BEST PRACTICES FOR WORK ZONE SAFETY DURING TRAFFIC CONTROL PLACEMENT, REMOVAL, AND MODIFICATION – PHASE I

Final Report

PROJECT SPR 839

RESEARCH

Oregon Department of Transportation

BEST PRACTICES FOR WORK ZONE SAFETY DURING TRAFFIC CONTROL PLACEMENT, REMOVAL, AND MODIFICATION – PHASE I

Final Report

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by

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16. Abstract:

Studies have shown that drivers are at a higher risk of being involved in a crash when travelling through a work zone compared to normal driving conditions. Research further suggests that the crashes that occur in work zones are, on average, more severe than crashes that occur outside of work zones. The periods while temporary traffic control is being set-up, removed, or modified are also especially concerning given the exposure of the workers to traffic and the transition in the driving environment. This study aims to investigate the safety hazards and risk present during set-up, removal, and modification of temporary traffic control on high-speed roadways, and identify potential practices for improving safety during the traffic control deployment and removal processes. To date, the researchers have performed a comprehensive literature review on the study topic and conducted a survey of state department of transportation and highway construction contractor personnel. The results reveal a lack of a standard process/procedure and detailed guidance for setting up and removing traffic control. The survey results expose steps in the process that pose high risk to workers and motorists, such as when the traffic control is being placed to initially set the taper to close a lane. This document is an interim report that describes the study results to date and provides a proposed methodology for the remaining study tasks.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
M	meters	3.28	feet	ft
M	meters	1.09	yards	yd
Km	kilometers	0.621	miles	mi
AREA				
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
Ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
VOLUME				
Ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
MASS				
G	grams	0.035	ounces	oz
Kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DEDICATION AND RECOGNITION

The research efforts and outcomes of this study are dedicated to those workers and motorists who have been injured or lost their lives in highway maintenance and construction work zones. Our work is dedicated to their lives and to preventing additional worker and motorist injuries and fatalities in the future.

The authors would also like to recognize former TAC member Dennis Barlow who sadly passed away this past summer. Dennis's dedication to improving worker safety through his long career in roadway construction and at the Associated General Contractors Oregon-Columbia Chapter provides inspirational guidance to all involved in roadway construction.

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1.0 INTRODUCTION

1.1 PROBLEM STATEMENT

Safety in construction and maintenance work zones continues to be a top priority for ODOT and other transportation agencies across the country. The US Bureau of Labor Statistics (BLS) reports in its most recently published data that the construction industry experienced approximately 1,000 worker fatalities—more than three fatalities each workday—in 2018 due to construction operations (BLS 2020a). The industry with the second greatest number of fatalities is transportation and warehousing (BLS 2020a). The BLS data reveal that the rates of worker fatalities experienced in construction and transportation (9.5 and 14.0 per 100,000 full-time equivalent workers, respectively) are higher than all other industries except the agriculture, forestry, fishing, and hunting industry (23.4). BLS also reports that the rates of nonfatal occupational injuries and illnesses for the construction industry and the transportation and warehousing industry in 2018 were 3.0 and 4.5, respectively (BLS 2020b), both of which are higher than the rate for all industries combined (2.8). These rates amounted to approximately 200,000 injuries/illnesses in construction and 220,000 injuries/illnesses in transportation and warehousing.

Many of the fatalities and injuries occur due to motor vehicle crashes in which both workers and the travelling public are injured or killed. The US Department of Transportation (USDOT) reports that 36,560 people died in motor vehicle crashes on roadways across the US in 2018 (USDOT 2019). Of those crash-related fatalities, many occurred in work zones. In 2018, there were 755 fatalities in work zones (Workzonesafety.org 2019). Worker fatalities in work zones amounted to 124, and 238 involved large trucks or busses. Some of those injuries and fatalities occurred in Oregon.

Archival data shows that clearly there is room for improvement with respect to safety in construction and maintenance work zones. As a result, addressing and preventing work zone crashes is a high priority. Work zone injuries and fatalities have a high emotional impact on the public and our workforce. The impacts also go beyond the social and emotional effects of the loss of life and injured citizens. The cost associated with each fatal crash can amount to millions of dollars (Blincoe et al. 2015). Additional losses incurred by the public due to road closures, decreased mobility, and increased travel times as a result of crashes in work zones can have a negative impact on a state’s economy (Blincoe et al. 2015).

1.1.1 Background and Significance of the Work

Studies have shown that drivers are at a higher risk of a crash when they are in a work zone (Hall and Lorenz 1989; Meng et al. 2010; Weng and Meng 2011). Research further suggests that the crashes that do occur in work zones are, on average, more severe than crashes that occur outside of work zones, and the crashes impact both workers and drivers (Bédard et al. 2002; Ha et al. 1995; Ullman et al. 2006). In addition, rate of speed is positively correlated to the severity of a crash. A higher rate of speed creates a higher level of energy, and typically results in a more severe crash (FHWA, 2018).

Past research studies sponsored by ODOT that were related to safety in construction and maintenance work zones focused on traffic control measures in place during the work operations (e.g., SPR 791, SPR 790, SPR 769, SPR 751, and ODOT Work Order No. 19-03). The studies collected and analyzed data (typically vehicle speed data) after the traffic control was put in place and while the construction and maintenance work was being conducted. The studies successfully resulted in recommendations for the design of work zones and selection of traffic control measures to lower vehicle speeds, reduce crahes, and enhance work zone safety. Many of the recommendations are now being put into practice on current construction projects and during roadway maintenance.

Before the temporary traffic control is present on the roadway, time and effort are required to place the traffic control devices on the roadway. The temporary traffic control may need to be modified during construction, and must be removed after the work is complete. During these periods of time, the workers installing/removing/modifying the traffic control devices are often exposed to additional risk and/or different hazards than during the course of the work after the traffic control is set up. In addition, during these periods, passing motorists are transitioning from the normal traffic flow and patterns to the temporary traffic flow and patterns. These transition periods can create different roadway environments for both drivers and workers, create confusion about the driving path, distract drivers, and alter the driving path such that a queue temporarily develops that results in both safety and mobility impacts. Prior studies conducted by ODOT, however, did not address safety during the process to place, remove, and modify traffic control measures.

The safety issues created during these transition periods were mentioned in a recent ODOT Industry Staging Meeting involving ODOT staff, contractors, the Oregon Trucking Association, and other stakeholders. During the meeting there was discussion about the prevalence of crashes, near misses, risky driver behavior, and hazardous worker exposures during the periods of time when traffic control measures are being put in place and removed from the roadway. Recent worker fatalities on Oregon roadways have occurred during the operations undertaken to set up or modify the traffic control.

Research has been conducted that addresses safety risk at specific locations within the work zone (e.g., the transition and active work areas) after the traffic control is set up. However, as mentioned above, prior ODOT research has not focused on best practices during the periods of time when the traffic control is being set up, removed from the roadway, and modified during the work operations. In addition, limited guidance is available in the *Oregon Temporary Traffic Control Handbook* (ODOT 2016) and the *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA 2012) regarding the process of placing, modifying, and removing traffic control, the sequence of activities during these operations, and the safety risks to be expected in each step of the operations. Performance of the work and safety of the workers during these operations are the contractor's responsibility. During maintenance operations, ODOT maintenance crews take on this responsibility. Due to the potential increased risk exposures during traffic control transition periods, research is needed to identify traffic control implementation practices that lead to hazardous situations and develop guidance to reduce the risk associated with these traffic control transition periods. Research questions that remain unanswered include:

1. What are the overarching principles and common practices associated with planning and executing the operations during the temporary traffic control transition periods?

2. What aspects of the set-up, removal, modification process are particularly hazardous and create high levels of risk for workers and motorists?

3. What guidance should be given to state DOTs and contractors to help improve safety during temporary traffic control transition periods?

This study aims to answer the research questions stated above. By doing so, the research is expected to provide a significant contribution to roadway work operations performed for and by ODOT. A significant amount of funding is spent by ODOT on construction and maintenance annually. According to its 2019-2021 budget, ODOT will spend $567 million on highway maintenance, $405 million on preservation projects, $557 million on bridge projects, $167 million for modernization of highways, and $387 million on operations/safety programs (ODOT 2019). These amounts total to $2.08 billion, which is approximately 46% of ODOT’s $4.52 billion budget for the biennium. Research shows that for every dollar spent on improving safety on a construction project, there is a return of three dollars in benefits to project cost (Ikpe et al. 2012). Cost savings through improved safety could be used for other ODOT needs, including expanding the scope of projects undertaken by ODOT.

A safe and efficient transportation system is a central component of ODOT's mission. Protecting the safety of both the traveling public and ODOT employees and other workers who build, operate, and maintain the state's transportation system is one of ODOT's core values. The proposed research will help ODOT fulfill its mission by further identifying ways to improve safety in construction and maintenance work zones, and by providing ODOT personnel and contractors with guidance to minimize and mitigate safety hazards associated with work zones.

1.2 RESEARCH OBJECTIVES

The overall goal of this research is to develop additional knowledge and guidance for state transportation agencies and contractors that can be used to improve driver and worker safety on roadways. The part of work zone safety specifically targeted by the research is that during the set-up, removal, and modification of temporary work zones on high-speed roadways. These operations are commonly performed by contractors on construction projects and by ODOT personnel when performing roadway maintenance. As described above, these operations also create unique hazards for workers and motorists to recognize, comprehend, and respond to, and have received limited attention in prior ODOT research.

The research focuses on temporary construction and maintenance operations on multi-lane, high-speed roadways (e.g., Interstates 5, 205, and 84 in Oregon). The work operations targeted are those which include traffic control to close off one or more lanes of traffic to accommodate the work operations. For example, traffic control measures may be needed to reduce free flow traffic conditions by one or two lanes to allow for repaving or restriping on the roadway. The traffic control devices deployed in such situations may include a variety of devices such as temporary signage, barriers, striping, variable message signs, radar speed signs, flaggers, and other common traffic control technologies. Temporary barriers may include barrels/drums or cones, and/or positive protection such as a Jersey barrier/K-rail. Both daytime and nighttime operations are considered in the study. Appropriate average annual daily traffic (AADT) levels for such cases are reviewed with ODOT and considered within the research when selecting specific work operations and roadway locations to study.

To meet this goal, the proposed research involves examining the conditions and practices during traffic control set-up, removal, and modification to assess the associated risk and identify potential risk reduction measures. Specifically, the objectives of the research are to:

1. Document the guiding principles, common work practices, and corresponding risk exposures during traffic control transition periods;

2. Identify promising practices to improve safety during the transition periods;

3. Compare differences in risk and implementation feasibility associated with current and promising practices through both quantitative and qualitative measures; and

4. Develop guidance for ODOT and contractors to enhance safety during the transition periods.

Given that the study focuses on active work operations, the research requires close communication and cooperation with ODOT staff and construction contractors. For onsite observations and data collection, the researchers discuss and coordinate performance of the study tasks with those involved in planning and performing the work operations. The research activities are conducted such that they do not interrupt or inhibit the work operations, and do not put the workers and researchers at greater risk of injury.

1.3 BENEFITS

The research study is expected to provide ODOT and other transportation agencies with new information that can be implemented during construction and maintenance work to help improve roadway safety. The study will provide information about hazardous situations during temporary traffic control operations, along with guidance to minimize the risk of worker and motorist injuries and fatalities. Such information can be utilized to strategically plan and execute work zone traffic control operations. The recommendations and guidance will help guide both ODOT staff and contractors on how to safely perform the set-up, removal, and modification operations on future projects. The ultimate benefactors will be the motorists travelling through the work zones and the workers on the roadway who create, and work in, the work zones.

The construction and maintenance programs within ODOT are extensive, with many workers on the roadways throughout the year all over the state. Each work zone exposes drivers and workers to risk of injury. On average, Oregon experiences approximately 500 crashes in work zones each year (ODOT 2017a; 2017b). Each crash has the potential to cause injury or death to a driver and/or worker. The proposed research has direct influence on the risk of injury/fatality related to work zones, a driving environment that often creates additional risk to drivers and impacts mobility. It is expected that the research will contribute to ODOT further reducing the number of crashes in work zones.

Safety and mobility affect the economic efficiency of both ODOT and the state's economy, as well as the public's perception of ODOT and construction contractors. A substantial portion of the public's interaction with ODOT operations occurs during roadway construction and maintenance. The guidance developed through the study will highlight ways in which ODOT and contractor interaction with the driving public, during the temporary traffic control transition periods, can be tailored to accommodate driver needs and behavior. Implementing this guidance is expected to result in better relations with the driving public as a result of roadway operations that minimize safety risk and mobility impacts. Improving safety and mobility will also lead to lower overall construction and maintenance costs and greater potential for ODOT to continue to support the state's economy and fulfill its mission.

1.4 IMPLEMENTATION

The study outputs will include guidance for efficient and effective placement, removal, and modification of temporary traffic control. This output is targeted at those ODOT and contractor personnel who plan such operations and also those who conduct the operations on the roadway. The output will be communicated in the form of a research report submitted to ODOT that desicribes in detail the conduct and findings of the study along with recommended guidance for implementation in practice. In addition, the researchers will prepare and submit to ODOT a research note that summarizes the study findings, potential impact, and recommendations for implementation. The research report and research note will be submitted to ODOT for publication and distribution.

As additional outputs, after completion of this work, the researchers plan to submit one or more papers on the study for publication in an academic journal and/or conference (e.g., Transportation Research Board Annual Conference). The researchers will also submit an abstract on the study for consideration as a presentation at the Northwest Transportation Conference following the completion of the study. Lastly, when invited and sufficient resources/time are available, the researchers will give presentations on the study at local and regional meetings, conferences, and workshops of organizations and associations (e.g., Asphalt Pavement Association of Oregon, and AGC of Oregon).

It is expected that the research outputs will be used by the ODOT Transportation Safety Division and the Region Transportation Safety Coordinators in each ODOT Region as they plan and design traffic control for work zones. The results are expected to be incorporated into the activities of the Statewide Construction Office and implemented through communication and education of the Construction Project Managers statewide. Lastly, it is also expected that the guidance will be beneficial to and used by ODOT Maintenance personnel as they plan and implement temporary traffic control during maintenance operations.

2.0 LITERATURE REVIEW

This section of the report provides in-depth content related to work zone traffic control, including a glossary of terms used in the report. Detailed results from the literature review are provided that describe the purpose of traffic control devices, work zone classifications, traffic control devices commonly used, and other content regarding the procedures used for placing, removing, and modifying traffic control devices during roadway construction and maintenance operations. In addition, the impacts of nighttime and daytime work zones are also presented as part of the comprehensive literature review in order to fully capture the details associated with working conditions and provide a thorough understanding of the current research topic. The literature section is organized according to the following topics:

- Key definition of terms;
- Purpose of temporary traffic devices, descriptions of traffic control devices that are used in the research study, and other studies related to temporary traffic control;
- Work zone components and duration classifications;
- Existing practical procedures for traffic control set-up and removal in work zones;
- Daytime and nighttime work zone comparison (crash severity, location of accident, cause of work zone crash, and cost of traffic controls); and
- Recommendations from previous studies on minimizing the amount of time required for installing and removing temporary traffic control devices

2.1 GLOSSARY

Clear zone: An unobstructed area that is used for recovering errant vehicles. Generally, the area is provided beyond the edge of the travel lanes including any shoulders. (ODOT, 2011)

Edge of travel way: The edge of the roadway that vehicles travel on, not including the shoulders. The edge is often delineated by the fog line or edge of pavement. (ODOT, 2011)

Exterior lane: A lane that is bordered by a shoulder along one edge. (Oregon Traffic Control Supervisor Certificate, 2020)

Interior lane: A lane that is located at the center of a three-lane roadway, which is bordered by travel lanes on both sides. (Oregon Traffic Control Supervisor Certificate, 2020)

Rolling roadblock (also known as a “Slow Roll” or a “Rolling Slowdown”): A temporary traffic control activity that is used to slow down and control traffic to clear a section of roadway and allow a short duration of work operation on the freeway/highway to be executed. A rolling roadblock is typically used on a freeway or other controlled access highway. (NYSDOT, Revised 2015)

Sight distance: The length of unobstructed roadway that is clearly visible to drivers. (ODOT, 2011)

Temporary traffic control (TTC) zone: An area of a highway where road users experience a changed condition of the roadway environment because of the presence of a work zone, an incident zone, or a planned special event. The TTC zone is created through the use of temporary traffic control devices, law enforcement officers, or other authorized personnel. (FHWA, 2009; Ohio DOT, 2012)

Traffic control device (TCD): All traffic control devices including signs, signals, markings, and other devices that are used to regulate, warn, or guide traffic users. (ODOT, 2011)

Travel way: The portion of the highway set aside for, and used by, moving vehicles, exclusive of berms and shoulders. (ODOT, 2021)

Work space/area: The portion of the highway closed to road users and reserved for workers, equipment, material, and a shadow vehicle if one is used. Work spaces/areas are usually separated by channelizing devices or temporary barriers to exclude public vehicles and pedestrians from entering the work area. (Portland Bureau of Transportation, 2019)

Work zone: An area of a highway that is temporarily occupied by construction, maintenance, or utility work activities. A work zone extends from the first ROAD WORK AHEAD warning sign to the END ROAD WORK sign or the last TTC device. (FHWA, 2009)

2.2 WORK ZONES AND TEMPORARY TRAFFIC CONTROL

As defined above, work zones are areas of a roadway in which work operations are temporarily being undertaken to expand and/or maintain the roadway. Temporary traffic control is needed on an active roadway to close off the work area from live traffic and allow the construction or maintenance work to take place. A substantial amount of information about work zones and temporary traffic control is available in literature. This section provides descriptions of work zones and temporary traffic control characteristics that relate to the present study.

2.2.1 Purpose of Temporary Traffic Control

The primary purpose of temporary traffic control (TTC) is to ensure safe passage through a work zone and enhance effective movement of road users through or around work zones while reasonably protecting road users, workers, responders to traffic accidents, and equipment (FHWA, 2009). The Oregon Technology Transfer Center mentions the following goals of temporary traffic control: (1) make the work site safe; (2) ensure traffic is moving safely; (3) minimize liability; (4) meet all applicable regulations and standards; and (5) minimize motorist inconvenience (Oregon Technology Transfer Center, 2016). Section 1A.02 of the MUTCD lists five fundamental requirements for traffic control devices to be effective (MUTCD, 2009):

- Fulfill a need;
- Command attention;
- Convey a clear, simple meaning;
- Command respect from road user; and
- Give adequate time for proper response.

2.2.2 Work Zone Classifications

Work zone duration is a factor that is used to determine the type and number of traffic control devices used in a roadway work zone. Work duration is also used to classify the type of work zone. According to Federal Highway Agency (FHWA), work zone operations are classified into five different categories relative to the length of time that the operation occupies the work zone location (FHWA, 2009). The FHWA classifications of work operations are:

1. **Long-Term Stationary:** Any type of work that occupies a location for more than 3 days.
2. **Intermediate-Term Stationary:** Any type of work that occupies a location for more than 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 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 is associated with intermittent or continuous moving.

The present study targets the placement, removal, and modification of traffic control for all of different durations of work zone operations.

Standard descriptions of the areas within a work zone are also provided in literature. Section 6C.03 of the MUTCD and Section 2.1 of the Oregon Temporary Traffic Control Handbook (OTTCH) (ODOT, 2011) define and describe the areas within a work zone. Work zones typically consist of four areas, some of which include multiple sections, which are illustrated in Figure 2.1 and defined as follows:

1. **Advance Warning Area:** An area that is established to give road users enough time to react to any downstream change that has been made within the transition area.
2. **Transition Area:** An area where traffic enters from the normal traffic path into a temporary path around the work area.
3. **Activity Area:** This area consists of two sections, the buffer space and the work space. Each section is described as follows:

a) **Buffer Space**: A closed portion of the roadway that is reserved for extra space for the purpose of enhancing safety for both motorists and workers. This closed space is located in-between the transition area and the work area.

b) **Work Space**: The portion of the roadway where work activities are being conducted, and which should be protected from traffic intrusion and clearly delineated. This area is usually occupied by workers, materials, and equipment.

4. **Termination Area:** An area where traffic exits the work zone and returns to the normal roadway path. The length of the termination area is typically short.

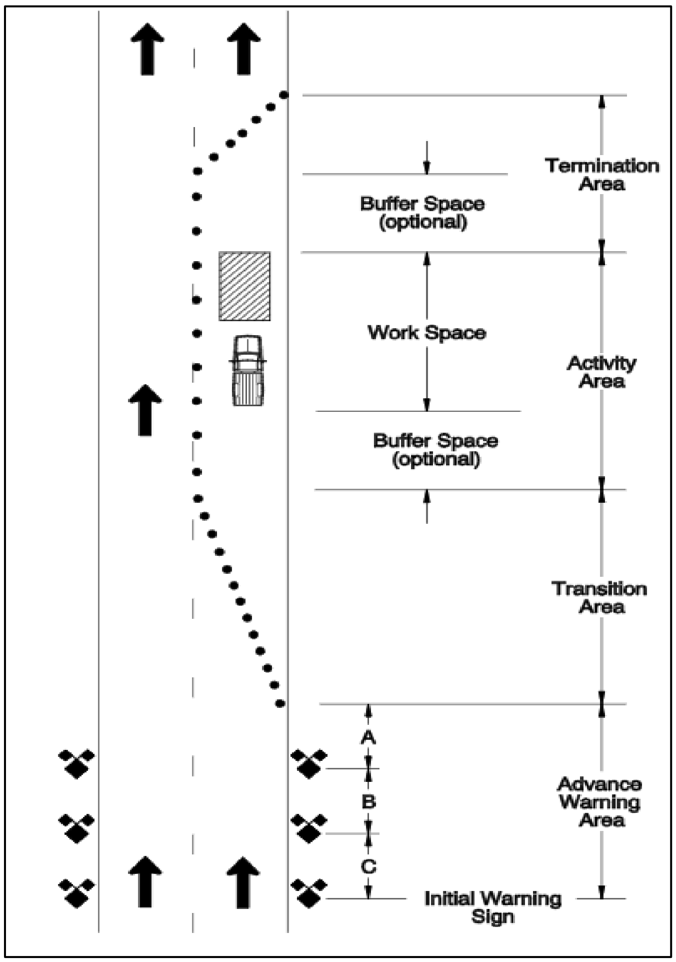

Figure 2.1: Work zone areas (ODOT, 2011)

The present study considers the activities to set-up, remove, and modify the traffic control in all of the designated work zone areas.

2.3 TEMPORARY WORK ZONE TRAFFIC CONTROL DEVICES

2.3.1 Types of Traffic Control Devices

A wide variety of devices and practices are used to temporarily control traffic in work zones. As part of the literature review, the researchers searched for traffic control devices commonly used in work zones. The researchers searched different publicly available online sources, regulatory standards and guidance, journal and conference papers, the US Department of Transportation website, online periodicals, and traffic control device manuals. The search revealed a long list of available traffic control devices used in work zones. Table 2.1 describes traffic control devices and practices that are currently available and commonly used in temporary roadway work zones. Other traffic control devices are available that are designed to be used in unique situations.

Table 2.1: Traffic Control Devices and Practices

Traffic Control Device	Description	Reference
Signage and Message Boards		
Portable changeable message sign (PCMS)	An electronic sign equipped with lighting and incorporates a programing function to display dynamic messages to road users based on upcoming work zone conditions. It can be mounted on either a trailer or work vehicle.	Gambatese and Zhang, 2014
Arrow board	An illuminated device that displays traffic patterns and is used to warn incoming traffic of an upcoming merging lane or shows flashing lights to indicate a warning where road users should proceed with caution.	Datta et al., 2016
Temporary sign	A roadway sign that is temporarily used for a short-term work zone operation to regulate, guide, and warn road users during roadway construction and maintenance.	Gambatese and Zhang, 2014
Stationary sign	A sign installed on the roadway to provide warnings, guidance, and regulatory information to road users.	MUTCD, 2009
Sign flag	A colored flag located on the top of a roadway sign that is used to attract driver attention.	Gambatese and Zhang, 2014
Portable Temporary Signal (PTS)	A signal that is used for controlling traffic through a short-term section of a work zone. The signal is a self-contained, self-powered, illuminate signal with green-yellow-red lamps.	ODOT, 2011
Lane Delineators		
Tubular and conical marker	A common channelizing device, such as tube or cone, used to delineate the roadway and direct traffic through the work zone. This device is effectively used to override the existing pavement marking for a short-term operation (less than three days).	Gambatese and Zhang, 2014
Traffic cone	A device that is used to warn road users about upcoming or nearby roadway conditions and hazards, and direct road users to stay on a safe path while proceeding through a hazardous area.	Nemire, 2012
Plastic drum/barrel	A large plastic drum, also referred to as a barrel, that is primarily used for delineating a travel lane, identifying work areas, and constructing a lane closure taper.	Gambatese and Zhang, 2014

Traffic Control Device	Description	Reference
Channelizing device	Devices that are used to draw driver attention to stay in a desired vehicle path, divide opposing traffic flow, or partially or totally restrict roadway use. Channelizing devices include cones, drums/barrels, barricades, barriers, and vertical panels.	WisDOT, 2020
Temporary lane marking	Pavement markings or adhesive devices that are utilized to provide road users a clear, defined travel path through a work zone when the permanent markings are either removed or obliterated during work activities.	MUTCD, 2009
Barriers		
Barricade	A portable or fixed device that consists of one to three rails with proper marking, and is used for closing, delineating, or restricting 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. Each type has a different purpose for its use.	Infrastructure Training & Safety Institute, 2011
Mobile barrier	A trailer towed by a semi-truck cab that serves as a protection wall for workers while performing road work. The barrier is used to eliminate or reduce the hazardous exposure of workers to errant vehicles.	Tymvios and Gambatese, 2014
Truck mounted attenuator (TMA)	An energy absorbing device that is connect to or towed behind a heavy vehicle and is used to protect workers and reduce the severity of crashes when a vehicle intrudes into a work zone. TMAs can be mounted on a work vehicle, protection vehicle, or a shadow vehicle.	ODOT, 2011
Blockade vehicle	A temporary road closure vehicle that is used to slow or terminate upstream traffic flow through a work zone. A common type of traffic control technique that is utilized in short-term full closures of highway traffic to mitigate the proximity of workers to passing vehicles. Typically, blockades allow for faster completion of road work activities.	FHWA, 2019
Shadow vehicle	A vehicle such as a truck or other work vehicle that is used to protect workers or equipment from an errant vehicle passing by the work area. The shadow vehicle is placed behind (upstream of) the workers and equipment for protection and is typically equipped with traffic control devices such as flashing lights, changeable message sign, flashing arrow board, and/or oscillating, high intensity rotating lights.	MUTCD, 2009
Speed Detection and Enforcement		

Traffic Control Device	Description	Reference
Photo-radar speed enforcement system	A speed enforcement system that uses radar to measure a driver's speed and automatically capture a picture of the vehicle for speed enforcement purposes when the driver exceeds the speed limit in the work zone.	Gambatese and Zhang, 2014
Radar speed monitoring display	A speed display panel used to provide feedback to road users regarding their vehicle speed. It commonly displays a message that containing "Your speed is XX" along with the posted speed limit.	Gambatese and Zhang, 2014
Police enforcement	The presence of a police officer in a vehicle, and parked within or before a work zone, or patrolling through the work zone. The police might issue citations for speeding vehicles in the work zone.	The Roadway Safety Consortium, n.d.
Site Access/Site Control		
Flagger	A qualified worker, who is well trained and equipped with high-visibility safety apparel, and whose role is to control traffic into and out of a work zone. A flagger typically stands on the roadway and holds a Stop/Slow paddle, lights, and/or red flag to facilitate and control movement of road users through the work zone.	Li and Bai, 2009
Automated flagger assistance device (AFAD)	An automated flagging device that is remotely controlled by a qualified person and equipped with red/yellow signal heads, a movable traffic control arm, and high visibility signage. Its purpose is to guide and control traffic through a work zone in place of a human flagger. It is a safe alternative approach over traditional methods of flagging since it reduces the risk of exposure of a worker to traffic. There are two types of AFADs: one with Stop/Slow paddles mounted on a trailer, and the other with red/yellow lens with mechanical gate arm.	USDOT, 2017
Lighting		
Floodlight	Floodlights are used to illuminate work areas during nighttime operations in work zones, such as flagger stations, equipment crossings, and other areas located near intersections.	ODOT, 2011
Warning light	A light mounted on a vehicle, piece of equipment, or other devices (e.g., temporary sign, barricade, etc.) to warn motorists of an upcoming or nearby hazard. The light can be high-intensity, rotating, flashing, oscillating, or strobe warning light with 360-degree visibility.	ODOT, 2011

Traffic Control Device	Description	Reference
Wearable lighting	A personal light worn by a worker that is typically designed to enhance visibility of the worker within work zone during nighttime work.	Nnaji et al., 2020
Driving Behavior		
Lane narrowing	A narrowing down of the width of a travel lane for the purpose of reducing vehicle speeds. Cones, barrels/drums, or other barriers are typically used to narrow the lane.	Gambatese and Zhang, 2014
Portable rumble strip	A movable device that is installed on the roadway surface to attract the driver's attention to upcoming roadway conditions by vibrating the vehicle when the vehicle travels over the rumble strip. The portable rumble strip is classified in two categories: conventional adhesive rumble strips, and innovative non-adhesive portable plastic rumble strips.	Wang et.al, 2013
Ambulance and fire truck	An ambulance or fire truck parked in advance of a work zone in order to grab the attention of the road users and help slow down the traffic.	Gambatese and Zhang, 2014
Pilot car	A vehicle used to lead and guide traffic within and through a complex work zone area by driving in front of the traffic queue. The vehicle maintains a speed of traffic to ensure safe passing through the work zone.	OTTCH, 2011
Ghost police vehicle	A police vehicle that is parked before or within the work zones without the presence of a police officer inside the vehicle.	Gambatese and Zhang, 2014
Drone radar	An unmanned aerial vehicle (UAV) containing an electronic radar system that can transmit over a microwave-frequency band. Normally, the vehicle equipped with radar detection device to receive the transmitted radar signals from the drone is a police enforcement vehicle located nearby. As a result, passing vehicles that have radar detectors will believe that a police officer is close by and reduce their speeds, which causes other vehicles to slow down as well.	Gambatese and Zhang, 2014

According to ODOT policies, all highway construction projects may only use traffic control devices that meet the list of requirements on the ODOT Qualified Product List (QPL) and which are presently included on the QPL. While not the focus of the present study, many studies have been previously conducted to investigate and develop temporary traffic control devices (e.g., Bligh et al., 2006, Strawderman et al., 2013, Yang et al., 2009, Bryden et al., 2002, Wang, 2006, Terhaar et al., 2016). Additionally, many previous studies have assessed the effectiveness of temporary traffic control devices after the devices are in-place in the work zone (e.g., Gambatese et al., 2014, Zech et al., 2005, Liste et al., 1976, Fontaine et al., 2001, Benekohal et al., 1992, Brewer et al., 2006, Debnath et al., 2012, Finley at al., 2011, Zhang & Gambatese, 2017, Miller et al., 2009, Zhu et al., 2015, Li et al., 2009, Yang et al., 2015, Jafarnejad et al., 2017, Gan et al., 2018). For the purposes of the present study, it is assumed that the temporary traffic control devices investigated and used on the case study projects are on the ODOT QPL, and that the devices are effective in performing their intended functions.

2.3.2 Technologies for Placing and Removing Traffic Control Devices

Worker exposure to safety hazards during placement and removal of traffic control devices, primarily exposure to passing traffic, is a significant concern for DOTs and construction contractors. Hence, technologies have been developed and are used to enhance the safety of workers while placing and removing devices in work zones. Among these technologies, a platform on which workers can safely stand while deploying and removing the devices is one of the devices that have been developed. Some platforms have been evaluated by the Occupational Safety Health Administration (OSHA) to confirm that they meet OSHA regulations. The American Traffic Safety Services Association (ATSSA) highlighted a variety of different types of platforms that are currently used across the US (ATSSA, n.d.). Examples of work platforms that are commonly used for the placement and removal of work zone traffic control are shown in Figures 2.2 to 2.5.

Figure 2.2: Work platform on rear of truck (ATSSA, n.d.)

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.)

Figure 2.5: Cone truck platform (ATSSA, n.d.)

In a study of automated equipment for traffic control placement and removal, Clint (1999) developed a prototype for an automated cone machine (ACM) for deploying and retrieving traffic cones. Figure 2.6 shows an ACM. The ACM can be operated by a single operator to place and retrieve cones for a lane closure operation. The ACM can carry a larger number of cones and be used for lane closures that require 250 or more cones.

Figure 2.6: Traf-tech automated cone machine (ACM)
(http://ahmct.ucdavis.edu/projects/cone-machine/)

In a similar study (Wang et al., 2019), the researchers developed a proposed system consisting of a flexible manipulator based on active-passive joint coupling technology, a mechanical claw, and a retrieval device that can grab and pick up vertical cones. The system was developed based on a kinematic model which provides workplace analysis in terms of safety and the mechanism coupling condition. The path of the claw is planned, and the prototype shows that the proposed system can quickly deploy and remove cones in a safe way, and can be used in traffic accident zones to provide protection for emergency responders. Figure 2.7 shows the technology developed.

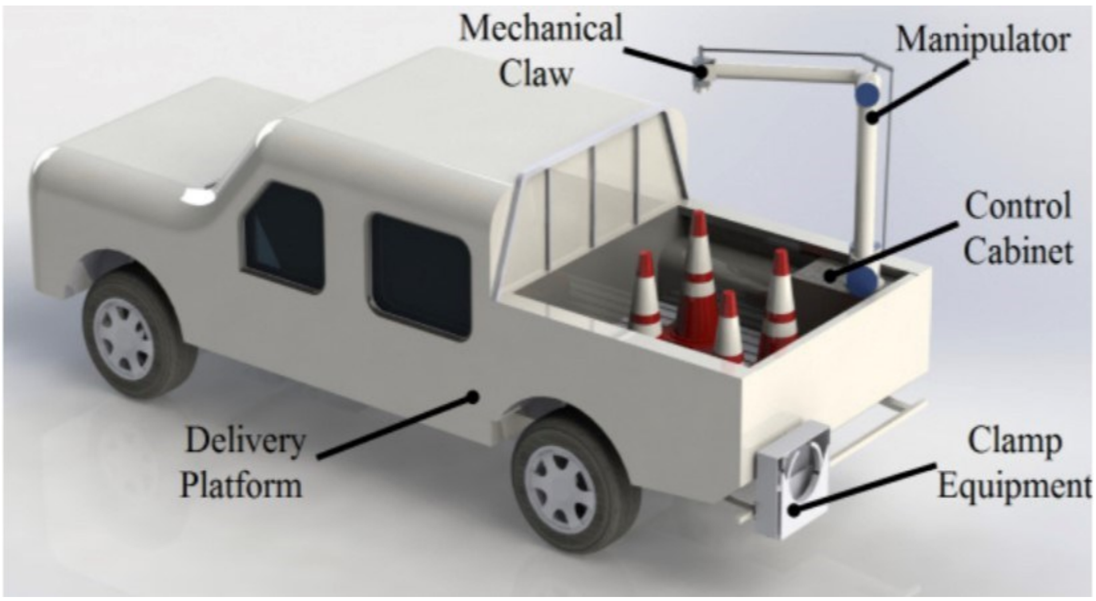

Figure 2.7: Automated cone placement and retrieval technology (Wang et al., 2019)

An innovative technology called "Barrel Mover" enables moving barrels/drums without requiring a worker to be on foot on the roadway. The Barrel Mover is attached to the front of a work vehicle by removing the existing tow hooks and replacing them with the Barrel Mover 5000 mounting bracket as shown in Figure 2.8. According to the manufacturer, this safety technology removes workers from exposure to live traffic and is recognized as a creative method for time-savings, cost-reduction, and increasing productivity when removing barrels/drums from work zones (Barrelmover5000, 2015; IEN, 2018).

Figure 2.8: Truck mounted with barrel mover (Barrelmover5000, 2015)

Another technology is available that is used for placing and removing temporary rumble strips. This device is connected to the front of a truck by mean of a standard DIN plate as shown in Figure 2.9. The device was developed based on the concept of using hydraulic and magnetic principles which enable workers to fully automatically pick and place temporary rumble strips in work zones (Trafficsafetysystems.eu, n.d.). The operation can help remove workers from exposure to live traffic, especially when the workers are placing and removing the rumble strips.

Figure 2.9: Truck mounted with rumble strip pick and place machine (Trafficsafetysystems.eu, n.d.)

2.3.3 Traffic Control Device Placement Considerations

To improve work zone safety for both passing motorists and roadway construction workers, consideration is given to the placement and removal of temporary signs. Studies have been conducted to investigate safety related to sign placement. One study by Jin et al. (2019) investigated the quality of temporary sign placement in a work zone and found that technologies can effectively be used to assess the quality of temporary sign placement. Many safety-related issues were identified which correspond to traffic control devices in work zones. Table 2.2 presents common issues that occur with the traffic control devices after the devices have been located in the work zone. Three major findings can be drawn from the study. First, legibility and visibility of the sign should be maintained throughout the whole project's lifetime. Second, contractors should perform inspections from the road user's point of view to ensure the traffic control performs as intended, is placed at the appropriate location, and is raised to the recommended height. Third, an advance warning sign should be placed in a timely manner so that it can provide information on road work presence, posted speed limits, and the end of a work zone to driver in a timely manner. In addition, the study advised removing, rotating, or covering the signs when the signs are no longer required in the work zone.

Table 2.2: Traffic Control Device Issues in Work Zone (Jin et al., 2019)

Type of Traffic Control Device	Issues of Concern
Conventional Static Sign	Sign visibility and legibility issues due to: 1. Sheeting; 2. Poorly maintained signs (signs were smudged and/or streaked) 3. Prolonged messages 4. Signage obstruction
	Inadequate number of signs for: 1. Ramp closures 2. Detours 3. Lane closures 4. Advance warning areas
	Inapplicable and incorrect signs: 1. Inapplicable signs not covered 2. Incorrect signs posted 3. More than one "End Road Work" sign installed
	Improper sign placement: 1. Signs placed too low 2. Signs not level or centered with other signs 3. Advance warning signs placed out of sequence 4. Construction signs mounted directly in front of or on top of regulatory signs 5. Overlapping signs from adjacent projects 6. Poor sign spacing among temporary and permanent signs
Portable Changeable Message Signs	1. Messages displayed contained too much information 2. Messages displayed confusing 3. Placement height too low 4. Units malfunctioning 5. Improper use
Arrow board Panels	Displays on arrow board panels incorrect
Channelizing Devices	1. Quality of drums, cones, and barricades did not meet standard (were bent or distorted, or scuffed or missing reflective tape) 2. Quantity of cones/drums/barrels insufficient 3. Cones knocked over
Pavement Markings	1. Conflicting pavement markings not covered 2. Temporary markings missing or worn

In another recent study, Bai et al. (2015) conducted research to determine effective placement locations for a PCMS upstream of a work zone to mitigate the accidents caused by trucks in the work zone. Three different locations for the PCMS were investigated for placement of the PCMS: 750 feet away from the W20-1 (Road Work Ahead) sign; 575 feet away from the W20-1 sign; and 400 feet away from the W20-1 sign. The results of the study indicated that deploying the PCMS 575 feet away from the W20-1 sign is the best option for reducing speed variability between trucks and passenger cars, which can potentially reduce the risk of vehicle crashes in the work zone.

Graham et al. (1979) developed criteria for the use and placement of arrow boards in work zones. The criteria were developed to assist decision-making about arrow board use and the placement of arrow boards to provide the safest and most efficient traffic movement. The study was conducted by placing the arrow board in many different types of zones to see how effective the sign is in reducing vehicle speeds. Based on the results of the study, it was concluded that when the arrow board was placed on the roadway shoulder, either at the beginning of the taper or upstream of the beginning of the taper, the board was found to be more effective in promoting safe lane changes than when the board was placed in the closed lane in the middle of the taper.

The Indiana DOT (2013) provided helpful questions to guide roadway contractors in decision-making when selecting specific traffic control devices to set up. The five questions to consider are:

1. Regarding the worksite, what type of roadway (e.g., two-lane or multi-lane) will the work be conducted on?

2. Does the work operation involve working on the shoulder or roadway, or both?

3. How long does it take to occupy the work area?

4. Is there any extra precaution needed?

5. Is a lane currently restricted or encroached upon?

2.4 TRAFFIC CONTROL REGULATIONS AND GUIDANCE

This section provides an overview of documents such as traffic control manuals, handbooks, specifications, guides, and other sources related to work zone traffic control devices that were found during the literature review. Special focus is placed on content in the documents that covers the process of placing, removing, and modifying temporary traffic control. The documents described below are published by ODOT and the Federal Highway Administration. A simple search of the internet will reveal similar documents in many other states across the country.

2.4.1 Oregon Temporary Traffic Control Handbook (OTTCH)

The Oregon Temporary Traffic Control Handbook contains information of general standards, and practices for temporary traffic control work zones that operate for three days or less on public roads in Oregon. The handbook adopts the principles set forth in Part 6 of the MUTCD and the Oregon MUTCD supplements.

Section 2.5 of the handbook addresses sign placement and specifically targets the design of signs. For example, it mentions that signs on non-freeways may be installed using spacing distances up to 2 times those shown on the Sign Spacing & Buffer Lengths Table (Table 2-4 in the OTTCH handbook). In addition, Figure 4.1 in Section 4.3 of the handbook illustrates portable changeable message sign installation. The description provided for Figure 4.1 mainly relates to the design of the PCMS. It includes information about the location where the PCMS is to be placed, the required height of the PCMS above the ground, visibility of the sign, and the direction that the sign needs to face.

Furthermore, the handbook provides a reference on installation of temporary pavement markers in Chapter 5. As described in the handbook, the installation of temporary flexible pavement markers depends on average daily traffic and the posted speed limit. Notably, description of the installation of flexible pavement markers is more related to the design of temporary pavement markers, which includes the spacing of the pavement markers and the number of markers used to simulate each type of line. Information about the process of placing the pavement markers is not included in the OTTCH.

2.4.2 Manual on Uniform Traffic Control Devices (MUTCD)

The MUTCD provides a comprehensive resource for traffic control devices that is used as a standard by state DOTs. Most of the information provided in the MUTCD focuses on the design of traffic control devices and the traffic control plan. For example, the MUTCD describes the standards for the size, spacing, and location of signs, and the mounted height of the signs. The manual provides similar characteristics for other types of traffic control devices such as barriers, cones, and barrels/drums. Moreover, the manual provides definitions of traffic control devices, describes the purpose of the devices, their application, and the standards that should be followed for implementation of the devices to ensure work zone safety.

Apart from this content, Sections 1A.04, 2A.17, 2B.10, 2L.06, 4B.02, and 7B.05 of the MUTCD address topics related to the installation of permanent traffic control devices. Section 4B.02 addresses the removal of permanent traffic control devices. Although the majority of the MUTCD sections are related to permanent traffic control devices, some sections address topics related to temporary traffic control in work zones. Chapter 6 of the MUTCD provides detailed content on temporary traffic control. It contains procedures for flaggers, which are described in another section of this report below.

In Section 6G.19, the MUTCD addresses the use of temporary traffic control devices during nighttime hours. The guidance provided is as follows:

- Consideration should be given to enhancing traffic control to improve visibility and driver guidance, and enhanced protection for workers.
- Additional lights and retroreflective markings should be provided to workers, work vehicles, and equipment.
- Stationing uniformed law enforcement officers and lighted patrol cars should be deployed at nighttime work locations where high-speed or impaired drivers cause a concern and might result in undue risk for workers or other road users.

Further, Section 6G.02 points out the unfeasibility of using long-term procedures or devices in intermediate-term stationary temporary traffic control (TTC) work zones. In intermediate-term stationary work zones, it might not be feasible to use traffic control procedures that would be desirable for long-term stationary TTC work zones, such as altered pavement markings, temporary traffic barriers, and temporary roadways. Utilizing these devices and procedures may increase the time required to set up and remove devices, which could possibly extend the project's timeline and, thus, increase the duration of worker exposure to live traffic.

2.4.3 Blue Book (Oregon Technology Transfer Center, 2016)

The Oregon Technology Transfer Center's Blue Book contains information on the following topics: (1) basic knowledge of traffic control standards; (2) descriptions of personal protective equipment and equipment requirements for flaggers; (3) explanations of flagging positions and stations; (4) instructions for using proper flagging signals; (5) hazards involved in flagging and traffic control; (6) procedures to install traffic control on a two-way road using two flaggers; and (7) details about how to set up effective traffic control on a multi-lane roadway using one flagger. This book is based on the MUTCD (2009 edition) and the OTTCH (2011 edition). Some parts of the book discuss topics relevant to the set-up and removal of temporary traffic control. As stated in the book, signs and cones are placed on the roadway in the same sequence that the motorists will see them. Prior to the signs being placed, the location of the work must be identified. For a particular work location with a two-lane or two-way roadway with flaggers, the worker should install the initial sign ½ mile away from the work activity. To ensure sign spacing is accurate, the book suggests using highway mile markers and the vehicle odometer for convenience.

Furthermore, the Blue Book mentions that flagging operations should be executed while installing and removing the traffic control devices in the work zone. In addition, the book illustrates the hand signaling procedures to be used by flaggers.

2.4.4 Oregon Standard Specifications for Construction (2021)

Section 00221.40 – General within the Oregon Standard Specification for Construction provides general instructions on the installation and removal of temporary traffic control devices. The standard specs also provide broad guidance on inspection, movement, operations, and maintenance of the traffic control devices. As described in Section 00221.40, any work activities associated with traffic control devices (TCDs), including installing, inspecting, moving, operating, maintaining, and removing TCDs, shall follow according to the project plan and specifications, and the following procedures:

- Install, maintain, and move all TCDs by executing with the direction of traffic
- Provide additional traffic control measures (TCMs) according to Section 00221.02 when necessary or directed
- Turn, cover, or take down the existing TCDs as instructed when they are not required or conflict with temporary devices
- Remove and obliterate, without detriment to the wearing surface, all evidence of all temporary TCDs when the contract is completed
- Take down TCDs in a sequence reverse of the set-up

Part (e) of Section 00222.40 covers the specification for temporary sign placement that needs to be followed when installing temporary signs. Similarly, Part (c) addresses the procedure for removing inconsistent temporary signs. When there is a discrepancy between temporary sign messages and the work zone conditions, traffic pattern, or staging configuration, and when signs are still needed, the specification provides the following instructions:

- Cover the sign to ensure it is invisible to traffic
- Remove or cover sign flag boards
- Use covers meeting the requirements of Section 00222.12 when covering signs and sign flag boards

2.4.5 Traffic Control Supervisor Certificate (ODOT, 2020b)

ODOT Traffic Control Supervisor Certificate documentation provides a reference that describes the process of installing and removing traffic control devices in temporary work zones. The documentation describes the preparation, sequence of device installation, treatment of existing signs, and use of the protection vehicles (ODOT, 2020b). Section 11.3 of Chapter 11 in the document presents the installation sequence for the traffic control devices. The sequence described is as follows:

Devices are placed in the direction of the traffic flow. The first device placed must be the first advance warning sign. The installation process shall then proceed with the following areas:

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

In addition, if traffic movement in both directions will be distracted by work activities, such as when work takes place in the center lane, the devices can be placed in both directions at the same time, beginning at each end farthest from the activity area. Alternately, one direction can be set up before the other.

Moreover, the manual recommends techniques that can be used to quickly install traffic control devices in work zones. It suggests that using paint on roadway surface to mark the location of each device can help save time and effort, especially for signs or channelizing devices that will be placed and removed frequently during the work operation. The manual also mentions that flashing arrow displays and PCMSs can be useful to enhance safety for workers when they are placing and removing the channelizing devices in the work zone.

2.5 PRIMARY VARIABLES TO CONSIDER FOR TRAFFIC CONTROL SET-UP AND REMOVAL

Installing and removing traffic control devices in work zones demand significant attention and care. Since roadwork conditions, traffic, and work zone operations vary from one location to another, it is useful 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). Specific considerations with respect to each variable include (MassDOT, 2017):

> **Location of the work:** Different types of work operations, such as maintenance, short-term construction, and utility work, are impacted by the location of the work. Generally, the closer the active work area is to the roadway, the more traffic control devices are needed.
>
> **Type of roadway:** The work area can be dramatically influenced by the characteristics of the roadway. Significant hazards might be associated with roadway design as the complexity of the roadway increases. Maximum protection should be implemented by assessing the worst hazard that occurs on the worksite.
>
> **Speed of traffic:** Speed is one of the major factors considered when determining the need for traffic control. Generally, as speed approaching the work area increases, the size and number of traffic control devices should be greater and their spacing smaller.

Other factors, such as sight obstructions, must also be taken into account when planning traffic control devices. Assessing the work area by driving through the work zone should be done to determine if any extra precautions are needed to reduce the possibility of obstructions that road users might encounter and potentially disrupt the driver's view within the work zone.

2.6 PROCEDURES FOR SETTING UP AND REMOVING TRAFFIC CONTROL IN WORK ZONES

One of the main activities that needs to be performed during work zone operations is to manage the construction/maintenance work and maintain traffic through the work zone (USDOT, 2006). Ensuring proper installation of work zone traffic control is a critical stage for worker safety (ConeZonebc.com, 2015). The complexity of traffic control set-up in a work zone can mislead or confuse drivers which, in turn, may cause an increase in driver perception reaction time to 4.5-5 seconds (Johnston et al., 2003). This change in reaction time is a dramatic increase from the 2.5 seconds that is used for perception reaction time in road design, and a potential negative impact to safety. Workers exposed to traffic impose greater risk to their safety during traffic control installation and removal than during the actual maintenance work itself (Dudek et al, 1989). Typically, overseeing the operation is a traffic safety officer who administers the placement and removal procedures for traffic devices in all phases of work (District Department of Transportation, 2006). The following sections describe the procedures for installing and removing temporary traffic control in work zones that are described in present literature on the topic.

2.6.1 Procedures for Setting up Traffic Control in Work Zones

The procedure followed for traffic control placement in a work zone is extremely critical to ensuring not only public safety, but also the safety of the workers who are involved in the operation. The devices should be placed in a manner which reduces worker exposure to intruding vehicles and to the risk of falling from work vehicles (Bryden et al, 2012). When work zone traffic control devices are installed consistently, drivers will comfortably experience safe driving on a roadway. Thus, driver expectancy and compliance can be more effective when standard traffic control placement procedures are followed (ODOT, 2011). Consistent and proper application of traffic control devices in work zones focuses on two essential functions (ODOT, 2011): (1) reduce work zone crash rates, and (2) reduce the severity of crashes.

The literature review exposed a variety of recommended procedures for installing traffic control devices in work zones. The procedures for installing specific types of traffic control devices are described in the subsections below.

2.6.1.1 General Guidelines for Traffic Control Set-up

The following general guidelines are provided to ensure the safety of workers, motorists, and others impacted during the placement of traffic control devices for a work zone (ConeZonebc.com, 2015):

- Make sure that all required devices such as cones, signs, and barriers are close by. All devices should be clean and in good condition.
- Set up work zone devices in the order that drivers will face them. Start with the farthest device upstream of the work area, and do not turn back into traffic while setting up the work zone.
- Once the work zone is set up, drive through the work zone to see from a driver's view if the devices are installed properly and convey clear guidance without creating confusion for the road users.
- Maintain the devices in place throughout the day/night.
- Remove individual devices as soon as possible when they are no longer needed.
- Remove the entire work zone as soon as possible when the work is completed. In general, removal should proceed in a reverse order from the installation procedure.

2.6.1.2 Channelizing Device Placement

ODOT Traffic Control Supervisor Certificate documentation briefly describes the general process of installing channelizing devices in work zones. When implementing lane closures, tapers are first laid out in a straight line starting at the shoulder. Each channelizing device is then deployed in sequence moving downstream. When placing devices by hand, the device placement should begin from the shoulder with the worker looking towards the oncoming traffic as he or she moves into the lane to place the device. Guidance for placing specific types of channelizing devices is as follows:

2.6.1.2.1 Cone Placement

In Chapter 2 of the OTTCH, Subsection 2.4 "Device Placement" briefly explains the process of placing traffic cones in a work zone. The process is described as follows:

1. **Determine the taper length and spacing:** using the table "Taper Lengths and Device Quantities" in the OTTCH handbook.

2. **Placing first cone:** Starting from the workspace or buffer, measure off the taper length along the edge of travel way or fog line. At the edge of travel way or fog line, place the first cone to indicate merging or shifting taper, or at the edge of travel way for shoulder work.

3. **Placing second cone in the taper:** Move back towards the workspace, moving along the edge of travel way a distance equal to the posted speed. Then step over one foot into the roadway and place the second cone.

4. **Placing the third cone:** Move toward the work area a distance equal to the posted speed, then move two feet from the edge of the travel way into the roadway and begin to place the third cone.

5. **Placing the remaining cones in taper:** Continue moving back towards the work area and move an additional one foot each time and place a cone until reaching the end of the taper.

6. **After setting up the work zone:** Drive or walk through the work zone to ensure proper set-up of the work zone and adjust it if needed.

The ODOT Traffic Control Supervisor Certificate manual also provides safety guidelines for cone placement. Cones can be either placed by workers on foot or from a moving vehicle. In the case where the worker is working from a vehicle, the truck should be mounted with an approved worker platform and railing. On high-speed roadways, use of a protection vehicle is recommended to protect the worker who is working from the back of the truck.

2.6.1.2.2 Cone and Sign Placement on Multi-Lane Roads and Freeways

On multi-lane roads and freeways, sign and cone placement can be hazardous due to the volume of traffic and the traffic speed. Furthermore, many freeways have narrow shoulders on the median side of the travel lane which makes it more challenging for workers to park their work vehicle off the travel way. It is beneficial to use a protective vehicle with a TMA to protect workers from approaching traffic during traffic control set-up. In order to enhance worker safety and to adequately notify and protect motorists at the same time, the following lane closure procedures are recommended in the Blue Book (Oregon Technology Transfer Center, 2016):

1. Move the protective vehicle to a point in the roadway an estimated 200 feet from the first advance warning sign for the lane closure and stop on the shoulder.

2. Turn on the flashing light and arrow panel. Then, initiate the arrow panel in caution mode and after approximately 2 minutes, display the correct pass arrow.

3. Move the protective vehicle along the shoulder to the first sign location and stop approximately 100 feet before the sign placement and behind the sign vehicle in a blocking position.

4. Place the first sign, then move to the next advance sign location. For the second sign, repeat Step 3 and install the second sign. Then, repeat the same procedure for the rest of the signs until all of the advance warning signs are placed.

5. After installing all the advance warning signs for the lane closure, move the protective vehicle into the lane that needs to be closed to a point 100 feet in advance of the closing taper location. Then, install the channelizing device for the taper in the shielded lane.

6. Move the protective vehicle from the roadway and past the taper on the shoulder and stay in position until the flashing arrow panel is placed and operated (if flashing arrow is used). Move the protective vehicle with the workers as they progress to set up the remaining devices as additional protection.

7. In the case where a portable changeable message sign is available, place the PCMS with a proper message approximately one mile ahead of the initial sign placement position.

8. In addition to a protective vehicle, a shadow vehicle might be implemented on either the right or left shoulder depending on shoulder width, with an appropriate sign or PCMS message warning traffic of the coming lane closure.

9. While the protective vehicle is stationary or stopped behind the work vehicle placing signs and cones, it should be in gear, if possible, or in park for automatic transmission vehicles, and the front wheels should be positioned in the direction of the desired path if crashed into by a motorist.

2.6.1.3 Center Lane Closure on Freeway

The ODOT Traffic Control Supervisor Certificate manual provides a short description of procedures for closing the center lane on a freeway. The sequences for center lane closure included in the manual are presented below:

1. Advance warning signs are installed on both sides of the roadway and the exterior lane is closed to create an “empty” workspace.

2. The protection vehicle, desirably equipped with a flashing arrow display and a TMA, moves to the downstream end of the closed exterior lane and blocks the adjacent center lane.

3. The taper which directs traffic to the previously closed exterior lane is installed and channelization for the closed center lane is created on both sides of the activity area.

4. Required signing is installed in the closed center lane and the protection vehicle may be moved to a blocking position in the workspace.

5. In the final configuration, traffic is allowed to proceed around both sides of the activity area.

Figure 2.10 shows an example of a center lane closure on a freeway after placement of the temporary traffic control is complete (MUTCD, 2009).

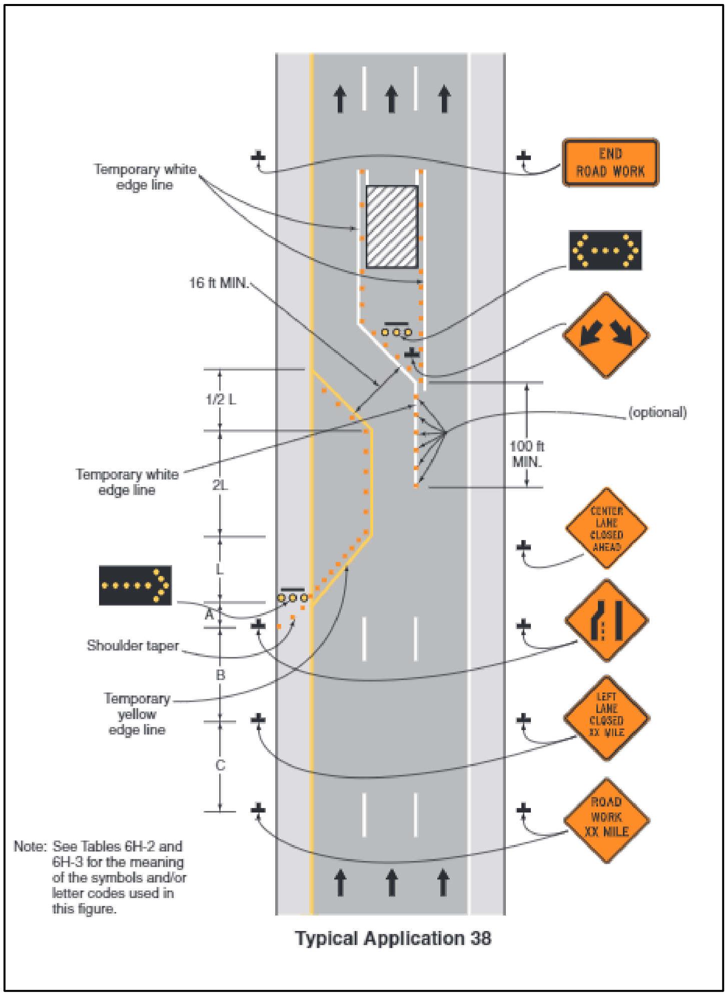

Figure 2.10: Center Lane closure on a freeway (MUTCD, 2009)

2.6.1.4 Exterior Lane Closure on Freeway

The ODOT Traffic Control Supervisor Certificate manual also documents the procedures for exterior lane closure. The exterior lane is restricted by implementing a protection vehicle with a TMA along the shoulder or exterior lane, if no shoulder is accessible. The traffic control set-up process is described as follows:

1. First, the protection vehicle should stop in a blocking position at least 100 feet upstream while the first advance warning sign is installed. The same operation should be repeated for all warning signs (first for one side, then the other side of the roadway). Use of a vehicle equipped with warning lights and a flashing arrow display is recommended.

2. After all signs are in place, the channelizing devices are then installed. While workers install the taper in front of the protection vehicle, the protection vehicle should gradually encroach on the exterior lane.

3. Finally, the protection vehicle occupies the closed lane while the channelizing devices for the activity area are installed.

2.6.1.5 Rolling Roadblock on Freeway/Highway

The New York State Department of Transportation (NYSDOT) provides a detailed description of procedures for implementing a rolling road block on a freeway or highway to permit traffic control placement (NYSDOT, 2015). The procedure is as follows:

Step 1: The rolling roadblock is formed near the assigned starting point, and any on-ramp shall be closed simultaneously or immediately after, depending on how far downstream the ramps are.

Step 2: On-ramp traffic shall be halted and held by a qualified flagger.

Step 3: A clearance vehicle initially located immediately downstream of the rolling roadblock shall follow the last vehicle traveling in advance of the rolling roadblock to confirm that there is no presence of vehicles or parked vehicles and no open on-ramps or other access entrances, and to inform the work crew that the road is free from traffic and closed.

Step 4: Work in the roadway begins. The clearance vehicle should stop and hold its position immediately upstream of the work site waiting until the work is completed to provide a visual indication to the approaching roadblock whether the work is completed, and the roadway is cleared. The roadblock shall move downstream at the pre-planned speed and be in constant communication with the work site. Then, the speed of the roadblock can be adjusted to accommodate the pace of the work. Either a truck with an equipped variable message sign (VMS) or towing a trailer-mounted VMS placed on the right shoulder should keep an approximately 1,500-foot following distance behind (upstream of) the end of the queue. As the roadblock goes beyond an on-ramp, ramp traffic can be released when the main road traffic queue disperses or moves downstream, and main line traffic can safely hold the capacity of the vehicle on-ramp. The procedure and timing shall be planned at the preconstruction meeting.

Step 5: After the lane closure operation has finished, the work crew shall inform the rolling roadblock and the clearance vehicle shall pass the site. The blocking vehicle should speed up and pull over to the right side of the roadway starting from the left lane. In a situation where police are used, the police should continue with the flow of traffic to ensure speed acceleration of released vehicles is controlled. Inactivate or adjust portable variable message signs (PVMS) as needed.

Figure 2.11 illustrates the process of implementing the rolling roadblock on a freeway or expressway.

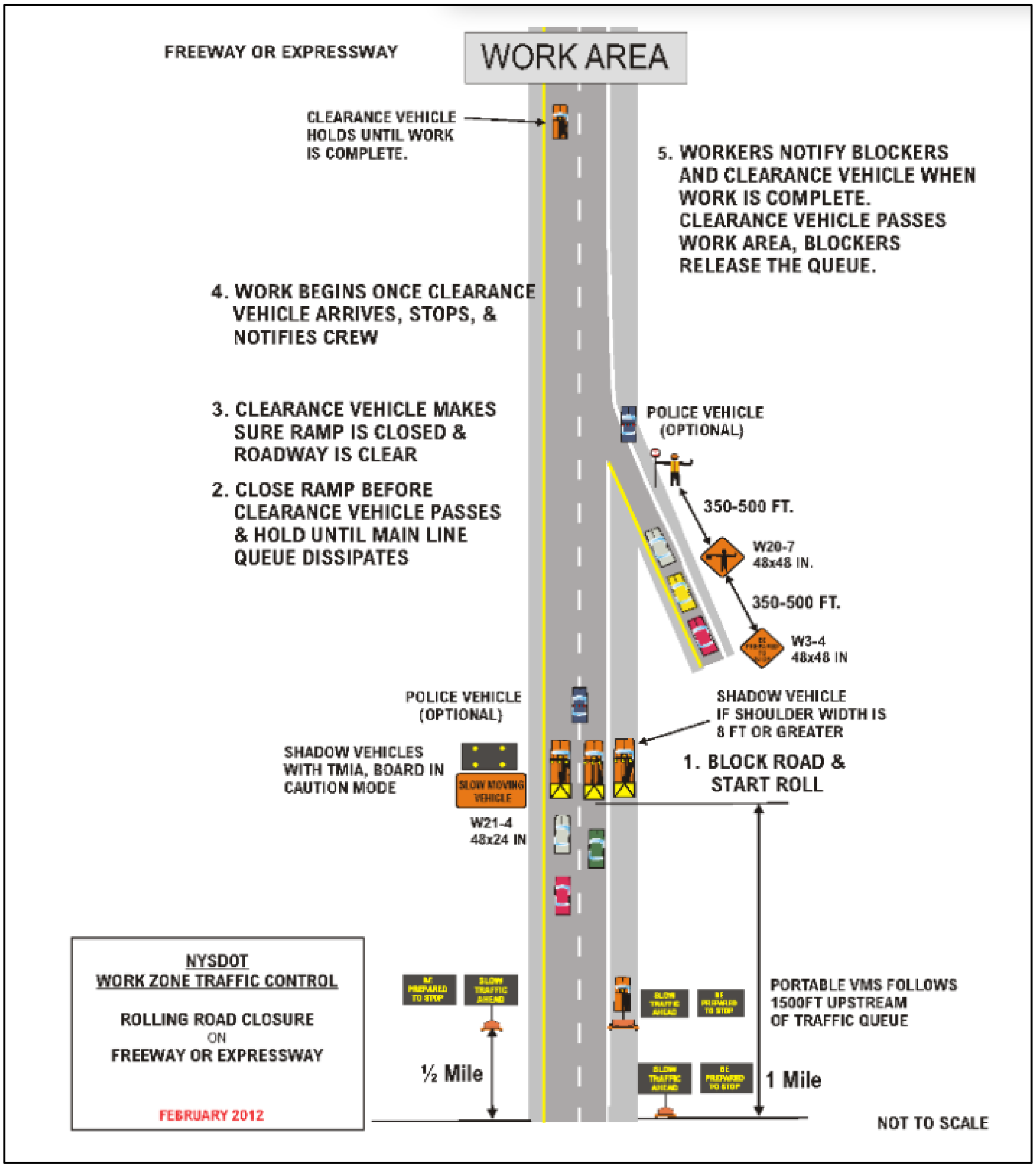

Figure 2.11: Procedure for rolling roadblock (NYSDOT, 2015)

2.6.1.6 Nighttime Highway Work Zone Closure

When performing nighttime work, the order of the steps for installing temporary traffic control in a work zone is critical to ensure the traffic and workers are provided a high level of protection as the work operation progresses (Bryden and Mace, 2002). National Cooperative Highway Research Highway Program (NCHRP) Report #476 provides a description of the sequence of operations for installing work zones at night. The sequence for set up is described as the following:

1. Activate changeable message signs to inform drivers of detour, divisions, and other traffic changes.

2. Install or disclose detour route sign and activate other temporary traffic controls within detours.

3. Install or disclose detour advance warning signs for detours, closure, and other temporary traffic paths.

4. Install all portable lighting units at all closure points and other critical points before establishing closures. Lights should be adjusted to eliminate glare.

5. Execute on-ramp closures for sections of roadway to be closed or restricted by placing barricades or other devices at closure points.

6. If off-ramps are to be closed, place advance signing, and effect closure by deploying channeling device, signs, and barricades. While closure is placed, either a police patrol vehicle or well-lit work vehicle, or both, must be present to temporarily block the ramp.

7. Install arrow panels on the shoulder or other areas where they will not disturb traffic and beyond the clear zone if they are not to be used during daytime. During nonworking hours, light towers and other equipment are securely stored in the median beyond the roadside clear zone (for example, see Figure 2.12).

8. Place channelizing devices to complete shift, diversion, or lane closure.

Figure 2.12: Equipment stored in median beyond roadside clear zone (Bryden and Mace, 2002)

2.6.1.7 Stationary Lane Closure General Requirement (VDOT, 2019)

In 2009, the Virginia Department of Transportation (VDOT) published a new version of its guideline titled "Guideline for Temporary Traffic Control," which includes practical guidance for installing stationary lane closures in the same flow of traffic. The steps prescribed for installing the lane closure are:

1. Install all warning signs
2. Install shoulder taper (if required)
3. Set arrow board on the shoulder at the beginning of the merging taper
4. Install channelizing devices to create a merging taper
5. Install channelizing devices along the buffer space
6. Continue putting down channelizing devices along the work area at the designated spacing
7. Install channelizing devices in the termination area
8. Install the "END ROAD WORK" sign approximately 500 feet beyond the last device in the lane closure
9. If necessary, place a truck mounted attenuator (TMA) vehicle 80 to 120 feet from the first work crew or hazard approached by motorists

The following sections describe the practical procedures for installing stationary lane closures for multi-lane highways, which uses a similar set-up approach.

2.6.1.8 Stationary Lane Closure on Multi-Lane Highway

The field guide on "Installation and Removal of Temporary Traffic Control for Safe Maintenance and Work Zone Operation," published by the American Traffic Safety Service Association (ATSSA), provides guidance on the placement and removal procedures for temporary traffic control in work zones. The guide includes procedures for installing a stationary lane closure on a multi-lane highway. The steps are explained as follows:

1. Identify the beginning of the workspace and mark the location. Note: When using paint, use white or pink color only, as the other designated colors are used for the types of utility.
2. Start from the beginning of the workspace, measure the buffer distance, and mark the beginning of the buffer space.
3. From the beginning of the buffer space, measure the taper length and mark the beginning of the taper.

4. From the start of the taper, measure the advance warning sign spacing, shown in Figure 2.13, and mark each location.

5. Place advance warning signs in advance warning area by starting with signs located on the right shoulder first, and then place the sign on the left shoulder, if appropriate. The intent of each sign is to:

   - 1st sign: Attract the road user's attention

   - 2nd sign: Indicate to the road user what is being approach

   - 3rd sign: Direct the road user to what needs to be done

6. On the shoulder, place the arrow panel prior to the taper or place it as close as possible to the beginning of the taper.

7. Place traffic control devices and arrow board panel in the transition area with the movement of traffic. During installation, it is recommended to use a truck-mounted attenuator on the lead vehicle or shadow vehicle.

8. Along the activity area, place traffic control devices:

   - Begin installing in the buffer space with the flow of traffic

   - Continue placing traffic devices along the workspace

9. Install traffic control devices at the termination area with the movement of traffic.

10. Inspect the work zone by driving through the work zone, documenting observations, and correcting any deficiencies, if needed.

Observe motorists driving through the work zone to identify trends that make it difficult for motorists to maneuver through the work zone.

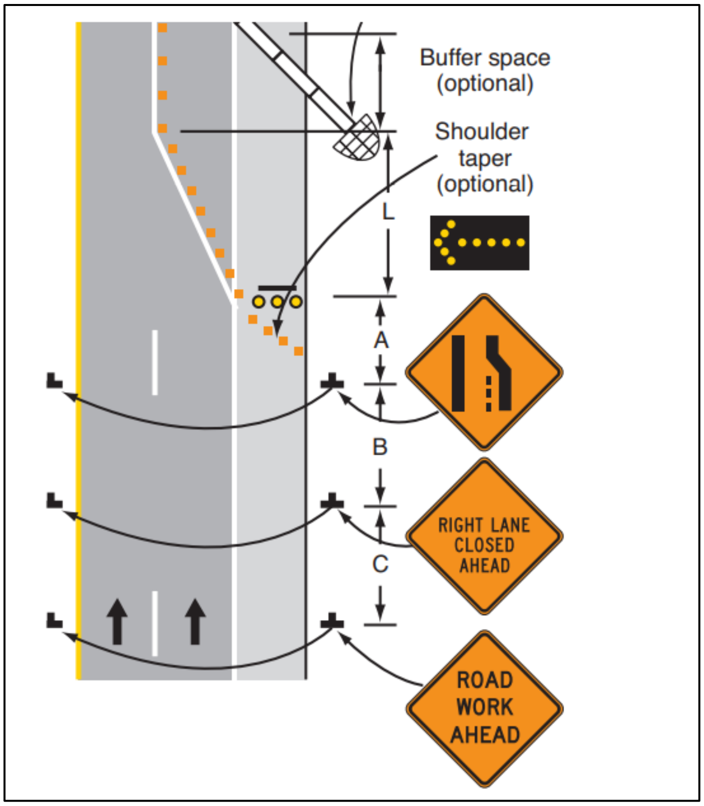

Figure 2.13: Advance warning sign spacing illustration (ATSSA, 2008)

2.6.1.9 Stationary Lane Closure on Multi-Lane Primary, Secondary, and Interstate Routes (SCDOT, 2019)

The manual "Work Zone Traffic Control Procedure and Guidelines for SCDOT Maintenance Activity," published by the South Carolina Department of Transportation (SCDOT, 2019), presents a procedure for installing a stationary lane closure on multi-lane primary, secondary, and interstate routes. The recommended procedure is very similar that described above in the general requirements for stationary lane closures. However, the SCDOT procedure is more specifically focused on stationary lane closures on multi-lane primary, secondary, and interstate routes. The description of the procedure in this section more thoroughly explains the process. Additionally, the procedure addresses the general practice of stationary lane closures, but not precisely for multi-lane highway primary, secondary, and interstate routes. The stationary lane closure procedure for those cases is as follows:

1. First, install the advance warning area. Install the advance warning signs along the shoulder area, in the opposite direction of the traffic lane intended for closure. During the operation process, the work vehicle should occupy the shoulder area when applicable. The shadow vehicle should maintain its operation within the same portion of travel lane and shoulder area as the work vehicle. Both vehicles shall be mobile and operate in the same direction of the traffic.

2. Keep performing the installation of the advance warning area. Once the installation of the advance warning signs on the shoulder opposite of the travel lane intended for closure is finished, in the shoulder area adjacent to the travel lane intended for closure, install the advance warning signs. While the operation takes place, the work vehicle should occupy the shoulder area when applicable. It is recommended that the shadow vehicle operate in the same portion of the travel lane and the shoulder area as the work vehicle. Both vehicles shall be mobile and operate in the same direction of the traffic as mentioned for the previous step.

3. Upon completing the set-up of static advance warning signs in the shoulder area, in the case where a trailer-mounted changeable message sign is needed as part of the advance warning sign array, install the trailer-mounted changeable message sign. Performing this process should be in a manner which allows the work vehicle and the shadow vehicle to occupy the shoulder areas as applicable and reduce encroachment onto the adjacent lane. Both vehicles shall be mobile and operate in the same direction of the traffic flow.

4. After completing the set-up of the advance warning area, begin to install the transition area, which includes the taper areas. Place all the traffic control devices for the taper. The shadow vehicle and work vehicle should operate within the blocked travel lane. While setting up traffic control devices in the taper area, the work vehicle should be mobile through the transition area in the same direction of traffic. It is recommended that the shadow vehicle remain within the travel lane intended for closure no further than 100 feet in advance of the beginning of the taper as the work vehicle is placing the traffic control devices through the transition area.

5. After completing the set-up of the transition area, install the activity area, which includes the tangent portion of the lane closure and the work area. While installing the traffic control devices along the tangent portion of the lane closure, the work vehicle should operate along the activity area in the same direction of the traffic. The shadow vehicle is not required at this period of operation since the work vehicle is operating in a limited space of the closed travel lane.

The SCDOT manual also mentions that when installing or removing the lane closure on a high-speed, high-volume route, it is mandatory to use a truck-mounted attenuator following the work vehicle with a shadow vehicle supplemented with a truck-mounted advance warning arrow panel. Use of an additional shadow vehicle is recommended, if needed. The shadow vehicle should occupy the same portion of the travel lane and the shoulder area as the work vehicle and should move in the same direction as the traffic. On the other hand, in the case where an additional shadow vehicle is required, the initial shadow vehicle that is encountered by oncoming traffic might be accompanied with either a truck-mounted advance warning arrow panel or truck-mounted changeable message sign. In a situation where the truck mounted with a changeable message sign is implemented, SCDOT recommends always providing the initial shadow vehicle with the truck-mounted changeable message sign and supplement all of the subsequent shadow vehicles with truck-mounted advance warning arrow board panels.

2.6.1.10 Lane Closure for High Speed (≥ 45MPH) Roadway

The Massachusetts Department of Transportation (MassDOT) provides a procedure for installing lane closures for both low-speed and high-speed roadways. MassDOT defines high-speed roadways as roadways that allow the traffic to travel at a minimum speed of or greater than 45 mph. MassDOT advises installing all devices in the same order as the direction of traffic flow. The steps recommended for lane closures on a high-speed roadway are:

1. Install all advance warning signs, which begin with the “ROAD WORK XXX” (W20-1) sign, and end with either the “END ROAD WORK” or “DOUBLE FINES END” signs.
2. Install all signs starting with the opposite side of the intended closed lane. Then, install signs on the shoulder that is tangent to the closed lane.
3. If necessary, install shoulder taper.
4. Install arrow board on shoulder as close as possible to the beginning of the merging taper or prior to the merging taper.
5. Create the merging taper by installing the channelizing devices. During installation, it is recommended to use a shadow vehicle mounted with a TMA on the roadway.
6. Install buffer space with the designated spacing.
7. Keep installing work area with the designated spacing.
8. Install termination area as necessary.
9. Place the shadow vehicle mounted with a TMA in advance of the first work crew or hazard approached by the motorists. Multiple shadow vehicles may be required depending on the number of lane and shoulder closures implemented.

2.6.1.11 Lane Closure for Short-Term or Moving Operation Using Single Flagger

The *Temporary Traffic Control Handbook* published by Wiegand and Richards (2016) provides a reference for temporary traffic control in work zones with the aim of enhancing safety and efficiency for all road users. The handbook notes that flagging is considered as one of the most hazardous jobs in temporary traffic control. Carefully reviewing the flagger’s instructions before implementing the flagging activities is recommended. The handbook describes single flagging procedures for lane closures in short-term and moving operations.

A single flagger is normally used for low volumes of traffic with a short work duration on a straight roadway. It is highly suggested to use the procedures only in daylight hours, with traffic volume less than 2,000 vehicles per day and good sight distance in the work zone. In addition, no parking is allowed on the opposite side of the roadway from the work area, and traffic in the open lane should flow freely.

The flagging process presented in the handbook recommends that the flagger should stop the first vehicle in the closed lane and move toward the centerline to stop other vehicles. The work vehicle containing warning lights may be replaced by a Type III barricade. The alternative option of using two flaggers is used if the flagger's view is limited and the flagger is unable to see the upcoming traffic.

2.6.1.12 Lane Closure on Two-Lane Road using Two Flaggers

In addition to using one flagger for a lane closure, the *Temporary Traffic Control Handbook* (2016) contains recommendations for conditions when two flaggers should be used. In the case where a flagger's view of approaching traffic is shorter than 1/4 mile or sight distance is restricted, and when excessive traffic delays occur, use of a second flagger is recommended. The handbook contains no description of the procedure for implementing a lane closure on two-lane roads using two flaggers. Figure 2.14 illustrates the traffic control layout when using two flaggers for a lane closure on a two-lane road where the sight distance is limited due to the curvature of the road.

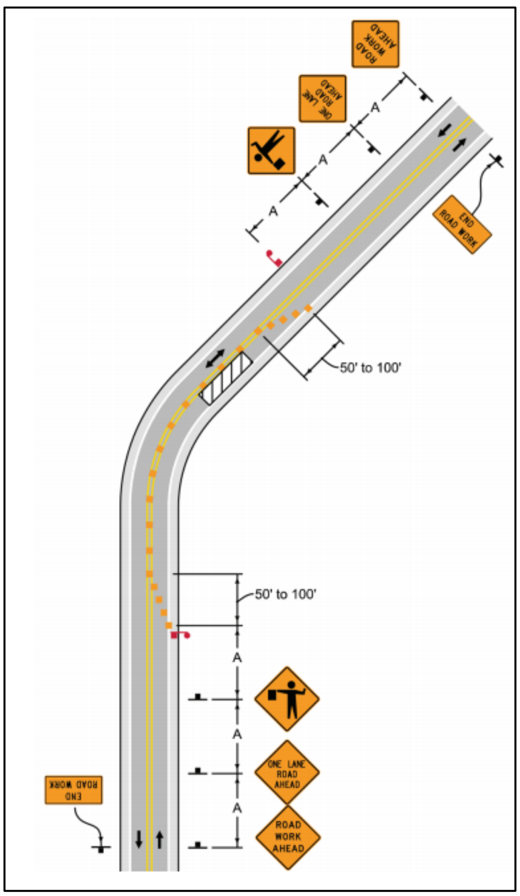

Figure 2.14: Lane closure on two-lane road using two flaggers (Weigand, 2006)

2.6.1.13 Flagging Procedures

The OTTCH presents the flagging gestures described in Section 6E.07 of the MUTCD. The gestures describe how to stop traffic, how to let traffic proceed, and how to alert and slow the traffic. Each action is described as follows:

- **To stop traffic:** The flagger shall face the road user and position the STOP paddle face toward the road user with the arm extended horizontally away from the body in a stationary position. The free arm shall be raised with the palm of hand above the shoulder and facing toward the oncoming traffic.

- **To direct stopped traffic to proceed:** The flagger shall face the road user with the SLOW paddle pointing toward the road users in a stationary position with arm extended horizontally from the body. The flagger shall use the free hand to indicate a proceed motion and for the road user to proceed.

- **To alert or slow traffic:** The flagger shall face the road user while pointing the SLOW paddle in a stationary position to the road users with the arm extended horizontally away from the body. To notify or slow traffic, the flagger shall use the free hand with palm downward, and motion up and down.

2.6.1.14 Detour Installation

The ATSSA field guide (2008) also describes the procedure for installing a detour around the work zone. The process of installing a detour is different from the procedures recommended for other road closure operations. The following steps are part of the procedure for installing a detour (ATSSA, 2008):

1. Place the last sign that motorists will see which guides motorists back to the route where they detoured from.

2. Place the remaining signs working back toward the beginning of the detour. Once all the signs are in place, the motorists are allowed to use the detour.

Figure 2.15 shows the traffic control signage along with the sign installation and removal process. All detour signs may be placed in the field at the same time, if desirable and sufficient work staff is available. In addition, detour signs can be installed one after another and covered until ready for use.

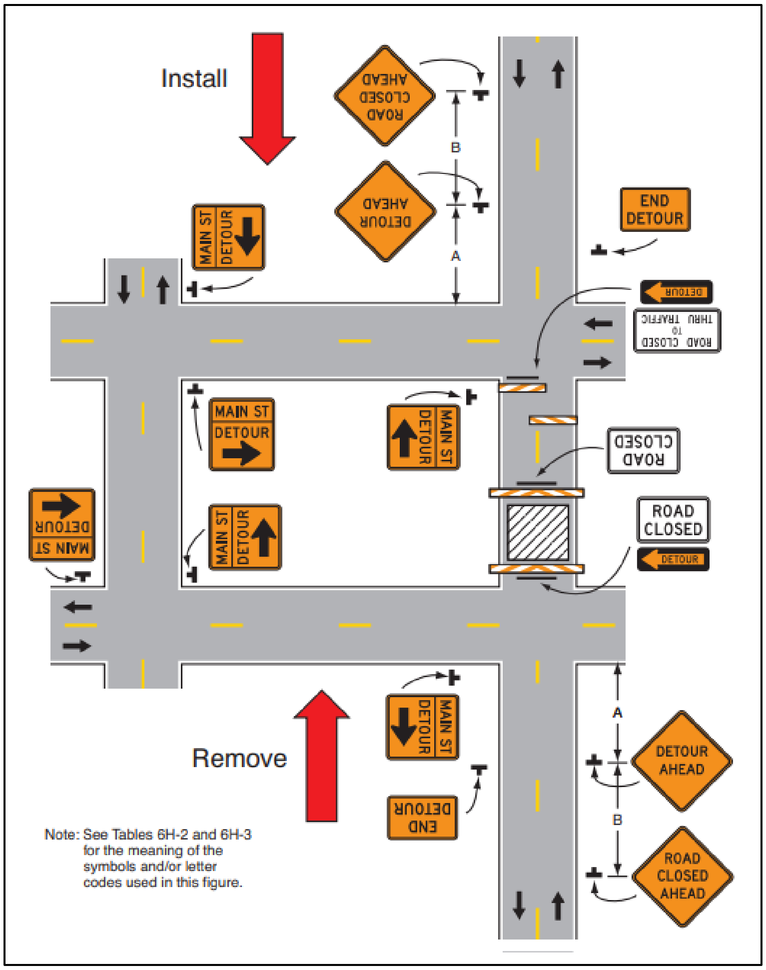

Figure 2.15: Detour sign installation and removal (ATSSA, 2008)

2.6.1.15 Advance Warning Sign Sequence

Proper signing in a work zone requires the right sign to be used at the designated spacing and placed in the appropriate sequence (Oregon Technology Transfer Center, 2016). According to MUTCD and TxDOT standards, the advance warning signs should be installed in the following sequential order when a flagger is used in the work zone:

1. Install the "ROAD WORK AHEAD" sign
2. Install the "ONE LANE ROAD XXX Ft" sign
3. Install the "BE PREPARED TO STOP" sign
4. Install the "FLAGGER" symbol sign with distance plaque

However, the advance warning sign sequence described above slightly contradicts the sign placement sequence stated in the "Flagging Station" section of the Blue Book published by the Oregon Technology Transfer Center. The "ONE LANE ROAD XXX

Ft" sign is not recommended in the Oregon Technology Transfer Center document, although the sequential order of placement of the signs remains the same. As mentioned on the Oregon Technology Transfer Center website, the advance warning signs shall be installed in the following order:

1. Install "ROAD WORK AHEAD" sign
2. Install "BE PREPARED TO STOP" sign
3. Install "FLAGGER AHEAD" sign with a symbol depicting a flagger holding a STOP/SLOW paddle

2.6.1.16 Installation of Automated Flagger Assistance Device (AFAD) and Portable Traffic Signal (PTS)

The article titled "Evaluation of Alternative Methods of Temporary Traffic Control on Rural One-Lane, Two-Way, Highway" (Finley et al., 2015) describes research that evaluated the effectiveness of various types of temporary traffic control devices in rural areas. The article addresses the processes of installing automated flagger assistance devices (AFADs) and portable traffic signals (PTSs) that were implemented in the study. The process followed for installing an AFAD included the following steps:

1. Workers placed the advance warning signs in both directions of traffic.
2. Workers installed the first AFAD and "STOP HERE ON RED" sign in one direction of travel.
3. Workers activated both AFADs.
4. Using the remote-control unit, workers installed the first AFAD in the proceed phase (i.e., flashing circular yellow indication with the gate arm raised).
5. Workers installed the second AFAD and "STOP HERE ON RED" sign in the other direction of traffic. The second AFAD was automatically in the stop phase (i.e., steady circular red indication with the gate arm down).
6. Flaggers used the remote-control unit to control both AFADs and alternate one-way movement of the two original travel lanes though the work area.

Finley et al. (2015) also describe their implementation procedures for installing portable traffic signals. The following steps were taken to install the PTSs:

1. Workers installed the advance warning signs in both directions of travel.
2. Workers placed the first PTS and "STOP HERE ON RED" sign in one direction of travel. Workers turned on the PTS unit. One worker was left at the PTS.

3. Workers installed the second PTS and “STOP HERE ON RED” sign in the other direction of travel. After that, workers powered on both PTSs. The PTSs automatically controlled the one-way movement of the two original travel lanes through the work area.

4. Workers adjusted the signal timing as needed.

2.6.1.17 Installation of Work Zone Lighting System

Before work begins at nighttime, the contractor must ensure that all necessary lighting equipment is installed (Bryden et al., 2002). The lighting equipment includes any fixed lighting and supplemental lighting that is placed on the roadway, mobile machinery, or equipment. The contractor should eliminate objectionable glare in the work area by placing, aiming, and adjusting the lighting fixtures to provide the standard required level of illuminance and uniformity in the work area yet eliminate glare for the workers and passing motorists. For instance, when an arrow board or PCMS is utilized at night, the adjacent flashing warning light must be turned off to avoid glare and confuse the driver (ATSSA, n.d.). The contractor must reduce glare that exceeds the acceptable level for all travel paths. Shields, visors, or louvers may be provided as needed to mitigate objectionable levels of glare.

ATSSA also provides a guideline for using warning lights in work zones. Red warning lights can be used when they flash simultaneously, and amber lights can be used either flashing simultaneously or alternating. Depending on state regulations, blue lights are only allowed for use on an emergency vehicle. Vehicles equipped with work lights on the rear of the vehicle must be protected by traffic control equipment such as an attenuator truck, if used in a work zone.

2.6.2 Procedure for Removing Traffic Control from Work Zone

The MUTCD states that when work is completed or suspended, all temporary traffic control shall be removed from the work zone as soon as possible when no longer required (FHWA, 2009). In a period of work suspension, TTC devices that are no longer needed shall be covered or removed. When traffic control devices are removed, the devices shall be stored outside of the clear zone. The clear zone distance depends on vehicle speed, and is provided by state DOT standards or the AASHTO roadside design guide (ATSSA, 2008). The following sections describe the TTC device removal process in different types of work zones.

2.6.2.1 Stationary Lane Closure Removal

ATSSA (2008) describes the process of removing traffic control devices used for stationary lane closures as follows:

1. Withdraw devices from the termination area in the direction opposite of the traffic flow. During removal, use a truck-mounted attenuator on the lead vehicle or a shadow vehicle if applicable.

2. Withdraw devices from the activity area in the direction opposite of the traffic flow.

    - Ensure the workspace is clear and clean before removing devices.

    - Begin removing devices from the buffer space.

3. Withdraw devices from the transition area in the direction opposite of the traffic flow.

4. Withdraw the advance warning signs in the advance warning area in the direction opposite of the traffic flow. Keep the first advance warning sign in place until all other devices have been removed.

However, the TTC removal procedures for stationary lane closures described above are slightly different that those recommended by some state DOTs. For example, in the *Guidelines for Temporary Traffic Control* published by the Virginia Department of Transportation (VDOT, 2019), it is recommended that the advance warning signs be removed starting from the first advance warning sign, rather than leaving the first advance warning sign to be removed last as recommended by ATSSA. As stated in the VDOT guideline, temporary traffic control devices used for stationary lane closures should be removed in the following order:

1. Remove channelizing devices from the far end of the road closure to the widest part of the merging taper.

2. Place removal vehicle on the shoulder and begin removing devices from the taper by hand and place onto the work vehicle.

3. Remove the arrow board after the roadway is free from traffic.

4. Moving with the flow of traffic, remove all advance warning signs beginning with the "ROAD WORK AHEAD" sign and ending with the "END ROAD WORK" sign.

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

In addition to ATSSA and VDOT descriptions of traffic control for a stationary lane closure, the South Carolina Department of Transportation (SCDOT) also provides a description of the removal process for stationary lane closures on multi-lane primary, secondary, and interstate routes (SCDOT, 2011). The process is different than the standard process for traffic control removal described in the previous section of this report. As stated in the standard removal procedure, the removal process begins with removing temporary traffic control devices from the termination area and finishes with the advance warning area. However, the SCDOT procedure begins with removing TTC devices in the activity area. The SCDOT procedure is as follows (SCDOT, 2011):

1. First, remove the activity area. Remove all traffic control devices that delineate the tangent of the lane block. The traffic control devices must be removed in the reverse direction from the direction traveled by the work vehicle while setting up traffic control devices. Start removing traffic control devices from the far end of the downstream end of the activity area and continue to remove the devices toward the downstream end of the taper area. It is recommended that work vehicles move and operate within the closed travel lane in a direction opposite to the direction of traffic. During this period, the shadow vehicle is not required when the work vehicle is working within the closed travel lane since the space available within the close travel lane is commonly limited. During nighttime removal operations, the work vehicle should operate as far away as possible from the near edge of the adjacent travel lane open to traffic.

2. Once the removal of the tangent section is completed, remove the transition area composed of the taper. The work vehicle and shadow vehicle should operate in the same direction as the direction of the traffic flow and operate within the same travel lane as the taper. It is not recommended to remove traffic control devices in a direction that is against the direction of the traffic flow. The removal process in the taper area must be in the same direction as the traffic. Use of a shadow vehicle in advance of the beginning of the taper area is recommended, and the shadow vehicle should operate within a distance of no more than 100 feet in advance of the work vehicle as the work vehicle removes the traffic devices.

3. In the case where a trailer mounted changeable message sign is used, remove the trailer mounted changeable message sign after finishing the removal of the taper. The trailer mounted changeable message sign should be removed before starting the removal of the static advance warning signs. Implement the removal process in a manner such that the work vehicle and shadow vehicle operate and occupy the shoulder areas as much as they can and reduce encroachment onto the adjacent travel lane. Both vehicles should operate and move in the same direction as the traffic.

4. After completing the removal of the changeable message sign, next remove the advance warning area. Take down the advance warning signs in the shoulder area that are next to the previous travel lane closure. Begin to remove the advance warning signs in the same direction as the traffic. While implementing the removal process, it is recommended that work vehicles use the shoulder area as applicable. The work vehicle and shadow vehicle should operate in the same direction as the traffic while removing the advance warning signs and should operate through the advance warning area in the same direction as the traffic flow.

5. Continue to remove the advance warning area. Begin removing the advance warning signs in the shoulder area next to the previous lane closure. The process for removing the advance warning signs should be in the same direction as the traffic. The work vehicle should occupy the shoulder area while implementing this removal process. The shadow vehicle should operate within the same portion of the travel lane and the worker vehicle should operate on the shoulder area.

Both vehicles should operate in the same direction as traffic and operate through the advance warning area while removing the advance warning signs.

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

The process used for lane closure removal on a high-speed roadway is generally performed against the traffic flow except for the advance warning signs (MassDOT, 2017). The removal procedures on both low-speed and high-speed roadways (speed at lease 45mph) are described by MassDOT. The following sequence is MassDOT's procedure for lane closure removal on high-speed roadways:

1. Remove channelizing devices beginning with the far end of the activity area and work backward to the widest part of the merging taper.

2. Shadow vehicle should be located in a block mode position to protect workers removing devices and move backward as the devices are removed from the roadway.

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

4. Remove the arrow board once the traffic is clear or if it is safe to do so.

5. Return back to the beginning of the work zone and, moving with traffic flow, remove the advance warning signs on the opposite side of the closed lane first. Then remove the advance warning signs on the other side of the roadway.

6. At no time should a worker run/walk across the multiple lanes of traffic to remove advance warning signs on both sides of the roadway simultaneously.

7. Record the time that the signs were removed in the logbook.

2.6.2.4 Detour Sign Removal

ODOT Traffic Control Supervisor Certificate documentation (ODOT, 2020b) states that the first signs to be removed when the detour is no longer necessary are those signs which the motorist would normally encounter at the upstream terminus of the detour. Likewise, ATTSA also provides information on the procedure for removing TTC devices for a detour. The detour removal procedure is performed in a reverse order compared to a standard removal procedure for a normal stationary lane closure. The removal of a detour is explained as follows:

1. Remove the signs at the beginning of the detour

2. Withdraw the other signs with the direction of the traffic flow, as shown in Figure 2.15.

2.6.2.5 Trailer Mounted Attenuator Removal

According to ATSSA, work vehicles with trailer-mounted attenuators that are used for the removal process create an issue of concern while backing up when the attenuator is raised up. When the attenuator is in the raised-up position, the TMA makes it difficult to control the trailer. The Maine DOT provides guidance when using a vehicle with a truck mounted attenuator to enhance safety. When a vehicle with a truck-mounted attenuator is used, the traffic control devices are removed by backing up against the traffic flow. However, when only a work vehicle with a trailer-mounted attenuator is available, the trailer should be removed before backing up against the traffic flow. This guidance assumes that backing up without the presence of an attenuator is less risky than backing up with a trailer-mounted attenuator.

2.6.2.6 Cone and Sign Removal

The Oregon Technology Transfer Center provides a general reference for cone removal which briefly describes how to safely conduct cone removal in a work zone. The Oregon Technology Transfer Center describes that cone removal should be executed by working toward traffic from the upstream area, and either collecting the cones directly and then putting them back into a vehicle or placing them on the shoulder for later pick-up. In addition, the vehicle operator must not back up the vehicle toward the traffic. This procedure is consistent with the guidance contained in the ODOT Traffic Control Supervisor Student Manual (ODOT, 2020a).

Removing signs, however, does not have to be performed in a manner opposite (reverse) of their placement. If removing the signs in reverse is safe to do so, it is desirable. The most important consideration is withdrawing the signs using a safe practice, not necessarily moving upstream toward the oncoming vehicles.

2.7 PROCEDURE FOR SETTING UP AND REMOVING TRAFFIC CONTROL AT ACCIDENT AND FIRE LOCATIONS

Set-up and removal of temporary traffic control is also conducted following an accident on a roadway and in situations when there is a fire nearby. The researchers also searched for and reviewed literature related to setting up and removing temporary traffic control at accident locations and in the presence of nearby fires.

2.7.1 Cone Placement for Lane-Blocking Incidents

The US Department of Transportation (USDOT, 2020) provides a thorough description in field operation guides for controlling traffic using temporary traffic control following an accident. The procedures used for cone placement to close a lane are also contained in the description. The procedure describes how many cones need to be carried by at least the vehicle used for the lane-blocking operation, the spacing of cones for the set-up, the sequence order of the cone deployment, and the body posture of the personnel conducting the operation. Similarly, the Emergency Responder Safety Institute (Emergency Safety Institute, n.d.) also provides a recommendation for setting up a cone taper at incident areas.

2.7.2 Cone and Flare Placement in Fire Situations

For an extreme condition such as when there is a fire nearby, the US Department of Agriculture (USDA) provides a procedure for cone and flare placement to help define the work area and provide visibility in the work area to enhance road user safety (USDA, n.d.). The procedure describes how cones/flares should be placed by counting paces while walking along the roadway, how many feet that the second, third, fourth, and fifth cones/flares need to be offset from the shoulder toward the road, the location of the final cone/flare, and the worker's body posture while placing the cones/flares.

2.7.3 Establishment of Advance Warning and Transition Areas on Highway related to Accident

The Emergency Responder Safety Institute (Emergency Safety Institute, n.d.) has also established procedures for setting up traffic control such as cones, signs, and flares in the advance warning and transition areas on a highway after an incident occurs. The procedure includes the following steps:

1. Deploy the first device along a shoulder or edge of lane of highway while standing in the safe area.

2. Move a distance of ten paces back toward the incident scene along a safe pathway area. When it is safe, enter into the nearest travel lane a distance of one pace or approximately 3 feet, and deploy the second device.

2.8 WORK ZONE SET-UP AND REMOVAL DURING THE DAYTIME AND NIGHTTIME

State DOTs often choose to perform construction and maintenance work during the nighttime hours to minimize the impacts of the work operations on the travelling public. Differences in traffic volumes and speeds, driver behavior, and site conditions between daytime and nighttime conditions should be taken into consideration when planning and conducting traffic control installation and removal. This section summarizes literature related to the topics of work operations and safety risk when the temporary traffic control deployment and removal is conducted during the daytime and nighttime.

2.8.1 Work Zone Risk Comparison between Daytime and Nighttime

Research has been conducted to explore the safety risk associated with daytime and nighttime work zones. For example, according to data on fatal accidents in highway work zones in the state of Illinois from 1996 to 2001, statistical evidence shows that nighttime construction is about 5 times more hazardous than daytime construction (Arditi et al., 2007). However, this study result conflicts with other researcher's findings. A study conducted by Ha and Nemeth (1995) aimed to investigate means by which traffic control devices improve work zone safety. One of the study conclusions was that accidents tend to increase more noticeably during daytime than nighttime. Similarly, another study conducted an assessment of the safety impacts of active nighttime work zones in Texas (Ullman et al., 2004). The researchers found that when nighttime traffic volumes are 50% or lower than daytime off-peak periods, the impact on reduced crash risk in nighttime work is more significant than during daytime operations (i.e., the decrease in risk of crashes during the nighttime is greater). This result is also consistent a study of crash severity by Zhang and Hassan (2019) that compared nighttime and daytime work zones. The outcome of the study indicated that the probability of a passenger car being involved in a fatal crash with a work zone present compared to without a work zone present increases more dramatically for daytime work zones than nighttime work zones, with percentage increases of 549.4% and 58.7%, respectively.

However, some studies show that there are no significant changes in terms of risk exposure between daytime and nighttime work zones. According to NCHRP Report No. 627 titled “Traffic Safety Evaluation of Nighttime and Daytime Work Zones,” working at night does not significantly contribute greater crash risk for an individual motorist passing through the work zone than in the daytime (Ullman et al., 2008). Furthermore, this study result is also supported by a research study by Garber and Zhao (2002) that investigated crash characteristics in work zones. The researchers found that the severity of nighttime and daytime work zone crashes was not significantly different.

In addition, Zhang and Hassan (2019) found that during rainy conditions, the fatality rate tends to increase in the nighttime while it decreases during the daytime. The level of injury severity was recognized as having a positive relationship with the increase in speed, particularly for male drivers. The researchers also found that passenger vehicles are more likely associated with fatal crashes during daytime than the nighttime. Moreover, the fatality probability tends to be higher during daytime than nighttime when workers and pedestrians are involved. The study also showed that the probability of older drivers being involved in a fatal crash was lower at night. In contrast, a higher rate of involvement in a fatal crash at night than in the daytime was found for young drivers. During the nighttime, the high speeds of passenger and heavy vehicles in work zones result in a higher risk of being involved in a fatal crash due to making a sudden lane change in the lane closure for the work zone. Highway accidents in construction work zones tend to occur at a higher percentage compared with maintenance and utility work zones in terms of both length of work and traffic volume (Pigman et al., 1990).

Table 2.3: Research on Work Zone Risk Severity during Daytime and Nighttime Work Operations

Researchers	Study Location	Crash Data Gathering & Year of Data	Research Objective	Research Methodology	Major Findings
Arditi et al., (2017)	Illinois highway work zones (1996-2001)	Data were gathered from FTP site in Web-Based Encyclopedia of Fatality Analysis Reporting System (FARS) Years of data collection: 1996 - 2001	The purpose was to determine the safety difference between daytime and nighttime work operations on highway construction projects	Examined fatal accidents in Illinois highway work zones in the period from 1996-2001. Factors such as lighting and weather conditions were incorporated into the study as control parameters to find out the impact on the frequency rate of fatal accident occurring in work zones.	Nighttime construction is five times more hazardous than daytime construction.
Ha and Nemeth (1995)	Highway work zones in Ohio	Data were received from accident reports submitted by law enforcement agencies to the Department of Highway Safety. Years of data collection: 1982 – 1986	The goals were to determine the seriousness and nature of work zone safety issues, identify the cause-and-effect relationships of accidents in work zones, and provide recommendations for work zone safety improvements.	Work zone accident statistics and accident characteristic were compared with statewide accident characteristics. Then, nine individual construction sites were examined in detail to identify problems. Based on the observations, the researchers generated a recommendation for improving work zone traffic control.	Work zone accidents are slightly less severe than all other types of accidents. Accidents tend to increase more in daytime work zones than nighttime work zones. Major causes of accidents in work zones are traffic control confusion, traffic slow down, lane changing or merging, drinking alcohol, soft shoulder, and lack of guardrails.
Ullman et al., (2004)	Texas interstates and major urban	Data derived from Texas Department of Public Safety (DPS)	The goals of the study were to quantify the estimated risk	Conducted a survey of TxDOT, construction, and maintenance traffic	Nighttime crashes in work zones were slightly more frequent in general than

Researchers	Study Location	Crash Data Gathering & Year of Data	Research Objective	Research Methodology	Major Findings
	arterials. Work zones in 25 Texas districts such as Austin, Dallas, El Paso, Fort Worth, and Houston.	Years of data collection: 2002 - 2003	experienced by workers and motorists during nighttime work activities, and to develop cost effectiveness of solutions to address the major factors that contribute to increased safety risk in nighttime work zones.	engineers in all 25 districts and analyzed the crash data from the DPS database to determine whether the risk of crashes during nighttime work is higher than during daytime work.	those during inactivity at night. Nighttime work avoids the creation of traffic queues, which reduces erratic maneuver rates. Combined with the fact that traffic volumes at nighttime can be 50% lower than daytime off peak volumes, the impacts on reduced crash risk are more significant during the nighttime than during the daytime. Crash rates when a work zone is present may increase in most of work zones, but the magnitude of increase is not statistically significant.
Zhang and Hassan (2019)	Egypt highway maintenance and rehabilitation projects	Data received from Ministry of Interior. Years of data collection: 2010 - 2016	The purpose was to determine the factors that influence crash severity in daytime and nighttime work zone crashes.	Used separate multinomial logit models to analyze crash data to determine the differences in injury severity between daytime and nighttime crashes.	The probability of older drivers being in a fatal crash at night is less than in the daytime. Younger drivers have a lower probability of being in a fatal crash at night than in the daytime. During the nighttime, passenger cars and heavy

Researchers	Study Location	Crash Data Gathering & Year of Data	Research Objective	Research Methodology	Major Findings
					vehicles driving at high speeds in work zones with a lane closure and making a sudden maneuver are at a high risk of being involved in a fatal crash.
Ullman et al., (2008)	New York highway work zones and work zones observations in four other states (California, North Carolina, Ohio, and Washington)	Data obtained from NYSDOT Work Zone Accident database and other practical work zone observations in California, North Carolina, Ohio, and Washington. Years of data collection: 2000 - 2005	The objectives were to determine both daytime and nighttime crash rates and develop a management practice for safety promotion in work zones during nighttime and daytime work operations.	First, examined the different types and severities of crashes and work in work zones during the nighttime and daytime by utilizing the NYSDOT crash data. Then, collected and analyzed crashes in California, North Carolina, Ohio, and Washington using an empirical Bayesian (EB) statistical approach.	Compared to when no work zone was present, the probability of motorists being injured in a crash increased by 66% for a daytime work zone, and by 61% for a nighttime work zone, when work activities were occurring, and lane closures were implemented. When lane closures were in place and work was being conducted, there was a 42.3% increase in severe crashes when work was performed at night and a 45.5% increase in daytime work zones. The increased cost of work zone crashes compared to expected crash cost based on pre-construction crash records in nighttime work

Researchers	Study Location	Crash Data Gathering & Year of Data	Research Objective	Research Methodology	Major Findings
					tends to be lower than daytime work when the work was active, and the lane closure was implemented.
Garber and Zhao (2002)	Virginia highway work zones.	Data received from Virginia police accident reports. Years of data collection: 1996 - 1999)	The objectives were to identify the predominant location of crashes in work zones, compare the distribution of work zone and non-work zone crashes, and determine the severity distribution in each crash location.	Performed proportionality tests using NCSS 2000 software to compare the distribution characteristics of work zone crash data that was obtained from police accident reports.	The activity area is the most dangerous area in a work zone, in terms of the cause a fatal crashes and total number of crashes. Speed is the predominant cause of rear end crashes in work zones. The severities of nighttime and daytime work zone crashes were not significantly different.

2.8.2 Distribution of Work Zone Crashes by Location

Garber and Zhao (2002) conducted a study in Virginia to determine the crash characteristics in work zones and identify the different aspects of work zone and non-work zone crashes. In their study, the researchers addressed the predominant locations in work zones where crashes occur. Based on their observations, 1,484 work zone crashes were identified and distributed to each location within the work zones. The study divided daytime and nighttime work as follows: daytime work is from 7:00AM to 7:00PM, and nighttime work is from 7:00PM to 7:00AM. The results of the study indicate that the activity area is the predominant crash location, followed by the transition area, advance warning area, longitudinal buffer area, and termination area in terms of decreasing crash frequency. Moreover, the researchers also compared work zone crash location distribution between daytime and nighttime work. Figures 2.16 and 2.17 depict the location distributions for work zone crashes during the daytime and nighttime, respectively.

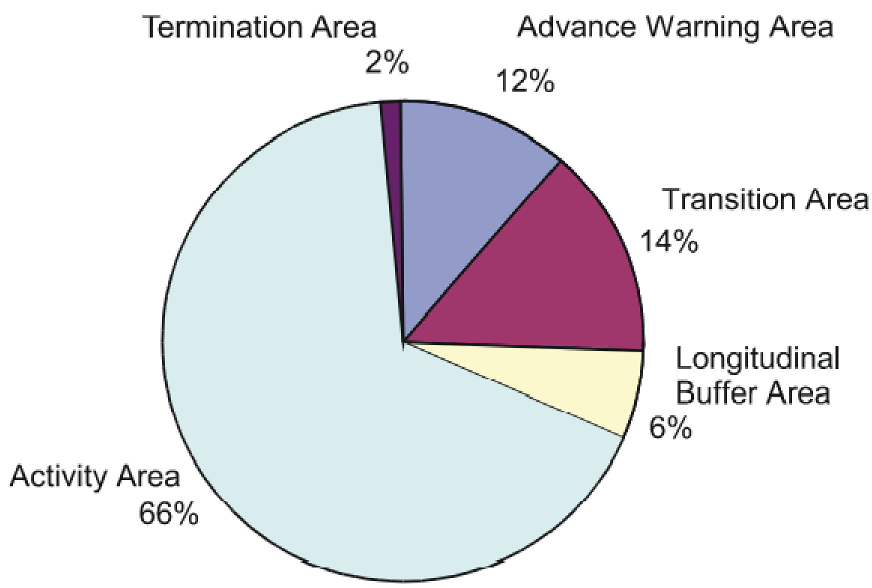

Figure 2.16: Location distribution for work zone crashes during daytime work (Garber and Zhao, 2002)

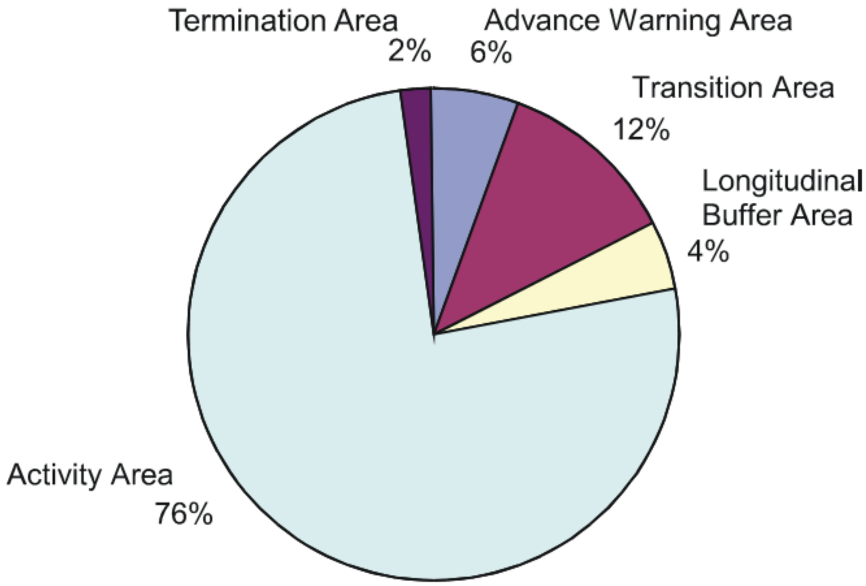

Figure 2.17: Location distribution for work zone crashes during nighttime work (Garber and Zhao, 2002)

By comparing both daytime and nighttime work zone area crashes, Garber and Zhao concluded that the percentage of nighttime work zone crashes in the activity area is higher than the daytime work zone crashes in the activity area. However, the percentage of crashes in the transition area was recognized as lower in the nighttime than in the daytime. Overall, both daytime and nighttime work zone crash rates were found to be not significantly different.

Similar studies have also investigated crash location in a work zone. The results of the studies by Pigman et al. (1990) and Hargroves (1981) are closely related to the findings from the study noted above. Pigman et al. and Hargroves found the work area, combining the buffer and activity areas, contained the highest frequency of crash rates, namely 44.7% and 54.1%, respectively. However, there is also a contrary finding from another study. Nemeth and Rathi (1983) found that the bi-directional zone where vehicles pass in opposite directions was the work zone location in which the majority of accidents occur.

2.8.3 Work Zone Crashes related to Traffic Control Conditions

According to NCHRP Report No. 627 (Ullman et al., 2008), the researchers explored the work zone conditions in which crashes occurred. The research focused on both daytime and nighttime crashes on freeways and expressways in New York, Washington, Ohio, California, and North Carolina. Based on their analyses, the researchers found that utilizing different types of work zone traffic control can make a significant difference in daytime and nighttime work zone crashes on freeways and expressways. Table 2.4 describes work zone crashes associated with different traffic control condition. As shown in Table 2.4, it was found that a lane closure was present in a higher percentage of nighttime crashes (57.7%) than daytime crashes (50.4%). A greater percentage of daytime crashes occurred when minor traffic control was present, but no work occurring (17.2% of daytime crashes compared to 7.6% of nighttime crashes). Work is conducted at night primarily because it is more convenient to implement lane closures at night since the traffic volume is lower than during the daytime, and it allows workers to work over a longer period of time than just during the daytime off-peak period between morning and afternoon rush hours (Shepard and Cottrel, 1986).

The higher relative frequency of temporary lane closures at nighttime may also explain the higher percentage of crashes during traffic control set-up and removal at night compared to daytime. As shown in Table 2.4, traffic control set-up/removal was present in 14.2% of nighttime crashes and 3.1% of daytime crashes. Performing temporary lane closures requires setting up and taking down temporary traffic control devices each night so that all traffic lanes can be returned to normal operations for peak travel periods. The frequency of the traffic control operations for nighttime operations contributes to a higher frequency of these activities at night compared to daytime hours. In addition, Table 2.4 shows that the presence of a flagging operation is associated with a higher percentage of daytime crashes than nighttime crashes.

Table 2.4: NYDOT Work Zone Crashes by Traffic Control Condition (Ullman et al., 2008)

Type of Work Zone Traffic Control in Use	Percent of Daytime Crashes (n = 1757)	Percent of Nighttime Crashes (n = 316)
Lane Closure	50.4%	57.6%
Minor Traffic Control, Work Inactive	17.2%	7.6%
Minor Traffic Control, Work active	8.3%	9.5%
Flagging	8.0%	3.2%
Shoulder Closure	5.4%	0.9%
Median Crossover	3.3%	1.3%
Lane Shift	3.2%	0.9%
During Traffic Control Set-up and Takedown	3.1%	14.2%
Full Road or Bridge Closure	0.7%	3.8%
Other	0.4%	1.0%
Chi-Square test results	Daytime and nighttime distributions are significantly different from each other	

2.8.4 Cost of Implementing Traffic Control in Work Zones

Hinze and Carlisle (1990) investigated different project variables affected by nighttime construction work. The researchers reported that state personnel and some contractors claimed the estimated cost of adding traffic control on a nighttime project was 25% higher than during the daytime. Although there was such a claim by some of the participants, many contractors mentioned there was no significant difference in the cost of implementing traffic control during the daytime and the nighttime.

A more recent study revealed that nighttime operations are usually more expensive than daytime work since nighttime work involves many additional cost factors such as overtime payment, lighting expenses, and costs associated with enhanced traffic control (Mostafavi et al., 2012). A similar statement is mentioned in the NYDOT Highway Design Manual (NYDOT, 2020). The manual states that nighttime operations require enhanced traffic control for vehicles and pedestrians, which results in increased project cost and duration. In addition, the traffic control set-up and removal processes can be complex and unfeasible for nighttime work operations if devices cannot be removed in time before the daytime rush hour begins.

Agdas and Ellis (2010) conducted research involving an analysis of the costs of temporary traffic control on highway projects. Based on their findings, the cost to implement work zone traffic control on highways is estimated to be approximately 6 to 10 percent of the total cost of the highway construction. Another study by Ullman et al. (2005) compared the cost of crashes that occur in nighttime work zones to the cost of placing traffic control measures to offset the crashes. Table 2.5 presents the comparison between the crash cost in nighttime work zones and the costs of using additional traffic control on interstates freeways. As can be seen in the table, at lower annual average daily traffic (AADT) levels, crash costs do not exceed the cost of implementing traffic devices (in this case, drums/barrels). However, at higher AADT levels, the amount of expected crash cost due to nighttime work is higher than the cost of placing additional traffic control devices in interstate freeways.

Table 2.5: 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)

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

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

2.9 RISK COMPARISON BEFORE AND DURING WORK ZONE CONSTRUCTION

Risk assessment comparing the period before work zone establishment to the period during construction has gained more interest from researchers. In one study, an analysis of case studies was conducted at 20 different site locations on highway construction and road maintenance projects to determine the accident rate before and during the work (Pigman and Agent, 1990). Based on the case study analyses, the researchers concluded that the accident rate during the construction period was higher than during the period before the work zone was in place. This finding is consistent with other studies (e.g., Graham et al., 1978; Nemeth and Migletz, 1978). The most frequent types of accidents that occurred were sideswipes and rear end collisions. The common factors contributing to the accidents were listed as driver inattention, following too close, and failure to yield right of way. Furthermore, work zone accidents were found to be more severe than other accidents. Accidents involving trucks were found to be more severe during darkness, and the percentage of trucks involved in work zone accidents (25.7%) was higher than in non-work zone accidents (9.6%) (Pigman and Agent, 1990). The researchers also found that work zone accidents are more severe than accidents that do not occur in a work zone, and higher severity accidents usually occur in the advance warning area compared to other areas of the work zone.

Another study investigated the accident rate on 79 construction projects in seven states (Graham et al., 1978). The number of accidents was recorded before and during construction. Table 2.6 shows the percentage increase in accident rates in rural and urban projects during construction compared to the period before construction. The study findings show that urban projects experience a slightly greater percentage increase in accident rate compared to rural projects. Furthermore, the researchers also compared the effects of each type of road on the accident rate before and during construction.

Table 2.5: Mean Accident Rate of Urban and Rural Projects (Graham et al., 1978)

Setting	Mean Accident Rate*		
	Before Construction	**During Construction**	**Change (%)**
Urban	170.96	190.44	+11.4
Rural	87.78	96.62	+10.1

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

Graham et al. (1978) also investigated other impacting project and roadway factors. Table 2.7 illustrates how different types of roadways impact the mean accident rates before and during construction. The accident rates before and during construction were also investigated based on different types of construction work. Table 2.8 shows the results of the analysis with respect to type of work.

Table 2.6: Mean Accident Rate Corresponding to Various Types of Roadways (Graham et al., 1978)

Roadway Type	Number of Projects	Mean Accident Rate*		
		Before Construction	During Construction	Change (%)
Six- or eight-lane interstate reduced to two lanes each direction	8	121.23	127.64	+5.3
Six-lane interstate reduced to one lane each direction	3	142.44	305.76	+114.6
Four-lane interstate reduced to one lane each direction	22	85.10	143.47	+68.6
Four-lane interstate reduced to two lanes, two ways	2	25.43	62.86	+147.2
Four-lane divided roadway reduced to one lane each direction	5	196.71	225.91	+14.8
Four-lane divided roadway reduced to two lanes, two ways	5	110.68	128.23	+15.9
Four-lane divided roadway on new alignment	6	155.68	125.33	-19.5
Four-lane undivided roadway reduced to two lanes	3	500.91	476.24	-4.9
Five-lane undivided roadway with two-way left turn lane reduced to two lanes	3	305.15	485.09	+59.0
Two-lane roadway reduced to one lane	7	227.14	297.33	+30.7
Two-lane roadway on new alignment	11	397.98	340.96	-14.3
Total	75			

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

Table 2.7: Mean Accident Rate by Type of Construction Work (Graham et al., 1978)

Roadway	Number of Projects	Mean Accident Rate*		
		Before Construction	During Construction	Change (%)
Resurfacing, pavement patching	26	92.33	99.40	+7.7
Bridge work	5	55.17	82. 79	+50. 1
Median barrier work	15	116.97	127.42	+8.9
Widening of existing roadway	12	360.69	370. 76	+2 .8
Upgrading to Interstate standards	9	104. 78	121.65	+16.1
Reconstruction of existing roadway	2	174.36	232.48	+33.3
Construction of new roadway (new alignment)	5	133.43	133.92	+0.4
Other	1	85.85	85.85	+0.1

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

In a more recent study, Rista et al. (2017) found that when work activity requires a closure of travel lanes, the frequency of crashes for individual motorists surges by 66% during daytime work and by 61% at nighttime when compared with similar non-work zone conditions. These findings are consistent with those from the study by Srinivasan et al. (2011).

2.10 TIME REQUIRED FOR TRAFFIC CONTROL SET-UP AND REMOVAL

Several studies have identified a correlation between the overall duration of the work, which the time required for traffic control set-up and removal contributes to, and crash risk. A study conducted by Khattak et al. (2002) showed that longer duration work zones often significantly increase both injury and non-injury crash frequency. Therefore, it is beneficial to shorten the work zone duration as much as possible and reduce worker exposure to safety risk. Part 6 of the Minnesota MUTCD (2019), and the handbook titled “Guidelines for Traffic Control in Short Duration/Mobile Work Zones” published by the Kentucky Transportation Center (2008), state that a short duration work operation often consumes a longer time to install and remove traffic control devices than the actual performance of the work. Furthermore, Datta et al. (2016) mentioned that as work duration decreases, more attention should be invested in the time required for traffic control set-up and removal. Datta et al. suggest the following strategies to reduce the time required to place and remove traffic control devices:

- Reduce the number of traffic control devices used in the work zone
- Eliminate the need to remove or cover permanent traffic control devices

- Substitute vehicle-mounted devices in place of ground mounted devices
- Utilize lightweight portable sign supports
- Utilize lighter weight or smaller channelizing devices. For instance, it is preferable to use cones instead of drums.
- Implement work vehicles to place channelizing devices.

2.11 HIERACHY OF TRAFFIC CONTROLS

The hierarchy of controls provides guidance related to the effectiveness and reliability of safety controls. Those controls that are higher in the hierarchy are more effective and reliable in mitigating safety hazards. Figure 2.18 depicts the hierarchy of controls in relation to temporary traffic control devices. As can been seen in the figure, the hierarchy outlines the priority sequence of traffic control methods listed from the most effective and protective at the top of the hierarchy (elimination/substitution) to the least effective control at the bottom of the hierarchy (traffic control persons). Controls should be selected to effectively mitigate the risk present in the work zone. In many cases, multiple controls may be needed or desired to mitigate all of the hazards present and lower the amount of risk to an acceptable level.

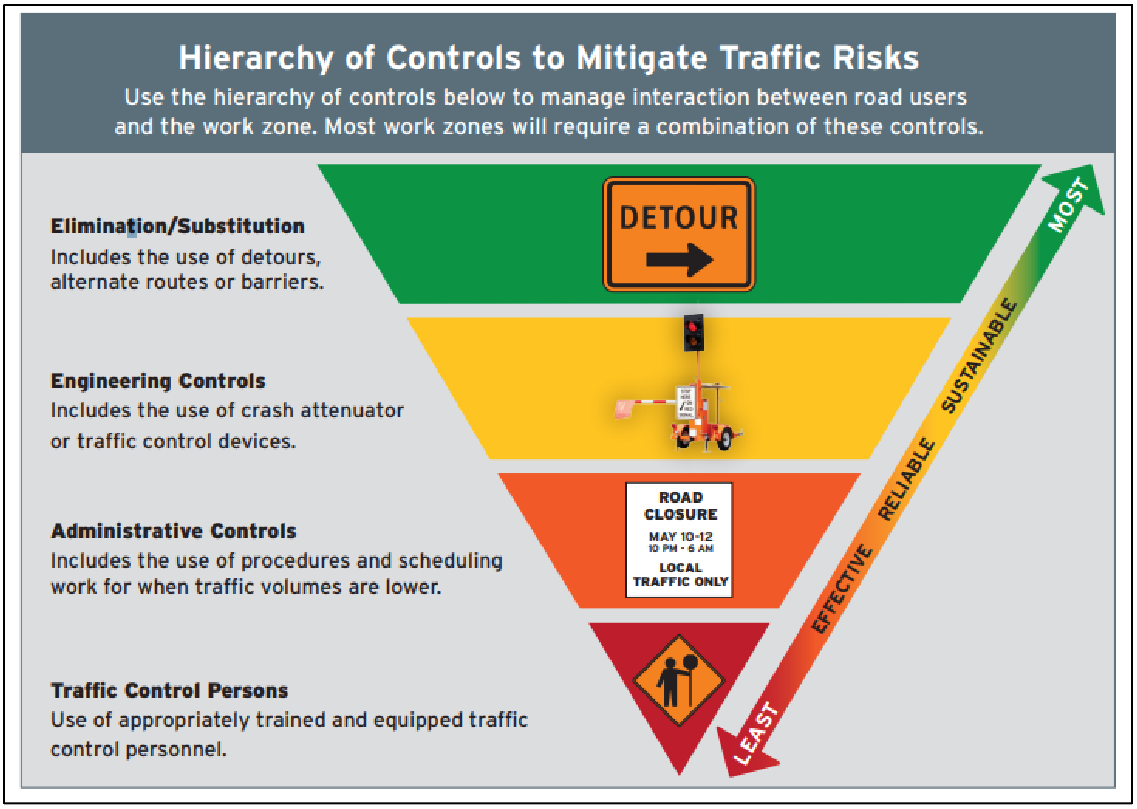

Figure 2.18: Hierarchy of traffic controls (ConeZonebc.com, 2020)

The 12th edition of the Ohio Department of Transportation's *Temporary Traffic Control Manual* (ODOT, 2012) states that work duration is an essential factor to decide the number and types of traffic control devices to use in a work zone. The period of time in which a work operation occupies a location is defined as the duration of the work zone (ODOT, 2012). Reducing the duration of the work zone to improve safety is an administrative control.

To help reduce traffic exposure risk for both workers and road users, the *BC Traffic Control Manual* (ConeZonebc.com, 2018) describes a wide range of traffic control devices beyond signs, cones, and barriers that contractors can adapt for road construction and maintenance projects. Table 2.8 provides a reference for selecting traffic control devices for a project that incorporates considerations of effectiveness highlighted in the hierarchy of controls.

Table 2.8: Traffic Control Devices for Specific Project (ConeZonebc.com, 2018)

IF YOUR PROJECT	CONSIDER THESE DEVISES as part of your Traffic Control Plan					
	Dynamic Message Signs	**Flashing Arrow Boards**	**Temporary Rumble Strips**	**Crash Attenuators**	**Automated Flagger Assistance Devices**	**Portable Traffic Signals**
						
Requires work activity near or at the roadside	✓		✓	✓		
Impacts highway or roadway lane operations (e.g., partial/full lane closure)	✓	✓ (In arrow or caution mode, as appropriate)	✓			
Does not directly impact highway or roadway lane operation (e.g., shoulder work)	✓	✓ (In flashing caution mode, without arrowheads)		✓		
Requires a lane closure on a two- or multi-lane road	✓	✓	✓	✓		

Has no or limited escape routes for workers in the case of an errant vehicle in a stationary work zone	✓			✓	✓	✓
Requires single-lane alternating traffic in a short-duration, stationary work zone	✓		✓		✓	
Requires single-lane alternating traffic in a long-duration, stationary work zone	✓		✓		✓	✓
Requires work activity in a mobile or stationary high speed work zone	✓ (Truck-mounted if in a mobile zone)			✓		

2.12 SUMMARY OF LITERATURE AND POINT OF DEPARTURE

Guidance for placing, removing, and modifying temporary traffic control is available to contractors and states departments of transportation; however, the information varies between states, and sparse within each document. Standard procedures across the US and detailed descriptions of the procedures are still lacking. Additional knowledge is needed to enhance the information available and provide best practices. In addition, the guidance provided is based largely on work zone experience and common practice; few rigorous research studies have been conducted to address worker and motorist safety issues during the roadway transition period when traffic control is set-up, removed, and modified.

Research questions related to the topic of temporary traffic control set-up, removal, and modification that remain to be answered include the following:

1. What are the overarching principles and common practices when planning and executing the operation during the temporary traffic control transition period?

2. What aspects of the set-up, removal, and modification procedure lead to the most hazardous situations and create a safety concern for motorists and workers?

3. What guidance should be provided for state DOTs and contractors to follow during placement, removal, and modification of traffic control in order to ensure the desired level of safety is satisfied during the transition periods?

4. Are analytical tools or technologies available that can be implemented to conduct real-time risk assessments of placing and removing traffic control devices in work zones and provide guidance for contractors and state DOTs?

5. What equipment and technologies for placing and removing traffic control in work zones are available that can address worker and motorist safety during the transition periods?

6. What criteria need to be considered when selecting and planning traffic control operations in work zones?

Among the research questions listed above, the present study is designed to specifically answer the first three questions (Questions 1 – 3). The scope of work to be implemented enables the researchers to address these questions. While not the focus of the present study, the research may also point to or suggest answers to Questions 4 – 6 depending on the data collected.

3.0 SURVEY OF CURRENT PRACTICE

As stated in the description of Task 3 of the work plan, the goal of the survey of current practice is to gather and learn from the industry's perspectives and experiences related to work zone operations on high-speed roadways related to traffic control set-up, removal, and modification. The survey targets input from roadway contractors and state departments of transportation across the US. In addition, the survey provides an opportunity to gather examples of work zone set-up, removal, and modification practices and procedures for reference in the subsequent study tasks.

3.1 SURVEY QUESTIONAIRE

As an initial step in the survey process, the researchers developed a list of questions to include in the survey questionnaire. The questions were based on the findings of the literature review and designed to meet the targeted research questions and study scope of work. After an initial set of questions was prepared, the researchers presented the draft questions to the study Technical Advisory Committee (TAC) for input and review. Feedback received from the TAC was incorporated into the survey questionnaire to create the final list of questions. The questionnaire included four sections of questions as follows:

- Information about the respondent's work location, title, work experience, involvement with traffic control operations, and similar personal demographic information
- Description of practical procedures for traffic control set-up, removal, and modification
- Safety risk of traffic control activities and tasks that workers and motorists commonly encounter
- Recommendations for ways to improve safety during temporary traffic control set-up, removal, and modification

A copy of the survey questionnaire is provided in the Appendix. After incorporating input from the TAC, the survey questionnaire, protocol, recruitment emails, and explanation of research documents were submitted to the OSU Institutional Review Board (IRB) for review and approval for research involving human subjects. Input on the survey documents from the IRB was incorporated into the survey, and the survey process commenced following approval from the IRB.

3.2 SURVEY SAMPLE

The target population for the survey consisted of those personnel working in departments of transportation and roadway construction companies who are actively involved in roadway construction and maintenance across the US. To conduct the survey, the researchers used a purposive sample consisting of contacts at state departments of transportation and roadway construction companies. For state DOT personnel, those included were personnel listed on the state DOT research office contact list from each of the 50 US states.

The researchers also utilized contact lists from recently completed ODOT research studies, which included both DOT and industry contacts, and from industry organization websites such as the Associated General Contractors (AGC) of Oregon and Washington, AGC of America, and the webpages of roadway construction firms located in the Pacific Northwest. The contact lists were merged and then organized into two groups based on the TAC's feedback: state department of transportation personnel and industry personnel (i.e., roadway contractors/subcontractors). The final lists contained 866 DOT contacts and 716 industry contacts. These contacts are in addition to those on the state DOT research office contact list mentioned above.

The email sent to the contacts to distribute the survey asked the recipients to complete the questionnaire if they were knowledgeable about traffic control operations and, if not, to forward the survey on to others in their organization who might be knowledgeable. In addition, the DOT personnel were asked to forward the survey questionnaire on to several key contractors in their state who they work with regularly. As a result, due to the snowball sampling, the final number of recipients of the survey questionnaire is not known.

3.3 SURVEY DISTRIBUTION

To distribute the survey questionnaire, the survey questions were first uploaded into the Qualtrics web-based survey system that is hosted and administered by OSU. A link to the online survey was then generated for inclusion in emails. The researchers initially sent the link to the TAC members to pilot test the survey and provide additional feedback. Comments received were reviewed by the researchers, who revised the survey questionnaire and recruitment information accordingly.

The survey questionnaire was distributed in two ways. The ODOT Research Office sent recruitment emails containing the survey link and explanation of research to each of the state DOT research offices to request their participation in the survey. The researchers also distributed similar emails to the personnel on the other contact lists. To help increase the number of responses, two subsequent follow-up emails were sent to remind the personnel to complete the survey.

3.4 SURVEY RESULTS

A total of 107 survey responses were received from both state DOTs and construction contractors. Among these responses, 65 participants fully completed the survey (62.6% of the total responses). The remainder of the responses were incomplete to varying degrees. However, incomplete survey responses provided some data to parts of questions, which enabled the researchers to utilize incomplete responses where possible and increase the dataset. All parts of the survey responses were utilized where the questions were sufficiently answered.

3.4.1 Respondent Personal and Organizational Demographics

A total of 84 respondents provided information related to their organization. Figure 3.1 presents the distribution of the 84 respondents based on their employer organization. The majority of the responses (60.7%) came from local, state, and federal transportation agencies. Of those respondents who are employed at a local, state, or federal transportation agency, their job titles include safety manager or safety engineer, inspector, traffic control designer, roadway engineer, maintenance supervisor, and project engineer. On the industry side, 34.5% of the responses came from construction general contractor and subcontractor firms, and from personnel with titles such as project manager and safety manager. Lastly, respondents from other organizations, such as consultant firms and research organizations, amounted to approximately 4.8% of the respondents. Figure 3.2 shows the percentage of respondents according to job title for both DOT and contractor respondents.

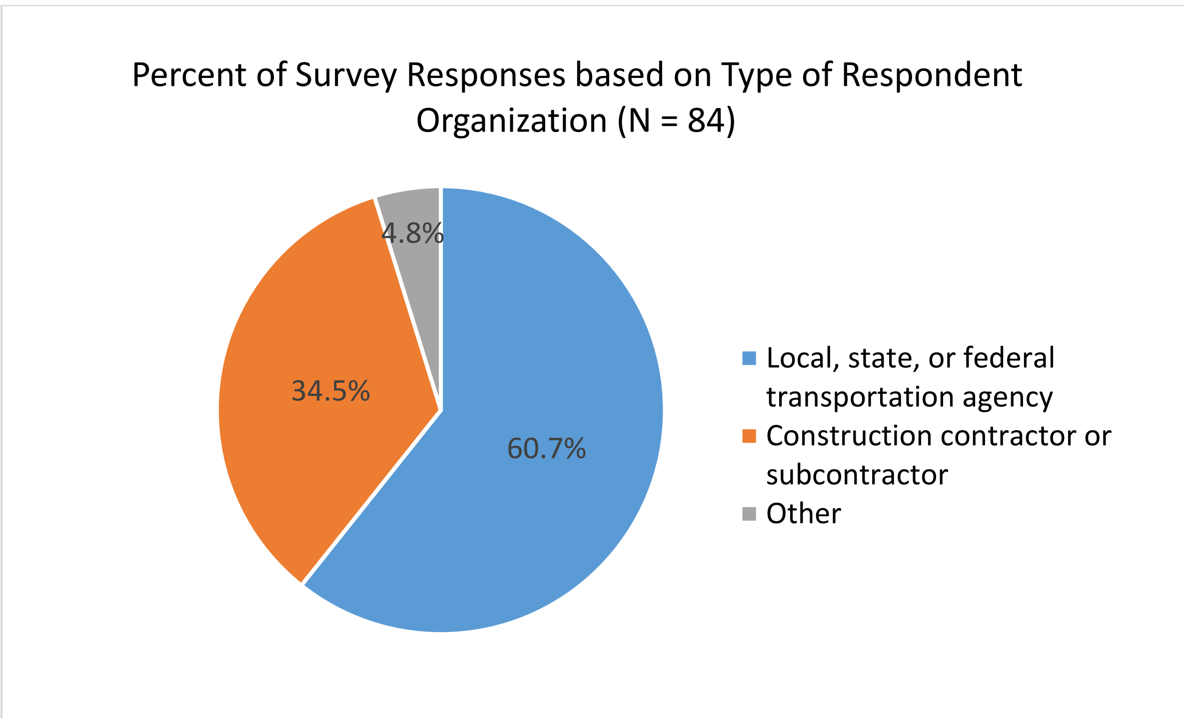

Figure 3.1: Distribution of survey responses based on respondent organization type

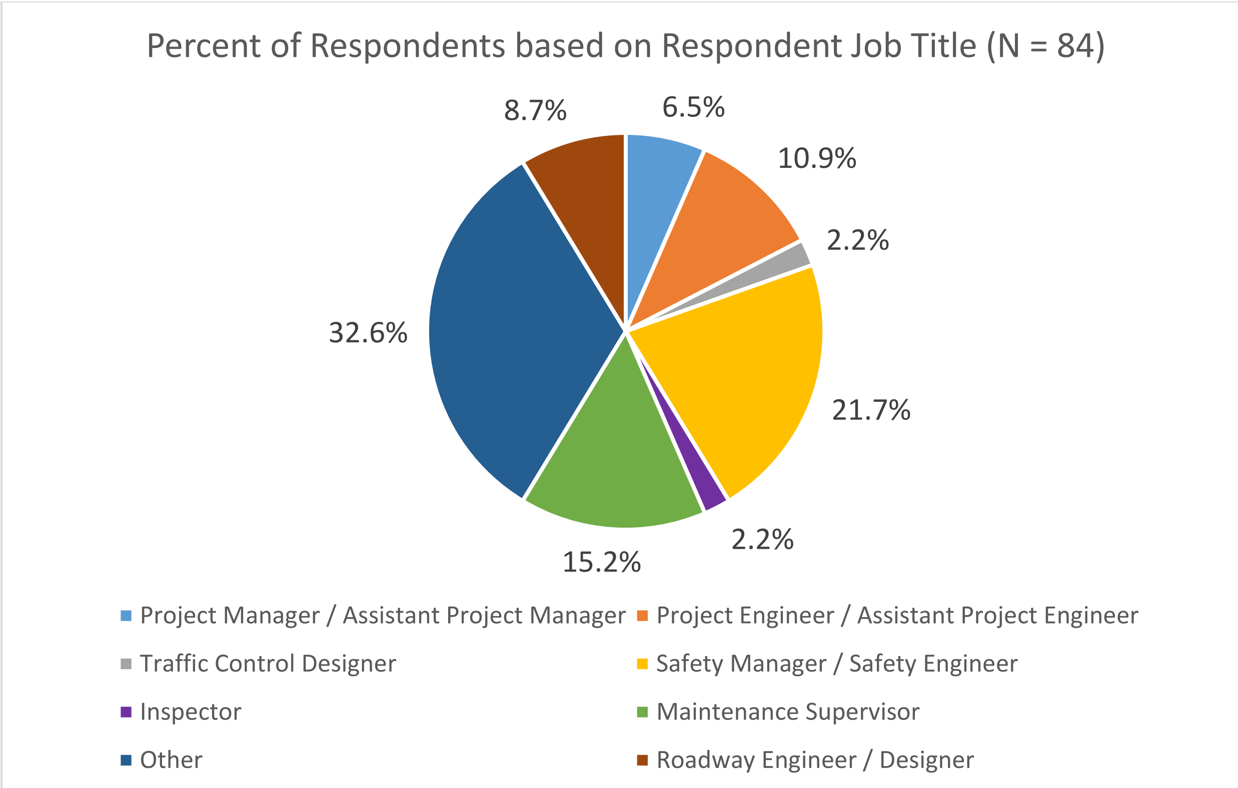

Figure 3.2: Distribution of respondents based on respondent job title

The questionnaire asked the respondents in which state they are physically located. Seventy-three respondents provided their location. At least one response came from 26 different states across the US. Table 3.1 shows the number of responses received from each state, and the states from which responses were not received. The most responses were received from Rhode Island (22), followed by Massachusetts (12), Indiana (8), California (6), and Missouri (6). The relatively high number of respondents from Rhode Island could be an indication of a significant interest of work zone safety in Rhode Island, or particular motivation to participate in the survey.

Table 3.1: Distribution of Survey Responses based on Respondent Location

State(s)	Number of Responses	Number of States
AL, AK, AR, FL, GA, IL, LA, ME, MS, NV, NE, ND, NJ, NM, NC, OK, PA, TX, UT, VA, SD, WV, WI, WY	0	24
AZ, DE, ID, IA, KY, MD, MN, MT, NH, NY, VT	1	11
CO, OR, KS, SC	2	4
CT, HI, TN, WA	3	4
OH, MI	4	2
CA, MO	6	2
IN	8	1
MA	12	1
RI	22	1
Total	**73**	**50**

Regarding respondent work experience in the transportation/construction industry, a total of 78 respondents answered this question. As can be seen in Figure 3.3, the majority of respondents (52.6%) have more than 20 years of experience in the transportation/construction industry, followed by those with 11-15 years (16.7%), 6-10 years (14.1%), and 16-20 years (12.8%). The average number of years of experience was 13 years. For those who answered this question, no responses were received from personnel who have less than a year of experience in the industry. The responses to this question suggest that the survey was answered by personnel who have an extensive amount of experience in the transportation/construction industry.

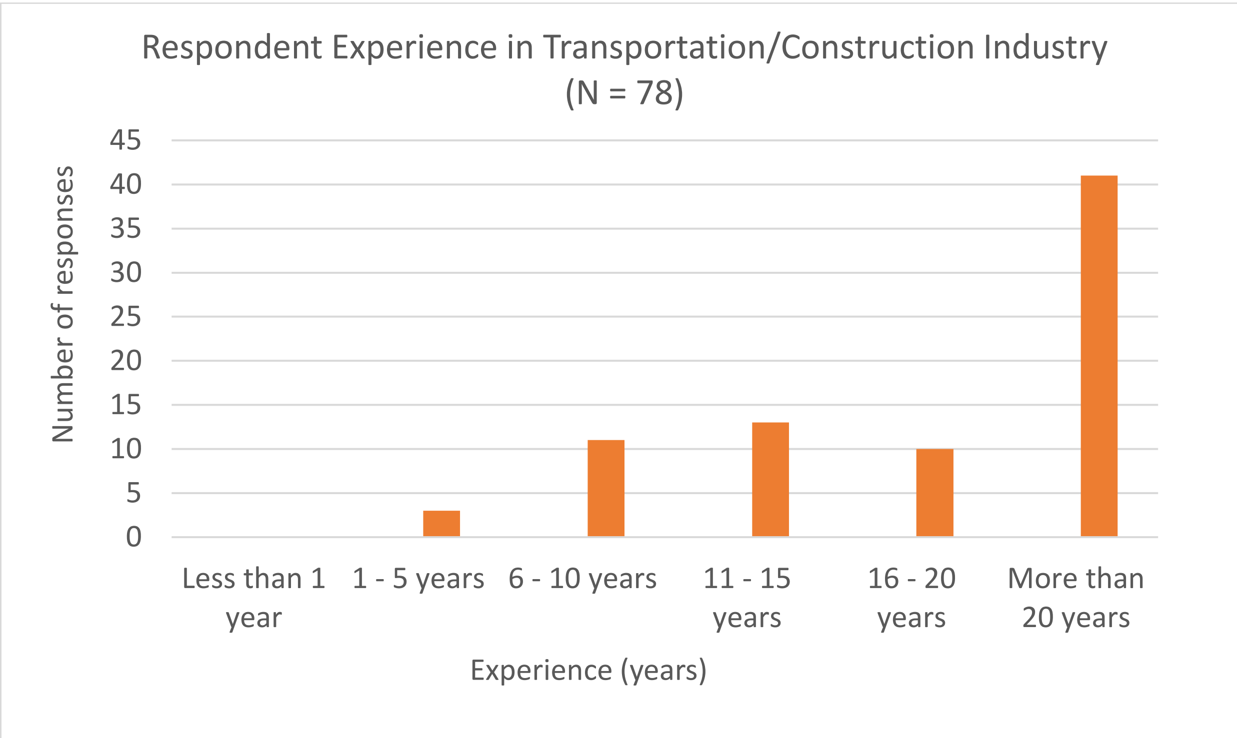

Figure 3.3: Respondent experience in transportation/construction industry

Figure 3.4 shows the distribution of respondents based on the size of organization in which they work. The highest percentage of respondents (57.0%) work for organizations with more than 1,000 employees. Since a majority of the respondents work for a local, state, or federal department of transportation, it is comprehensible that the percentage of large organizations represented in the dataset is high. Smaller organizations were typically represented by personnel working in construction contracting firms.

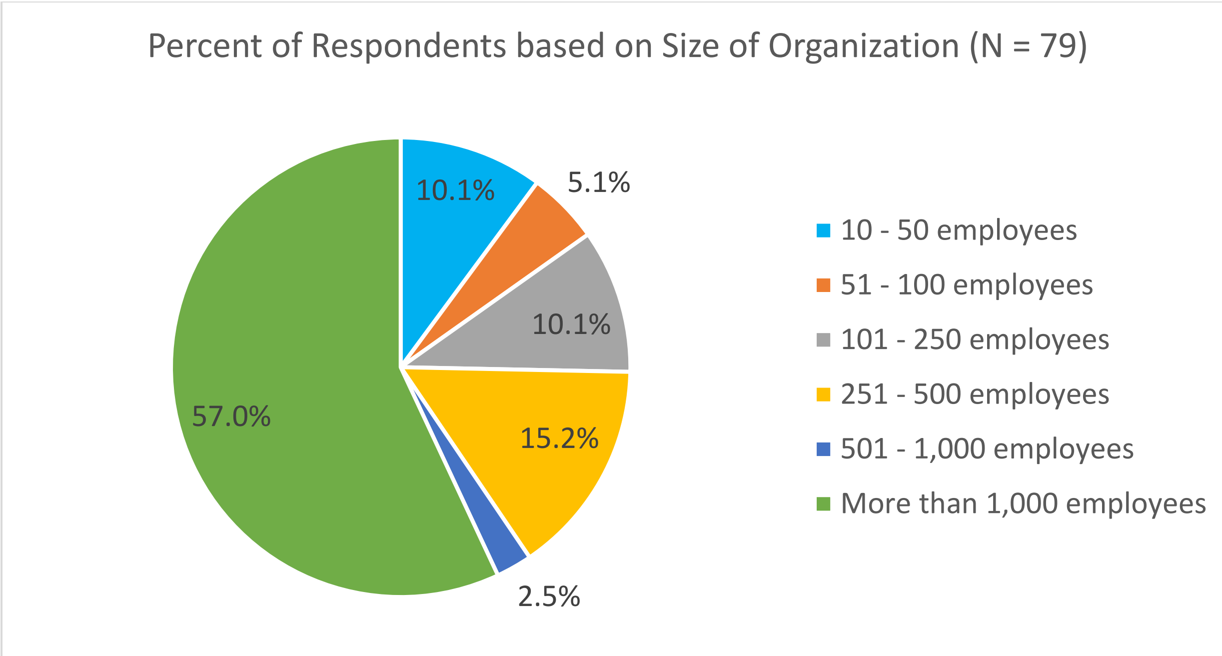

Figure 3.4: Distribution of respondents based on size of respondent organization

3.4.2 Respondent Involvement with Traffic Control Set-up and Removal

The next section of the survey targeted the amount of involvement that the respondents have with traffic control set-up and removal to verify the competency of the respondents and their suitability for participation in the survey. Of interest was their level of involvement in planning and performing the set-up and removal of temporary traffic control in work zones.

Figure 3.5 illustrates the percentage of time that the respondent's job involves activities related to planning and performing set-up and removal of temporary traffic control in work zones. The majority of respondents indicated that approximately 0% to 20% of their job is associated with planning (43% of respondents) and executing (75% of respondents) traffic control set-up and removal. Thirty-eight percent of the respondents are involved with planning traffic control for 41% or more of their jobs. Similarly, 14% of respondents are involved in performing traffic control set-up and removal for 41% or more of their jobs. This data indicates that, for many of the respondents, involvement with traffic control set-up and removal is a small portion of their work role and activities.

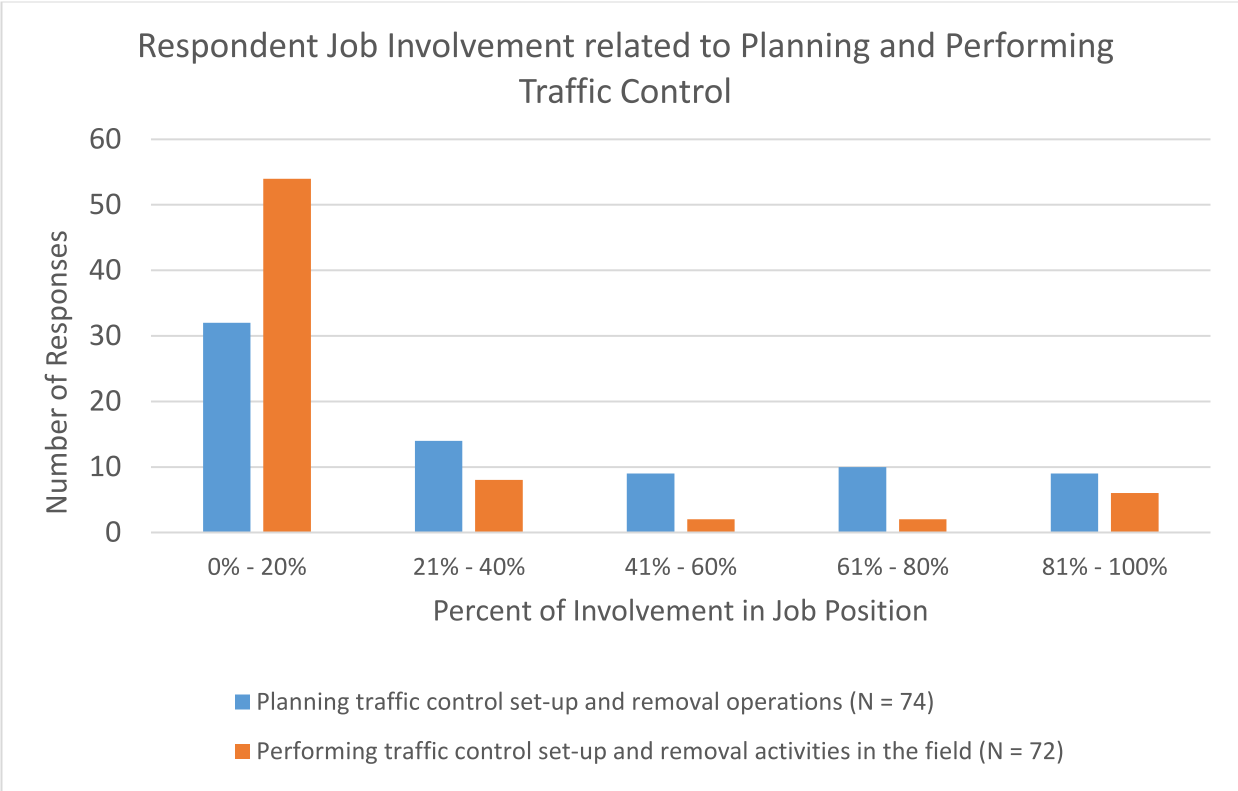

Figure 3.5: Distribution of respondents based on involvement in traffic control set-up and removal

For those respondents who indicated levels of involvement in planning and performing traffic control set-up and removal in the 0%-20% range (i.e., low level of involvement), a follow-up question was asked about the nature of their involvement. This question permitted the researchers an opportunity to confirm the respondent's suitability for inclusion in the survey. In response to this question, the typical tasks that they are involved in are: planning and reviewing work zone traffic control plans, developing policy guidance and specifications for traffic control, supervising traffic control work crews, inspecting traffic control set-up and removal, and training work crews related to safe practices of work zone set-up and removal. Based on these responses, all of the respondents were included in the dataset.

A second research question was posed to help further confirm the level of knowledge of the participants. The question asked the respondents about their level of familiarity with the planning and execution of temporary traffic control. Figure 3.6 illustrates the responses to this question. The majority of respondents indicated that they are either very or extremely familiar with both traffic control planning and execution. Fourteen respondents indicated that they are moderately familiar with executing temporary traffic control set-up and removal, while nine are moderately familiar with the planning of traffic control. Only a small percentage of respondents rated themselves as being "not familiar," "minimally familiar," or having "low familiarity." Notably, this result contradicted what the researchers expected as the majority of respondents previously indicated that planning and performing traffic control was no more than 20% of their job duties. However, the responses to this question and the previous question provided confidence that, while their daily involvement with traffic control may be low, their level of experience combined with the nature of their involvement is such that they are knowledgeable about the topic. Therefore, all respondents were retained in the dataset; no responses were omitted.

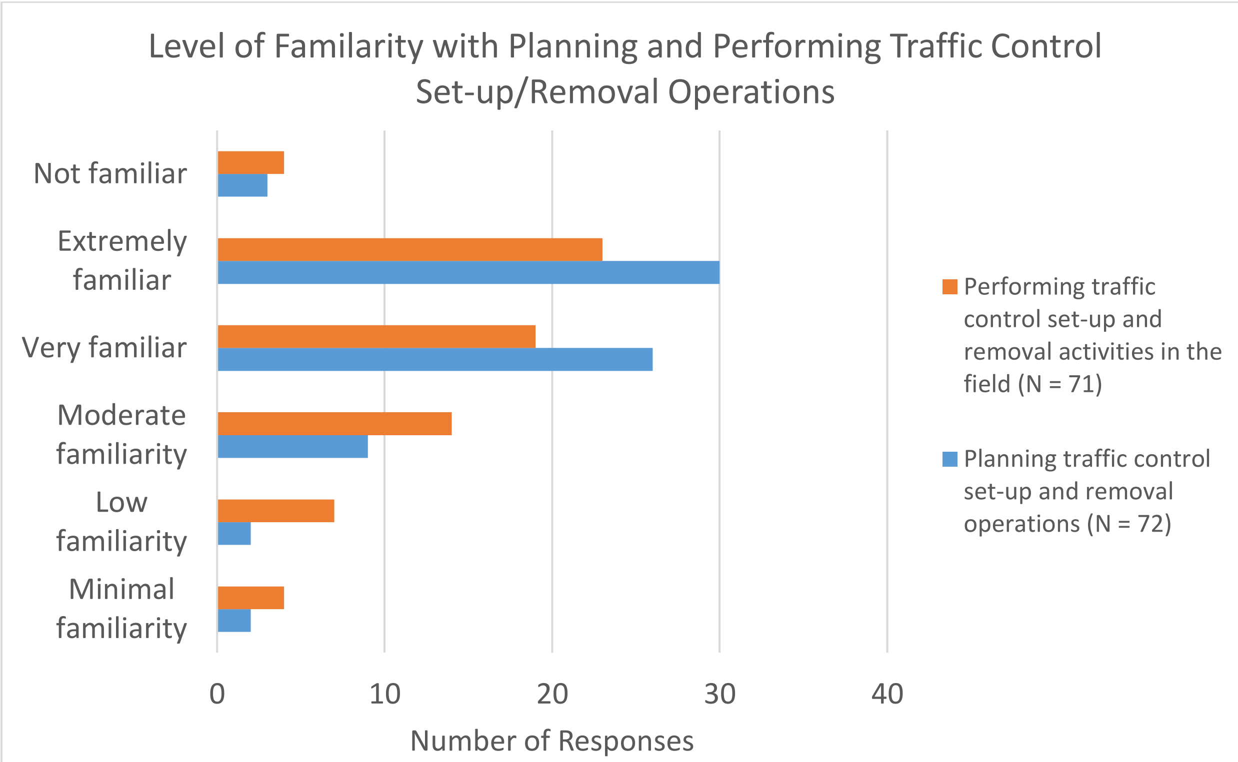

Figure 3.6: Distribution of respondents based on familiarity with traffic control planning and execution

3.4.3 Safety Impacts associated with Traffic Control Set-up and Removal Activities/Tasks

Section 3 of the survey was designed to gather insightful knowledge and respondent experience regarding the challenges of, and safety impacts associated with, temporary work zone traffic control set-up and removal. Initially, the participants were asked to indicate all tasks associated with the placement of traffic control devices that they had experience with on their projects. This question was designed to indicate which tasks the respondent should be asked about further in the survey. Figure 3.7 shows the results from this question. The primary activities which the respondents have experience with are the placement of temporary cones/barrels for the lane closure (96.9% of respondents), placement of signage (95.4%), placement of variable message signs (90.9%), and accessing the roadway to block or slow down traffic (89.4%). It can also be observed that the least common activities in which they are involved in are the placement of radar speed signs (51.5%) and other activities (13.6%) such as the placement of TMAs, arrow boards, and portable traffic signals.

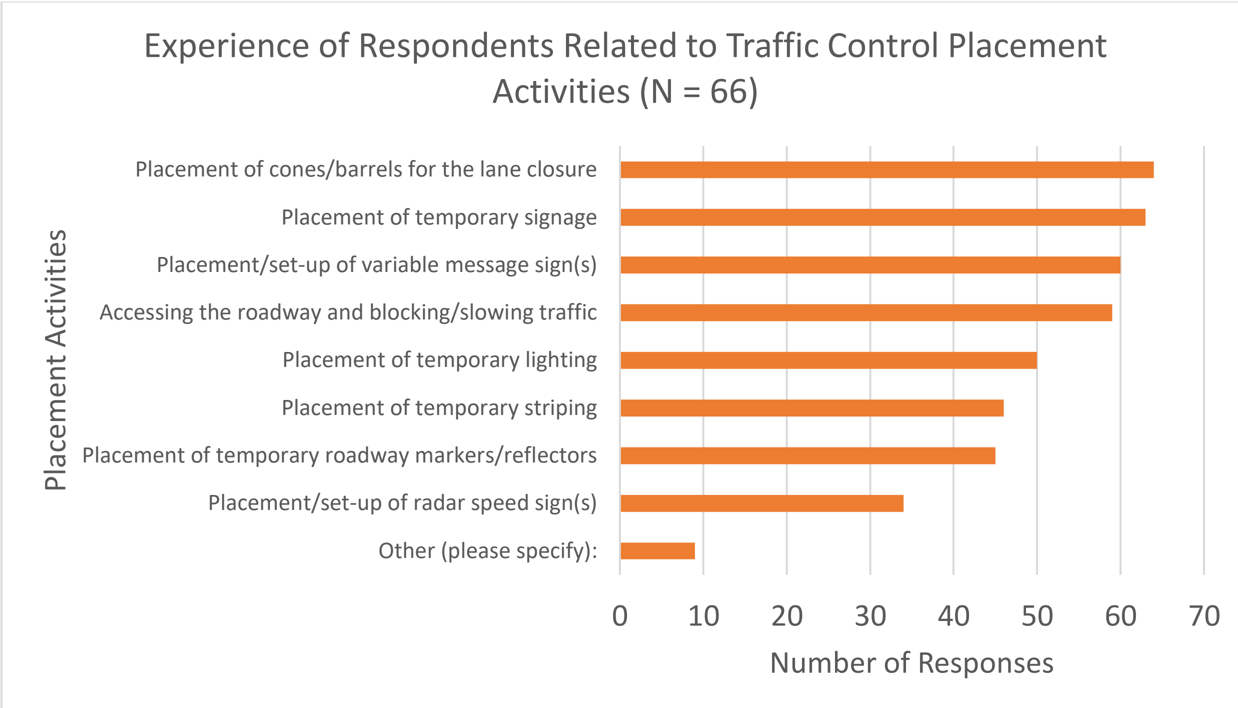

Figure 3.7: Experience of respondents related to traffic control placement activities

The next set of questions aimed to identify challenges faced when setting up and removing traffic control as well as the level of impact to safety for each activity/task during the work operation. In Question #3.2, respondents were given a brief list of potential work operation issues and asked to rank the issues for each activity/task based on the issue's impact on motorist and worker safety risk while performing the activity/task. The respondents were only asked to provide input on those activities/tasks in which they had experience with as indicated in their response to the previous question. The issues listed related to operational concerns associated with resources, personnel, planning, and time constraints. In an initial review of the responses, the researchers noticed that some of the responses were invalid due to respondents misunderstanding the question instructions. Some of the respondents made obvious mistakes when answering the question. For example, one respondent started ranking the issues by entering a value of "8", even though there were only five items to rank, and the respondent did not complete the question. The question asked the respondent to provide a ranking from 1 to 5, and asked the respondent to enter "0" if there is no impact to safety during traffic control set-up and removal. The researchers excluded invalid responses from the dataset and analysis.

Table 3.2 shows the results from the question. The table shows the number of responses and the weighted ranking following the data cleansing process. The weighted ranking is calculated as shown in Equation 3-1:

$$\boldsymbol{Weighted\,ranking} = \frac{(\boldsymbol{n}_{(1)_1}) \times \boldsymbol{R_1} + \cdots + (\boldsymbol{n}_{(2)_1}) \times \boldsymbol{R_1} + \cdots + \boldsymbol{n}_{(i)_j} \times \boldsymbol{R_i}}{\boldsymbol{N}_{total_{(ea.activity)}}}$$

(3-1)

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)

$N_{total(ea.\ activity)}$ = total number of responses for each activity

The weighted ranking values associated with each activity were calculated by obtaining the number of responses from the ranking of each issue related to each traffic control placement activity ($n_{(i)j}$), multiplying this value by the numerical ranking scale (R_i), and dividing by the total number of responses received for each placement activity ($N_{total(ea.\ activity)}$). The weighted ranking values calculated are shown in Table 3.2. Of the work operation issues evaluated, "workers not following planned process" was consistently ranked the highest amongst all activities/tasks in terms of impact on motorist and worker safety (average ranking = 2.31). The other work operations, ranked in order from highest to lowest impact were lack of available equipment or equipment breakdown (average ranking = 2.70), planned process not applicable to field conditions (2.88), time pressure to complete the set-up/removal (2.99), and lack of available workers (3.29).

Table 3.2: Weighted Ranking of Impact of Work Operational Issues on Motorist and Worker Safety Risk (a lower value indicates a higher ranking)

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

Average	3.29		2.31		2.70		2.88		2.99		
Minimum	2.98		2.02		2.21		2.69		2.59		
Maximum	3.64		2.51		3.04		3.06		3.41		

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.

The weighted ranking calculation was also applied to the responses received from similar subsequent survey questions (e.g., Questions 3.3, 3.4, 3.7, 4.3, and 4.4). Question #3.3 asked the respondents to rank three roadway/jobsite issues in terms of their impact on motorist and worker safety risk during traffic control set-up and removal. The three roadway/jobsite issues provided were: lack of light, difficulty accessing lane or blocking traffic, and lack of space available for workers/equipment. Similar to the responses to Question #3.2, a preliminary review of the responses revealed incorrect response values. Rather than ranking the issues from 1 to 3, some respondents entered various other numbers. Therefore, the researchers cleansed the data to remove those responses in which the respondent did not correctly respond to the question prompts. Table 3.3 shows the results. Notably, all traffic control placement activities/tasks have a consistent ranking order with respect to the impact of the roadway/jobsite issues on worker and motorist safety. The respondents indicated that the issue that leads to the greatest impact is a lack of space available for workers and equipment (average ranking = 1.61), followed by difficulty in accessing a lane or blocking traffic (1.78), and finally a lack of light in the work zone (2.18).

Table 3.3: Weighted Ranking of Impact of Roadway/Jobsite Issues on Motorist and Worker Safety Risk (a lower value indicates a higher ranking)

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

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.

Question #3.4 similarly asked the respondents to rank the impact on motorist and worker safety, however, the question focused on traffic/motorist issues such as a high speed of passing vehicles, a high volume of traffic, and a high volume of trucks. A total of five issues were provided, and the respondents were asked to rank the issues from 1 to 5 (1 = greatest impact, 5 = least impact, and 0 = no impact). Table 3.4 shows the results from the question in terms of the weighted rankings. The weighted rankings reveal that the motorist/traffic issues were ranked in the same order for all of the activities/tasks. During traffic control placement/removal activities, workers believe the motorist/traffic issues have the same order in the risk hierarchy. A high speed of passing vehicles was ranked as the most impactful of all of the motorist/traffic issues for all of the activities/tasks (average ranking = 1.50). In terms of average ranking, the order of the remaining motorist/traffic issues, from most to least impactful, was: aggressive drivers (average ranking = 2.06), high volume of traffic (2.64), high volume of trucks (3.39), and traffic congestion (3.82). It is understandable that traffic congestion would pose the least risk given that congestion typically results in low vehicle speeds.

Table 3.4: Weighted Ranking of Impact of Motorist/Traffic Issues on Motorist and Worker Safety Risk (a lower value indicates a higher ranking)

Activity/Task	*Weighted Ranking of Impact of Motorist/Traffic Issues on Motorist and Worker Safety*										
	High speed of passing vehicles	N	High volume of traffic	N	High volume of trucks	N	Traffic congestion	N	Aggressive drivers (e.g., impatient, late merge, following too close, etc.)	N	Average Ranking
Accessing the roadway and blocking/slowing traffic	1.69	51	2.68	50	3.38	50	3.88	50	1.84	50	2.69
Placement of temporary signage	1.43	54	2.72	53	3.42	53	3.79	53	2.13	53	2.70
Placement of cones/barrels for the lane closure	1.45	55	2.65	54	3.43	54	3.93	54	1.93	54	2.68
Placement of temporary lighting	1.55	42	2.69	42	3.60	42	3.95	42	2.17	42	2.79
Placement/set-up of variable message sign(s)	1.57	51	2.75	51	3.47	51	3.76	51	2.29	51	2.77
Placement of radar speed sign(s)	1.61	28	2.43	28	3.11	28	3.61	28	2.21	28	2.59
Placement of temporary striping	1.38	39	2.59	39	3.31	39	3.77	39	1.95	39	2.60
Placement of temporary roadway markers/reflectors	1.34	38	2.61	38	3.39	41	3.89	38	1.95	38	2.64
Average	1.50		2.64		3.39		3.82		2.06		
Minimum	1.34		2.43		3.11		3.61		1.84		
Maximum	1.69		2.75		3.60		3.95		2.29		

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.

3.4.4 Safety Impacts of Traffic Control Set-up compared with Traffic Control Removal

Survey Question #3.5 asked the respondents their opinion about the safety risks associated with traffic control set-up compared to the safety risks during removal. The question asked, "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?" and provided several responses to choose from. The results are shown in Figure 3.8. Based on a total of 58 responses to this question, the majority of respondents (55.2%) indicated that safety risks associated with both set-up and removal are the same and have the same ranking. Nineteen respondents (32.8%) believe that the safety risk during set-up is greater than during removal.

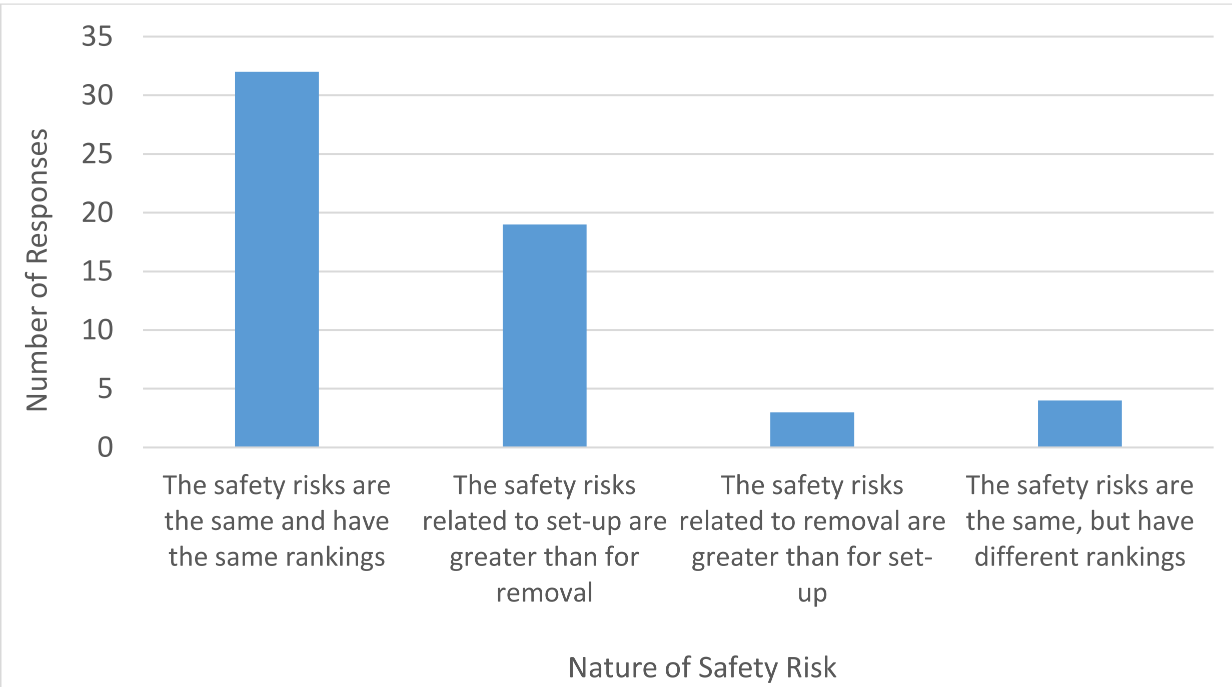

Figure 3.8: Safety risk associated with traffic control set-up vs. removal (N = 58)

The next survey question (Question #3.6) asked for further clarification and explanation from those respondents who indicated that the risks and rankings are not the same. No explanations were provided from the respondents who claimed "The safety risks related to removal are greater than for set-up" and "The safety risks are the same, but have different rankings." However, some respondents who indicated that safety risk during set-up is higher than during removal provided explanations to support their responses. The responses received are similar, and include the following:

- When removing the work zone closure, road users are already aware of the work zone pattern and work zone condition ahead when approaching the transition zone since the temporary traffic devices are already set up in place. Therefore, the speed of traffic tends to be reduced throughout the work zone during removal.

- During the removal of traffic control devices in the work zone, the removal procedure is done in the reverse direction of the traffic. Therefore, workers are protected somewhat by the existing traffic control devices. On the other hand, when setting up temporary traffic control, there are no traffic control devices in place to protect the workers from traffic.

- Removal can be done within existing lane closure, while the initial set-up exposes personnel to passing traffic.

- Traffic control set-up is changing the traffic pattern to a smaller area which is more dangerous than changing the traffic pattern to a bigger area during removal.

- For nighttime work, temporary traffic control set-up takes place in the evening during the peak hours as road users travel back from work to their houses. Therefore, it introduces higher risk than during removal in the early morning.

3.4.5 Traffic Control Set-up and Removal Planning/Design Goals

The paramount goal during traffic control set-up and removal is the safety of motorists and workers. However, goals related to quality, cost, productivity, and other performance criteria are also considered during the planning and design of traffic control operations. Competing priorities to meet the various goals may influence safety and work performance. Question #3.7 provided a list of goals and asked the respondents to rank the goals in terms of their priority when planning and designing the operation to set-up and remove temporary traffic control. The respondents were instructed to start with 1 as the top priority, 2 as the second priority, and so forth. A value of zero is entered if it is not a priority. Table 3.5 shows the results, including the weighted ranking calculated using Eqn. 3.1. The number of responses received varied for each goal depending on the hierarchy of ranking. None of the respondents indicated that any of the goals are not a priority. Based on the weighted ranking of each goal, the goal that is considered to be the most important to the majority of respondents is motorist and worker safety (weighted ranking = 1.03), followed by quality of the traffic control placement (2.91), mobility of motorists through the work zone (3.06), number of worker required (3.91), coordination with the construction/maintenance work operations (4.00), amount of resources required (4.21), amount of time required (4.24), and cost of the operation (6.46). One respondent indicated an additional goal (availability of law enforcement assistance) as the top priority. It is interesting to note that the respondents understand and abide by the goal for temporary traffic control stated by FHWA (2009) in which the primary purpose of the traffic control is to provide for movement of road users through the work zone while protecting the road users and workers from traffic accidents and equipment.

Table 3.5: Ranking of Goals considered when Planning and Designing Temporary Traffic Control Operations (a lower value indicates a higher ranking)

Goals	Number of Responses at each Ranking Level									Weighted Ranking
	1	2	3	4	5	6	7	8	9	
Motorist and worker safety	34	1	0	0	0	0	0	0	0	1.03
Quality of the traffic control placement	8	8	8	5	2	4	0	0	0	2.91
Mobility of motorists through the work zone	5	12	8	4	2	1	2	1	0	3.06
Number of workers required	2	7	7	3	7	4	3	0	0	3.91
Coordination with the construction/maintenance work operations	6	6	2	5	6	3	4	2	0	4.00
Amount of resources (equipment and materials) required	2	8	3	5	3	9	1	2	0	4.21
Amount of time required	3	6	5	4	6	2	8	0	0	4.24
Cost of the operation	2	3	2	0	0	3	3	13	0	6.46
Other (please specify):	2	0	0	0	0	0	0	0	1	9

Notes: Ranking where 1 = highest priority, 2 = second-highest priority, and so forth. 0 = not a priority.

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

Two survey questions asked about safety risk associated with setting up and removing traffic control in specific areas within the work zone. One question focused on worker safety and the other addressed motorist safety. For both questions, the respondents were asked to rate the level of safety risk in the following work zone areas: advance warning area, transition area, activity area (including buffer space and work space), and termination area. A scale of 0 to 5 was used where 0 = no risk/I don't know, 1 = very low risk, and 5 = extremely high risk.

The results with respect to worker safety (Question #4.1) are shown in Figure 3.9. The area that received the most responses for "extremely high risk" was the transition area (53.57% of responses). The activity and advance warning areas were also identified as creating extremely high risk for workers. The majority of respondents reported only low to moderate risk in the termination area. The weighted average responses for each area, based on the rating scale of 0 to 5, are as follows:

- Advance warning area: 3.64
- Transition area: 4.34
- Activity area: 3.62

- Termination area: 2.60

The weighted averages reveal that the transition area was identified as the riskiest location within the work zone, follow by both the activity area and advance warning area, while the least risky location is the termination area. This result is different than that found in previous research related to the safety risk while the construction/maintenance work is taking place after the traffic control is set up. Garber and Zhao (2002) found the activity area was the most dangerous area in both daytime and nighttime work zones. However, the present and prior studies provide similar findings that the termination area is the lowest risk area.

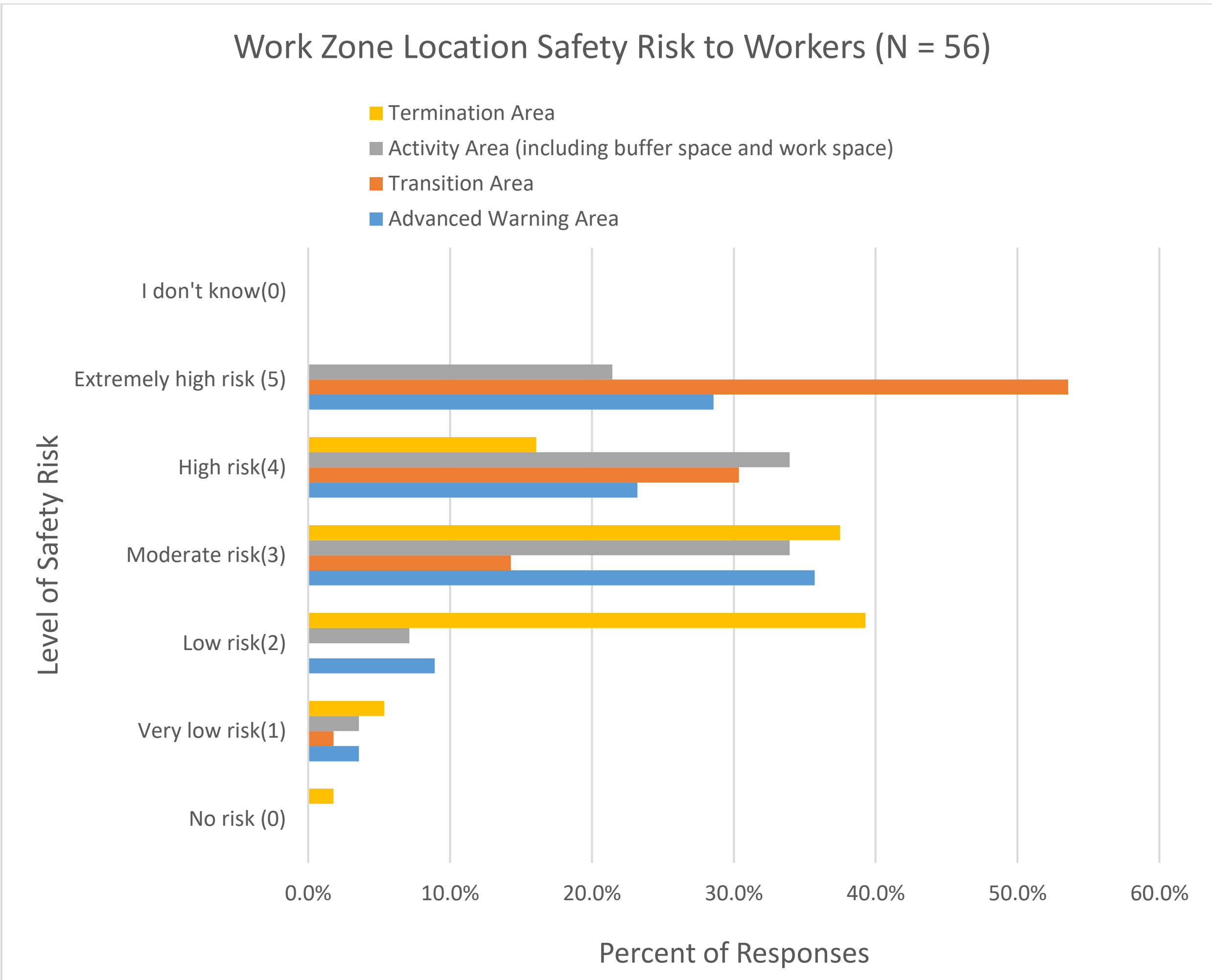

Figure 3.9: Safety risk to workers during traffic control set-up/removal based on work zone area (N = 56)

The second question (Question #4.2) targeted motorist safety in each work zone area. Figure 3.10 shows the results from this question. The transition area was again identified as the work area that posed the most risk to motorists. The weighted average rating for the transition area was calculated to be 3.87. The weighted average ratings for the other areas are 3.07 for the activity area, 2.70 for the advance warning area, and 2.10 for the termination area. Similar to the impact on workers, the safety risk to motorists during traffic control set-up/removal is considered greatest in the transition area.

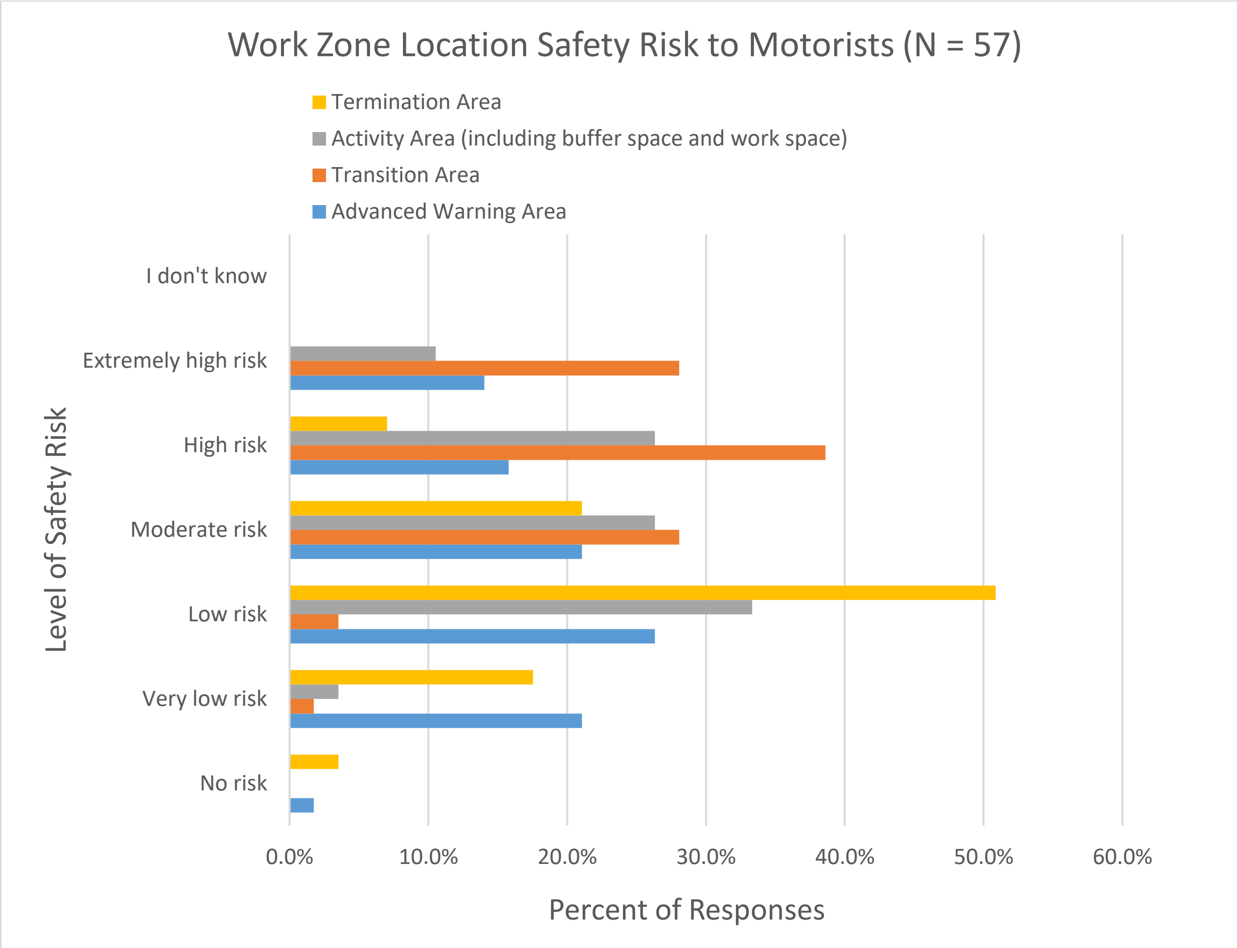

Figure 3.10: Safety risk to motorists during traffic control set-up/removal based on work zone area (N = 57)

3.4.7 Impact of Time of Work on Safety Risk

Construction and maintenance activities may be conducted in the daytime or nighttime. Each work period presents site conditions that may create hazards during the set-up and removal of temporary traffic control. Two questions explored the impacts of daytime and nighttime traffic control operations on safety; one question targeted worker safety (Question #4.3) and the other question focused on motorist safety (Question #4.4). Both questions asked the respondent to rank specified daytime and nighttime working conditions in terms of their impact on safety. Six different conditions were presented, three for daytime and three for nighttime. The work conditions, along with the respondent rankings are shown in Tables 3.6 and 3.7 for worker safety and motorist safety, respectively. For worker safety, the respondents indicated that traffic control set-up and removal during the nighttime (7:00pm to 7:00am) with high traffic volume but no congestion tends to be the riskiest work condition (weighted ranking = 2.63). Based on weighted ranking, nighttime traffic control placement and removal is typically viewed as being more risky for workers than daytime traffic control operations. The results for motorist safety are quite similar to that for worker safety. Nighttime work operations with high traffic volume but no congestion was ranked the highest in terms of impact to motorist safety (weighted ranking = 2.78). In addition, for motorist safety, all three nighttime conditions were rated as being riskier than the daytime conditions.

Table 3.6: Ranking of Daytime and Nighttime Work Conditions in terms of Risk to Worker Safety (a lower value indicates a higher ranking)

Work Condition	Number of Responses for Each Ranking						Total Responses	Weighted Ranking
	1	2	3	4	5	6		
Nighttime (7:00PM - 7:00AM) with high traffic volume but no congestion	13	14	16	9	2	2	56	2.63
Nighttime (7:00PM - 7:00AM) with low traffic volume and free-flow speeds	17	11	7	3	7	11	56	3.09
Daytime (7:00AM - 7:00PM) with high traffic volume but no congestion	8	8	10	23	5	2	56	3.27
Nighttime (7:00PM - 7:00AM) with high traffic volume and congestion	10	3	14	4	21	4	56	3.63
Daytime (7:00AM - 7:00PM) with low traffic volume and free-flow speeds	2	8	8	13	12	13	56	4.14
Daytime (7:00AM - 7:00PM) with high traffic volume and congestion	6	12	1	4	9	24	56	4.25

Note: Respondent ranking where 1 = greatest level of impact, 2 = second-highest level, … 6 = least level of impact.

Table 3.7: Ranking of Daytime and Nighttime Work Conditions in terms of Risk to Motorist Safety (a lower value indicates a higher ranking)

Work Condition	Number of Responses for Each Ranking						Total Responses	Weighted Ranking
	1	2	3	4	5	6		
Nighttime (7:00PM - 7:00AM) with high traffic volume but no congestion	11	13	15	11	3	2	55	2.78
Nighttime (7:00PM - 7:00AM) with high traffic volume and congestion	12	6	14	7	12	4	55	3.24
Nighttime (7:00PM - 7:00AM) with low traffic volume and free-flow speeds	16	8	6	2	13	10	55	3.33
Daytime (7:00AM - 7:00PM) with high traffic volume but no congestion	5	9	9	24	7	1	55	3.40
Daytime (7:00AM - 7:00PM) with high traffic volume and congestion	9	14	1	2	10	19	55	3.85
Daytime (7:00AM - 7:00PM) with low traffic volume and free-flow speeds	2	5	10	9	10	19	55	4.40

Note: Respondent ranking where 1 = greatest level of impact, 2 = second-highest level, … 6 = least level of impact.

3.4.8 Frequency of Safety-related Incidents involving Motorists

The respondents were asked to provide estimates of the frequency in which near misses and crashes occur during traffic control set-up and removal operations (Questions #4.5 and #4.6). While crashes are reported and more easily tracked, near misses may go unreported yet are just as important to consider when assessing safety risk. The respondents could select frequencies ranging from less frequently than once a year to more than once per work shift. To ensure a common understanding of the terms, definitions of "near miss" and "crash" were provided with the questions. The terms were defined as follows:

- *Near miss*: An incident in which no injury, fatality, or property damage occurred.
- *Crash*: An incident involving a public vehicle that resulted in an injury, fatality, and/or property damage.

The responses from the questions are summarized in Figure 3.11. The figure shows that near misses are experienced more often than crashes. None of participants report seeing near misses less frequently than once a month. More than half of the respondents who answered this question

(57%) indicated that they witness a near miss once per work shift or more than once per work shift. On the other hand, the respondents indicated that they observe a crash as frequently as once a week.

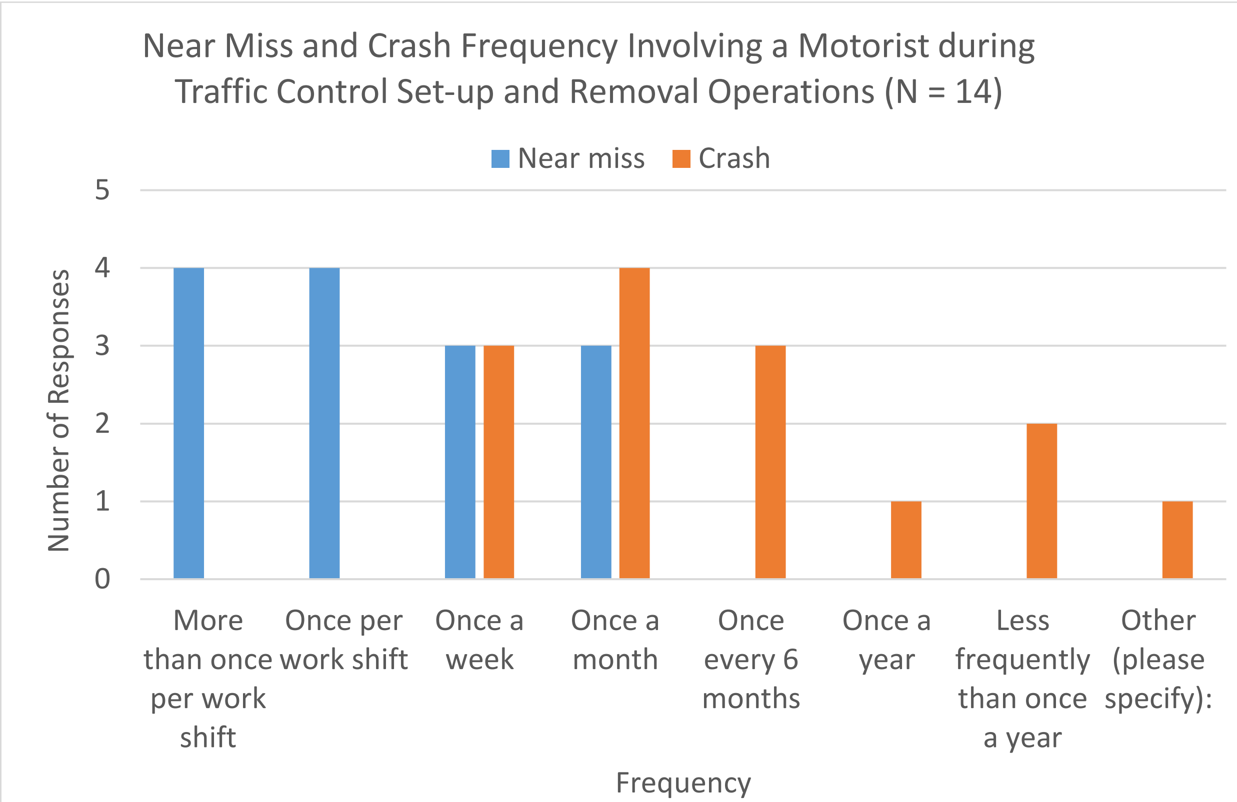

Figure 3.11: Reported frequencies of near misses and crashes during temporary traffic control set-up and removal operations (N = 14)

3.4.9 Safety Risk based on Specific Traffic Control Activity/Task being Performed

The survey also explored the respondent's perception of the level of safety risk associated with specific activities/tasks commonly performed as part of the traffic control set-up and removal processes. For example, one activity is the placement of temporary signage on the roadway. Respondents were asked to rate the level of safety risk to workers (Question #4.7) and to motorists (Question #4.8) during placement of the temporary signage. Ratings were given on a scale of 0 to 5 where 0 = No risk/I don't know, 1 = very low risk, and 5 = extremely high risk.

Table 3.8 shows the full list of activities/tasks rated, along with the results with respect to worker safety. In terms of weighted average rating, accessing the roadway and blocking/slowing traffic was given the highest risk rating (weighted average rating = 4.45) for the safety of workers. Other high-risk activities/tasks identified by the respondents were: placement of cones/barrels for the lane closure (weighted average rating = 4.38), and the placement of temporary striping (3.83). Amongst the activities/tasks listed, the placement of temporary lighting was identified as posing the least risk to workers (weighted average rating = 2.98).

Table 3.8: Rating of Traffic Control Activities/Tasks in terms of Risk to Worker Safety

Activity/Task	Number of Responses at Risk Level							Total Number of Responses	Weighted Average
	I don't know (0)	No risk (0)	Very low risk (1)	Low risk (2)	Moderate risk (3)	High risk (4)	Extremely high risk (5)		
Placement of temporary lighting	0	0	1	11	20	8	2	42	2.98
Placement/set-up of radar speed sign(s)	0	1	0	4	15	4	3	27	3.11
Placement/set-up of variable message sign(s)	0	0	1	11	20	12	6	50	3.22
Other (please specify):	0	1	1	0	0	3	3	8	3.50
Placement of temporary striping	0	1	0	4	11	16	6	38	3.55
Placement of temporary roadway markers/reflectors	0	1	0	5	11	11	9	37	3.57
Placement of temporary signage	0	0	1	3	15	18	15	52	3.83
Placement of cones/barrels for the lane closure	0	0	0	1	8	14	30	53	4.38
Accessing the roadway and blocking/slowing traffic	0	0	0	1	4	16	28	49	4.45

The results with respect to motorist safety are shown in Table 3.9. Similar to the ratings for worker safety, those activities/tasks that were rated high in terms of risk to motorists were accessing the roadway and blocking/slowing traffic (weighted average rating = 3.76), placement of cones/barrels for the lane closure (3.55), and the placement of temporary striping (3.08). Interestingly, the outcome indicates that the three activities/tasks with the highest perceived levels of risk were the same for both motorist safety and worker safety.

Table 3.9: Rating of Traffic Control Activities/Tasks in terms of Risk to Motorist Safety

Activity/Task	Number of Responses at Risk Level							Total Number of Responses	Weighted Average
	I don't know (0)	No risk (0)	Very low risk (1)	Low risk (2)	Moderate risk (3)	High risk (4)	Extremely high risk (5)		
Placement of temporary lighting	0	2	8	15	9	7	0	41	2.27
Placement/set-up of radar speed sign(s)	0	2	6	6	8	3	2	27	2.37
Placement/set-up of variable message sign(s)	0	2	10	14	12	9	3	50	2.50
Placement of temporary signage	0	2	7	17	14	6	6	52	2.63
Placement of temporary roadway markers/reflectors	0	1	3	11	11	7	4	37	2.86
Other (please specify):	0	1	1	0	2	4	0	8	2.88
Placement of temporary striping	0	1	3	9	9	11	5	38	3.08
Placement of cones/barrels for the lane closure	0	0	2	7	18	12	14	53	3.55
Accessing the roadway and blocking/slowing traffic	0	0	4	2	12	15	16	49	3.76

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

The last section in the survey contained open-ended questions about the practices and technologies commonly utilized for setting up and removing temporary traffic control. To ensure that the respondents were answering the questions with respect to a consistent context, the respondents were prompted to assume the following scenario when answering the question: 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.

One question (Question #5.1) asked the respondents to share best practices that they recommend for ensuring safe and effective set-up and removal of the temporary traffic control. Of those common responses received, respondents advised using protective equipment, such as trucks with truck-mounted attenuators, or deploying highway patrol vehicles during the set-up and take down operations. These practices were identified as helping to lower the crash/injury severity when a crash occurs, and reducing the speed of traffic passing the work operation. Some respondents suggested having a clear plan for setting up and removing traffic control devices, active communication, proper training, and adherence to standard procedures and guidelines such as installing the traffic control devices in the direction of traffic and then removing the traffic control devices against traffic. The respondents also recommended having a competent person stand-by and oversee the set-up and removal process in the field, which can mitigate the probability of a crash and provide feasible traffic control operations to improve traffic flow through the work zone. Other respondents mentioned using attention attracting devices, such as advance message boards, flashing lights, blue lights, and arrow boards, to help alert road users of the roadwork conditions ahead, encourage early lane merging, and increase road-user awareness during operational maneuvers through the transition area. Furthermore, employing more than one person during set-up and removal of traffic control was also recommended. Having multiple workers involved in the set-up and removal operations can help lessen the pressure from a single person and mitigate the possibility of the worker running across traffic lanes to access, place, or retrieve traffic control devices.

Another question solicited examples of traffic control set-up and removal practices that are not recommended (Question #5.3). One respondent indicated that not having a standard set-up/removal procedure is not recommended. Lacking a standard procedure for workers to follow may result in workers installing or removing traffic control devices without following appropriate sequences that provide for safe work operations. Some respondents mentioned not performing traffic control set-up/removal when there is a lack of visibility in the work zone or lack of highly visible PPE on workers (e.g., not wearing reflective apparel, or reflective apparel covered with dirt). Furthermore, other respondents suggested not conducting traffic control operations when there is inadequate proper protection such as a truck mounted with a TMA, a dome light, high visible PPE, and flashing lights. Lastly, some respondents stated that, when workers do not have a proper traffic control plan and training, the workers should not attempt to take a lane or remove the traffic control from the closed lane.

The survey also asked the respondents for more details about specific written procedures that their organization has for traffic control operations. The researchers were interested in collecting additional examples of standard procedures to complement those already found as part of the literature review. A total of 22 respondents indicated that their organization has standard procedures, and some provided a link to the website containing the procedures/guidelines. The following website links were provided:

- http://epg.modot.org/index.php?title=616.23_Traffic_Control_for_Field_Operations
- https://deldot.gov/Publications/manuals/de_mutcd/index.shtml
- https://epg.modot.org/index.php/Category:616_Temporary_Traffic_Control
- https://portal.ct.gov/DOT/Traffic-Engineering/Traffic-Special-Provisions
- https://azdot.gov/sites/default/files/2019/09/TrafficControlDesignGuidelines2019.pdf

Other respondents indicated that their organizations follow the guidance set forth in the MUTCD, Ohio MUTCD, MassDOT specifications, and Caltrans Standard Specification Section 12 titled "Temporary Traffic Control." Ten of the 22 respondents stated that their organization does not have standard procedures for traffic control operations. Several of the respondents indicated that they have some training courses provided by outside organizations, such as ATTSA, for traffic control supervisors. Lastly, several respondents did not know whether their organization/company has a written traffic control set-up and removal plan.

The final survey question asked the respondents to share any innovative technologies and/or practices that they have seen or used for ensuring safe and effective set-up and removal of temporary traffic control in work zones. The most common suggestions were to use an automated cone retrieval truck, which can automatically install and remove traffic cones faster than a normal cone truck and eliminate the risk of workers being exposed to live traffic. Similarly, other respondents suggested using an autonomous truck and a truck that has a front bumper mounted with a roller, which can move barrels easily from the traffic lane to a side lane without using any workers on foot on the roadway. One respondent recommended using a Traffic Pro Bed truck (https://www.youtube.com/watch?v=t9klRjxo0cg). The respondent felt that the truck provides many convenient features in term of equipment organization such as safety restraint systems built-in, a flexible height adjustment bucket, automatic cone drive system, high-grade visibility, and a light, all of which enable safely working in every circumstance of setting up and removing traffic control devices. While not commonly considered a technology, some respondents recommended using law enforcement officer presence in the work zone to maintain a safe speed through the work zone. Other feedback included using devices that help workers feel more comfortable in a work zone environment, such as a crash truck/attenuator with an audible alert system, radar speed feedback signs, adequate lighting in transition zones including equipment, and highly reflective PPE.

3.4.11 Risk Analysis Evaluation and Summary

The survey results provide an opportunity to gain further understanding of the risk associated with temporary traffic control set-up and removal. Of interest is determining the points in the set-up and removal process when risk to workers and motorists is the greatest. Specifically, the results allow for determining which activities/tasks present the greatest safety risk and, when the activities/tasks are performed, what conditions increase the risk. Impactful conditions could be associated with the work itself (work process, workers, equipment, resources), the roadway and surrounding environment, and/or the passing traffic. The survey results can also be used to highlight where in the work zone the greatest risk is present, e.g., advance warning area, transition area, activity area, or termination area. An analysis to determine when and where the risk is greatest can then be used to guide the selection and application of specific controls (treatments) to eliminate or minimize the risk.

Table 3.10 provides a summary analysis of the survey results to highlight the conditions that affect safety risk associated with each step in the set-up and removal process, along with the location where the steps take place in the work zone. The table is designed to indicate when and where risk is greatest and, hence, where controls should be targeted to provide the greatest impact. The values presented in the table are the weighted average rankings shown in Tables 3.2, 3.3, and 3.4 above. As described above, the rankings range from 1 – 5, where 1 = greatest impact to safety, 2 = second-highest impact to safety, and so forth. A lower ranking indicates greater impact to safety.

To highlight the conditions that pose the greatest risk, the weighted rankings can be used to organize the conditions into three categories based on the perceived relative level of safety risk present. The following values were used to separate the conditions into three risk categories:

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

High risk: Weighted average ranking < 2

As shown in Table 3.10, those conditions which create moderate risk are shaded in light gray and conditions that create higher risk are shaded in dark gray. Unshaded cells represent conditions ranked as creating lower risk. The work zone areas are denoted by the following acronyms: AWA = Advance warning area, TRA = Transition area, AA = Activity area, and TMA = Termination area. These acronyms are used to indicate where in the work zone the activity/task occurs. The weighted average rankings show the work, roadway, and traffic conditions when risk is perceived as being low, moderate, and high for the particular activity/task.

The table reveals that the primary conditions when the risk is the greatest are mainly related to difficulty in accessing the lane or blocking traffic, a lack of space available for workers or equipment, and the high speed of passing vehicles. All of these conditions were identified with a high ranking in terms of risk for every work activity/task and are impactful in every location in the work zone. Those conditions that present moderate-to-high level of risk (mean weighted average ranking greater than but close to 2) include workers not following the planned process, a lack of light, and aggressive drivers. For the conditions that present a moderate-to-high level of risk, the results indicate that the conditions are impactful over all of the work zone areas, which was similar to the result for the high-risk conditions. However, the results from survey Questions 4.1 and 4.2 showed that the transition area was identified as the most dangerous location within the work zone area. These results can be used as evidence of where and when the greatest risk typically exists when setting up and removing the traffic control in the work zone.

Table 3.10 also shows when and where the risk is perceived to be lower (weighted average ranking > 3). A lack of available workers is a viewed as a work condition that does not present a high level of risk. Similarly, a high volume of trucks and traffic congestion are traffic conditions that were not ranked highly in terms of safety risk to motorists and workers.

Table 3.10: Summary Weighted Average Rankings of Safety Risk

Activities/ Tasks	Location in work zone	Work Conditions					Roadway Conditions			Traffic Conditions					Mean weighted average ranking
		Lack of available workers	Workers not following planned process	Lack of available equipment or equipment breakdown	Planned process not applicable to field conditions	Time pressure to complete set-up and removal	Lack of light (e.g., nighttime work)	Difficult accessing lane or blocking traffic	Lack of space available for workers or equipment	High speed of passing vehicles	High volume of traffic	High volume of trucks	Traffic congestion	Aggressive drivers	
Accessing the roadway and blocking or slowing traffic	AWA, TRA, AA, TMA	2.98	2.24	2.84	3.28	2.82	2.12	1.78	1.58	1.69	2.68	3.38	3.88	1.84	2.55
Placement of temporary signage	AWA, TRA, AA, TMA	3.09	2.02	3.04	3.06	2.94	2.26	1.87	1.66	1.43	2.72	3.42	3.79	2.13	2.57
Placement of cones/barrels for the lane closure	TRA, AA, TMA,	3.02	2.17	2.94	3.02	2.93	2.24	1.72	1.65	1.45	2.65	3.43	3.93	1.93	2.54
Placement of temporary lighting	AA	3.64	2.47	2.21	2.69	3.21	1.95	1.93	1.88	1.55	2.69	3.60	3.95	2.17	2.61
Placement/set-up of variable message sign(s)	AWA	3.39	2.33	2.43	2.71	3.41	2.27	1.96	1.51	1.57	2.75	3.47	3.76	2.29	2.60
Placement of radar speed sign(s)	AWA	3.43	2.25	2.56	2.71	3.21	2.25	1.67	1.32	1.61	2.43	3.11	3.61	2.21	2.49
Placement of temporary striping	AWA	3.54	2.51	2.72	2.69	2.59	2.15	1.64	1.59	1.38	2.59	3.31	3.77	1.95	2.49

Placement of temporary roadway markers and reflectors	TRA, AA, TMA	3.21	2.47	2.87	2.84	2.81	2.80	1.66	1.71	1.34	2.61	3.39	3.89	1.95	2.58
Mean Weighted Average		3.29	2.31	2.70	2.88	2.99	2.26	1.78	1.61	1.50	2.64	3.39	3.82	2.06	

Notes: A lower value indicates greater safety risk. AWA = Advance work area; TRA = Transition area; AA = Activity area; and TMA = Termination area

4.0 METHODOLOGY

As indicated above, this research study aims to develop additional knowledge and guidance about temporary traffic control set-up, removal, and modification practices on high-speed roadways to improve driver and worker safety during the work operations. Figure 4.1 depicts the overall research plan to meet the study objectives that were included in the study work plan. This interim report presents the results of the literature review and DOT/contractor survey, which are part of Phase 1 of the study. Based on the results of these initial tasks, the researchers recommend continuing with the initial research approach as planned, with additional attention given to specific focus areas identified in the literature review and surveys and summarized below.

The study design includes multiple tasks intended to collect knowledge relevant to the topic, evaluate current and recommended practices, and develop guidance for ODOT. The overall plan contains four main phases. The first phase (Phase I) documented existing knowledge and practice related to the operations conducted during temporary traffic control transition periods. Phase I is complete and described above in this interim report. Phase II involves hazard identification and risk assessment associated with the typical jobsite activities undertaken to set-up, remove, and modify temporary traffic control on the roadway. Phase III entails identifying and evaluating potential recommended practices to further improve worker and motorist safety during temporary traffic control transition periods. Completion of all three phases will be followed by the preparation and submittal of a final research report that will include guidance for future practice (Phase IV). Figure 4.1 also shows the research activities (i.e., data collection and analysis, and document preparation) to be conducted in each phase to fulfill the objectives. The specific tasks in each phase, along with the data needed, are described in more detail below.

The research methodology described below is intended to provide further structure to, and confirmation of, the research plan following the knowledge gained from Tasks 1-3. The literature review, survey results, and draft research methodology are submitted to the TAC for review and comment. A TAC meeting (Task 5, TAC Meeting #2) will be held to discuss the documents and prepare for the next steps in the study. Feedback from the TAC will be incoporated into the final versions of each document. The completion of Tasks 1-3 will constitute the completion of Phase I of the study.

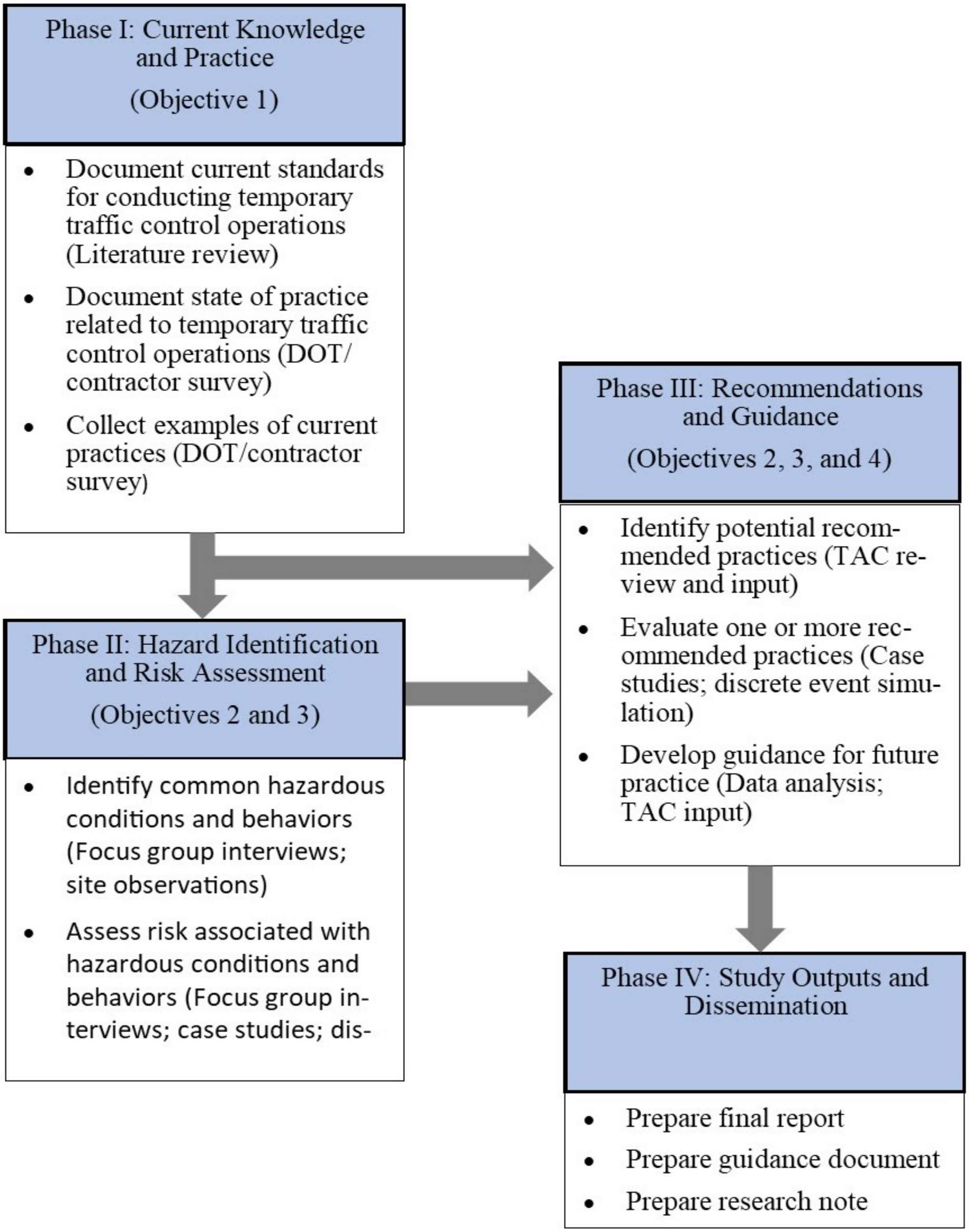

Figure 4.1: Research plan

4.1 RESEARCH TASKS

The completion of the literature review (Task 2) and DOT/contractor survey (Task 3) provides the initial data needed for the study. Table 4.1 presents detail about the data needed with respect to each of the research objectives. The data are collected and analyzed as part of the tasks as described below.

Table 4.1: Data Requirements for the Study

Phase	Research Objective	Data Needed	Research Tasks
I	1. Document current knowledge and practice	Principles followed when planning traffic control operations Common practices employed with implementing traffic control operations	2, 3
I, II, III	2. Identify promising practices	Examples of practices in other states Suggestions for new practices	1, 3, 5
II, III	3. Compare practices based on risk and feasibility of implementation	Typical steps, order, and timing of traffic control operations Personnel and equipment used/needed for traffic control operations Hazards and exposures associated with the traffic control operations	6, 7, 8
III	4. Develop guidance for future traffic control operations	Characteristics and impacts of different options for traffic control operations	9

Starting with the list of common and promising practices identified in Phase I, Phase II focuses on evaluating the hazards present during the work practices and the risk associated with each hazard. This phase begins with Task 6 to gather input from industry regarding the hazards associated with traffic control operations. Task 6 is intended to expose those parts of the work operations in which the risk of vehicle crash and worker injury/fatality are especially high. Where possible, quantitative and qualitative measures from the literature will be used to quantify risks. Determination of the hazards and risk will also be accomplished through the use of focus group interviews of DOT, construction, and traffic control personnel. The personnel will be asked to provide input on the safety issues present during the traffic control transition periods. For Task 7, the researchers visit ongoing construction and maintenance operations to observe and document the typical traffic control operations in Oregon. During the observations, the prevalance of situations that pose high risk to workers are recorded for analysis.

To date, the researchers have conducted two focus group interviews with ODOT personnel and contractor personnel (Task 6). The researchers have also conducted visits to multiple construction and maintenance project sites to observe the traffic control operations (Task 7). The analysis of the data collected in the focus group interviews and observations is in progress and will be reported at a later date. Completion of Tasks 6 and 7 will constitute the completion of Phase II.

The outputs of Tasks 6 and 7 provide information that enables identifying promising practices to study further. Task 8 begins with obtaining the TAC's input regarding which practices to evaluate further in the field. It is expected that one or two promising practices will be selected to investigate further. Those practices selected will then be evaluated as part of Task 8. With ODOT's assistance, the researchers will identify potential projects on which to implement the selected practices. The practices will then be implemented by the construction contractors and/or ODOT staff. When implemented, the researchers will document the practice (e.g., video record the operation) and, while observing the operations, record any safety concerns and speeds of passing vehicles. Finally, the researchers will interview the workers to gain their perspectives on the feasibility of the recommended practices and their impact on safety.

Following the implementation and evaluation of promising practices, in Task 9 the researchers will prepare a draft guide that describes the recommended practices and supports ODOT personnel when implementing the practices on site. The guide will be provided to ODOT for review, evaluation, and feedback. The completion of Tasks 8 and 9 will constitute the completion of Phase III.

Lastly, the research findings will be documented in Phase IV (Tasks 10-14). The study activities will include the preparation, submittal, and presentation of a final research report that describes the study methods, results, conclusions, and recommendations for practical implementation of the results. A research note that succintly summarizes the findings of the study will also be drafted and submitted to ODOT. The research report, research note, and guidance document will constitute the formal outputs of the study.

The remaining research tasks to be undertaken to complete the study (Tasks 5 – 14) are described in detail below.

Task 5: TAC Meeting #2

The PI will meet with the TAC and ODOT Research Coordinator to discuss and plan the next steps of the study. This TAC meeting is intended to set the course for the completion of the study. The PI will prepare a presentation and supporting material for the meeting. Following the meeting, the PI will incorporate the information and recommendations provided by the TAC into the study and, if needed, revise the planned research activities, schedule, and budget based on the input provided by the TAC.

Task 6: Focus Group Interview

The researchers will gather input from ODOT and industry pesonnel regarding the hazards associated with traffic control operations. This task is intended to expose those parts of the work operations in which the risk of vehicle crash and worker injury/fatality are especially high. Determination of the hazards and risk will be accomplished through the use of focus group interviews of DOT, construction, and traffic control personnel. One or more focus group interviews will be convened. The TAC members will be asked to participate in the focus groups. A list of questions will be developed to guide the focus group discussion. Questions will be asked to gather the following information:

- For those traffic control activities/tasks identified in the previous tasks, the safety issues associated with each activity/task
- The perceived relative risk associated with each traffic control activity/task
- Those activities/tasks that the research study should focus on to improve safety
- Ideas for how to change the traffic control operations to mitigate the perceived risk

The researchers will record the discussions for subsequent analysis. The analysis will target common trends and themes that are exposed during the focus group discussions. Where possible, quantitative and qualitative measures from the literature and ODOT sources will also be used to quantify risks. For example, near misses and crashes that are reported by ODOT Maintenance personnel could be reviewed to identify the traffic control conditions and actions in which safety issues commonly occur. This information, along with the extent to which the traffic control operations take place, can be used to assess the risk associated with specific parts of the operation.

Task 7: Onsite Observations

The researchers will visit ongoing construction and maintenance operations to observe and document typical traffic control operations in Oregon. Two to three different construction and/or maintenance operations will be observed based on the availability of operations. The researchers will collaborate with ODOT staff to identify available operations to observe. During the observations, the prevalance of situations that pose high risk to workers will be recorded for analysis. This task will only include observations; no changes to the planned operations will be made or new treatments applied and evaluated at this point. Following the observations, and with hazard and risk information collected in prior tasks, the researchers will analyze the operations to assess the associated risk and identify potential changes to the operations. Given that the study focuses on an operational process, an analysis technique that incorporates time, such as discrete event simulation, will be used to account for hazards and risk at different points in the process.

Task 8: Selection, Implementation, and Evaluation of Promising Practices

Task 8 begins with obtaining the TAC's input regarding which practices (identified in prior tasks) to evaluate further in the field. It is expected that those tasks which are deemed to be promising, but which further data and analysis are needed to verify their feasibility and benefit, will be selected. The TAC will be asked to select one or more promising practices to investigate further through implementation as part of actual temporary traffic control operations, and within the time and budget constraints of the study.

The results of the tasks completed to date highlight points in the traffic control set-up and removal process in which further risk mitigation measures are needed or warranted, along with promising means to mitigate the risk. Elements of the work process that were identified as particularly hazardous to workers and/or motorists include:

- Initial set-up of signs and taper in work zone

- Set-up and removal of traffic control close to an open on-ramp
- Picking up knocked over cones in a live traffic lane
- Set-up and removal of traffic control nearby blind spots which result in limited driver and worker sight distance
- Set-up and removal of traffic control devices in the wrong sequence order
- Complicated work zones that confuse drivers and, as a result, negatively impact surrounding drivers
- Lack of personal fall restrain system on cone trucks for the worker placing and removing cones and barrels/drums
- Insufficient space available for the crash truck to protect the cone truck near open on-ramps
- Setting up the TMA on the freeway next to a live traffic lane
- Worker climbing up on a roadway divider to give a hand signal to a work vehicle operator as the work vehcile is backing up after merging from the fast lane into the work zone
- Bind spot occur for the truck drivers as the truck is backing up to remove the TTC devices in the work zone closure.
- Backing up trucks causing confusion to drivers
- Loud engines from passing trucks expose workers to hearing loss and make it difficult for workers to communicate with each other
- Missing physical component of equipment, such as on the passenger side of the cone truck when there is no ladder or step to climb up on the truck
- Setting up the truck-mounted TMA on the back of a truck without any protection in place
- Misleading arrow sign indication on the arrow board mounted on a truck
- Reading the traffic control plan while driving the truck to the work zone

The site observations and interviews revealed that conditions which lead to or require improvisation by workers during the traffic control operations can create a safety concern. Task-level decisions made in response to field conditions, especially when made at the last-minute, were identified as possible causes that put workers and motorists in dangerous situations. In this context, the last-minute changes primarily refer to those changes to the operations during the performance of the work that are required to implement or remove the lane closure. Changes and corresponding field decisions that were identified as potentially contributing to a higher level of risk include:

- Location of where to park the truck on the freeway shoulder
- Location of where worker should exit the truck and stand relative to the truck while setting up or removing a temporary sign
- Spacing between work vehicle and cone truck during the work operation and when parked on the roadway
- Distance in which the first crash truck should be offset into the travel lane relative to the second crash truck during placement of the taper
- The process when a work vehicle and crash truck need to merge into or leave a traffic lane to set up or remove traffic control signs
- Location where signs should be installed
- When to block traffic on an on-ramp
- When a work vehicle and crash truck need to relocate from the shoulder to an on-ramp lane to place cones at the entrance of the on-ramp
- When to turn on the VMS or flashing yellow warning light on the truck when reaching the work zone area
- When a barrel needs to be moved from the shoulder and placed on the roadway
- When a worker needs to run across an on-ramp lane to setup or remove a sign on the on-ramp
- Where and when to lower the TMA, i.e., either stop on side of roadway and lower the TMA, or lower the TMA while travelling on the roadway
- When to begin to set up the traffic control devices near the on-ramp after the crash truck blocks on-ramp traffic
- When to pick up knocked down cones on the roadway
- When to turn on/off the arrow board or VMS on the crash truck while on the roadway

Concerns were also raised related to changes and decisions made by project management personnel, ODOT staff, and the traffic control supervisor at the overall project or work planning level. Correlation between project-level decisions and task-level decisions often exists when implementing the traffic control in the work zone. During the focus group interviews, contractors mentioned that a short and restricted amount of time available to set up and remove traffic control adds pressure on the traffic control crew to take shortcuts and cut corners when installing and removing the traffic control. Work crew safety often is compromised when there is a tight timeframe for the set up and removal operation. This feedback indicates that management level decisions can negatively impact the safety performance of the roadway and maintenance crew on the site. Other project-level decisions mentioned which affect safety were related to contractor issues such as insufficient budget to purchase protection equipment/material, a lack of skilled labor in the market, and a lack of traffic control worker training. These conditions were identified as often creating significant risk for the traffic control crews when they are out in the field implementing and removing the lane closure.

The researchers also received input on how to improve safety during traffic control set-up and removal. The following ideas/suggestions for mitigating the risk have been identified, and could be considered by the TAC for further investigation in future tasks:

- Deploy multiple portable radar speed signs: upstream of the initial sign placement, prior to the taper, within the work zone, and at on-ramps
- Place flashing blue lights on the barrels/drums in the taper area
- Deploy law enforcement at the location of the first sign set up in the work zone
- Equip every work truck with a camera that provides a 360° view of the area surrounding the truck
- Attach a sensor device to workers to provide an alert when a truck is backing up nearby
- Implement a railway crossing gate control at on-ramp entrances, or use a red traffic light at on-ramps while workers are setting up traffic control near the on-ramps
- Use an automatic cone retrieval truck
- Provide a magnetic base for cones to prevent the cones from being knocked over
- Implement a mobile barrier on curved road structures
- Use a truck equipped with a barrel mover instead of workers on foot to move barrels from the roadside to the lane, and vice versa
- Implement a rolling slow down for the initial sign set-up
- Make a publice service anouncement of the work zone in advance (e.g., provide a message on a PCMS 1 month before road construction starts indicating the upcoming construction work)
- Use highly reflective material for cones and barrels, especially at the taper area
- Extend the taper length to provide more time for drivers to merge into the through lane

- Provide additional advance warning signs when the road is curvy or in hazadous weather conditions (e.g., snow and rain)

- Provide flashing yellow lights on cones close to ramps to attract more attention from the drivers entering/exiting the roadway

The suggestions/ideas for mitigating can be organized according to their objective, type, and placement location to assist in selecting one or more for further study (treatments). Table 4.2 presents each potential treatment along with corresponding information related to treatment objective, type, and placement location. The table shows that treatments are suggested which both pre-condition the drivers before they enter the work zone and maintain driving behavior while they are in the work zone. Some treatments are designed to improve efficiency and safety controls used during the traffic control operation. Most of the suggested treatments are implemented on the equipment or worker, and represent engineering controls.

Table 4.3 correlates the treatments to the high risk conditions and moderate risk conditions identified in Table 3.10. The correlation is based on the ability of the treatment to mitigate the impacting condition. For example, flashing blue lights located on equipment mitigate the risk associated with the high speed of passing vehicles, aggressive drivers, and lack of light (e.g., nighttime work). The table reveals that most of the recommended treatments positively influence high vehicle speed and aggressive drivers.

Table 4.2: Characterization of Recommended Treatments

Treatments	Objective			Location				Type		Type of Control in Hierachy of Controls				
	Pre-condition driving behavior before work zone	Maintenance of driving behavior in work zone	Efficient or reduced effort and improved safety controls for traffic control crew	Prior to work zone	On roadway in work zone	On equipment or worker in work zone	Other	Change in roadway, worker, or equipment feature	Change in work process or procedure	Elimination	Substitution	Engineering	Adminstation	PPE
PCMS with radar speed board located before Road Work Ahead signs	X			X				X				X		
Flashing lights on work equipment (e.g., blue lights)		X				X		X				X		
Flashing lights on roadway (e.g., electronic orange "pucks")	X			X								X		

Balloon lights or light towers located at regular spacing in work zone		X			X			X				X		
Attach sensors to workers and equipment to give an alert when in close proximity			X			X		X				X		X
Police enforce-ment	X	X		X	X			X				X	X	
360° camera on every truck to view surround-ing area			X			X		X				X		
Railway crossing gate control at on-ramps			X				X	X				X		
Automatic cone retrieval truck			X			X		X	X		X	X		

Magnetic base for cones			X			X		X			X			
Mobile barrier		X	X			X		X	X			X		
Barrel mover truck			X			X		X	X		X			
Rolling slow down during traffic control operations	X			X					X	X				
Public service announce-ment of work zone operations	X	X					X		X				X	
Highly reflective material on cones and barrels		X				X		X			X			
Extend taper length		X			X			X				X		

Provide additional advance warning signs	X			X				X				X		
Provide flashing yellow lights on cones		X				X		X				X		

Table 4.3: Relationship between Suggested Treatments and High and Moderate Risk Conditions

Treatment	High Risk Conditions			Moderate Risk Conditions		
	Difficult accessing lane or blocking traffic	Lack of space available for workers or equipment	High speed of passing vehicles	Aggressive drivers	Lack of light (e.g., nighttime work)	Workers not following planned process
PCMS with radar speed board located before Road Work Ahead signs			X	X		
Flashing lights on work equipment (e.g., blue lights)			X	X	X	
Flashing lights on roadway (e.g., electronic orange "pucks")			X	X	X	
Balloon lights or light towers located at regular spacing in work zone					X	
Attach sensors to workers and equipment to give an alert when in close proximity		X			X	
Police enforcement	X		X	X	X	
360° camera on every truck to view surrounding area		X			X	X
Railway crossing gate control at on-ramps	X	X	X	X		
Automatic cone retrieval truck		X		X		X

Magnetic base for cones				X		
Mobile barrier	X		X	X		
Barrel mover truck		X				X
Rolling slow down during traffic control operations	X	X	X	X		
Public service announcement of work zone operations			X	X		
Highly reflective material on cones and barrels				X	X	
Extend taper length				X		
Provide additional advance warning signs			X	X		
Provide flashing yellow light on cones			X	X	X	

After idenfying promising practices to study further, the researchers, with ODOT's assistance, will identify three potential projects (case studies) on which to implement the selected practices. The case study projects are expected to be located on high-speed roadways (e.g., Interstate 5) in Oregon, and involve temporary closure of one or more lanes of traffic to allow the work to proceed. It is also expected that the traffic control design for the projects will be similar to that typically designed for construction and/or maintenance work in Oregon. The promising practices will then be implemented by the construction contractors and/or ODOT staff. Due to the lack of control that the researchers and ODOT Research have over the contractors and ODOT staff, implementation may impact the study schedule. The researchers will aim to select opportunities for implementation that allow for maintaining the planned study schedule.

The field staff will be asked to conduct the operations according to two procedures: as originally planned and designed without the new, promising practice (control), and as revised with the promising practice (treatment). Unless fewer days of data collection are available or needed, data will be collected for two days of control and two days of treatment on each case study project. The data collected on the control days will be used as the baseline for comparison. For both the treatment and control cases, the researchers will document the operations (e.g., video record, photograph, and record pesonal observations) and record any observed benefits, limitations, and safety concerns. The observations and video recordings will be performed from inside the work vehicles, inside the researchers' personal vehicles, and/or at a safe location in the right-of-way (e.g., on the shoulder or median) depending on the nature of the operation and the traffic and site conditions. Vehicle speeds adjacent the traffic control operations will also be recorded. To place the speed sensors on the roadway, OSU will need assistance from ODOT personnel and/or the contractor (e.g., rolling slowdown). Finally, while onsite, the researchers will interview the workers to gain their perspectives on the feasibility of the promising practices and their impact on safety.

The researchers will analyze the data collected to assess the impacts of the applied treatment(s) and highlight the potential feasibility and value of their application in practice. Discrete event simulation (DES) or similar analysis technique that allows for analysis at discrete points in time during the work operation will be used. DES is used to model the operation of a system as a series of distinct events in time. Each event occurs at a particular instant in time and marks a change of state in the system. Between consecutive events, no change in the system is assumed to occur. This assumption allows for directly stepping to the occurrence time of the next event. For application to the operations associated with temporary traffic control, the researchers will use DES to evaluate the hazards and risk at different points in time during the operation, which will then allow for quantification of the cumulative risk for the entire operation. Comparisons of risk will be made for both the control and treatment cases to objectively show whether the treatment is beneficial.

Task 9: Develop Guidance Document

The results of the application and evaluation of the selected practices (Task 8) combined with the findings from the literature review, focus group interviews, survey, and onsite observations, will inform the development of recommendations for set-up, removal, and modification of temporary traffic control. These recommendations will be described in a guidance document that provides detailed information for ODOT staff and contractors to help them plan and implement traffic control operations. Following initial development of the guidance, the researchers will consult with the TAC to obtain their input. Feedback from the TAC will be incorporated into the final version of the document.

Task 10: Draft Final Report

The researchers will prepare a publication-ready draft final report according to the prescribed ODOT report format. The report formatting will include the prescribed fonts, spacing, citations, and graphics. Report contents will include: an updated abstract (in accordance with ANSI/NISO Z39.14-1997, Rev. 2015, "Guidelines for Abstracts"), acknowledgement, disclaimer, introduction, updated literature review (Task 2), final research methodology (Task 4), draft description and analysis of data collected (Tasks 3, 6, 7, 8), discussion of results, conclusions, and potential for future research, application, or technology transfer, and other sections as appropriate. The report will also include the guidance document (Task 9).

Task 11: Draft Research Note

The researchers will write a 1,000 – 1,500-word summary of the research study. The summary will concisely document the research findings, value of the research to the agency, science, and society, and any limitations on the use of the findings. ODOT will provide a template for the research note. The research note will serve as an executive summary of the study. The final research note is intended for distribution to the general public and will have a Flesch-Kincaid Grade Level between eight (8) and thirteen (13).

Task 12: TAC Meeting #3

TAC meeting #3 will be conducted to present the final research findings. The draft final report and draft research note will be submitted for TAC review prior to the TAC meeting. The PI will prepare a presentation and supporting documents to be presented at the TAC meeting that describe the results of the study and recommendations. The TAC will offer advice on the content and clarity of these work products. The TAC will also advise on post-research implementation.

Task 13: Final Report

Task 13 will entail revising the draft final report to incorporate edits identified by the ODOT Research Coordinator after the last TAC meeting.

Task 14: Final Research Note

Task 14 includes revising the draft research note to incorporate edits identified by the ODOT Research Coordinator after the last TAC meeting.

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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 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?

	0% - 20%	21% - 40%	41% - 60%	61% - 80%	81% - 100%
Planning traffic control set-up and removal operations (1)	○	○	○	○	○
Performing traffic control set-up and removal activities in the field (2)	○	○	○	○	○

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 <u>short-term</u> (e.g., 1 day or night) operations on <u>high-speed roadways</u> with multiple lanes in each direction (e.g., freeway) and <u>free-flow</u> traffic (no congestion) that requires the closure of one or more lanes.

	Not familiar	Minimal familiarity	Low familiarity	Moderate familiarity	Very familiar	Extremely familiar
Planning traffic control set-up and removal operations (1)	○	○	○	○	○	○
Performing traffic control set-up and removal activities in the field (2)	○	○	○	○	○	○

Q3.0 **Section 3. Temporary Traffic Control Set-up and Removal Activities/Tasks and Safety Impacts**

<u>Based on your personal experience</u>, 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, **<u>safety risk</u>** 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 <u>short-term</u> (e.g., 1 day or night) operation on a <u>high-speed roadway</u> with multiple lanes in each direction (e.g., freeway) and <u>free-flow</u> 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): ____

Carry Forward Selected Choices - Entered Text from "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."

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:

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

	Lack of available workers	Workers not following planned process	Lack of available equipment or equipment breakdown	Planned process not applicable to field conditions	Time pressure to complete the set-up/removal
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):					

Carry Forward Selected Choices - Entered Text from "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."

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.

	Lack of light (e.g., nighttime work)	Difficulty accessing lane or blocking traffic	Lack of space available for workers/equipment
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):			

Carry Forward Selected Choices - Entered Text from "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."

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.

	High speed of passing vehicles	High volume of traffic	High volume of trucks	Traffic congestion	Aggressive drivers (e.g., impatient, late merge, following too close, etc.)
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):					

Q3.5 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

Display This Question:

If To what extent are the safety risks associated with the set-up of temporary traffic control simil... = 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 simil... = 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 simil... = 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 Approximately what percentage of your job involves the following roles related to the set-up and... = 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... = 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... = 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... = 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.

	No risk	Very low risk	Low risk	Moderate risk	High risk	Extremely high risk	I don't know
Advanced Warning Area							
Transition Area							
Activity Area (including buffer space and work space)							
Termination Area							

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.

	No risk	Very low risk	Low risk	Moderate risk	High risk	Extremely high risk	I don't know
Advanced Warning Area	○	○	○	○	○	○	○
Transition Area	○	○	○	○	○	○	○
Activity Area (including buffer space and work space)	○	○	○	○	○	○	○
Termination Area	○	○	○	○	○	○	○

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.

______ Daytime (7:00AM - 7:00PM) with high traffic volume but no congestion
______ Daytime (7:00AM - 7:00PM) with high traffic volume and congestion
______ Daytime (7:00AM - 7:00PM) with low traffic volume and free-flow speeds
______ Nighttime (7:00PM - 7:00AM) with high traffic volume but no congestion
______ Nighttime (7:00PM - 7:00AM) with high traffic volume and congestion
______ 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.

_______ Daytime (7:00AM - 7:00PM) with high traffic volume but no congestion
_______ Daytime (7:00AM - 7:00PM) with high traffic volume and congestion
_______ Daytime (7:00AM - 7:00PM) with low traffic volume and free-flow speeds
_______ Nighttime (7:00PM - 7:00AM) with high traffic volume but no congestion
_______ Nighttime (7:00PM - 7:00AM) with high traffic volume and congestion
_______ Nighttime (7:00PM - 7:00AM) with low traffic volume and free-flow speeds

Display This Question:

If 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 [21% - 40%]

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 [41% - 60%]

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 [61% - 80%]

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 [81% - 100%]

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): ____

Display This Question:

If 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 [21% - 40%]

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 [41% - 60%]

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 [61% - 80%]

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 [81% - 100%]

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): ____

Carry Forward Selected Choices - Entered Text from "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."

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.

	No risk	Very low risk	Low risk	Moderate risk	High risk	Extremely high risk	I don't know
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):	

Carry Forward Selected Choices - Entered Text from "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."

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.

	No risk	Very low risk	Low risk	Moderate risk	High risk	Extremely high risk	I don't know
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):

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.

____