA</td>
<td>2.98</td>
<td>2.24</td>
<td>2.84</td>
<td>3.28</td>
</tr>
<tr>
<td>Placement of temporary signage</td>
<td>AWA, TRA, AA, TMA</td>
<td>3.09</td>
<td>2.02</td>
<td>3.04</td>
<td>3.06</td>
</tr>
<tr>
<td>Placement of cones/barrels for the lane closure</td>
<td>TRA, AA, TMA</td>
<td>3.02</td>
<td>2.17</td>
<td>2.94</td>
<td>3.02</td>
</tr>
<tr>
<td>Placement of temporary lighting</td>
<td>AA</td>
<td>3.64</td>
<td>2.47</td>
<td>2.21</td>
<td>2.69</td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
<td>AWA</td>
<td>3.39</td>
<td>2.33</td>
<td>2.43</td>
<td>2.71</td>
</tr>
<tr>
<td>Placement of radar speed sign(s)</td>
<td>AWA</td>
<td>3.43</td>
<td>2.25</td>
<td>2.56</td>
<td>2.71</td>
</tr>
<tr>
<td>Placement of temporary striping</td>
<td>AWA</td>
<td>3.54</td>
<td>2.51</td>
<td>2.72</td>
<td>2.69</td>
</tr>
<tr>
<td>Placement of temporary</td>
<td>AWA</td>
<td>3.21</td>
<td>2.47</td>
<td>2.87</td>
<td>2.84</td>
</tr>
<tr>
<td>roadway markers and reflectors</td>
<td>3.29</td>
<td>2.31</td>
<td>2.70</td>
<td>2.88</td>
<td>2.99</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Mean Weighted Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2 Focus Group Interviews

This section of the thesis describes the results from the focus groups interviews. As stated above, the interviews targeted Oregon Department of Transportation personnel and Oregon roadway construction and maintenance contractors. The interviews of both groups were held online via Zoom on different dates and lasted for about 1 hour and 30 minutes. The contractor focus group interview took place on August 24, 2021, from 2:00pm to 3:00pm (PST), whereas the ODOT focus group interview was held on August 26, 2021, from 8:00am to 9:30am (PST). The total number of participants joining the interviews were 5 participants for the contractor group and 4 participants for the ODOT group. Table 5.9 provides a summary of the input from both focus groups in terms of similar perspectives and dissimilar perspectives that they had on the main interview questions related to the topic of the research.
Table 5.9: Results of Focus Group Interviews

<table>
<thead>
<tr>
<th>Similar Perspectives, both ODOT and Contractors</th>
<th>Dissimilar Perspectives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ODOT Personnel</td>
</tr>
<tr>
<td>1. What Safety Issues are Associated with Temporary Traffic Control Set-Up and Removal?</td>
<td></td>
</tr>
<tr>
<td>• Driver behavior influenced by alcoholic substances and pressure from work causes safety concerns to work crews while setting up and removing the traffic control from work zone.</td>
<td>• Working too close to high speed passing vehicles, especially when working on traffic control installation and removal close to on-ramp.</td>
</tr>
<tr>
<td>• Lack of protective devices/equipment and pre-warning message devices to protect work crews and inform drivers of road work condition ahead while operating the traffic control.</td>
<td>• Drivers videotape work zone traffic control operation while driving through the work zone.</td>
</tr>
<tr>
<td>• Lack of skills and knowledge of traffic control crew in setting up and removing the traffic control devices. Due to this reason, work crews sometime were reported using their own judgement to set-up and remove traffic control devices without following standard procedures for the traffic control operation.</td>
<td>• Insufficient space available for the sign set-up, especially when installing signs on the bridge structure. As a result, workers consumed significant time on finding a set-up spot. Hence, exposing workers to the passing traffic for a longer period of time.</td>
</tr>
<tr>
<td></td>
<td>• Installing traffic control devices on a complex configuration of a highway work zone. One ODOT personnel witnessed this issue on I-84 along the Columbia River near Multnomah Falls where drivers were typically confused about the direction to go in a work zone as a result of an exit located on the left side of the roadway.</td>
</tr>
<tr>
<td></td>
<td>• Drivers swerve their vehicle to avoid rumble strips placed in a work zone.</td>
</tr>
<tr>
<td>2. What are the Three Riskiest Processes of Temporary Traffic Control Set-up and Removal?</td>
<td></td>
</tr>
<tr>
<td>• Initial setup of the first advance warning signs and merging taper were deemed as the riskiest processes during traffic control set-up and removal.</td>
<td>• The third riskiest process was high speed of passing vehicles during all activities of the set-up and removal operation.</td>
</tr>
</tbody>
</table>
- Operating traffic control installation/removal close to an on-ramp was described as the second-most hazardous process.

### 3. What are the Challenges Associated with Traffic Control Set-up and Removal?

<table>
<thead>
<tr>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of labor force resulting in increasing workload pressure on traffic control crews to get the task done.</td>
</tr>
<tr>
<td>Complexity of the road configuration such as a curvy road, and limited sight distance of drivers driving in work zone. As a result, increasing the drivers’ reaction time to an obstacle in a worker zone.</td>
</tr>
<tr>
<td>Light and glare in a work zone impair drivers’ visibility while driving through the work zone.</td>
</tr>
<tr>
<td>Complexity of road structures also cause difficulty for workers to find the best spot to set up signs, especially when working on bridge structures. They often struggle to find a spot to install the signs.</td>
</tr>
<tr>
<td>Due to budget constraints, interviewees reported a lack of providing protective equipment for traffic control crews to operate the lane closure.</td>
</tr>
<tr>
<td>Over speed vehicles driving through the work zone during the traffic control set-up and removal operation.</td>
</tr>
<tr>
<td>Drivers disobeying the work zone traffic signs while maneuvering through the work zone.</td>
</tr>
<tr>
<td>Having tight schedules for the traffic control set-up and removal operation.</td>
</tr>
<tr>
<td>Difficulty in creating public’s understanding of the safety risks associated with the traffic control set-up and removal in a work zone.</td>
</tr>
</tbody>
</table>
4. What are the Challenges Associated with Traffic Control Setup and Removal during Daytime Compared to Nighttime?

- At night, the traffic volume is lower than daytime. Hence, vehicles drive faster than in the daytime, which poses a safety concern to workers during the set-up and removal operation at night.

- Nighttime often results in poorer visibility than daytime. Due to this reason, there is an increase in reaction time of drivers driving at night which results in a higher probability of accidents occurring within a work zone than in the daytime.

- The darker it gets, the greater the number of intoxicated drivers and aggressive drivers. As a result, it does not feel safe for workers to operate the traffic control set-up and removal at night.

- More resources are required for a nighttime traffic control operation to enhance visibility of the work zone than in a daytime operation.

5. What Suggestions do You have for the Research Study for Improving the Safety of Workers and Motorist during Traffic Control Installation and Removal Operation?

- Provide workers on-site safety training on work zone traffic control operations related to set-up and removal.

- Deploy highway patrol vehicles during the set-up and removal operation.

- Implement the use of radar speed boards in work zones to keep the speed in the work zone constant.

- Enhance visibility in the work zone by using additional lighting, reflective materials, equipment, and PPE.

- Install extra signs for “Lane closed ahead” sign to remind road users of upcoming closed lane.

- Provide more public service announcements prior to the start of the project.

- Provide more public service announcements before road construction or maintenance projects start.

- Work zone traffic control designers should actively collaborate and listen to the feedback from contractors regarding their experiences with the use of traffic control devices (e.g., safety of implementing devices in work zone and their impact on the public).
### 6. Which Parts of the Set-up/Removal Process should the Study Focus on to Significantly Improve Safety of Workers and Motorists?

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<tr>
<td>• Integrate into a guideline the use of a headlamp on workers and reflective materials for tapers.</td>
<td>• Increase the timeframe of the traffic control set-up and removal operation to ensure safe practices and high quality of the operation.</td>
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<tr>
<td>• Increase public incident response vehicles in a work zone while setting up and removing a work zone.</td>
<td>• Use radar speed board either upstream of the transition area or within the work zone.</td>
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### 7. ODOT Expectations from Contractors to Ensure Safe Operation of Traffic Control Set-up and Removal (Applies to ODOT interviewees only)

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<tr>
<td>• Have sufficient protective devices or equipment before performing traffic control set-up and removal</td>
<td>• Explore a method for safely deploying and removing temporary rumble strips in the work zone.</td>
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<tr>
<td>• Follow work zone traffic control installation and removal standards and guidelines</td>
<td>• Conduct a study of the most effective sequential arrow that should be used in a work zone during the traffic control operation.</td>
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<td>• Develop a contingency plan for the traffic control set-up and removal operation</td>
<td>• Investigate traffic control indicators such as variable message boards showing “SLOW DOWN” messages to drivers in the work zone.</td>
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<tr>
<td>• Inspect traffic control device quality and condition before use</td>
<td>• Actively collaborate with traffic control inspector on safety plan and procedure for traffic control set-up and removal operation</td>
</tr>
<tr>
<td>• Actively collaborate with traffic control inspector on safety plan and procedure for traffic control set-up and removal operation</td>
<td>• Maintain safe practices of the work zone closure installation and removal throughout the whole operation and entire work zone</td>
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5.2.1 Summary of Focus Group Interviews

Based on the focus group interviews, it can be concluded that the safety issues generally linked with the traffic control set-up and removal operations are: driver behavior, lack of equipment and materials during the operation, insufficient space available for workers and equipment, high speed of passing vehicles, unpredictable events occurring such as a knocked over cones rolling on a live traffic lane, and lack of light. These findings were clearly confirmed by the results from the survey, where a majority of these issues were also identified as the main issues that the survey respondents encountered while implementing traffic control operations. Among those issues identified, the results from Question #3.4 show “Aggressive drivers” associated with driver behavior was considered as the major critical issue among the other traffic and motorist issues that pose the highest safety impact to workers and motorists. In addition, Question #3.3 indicates “Lack of space available for workers/equipment” was identified as the issue that presents the highest safety impacts in terms of roadway and jobsite issues.

Further findings on the three riskiest processes during the traffic control set-up and removal operation reveals that both groups of interviewees have a similar perspective regarding the hierarchy of the processes for the top and second-most risky traffic control activities. Both groups viewed the part of the traffic control installation involving set-up of the first sign was the most dangerous process during set-up, whereas deploying traffic control devices close to an open on-ramp was perceived as the second-most risky process in the operation. Interestingly, the results from Questions #4.1 and #4.2 in the survey also show a very similar result, especially when asked to rank the safety risk level associated with the traffic control operation based on work zone area in which the “transition area” was identified as the highest risk area in work
zones. Regarding to the third-most risky activity, but not necessary related to the process, the perspective from the ODOT group was different from the contractor group. On one hand, the ODOT group mentioned that a large speed variation in the work zone occurs while setting up and removing traffic control. This condition is not necessary specific to one set-up/removal activity, but to the whole operation, and poses a significant safety impact to workers and motorists. The statement was also supported by evidence from a recent ODOT study titled “Speed Variation and Safety in Work Zone” (Gambatese and Jin, 2021), which found that the difference between vehicle speed and average vehicle speed in a work zone was one of the factors that influences work zone crashes. On the other hand, the contractor group viewed picking up a knocked over cone on a live traffic lane was an unpredictable and potentially disastrous event that can adversely affect the safety of workers and motorists during the operation.

The traffic control step-up and removal challenges should be considered when planning and designing the traffic control operation. The identified challenges stated by ODOT and contractor personnel are: complexity of road structure, lack of public understanding on risks associated with the traffic control set-up and removal operation, lack of labor force, limited budget, poor lighting, excessive glare, and a tight schedule for setting up and removing the traffic control. Those challenges are perceived as a “domino effect” where the one challenge is the root cause and ultimately effects the other tasks or activities. For instance, due to a limited budget, the contractor reduces the number of protective equipment purchased and provides less training for their workers than the standard requirement for the lane closure operation. As a result, the combined conditions increase the probability of risk exposure to workers. This phenomenon may be an indication of the reasons why the finding from Question #3.2 in the survey indicated a lack of available equipment was ranked as the second highest impact to worker and motorist safety.
The safety and quality of the traffic control set-up and removal can be impacted differently depending on whether the work is performed in the daytime or nighttime. When asked which time of the day is preferable to perform the traffic control set-up and removal, both groups provided the same answer that daytime is preferable to nighttime operation. The groups indicated that it is generally safer in the daytime due to several reasons, such as better visibility in the daytime, daytime vehicle speed is lower as a result of high traffic volume, less probability of odd events such as intimidating drivers (e.g., drunk drivers and intoxicated drivers), and less cost for the traffic control demand. This result is consistent with the results found from survey questions #4.3 and #4.4, in which the majority of respondents typically ranked daytime operations as safer than nighttime traffic control operations. A previous study by Mostafavi (2012) also reveals that nighttime traffic control operations are likely associated with more cost than daytime operations since nighttime operations require more traffic control devices to enhance the quality and brightness of a work zone, and require other costs associated with enhanced traffic control, and overtime payment. These impacts could potentially pose challenges for work crews to perform traffic control operations safely at night.

5.3 Field Observations

The following sections of the thesis describe the results from the field observations which include the set-up and removal processes of temporary traffic control, and hazardous elements of the work process that present safety concerns to workers and motorists. As described above, three projects located in Oregon were selected for the field observations. Each of the projects is described in detail below.
5.3.1 Project 1: I-5 Paving Project between I-205 and Boone Bridge

5.3.1.1 Project description

The project site was situated along I-5 southbound between I-205 and Boone Bridge in Wilsonville, Oregon. The goal of the project was to repave and resurface the highway as well as to rehabilitate the bridge structure to increase its life expectancy. The estimated total cost of project was $9,976,289. The roadway contractor responsible for this project was Oregon Mainline Paving. The project construction schedule began in Spring 2021 and the project was completed in late 2021. The on-going scope of work during the site observation were restriping, concrete repair, and some repaving work.

5.3.1.2 Observation description

The observation took place on June 7, 2021 on a section of I-5 that contains four lanes in each direction. Three lanes were closed on southbound I-5 with each lane closed at different designated times. The researchers and contractor personnel first met at the project yard prior to departing to the work zone site. They discussed the best techniques for the observation, safety precautions that needed to be implemented, and the traffic control plan for where to begin the lane closure. How to coordinate between the work crew while performing the lane closure operation was then discussed at the office at the project yard. As stated above, the researchers documented the traffic control operation information using note-taking, video-taping, photographing, and interviews.
5.3.1.3 Traffic control set-up procedure

Three lanes of a section of I-5 southbound were terminated in three closure stages. The first stage was the A-lane closure, follow by the second stage to close the B-lane, and lastly the C-lane closure. The work zone traffic control set-up time varied from one stage to another due concerns about the impacts of the closure on public vehicles. The A-lane closure started at 7:42pm, then the B-lane closure at 9:45pm, and lastly the C-lane was closed after the B-lane was fully closed to traffic. During the observation, the researchers only observed the full process of the traffic control set-up for the A-lane and the B-lane. The lane closure processes for the A- and B-lanes were as follows:

Procedure for A-lane closure:

1. Set up the advance warning signs on both sides of roadway. The process of setting up the advance warning signs was performed by setting up the signs on the edge of the right shoulder first, then setting up the signs on the edge of the left shoulder. Then, the advance warning signs were installed in the following order starting from the right side to the left side of roadway: “Road Work Ahead”, “Left Lane Closed in ½ mile”, and “Left lane closed” sign. Two vehicles were used to set-up the signs on both shoulders. One of the vehicles was a truck mounted with an attenuator and used for installing signs on the left shoulder, and the other vehicle was a pick-up truck with a TMA used for installing signs on the right shoulder.

2. While installation of the “Left lane closed” sign on the left shoulder was taking place, the traffic control crew working on the right shoulder simultaneously began installing barricade on the left shoulder.
3. Then, the crew installed an arrow board downstream of the barricade and set it to “Caution mode” with four dots flashing on the panel.

4. Once the “Left lane closed” sign on the left shoulder was installed, the crew turned on the arrow board to “Merge right” mode.

5. Lined up the exiting barrels located on the side of the left shoulder to form a left shoulder taper.

6. Installed a merging taper on the A-lane. Three work crew members were used: one member pulling barrels from the side of the left shoulder and passing it to another work crew member to install the taper, and two work crew members aligning the barrels to create a merging taper for the A-lane. During the first taper installation, a cone truck mounted with a TMA was used as a protection vehicle by slightly encroaching on the traffic lane (A-lane) as the taper was extended into the lane.

7. Installed cones along the skip line between the A-lane and B-lane from the cone truck. Two workers were located on the back of the truck for placing cones. One worker was the cone installer, and the other worker was the cone passer. As the installation process of the cones along the skip line occurred, another work crew member worked on installing the following signs on the edge of the right shoulder and at on-ramps as follows:
   a. Installed “Left 2 lanes closed ½ miles” on the on-ramps
   b. Then, installed the “Left lane closed” sign on the edge of the right shoulder
   c. Lastly, installed the second “Left lane closed” sign on the edge of the right shoulder
Process for B-lane closure:

As mentioned above, the process for the B-lane closure started at 9:45pm after the completion of the A-lane closure. The B-lane closure process can be described as follows:

1. Installed the second merging taper on the B-lane. The processes for installing the merging taper for the B-lane was similar to installing the merging taper for the A-lane. While installing the second (B-lane) merging taper, the barrels were already laid out on the skip line between the A- and B-lanes. The work crew just simply shifted the barrels from the skip line between the A- and B-lanes to form a second merging taper. One worker pulled barrels and passed them to the other two workers for aligning the barrels to form a merging taper on the B-lane. While installing the merging taper, the work vehicle (cone truck) mounted with a TMA slowly encroached into the B-lane to protect the workers as they installed the merging taper.

2. After the merging taper on the B-lane was installed, the cones along the skip line between the B- and C-lanes were installed from the work vehicle. The cones were already laid out on the skip line between the A-lane and the B-lane. Therefore, one worker standing on the work vehicle simply picked up the cones while the vehicle travelled on the B-lane and passed the cones to another worker on the vehicle to place on the skip line between the B-lane and C-lane.

3. Continued installing cones on the skip line between the B-lane and C-lane by repeating step 2 until the start of the third merging taper.
Procedure for C lane closure:

The operation of C-lane closure occurred late in the late night and the researchers did not have an opportunity to observe the operation for the C-lane closure. However, it can be assumed that the process followed for the C-lane closure was similar to the process used for the B-lane closure described above. In addition, at the end of the C-lane closure, the work crew installed the termination area.

5.3.1.4 Traffic control removal procedure

For nighttime work, the traffic control removal operation usually takes place in the early morning after the roadwork maintenance is completed. Unfortunately, researchers were not able to observe the full process of the entire work zone removal, but contractors briefly were able to show how they remove cones from a skip line between A- and B-lanes. The process of cone removal started by backing up the work vehicle mounted with a TMA with two workers located on the back of the work vehicle. One crew member was the cone remover and the other crew member was the cone keeper. While the work vehicle backed up at a slow speed, the cone remover picked up the cones from the skip line and passed them to the cone keeper for stockpiling on the truck. The researchers also recorded a video of the removal process for future reference.

5.3.2 Project 2: I-5 Road Surfacing, Milepost 216-235

5.3.2.1 Project description

Traffic control for a concrete section in the southbound direction of I-5 between milepost 216 and 235 was observed. The roadway has two lanes in each direction at this location. At this location, the road was aging and starting to deteriorate and rut due to studded tire and chain use.
The road required resurfacing to repair the deteriorated sections. The maintenance cost of the project was estimated to be approximately $15,300,000 under a contract with Oregon Mainline Paving. The ongoing operation tasks during the observation included grinding the concrete to reduce rutting and repairing the concrete where rebar was exposed on the roadway surface.

5.3.2.2 Observation description

The observation began on Wednesday, June 9, 2021 at 6:00pm at the project laydown yard on I-34, which is located east of Corvallis. To begin, the researchers first met with the ODOT inspector and contractor personnel to discuss the traffic control set-up and removal operation plan and process. The observation methods and safety guidelines were also discussed during the brief meeting. After the meeting, the researchers then departed the project yard to go to the work zone site, which was about a 15-minute drive from the yard. The B-lane next to the right shoulder was to be closed for the road maintenance. To ensure all important notes were captured, a similar observation process as that used for Project 1 was used that included note-taking, worker interviews, photographing, and video-taping.

5.3.2.3 Traffic control set-up procedure

The work zone closure operation of two lanes in each direction of I-5 southbound between milepost 216 and 235 began at 7:52pm and lasted for approximately 40 minutes to complete the entire closure for the B-lane. The A-lane remained open to traffic. The equipment and traffic control devices used to perform the lane closure operation were: a truck mounted with a TMA, a cone truck, arrow boards, cones, temporary signs, barrels, and a barricade. The whole lane closure for the B-lane was completed at 8:40pm. The process followed to create the lane closure for the B-lane is described below:
1. Set up the advance warning signs on both sides of the roadway. The process for installing the advance warning signs involved two work vehicles mounted with TMAs. First, the work crew installed the “Road Work Ahead” sign on the left shoulder, then installed another “Road Work ahead” sign on the right shoulder. Then, the work vehicles, one on each side of the roadway, installed the following signs in order starting from the left side to the right side of the roadway: “50mph Speed ahead”, “Speed Limit 50mph”, “Right Lane Closed ½ mile”, and lastly, “Right Lane Closed.”

2. Once the advance warning signs were installed, the work crew installed the arrow board on the right shoulder.

3. Placed the barricade in front of the arrow board simultaneously as the shoulder taper was installing.

4. Installed the merging taper on the B-lane using barrels to form a taper. During the installation process, work crews pulled the barrels from the right shoulder and placed them on the B-lane to create a taper. As the workers installed the taper, the work vehicle mounted with a TMA and a changeable message sign showing the message “SLOW FOR WORKERS” slowly encroached into the traffic lane to protect the workers.

5. Lastly, using the cone truck with a TMA, the workers installed cones along the skip line between the A- and B-lanes until the end of the work zone to form the full lane closure. During this operation, two work crew members, excluding the truck driver, were used, one was the cone installer and the other was the cone passer.
5.3.2.4 Traffic Control Removal Procedure

The traffic control removal operation on the B-lane began early the next morning at 4:26am and was fully completed by 5:25am. The B-lane traffic control removal procedure consisted of the following steps:

1. Removed cones along the skip line between the A- and B-lanes. The removal operation started from the downstream end of the work zone and progressed back upstream until the end of the merging taper by backing up the cone truck. A protection vehicle with a TMA was situated upstream of the cone truck to protect the cone truck. Two workers worked from the back of the cone truck during the removal process. One crew member was the cone remover, and the other crew member was the cone keeper.

2. Close to the very end of the merging taper, there were two cones left on the skip line. One worker suddenly left the cone truck to pick up the other remaining cones on foot and put them back on the cone truck.

3. Removed the merging taper starting from the downstream end to the upstream end of the taper by placing the barrels on the side of shoulder. During this process, the work crew members were protected by the protection vehicle mounted with a TMA. As the workers proceeded to remove the barrels, the protection vehicle moved slightly back towards the shoulder.

4. Once the merging taper was removed from the lane, the workers removed the barricade and placed it back on the pick-up truck.

5. The workers then removed the shoulder taper starting from the downstream end of the taper to the upstream end of the taper.
6. Lowered the trailer-mounted arrow board at the start of the merging taper and attached it to the pickup truck for removal from the site.

7. Removed advance warning signs on the left shoulder.

8. Circled back to the start of the work zone and removed the advance warning signs on the right shoulder starting from the first warning, “Road Work Ahead” sign, approached by the traffic users.

9. Removed the following signs in sequence in the same direction as the traffic:
   a. “50 mph Speed Ahead” sign
   b. “Speed Limit 50 MPH” sign
   c. “Right lane closed ½ mile” sign
   d. “Right lane closed” sign

5.3.3 Project 3: I-405 Fence Repairing on Marquam Bridge

5.3.3.1 Project Description

The location of the project was on the top deck of the Marquam Bridge that spans across the Willamette River in the Portland metropolitan area. The work operation occupied from the I-405 southbound lanes to the top deck of the Marquam Bridge. Inspection of the bridge revealed that a section of a fence on the bridge was structurally damaged due to an accident caused by a truck. The damaged public property included bridge rail and posts. Potential hazards associated with the damaged property, such as falling of damaged rails and fence onto motorists travelling below the bridge, could occur at any moment. To avoid the life-threatening hazard to the public, the ODOT maintenance team was assigned to fix the issues.
5.3.3.2 Observation description

On July 15, 2021, the researchers went to the ODOT Maintenance shop in Clackamas, OR to meet with the ODOT bridge maintenance crew. The intent of the meetings was to fully understand the planned traffic control set-up and removal process, what to expected during the operation, strategies for observing the traffic control operation, and safety practices before proceeding to and while at the work zone site. After the meeting finished, all work crew members along with the researchers proceeded to the work zone site and performed their duty as assigned. During the observation, questions related to hazardous processes were asked to the work crew members. In the meantime, note-taking, photographing, and video-taping of the traffic control operation were also conducted to capture the work practices.

5.3.3.3 Traffic Control Setup Procedure

The work zone closure operation began at 10:00pm and finished at 10:47pm. Due to the bridge maintenance work, the B-lane was terminated for the operation. The length of the work zone was approximately 1.3 miles, measured from the first advance warning sign to the termination area of the work zone. The equipment and traffic control devices used in the work zone operation included: cones, trucks with a TMA, cone truck, arrow boards, warning signs, radio devices, flashing lights, and PPE equipment for the traffic control crew. The work zone closure set-up process was as follows:

1. Set up the attenuator on the first protection vehicle on the left shoulder of I-405 northbound prior to the vehicle arriving at the site. In a meantime, the second protection vehicle protected the first protection vehicle by encroaching into the adjacent traffic lane. While setting up the attenuator, the other two protection vehicles were stationary in a
blocking mode behind the second protection vehicle to protect the first and second protection vehicles in front of them. All vehicles were equipped with a message/arrow board containing a message to merge to the open lane, and with a flashing light turned on when setting up the attenuator.

2. Set up the “Right lane closed” sign in the median from I-405 northbound (i.e., from the opposite side of the roadway). Two protection vehicles were placed behind the work crew working on sign installation. All vehicles displayed “Merge to the right” messages on the arrow board with their flashing yellow lights on while the operation took place.

3. Installed “Right lane closed ahead” sign in the median from I-405 northbound. Two protection vehicles were used to cover workers while setting up the sign. All protection vehicles encroached into the traffic lane with an arrow board showing “Merge to the right” and flashing yellow light indicated.

4. Installed the “Bridge Work Ahead” sign in the median from I-405 northbound. While a worker placed the sign, two protection vehicles were line up upstream of the worker with the front of the vehicle leaning toward the traffic lane to protect the worker. The “Merge to the right” message and flashing yellow lights were present on all vehicles during the operation.

5. Circled back to I-405 southbound and proceeded toward the advance warning area.

6. Installed “Bridge work ahead” sign on the right shoulder of I-405 southbound. While a worker was working on sign installation, the same two protection vehicles protected the worker from the back by leaning into the traffic lane with a message board displaying “Merge to the left lane”. All vehicles were equipped with a flashing yellowing light while installing the sign.
7. Installed “Right lane closed ahead” sign on the right shoulder of I-405 southbound. Due to insufficient space for protection vehicles to park, the first protection vehicle parked at a neutral area, the paved triangular space between the on-ramp and the highway lane, and the second protection vehicle parked at a convenient location behind the first protection vehicle where it is safe to park.

8. Installed “Right lane closed” sign on the right shoulder of I-405 southbound. The same practices described in step 6 were applied when protecting the work crews setting up the sign.

9. Once the advance warning area was established, the workers placed the third protection vehicle at the top of the Broadway Street on-ramp to block traffic from entering the on-ramp prior to installing the first merging taper near the Broadway Street on-ramp.

10. Installed the first merging taper and arrow board near the on-ramp once the on-ramp traffic terminated. The same practices described in step 6 were applied when stationing the protection vehicles. While workers were installing the taper and arrow board, the first protection vehicle was positioned at a neutral area, whereas the second protection vehicle was parked at a convenient location behind the first protection vehicle.

11. Continued to install the first merging taper from the cone truck, starting from the first arrow board until progressing downstream of the first merging taper. The same practices as shown in step 6 were applied when protecting the work crews operating the traffic control set-up.

12. Installed the second merging taper near the 5th Avenue off-ramp. The taper was installed by workers on foot until the two farthest right lanes were closed. In the meantime, all of
the protection vehicles, including the work vehicle parked on the right shoulder of I-405 southbound close to the 5th avenue on-ramp, were stationed upstream of the work.

13. Continued installing cones on the skip line between lanes A and B from the second merging taper until downstream of the work zone. The process for installing cones was operated from the work vehicle and was protected by the two protection vehicles followed the work vehicles. All vehicles indicated a “Merge to the left lane” message on the arrow board with a flashing yellow light turned on.

5.3.3.4 Traffic Control Removal Procedure

Removal of the work zone traffic control began early in the morning the next day (July 16, 2021) at 4:36am. The researchers were not able to observe the process of removing the advance warning signs. However, the researchers had an opportunity to observe the process to remove the traffic control from the termination area to the first merging taper, which took less than 20 minutes to complete. The removal operation was completed at 4:53am. A detailed description of the removal process is provided below:

1. First, removed the cones from the skip line between the A-lane and B-lane starting from the downstream end of the work zone until the second merging taper. The removal process was performed using a work vehicle backing up toward the upstream end of the work zone with one protection vehicle used to protect the work vehicle from the back. A caution mode was displayed on the arrow board on the protection vehicle while backing up the vehicle.

2. As the work vehicles proceeded with the traffic removal operation close to the downstream end of the second merging taper, the third protection vehicle that was
initially placed at the downstream end of the second merging taper was removed for the first two work vehicles to continuously operate the removal operation.

3. Continued to remove the second merging taper starting from downstream to upstream in the work zone. The protection vehicle backed up slowly behind the work vehicle as the removal operation was on-going.

4. Prior to removing the first merging taper, the third protection vehicle was placed on the top of the on-ramp to block on-ramp traffic and ensure a safe removal operation for the first merging taper.

5. Once on-ramp traffic was blocked, removed the first merging taper starting from the downstream end of the taper until the start of the first taper. The removal was performed by continually backing up the work vehicle slowly with assistance from the protection vehicle behind it.

6. Removed the arrow board at the first merging taper. The protection vehicle was placed behind the work vehicle while a worker removed the arrow board.

7. After the arrow board was removed, the third protection vehicle that blocked the on-ramp traffic released the on-ramp traffic.

5.3.4 Hazardous elements of work processes based on field observations

The results from the field observations exposed dangerous instances during the operations that presented safety concerns to workers and motorists. The data collection method used relied on a subjective approach based on field observations by the researchers. The quantitative data collected during the observations was then analyzed to obtain the results. The identified hazardous conditions associated with the traffic control set-up and removal included:
• Setting up the initial signs and taper in work zone.
• Operating the temporary traffic control set-up and removal close to an open on-ramp.
• Insufficient personal fall restrain system on the work vehicle to secure workers while placing and removing channelizing devices such as cones and barrels.
• Not following the planned sequence for the traffic control set up and removal process
• Missing physical components on the truck to provide for safety of the workers, such as a step or ladder on the passenger side of the work vehicle for passengers to use to climb up on the vehicle.
• Setting up the TMA close to a live traffic lane
• The driver of the work vehicle reading the traffic control plan while driving to the work zone
• Lack of space available for protection vehicle to protect the cone truck near the on-ramp
• Driver confusion caused by backing up the truck during the removal operation
• Wrong indication on the arrow sign mounted on a truck
• Setting up (lowering) the TMA on the back of the truck without a sufficient protection device present.
• The loud truck engine created a high noise level for the workers and made it harder for the workers to communicate with each other during the traffic control operation.
• Blind spot present for the truck driver while backing up the truck.
• A worker climbing up the roadway divider to give a hand signal to the driver of the work vehicle after merging from the fast lane into the work zone.
• Retrieving knocked over cones in a live traffic lane
While not included in the study, an alternative objective method used to assess the risk could be based on quantitative data collected based on actual field measurements and historical data associated with traffic control activities. The safety risk related to each traffic control activity could be determined by using Equation 5.1:

\[ \text{Safety Risk} = \text{Frequency} \times \text{Severity} \times \text{Exposure} \]  
(Eqn.5.2)

Where,  
Frequency = Frequency of injury or incidents per traffic control activity, (e.g.: 1/hrs)

Severity = Severity of injury per traffic control activity, (e.g.: numerical value associated with high, medium, or low severity)

Exposure = Duration of each traffic control activity during set-up and removal  
(e.g.: 0.05 hrs)

The exposure data can be obtained by observing and measuring the actual time it takes workers to perform each activity when installing and removing the traffic control. The severity and frequency of incident values could be extracted from other sources such as OSHA reports, an ODOT or OSP crash database, contractor injury/fatality reports, or other data sources that provide sufficient info related to frequency and severity of injury/fatality incidents that occur during traffic control set-up and removal.

The discussion section of the thesis will present treatments that could be implemented to alleviate the problems listed above and the associated safety risks during traffic control set-up and removal operations.
6. DISCUSSION

Temporary traffic control devices in work zones are extremely essential and necessary to ensure safe movement of roadway users within the work zone, especially prior to and during the road maintenance and construction work operations taking place. The typical traffic control set-up procedure usually begins upstream of the advance warning area and progresses to downstream of the termination area in the work zone, except when installing traffic control devices on a detour route which progresses from downstream to upstream along the detour route. However, the traffic control removal process is in the opposite direction of the standard process of used for traffic control set-up.

The most common work zone traffic control activities associated with highway work zone closures include temporary sign placement, cone and barrel placement, arrow board placement, placement of temporary lighting, and so forth. Each of those activities poses safety risk to a varying degree. The most hazardous traffic control activities or situations that threaten worker and motorist safety as ranked by the focus group interviewees from ODOT and Oregon roadway construction and maintenance personnel are: installing initial signs and merging taper, installing and retrieving traffic control devices close to open on-ramp, picking up knocked over cones and barrels on a live traffic lane, and operating any traffic control set-up and removal activities that are close to vehicles passing by at high speed. In addition, the results from the survey and focus group interviews indicate that the transition area is perceived as the “highest risk area” in a work zone while installing the work zone closure. It is reasonable that the transition area presents higher risk than other locations in a work zone since it reduces the number of lanes available for use and merge the traffic with the through traffic lane. On the other
hand, the results from the analysis of the weighted rankings from the survey highlighted not only the transition area is posing high risk, but all areas of the work zone present high risk, especially in situations in which all traffic control activities encounter difficulty in accessing a lane or blocking traffic, there is a lack of space available for workers or equipment, and there are vehicles passing by at high speeds during the set-up and removal periods.

In order to mitigate identified risks presented during the traffic control set-up and removal operation, the researchers identified a list of treatments based on feedback from the ODOT and contractor focus group interviews, survey, and site observations. The identified treatments are listed below, and can be options for future researchers to consider when conducting studies related to the topic of work zone safety:

- Place multiple portable radar speed signs in following areas: upstream of the initial warning sign placement, prior to the taper, within the work zone, and at on-ramps.
- Mount flashing blue lights on barrels/drums in the merging taper area.
- Attach a warning device, such as sensor device or proximity alert system, to alert nearby workers of a backing-up truck.
- Deploy law enforcement at the initial sign set-up area in the work zone.
- Utilize an automatic cone retrieval truck.
- Implement a railway crossing gate control at on-ramp entrances, or use red traffic lights at on-ramps to stop traffic entering the on-ramps when workers are setting-up traffic control devices near the on-ramps.
- Use a mobile barrier when operating work zone closures near curved road structures.
• Provide public service announcements of work zones in advance of the work (e.g., provide a message of the upcoming roadwork activity on a PCMS one month before the road construction or maintenance starts).

• Use a rolling slow down for setting up the first sign in a work zone.

• Extend the merging taper length to allow more time for drivers to react to or merge into the through lane.

• Provide a magnetic base for cones to prevent the cones from being knocked over.

• Utilize a truck equipped with a barrel mover to move barrels from the road side to the lane in a work zone, or vice versa, instead of moving the barrels using workers on foot.

• Install additional advance warning signs when the road is curvy or in hazardous weather conditions such as snow or heavy rain.

• Use highly visible or reflective material for cones and barrels in a work zone, especially for the taper.

• Place flashing yellow lights on cones that are located close to on-ramps to attract the attention of road users entering/exiting the roadway.

To assist in making decisions in selecting identified treatments, the researchers developed Table 6.1 which organizes potential treatments according to objective, type, and placement location. The table shows each treatment with its purpose, which can be used to pre-condition driving behavior before drivers enter the work zone and maintain safe driving behavior while they travel within the work zone. Of those treatments suggested, some are designed to enhance efficiency and safety during the traffic control operation. Most of the treatments suggested are identified as engineering controls and are mainly implemented on the workers or the equipment.
Furthermore, Table 6.2 was developed to address the moderate and high risk conditions identified in Table 5.8. The correlation shows the ability of the treatments to mitigate the impacting condition. For instance, utilizing a PCMS with radar speed board and place them before the “Road Work Ahead” sign can mitigate risk related to the high speed of passing vehicles, and aggressive driver behavior. As can be seen from the table, the majority of suggested treatments positively address the conditions that are impacted by an issue related to aggressive drivers and high vehicle speeds. As a guide for selecting treatments to implement in field operations, contractors should prioritize treatments that target high risk activities and consider wisely the treatments based on the following criteria: availability of treatment, cost of treatment implementation, duration of the actual workzone operation versus the traffic control operation, objective of the treatment, feasibility of treatment, long term and short-term effectiveness of treatment, hierarchy level of treatment (e.g., higher level of control would be better), and ability of treatment to serve multi-purposes in risk reduction.
Table 6.1: Characterization of Recommended Treatments

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Objective</th>
<th>Location</th>
<th>Type</th>
<th>Type of Control in Hierachy of Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-condition driving behavior before work zone</td>
<td>Maintenance of driving behavior in work zone</td>
<td>Prior to work zone</td>
<td>Efficient or reduced effort and improved safety controls for traffic control crew</td>
<td>Change in roadway, worker, or equipment feature</td>
</tr>
<tr>
<td>PCMS with radar speed board located before Road Work Ahead signs</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Change in work process or procedure</td>
</tr>
<tr>
<td>Flashing lights on work equipment (e.g., blue lights)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Change in work process or procedure</td>
</tr>
<tr>
<td>Flashing lights on roadway (e.g., electronic orange “pucks”)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Change in work process or procedure</td>
</tr>
<tr>
<td>Balloon lights or light towers located at regular spacing in work zone</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Change in work process or procedure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attach sensors to workers and equipment to give an alert when in close proximity</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Police enforcement</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>360° camera on every truck to view surrounding area</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Railway crossing gate control at on-ramps</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Automatic cone retrieval truck</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Magnetic base for cones</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mobile barrier</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Barrel mover truck</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Rolling slow down during traffic control operations</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Public service announcement of work zone operations</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highly reflective material on cones and barrels</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Extend taper length</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Provide additional advance warning signs</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Provide flashing yellow lights on cones</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Treatment</td>
<td>High Risk Conditions</td>
<td>Moderate Risk Conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>--------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Difficult accessing lane or blocking traffic</td>
<td>Lack of space available for workers or equipment</td>
<td>High speed of passing vehicles</td>
<td>Aggressive drivers</td>
</tr>
<tr>
<td>PCMS with radar speed board located before Road Work Ahead signs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flashing lights on work equipment (e.g., blue lights)</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Flashing lights on roadway (e.g., electronic orange “pucks”)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Balloon lights or light towers located at regular spacing in work zone</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Attach sensors to workers and equipment to give an alert when in close proximity</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Police enforcement</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>360° camera on every truck to view surrounding area</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Railway crossing gate control at on-ramps</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Automatic cone retrieval truck</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Magnetic base for cones</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile barrier</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Barrel mover truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rolling slow down during traffic control operations</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Public service announcement of work zone operations</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highly reflective material on cones and barrels</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Extend taper length</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Provide additional advance warning signs</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Provide flashing yellow light on cones</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
7. LIMITATIONS

The study contains limitations that affect the ability to extend the results to larger populations with confidence. For example, as the focus group interviews solely targeted participants from the Oregon Department of Transportation (ODOT) and roadway construction and maintenance contractors in Oregon, the results could be slightly biased and not represent the perceptions of the population across the US as a whole regarding safety risks associated with work zone traffic control set-up and removal operations. The scope of inference is more reliable when making judgements on risk present in traffic control operations in the State of Oregon.

In addition, the results from Questions 3.2, 3.3, and 3.4 in the survey may be slightly biased when asking respondents to rank roadway, jobsite, work operation, and motorist/traffic issues with respect to motorist and worker safety. Survey participants who responded to those three questions can be classified into two groups: (1) personnel who either work for state DOT or a roadway contractor and have extensive knowledge related to traffic control operations, and (2) those who are considered as motorists without having any experience related the traffic control set-up and removal. Personnel who have experience with traffic control set-up and removal could confidently assess safety risk for both workers and motorists since they are also assumed to be a motorist who has experience driving in work zones during the traffic control operation. However, for those who are mainly classified as motorists without having any traffic control experience would not be able to confidently respond when asked to rank the issues with respect to worker safety. The responses received from motorists without traffic control experience are more accurate when asked to rank issues on motorist safety than worker safety.
Furthermore, the small samples of participants from ODOT and contractor groups introduce additional impacts on data reliability into the study. Nevertheless, the industry and state surveys, along with the site observations, reveal some common findings with the focus group interview results when investigating subjects related to work zone traffic control set-up and removal. As a result, the use of multiple methods provides strong evidence to confirm the results from the focus group interviews are truly logical and accurate. Moreover, the results in the personal demographics section of the survey reveal the average experience of respondents working in the transportation and construction industry was 13 years, with the majority of respondents indicating that they are very familiar with traffic control planning and execution. These results strongly help to further verify that the participants have vast experience with respect to work zone traffic control placement and removal, thereby supporting the accuracy of the study findings.

Overall, even though there are limitations present in the current study, the level of impact of the limitations on the overall study is believed to be very low. The findings in this study are still valid for future use and reference, and can be widely distributed both locally and internationally to enhance safety in work zones, particularly during the period of traffic control set-up and removal.
8. CONCLUSIONS

The goal of the study was to identify ways to improve the work zone safety, particularly during the period when the traffic control is being set-up, modified, and removed. This goal is achieved by investigating the risks and safety hazards associated with the traffic control operations and developing potential recommendations to ensure the highest levels of motorist and worker safety. To ensure the overall goal and the objectives of the studies were fulfilled, four different research methods were implemented: a review of existing literature on work zone safety, industry and state DOT surveys, focus group interviews, and site observations.

The literature review exposed existing technologies, such as an automated cone retrieval truck and a standing platform for placing and removing devices, that are available to assist work crews in safety performing the operations of setting up and removing traffic control devices. The innovative technologies aim to mitigate the risk exposure of workers in direct contact with hazardous activities and enhance ease-of-use. The findings also reveal guidance from state practices on work zone traffic control set-up and removal procedures available for the operational uses. The general process of the traffic control set-up on a high-speed roadway usually begins upstream of the work zone and proceeds toward the downstream end of the work zone, excluding detour installation. Whereas, the process is reversed for removal operations starting from the far end of the termination area and working backward upstream to the advance warning area. However, existing guidance provides limited descriptions and detail on the setup and removal procedures, and the guidance varies from state to state. The most common guidance for work zone traffic control operations that the researchers encountered was for stationary lane closure installation and removal. Availability of guidance on other work operations and
conditions (e.g., installing a work zone closure on a multi-lane freeway that requires lane closure of two or more lanes) is still insufficient for contractors and state DOTs.

In addition, analyses of the survey and focus group interview results highlighted conditions of the traffic control activities in which traffic control crews are in danger while conducting the work zone closures. The results from focus group interviews indicate the highest risk traffic control activities identified were: placing the initial signs and merging taper, retrieving knocked over cones and barrels in a live traffic lane, and working on device installation and removal close to an open on-ramp. Furthermore, results from the survey show high-risk and moderate-risk situations present in all traffic control activities. High-risk situations occur in all traffic control activities and exist particularly when there is difficulty in accessing lanes or blocking traffic, there is a lack of space available for workers and equipment, and there is a high speed of passing vehicles. Whereas for all traffic control activities, a moderate risk situation is present when workers do not follow the planned process, there is a lack of light, and aggressive drivers are present. Both high risks and moderate risks are present in all locations of the work zone starting from the advance warning area till the transition area. Extra effort and attention should be invested mitigating those particular identified hazardous conditions associated with traffic control activities.

Furthermore, the survey and focus group interview results indicate that daytime traffic control operations (7:00am – 7:00pm) are generally safer than nighttime operations (7:00pm-7:00am). The primary reasons given for such a claim were: daytime generally contains a higher volume of traffic which results in lower speeds of passing vehicles; better visibility in the daytime; lower costs for enhancing traffic control devices for daytime operation and smaller probability of odd events, such as less intoxicated drivers and stressful drivers on the roadway,
occur during the daytime than in the nighttime. It is also believed that the most hazardous condition during nighttime traffic control operations, generally are undertaken from 7:00pm to 7:00am, occurs when there is high traffic volume but not congestion.

The on-site observations reveal elements of work processes that are risky for motorists and workers. Of those elements recognized during the observations, some are similar to the results found from the survey and focus group interviews. Brief examples of elements that induce risks during the traffic control operation are, among others: reading the traffic control plans while driving the truck to the work zone, insufficient space available for protection vehicles to cover the work vehicles, setting up signs in the wrong order, misleading arrow sign on arrow board mounted on a truck, setting up and removing traffic control close to an open on-ramp, and installing the initial signs and taper. The results of the observations indicate that further risk mitigation measures are needed, along with means to mitigate the risk.

To reduce the impacts of, and mitigate, the risks identified in traffic control set-up and removal operations, the current study proposes several alternative treatments which can be further investigated and applied in practices. The recommended treatments are available in Table 6.1 with the inclusion of characterization of treatments which shows treatment objectives, placement locations, and the effectiveness of each treatment in reducing risk. As a supplement, Table 6.2 was developed to target the high risk and moderate risk conditions that are present in traffic control operations. Examples of the potential treatments include placing flashing blue lights on cone devices, placing a radar speed board with a PCMS in advance of the “Road Work Ahead” sign, implementing a rolling slowdown during the initial sign set-up, and using an automated cone retrieval truck during set-up and removal. The majority of suggested treatments
primarily target speed reduction in work zones, which aims to increase safety during traffic control placement and removal in work zone.
9. RECOMMENDATIONS

State guidelines and procedures for work zone traffic control set-up and removal are available to a limited extent and generally contain very broad meanings for their use. It is essential for state DOTs and future studies to develop a temporary traffic control standard procedure for each specific type of work zone operation that specifically contains the number of resources used in work zone traffic control operations, such as the quantity of traffic control devices, time required for each traffic control activity, and location of workers and work vehicles to be positioned in a work zone while installing and removing the traffic control. By doing so, this information helps ensure the proper standard of care in traffic control operations is followed and maintained throughout the whole operation. Providing this information is expected to increase efficiency in the traffic control operation, and enhance the safety of both motorists and workers in work zones.

To ensure the highest level of safety performance during traffic control operations, roadway construction and maintenance contractors should only attempt to perform traffic control work activities when sufficient protective devices and equipment are available. Following the traffic control installation and removal plan and guidelines is a must. A traffic control contingency plan should include at least the following elements: alternative methods of device placement and removal, and escape routes for an emergency event. In addition, the plan should be developed in advance of the lane closure operation. Contractors should actively communicate with traffic control crews and work zone traffic control planners on safety plans and procedures that concern traffic control set-up and removal operation. Inspecting traffic control device quality and conditions should always be done before they are used. It is necessary to maintain safe traffic
control operation practices throughout the entire work zone placement, even while maintenance work operations are taking place.

Future researchers should develop a work zone driving simulator to predefined risks associated with each traffic control activity as well as to identify how worker and driver behavior changes over periods of time based on given roadway factors such as weather, vehicle speed, traffic volume, lack of work crew members, level of visibility, road configuration, and so forth. As a result, this research will help road contractors to better visualize risks in reality in advance, prior to going out to the work zone site, and to be prepared to take additional measures against hazards.

The current study involved a limited number of participants for both ODOT and roadway contractor focus groups. Future studies should target more participants from both local and international locations to ensure that the study results can be interpreted widely and are accurate for the current research topic.

Last but not least, due to time and budget constraints, the present study only focused on implementing radar speed boards, PCMS, and electronic road flares for the case studies. However, additional investigation of the recommended treatments should be carried out further to examine the level of effectiveness of each treatment in reducing work zone crashes, risk exposure, and vehicle travel speed in work zones. This additional research will benefit not only those who work in the transportation and construction industry, but also promote the highest safety standard of life across the country and boost the country’s overall economic performance.
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11. APPENDICES

APPENDIX A: WORK ZONE TRAFFIC CONTROL SET-UP AND REMOVAL SURVEY
Work Zone Traffic Control Set-up and Removal Survey

“Best Practices for Work Zone Safety during Traffic Control Placement, Removal, and Modifications” (SPR 839)

Study Sponsor: Oregon Department of Transportation (ODOT)

Survey Introduction:
This survey is part of a larger study to investigate ways to improve worker and motorist safety during the set-up, removal, and modification of temporary traffic control for roadway construction and maintenance. The study aims to document current and promising practices, evaluate safety risk, and provide guidance on work zone set-up, removal, and modification operations.

Study Context:
The study focuses specifically on temporary traffic control set-up and removal for construction and/or maintenance work zones under the following conditions: short-term (e.g., 1 day or night) operations on high-speed roadways with multiple lanes in each direction (e.g., freeway) and free-flow traffic (no congestion) that requires the closure of one or more lanes. Please answer the survey questions with respect to this context.

What will happen during this survey and how long will it take?

- You will be asked to express your opinion and share your experience related to the process and practices associated with the set-up, removal, and modification of temporary traffic control for roadway construction and maintenance operations.
- You will also be asked your opinion about the safety risk associated with the operations.
- Lastly, you will be asked about best practices and innovative technologies for setting up, removing, and modifying temporary traffic control. You may print or take a screenshot of the consent page for your records.
It is expected that the survey will take approximately 15 minutes to complete.

The information you provide is for research purposes only. Some of the questions are personal, however no identifying information (e.g., name, employer, etc.) is requested or needs to be provided. You can choose not to answer any of the questions if you wish.

*Thank you for participating in this survey!*
ADDITIONAL SURVEY INFORMATION

How will my information be used?

Your responses to the survey questions will be summarized in a final research report and one or more academic papers. All publications of the study results will not include any information about your identity or affiliation. A summary of the results will be created for the benefit of the research team. However, the summary will not include personal information of the participants (e.g., name, title, company, etc.).

All information provided will be kept strictly confidential and viewed only by the researchers and the funding agency (ODOT). Your information and responses that are collected as part of the research will not be used or distributed for future research studies. Survey responses will be provided to ODOT as part of the study requirements, however the data provided will not include any identifying information such as personal and company/organization names or other identifying information.

What are the risks of this study to the participants?

The survey has minimal risks, and all information that you provide will remain confidential, be used for research and educational purposes only, and accessed only by the researchers.

Accidental disclosure of the survey responses and personal information: Personal identities are not required to complete the survey. Thus, survey responses cannot be traced to individual people or companies/organizations.

Internet: The security and confidentiality of information collected from you online cannot be guaranteed. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

What are the benefits of this study to the participants?

There are no direct benefits to you from this study. However, the research will be beneficial to the construction industry as a whole. With your feedback and response to the survey, more reliable and accurate ways to ensure work zone safety can be achieved.
Do I have a choice to be in the study?

Participation in the study is voluntary. Participants may refuse to answer any questions and/or may withdraw from the study at any time. Participation or non-participation will not affect your relationship with your company/organization.

What if I have questions?

Participants are encouraged to ask any questions at any time about the study and its procedures, or about their rights as a participant. The investigators’ names and contact information are included below so that you may ask questions and report any study-related problems.

- John Gambatese, School of Civil and Construction Engineering, Oregon State University, 101 Kearney Hall, Corvallis, OR 97331, Tel.: (541) 737-8913, john.gambatese@oregonstate.edu
- Serey Raksa Moeung, School of Civil and Construction Engineering, Oregon State University, 101 Kearney Hall, Corvallis, OR 97331, Tel.: (425) 625-7685, moeungs@oregonstate.edu

If you have any questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office at 541-737-8008 or by e-mail at irb@oregonstate.edu.
Q1.0 Section 1. Organization and Personal Demographic Information

Please answer the following general questions about the organization you work for and your background and experience.

Q1.1 Please select the type of organization that you work for:

- Local, state, or federal transportation agency
- Construction contractor or subcontractor
- Other (please specify): _____________________________

Display This Question:
If Please select the type of organization that you work for: = Local, state, or federal transportation agency

Q1.1a Please select the job title that best describes your work position:

- Project Manager / Assistant Project Manager
- Project Engineer / Assistant Project Engineer
- Roadway Engineer / Designer
- Traffic Control Designer
- Safety Manager / Safety Engineer
- Inspector
- Maintenance Supervisor
- Maintenance Crew Member
- Traffic Control Crew Member
- Other (please specify): _____________________________

Display This Question:
If Please select the type of organization that you work for: = Construction contractor or subcontractor
Q1.1b Please select the job title that best describes your work position:

- Project Manager / Assistant Project Manager
- Project Engineer / Assistant Project Engineer
- Project Superintendent / Assistant Project Superintendent
- Safety Manager / Safety Engineer
- Foreman
- Equipment Operator
- Laborer
- Other (please specify): ____________________________________________

Display This Question:

If Please select the type of organization that you work for: = Other (please specify):

Q1.2 What is your job title/position?

____________________________________________________________________

Q1.3 How many years of experience do you have working in the transportation/construction industry?

- Less than 1 year
- 1 - 5 years
- 6 - 10 years
- 11 - 15 years
- 16 - 20 years
- More than 20 years
Q1.4 What is the size of your company/organization? (Approximate number of employees)
  ○ Less than 10 employees
  ○ 10 and 50 employees
  ○ 51 and 100 employees
  ○ 101 and 250 employees
  ○ 251 and 500 employees
  ○ 501 and 1000 employees
  ○ More than 1000 employees

Q1.5 What state do you work in? If you work in more than one state, select the state in which you conduct most of your work.

▼ Select state (58) ... WY (57)

Q2.0 Section 2. Involvement with Temporary Traffic Control

Please answer the following questions regarding the extent and nature of your involvement with setting up and removing temporary traffic control for construction and/or maintenance work zones.
Q2.1 Approximately what percentage of your job involves the following roles related to the set-up and removal of temporary traffic control in work zones?

<table>
<thead>
<tr>
<th>Planning traffic control set-up and removal operations (1)</th>
<th>0% - 20%</th>
<th>21% - 40%</th>
<th>41% - 60%</th>
<th>61% - 80%</th>
<th>81% - 100%</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>Performing traffic control set-up and removal activities in the field (2)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Display This Question:

If Approximately what percentage of your job involves the following roles related to the set-up and... = Planning traffic control set-up and removal operations [0% - 20%]

Or Approximately what percentage of your job involves the following roles related to the set-up and... = Performing traffic control set-up and removal activities in the field [0% - 20%]

Q2.1a Please describe the nature of your involvement, if any, in the set-up and removal of temporary traffic control for work zones.

__________________________________________________________________________
Q2.2 Please indicate your level of familiarity with each of the following roles related to the set-up and removal of temporary traffic control in short-term (e.g., 1 day or night) operations on high-speed roadways with multiple lanes in each direction (e.g., freeway) and free-flow traffic (no congestion) that requires the closure of one or more lanes.

<table>
<thead>
<tr>
<th></th>
<th>Not familiar</th>
<th>Minimal familiarity</th>
<th>Low familiarity</th>
<th>Moderate familiarity</th>
<th>Very familiar</th>
<th>Extremely familiar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning traffic control set-up and removal operations (1)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Performing traffic control set-up and removal activities in the field (2)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>
Q3.0 **Section 3. Temporary Traffic Control Set-up and Removal Activities/Tasks and Safety Impacts**

**Based on your personal experience**, please answer the following questions about the safety impacts associated with temporary work zone traffic control set-up and removal activities/tasks.

Several of the following questions are about safety risk and ask for your ranking related to three categories:

- Work operations
- Traffic/motorist conditions
- Roadway/jobsite features

For these questions, **safety risk** is the combination of the probability and severity of an injury or fatality.

When answering the questions, assume that the traffic control will be used for a **short-term** (e.g., 1 day or night) operation on a **high-speed roadway** with multiple lanes in each direction (e.g., freeway) and **free-flow** traffic (no congestion) that requires the closure of one or more lanes.

Q3.1 Which of the following **activities/tasks** related to temporary traffic control set-up and removal do you have experience with? Please select all that apply, and add other activities/tasks to the list if needed.

- [ ] Accessing the roadway and blocking/slowing traffic
- [ ] Placement of temporary signage
- [ ] Placement of cones/barrels for the lane closure
- [ ] Placement of temporary lighting
- [ ] Placement/set-up of variable message sign(s)
- [ ] Placement/set-up of radar speed sign(s)
- [ ] Placement of temporary striping
- [ ] Placement of temporary roadway markers/reflectors
- [ ] Other (please specify): __________________________________________________________
Q3.2

For each of the temporary traffic control set-up and removal activities/tasks listed below, please rank (from 1-5) each of the work operation issues in terms of its impact on motorist and worker safety risk while performing the activity/task.

**For each row**, enter a ranking from 1-5 in each column. Start with 1 as the greatest impact to safety, 2 as the second-highest impact to safety, and so forth. Enter "0" if it is not an impact to safety when performing the activity/task. An example is provided below:

<table>
<thead>
<tr>
<th>Activities/Tasks</th>
<th>Lack of available workers</th>
<th>Workers not following planned process</th>
<th>Lack of available equipment or equipment breakdown</th>
<th>Planned process not applicable to field conditions</th>
<th>Time pressure to complete the set-up/removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity/task #1</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Activity/task #2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Activity/task #3</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

- Accessing the roadway and blocking/slowing traffic
<table>
<thead>
<tr>
<th>Placement of temporary signage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placement of cones/barrels for the lane closure</td>
</tr>
<tr>
<td>Placement of temporary lighting</td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
</tr>
<tr>
<td>Placement/set-up of radar speed sign(s)</td>
</tr>
<tr>
<td>Placement of temporary striping</td>
</tr>
<tr>
<td>Placement of temporary roadway markers/reflectors</td>
</tr>
</tbody>
</table>
Q3.3

For each of the temporary traffic control set-up and removal activities/tasks listed below, please rank (from 1-3) each of the roadway/jobsite issues in terms of its impact on motorist and worker safety risk while performing the activity/task.

For each row, enter a ranking from 1-3 in each column. Start with 1 as the greatest impact to safety, 2 as the second-highest impact to safety, and so forth. Enter "0" if it is not an impact to safety when performing the activity/task.

If needed, please refer to the previous question for an example of how to enter your rankings.

<table>
<thead>
<tr>
<th>Lack of light (e.g., nighttime work)</th>
<th>Difficulty accessing lane or blocking traffic</th>
<th>Lack of space available for workers/equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessing the roadway and blocking/slowing traffic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of temporary signage</td>
<td></td>
<td></td>
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<tr>
<td>--------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of cones/barrels for the lane closure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of temporary lighting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement/set-up of radar speed sign(s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of temporary striping</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of temporary roadway markers/reflectors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (please specify):</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Q3.4

For each of the temporary traffic control set-up and removal activities/tasks listed below, please rank (from 1-5) each of the **traffic/motorist** issues in terms of its impact on **motorist and worker safety risk** while performing the activity/task.

For each row, enter a ranking from 1-5 in each column. Start with 1 as the greatest impact to safety, 2 as the second-highest impact to safety, and so forth. Enter "0" if it is not an impact to safety when performing the activity/task.

If needed, please refer to the previous question for an example of how to enter your rankings.

<table>
<thead>
<tr>
<th>High speed of passing vehicles</th>
<th>High volume of traffic</th>
<th>High volume of trucks</th>
<th>Traffic congestion</th>
<th>Aggressive drivers (e.g., impatient, late merge, following too close, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessing the roadway and blocking/slowing traffic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of temporary signage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement of cones/barrels for the lane closure</td>
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<tr>
<td>-----------------------------------------------</td>
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<tr>
<td>Placement of temporary lighting</td>
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<td></td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
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<tr>
<td>Placement/set-up of radar speed sign(s)</td>
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<tr>
<td>Placement of temporary striping</td>
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</tr>
<tr>
<td>Placement of temporary roadway markers/reflectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (please specify):</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Q3.5 To what extent are the safety risks associated with the set-up of temporary traffic control similar to the safety risks associated with the removal of temporary traffic control?

- The safety risks are the same and have the same rankings
- The safety risks are the same, but have different rankings
- The safety risks related to set-up are greater than for removal
- The safety risks related to removal are greater than for set-up

Q3.6 Please explain your answer to the previous question regarding the difference in safety risk between temporary traffic control set-up and temporary traffic control removal.

Display This Question:

If To what extent are the safety risks associated with the set-up of temporary traffic control similar to the safety risks associated with the removal of temporary traffic control? = The safety risks are the same, but have different rankings

Or To what extent are the safety risks associated with the set-up of temporary traffic control similar to the safety risks associated with the removal of temporary traffic control? = The safety risks related to set-up are greater than for removal

Or To what extent are the safety risks associated with the set-up of temporary traffic control similar to the safety risks associated with the removal of temporary traffic control? = The safety risks related to removal are greater than for set-up

Display This Question:

If Approximately what percentage of your job involves the following roles related to the set-up and removal of temporary traffic control? = Planning traffic control set-up and removal operations [21% - 40%]

Or Approximately what percentage of your job involves the following roles related to the set-up and removal of temporary traffic control? = Planning traffic control set-up and removal operations [41% - 60%]

Or Approximately what percentage of your job involves the following roles related to the set-up and removal of temporary traffic control? = Planning traffic control set-up and removal operations [61% - 80%]

Or Approximately what percentage of your job involves the following roles related to the set-up and removal of temporary traffic control? = Planning traffic control set-up and removal operations [81% - 100%]
Q3.7 Please rank each of the following goals/outcomes in terms of its priority when you plan/design the operation to set-up and remove temporary traffic control in work zones. Start with 1 as the top priority, 2 as the second priority, and so forth. Enter "0" if it is not a priority.

- Motorist and worker safety
- Mobility of motorists through the work zone
- Amount of time required
- Cost of the operation
- Quality of the traffic control placement
- Number of workers required
- Amount of resources (equipment and materials) required
- Coordination with the construction/maintenance work operations
- Other (please specify):

Q4.0 Section 4. Nature of Safety during Temporary Traffic Control Set-up and Removal

Based on your personal experience, please answer the following questions about safety during temporary work zone traffic control set-up and removal.

For these questions, safety risk is the combination of the probability and severity of an injury or fatality.

When answering the questions, assume that the traffic control will be used for a short-term (e.g., 1 day or night) operation on a high-speed roadway with multiple lanes in each direction (e.g., freeway) and free-flow traffic (no congestion) that requires the closure of one or more lanes.

Q4.1 For each of the work zone areas listed below, please rate the level of safety risk to workers during the set-up and removal of temporary traffic control within the work zone area.

<table>
<thead>
<tr>
<th>Advanced Warning Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>No risk</td>
</tr>
</tbody>
</table>

Q4.2 For each of the work zone areas listed below, please rate the level of safety risk to motorists driving through the work zone during the set-up and removal of temporary traffic control within the work zone area.

<table>
<thead>
<tr>
<th>Work Zone Area</th>
<th>No risk</th>
<th>Very low risk</th>
<th>Low risk</th>
<th>Moderate risk</th>
<th>High risk</th>
<th>Extremely high risk</th>
<th>I don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Warning Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transition Area</td>
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</tr>
<tr>
<td>Activity Area (including buffer space and work space)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Termination Area</td>
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</tr>
</tbody>
</table>
Q4.3 Please arrange the following conditions in the order that represents the level of safety risk to **workers** when setting up and removing temporary traffic control.

Start with 1 as the condition that presents the **greatest** safety risk.

1. Daytime (7:00AM - 7:00PM) with high traffic volume but no congestion
2. Daytime (7:00AM - 7:00PM) with high traffic volume and congestion
3. Daytime (7:00AM - 7:00PM) with low traffic volume and free-flow speeds
4. Nighttime (7:00PM - 7:00AM) with high traffic volume but no congestion
5. Nighttime (7:00PM - 7:00AM) with high traffic volume and congestion
6. Nighttime (7:00PM - 7:00AM) with low traffic volume and free-flow speeds

Q4.4 Please arrange the following conditions in the order that represents the level of safety risk to **motorists driving through the work zone** when setting up and removing temporary traffic control.

Start with 1 as the condition that presents the **greatest** safety risk.

1. Daytime (7:00AM - 7:00PM) with high traffic volume but no congestion
2. Daytime (7:00AM - 7:00PM) with high traffic volume and congestion
3. Daytime (7:00AM - 7:00PM) with low traffic volume and free-flow speeds
4. Nighttime (7:00PM - 7:00AM) with high traffic volume but no congestion
5. Nighttime (7:00PM - 7:00AM) with high traffic volume and congestion
6. Nighttime (7:00PM - 7:00AM) with low traffic volume and free-flow speeds
Q4.5 Approximately how often do you experience or witness a **near miss** involving a motorist during traffic control set-up and removal operations?

For this question, a **near miss** is defined as an incident in which no injury, fatality, or property damage occurred.

- More than once per work shift
- Once per work shift
- Once a week
- Once a month
- Once every 6 months
- Once a year
- Less frequently than once a year
- Other (please specify): ____________________________
Q4.6 Approximately how often do you experience or witness a crash involving a motorist during traffic control set-up and removal operations?

For this question, a crash is defined as an incident involving a public vehicle that resulted in an injury, fatality, and/or property damage.

- More than once per work shift
- Once per work shift
- Once a week
- Once a month
- Once every 6 months
- Once a year
- Less frequently than once a year
- Other (please specify):  

Q4.7 For each of the activities/tasks listed below, please rate the level of safety risk to workers during the process of setting up and removing temporary traffic control.

<table>
<thead>
<tr>
<th>Activity</th>
<th>No risk</th>
<th>Very low risk</th>
<th>Low risk</th>
<th>Moderate risk</th>
<th>High risk</th>
<th>Extremely high risk</th>
<th>I don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessing the roadway and blocking/slowing traffic</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Placement of temporary signage</td>
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</tr>
<tr>
<td>Placement of cones/barrels for the lane closure</td>
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<tr>
<td>Placement of temporary lighting</td>
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<td></td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
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</tbody>
</table>
### Q4.8

For each of the activities/tasks listed below, please rate the **level of safety risk** to **motorists passing through the work zone** during the process of setting up and removing temporary traffic control.

<table>
<thead>
<tr>
<th>Activity</th>
<th>No risk</th>
<th>Very low risk</th>
<th>Low risk</th>
<th>Moderate risk</th>
<th>High risk</th>
<th>Extremely high risk</th>
<th>I don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessing the roadway and blocking/slowing traffic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Placement of temporary signage</td>
<td></td>
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<tr>
<td>Placement of cones/barrels for the lane closure</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Placement of temporary lighting</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement/set-up of variable message sign(s)</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Q5.0 Section 5. Temporary Traffic Control Set-up and Removal Practices and Technologies

Based on your personal experience, please answer the following questions about practices and technologies for temporary traffic control set-up and removal in work zones.

When answering the questions, assume that the traffic control will be used for a short-term (e.g., 1 day or night) operation on a high-speed roadway with multiple lanes in each direction (e.g., freeway) and free-flow traffic (no congestion) that requires the closure of one or more lanes.

Q5.1 Please share any best practices that you recommend for ensuring safe and effective set-up and removal of temporary traffic control in work zones.

Q5.2 Does your organization have specific written procedures for the set-up and removal of temporary traffic control? If so, could you please provide a link to the resources in the textbox
below if they are available online. If not available online, you can respond to the survey email with the electronic files attached.

Q5.3 Please share any practices that you would not recommend for ensuring safe and effective set-up and removal of temporary traffic control in work zones.

Q5.4 Please share any innovative technologies and/or practices that you have seen or used for ensuring safe and effective set-up and removal of the temporary traffic control in work zones.
APPENDIX B: FOCUS GROUP INTERVIEW QUESTIONS
Interview Questions for Contractor Focus Group

SAFETY ISSUES ASSOCIATED WITH EACH ACTIVITY/TASK

General Questions:

1. What are the common tasks/activities performed when setting up and removing temporary traffic control for different types of work zones? Example: multi-lane closure vs. single lane closure operation.
2. What safety issues are associated with temporary traffic control set-up and removal?

Follow-up questions if not already addressed:

Q2 Follow-up questions:

- Are there safety issues related to any of the following factors?
  - Lack of space available for workers or equipment
  - Complexity of roadway
  - Lack of adequate light during nighttime work
  - Worker behavior
  - Driver behavior
  - Weather conditions

PERCEIVED RELATIVE RISK ASSOCIATED WITH EACH ACTIVITY/TASK

General Questions:

3. Please describe the safety risk associated with the traffic control set-up/removal activities/tasks from the least to the most risky activities/tasks.
4. What are the challenges associated with setting up and removing temporary traffic control?
5. What are the specific challenges associated with setting up and removing temporary traffic control during the daytime compared to during the nighttime?

Follow-up questions if not already addressed:

Q3 Follow-up questions:

- Describe the risk associated with the following activities:
  - Installing advance warning and other signs
  - Installing merging taper(s)
  - Installing cones on lane line in activity area, including the buffer space
  - Installing termination area
  - Removing advance warning and other signs
  - Removing merging taper(s)
o Removing cones on lane line in activity area, including the buffer space

Q4 Follow-up questions:

- Do any of the following factors impact the set-up and removal of traffic control and, if so, how?
  - Tight schedule
  - Heavy traffic
  - Inadequate equipment and/or material/supplies
  - Not enough workers
  - Driver behavior
  - Roadway layout or condition (e.g., curvy road, steep grades road)

TRAFFIC CONTROL QUALITY CONTROL

General Questions:

6. What aspects of traffic control set-up and removal are commonly difficult to control?
7. What additional project resources or modifications would help improve safety when setting up and removing traffic control?

ACTIVITIES/TASKS THAT THE RESEARCH SHOULD FOCUS ON

General Questions:

8. Which part(s) of the setup/removal process should the study focus on to significantly improve the safety of workers and motorists?

IDEAS FOR HOW TO CHANGE TRAFFIC CONTROL OPERATIONS TO MITIGATE SAFETY RISK

General Questions:

9. What recommendations do you have to improve the safety of workers and motorists during temporary traffic control installation and removal operations? What should we investigate further?

Follow-up questions if not already addressed:

Q9 Follow-up questions:

- Do you have any suggestions for changes to any of the following?
  - Technology/equipment used (e.g., use of an autonomous cone truck or protection vehicle; use of radar speed detector and VMS on truck)
- Set-up/removal process
- Timing of the operation (e.g., daytime/nighttime)
- Resource availability/usage (equipment, workers, materials/supplies)
- Worker skills/abilities.behavior (e.g., training)
- Communication/planning
Interview Questions for DOT Focus Group

SAFETY ISSUES ASSOCIATED WITH EACH ACTIVITY/TASK

General Questions:

10. What are the common tasks/activities performed when setting up and removing temporary traffic control for different types of work zones? Example: multi-lane closure vs. single lane closure operation.

11. What safety issues are associated with temporary traffic control set-up and removal?

Follow-up questions if not already addressed:

Q2 Follow-up questions:

• Are there safety issues related to any of the following factors?
  o Lack of space available for workers or equipment
  o Complexity of roadway
  o Lack of adequate light during nighttime work
  o Worker behavior
  o Driver behavior
  o Weather conditions

PERCEIVED RELATIVE RISK ASSOCIATED WITH EACH ACTIVITY/TASK

General Questions:

12. Please describe the safety risk associated with the traffic control set-up/removal activities/tasks from the least to the most risky activities/tasks.

13. What are the challenges associated with setting up and removing temporary traffic control?

14. What are the specific challenges associated with setting up and removing temporary traffic control during the daytime compared to during the nighttime?

Follow-up questions if not already addressed:

Q3 Follow-up questions:

• Describe the risk associated with the following activities:
  o Installing advance warning and other signs
  o Installing merging taper(s)
  o Installing cones on lane line in activity area, including the buffer space
  o Installing termination area
  o Removing advance warning and other signs
  o Removing merging taper(s)
Removing cones on lane line in activity area, including the buffer space

Q4 Follow-up questions:

- Do any of the following factors impact the set-up and removal of traffic control and, if so, how?
  - Tight schedule
  - Heavy traffic
  - Inadequate equipment and/or material/supplies
  - Not enough workers
  - Driver behavior
  - Roadway layout or condition (e.g., curvy road, steep grades road)

TRAFFIC CONTROL QUALITY ASSURANCE

General Questions:

15. What are the expectations of the contractor or maintenance crew when setting up and removing traffic control?
16. What aspects of traffic control set-up and removal commonly require close or additional inspection?

ACTIVITIES/TASKS THAT THE RESEARCH SHOULD FOCUS ON

General Questions:

17. Which part(s) of the setup/removal process should the study focus on to significantly improve the safety of workers and motorists?

IDEAS FOR HOW TO CHANGE TRAFFIC CONTROL OPERATIONS TO MITIGATE SAFETY RISK

General Questions:

18. What recommendations do you have to improve the safety of workers and motorists during temporary traffic control installation and removal operations? What should we investigate further?

Follow-up questions if not already addressed:

Q9 Follow-up questions:

- Do you have any suggestions for changes to any of the following?
- Technology/equipment used (e.g. use of an autonomous cone truck or protection vehicle; use of radar speed detector and VMS on truck)
- Set-up/removal process
- Timing of the operation (e.g., daytime/nighttime)
- Resource availability/usage (equipment, workers, materials/supplies)
- Worker skills/abilities/behavior (e.g., training)
- Communication/planning