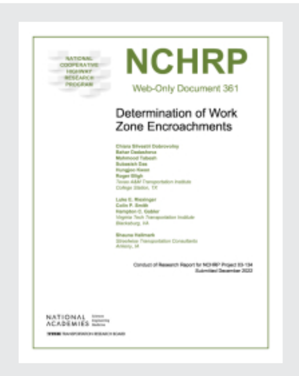

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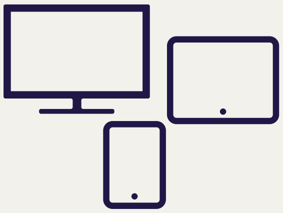

NCHRP

Web-Only Document 361

Determination of Work Zone Encroachments

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Conduct of Research Report for NCHRP Project 03-134
Submitted December 2022

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TABLE OF CONTENTS

NCHRP Web-Only Document 361 contains the conduct of research report for NCHRP Project 03-134 and accompanies *NCHRP Research Report 1055: Addressing Encroachment-Related Safety Issues in Work Zones: A Guide.* Readers can read or purchase *NCHRP Research Report 1055* on the National Academies Press website (nap.nationalacademies.org).

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	Definition
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
Caltrans	California Department of Transportation
CDS	Crashworthiness Data System
CRSS	Crash Report Sampling System
DAS	Data Acquisition System
DOT	Department of Transportation
EDR	Event Data Recorder
F.A.I.	Federal Aid Interstate
FARS	Fatality Analysis Reporting System
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FOT	Field Operational Test
GAD	General Area of Damage
GES	General Estimates System
GPS	Global Positioning System
H&K	Hutchison and Kennedy
HSIS	Highway Safety Information System
IS	Impact Severity
ITS	Intelligent Transportation System
MASH	Manual for Assessing Safety Hardware
MP	Mile Post
MUTCD	Manual on Uniform Traffic Control Devices
NASS	National Automotive Sampling System
NCHRP	National Cooperative Highway Research Program
NDS	Naturalistic Driving Study
NHTSA	National Highway Traffic Safety Administration
NMVCCS	National Motor Vehicle Crash Causation Survey
NWZSIC	National Work Zone Safety Information Clearinghouse
NYSDOT	New York State Department of Transportation
OBMS	Onboard Monitoring System
OR	Odds Ratio
PCB	Portable Concrete Barrier
PDO	Property Damage Only
PEW	Peer Exchange Workshop
RDG	Roadside Design Guide
ROR	Run-off-Roadway

RSAP	Roadway Safety Analysis Program
RSE	Roadside Equipment
S.D.	Standard Deviation
SHL	Specific Horizontal Location
SHRP2	Second Strategic Highway Research Program
SPMD	Safety Pilot Model Deployment Data
SVC	Single-Vehicle Crash
TL	Test Level
TMA	Truck-Mounted Attenuator
TRB	Transportation Research Board
TTC	Temporary Traffic Control
UMTRI	University of Michigan Transportation Research Institute
VMS	Variable Message Sign
VTTI	Virginia Tech Transportation Institute

SUMMARY

Over 102,000 work zone crashes occurred in 2020 in the United States, which equates to a work zone crash every 5.2 minutes. A fatal work zone crash occurs every 10.2 hours and, in 2020, accounted for 2.2 percent of all U.S. roadway fatalities (857 of 38,824) (National Work Zone Safety Information Clearinghouse [NWZSIC], 2022). U.S. roadway work zone fatalities increased by 19 percent from 2015 to 2020, and the Federal Highway Administration cited additional traffic, distracted driving, and an increase in construction projects as possible factors for the increase (Slowey and Zubrzycki, 2018).

Work zone crashes are a safety concern not only for the traveling public, but for highway workers as well. In 2016 alone, 143 work zone associated fatalities occurred, with 61 percent of those being workers struck by a highway vehicle (NWZSIC, 2022). Therefore, addressing work zone crashes is critical for both the traveling public and highway workers. A few researchers have attempted to investigate crashes that involve intrusions into the workspace. Bryden et al. (2000), Ullman et al. (2008), and Ullman et al. (2011) used data collected by the New York State Department of Transportation on work zone crashes to investigate the frequency, severity, and causes of intrusion crashes occurring in that state. Researchers found that approximately 9 percent of all work zone crashes involved intrusions into the workspace, but this percentage increased at night (possibly due to smaller, more focused work operations occurring during that time period). Researchers also found that workers were struck in about 9 percent of those intrusion crashes during daytime operations and in about 31 percent during nighttime operations. Unfortunately, detailed information about the characteristics of the intruding vehicles (speeds, encroachment angles, trajectories, etc.) was not captured.

To help address work zone crashes, the research team identified the need to collect and investigate vehicle encroachment conditions associated with work zone locations to develop a better understanding of the adequacy of existing guidelines and assess the need to potentially revise such guidance for proper implementation.

The research team collected and investigated available data from vehicle encroachment conditions associated with work zone locations. Data were mainly collected from available and applicable naturalistic driving studies, shared state crash databases, and National Motor Vehicle Crash Causation Survey and National Cooperative Highway Research Program Project 17-43 databases. Exploratory data analysis and cluster correspondence analysis were conducted to investigate encroachment, roadway, roadside, work zone, and driver behavior conditions.

A peer exchange workshop was conducted to provide an overview of the project draft products, engage agency participants in discussions, solicit feedback for potential content inclusion in the final guidance document, and identify future research needs. Based on participant feedback, several common themes emerged, along with various research project ideas for future exploration. This report provides recommendations for additional research within this topic area.

This study culminated with a better understanding of available resources to best address guidance for implementation of safety measures in work zones. In line with the efforts performed to investigate vehicle encroachment conditions associated with work zone locations, one of the project objectives was to support potential updates to the *Manual for Assessing Safety Hardware* (MASH), the *Roadside Design Guide* (RDG), and the *Manual on Uniform Traffic Control Devices* (MUTCD).

Researchers concluded that there is not sufficient evidence to support the need to revise current guidance pertaining to impact conditions in MASH. Also, the current guidance from the RDG on clear zone requirements seems to be appropriate considering the recorded lateral extensions of encroachments in work zone locations. However, based on the project findings, potential guidance implications for the MUTCD include the following:

- <u>Section 6C.04. Advance Warning Area</u>: This section discusses traffic control devices for the advance warning area. The findings suggest that around 9 percent of work zone encroachment-related crashes occur in the advance warning area. However, no other information was available to suggest additional guidance needs to be provided.
- <u>Section 6D.03. Worker Safety Considerations</u>: This section discusses use of temporary traffic barriers, which is based on factors such a lateral clearance of workers from adjacent traffic and speed reduction. The findings suggest encroachment speeds are 49.7 mph for left-side encroachment and 51.0 mph for right-side encroachment. Additionally, 8 percent of encroachment crashes in work zones strike work zone equipment. The suggested recommendations in this section could be examined to determine whether they are sufficient given likely lateral clearance when a vehicle encroaches into the work zone environment.
- <u>Section 6F. Temporary Traffic Control Devices</u>: This section outlines considerations for traffic devices in work zones. The findings suggest right-side encroachments are higher than left-side encroachments in work zones (8.5 vs. 5.2 ft). Section 6F could offer guidance on the amount of lateral clearance that should be provided with use of traffic control devices placed on the left or right shoulder.

Products of this research study include proposed current guidance revisions; a dataset that incorporates collected data, including a complementary report, NDS Data Collection, that provides a list of the element attributes and description of the features, sources, and methods used for data extraction; and research project ideas for future exploration.

CHAPTER 1. INTRODUCTION AND OVERVIEW

INTRODUCTION

Over 102,000 work zone crashes occurred in 2020 in the United States, which equates to a work zone crash every 5.2 minutes. A fatal work zone crash occurs every 10.2 hours and, in 2020, accounted for 2.2 percent of all U.S. roadway fatalities (857 of 38,824) (National Work Zone Safety Information Clearinghouse [NWZSIC], 2022). U.S. roadway work zone fatalities increased by 19 percent from 2015 to 2020, and the Federal Highway Administration (FHWA) cited additional traffic, distracted driving, and an increase in construction projects as possible factors for the increase (Slowey and Zubrzycki, 2018).

National Cooperative Highway Research Program (NCHRP) Report 869 (NCHRP Project 17-61) listed a number of reasons why work zones can adversely affect the safety of traffic approaching and passing through them (Ullman et al., 2017). Generally, work zone equipment, traffic control devices, and workers are located in close proximity to travel lanes, which can increase the probability of vehicles crashing into the work zone equipment or hitting the roadway workers. Garber and Woo (1990) found a 57 percent increase in crashes on multilane highways in Virginia and a 168 percent increase on two-lane urban highways compared to crash rates in the period before the onset of work zones. Nemeth and Migletz (1978) also showed that crash rates during construction increased significantly compared to the period before construction. Hall and Lorenz (1989) found that crashes during construction increased by 26 percent compared to crashes in the same period in the previous year when no construction occurred. Similarly, Rouphail et al. (1988) found that the crash rates during construction increased by 88 percent compared to the before period for long-term work zones; on the other hand, results from the same study indicated that the crash rates for short-term work zones were not affected by the roadwork.

Moreover, many work zones require drivers to temporarily change their travel path, and in some cases, their travel lanes, which can increase crash probability if the drivers are engaged in distracted behaviors and are not able to see the advance warning signals and pavement markings. Distracted driving, failure to yield, and traveling at unsafe speeds are among the most significant work zone crash-contributing factors. Liu et al. (2016) found that the likelihood of an injury was 10 percent higher when a driver involved in the crash committed an intentional improper action, such as speeding or following too closely. A review of 2014 Fatality Analysis Reporting System (FARS) data indicated that 71.4 percent of fatal work zone crashes were speeding related, while only about 30 percent of all fatal crashes were speeding related, indicating that driver behavior can have more devastating impacts on safety of work zones compared to non-work zones (National Highway Traffic Safety Administration [NHTSA], 2014).

Work zone crashes are not only a problem for the traveling public—they also are a serious concern for highway workers. In 2020, 117 work zone associated fatalities occurred, with 45 percent of those being workers struck by a highway vehicle (NWZSIC, 2022). Therefore, addressing work zone crashes is critical for both the traveling public and highway workers. A few researchers have attempted to investigate crashes that involve intrusions into the workspace. Bryden et al. (2000), Ullman et al. (2008), and Ullman et al. (2011) all used data collected by New York State Department of Transportation (NYSDOT) staff on work zone crashes to investigate the frequency, severity, and causes of intrusion crashes occurring in that state. Researchers found that approximately 9 percent of all work zone crashes involved intrusions into the workspace, but this percentage increased at night (possibly due to smaller, more focused work operations occurring during that time period). Researchers also found that workers were struck in about 9 percent of those intrusion crashes during daytime operations and about 31 percent during nighttime operations. Unfortunately, detailed information about the characteristics of the intruding vehicles (speeds, encroachment angles, trajectories, etc.) were not captured in that database.

RESEARCH GOAL

This research investigated vehicle encroachment conditions associated with work zone locations. This study culminated with a better understanding of available resources to best address guidance for implementation of safety measures in work zones. Guidance addressed to state departments of transportation (DOTs) and research practitioners was developed to improve safety for workers and the traveling public in roadway work zones. The guidance is intended to address all aspects of work zones, from planning (including when to use positive protection) through implementation, and be usable by any entity involved in the life cycle of the work zone.

DEFINITION OF WORK ZONE AND WORK ZONE ENCROACHMENT

The project team identified a *work zone* based on the following definition provided by FHWA: "A work zone is an area of roadway with construction, maintenance, or utility work activities. A work zone is typically marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign to the 'end Road Work Sign' or the last temporary traffic control device" (Turner, 1999). In addition, the MUTCD defines different work zone areas, such as advance warning area, transition area, activity area, and termination area (FHWA, 2009). The project team identified a *work zone encroachment* as the vehicle travel condition when such a vehicle inadvertently traverses across the boundaries of a work zone. Based on the different zone areas defined in the MUTCD, encroachments occurring in the advance warning area might be defined as departures across the edge line of the travel way, whereas those in the transition and activity areas could be across either a lane line or an edge line.

REPORT ORGANIZATION

Chapter 2 of this report summarizes the conducted literature review and state-of-the-practice review related to work zone safety. In addition, the report appendix provides the detailed state responses to a survey conducted for Task 2. Chapter 3 summarizes the potential implications of work zone encroachment databases for publications and guidelines by reviewing the data needs of these publications, and presents the list of potential data sources for obtaining the data elements. Chapter 4 provides a data collection plan in the form of a data catalog that presents a comprehensive list of combined data elements and relevant data sources. Chapter 5 provides an overview of the conducted encroachment data collection process, while Chapters 6 and 7 report the results of the conducted exploratory analysis, cluster correspondence analysis, and data mining, accounting for encroachment, roadway, roadside, work zone, and driver behavior conditions. Chapter 8 details the conducted peer exchange workshop and its outcomes. Chapter 9 provides a better understanding of available resources to best address guidance for implementation of safety measures in work zones and discusses proposed guidance revisions. Finally, Chapter 10 provides concluding remarks and recommendations for additional research.

CHAPTER 2. SUMMARY OF LITERATURE AND STATE OF THE PRACTICE

CHAPTER OVERVIEW

This chapter presents the results of the literature review on work zone safety and encroachment databases and the state-of-the-practice review.

WORK ZONE SAFETY

With over 90 percent of the national interstate highway network infrastructure completed, emphasis is now being placed on the rehabilitation and widening of existing highways rather than the construction of new ones (Garber and Patel, 1995). The need to repair, resurface, or replace sections of roadway or roadway structures will always exist. Work zones are required for workers to perform this work on an existing roadway with traffic in close proximity since it is often not possible or feasible to completely close a roadway during the required work. Over time, work zones have evolved from simple layouts that may not have been particularly effective in promoting safety into modern designs that attempt to maximize safety whenever possible. However, despite the best efforts of transportation officials, work zone crashes still occur (Schrock et al., 2004). Over 102,000 work zone crashes occurred in 2020 in the United States, which equates to a work zone crash every 5.2 minutes. A fatal work zone crash occurs every 10.2 hours and, in 2020, accounted for 2.2 percent of all U.S. roadway fatalities (857 of 38,824) (NWZSIC, 2022). U.S. roadway work zone fatalities increased by 19 percent from 2015 to 2020, and FHWA cited additional traffic, distracted driving, and an increase in construction projects as possible factors for the increase (Slowey and Zubrzycki, 2018). Furthermore, crash rates increase during roadwork (Whitmire et al., 2011), and work zone crashes are more severe than other crashes (Debnath et al., 2012).

The MUTCD defines different work zone areas, such as advance warning areas, transition areas, activity areas, and termination areas. For this study, the research team identified a work zone encroachment as "the vehicle travel condition when such a vehicle inadvertently traverses across the boundaries of a work zone." Based on the different zone areas defined by the MUTCD, encroachments occurring in the advance warning area might be defined as departures across the edge line of the travel way, whereas those in the transition and activity areas could be across either a lane line or an edge line. Garber and Zhao (2002) found that the most reported locations for crashes were the work zone activity areas, followed by the transition, advance warning, and buffer areas. While the advance warning, transition, and termination areas tend to be fairly limited (and consistent from work zone to work zone), the length of activity and buffer areas can vary widely from project to project. Thus, the distribution of crashes is somewhat skewed due to differences in exposure. Even so, Garber and Zhou also found that rear-end collisions tended to be the dominant crash type in all work zone areas, and these collisions were even more dominant in the advance warning areas.

NCHRP Report 869 (NCHRP Project 17-61) lists a number of reasons why work zones can adversely affect the safety of traffic approaching and passing through them (Ullman et al., 2017).

Generally, work zone equipment, traffic control devices, and workers are located in close proximity to travel lanes, which can increase the probability of vehicles crashing into work zone equipment or hitting roadway workers. Garber and Woo (1990) found a 57 percent increase in crashes on multilane highways in Virginia and a 168 percent increase on two-lane urban highways compared to crash rates before the onset of work zones. Hall and Lorenz (1989) found that crashes during construction increased by 26 percent over crashes in the same period in the previous year when no construction occurred. Similarly, Rouphail et al. (1988) found that crash rates during construction increased by 88 percent compared to the before period for long-term work zones. On the other hand, results from the same study indicated that crash rates for short-term work zones were not affected by the roadwork.

Driver behavior has also been found to be associated with high crash risk in work zones. Work zones require that drivers temporarily change their travel paths and travel lanes, which can increase the crash probability if the drivers are engaged in distracted behaviors and are not able to see advance warning signals and pavement markings. Distracted driving, failure to yield, and traveling at unsafe speeds are among the most significant work zone crash-contributing factors. Liu et al. (2016) found that the likelihood of an injury was 10 percent higher when the driver involved in the crash committed an intentional improper action, such as speeding or following too closely. A review of 2014 FARS data indicated that 71.4 percent of fatal work zone crashes were speeding related, while only about 30 percent of all fatal crashes were speeding related, indicating that driver behavior can have more devastating impacts on safety in work zones than in non-work zones (NHTSA, 2014).

Work zone crashes are not only a problem for the traveling public—they are a serious concern for highway workers too. In 2020 alone, 117 work zone associated fatalities occurred, with 45 percent of those fatalities the result of being struck by a highway vehicle (NWZSIC, 2022). Therefore, addressing work zone crashes is critical for both the traveling public and highway workers. A few researchers have attempted to investigate crashes that involve intrusions into the workspace. Bryden et al. (2000), Ullman et al. (2008), and Ullman et al. (2011) all used data collected by NYSDOT staff on work zone crashes to investigate the frequency, severity, and causes of intrusion crashes occurring in that state. Researchers found that approximately 9 percent of all work zone crashes involved intrusions into the workspace, but this percentage increased at night (possibly due to smaller, more focused work operations occurring during that time period). Researchers also found that workers were struck in about 9 percent of those intrusion crashes during daytime operations and about 31 percent during nighttime operations. Unfortunately, detailed information about the characteristics of the intruding vehicles (speeds, encroachment angles, trajectories, etc.) was not captured in that database.

The presence of a work zone can cause traffic congestion and create a more complex traffic environment for the traveling public. Traffic congestion may increase driver frustration, making drivers willing to engage in risky driving behavior in an effort to bypass delays (Maze et al., 2000). Risky driving behavior is still a major reason for the high likelihood of severe crashes in a work zone. Risky driving behavior encompasses the following: speeding, aggressive lane changing, careless/negligent/reckless driving, failing to give way to pedestrians, disregarding traffic control signals, and using an improper lane. A study conducted by Li and Bai (2006) reported that 92 percent of work zone crashes in Kansas are due to human error, including driver inattention and excessive speed (Li and Bai, 2009). Driver inattention, including not noticing road signs, could lead to noncompliance with the lower speed limits usually imposed in roadwork zones. Speeding is another factor associated with crash risk in work zones. Researchers in Victoria, Australia, found that more than 40 percent of cars and more than 70 percent of trucks exceeded signed speed limits in work zones (Haworth et al., 2002). In another Australian study, over 60 percent of drivers exceeded the 60 km/h speed limit, and 10 percent and 1 percent of drivers exceeded the limit by 15 km/h and 30 km/h, respectively (Debnath et al., 2012).

Variable message signs (VMSs) have more influence on speed reduction than traditional static signage. Studies have shown that VMSs were more effective than traditional traffic control devices in reducing the number of speeding vehicles (Garber and Patel, 1995; Garber and Srinivasan, 1998). A VMS is often combined with a speed measuring device in order to show drivers their instantaneous speeds and to display messages if they exceed the posted limit. Fontaine et al. (2000) found this combination reduced speeds by up to 16 km/h and lowered the percentage of vehicles speeding, whereas using a VMS alone resulted in about a 3 km/h speed reduction. Similar findings were also obtained by Maze et al. (2000). In that study, the authors found that speed feedback systems were more effective than police presence in reducing speeds in work zones. Likewise, in another study, motorists tended to maintain speed reductions after crossing the speed feedback system but increase speeds after passing a police officer (Arnold Jr., 2003). VMSs and speed feedback systems were also perceived as important measures to improve roadway worker safety by 92 percent and 87 percent of respondents, respectively, in a survey (MVA Consultancy, 2006). However, younger drivers, who are less likely to be concerned about roadway worker safety and are reluctant to change driving behaviors in work zones, were found to be less supportive of the measures (Debnath et al., 2012).

ENCROACHMENT DATA COLLECTION STUDIES

While current data suggest that work zones have a higher risk than non-work zones for crashes and fatal injuries, data on the impact conditions associated with work zone crashes are not well documented. Previous research regarding work zone safety encroachments indicates that a higher frequency of fatalities occurs in work zone encroachments than in non-work zone encroachments.

Roadway encroachment is defined as travel by a vehicle on roadway areas outside the limits of the designated lane(s) of travel. The potential path a vehicle may take during an encroachment is affected by numerous factors, including speed limit, various roadway (e.g., horizontal and vertical alignment, lane/shoulder width) and roadside (e.g., side-slope, access point density) characteristics, weather and lighting conditions, and driver behavior (e.g., steering, braking).

Early Encroachment Database Studies

Currently, very limited information exists regarding the encroachment conditions in work zones since there are no reliable datasets. Encroachment datasets were developed in two early studies: (a) Hutchinson and Kennedy (1962), and (b) Cooper (1980).

Hutchinson and Kennedy (1962): The runout lengths contained in the RDG are based on the Hutchinson and Kennedy study that investigated the frequency, nature, and causes of vehicle encroachments on medians of divided highways to obtain information needed to establish traffic safety criteria for median and cross-section design. The use of medians for separating traffic moving in the opposing direction of travel is one of the most important approaches to making the modern highway safer.

Hutchinson and Kennedy studied the significance and nature of vehicle encroachments on medians of divided highways in 1960. The ultimate objective of their study was to determine the desired width and cross section for highway medians in both rural and urban locations by considering safety, service to traffic, and economy, but the focus of this study was on traffic operation aspects rather than economic aspects. They reported that 43 percent of all rural fatal motor vehicle crashes were of the non-collision type crash, and 81 percent of those non-collision crashes occurred because the vehicle ran off the pavement. The specific objective of their study was to determine the significance and nature of vehicle encroachment. Several highway locations were studied in detail to determine frequency, nature, and cause of vehicle encroachment on medians.

Crash reports do not provide valuable information about the significance or nature of vehicle encroachment because there is no indication of the extent to which the median is successful as a stopping or recovery space for erratically moving vehicles and for the successful stopping or control of the vehicle. In addition, unreported cross-median vehicle movements or minor collisions often occur. Hutchinson and Kennedy's method consisted of analyzing the evidence at the site of vehicle encroachment. The study was performed during winter months between December 1 and March 31 in order to use snow cover to locate tire tracks made by encroaching vehicles. More thorough surveillance was provided in order to avoid losing evidence due to snowstorms, melting snow, and maintenance personnel activities. The record of each encroachment consisted of a sketch of the path of vehicular movement with dimensions, highway cross-section dimensions, type of median cover, approximate time of occurrence, and other pertinent data. A visual record of each encroachment was compiled using a series of color and black-and-white pictures. This dataset consisted of 296 shoulder and 26 median encroachments, respectively, and was limited to data from unintentional encroachments with lateral movements in excess of 3 ft. Encroachments involving less lateral movement were not recorded because of the extreme difficulty of detecting encroachments on the 3-ft stabilized shoulder. During the period of study, 302 and 26 unintentional encroachments were detected and recorded for Federal Aid Interstate (F.A.I.) Routes 74 and 57, respectively. Since data collection was conducted during winter months when the median was covered in snow, the data resulted in longer than usual encroachments.

According to Hutchinson and Kennedy, the frequency of encroachments at any given location also indicates the possible factors causing or influencing encroachments. Drivers act more independently at low traffic volumes; extensive freedom of movement is restricted only by physical features of the roadway, but as traffic volume increases, driver vehicle behavior is influenced to a greater and greater extent by the presence of other vehicles. The frequency of encroachment increased with traffic volume until an average daily traffic (ADT) volume of about 4,000 vehicles per day was reached. At subsequent higher traffic volumes, the frequency of encroachments decreased until a minimum was attained at about 6,000 vehicles per day.

The analysis of the nature of the median encroachments was conducted for F.A.I. Routes 74 and 57. Hutchinson and Kennedy studied the lateral extent of movement, length of travel, and angle of encroachment to analyze the nature of encroachments. The lateral extent of movement is defined as the perpendicular distance from the pavement edge to the path of the left front tire of the vehicle at some specified point in the encroachment pattern. The length of travel is the distance from the point at which the vehicle departs from the roadway to some specified point in the encroachment pattern, as measured along the left front tire path. The lateral extent of median encroachments can indicate the median width required to provide an appropriate vehicle stopping and recovery space. It can also serve as a measure of the effectiveness of the median cross section in controlling lateral vehicle movement. The length of vehicle travel during encroachment shows the reasonable extent to which the median should be free of obstacles that cannot be traversed safely at normal highway operating speeds.

The mean values of length of travel for F.A.I. Routes 74 and 57 were 293 ft and 292 ft, respectively. The greater the length of travel, the greater the probability that the vehicle would strike a median obstacle such as a culvert headwall, a drop inlet, or a ditch check. During the 3.5-year study of F.A.I. Route 74, 11.9 percent of all encroaching vehicles struck obstacles in the median, and many other vehicles came close to striking obstacles. The significance of obstacles in the median was even greater than would be indicated by an estimate of the crash costs and injuries resulting directly from collisions with these obstacles. Attempts to determine significant relationships between the three basic parameters—angle of encroachment and lateral and longitudinal encroachment travel distances—were not successful, probably due to a large number of variables that could not be measured. Because of the wide range of lateral and longitudinal encroachment travel distances that may be expected for any given encroachment angle, a wide range of lateral velocity components must be considered in the design of median barriers to achieve safe vehicle deceleration rates.

Discussion about the factors causing or influencing vehicle encroachments on the median of 24.6 mi of F.A.I. Route 74 between Champaign and Danville, Illinois, during the 3.5-year period of the study shows that light condition, fatigue, weather, grade separation structure, road signs, curves, and terrain features can cause encroachment. However, the driver is the ultimate variable because he or she is the conscious and subconscious sensor of landscape, vehicles, roadway alignment, weather, fatigue, light conditions, pavement surface conditions, and most other factors involved in erratic vehicle movements. To completely understand the driver would be to completely understand the individual, a goal beyond the reach of human capabilities.

Cooper (1980): The data in the Cooper study were collected from five Canadian provinces from June through October 1978 on two-lane undivided and four-lane divided roadways with annual average daily traffic (AADT) ranging from 700 to 29,300 vehicles operating at speeds from 56 mph to 67 mph. The total length of the roadway segments was 2,833 mi. Unlike the Hutchinson and Kennedy study data collection, which occurred during winter months, the Cooper study data collection occurred during non-winter months, which are prime months for roadway construction.

On the other hand, the roadways sampled for data collection in the Cooper study had relatively wide shoulders, approximately 13 ft, which could have prevented many narrow-angle encroachments from being detected. Additionally, roadways under work zone conditions may or may not have had shoulder room, especially if work zone barriers were placed close to the roadway edge line.

Other early studies: In consideration of the time and cost of encroachment data collection, Miaou (1997) developed an encroachment model based on a crash prediction model for two-lane rural roadways. Crash prediction models only capture the reported crashes; thus, they do not account for near-crashes or incidents that can happen due to encroachments. Neither the crash nor encroachment models developed in this study took into account driver behavior, which can be a contributor to vehicles encroaching or being involved in crashes. When conducting a meta-analysis of run-off-roadway (ROR) crash studies, Janssen et al. (2006) found that not many studies had examined the role of driving behavior in the chain of events leading to ROR crashes.

New Encroachment Database Studies

Hallmark et al. (2015): Hallmark et al. studied driver response to changing roadway characteristics and traffic conditions. Time series models were developed to incorporate the dynamic process of information acquisition and response as a driver negotiates a curve. The analysis evaluated the influence of roadway geometries or traffic conditions on drivers' lane-keeping behavior. For example, drivers on a rural two-lane roadway tend to have larger lane deviation from the centerline when there is an oncoming vehicle. Overall, existing encroachment datasets are not representative of a wide range of roadway characteristics. As a result, it is difficult to develop robust predictive models for encroachment conditions. Another area that has been under-researched is how the rate of encroachment event is impacted by driver behaviors and the presence of in-vehicle distractions, such as cellphone use. In particular, these underlying datasets do not reflect the true relationship between encroachment frequency and traffic. As a result, a more comprehensive approach to collecting encroachment data is needed to address these shortcomings in order to support updates to MASH, RDG, and MUTCD.

NCHRP 17-88: The objectives of the active NCHRP Project 17-88 are to develop a database of roadside encroachment characteristics for a variety of roadside conditions and roadway types and then analyze the database to evaluate (a) the factors that influence the nature and frequency of roadside encroachments; (b) the relationship between unreported and reported crashes; and (c) whether heavy vehicle, bus, and motorcycle encroachments resulting in a crash differ from passenger vehicle encroachments resulting in a crash. The NCHRP Project 17-88 encroachment database will record encroachments across the full range of highway vehicle types, including passenger vehicles, heavy vehicles, buses, and motorcycles, along with the entire spectrum of encroachment severities (Transportation Research Board [TRB], 2022).

STATE OF THE PRACTICE

The project team used a variety of state DOT publications and results of a survey of DOTs to review the state of the practice on use of positive protection in work zones The survey was developed by the research team with the objective of gathering agencies' policies pertaining to roadside encroachment-intruding work zones, and it was distributed to 50 state DOTs. The survey and results are presented in Appendix A and Appendix B, respectively. Based on the findings, Table 1 lists the data elements used in work zone positive protection practices. These data elements can be divided into three key data element groups:

- Work zone characteristics.
- Roadway and roadside characteristics.
- Operational characteristics.

The criteria that states use to assess whether to use positive protection in work zones are summarized in Table 1 to Table 3. When specific information was available, it was included. When only general information was available, an "X" was indicated. For instance, a number of states replied that they consider whether vehicles have escape paths within the work zone. Most of the guidance noted that states consider incorporating an escape path when deciding whether to use positive protection in work zones. However, no specific criteria were provided.

Table 1 illustrates the work zone characteristics that agencies use to assess the need for positive protection. The majority of the states consider presence of drop-off, presence of escape paths, duration, proximity of workers to moving traffic lanes, and work zone characteristics. Table 2 shows the roadway characteristics that agencies consider. The most common characteristics noted were shoulder type/width, lane type/characteristics, roadway geometry (presence/type of horizontal or vertical curves), sight distance, and type and class of roadway. Finally, Table 3 illustrates the operational characteristics that agencies examine when determining the need for positive protection. The most common consideration noted was speed, which may include speed limit, operating speed, or design speed of the facility scheduled for construction. Volume and vehicle mix were also commonly listed as criteria for consideration.

Table 1. Work Zone Criteria Used by State DOTs to Assess Need for Positive Protection in Work Zones

State	Clear Zone	Drop-off	Escape Path	Duration	Project Characteristics	Time of Day	Work Zone Characteristics	Worker Exposure	Other
Alabama	Presence of bridges/tunnels	X	X	> 2 wk	New vs. existing facility			Worker or equipment near traffic lane	
Alaska			X	≥ 2 wk	Impact on cost and duration	X	Presence of restrictions	Workers near traffic lane	Risk due to positive protection
Arkansas			X				Head-to-head when one lane is closed on 4-lane divided	• Long duration exposure • Workers near traffic lane	Roadside hazard in place overnight or longer
Colorado	Embankment height, height of fill section	X			Impact on cost and duration		• Impact on available lane width • Work area restrictions • Embankment • Separate opposite traffic (if multilane facility shifted to 2-lane-2-way for > 3 days or narrowed lanes)	X	Law enforcement near work zone
Connecticut	Available clear zone			X	Project scope				
Delaware	X	X	X	X	Impact on cost and duration	Night work	• Work area restrictions • Depth of excavation	Workers near traffic lane	• Risk due to positive protection • Access to/from workspace
Florida		X	No escape due to tunnel/ bridge	> 2 wk			Roadside hazards that remain overnight or longer	Workers near traffic lane	
Hawaii	Roadside hazards			X		X	Shoulder/roadway work		
Idaho			X	> 2 wk			Roadside hazards that remain overnight or longer	Workers near traffic lane	
Indiana				X		Nighttime	Shoulder/roadway work		Lane encroachment or restriction
Iowa		X	X	X			Roadside hazards that remain overnight or longer	Workers near traffic lane	
Kansas		X						Workers near traffic lane	
Louisiana						Work hour restriction			Access issues, accessibility
Maryland					• Location • Limits of work				Impacts on right-of-way, utilities, etc.

State	Clear Zone	Drop-off	Escape Path	Duration	Project Characteristics	Time of Day	Work Zone Characteristics	Worker Exposure	Other
					• Project type				
Massachusetts	Equipment within work zone	X							
Michigan	• Unprotected features (walls, piers, foundations) • Proximity to hazards	>=12"		X		Closure time	• Length • Severity of hazards • Size of work area • Barrier deflection distance • Location of work		Excavations
Minnesota	Proximity to hazards	X		X		X	Lane closures/detours	Workers near traffic lane	
Missouri						X	• Location of work • Type of work • Length		Weather conditions
Montana	X	X		X			• Location of work • Nature of potential conflict • Length of hazard • Two-way traffic on one roadway of a divided highway • Transition areas at crossovers and/or lane closures or lane transitions	Workers near traffic lane	• Dynamic deflection of barrier • Proximity to traffic & equipment
Nebraska			X	X			• Location of work • Type of work • Presence of other hazards		
Nevada			X	≥ 2 wk	Impact on cost and duration	X	• Type of work • Work area restrictions	Workers near traffic lane	• Risk due to positive protection • Access to/from workspace
New Hampshire	Offset distance	X	X	X	• Impact on cost and duration • Scope	X	Type of work		• Access • Cost
New Mexico	Zone of intrusion (minimum 5 ft)	X		X	• Impact on cost and duration • Scope	X	• Type of work • Work area restrictions	• Workers near traffic lane • Extent of worker exposure	• Access • Risk due to positive protection
New York				X			Type of lane closure/shift		
North Dakota		X	X				Obstructions		

State	Clear Zone	Drop-off	Escape Path	Duration	Project Characteristics	Time of Day	Work Zone Characteristics	Worker Exposure	Other
Ohio				X			Location		Impact on pedestrians and bicycle
Oklahoma	X	X		X			• Location (roadway, shoulder, off roadway) • Bridge construction		
Oregon			X	X	• Impact on cost and duration • Scope	X	Geometry or restrictions	• Type of worker activity • Distance and exposure durations	• Risk due to positive protection • Contractor access
Pennsylvania		within 12"							
South Carolina				X		Daytime vs. nighttime			
Tennessee	Roadside hazards (unfinished bridge decks, etc.)	X	X	≥ 2 wk			Lane closure	Proximity to traffic lane	
Texas		X							
Utah				Duration of specific work element			Location of work		
Vermont				X			Proximity to other work zones		Access management
Virginia	Distance to fixed object	X		X			• Length • Lateral/longitudinal buffer • Lane closure setup/takedown • Road closures and detours		
Washington			X	X					
West Virginia				X		X	Location (shoulder, within median, within traveled way)		
Wisconsin				X			Location of work		
Wyoming				X		X	Location (shoulder, within median, within traveled way)		

Table 2. Roadway Characteristics Used by State DOTs to Assess Need for Positive Protection in Work Zones

State	Cross Section	Geometry	Intersection	Location	Roadway Type	Visibility	Other
Alabama		Curve radius			Rural highway, freeway, and expressway		Soil slope
Alaska		Sharp curves			Roadway classification	Sight distance	
California	• Shoulder width • Number of lanes						
Colorado		X			• Weight posting of bridge for overweight vehicles • Roadway classification	Sight distance	Potential of vehicle intrusion into pedestrian space
Connecticut							
Delaware	Presence of objects that would adversely impact roadway departures	Horizontal curves				Sight distance	
Florida					Roadway classification		
Hawaii	2-lane vs multilane	• Horizontal curves • Vertical curves				• Shade/color contrast • Weather • Darkness	
Indiana	2-lane vs multilane						
Iowa	• Lane width • Number of lanes						
Louisiana		• Horizontal curves • Vertical curves • Bridges	Presence of adjacent interchanges				
Maryland	Lane width		X		Arterial or freeway	Sight distance	• Pedestrian and bicycle facilities • Proximity to roadways and businesses
Massachusetts	Non-recoverable slope						
Michigan	Lane width	• Horizontal curves • Vertical curves				Sight distance	
Minnesota				Urban vs. rural			
Missouri		• Horizontal curves • Vertical curves	Presence of intersections or interchanges		• Roadway type • Roadway classification		

State	Cross Section	Geometry	Intersection	Location	Roadway Type	Visibility	Other
Montana	Shoulder width	Geometry that may increase likelihood of roadway departure	X		• Roadway type • Roadway classification		
Nevada	Factors that would adversely impact roadway departures	X			Roadway classification	Sight distance	
New Hampshire	• Number and width of lanes • Shoulder type and width			Urban vs. rural	Roadway type		• Location of decision points, access arrangements • Presence of buffer • Adjacent land use
New Mexico	Factors that would adversely impact roadway departures	Features that may increase crash risk			Roadway classification	Sight distance	
New York	Number and width of lanes						
Ohio					Roadway type		
Oregon	Factors that would adversely impact roadway departures				Roadway classification		
South Carolina					Roadway type		
Tennessee	Shoulder width						
Vermont				Urban vs. rural	Primary network		Available detour routes
Virginia					Limited access or highway		
Washington	Lane width						
West Virginia			X		Roadway type		Pedestrian and bicycle facilities
Wisconsin							Presence of rail crossings
Wyoming	Lane width						

Table 3. Operational Characteristics Used by State DOTs to Assess Need for Positive Protection in Work Zones.

State	Crash	Speed	Vehicle Mix	Volume	Other
Alabama		Posted speed > 45 mph	High truck volumes	AADT	
Alaska	Consequences from roadway departures	Speed > 45 mph	X	Volume	
Arkansas		High operation speeds			
Colorado	X	Work zone speeds	X	ADT	
Connecticut					
Delaware	X	Work zone speeds	X	X	Pedestrian/bicycle exposure
Florida		Work zone speeds ≥ 45 mph	X		
Hawaii		X		X	
Idaho		Speed > 45 mph			
Indiana		X	X	X	
Iowa		X	X		
Louisiana		Speed enforcement			• Max expected queuing • Significant recurring congestion
Maryland		Speed limit		X	
Massachusetts					
Michigan		Traffic speed		Seasonal variations in traffic volume	Frequency of traffic stopping/turning movements
Minnesota			X	X	
Missouri		X	X	X	
Montana		Design speed		Seasonal fluctuations	
Nebraska				X	
Nevada		Speed > 45 mph	X	X	
New Hampshire	X	Work zone speed	Percent truck/work zone mix	• ADT • Daily hourly volume • Work zone volume	• Vehicles: dimensions, height, weight, acceleration and braking, center of gravity, cornering and turning stability • Surrounding socioeconomic factors
New Mexico	X	Work zone speed	X	X	
New York		Speed limit			Vehicle weights
Ohio		Traffic speed		X	Nature of traffic change when work underway
Oklahoma		Traffic speed	X	X	
Oregon		Traffic speed	X	X	
South Carolina		Traffic speed	X	X	
Tennessee		Speed > 45 mph			
Utah		Posted speed prior to construction			
Vermont	Existing crash rates		Car-truck-pedestrian-bicycle volume	• AADT • Peak hour traffic	

State	Crash	Speed	Vehicle Mix	Volume	Other
Virginia	ROR crash frequency, expected crashes	Traffic speed		X	
Washington		Speed limit		X	
West Virginia		Traffic speed		X	
Wisconsin		• Speed limit • Reduced speed through the work zone		ADT	
Wyoming		Speed limit			

CHAPTER 3. WORK ZONE ENCROACHMENT DATA: CURRENT PRACTICES, DATA NEEDS, AND SOURCES

CURRENT USES OF ENCROACHMENT DATA

The encroachment data collected in early studies by Hutchinson and Kennedy (1962) and Cooper (1980) are available for use to state DOTs. These data are not used directly but rather indirectly through FHWA and American Association of State Highway and Transportation Officials (AASHTO) guidelines, such as the MUTCD, RDG, and MASH. Any potential changes to the work zone encroachment data will affect these guidelines and thus the state practices. The following sections present the current practices used in the guidelines and related relevant information. This information was used to develop a comprehensive data catalog that the researchers employed to collect the work zone encroachment data.

Manual for Assessing Safety Hardware

The AASHTO (2016) MASH provides specifications that govern full-scale crash testing and evaluation of roadside safety features, including work zone barrier systems. The recommended test matrixes in MASH prescribe impact conditions in terms of vehicle type and weight, impact speed, and impact angle. Each roadside safety feature category is associated with specific test matrixes and test levels, containing indications of impact locations, impact speed, and impact angle. For example, there are six test levels defined for longitudinal barriers: the first three MASH test levels involve use of only passenger vehicles (a 2,420-lb passenger car and 5,000-lb pickup truck) and vary by impact speed. Higher test levels incorporate commercial trucks in addition to passenger vehicles.

Although the characteristics of work zones are inherently different from normal operating conditions on main lane highways, the impact conditions used to evaluate work zone devices (e.g., barriers, signs, lighting, etc.) are the same as those used for other types of systems that are not implemented in work zone areas, such as guardrails, median barriers, bridge rails, and permanent sign supports, primarily due to a lack of data related to work zone encroachment and impact conditions.

The passenger vehicle impact conditions in MASH are based on historical precedence of previous crash test standards that were verified through analysis of ROR crash data. Under NCHRP Project 17-22, Identification of Vehicular Impact Conditions Associated with Serious Ran-Off-Road Crashes, a database of approximately 890 single-vehicle ROR crashes was developed (Mak et al., 2010). These crashes are a subset of the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) crashes from 1997 to 2001 that occurred on highways with a posted speed of 45 mph or higher. The crashes were reconstructed using scene diagrams, narratives, scene and vehicle photographs, and roadway and roadside data (e.g., surface type, surface condition, and side-slope ratios) to estimate vehicle encroachment and impact conditions. The roadside safety feature impact conditions recommended in MASH approximate the 85th percentile speed and angle derived from distributions developed from the NCHRP 17-22 data. For high-speed roadways (Test Level [TL] 3 and higher), this corresponds to an impact speed of 62 mph and an impact angle of 25 degrees. This dataset does not include consideration of work zones. Thus, the impact conditions used in MASH for work zone roadside safety features are similar to other safety feature types by default, not design.

For example, work zone longitudinal barriers have several functions, including shielding motorists from hazards in the work area and providing positive protection for workers. Portable concrete barriers (PCBs) are the most widely used type of work zone barrier, although other types of barriers are available (e.g., steel). Due to the temporary and frequently changing nature of work zones, work zone barriers are designed to be easily transported, placed, and relocated. Therefore, unlike permanent concrete barriers, freestanding PCBs can undergo large displacements when subjected to a vehicle impact.

The design deflection of a work zone barrier is typically determined through full-scale crash testing. The magnitude of the barrier displacement is in large part attributable to the design impact conditions to which the barrier is tested. Several portable barrier systems tested to MASH TL-3 conditions have deflections greater than 5 ft.

This design deflection can have significant implications on the design of a work zone. A buffer space is typically required behind a work zone barrier to accommodate barrier deflection. The buffer space provides a recovery area for errant vehicles and separates traffic flow from workers or potential hazards (e.g., drop-offs) in the work activity area. Generally, no work activity should occur, and no equipment should be stored, within this space.

However, most work zones, besides those associated with new construction, are commonly restricted in terms of available space. Depending on the design deflection of the work zone barrier being used, an extra travel lane may have to be incorporated into the work activity area simply to provide the required buffer distance. Consequently, it is desirable to minimize the deflection of work zone barriers in order to reduce the required buffer distance behind the barrier and maximize the space available for traffic. If the desired buffer space cannot be accommodated, the barrier system may need to be restrained by anchoring it to the underlying pavement, deck, or soil through some means of pinning or bolting. Restraining barriers in this manner is expensive (due to required drilling, coring, epoxy, etc.), creates additional exposure for workers during installation, and can degrade barrier impact performance.

Some agencies reduce posted speed limits and operating speeds in work zones to justify a lower test level and lower barrier deflections. While speed reduction is a common safety measure to enhance the safety of both motorists and workers, this measure is not necessarily appropriate for all work zone situations, and the effect of the speed reduction on encroachment and impact conditions is not known.

Recognizing that the impact conditions used for designing and testing longitudinal barriers may be too conservative for some work zone applications, researchers used an 85th percentile impact severity (IS) as a basis for establishing a design deflection for work zone barriers (Sicking et al., 2003). The IS defined as follows:

$$IS = \frac{1}{2} m (v \sin\theta)^2 \quad (1)$$

where m is the mass of the impacting vehicle; v is the velocity of the impacting vehicle; and θ is the angle of impact.

The IS distribution was established using impact speed and impact angle distributions derived from reconstructed ROR crashes with poles and narrow bridges (Mak et al., 2010), and the mass distribution for vehicles involved in ROR crashes was developed from NASS CDS data (Ray, 1999). Use of the 85th percentile results in a nearly 50 percent reduction in barrier deflection. Researchers recommended the use of this reduced deflection for all work zone applications other than the placement of a barrier on the edge of a bridge deck (Sicking et al., 2003).

This practice is an indication that further research is needed to better define appropriate impact conditions for work zone barriers. In fact, no research has been conducted to investigate whether the test impact speed and angle should be different for work zone barriers to reflect different encroachment and impact conditions associated with work zone locations. The design impact conditions should be relevant and appropriate to the conditions in which the barrier is implemented. Overly conservative impact conditions will result in barrier systems that are more expensive to both construct (to achieve the required structural adequacy) and deploy (to achieve the required buffer distance associated with the barrier design deflection).

Another issue that requires further research is the appropriate MASH test level for different work zone locations. Most work zone barriers have historically been designed for MASH TL-3, which is only for passenger vehicles. However, work zones are also implemented in low-speed locations, where the posted speed limit is limited to 45 mph. MASH provides guidance for testing and evaluating roadside safety systems implemented at lower speeds: MASH TL-2 conditions involve passenger vehicles impacting safety systems at 44 mph nominal impact speed and at the critical angle considered appropriate for the specific investigated system category. More recently, PCBs are being designed to MASH TL-4, which includes an evaluation with a 22,000-lb single unit truck (Sheikh et al., 2018). Many permanent median barriers and bridge rails are designed for MASH TL-4, and some work zones may likewise benefit from the use of MASH TL-4 work zone barrier systems. More research is needed to determine the need for and appropriate use of MASH TL-4 work zone barriers based on factors such as speed and percent trucks.

Roadside Design Guide

Whereas MASH prescribes how the impact performance of a roadside safety device should be evaluated, the AASHTO (2011) RDG provides guidance regarding its implementation, placement, and use. There has been a concerted effort by AASHTO to update the guidance in the RDG to reflect current data and enable better data-driven decision-making. Chapter 2 of the RDG discusses the importance of the economic evaluation of roadside safety alternatives to enable a designer to make the best safety decisions with limited funds. This evaluation is accomplished through a benefit-cost analysis wherein the benefits are defined as a reduction in crash cost or risk. The RDG discusses the use of tools such as the Roadside Safety Analysis Program (RSAP) for performing such analyses.

A key component of calculating the risk and/or benefits that can be derived from a roadside safety treatment is understanding encroachment characteristics for a particular type of roadway or at a particular location. It is recognized in the RDG that encroachment rate can vary based on factors such as traffic volume, roadway alignment, and lane width. The encroachment studies referenced by the RDG are Cooper (1980) and Hutchinson and Kennedy (1962) were discussed earlier in this report. Much of the safety performance guidance currently in the RDG, or being developed for incorporation into the next edition, stems from the use of these old encroachment data in a risk- or benefit-cost-based analysis. Examples include guidance on the guardrail and median barrier test level selection and guardrail length of need.

Chapter 9 of the AASHTO RDG specifically addresses traffic barriers, traffic control devices, and other safety features used in work zones. This chapter describes both the safety and functional characteristics of these devices and provides guidance on their application and use. The RDG recognizes that barrier needs within a work zone can be influenced by a number of factors, including traffic volume, operating speed, offset, and duration of the work zone. Work zone encroachment data are needed in support of engineering risk or benefit-cost analysis related to use of barriers within work zones. Such analyses will result in guidance on barrier need, placement, and test level and will be expressed in terms of key work zone variables.

Manual on Uniform Traffic Control Devices

The FHWA (2009) MUTCD refers to both MASH and the RDG as governing publications regarding the design and use of temporary traffic control devices (including barrier use in work zones). Changes to those documents will, by reference, indirectly impact the MUTCD. In addition, the MUTCD is relatively silent on when and where positive protection in work zones should be used. However, the Code of Federal Regulations (23 CFR 630 Subpart K) requires agencies to establish criteria and guidelines regarding positive protection use in work zones.

The following guidelines are provided in the MUTCD to improve worker safety in work zones:

1. Training: Training for workers both on how to work next to motor vehicles and on temporary traffic control (TTC) techniques should be provided.
2. Temporary Traffic Barriers: Barriers are placed depending on factors such as lateral clearance, duration of work, traffic characteristics, and so forth.
3. Speed Reduction: Regulatory speed zoning, lane reduction, funneling, and the like should be considered to reduce traffic speeds to increase safety.
4. Activity Area: Work areas should be planned in such a way that minimum risk to workers due to construction vehicles exists.
5. Worker Safety Planning: A basic hazard assessment of the work zone area and the jobs must be conducted as per "Occupational Safety and Health Administration Regulations, General Safety and Health Provisions." Based on this assessment, it must be determined whether engineering, administrative, or personal protection measures are required. If so, these should be planned in accordance with the Occupational Safety and Health Act of 1970.

Combined Data Needs

Table 4 through Table 10 present the combined data needs based on the results of the literature, state-of-the-practice, and FHWA and AASHTO guidelines and publications reviews.

Table 4. Data Needs for Case ID

Data Element	Description/ Notes	Encroachment Databases			Publications and Guidelines				State DOT Research Needs
		H&K	Cooper	NCHRP 17-88	RDG	MASH	RSAP	MUTCD	
Case identifier	Case number or encroachment identifier	X	X	X					
Date	Date of encroachment/ crash	X	X	X					
Police-reported	Binary (yes or no)	X		X			X		X
Time	Time of day of encroachment			X			X	X	X

Note: H&K = Hutchinson and Kennedy. RSAP source is Ray et al. (2012).

Table 5. Data Needs for Roadway Description

Data Element	Description/ Notes	Encroachment Databases			Publications and Guidelines				State DOT Research Needs
		H&K	Cooper	NCHRP 17-88	RDG	MASH	RSAP	MUTCD	
Roadway identifier	Roadway name/ designation where encroachment was observed	X	X	X					
Encroachment location	Global positioning system (GPS), or route/ milepost	X	X	X					X
Travel direction	Compass direction of encroaching vehicle	X	X	X			X	X	
Posted speed limit	Posted speed limit	X	X	X		X	X	X	
Advisory speed limit	Advisory speed limit		X	X				X	
Design speed	Design speed for roadway segment			X	X				X
Traffic volume	Vehicles per day on roadway segment	X	X	X	X		X		X
Traffic volume by vehicle type	Vehicle volume by vehicle type, i.e., vehicle mix			X			X		X
Number of lanes	Number of lanes at point of departure			X			X	X	X
Lane width	Width of lane from which encroachment occurred			X			X		X
Lane marking	Lane marking at point of encroachment			X					X
Median width	Width of median in divided highways	X		X			X		
Median type	Median type, with or w/out barrier						X		
Median relative to edge	Distance of median from edge of the traveled way								
Median depth	Depth of median in divided highways	X		X					
Horizontal alignment	Horizontal alignment at point of departure, including radius of curvature and segment geometry	X	X	X			X	X	X
Vertical alignment or grade	Vertical alignment or cross-section profile or grade at point of departure	X	X	X			X	X	X

Data Element	Description/ Notes	Encroachment Databases			Publications and Guidelines				State DOT Research Needs
		H&K	Cooper	NCHRP 17-88	RDG	MASH	RSAP	MUTCD	
Terrain	Type of terrain through which roadway traverses: flat, rolling, mountainous						X		
Roadway configuration	Divided vs. undivided	X	X	X			X	X	X
Traffic control device	Traffic control device (stop sign, traffic light, other)							X	X
Rumble strips	Presence of rumble strips						X		
Functional class	Functional class of highway			X				X	X
Weather	Weather at time of encroachment (sun, rain, snow)			X					X
Lighting	Light at time of encroachment (day, night with illumination, night without illumination, dawn, dusk)			X					X
Interchange	Whether the crash's location was in an interchange area								X
Bridge capacity	Weight posting of bridge for overweight vehicles								X
Expected queuing	Recurring congestion or expected queuing								X
Rail crossings	Presence of railway crossings							X	X

Table 6. Data Needs for Access Management

Data Element	Description/Notes	Encroachment Databases			Publications and Guidelines				State DOT Research Needs
		H&K	Cooper	NCHRP 17-88	RDG	MASH	RSAP	MUTCD	
Access control	Level of access control (full, partial, none)			X				X	X
Access density	Access points per unit length of roadway			X			X		X
Land use	Rural, suburban, urban			X					X
Level of service	Quality of service for motor vehicle traffic using the TRB *Highway Capacity Manual* conventions, i.e., letters A through F, with A being the highest and F being the lowest			X					X

Table 7. Data Needs for Work Zone Attributes

Data Element	Description/Notes	Encroachment Databases			Publications and Guidelines				State DOT Research Needs
		H&K	Cooper	NCHRP 17-88	RDG	MASH	RSAP	MUTCD	
Type of construction	Type of construction								X
Time of work	Work during daytime or nighttime								X
Duration of work	Time period for which the work activity occurs						X		X
Length	Length of work area								X
Project location	Urban/rural setting								X
Location of work and level of encroachment	Outside shoulder, near shoulder, in median or in travel way								X
Available detour routes	Available detour routes								X
Environment and driver local characteristics	Elderly housing or college campus, urban or rural school								X
Proximity to other construction projects	Proximity to other construction projects								X
Weather conditions during work	Weather conditions such as rain that affect the visibility in the work zone								X
Depth of excavation	Depth of excavation								X
Buffer zone	Lateral and/or longitudinal area that separates road user flow (the traffic space) from the work space or other unsafe area								X
Median relative to edge	Distance of median from the edge of the traveled way								X
Reduced speed through the work zone	Reduced speed through the work zone								X
Benefit costs (project costs and cost of protection)	Expected crash costs (cost of installation and annual maintenance for positive protection vs. cost of crash)						X		X
Impacts to project cost and duration	Impact of encroachment to project cost and duration								X
Lane closure	Whether there is a lane closure situation due to work activity							X	X
Relative to shoulder	Location of work with respect to the shoulder either outside or on the shoulder							X	X
Relative to median	Whether the work is within the median of a divided highway							X	X

Data Element	Description/Notes	Encroachment Databases			Publications and Guidelines				State DOT Research Needs
		H&K	Cooper	NCHRP 17-88	RDG	MASH	RSAP	MUTCD	
Relative to intersection	Whether the work occurs within the traveled lane at an intersection							X	X
Grade crossing	Whether the work is within vicinity of a grade crossing							X	
Change in traffic operation	Changes made to accommodate traffic volumes on a limited space due to work activity, e.g., two-lane, two-way traffic operation on one roadway, crossovers, etc.							X	X
Beginning date of construction	Beginning date of construction								X
End date of construction	End date of construction								X
MP at beginning of work zone	Milepost at beginning of work zone								X
MP at termination of work zone	Milepost at termination of work zone								X
Roadside hazards	Unprotected features like walls, piers, foundations, unfinished bridge decks								X
Positive protection	Presence and type of positive protection at point of encroachment							X	X
Potential hazard from the device itself	Hazard presented to the workers and traffic while installing and removing the barrier								X
Barrier deflection	Distance the barrier will deflect								X
Workers' escape routes	No escape paths for work in tunnels, bridge, etc.								X

Table 8. Data Needs for Roadside Description

Data Element	Description/Notes	Encroachment Databases			Publications and Guidelines				State DOT Research Needs
		H&K	Cooper	NCHRP 17-88	RDG	MASH	RSAP	MUTCD	
Roadside surface type	Pavement, gravel, earth (soil or grass), combined (two or more surfaces), etc.	X		X					
Type of hazard	Point, area, or line hazards—signs, guardrails, etc.					X	X	X	
Departure side	Right/left encroachment	X	X	X					X
Roadside slope	Slope of roadside/median at encroachment location	X	X	X		X	X		X
Roadside cross section	Side-slope and back slope; H&K and 17-22 provide categories of cross-section shapes	X	X	X		X	X		X
Shoulder type/ width	Width and type of shoulder (paved, unpaved), both median shoulder and right shoulder	X	X	X			X	X	
Distance from edge	Distance relative to the edge of the traveled way								
Presence of curbs	Binary (yes or no); include type (perpendicular or sloped) if available			X	X	X			X
Pedestrian and bicycle facilities	Whether the roadside section consists of pedestrian or bicycle routes				X			X	
Edge drop-off type	None, primarily vertical or safety shape							X	X
Edge drop-off height	Distance from the road surface to the surrounding surface								X
Roadside businesses	Presence and type of roadside businesses								X

Table 9. Data Needs for Encroachment Description

Data Element	Description/Notes	Encroachment Databases			Publications and Guidelines				State DOT Research Needs
		H&K	Cooper	NCHRP 17-88	RDG	MASH	RSAP	MUTCD	
Trajectory	Encroachment trajectory—array of points or trajectory category	X		X					X
Encroachment type	Whether there is minor encroachment or no encroachment								
Longitudinal extent	Maximum longitudinal distance of encroachment in this trajectory segment	X	X	X	X				
Lateral extent	Maximum lateral distance of encroachment in this trajectory segment	X	X	X					
Departure speed	Resultant velocity of vehicle center of gravity at departure			X		X			
Departure angle	Travel direction of vehicle center of gravity with respect to a tangent to the road edge	X	X	X		X			
Vehicle orientation at departure	Angle between vehicle longitudinal axis and direction of travel at departure from the roadway			X		X			X
Vehicle stability at road departure	Tracking/non-tracking			X					X
Reentry angle	Angle at which vehicle reenters the roadway	X		X					
Impact speed	Speed at which the vehicle struck the fixed object			X		X			
Impact angle	Angle between vehicle longitudinal axis and fixed-object orientation			X		X			
Vehicle orientation at impact	Angle between the longitudinal axis of the vehicle and the direction of travel at impact			X		X			
Vehicle general area of damage (GAD)	GAD on the vehicle, e.g., front, left side, right side, or rear (using SAE J224 definition)/type of damage distribution			X		X			
Specific horizontal location (SHL) of impact on vehicle	SHL using SAE J224 definition; on front plane, for example, L=left corner, R=right corner, C=centerline, D=distributed damage			X		X			
Object struck	Roadside object struck	X	X	X		X		X	X
Offset to object struck	Lateral distance from road edge to object struck			X					X
Braking extent	Estimated extent of braking, distance during trajectory segment	X		X					X
Object influence	Object that influenced the encroachment, e.g., driver swerves to avoid a median obstacle	X		X					
Rollover	Binary (yes or no)			X					X

Table 10. Data Needs for Driver

Data Element	Description/Notes	Encroachment Databases			Publications and Guidelines				State DOT Research Needs
		H & K	Cooper	NCHRP 17-88	RDG	MASH	RSAP	MUTCD	
Vehicle type	Car, light truck, motorcycle, heavy truck, bus (manufacturer, type, and model)	X	X	X		X	X		X
Driver condition	Nominal, alcohol-involved, drowsy, asleep, distracted (if available)			X					X
Driver actions	Driver recovery/crash avoidance actions	X		X					X
Involvement of another vehicle	Binary (yes or no)			X					X
Intentional encroachment	Binary (yes or no)			X					X
Crash severity/injury severity	Maximum injury level in the vehicle (use AIS scale if possible)			X					X

DATA SOURCES

This section presents a summary of data source studies/databases that the research team initially identified as potentially applicable to the scope of this data collection and investigation study.

Naturalistic Driving Studies

The relevant NDSs identified by the researchers were as follows:

- **The Second Strategic Highway Research Program (SHRP2)** is the largest and most comprehensive NDS to date. The NDS data include 3,500 participants from six U.S. states (Florida, Indiana, New York, North Carolina, Pennsylvania, and Washington) who were observed during a 3-year period from 2010 to 2012. During this period, the NDS team collected 5.4 million trips and recorded 4,175 crashes and near-crashes. NDS data provide information concerning the four major aspects of naturalistic driving: (a) driver characteristics and questionnaires, (b) vehicle characteristics, (c) trip and vehicle kinematics data, and (d) event data (e.g., crash, near-crash, and baseline events). Trip data, some of the most frequently requested NDS data, include vehicle sensor data; video data; GPS location data of all trips; and brief, driver-initiated audio recordings. The video data include images of the driver's face that provide the most direct evidence of driving behavior, gaze direction, and the state of the driver in terms of fatigue or inattention. The NDS data are supplemented by the companion Roadway Information Database (RID) that captures detailed roadway data for around 12,500 centerline miles in the study states. Linked NDS and RID data provide a wealth of information that can help to address research questions concerning various areas of highway safety, design, and operations research. One of the RID layers is event data, which can be used to obtain the work zone information.
- **The 100-Car Naturalistic Driving Study** is a database involving 100 cars, 78 of which were privately owned. This database includes approximately 2 million vehicle miles; almost 43,000 hours of driving; 241 primary and secondary drivers; 12 to 13 months of data collection for each vehicle; and data from a highly capable instrumentation system, including five channels of video and many vehicle state and kinematic sensors. As a result, the data collection team was able to identify many extreme cases of driving behavior and performance, including severe drowsiness, impairment, judgment error, risk-taking, willingness to engage in secondary tasks, aggressive driving, and traffic violations. The event data (crashes, near-crashes, and other incidents) were classified by pre-event maneuver, precipitating factor, event type, contributing factors, associative factors, and avoidance maneuver. In addition to the event data, the 100-Car Database contains the vehicle speed, vehicle headway, time to collision, and driver reaction time (NHTSA, 2006).

Specialized Encroachment Databases

The researchers identified the following specialized encroachment databases:

- **NCHRP Project 17-43 (Long-Term Roadside Crash Data Collection Program)** has developed a comprehensive roadside safety database. Currently, the NCHRP 17-43 database is comprised of 851 road departures with full reconstructions and trajectories. The dataset is comprised of road departure cases extracted from the NASS CDS collected from 2011–2015. The immediate applications of the NCHRP 17-43 database will be much newer, more relevant data for (a) trajectories for improved work zone barrier length-of-need calculations, (b) trajectories and departure conditions for motorists who crashed while traversing a work zone, and (c) updated distributions of departure conditions (impact angle and impact speed) for potential updates to MASH crash test procedures.

- **NCHRP Project 17-88 (Roadside Encroachment Database Development and Analysis)** is an active project focused on (1) developing a database of roadside encroachment characteristics for a variety of roadside conditions and roadway types, and (2) analyzing the database to evaluate (a) the factors that influence the nature and frequency of roadside encroachments; (b) the relationship between unreported and reported crashes; and (c) whether heavy vehicle, bus, and motorcycle encroachments differ from passenger vehicle encroachments.

Crash and Crash Reconstruction Databases

The researchers also identified a number of crash and crash reconstruction databases:

- **FARS** is a nationwide census providing yearly data regarding fatal injuries suffered in motor vehicle traffic crashes (NHTSA, 2022). FARS data include records of the approximately 30,000–40,000 fatalities that occur on U.S. highways each year. FARS contains records of traffic fatalities in all vehicle types and crash modes—cars, light trucks, heavy trucks, bicycles, motorcycles, pedestrians, and other road users.
- **The NASS General Estimates System (GES)** database is a sample of approximately 50,000 police-reported crashes from across the United States (NHTSA, 2016). The database is comprised of crashes that span all severities—from property damage only to fatal crashes—and all vehicle types. The database contains sampling weights that can be used to obtain nationally representative estimates of crash frequency. In 2016, NHTSA replaced the NASS GES with the Crash Reporting Sampling System (CRSS). CRSS has a structure that is similar to GES, but with data collected at different U.S. sites.
- **NASS CDS** data are collected and made available by NHTSA. The data provide a national probability sample of tow-away crashes involving light vehicles. Many of the crashes include event data recorder (EDR) reports from one or occasionally two vehicles in the crash, allowing linkage of the information from the EDR to scene photos, diagrams, narratives, and coded data in the dataset.
- **The National Motor Vehicle Crash Causation Survey (NMVCCS)** is a NHTSA-sponsored nationwide survey of crashes involving light passenger vehicles, with a focus on the factors related to pre-crash events. A total of 6,949 crashes were investigated between January 1, 2005, and December 31, 2007. Of these cases, 5,470 cases comprise a nationally representative sample. The remaining 1,479 cases are suitable for clinical study. The data collected through the investigated crashes can provide a unique perspective on driver behavior factors that lead to work zone crashes. The NMVCCS contains an in-depth

investigation of over 300 vehicles involved in work zone collisions. Each investigated crash involved at least one light passenger vehicle that was towed due to damage. Data were collected on-scene for at least 600 data elements in the crash to capture information related to the drivers, vehicles, roadways, and environment. In addition, the NMVCCS database includes crash narratives, photographs, schematic diagrams, vehicle information, EDR data for some vehicles, detailed crash scene diagrams, on-scene photos of the crash site, and interviews with the driver.

- **The Highway Safety Information System** (HSIS) includes quality crash, roadway, and traffic data for California, Illinois, Maine, Minnesota, North Carolina (Charlotte only), Ohio, and Washington, as well as historical data for Michigan and Utah (HSIS, 2022).

Additional Relevant Data Sources

Finally, the researchers identified the following additional relevant data sources:

- **The Onboard Monitoring System (OBMS) Field Operational Test** collected data for 156 OBMS-instrumented large trucks with 317 commercial drivers over 18 months. The study was conducted by the Virginia Tech Transportation Institute (VTTI). The objective of the study was to assess the relationship between driving time and crash risk and fatigue and distraction on crash risk (Federal Motor Carrier Safety Administration [FMCSA], 2019). The study assessed whether an OBMS that provides real-time feedback to commercial truck and motor coach drivers can reduce crashes and near-crashes. The data acquisition system (DAS) included a forward collision warning and lane departure warning system (Hallquist, 2012) that uses a video-based lane tracking system. Data were collected for fleets in eight cities over seven states (Los Angeles, CA; Baton Rouge, LA; Selma, NC; Coraopolis, PA; Williamsport, PA; Escanaba, MI; Pembroke, NH; San Antonio, TX). The DAS included video cameras (including a forward roadway view), a GPS, an accelerometer to assess swerving and hard braking, and a speed sensor. The lane tracking system measured distance from the center of the vehicle to the left and right lane markings with an estimated maximum error of 6 inches and an average error of 2 inches. The lane tracker also reported angular offset between the vehicle center and the roadway centerline with an estimated maximum error of 1 degree. Lane crossings were also reported by the system (Boyle et al., 2016). Safety-critical events were also coded. Roadway data do not appear to have been coded with the identified events. Presence of a construction zone could be identified by cross-checking lane line crossings with the forward roadway view.
- **The European Naturalistic Driving and Riding for Infrastructure & Vehicle Safety and Environment**, known as **UDRIVE**, is the first large-scale NDS conducted in Europe. The study included passenger vehicles, trucks, and powered two-wheelers, and data were collected in six European Union states (Spain, France, Netherlands, Poland, Germany, United Kingdom). The objectives of the project were to assess road user behavior during normal and safety-critical events, with a particular focus on the prevalence and impact of driver behavior such as distraction and inattention. Another focus was the interaction between vehicles and pedestrians and cyclists. Data were collected for close to 2 years

(January 2015 to May 2017) and resulted in around 100,000 hours of vehicle data. Data collection included about 270 variables, including controller area network (CAN) data and video from eight cameras. Around 50 roadway attributes were collected and added to the data, which included variables such as speed limit, curve radius, traffic signs, and number of lanes. There do not appear to be supplemental data, such as the 511 data, included with SHRP2, which could be used to indicate work zones. Presence of a construction zone is one of the variables included in the data reduction codebook, which provides instructions for manual coding. As a result, a construction zone may be determined if it was already coded as part of data reduction for another project.

- **The Safety Pilot Model Deployment Data** (SPMD) collected vehicle and traffic data using vehicles equipped with vehicle-to-vehicle and vehicle-to-infrastructure communication devices. The vehicles used dedicated short-range communications to communicate basic safety messages, such as speed, location, and direction, at a frequency of 10 messages per second. The study was conducted by the University of Michigan Transportation Research Institute (UMTRI), and data were collected in Ann Arbor, Michigan, beginning in 2012. The study included around 3,000 passenger vehicles, transit buses, and four motorcycles and 30 pieces of roadside equipment (RSE) that covered 75 mi of roadways. The majority of the RSEs were located at signalized intersections. Others were placed to collect data for applications such as curve speed warning (U.S. Department of Transportation [USDOT], 2019a). Some test vehicles were collected with additional DASs, while a few were also equipped with cameras to record data both internal and external to the vehicle. Text-based data are readily available data, and the most recent version can be downloaded from the SPMD data webpage (USDOT, 2019b). Steering angle events are included in the archived data, which may be an indicator of encroachment angle. According to Bargman et al. (2015), planned construction projects (segment and intersection) conducted between August 2012 and August 2013 were included. However, no information was coded about presence of a work zone for reduced events.
- **The Integrated Vehicle-Based Safety System** was a field operational test that evaluated crash avoidance systems, including a forward collision warning system, lane departure warning system, lane change warning system, and curve speed warning system. The DAS included cameras (forward roadway), CAN buses to collect vehicle data, a GPS, an accelerometer, and a device to measure steering angle (Sayer et al., 2010). Sixteen passenger vehicles were equipped with collision warning systems and DASs, and 108 volunteer drivers in southeastern Michigan used the instrumented vehicle as their personal vehicle for a 40-day period that included a baseline period (12 days) and 28 days with the system active (Sayer et al., 2010). Around 6,000 hours and over 213,000 mi of driving were included in the light-duty vehicle dataset. The study also included 10 instrumented heavy trucks with 18 volunteer CDL drivers who participated in a 2-month period of baseline driving followed by an 8-month intervention period when the safety systems were enabled (Nodine et al., 2011). A structured database was developed during the course of the project that included all the channels and associated properties collected by the DASs as well as additional data elements

that were appended to the database from outside sources (Sayer et al., 2010). Triggered events were also event-logged by the system. Relevant data collection variables included lateral position, lane line types, road shoulder width, roadway curvature, lateral position, and lane position. Lateral position was measured as the offset between the estimated lane center and center of the vehicle. Around 12,760 lane departure events were recorded in the light vehicle dataset during steady-state driving. Vehicle trajectory data were also recorded for lane departure events. Maximum lane incursion distance was recorded as well. Encroachment events were identified during data collection, which included both the baseline and evaluation periods. A noted by Nodine et al. (2011), presence of construction zones was coded for forward collision warning (FCW) system alerts and accounted for 12 percent of out-of-path FCW system alerts that were coded. Encroachments can be utilized for both the baseline and intervention periods. However, it is expected that fewer encroachments occurred once the safety warning systems were turned on.

- **The Volpe Forward Collision Warning System Field Operational Test** (FOT) was conducted to assess an FCW system. Data were collected from 24 instrumented passenger vehicles and 38 drivers. Participants drove 3 months, 9 months, or 1 year (Nodine et al., 2019). The study was conducted in the greater Washington, DC, area. Data were collected for 3 weeks prior to the FCW and automatic braking system being turned on. Relevant variables collected included position, speed, lateral acceleration, longitudinal acceleration, steering wheel angle, and distance to forward objects. Cameras recorded the forward roadway as well as the driver. The instrumented vehicle (2013 Cadillac SRX) also had a lane departure collision warning system. Roadway data elements did not appear to have been collected in conjunction with the study but can be derived from the forward camera and vehicle position. Encroachments can be utilized for both the baseline and intervention periods. However, it is expected that fewer encroachments occurred once the safety warning systems were turned on.
- **The Automotive Rear-End Collision Avoidance System FOT**, conducted by UMTRI, was a naturalistic driving system study used to assess an automotive rear-end collision avoidance system that included an FCW system and adaptive cruise control. The FOT included 10 instrumented passenger vehicles and 66 drivers from March 2003 to November 2004 and was conducted primarily in Michigan. Each driver drove the instrumented vehicle for 4 weeks (first week as a baseline and 3 weeks with the system active). The study resulted in 163,000 km of driving. A forward roadway view video was included in the DAS. Relevant variables collected included lateral acceleration, steering wheel angle, compass heading, location, and speed (Najm et al., 2006). Crash, conflict, and low conflict events were identified using numerical data processing algorithms. Conflict and near-crash events were further coded. Variables coded included ambient light conditions, weather, type of roadway (coded as freeway or non-freeway), and traffic density.

CHAPTER 4. DATA COLLECTION PLAN

Based on the list of data needs and relevant data sources, the research team developed a comprehensive data catalog to indicate which variables to include in data collection, as well as the potential sources for these elements (Table 11 through Table 17).

Table 11. Data Sources for Case ID

Data Element	Description/Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
Case identifier	Case number or encroachment identifier	X	X	X	X	X	X	X	X	X	X	X			
Date	Date of encroachment/ crash	X		X*	X*	X	X*	X*	X*	X*	X*	X		X	
Police-reported	Binary (yes or no)	X		X	X	X	X	X	X	X	X	X			X
Time	Time of day of encroachment	X		X	X	X	X	X	X	X	X	X		X	

* Month, day of week, and year are available, but not the actual calendar day.

Table 12. Data Sources for Roadway Description

Data Element	Description/ Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS (EDR)	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
Roadway identifier	Roadway name/ designation where encroachment was observed					X	X	X							
Encroachment location	GPS, or route/milepost	X	X												
Travel direction	Compass direction of encroaching vehicle	X	X	X	X	X	X	X				X			
Posted speed limit	Posted speed limit	X	X	X	X	X	X	X	X	X	X	X			
Advisory speed limit	Advisory speed limit								X						
Design speed	Design speed for roadway segment	X				X	X	X	X	X	X	X			
Traffic volume	Vehicles per day on roadway segment	X										X			X
Traffic volume by vehicle type	Vehicle volume by vehicle type, i.e., vehicle mix	X													
Number of lanes	Number of lanes at point of departure	X		X	X	X	X	X	X	X	X	X			
Lane width	Width of lane from which encroachment occurred	X		X	X							X			
Lane marking	Lane marking at point of encroachment	X		X	X										
Median width	Width of median in divided highways	X		X								X			
Median type	Median type, with or w/out barrier	X		X	X							X			

Data Element	Description/ Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS (EDR)	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
Median relative to edge	Distance of median from edge of the traveled way														
Median depth	Depth of median in divided highways														
Horizontal alignment	Horizontal alignment at point of departure, including radius of curvature and segment geometry	X		X	X	X	X	X	X	X	X				
Vertical alignment or grade	Vertical alignment or cross-section profile or grade at point of departure	X		X	X	X	X	X	X	X	X				
Terrain	Type of terrain through which roadway traverses: flat, rolling, mountainous	X										X			
Roadway configuration	Divided vs. undivided	X		X	X	X	X	X	X	X	X	X			
Traffic control device	Traffic control device (stop sign, traffic light, other)					X	X	X	X	X	X	X			
Rumble strips	Presence of rumble strips			X	X				X						
Functional class	Functional class of highway	X		X	X	X	X	X				X			
Weather	Weather at time of encroachment (sun, rain, snow)	X		X	X	X	X	X	X	X	X	X		X	
Lighting	Light at time of encroachment (day, night with illumination, night without illumination, dawn, dusk)			X	X	X	X	X	X	X	X	X		X	
Interchange	Whether the crash's location was in an interchange area	X				X	X	X							
Bridge capacity	Weight posting of bridge for overweight vehicles														
Expected queuing	Recurring congestion or expected queuing														X
Rail crossings	Presence of railway crossings														

Table 13. Data Sources for Access Management

Data Element	Description/Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
Access control	Level of access control (full, partial, none)	X		X	X				X			X			
Access density	Access points per unit length of roadway														
Land use	Rural, suburban, urban			X	X	X	X	X				X			
Level of service	Quality of service for motor vehicle traffic using the TRB *Highway Capacity Manual* conventions, i.e., letters A through F, with A being the highest and F being the lowest														

Table 14. Data Sources for Work Zone Attributes

Data Element	Description/Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
Type of construction	Type of construction														
Time of work	Work during daytime or nighttime	X	X												
Duration of work	Time period for which the work activity occurs														
Length	Length of work area	X	X												
Project location	Urban/rural setting	X	X	X	X	X	X	X	X	X	X				
Location of work and level of encroachment	Outside shoulder, near shoulder, in median or in travel way	X	X												
Available detour routes	Available detour routes														
Environment and driver local characteristics	Elderly housing or college campus, urban or rural school														
Proximity to other construction projects	Proximity to other construction projects														
Weather conditions during work	Weather conditions such as rain affects the visibility in the work zone (at time of encroachment)	X	X	X	X										
Depth of excavation	Depth of excavation														

Data Element	Description/ Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
Buffer zone	Lateral and/or longitudinal area that separates road user flow (the traffic space) from the work space or other unsafe area	X	X												
Median relative to edge	Distance of median from the edge of the traveled way														
Reduced speed through the work zone	Reduced speed through the work zone														
Benefit costs (project costs and cost of protection)	Expected crash costs (cost of installation and annual maintenance for positive protection vs. cost of crash)														
Impacts to project cost and duration	Impact of encroachment to project cost and duration														
Lane closure	Whether there is a lane closure situation due to work activity														
Relative to shoulder	Location of work with respect to the shoulder either outside or on the shoulder	X	X												
Relative to median	Whether the work is within the median of a divided highway	X	X												
Relative to intersection	Whether the work occurs within the traveled lane at an intersection	X	X												
Grade crossing	Whether the work is within vicinity of a grade crossing	X	X												
Change in traffic operation	Changes made to accommodate traffic volumes on a limited space due to work activity, e.g., two-lane, two-way traffic operation on one roadway, crossovers, etc.	X	X												
Beginning date of construction	Beginning date of construction														

Data Element	Description/ Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
End date of construction	End date of construction														
MP at beginning of work zone	Milepost at beginning of work zone														
MP at termination of work zone	Milepost at termination of work zone														
Roadside hazards	Unprotected features like walls, piers, foundations, unfinished bridge decks	X													
Positive protection	Presence and type of positive protection at point of encroachment														
Potential hazard from the device itself	Hazard presented to the workers and traffic while installing and removing the barrier														
Barrier deflection	Distance the barrier will deflect														
Workers' escape routes	No escape paths for work in tunnels, bridge, etc.														

Table 15. Data Sources for Roadside Description

Data Element	Description/Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS (EDR)	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
Roadside surface type	Pavement, gravel, earth (soil or grass), combined (2 or more surfaces), etc.	X										X		X	
Type of hazard	Point, area, or line hazards—signs, guardrails, etc.	X													
Departure side	Right/left encroachment			X	X										
Roadside slope	Slope of roadside/median at encroachment location			X	X										
Roadside cross section	Side-slope and back slope; H&K and 17-22 provide categories of cross-section shapes	X													
Shoulder type/width	Width and type of shoulder (paved, unpaved), both median shoulder and right shoulder	X		X	X							X			
Distance from edge	Distance relative to the edge of the traveled way	X		X	X										
Presence of curbs	Binary (yes or no); include type (perpendicular or sloped) if available	X		X	X										
Pedestrian and bicycle facilities	Whether the roadside section consists of pedestrian or bicycle routes					X	X	X				X			
Edge drop-off type	None, primarily vertical or safety shape			X	X										
Edge drop-off height	Distance from the road surface to the surrounding surface														
Roadside businesses	Presence and type of roadside businesses														

Table 16. Data Sources for Encroachment Description

Data Element	Description/Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
Trajectory	Encroachment trajectory—array of points or trajectory category	X		X	X										
Encroachment type	Whether there is minor encroachment or no encroachment	X		X*	X*	X	X	X	X	X	X	X	X		
Longitudinal extent	Maximum longitudinal distance of encroachment in this trajectory segment (departure location)	X		X	X										
Lateral extent	Maximum lateral distance of encroachment in this trajectory segment (departure location)	X		X	X										
Departure speed	Resultant velocity of vehicle center of gravity at departure			X	X								X		
Departure angle	Travel direction of vehicle center of gravity with respect to a tangent to the road edge			X											
Vehicle orientation at departure	Angle between vehicle longitudinal axis and direction of travel at departure from the roadway			X	X										
Vehicle stability at road departure	Tracking/non-tracking			X	X										
Reentry angle	Angle at which vehicle reenters the roadway				X										
Impact speed	Speed at which the vehicle struck the fixed object			X	X								X	X	
Impact angle	Angle between vehicle longitudinal axis and fixed-object orientation			X	X										
Vehicle orientation at impact	Angle between the longitudinal axis of the vehicle and the direction of travel at impact	X		X	X	X	X	X				X			
Vehicle GAD	GAD on the vehicle, e.g., front, left side, right side, or rear (using SAE J224 definition)/type of damage distribution	X		X	X	X	X	X	X	X	X			X	

Data Element	Description/Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
SHL of impact on vehicle	SHL using SAE J224 definition; on front plane, for example, L=left corner, R=right corner, C=centerline, D=distributed damage			X	X					X	X				
Object struck	Roadside object struck	X		X	X	X	X	X		X	X				
Offset to object struck	Lateral distance from road edge to object struck			X	X										
Braking extent	Estimated extent of braking, distance during trajectory segment												X**	X**	
Object influence	Object that influenced the encroachment, e.g., driver swerves to avoid a median obstacle—critical pre-crash event	X				X	X	X	X	X	X		X		
Rollover	Binary (yes or no)			X	X				X	X	X			X	

* Classification of major or minor encroachment can be derived from the detailed trajectory coordinates stored in NCHRP 17-43 and 17-88.

** Braking extent can be derived from EDR data on time of braking application pre-crash, time of impact, and velocity change over this time interval.

Table 17. Data Sources for Driver

Data Element	Description/Notes	SHRP2	100-Car	NCHRP 17-43	NCHRP 17-88	FARS	CRSS	GES	NMVCCS	CDS	CISS	HSIS	Present EDR	Future EDR	State DOT
Vehicle type	Car, light truck, motorcycle, heavy truck, bus (manufacturer, type, and model)	X	X	X	X	X	X	X	X	X	X	X		X	
Driver condition	Nominal, alcohol-involved, drowsy, asleep, distracted (if available)	X	X	X	X	X	X	X	X	X	X	X	X	X	
Driver actions	Driver recovery/crash avoidance actions	X	X	X	X	X	X	X	X	X	X		X	X	
Involvement of another vehicle	Binary (yes or no)	X		X	X	X	X	X	X	X	X	X			
Intentional encroachment	Binary (yes or no)														
Crash severity/injury severity	Maximum injury level in the vehicle (use AIS scale if possible)	X		X	X	X	X	X	X	X	X	X			

CHAPTER 5. ENCROACHMENT DATA COLLECTION

In this project, data were collected mainly from NDSs, state crash databases, NMVCCS, and NCHRP 17-43. The research team collected data variables listed in Table 18 from all the databases wherever applicable. However, not all the variables were available in all databases; for example, encroachment conditions such as impact speed and angle cannot be collected from the crash databases. This variable can be collected from the NDS database, but doing so requires intensive data collection effort. On the other hand, the NDS database does not include many crash events, so it has limited post-crash data.

Table 18. Summary of Data Catalog

Case Information	Event Description	Encroachment Description
• Date • Time and type of crash • Latitude & longitude of the crash location	• Event type • Sequence of events • Vehicle type • Vehicle stability at road departure • Damage location and severity • Rollover	• Impact speed • Impact angle • Encroachment direction (left or right)
Roadway Description	**Roadside Description**	**Work Zone Description**
• Road ID • Posted speed limit • Traffic volume • Number of lanes • Median type and width • Terrain • Lighting • Road alignment	• Shoulder type • Shoulder width • Presence of curbs • Pedestrian and bicycle facilities • Roadside cross section • Roadside businesses	• Type and duration of construction • Project location and configuration • MP at the beginning/end of work zone • Roadside hazards • Positive protection and traffic control

Access Management	Driver Characteristics and Behavior
• Access control • Access density • Land use • Service level of the road	• Driver age • Sex • Driver distraction • Driver actions • Pre-incident maneuver • Post-maneuver control

DATA COLLECTION PROCESS

This section presents a summary of the data collection process and the utilized sources.

Naturalistic Driving Studies

The goal of NDSs is to address the role of driver behavior in highway safety. NDSs offer two key advantages: (a) detailed and accurate pre-crash information, including objective information about driving behavior; and (b) exposure information, including the frequency of behaviors in normal driving as well as the larger context of contributing factors. NDS data are collected from voluntary participants over a long period of time. The participants complete a consent form and take several tests and questionnaires. The participants' vehicles are then taken to a specific field for installing the DASs, which include radar units, cameras covering various fields of view, eye-forward monitors, an accelerometer, GPS units, incident push buttons, and so on.

For the purposes of this project, the research team identified and collected work zone encroachment data from 11 NDSs. Table 19 summarizes the selected studies and the number of potential events that were considered in this study.

Table 19. List of Studies Using Readily Available NDS Databases with Work Zone Events

Author and Year	Study Title	Study Code	Data Description
Zhou et al. (2019)	Evaluation of Work Zone Mobility by Utilizing Naturalistic Driving Study Data	NDS-1	Forward, rear-view video, and time series traces for traversed work zones are collected at 0.1-second intervals. Work zone configurations such as traffic control devices, area types, presence of dynamic message signs, and intelligent transportation system (ITS) technologies (ITS), as well as the presence of workers and equipment, are identified in these videos.
Hallmark et al. (2015)	Evaluation of Work Zone Safety Using the SHRP2 Naturalistic Driving Study Data	NDS-2	Detailed event tables (including trip summaries, vehicle, and driver survey results), forward video sequences, and time series data for 243 crash-related events and 420 baseline events.
Flannagan et al. (2019)	Analysis of SHRP2 Data to Understand Normal and Abnormal Driving Behavior in Work Zones	NDS-3	Time series data and front video sequences from 71 work zone crashes and near-crashes; time series data and front video sequences from 52 crashes and near-crash events for locations of interest; time series data and speed limit data for 50 crashes and 400 normative baseline events.
Li et al. (2016)	Evaluation of the Interaction between Horizontal and Vertical Alignment on Rural Two-Lane Roads	NDS-4	Data from 10 sites with five combinations of vertical and horizontal alignment. For each site, data for 25 trips were generated, and time series data for each trip segment included front video sequences. Combinations of low-, medium-, and high-risk vertical and horizontal alignments were identified using RID.
Perez et al. (2019)	Naturalistic Investigation of Contributing Factors by Crash Type	NDS-5	Kinematic data for all crashes of Level 1–3 along with baseline events (one of the data elements was construction zone).
Rufina et al. (2019)	Inferring Cognitive Workload and Crash Risk from Naturalistic Driving Data	NDS-6	Event data for all the crash, near-crash, and baseline; driver questionnaires; medical conditions & medications (one of the data elements was construction zone).
Layman et al. (2016)	Use of SHRP2 NDS Data to Evaluate Roadway Departure Characteristics	NDS-7	Driver, environmental, roadway, and vehicle factors that contribute to roadway crashes and near-crashes. The project also evaluated driver behavior on curves.
Sear et al. (2018)	Use of SHRP2 NDS Data to Evaluate Roadway Departure Crash Characteristics—Phase II	NDS-8	Crash/near-crash events, trips for locations with particular characteristics and matched baselines.
Perez (2017)	Explore Surrogate Measures of Safety Using SHRP2 Naturalistic Driving Data	NDS-9	The dataset contains video and time series data. Four separate trips containing a crash are included. Portions of the trips near the origin are not included, nor are coordinates for the crash locations. The trips end shortly after the crash occurs. Both forward and rear videos are included. The events are all single-vehicle roadway departure crashes, obtained across all the different study sites.
Perez et al. (2016)	Iowa State University CTRE S08: Analysis of the SHRP2 Naturalistic Driving Study Data S08-D; Assessing Lane Departures on Rural Two-Lane Curves	NDS-10	Kinematics data; clipped forward video, clipped rear video, driver questionnaires, vehicle data.

NDSs have focused on different aspects of work zone safety characteristics. Thus, based on the aim of each study, the collected features vary, and extracting the information for this study required a comprehensive investigation of the provided data. To reach this goal, first, the designed data structure for this study was reviewed, and the categories of the qualitative variables were determined. The extracted data were presented in separate categories: case information, roadway description, access management, work zone attributes, roadside description, and encroachment description. Figure 1 depicts the data extracted from the NDS databases for this study.

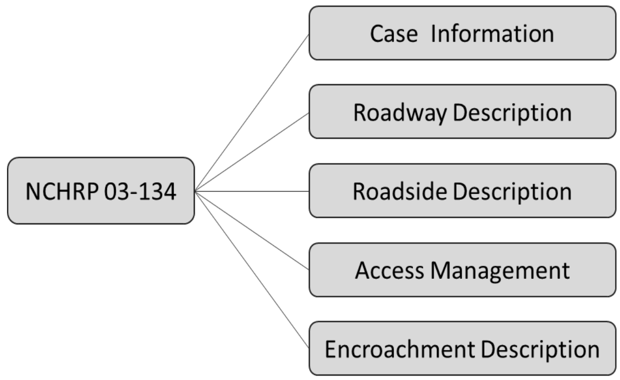


Figure 1. NCHRP 03-134 Data Tables Extracted from NDS Databases

The created dataset was populated by extracting data from the provided time series data, speed limit data, videos, and SHRP2 NDS website. Table 20 presents a detailed summary of the extracted data from the NDSs and the database from which each feature was extracted. Variables on case information were readily available from the NDS data. The research team obtained the roadway description data from the SHRP2 companion RID. The rest of the variables on access management (e.g., access density), work zone description (e.g., lane closure type), roadside elements (e.g., type of barrier), and encroachment description (e.g., departure angle) were collected manually from NDS videos.

Table 20. List of Extracted Features and Data Sources in NDS Database

Data Table	Feature	Data Source
Case Information	Date, time	Time Series Data
	Type of crash	Front Video Data
Roadway Description	Posted speed limit	SHRP2 Event Detail Data
	Road type and configuration, no. of lanes, median type, terrain	Front Video Data
	Road alignment, relation to the intersection, relation to crossing, relation to junction	SHRP2 Event Detail Data
	Lane width, lane marking	Time Series Data
	Lighting of the road, surface condition	Front Video Data
	Traffic flow	SHRP2 Event Detail Data
Roadside Description	Shoulder type, presence of curbs, pedestrian and bicycle facilities	Front Video Data
	Roadside businesses	SHRP2 Event Detail Data
Access Management	Access control, access density	SHRP2 Event Detail Data
	Land use, service level of the road	SHRP2 Event Detail Data
Work Zone Information	Roadside hazards, positive protection	Front Video Data
	Work zone traffic control	Front Video Data
Encroachment Description	Event type, relation to work zone	Front Video Data, SHRP2 Event Detail Data
	Encroachment angle, encroachment extent	Time Series Data
	Impact speed, impact angle	Time Series Data
	Visual obstruction	SHRP2 Event Detail Data
	Damage location and severity	Front Video Data, SHRP2 Event Detail Data
	Damage to work zone property	Front Video Data, SHRP2 Event Detail Data
	Rollover, airbag deployment	SHRP2 Event Detail Data
	Driver actions, pre-incident maneuver, post-maneuver control	SHRP2 Event Detail Data

The research team developed a data collection process to identify the variables relevant to this project. Figure 2 describes some of the positive protection types that were identified in the NDS data (not the exact image from the video).

Figure 2. Positive Protection Types

Because the encroachment data were not collected as part of the NDSs (e.g., impact or departure angle), some of the data were manually collected from videos. Figure 3 illustrates the data collection approach for estimating the impact angle during the encroachment.

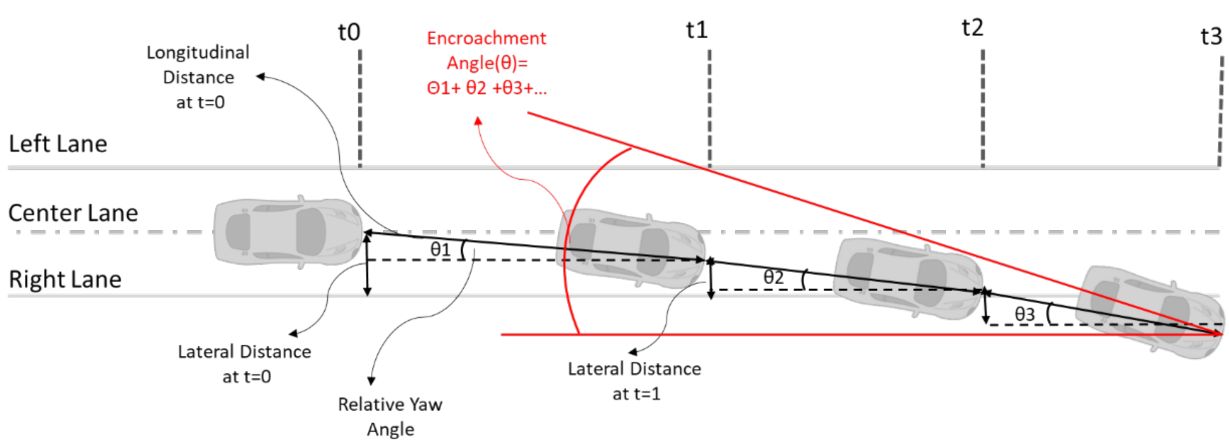


Figure 3. Calculating Encroachment Angle

Table 21 shows the number of crash and near-crash events extracted from the NDSs. A total number of 1,987 events were investigated. Encroachment in work zones was identified in 183 of the events, and road departures in non-work zone locations were found in 1,450 of the events. The link IDs of the near-crash events were obtained from VTTI to identify the roadway characteristics of these sites in the RID database.

Table 21. Summary of the Extracted Data from Three NDSs

Study	Event Type	Work Zone		Non-work Zone		Total
		Encroachment	*No Encroachment*	*Encroachment*	*No Encroachment*	
NDS-3	Crash	7	7	1	0	15
	Near-Crash	20	20	0	1	41
NDS-2	Crash	44	44	6	0	94
	Near-Crash	123	123	0	6	252
NDS-7	Crash	5	5	1,002	31	1,043
	Near-Crash	39	39	441	78	597
Total		183	1,450	238	116	1,987

State Crash Databases

A total of 27 state DOTs who previously agreed to share their work zone crash data were contacted. Out of those 27, 15 states shared their crash data with the team (Figure 4). The crash data obtained from states included only work zone crashes; non-work zone crashes were not available.

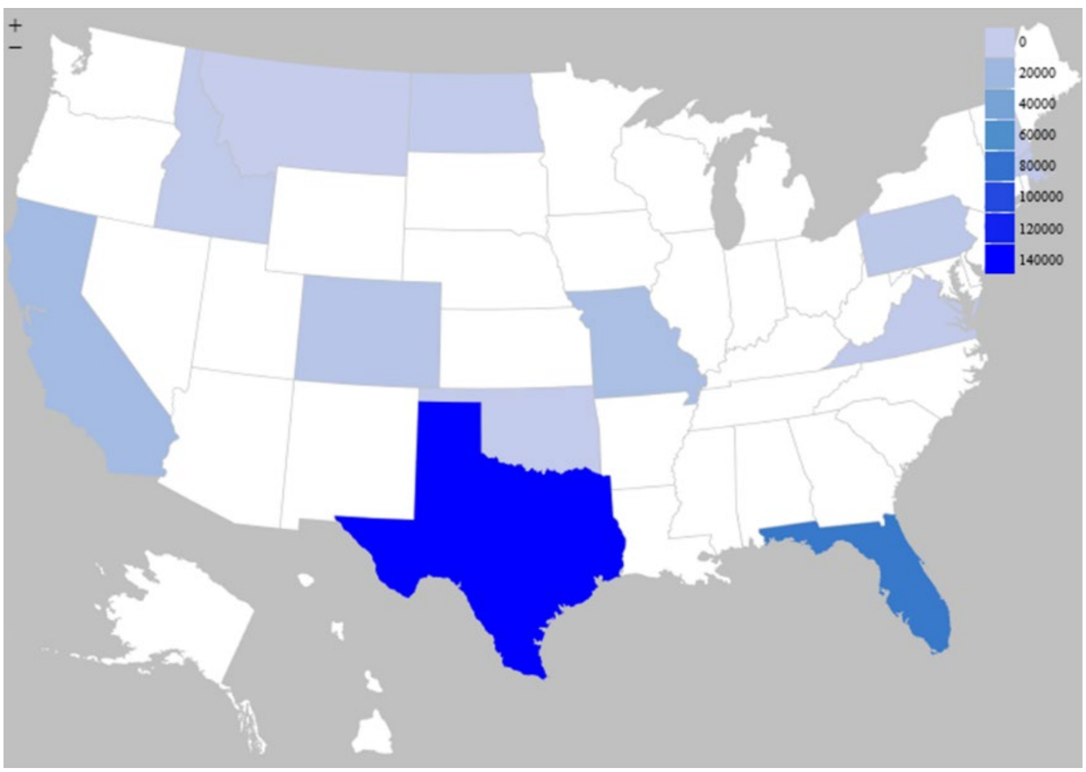


Figure 4. States Providing Crash Database

As mentioned earlier, state crash databases do not include pre-crash information such as encroachment and impact angle and speed. To identify the encroachment-related work zone crashes, the research team made some assumptions by reading crash reports and crash description variables. Crash details and sequence of events are among the most important data for determining encroachment events from other types of crashes. Some but not all the states record detailed information about the crash, sequence of events, most and first harmful event, and vehicle maneuver before and after the crash. Work zone layout and configuration information was missing in all the shared databases; however, in some databases, limited information about the crash location in the work zone area was reported. Driver information and road and roadside information were shared by some of the states. All databases were investigated, and the ones that had enough information for further data analysis were determined. Figure 5 shows general guidelines for filtering and identifying the WZ-related encroachment events. The filtering process can be summarized as follows:

1. The crash, vehicle, and driver data were merged through a unique crash identification number to create one single file. For the vehicle and driver data, just the vehicle that was contributing to the first harmful event was chosen, and from persons involved in the crash, just the driver information was selected.
2. Work zone and work zone related crashes were selected from the dataset. However, information about the work zone specifications was not available.
3. Due to the complexity and extension of the contributing factors to intersection- and junction-related crashes, these types of crashes were removed from the dataset. With that, the analysis focused on the encroachment and roadway departure crashes regardless of the intersection or junction location's specifications.
4. Encroachment is considered one of the significant crash types in single-vehicle crashes (SVCs). Thus, to determine encroachment crashes, first, SVCs were filtered from the collision type, and then harmful events were investigated. Events that contained encroachment, such as run-off-road, collision with a fixed object on the roadside, collision with maintenance equipment, and collision with a barrier, guardrail, etc., were selected.
5. From multiple-vehicle crashes, head-on, opposite sideswipe, and overturn events result from or will result in-vehicle encroachment. Thus, only these types of crashes were selected for multiple-vehicle crashes.
6. The left-side or right-side encroachment is a vital feature in encroachment analysis. The direction of the encroachment was determined from the available data on the location of the harmful event, type of crash, and type of fixed object included in the crashes.
7. After determining encroachment crashes in the dataset, each variable was investigated, and events with outlier values were removed. Also, redundant, unrelated, and less-informative features were removed from the dataset.

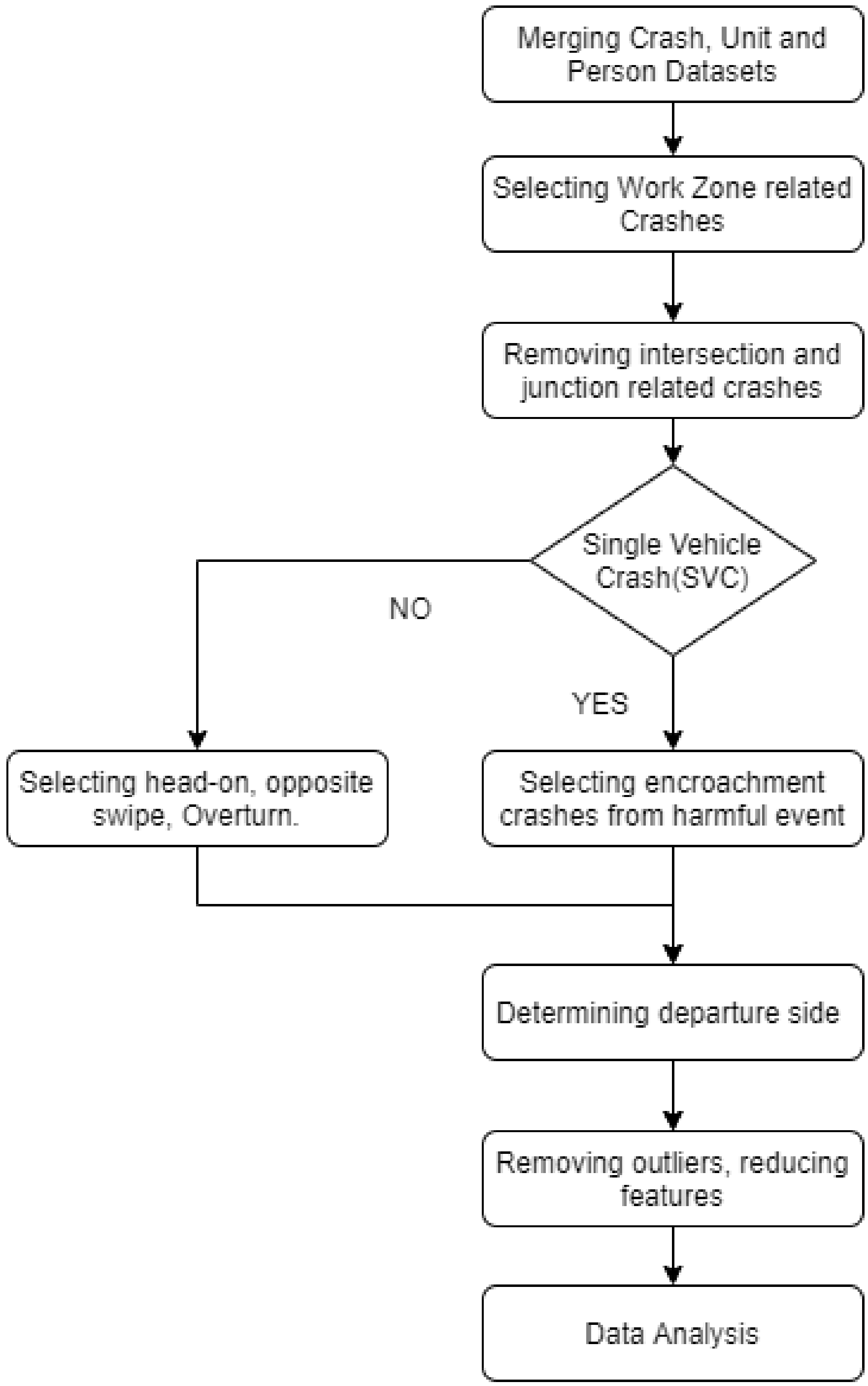


Figure 5. General Guideline for Filtering Encroachment Events

Table 22 presents information for the DOTs that responded to the data request and shared their crash data. Each state has a specific data structure and dictionary for crash data collection. Thus, the collected data were investigated, and the availability of the required information in each dataset was determined. Some of the datasets contain less information related to the required variables for this study.

Table 22. Summary of the Collected Crash Data from State DOTs

State	Period	Crash Details	Sequence of Events	Road and Roadside Info	Used in Analysis
California	2017–2019	—	—	—	N
Colorado	2014–2018	—	—	—	Y
Florida	2011–2019	✓	—	✓	Y
Idaho	2017–2019	✓	✓	✓	Y
Iowa	2016–2019	✓	—	—	Y
Massachusetts	2014–2018	✓	✓	—	Y
Missouri	2017–2019	—	—	✓	N
Montana	2017–2018	—	—	—	N
New Hampshire	2018–2020	—	—	✓	N
North Dakota	2017–2019	✓	—	✓	Y
Oklahoma	2016–2019	✓	—	✓	Y
Pennsylvania	2017–2018	✓	—	✓	N
Texas	2010–2019	✓	—	—	Y
Virginia	2013–2019	✓	—	✓	Y
Washington	2017–2019	✓	✓	—	Y

California Crash Database

The California Department of Transportation (Caltrans) provided information on crashes from 2017 to 2019. California crash data include information on crash specifications, persons, and units involved in 630,245 events. Information about work zone specifications was not available; however, the crashes related to road construction were selected as work zone-related events. A total of 16,700 crash events were work zone related. Intersection-related and junction-related events were removed from the database. The sequence of events was not available in the California crash database. The ACC_COLL_TYPE label was used for filtering the collision type. Head-on, overturn, and hit-object crashes were considered encroachment events. The direction of the sideswipe collision types was not determined. Thus, vehicle direction of travel was used for determining opposite-direction sideswipes. The sideswipe collisions in which vehicle direction of travel was different were selected as encroachment events. Type of fixed objects and first and most harmful events were not available in the California crash database.

From the driver information, only gender, age, and driver action before the crash were available. Roadway information included median type and width, shoulder type and width, road surface condition, number of lanes, and traffic control, which were provided as a separate file. The crash events and roadway information files were linked based on the district, county, route number, and post mile of the events. All extracted information was decoded based on the Caltrans data dictionary and merged into the existing database. After the filtering process, 2,467 encroachment cases were identified in the California data. The direction of encroachment was determined only for the head-on and opposite sideswipe crashes. The direction of encroachment was not available for the rest of the events.

Colorado Crash Database

Colorado DOT provided information on crashes from 2014 to 2018. The data included information on 7,510 events, including the location of the crash, first harmful event, driver information, driver impairment, and distraction reasons. All the crash events were work zone related. However, information on the type and specification of the work zones was not available. The database was filtered to isolate all encroachment cases. The filtering process included the following steps:

- Crash events at non-intersection locations were selected.
- Median, roadside, and shoulder were chosen as the location of the first harmful event.
- On-ramp crashes were filtered.
- Run-off-road, head-on, sideswipe opposite, collision with a fixed object, collision with maintenance equipment, and overturn as the first event in the sequence of events were chosen.
- From the on-road events, opposite sideswipe and head-on were selected.

After the filtering process, 503 encroachment cases were identified in the Colorado data. The direction and sequence of the encroachment were extracted from the event location and accident type information.

Florida Crash Database

Florida databases were set as a base for merging filtered data into a master database. The Florida crash database has comprehensive and detailed information on crash events. Categorical features are standard, and the levels were fully described. Crash information in each state database had a different categorical type. All the relevant features from state crash databases were selected. Levels of categorical data were recoded to make them consistent with the Florida crash database. New feature types in any state data that had useful information and were not included in the Florida database were added to the existing features.

Idaho Crash Database

Idaho DOT provided information on crashes for the period of 2017–2019. The Idaho data included information on 3,245 events including location of the crash, first and most harmful events, sequence of events, driver information, and driver impairment and distraction factors. All the crash events were work zone related; however, information on the type and specification of the work zones was not available. The database was filtered to isolate all encroachment cases. The filtering process included the following steps:

- Crash events at non-intersection locations were selected.
- Crash events at non-junction locations were selected.

- Run-off-road, head-on, sideswipe opposite, collision with fixed object, collision with maintenance equipment, and overturn as the first event in the sequence of events were chosen.
- Pedestrian and motor vehicle in traffic were removed from the first harmful event.
- Median, roadside, and shoulder were chosen as the location of the first harmful event.

After the filtering process, 203 encroachment cases were identified in the Idaho data. The direction and sequence of the encroachment were extracted from the sequence of events, first harmful event location, and type of fixed object information.

Iowa Crash Database

The team had access to and obtained permission to use the Iowa DOT crash database and extracted data for the period of 2016–2019. The Iowa data included information on crash specification, person, and units involved in the crashes. Iowa records whether a crash was work zone related, and this field was used to select work zone crashes. The crash specification file contained information on the crash type, harmful event and location, crash severity, contributing factors, and roadway and roadside specifications. The sequence of events leading to the crash was available. The unit file contained information on the type, model, and year of vehicle, as well as the area and severity of vehicle damage. The person file provided information on driver and passenger age and gender, driver impairment, and driver alcohol and drug test results. The crash, unit, and person files were queried through a unique crash identification number.

Crashes identified as work zone were first identified. Next, intersection crashes or those where intersection presence was unknown were removed. The next step was to review the sequence of events. The first sequence of events was reviewed for each vehicle in the non-intersection work zone crashes. Crashes were further filtered, and only those with one of the involved vehicles having one of the following as first in the sequence of events were included:

- Any type of roadway departure.
- Collision with an object located off the roadway (i.e., ditch, curb, signpost).
- Collision with a vehicle in the roadway where the manner of the collision was:
    - Head-on.
    - Sideswipe same direction.
    - Angle opposite direction.

A total of 255 encroachment events were determined from the provided crash database.

Massachusetts Crash Database

Massachusetts DOT provided information on crashes for the period of 2014–2018. The Massachusetts data included information on 2,700 events including location of the crash, first and most harmful events, sequence of events, crash narrative, road and roadside information, and driver impairment and distraction factors. The sequence of events and crash narratives were helpful in determining the encroachment cases in the data. The database was filtered to isolate all encroachment cases. The filtering process included the following steps:

- Crash events at non-junction locations were selected.
- Run-off-road, collision with fixed object, collision with maintenance equipment, and overturn as the first event in the sequence of events were chosen.
- Pedestrian and motor vehicle in traffic were removed from the first harmful event.
- Median, roadside, and shoulder were chosen as the location of the first harmful event.

After the filtering process, 180 encroachment cases were identified in the Massachusetts data. The direction and sequence of the encroachment were extracted from the narrative and sequence of events information.

Montana Crash Database

Montana DOT provided information on crashes for the period of 2017–2018. The Montana data contained information on 244 events, including the location of the crash, first harmful event, driver information, and roadway and roadside information. All the crash events were work zone related; however, information on the type and specification of the work zones was not available. The database was filtered to isolate all encroachment cases. A total of 61 encroachment events were identified. The direction of the encroachment was determined based on the sequence of events and collision type.

The filtering process included the following steps:

- Crash events at non-intersection locations were selected.
- Crashes that happened on a ramp were filtered.
- Run-off-road, head-on, sideswipe opposite, collision with a fixed object, collision with maintenance equipment, and overturn as the first event in the sequence of events were chosen.
- From the on-road events, opposite sideswipe and head-on were selected.

North Dakota Crash Database

North Dakota DOT provided information on crashes for the period of 2017–2019. The North Dakota data included information on 44,818 events, including crash details, harmful events, driver information, driver impairment and distraction factors, work zone relation, and injury and fatality details. The dataset lacked roadway and roadside information. Features like shoulder type, width, lane width, and roadside type were not included.

The filtering process included the following steps:

- Events at the work zone were selected.
- Non-intersection events were selected.
- Non-junction events were selected.
- The first event in the sequence of events that had encroachment potential was selected.

- For events with numbers 01 and 02 in the sequence of events (Motor Vehicle in Transport, Motor Vehicle in Transport in other Rdwy), the manner of the collision was filtered to get the head-on and opposite-direction crashes.

After the filtering process, 85 encroachment cases were identified in the North Dakota data. The direction and sequence of the encroachment were extracted from the sequence of events, first harmful event location, and type of fixed object information.

Oklahoma Crash Database

Oklahoma DOT provided information on crashes for the period of 2016–2019. The Oklahoma data included information on 1,647 events, including the location of the crash, first harmful event, driver information, and driver impairment and distraction factors. All the crash events were work zone related; however, information on the type and specification of the work zones was not available. The database was filtered to isolate all encroachment cases.

The filtering process included the following steps:

- Non-intersection events were selected.
- Non-junction events were selected.
- The first event in the sequence of events that had encroachment potential was selected.
- The direction and sequence of the encroachment were extracted from the event location and accident type information.

Pennsylvania Crash Database

Pennsylvania DOT provided information on crashes for the period of 2017–2019. The Pennsylvania data included information on 382,111 events, including crash details, harmful events, driver information, driver impairment and distraction factors, work zone characteristics, and injury, and fatality details. The dataset lacked roadway and roadside information. Features like shoulder type, shoulder width, lane width, and roadside type were not included.

The filtering process included the following steps:

- Events at the work zone were selected.
- From INTERSECTION, non-intersections were selected.
- From NON_INTERSECTION, non-intersections were selected.
- Events with SV_RUN_OFF_RD, indicating single-vehicle run-off-road, were selected.
- For collision type, head-on, sideswipe (opposite direction), and hit fixed object were selected.

After the filtering process, 442 encroachment cases were identified in the Pennsylvania data. The direction and sequence of the encroachment were extracted from VEH_POSITION, as indicated in Table 23.

Table 23. Encroachment Direction Labeling in Pennsylvania Crash Data

VEH_POSITION	Direction of Encroachment
00—Not applicable (for peds.)	Unknown
01—Right lane (curb)	Right
02—Right turn lane	Right
03—Left lane	Left
04—Left-turn lane	Left
05—Two-direction center turn lane	Left
06—Other forward moving lane	Unknown
07—Oncoming traffic lane	Left
08—Left of trafficway	Left
09—Right of trafficway	Right
10—HOV lane	Left
11—Shoulder rig	Right
12—Shoulder left	Left
13—One lane road	Unknown
98—Other	Unknown
99—Unknown	Unknown

Texas Crash Database

Texas crash data were obtained from the Crash Records Information System database. Texas DOT provided information on crashes for the period of 2016–2019. The Texas data included information on crash specification, person, and units involved in the 137,572 events. All the crashes were work zone related; however, information about the work zone specifications was not available. The crash specification file contained information on the crash type, harmful event and location, crash severity, contributing factors, and roadway and roadside specifications. The sequence of events leading to the crash was not available. The unit file contained information on the type, model, and year of vehicle, and the area and severity of vehicle damage. The person file provided information on driver and passenger age and gender, driver impairment, and driver alcohol and drug test results. The crash, unit, and person files were merged through a unique crash identification number to create one single file. For the vehicle and driver data, just the vehicles that contributed to the first harmful event were chosen, and from the person information, just the driver information was merged.

The database was filtered to isolate all encroachment cases. The filtering process included the following steps:

- Crash events at non-intersection locations were selected.
- First harmful events that included motor vehicle in transit, fixed object, and overturn were selected. Events related to animal, pedestrian, and unknown events were removed.
- All collision types related to one moving vehicle, head-on, and opposite sideswipe collision including more than one vehicle were selected.
- Fixed objects that included guardrail, concrete barrier, maintenance equipment, and objects usually located on the roadside were selected.
- Harmful events that happened at the roadside, shoulder, and median were selected.

After the filtering process, 17,570 encroachment cases were identified in the Texas data. The left-side and right-side encroachments were vital features in the encroachment analysis. The direction of the encroachment was determined from the available data on the location of the harmful event and the fixed object.

Virginia Crash Database

Virginia DOT provided information on crashes for the period of 2013–2019. The Virginia data included information on 185,676 events, including location of the crash, first harmful event, driver information, and driver impairment and distraction factors. Work zone related events were selected. However, information on the type and specification of the work zones was not available. The database was filtered to isolate all encroachment cases.

The filtering process included the following steps:

- Work zone related events were selected.
- Non-intersection events were selected.
- Non-animal events were selected.
- Non-pedestrian events were selected.
- Collision types were filtered, and head-on, opposite sideswipe, and SVCs were selected.
- The first event in the sequence of events that had encroachment potential was selected.
- The direction and sequence of the encroachment were extracted from the event location and accident type information.

Washington Crash Database

Washington DOT provided information on crashes for the period of 2017–2019. The Washington data included information on 913,246 events, including the location of the crash, first harmful event, driver information, and driver impairment and distraction factors. A total of 13,818 events were at the work zone. However, the information on the type and specification of the work zones was not available. The database was filtered to isolate all encroachment cases.

The filtering process included the following steps:

- Crash events at non-intersection locations were selected.
- Crash events at non-junction locations were selected.
- Collision types were filtered, and head-on, opposite sideswipe, and SVCs were selected.
- The first event in the sequence of events that had encroachment potential was selected.
- The first harmful event location was filtered.

NCHRP 17-43

The NCHRP 17-43 database is a collection of 1,581 road departure crashes extracted from the NASS CDS. The database includes the encroachment trajectory of the vehicle as well as detailed information about the roadside environment, such as the clear zone width, object performance, and presence of a work zone. For crashes with a known vehicle change in velocity (delta-v) as a result of the impact event, the impact speed and departure speed were reconstructed.

Of the 1,581 crashes in the NCHRP 17-43 dataset, nine were related to a work zone based on the NASS CDS scene photographs (Table 24). An additional two crashes related to a work zone were identified based on the crash descriptions provided by the NASS CDS investigator. These two vehicles had struck a fabric construction sign that was not present in the scene photographs. The NASS CDS crash investigator may analyze the crash scene up to 2 weeks after the crash occurred. Therefore, each of the 11 identified cases were inspected to predict if the work zone had appeared after the crash, and eight crashes were finally identified to have occurred in a work zone.

Within the NASS CDS database, each observation contributes a value of 1 to the unweighted frequency counts. However, a variable can assign a weight to each case to account for the NASS CDS sampling scheme. Therefore, when such a variable is utilized, each observation is expanded to the national level so that it contributes a weighted value for that observation, representing how often that type of crash occurs.

Table 24. Number of Cases in NCHRP 17-43

Selection Criteria	Cases	Weighted Cases
NCHRP 17-43 Database	1,581	510,254
Occurred in Work Zones	11	2,341
Manual Inspection	8	2,115

National Motor Vehicle Crash Causation Study

One of the goals of NCHRP 03-134 was to characterize the nature of work zone encroachments by examining national databases of in-depth crash investigations in work zones. One promising source for these in-depth crash investigations was the NMVCCS. The NMVCCS is an NHTSA-sponsored nationwide survey of crashes involving light passenger vehicles, with a focus on the factors related to pre-crash events. A total of 6,949 crashes were investigated between January 1, 2005, and

December 31, 2007. Of these, 5,470 cases comprise a nationally representative sample. The remaining 1,479 cases are suitable for clinical study. The data collected through the investigated crashes can provide a unique perspective on driver behavior factors that lead to work zone crashes. Each investigated crash involved at least one light passenger vehicle that was towed due to damage. Data were collected on-scene for at least 600 data elements in the crash to capture information related to the drivers, vehicles, roadways, and environment. In addition, the NMVCCS database includes crash narratives, photographs, schematic diagrams, and vehicle information, as well as detailed crash scene diagrams, on-scene photos of the crash site, and interviews with the driver.

The NMVCCS dataset was queried for crashes meeting the following criteria. Because NCHRP 03-134 focused on vehicle encroachments, cases were sought involving a roadway departure in work zones.

1. Crash occurred in a work zone.
2. The first event in the crash was a departure either to the left or right of the roadway.
3. Vehicle was a car or light truck. Because the NMVCCS only investigated light vehicles, this restriction is inherent in an NMVCCS analysis.

The reasons for the initial departure could include drift-out-of-lane crash, loss of control, or avoidance of a collision with another car, object, or animal.

The resulting dataset after applying these inclusion criteria was a dataset of 31 crashes. Candidate cases were first selected from the NMVCCS electronic database. Each case was then examined in the NMVCCS electronic case viewer to ensure that the case met the inclusion criteria. The initial dataset contained 32 cases. In one of these cases, however, there was no evidence of a work zone in either the scene diagram or the crash scene photos. This case was excluded.

CHAPTER 6. EXPLORATORY ANALYSIS OF ENCROACHMENT, ROADWAY, ROADSIDE, WORK ZONE, AND DRIVER BEHAVIOR CONDITIONS

This chapter presents the results of an exploratory data analysis on the encroachment, roadway, roadside, work zone, and driver behavior conditions. Encroachment data analyses were conducted separately for (a) encroachment databases (NDS and NCHRP 17-43), and (b) crash databases (state and NMVCCS), as described below. The rest of the analyses were conducted using both NDS and crash databases.

ENCROACHMENT CONDITIONS

NDS Database

NDS data were primarily used for extracting the encroachment angle and speed for work zone and non-work zone events. Figure 6 depicts the number of NDS events per relevance to (a) work zone and (b) encroachment direction. As observed, in non-work zone locations, there were 220 right-side and 179 left-side encroachments. Normally, the right side of the road has various fixed objects, such as guardrails, trees, etc., while the left side of the road has median barriers. For the work zone crashes, on the other hand, the number of left- and right-side encroachments are almost the same, indicating that the type of roadside barrier may not play a significant role in work zone encroachments.

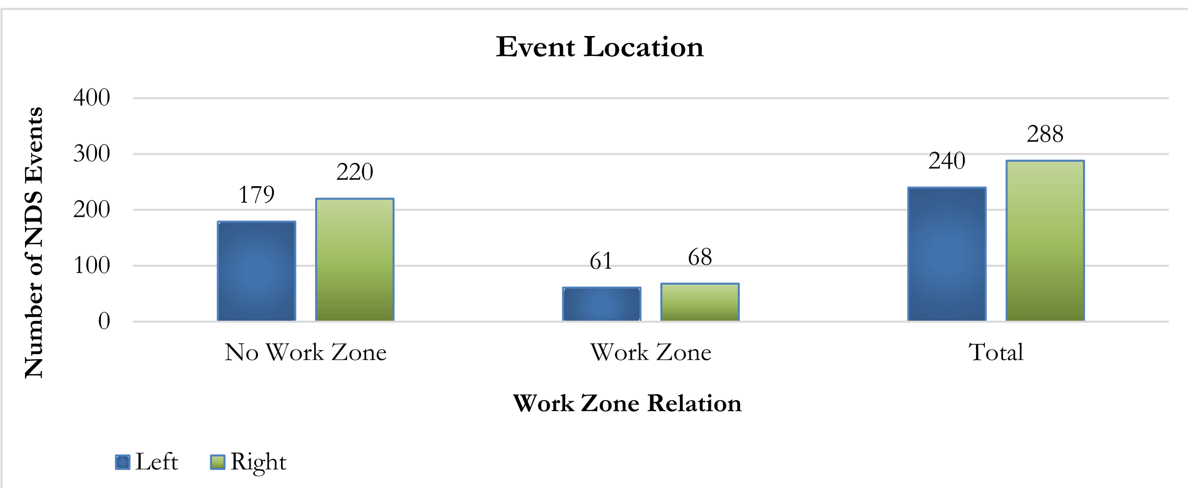


Figure 6. Event Location, NDS

For the purposes of this project, the researchers conducted an in-depth analysis of encroachment speed, angle, and lateral extensions using the NDS data. Lateral extension defines the lateral "trespass" beyond the travel lane edge line. These results helped inform the MASH and RDG guidelines. Table 25 depicts the descriptive statistics of encroachment angles and speeds per (a) relation to the work zone, and (b) direction of encroachment. The encroachment speed extracted from the NDS data indicates the speed at the time of encroachment or near-miss. Also, the posted speed limit value for the roadways of the investigated crashes was not available.

Figure 7 depicts the distribution of encroachment (departure) speeds and angles observed in encroachment events (work zone and non-work zone).

Table 25. Encroachment Speed and Angle per Encroachment Type

Encroachment Condition	Desc. Stat.	Work Zone (n=129)		Non-Work Zone (n=399)		Grand Total (n=528)	
		LSE (n=61)	RSE (n=68)	LSE (n=179)	RSE (n=220)	LSE (n=240)	RSE (n=288)
Encroachment Speed (mph)	Min	6.2	4.97	2.48	3.1	2.48	3.1
	Max	75.1	68.3	83.26	83.26	83.26	83.26
	Mean	31.67	34.2	38.59	36.77	36.78	36.17
	St. Dev.	15.53	14.63	18.05	14.51	17.66	14.5
	85^{th} %	49.7	51	60.9	51	59.7	51
Encroachment Angle (degrees)	Min	0	0	0	0	0	0
	Max	68	90	80	70	80	90
	Mean	21.94	20.10	19.70	19.47	20.2	19.6
	St. Dev.	11.03	14.03	12.13	11.48	11.87	12.07
	85^{th} %	31.8	29.6	30	31	31	31
Lateral Extension (ft)	85^{th} %	5.2	8.5	9.2	8.2	6.2	8.2

Note: LSE = left-side encroachment; RSE = right-side encroachment.

Since the roadside safety feature impact conditions recommended in MASH approximate the 85th percentile of previously calculated distributions of speed and angle data, it is good practice to investigate the 85th percentile of the new datasets that are being developed. Figure 7(a) indicates that the 85th percentile for work zone related encroachment speeds is 49.7 mph and 51 mph for left- and right-side encroachments, respectively. This compares to the recorded 85th percentile for non-work zone related encroachment speeds of 60.9 mph and 51 mph for left- and right-side encroachments, respectively. When considering the 85th percentile for all recorded encroachments, the values are 59.7 mph and 51 mph for left- and right-side encroachments, respectively. There is no difference in the 85th percentile value encroachment speed when comparing work zone and non-work zone related encroachments happening on the right side (51 mph in both cases). Also, when combining the values for the left and right encroachment sides, the 85th percentile results in 50.4 mph and 55.4 mph for work zone and non-work zone related encroachments, respectively.

Figure 7(b) indicates that the 85th percentile for work zone related encroachment angle is 31.8 degrees and 29.6 degrees for left- and right-side encroachments, respectively. This compares to the recorded 85th percentile for non-work zone related encroachment angle of 30 degrees and 31 degrees for left and right-side encroachments, respectively. When considering the 85th percentile for all recorded encroachments, the values are 31 degrees for both left- and right-side encroachments. There is not a significant difference in encroachment angle from a testing/design perspective when comparing work zone and non-work zone related encroachments happening on the right side (29.6 degrees vs. 31 degrees, respectively). The difference between the two values is less than the current MASH tolerance value of 1.5 degrees from the nominal value considered for testing. Also, when combining the values for the left and right encroachment sides, the 85th percentile results in 30.6 degrees for both work zone and non-work zone related encroachments.

Figure 7(c) indicates that the 85th percentile for work zone related encroachment lateral extension is 1.6 m (5.2 ft) and 2.6 m (8.5 ft) for left- and right-side encroachments, respectively. This compares to the recorded 85th percentile for non-work zone related encroachment lateral extension of 2.8 m (9.2 ft) and 2.5 m (8.2 ft) for left- and right-side encroachments, respectively. When considering the 85th percentile for all recorded encroachments, the values are 1.9 m (6.2 ft) and 2.5 m (8.2 ft) for left- and right-side encroachments, respectively. There is not a considerable difference in encroachment lateral extension when comparing work zone and non-work zone related encroachments happening on the right side (8.5 ft vs. 8.2 ft, respectively). Also, when combining the values for the left and right encroachment sides, the 85th percentile results in 7.1 ft and 8.7 ft for work zone and non-work zone related encroachments, respectively.

The research team then explored the relationship between the encroachment angle and speed for work zone and non-work zone encroachment events. As observed in the Figure 8 scatterplots, there is no specific relationship between departure speed and angles.

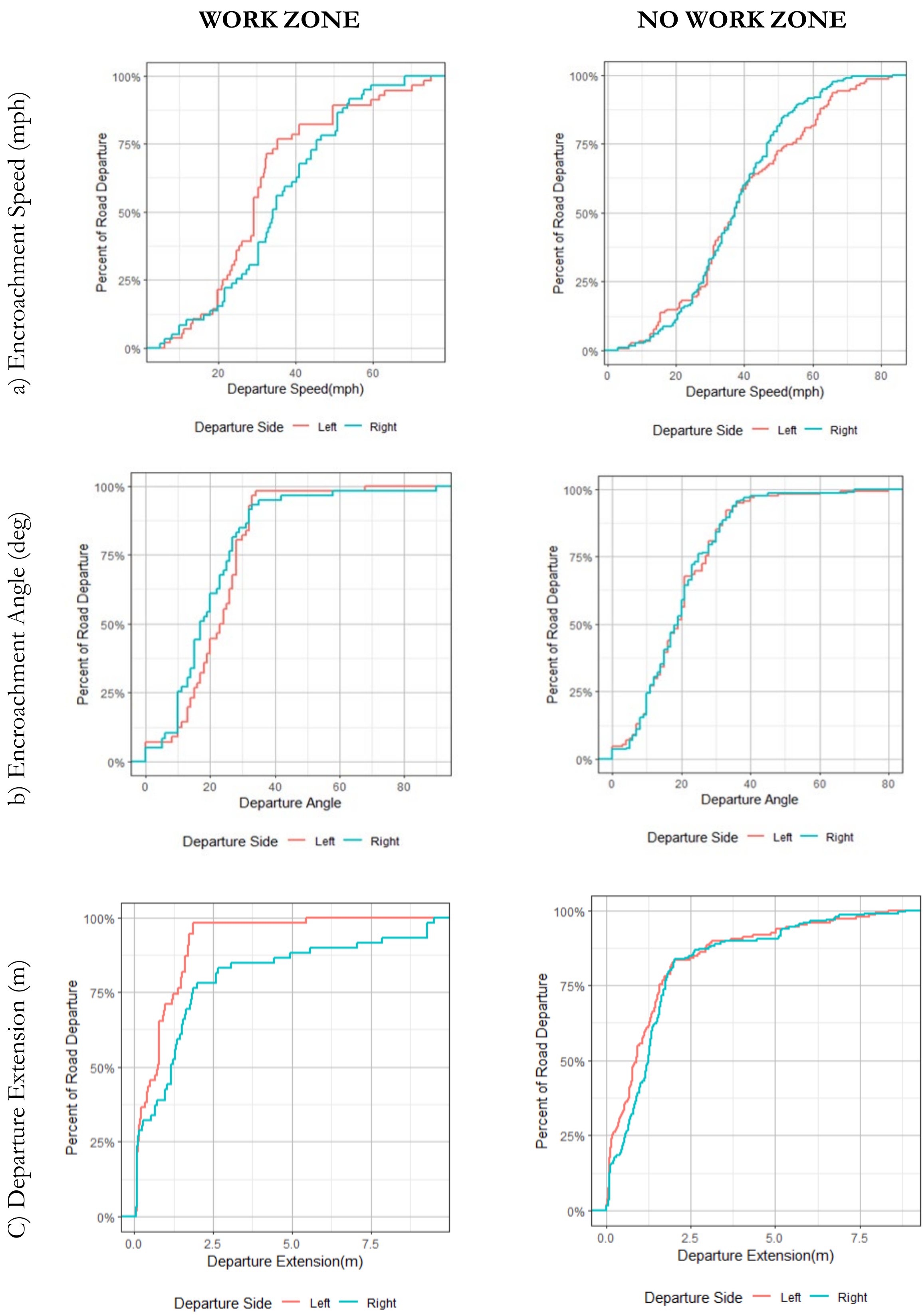
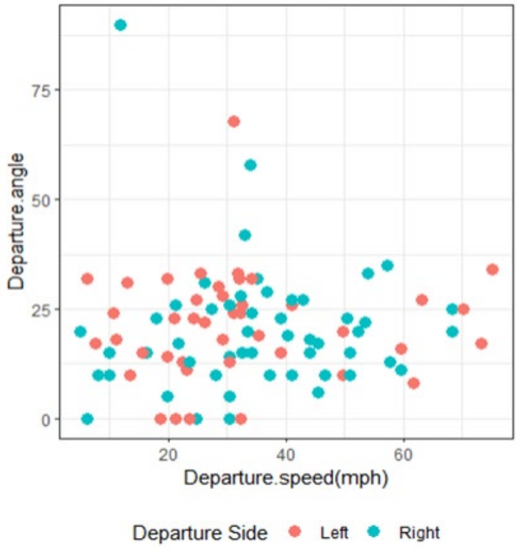
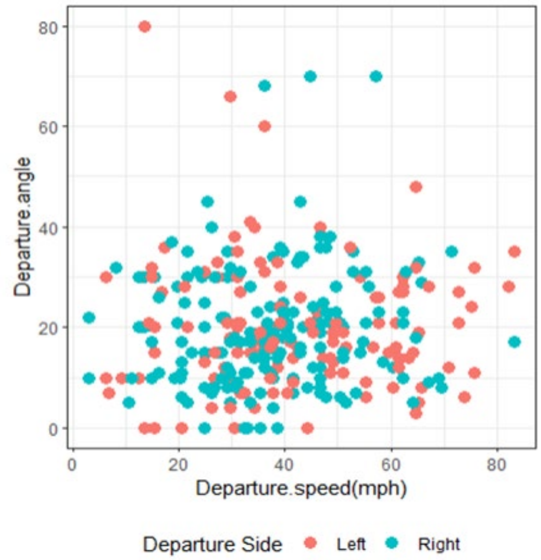


Figure 7. Encroachment Speed and Angle Distributions, NDS

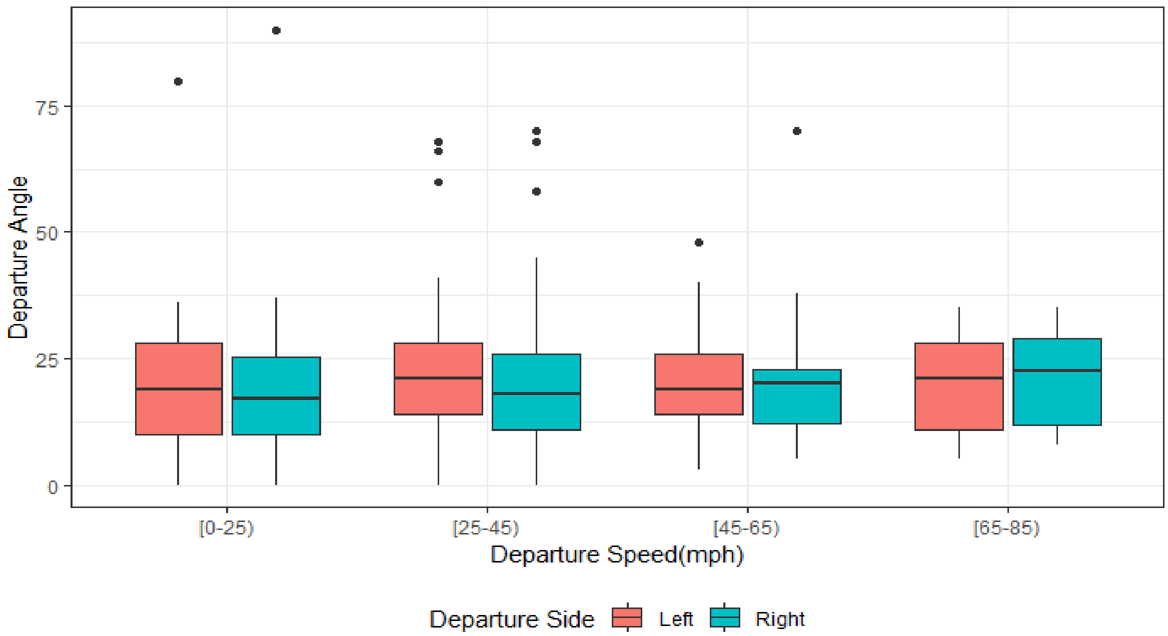




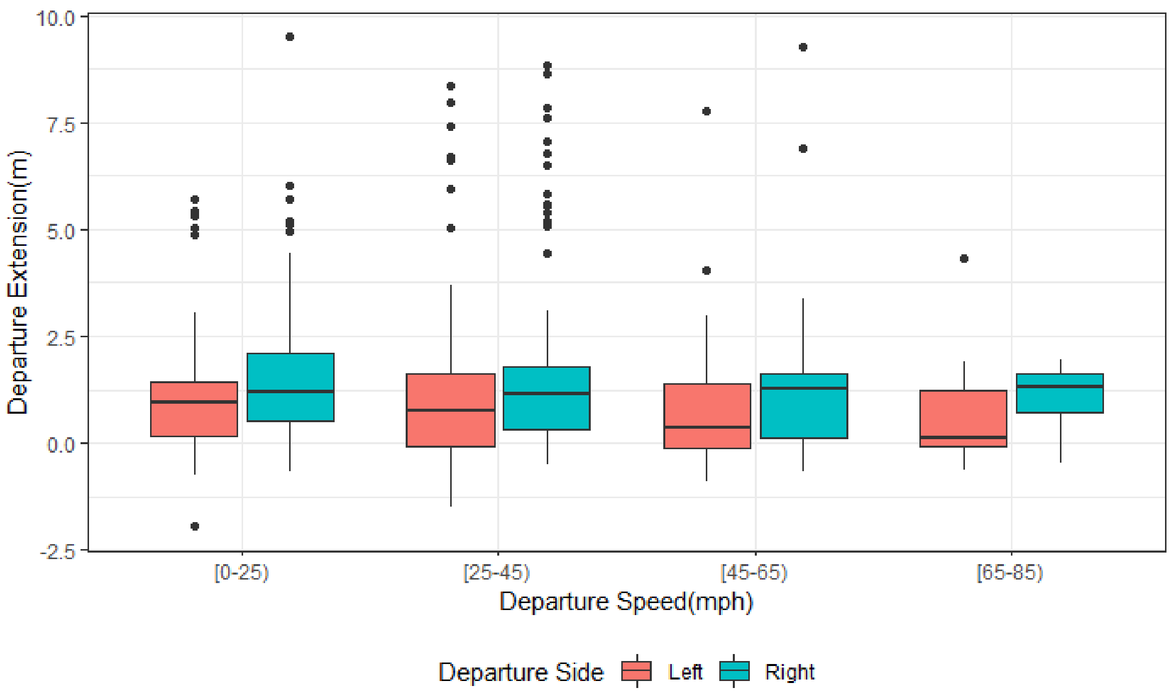
a) Work Zone b) Non-Work Zone

Figure 8. Scatterplots of Encroachment Speed and Angle, NDS

In addition to the scatterplots, the researchers also explored the encroachment angles and extensions per encroachment speed bins in work zones. For this, the researchers created box plots (Figure 9). Again, the departure angle seems to remain stable, and the mean value does not change significantly per encroachment speed. In terms of departure extension, this value seems to be decreasing as the encroachment speed increases, although not significantly. This may be due to the fact that in work zones, the travel lane is limited, thus not allowing for longer extensions as the vehicle departs the roadway.



a) Departure Angle per Departure Speed

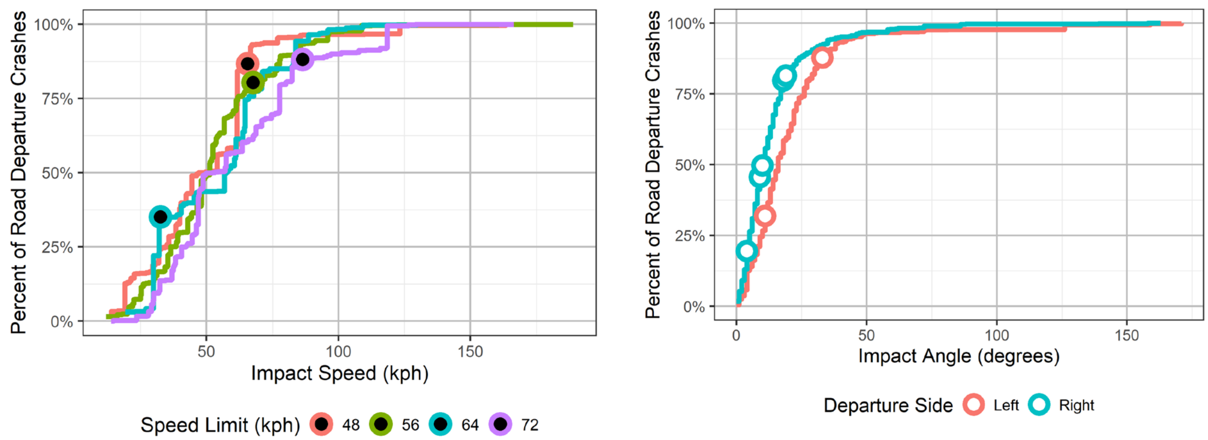


b) Departure Extension per Departure Speed

Figure 9. Left and Right Departure Angle and Extension per Speed Limit

NCHRP 17-43

Impact speed and angle of eight work zone crashes identified in NCHRP 17-43 are depicted in Figure 10. Five of these crashes included information on the impact speed. All of these five crashes, except for one case, had impact speeds below the 85th percentile. However, this did not account for the speed limit of the road. When accounting for the speed limit of the road, three crashes were above the 80th percentile for impact speed (Figure 10[a]). In each of these three cases, it is likely that the recorded speed limit was a reduced speed for the construction zone. In the three cases with high impact speeds, the finding may indicate that the drivers did not reduce their speed from the original speed limit of the road. The impact angles for the crashes in work zones were compared to all road departure crashes and did not appear to be different (Figure 10[b]).



a) Impact Speed
b) Impact Angle

Figure 10. Distribution of Impact Speeds and Angles, NCHRP 17-43

The distance to the first impact in work zones was compared to all crashes in the NCHRP 17-43 database (Figure 11). The distance to the first impact in a work zone was not smaller than in the rest of the NCHRP 17-43 database. Surprisingly, one of the longest impact distances in the dataset occurred in a work zone (case number 554017111). In that case, the vehicle departed when the road turned left to pass under an overpass. The vehicle climbed a hill and struck the bridge.

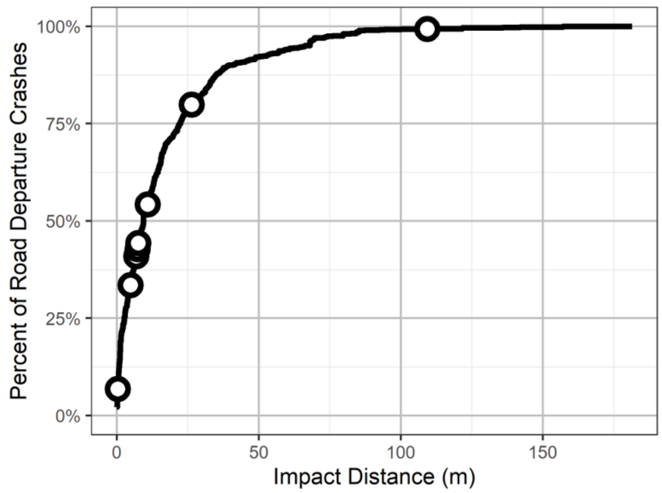


Figure 11. Distribution of Impact Distances, NCHRP 17-43

Of the eight work zone encroachments in the NCHRP 17-43 database, six had a maximum lateral encroachment under 11.5 ft (3.5 m) before impact, and one case involved the vehicle impacting a tree before leaving the roadway. An encroachment corridor was constructed that contained all the work zone encroachments. The maximum lateral encroachment increased by approximately half a meter for every additional meter traveled longitudinally.

As part of the ongoing NCHRP 17-43 project, encroachment speed and angle conditions were investigated using the available data from the developed 17-43 database. As part of the investigation, these values were also compared to those derived from the NCHRP 17-22 dataset. The consideration of these encroachment conditions could be valid for potential impact conditions for work zone safety barrier implementation, given the restricted nature and closer proximity of barriers to travel lanes.

The reconstructed speed at the first departure was similar between the NCHRP 17-43 and NCHRP 17-22 databases. The median departure speeds were 39.3 mph in the NCHRP 17-43 dataset and 40.7 mph in the NCHRP 17-22 dataset. The 85th percentile departure speeds were also similar, at 57.8 mph in the NCHRP 17-43 dataset and 57.0 mph in the NCHRP 17-22 dataset. The departure angle distribution was similar between the datasets as well. In general, right-side departures tend to have a smaller departure angle than left departures. For left-side departures, the 85th percentile angle was 31 degrees in the NCHRP 17-43 database and 29 degrees in the NCHRP 17-22 database. For right-side departures, the 85th percentile angle was 18 degrees in the NCHRP 17-43 database and 23 degrees in the NCHRP 17-22 database. Table 26 summarizes these data.

Additional analysis was performed under this project to investigate the 85th percentile for encroachments at both right and left sides. The analysis indicated that the 85th percentiles of the departure speed and angle were 55 mph and 22 degrees, respectively, when considering the right- and left-side encroachments collectively.

Table 26. Summary of Data Results from 17-43 and 17-22 Databases

Database	Encroachment	Median Departure	85th Percentile (right+left side)	85th Percentile (right side only)	85th Percentile (left side only)
17-43	Speed (mph)	39.3	57.8		
	Angle (deg)		22	18	31
17-22	Speed (mph)	40.7	57		
	Angle (deg)			23	29

State Crash Databases

Figure 12 shows the geographical distribution of the extracted encroachments identified in the crash databases. Texas had most of the crashes in the merged database, with almost 12,000 work zone encroachments. However, the crash database did not provide information about the impact speed, angle, and extensions. Therefore, the research team used these data for exploring the roadway, roadside, work zone, and driver behavior characteristics in encroachment events.

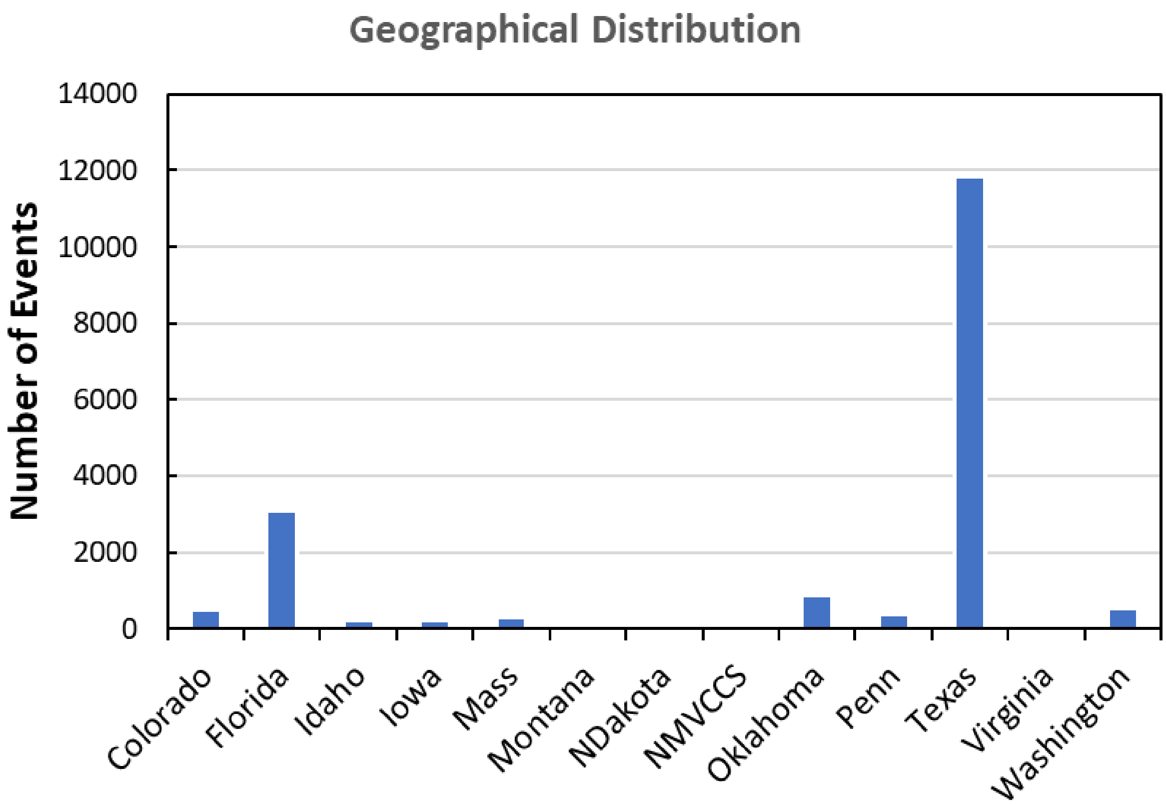
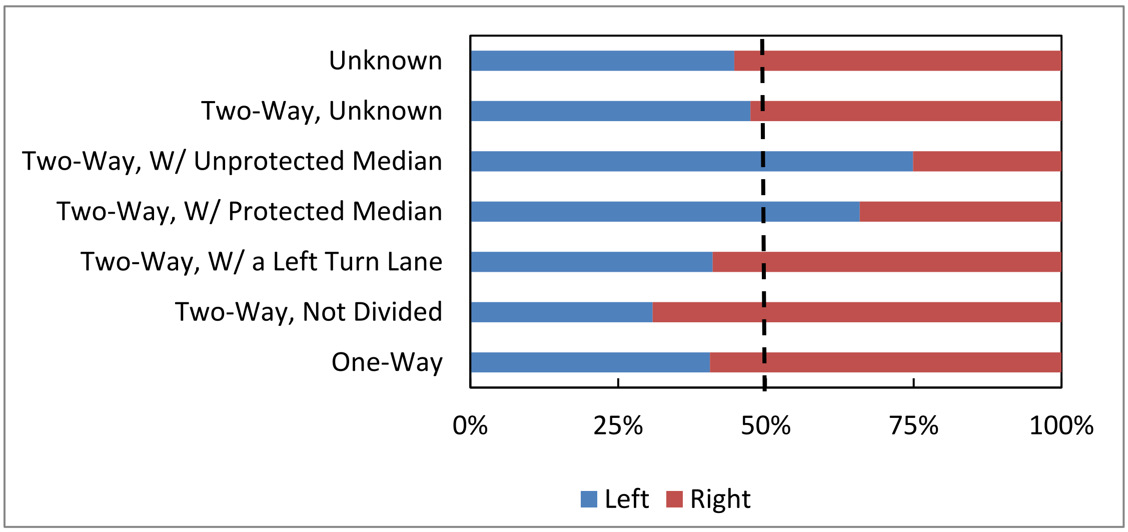


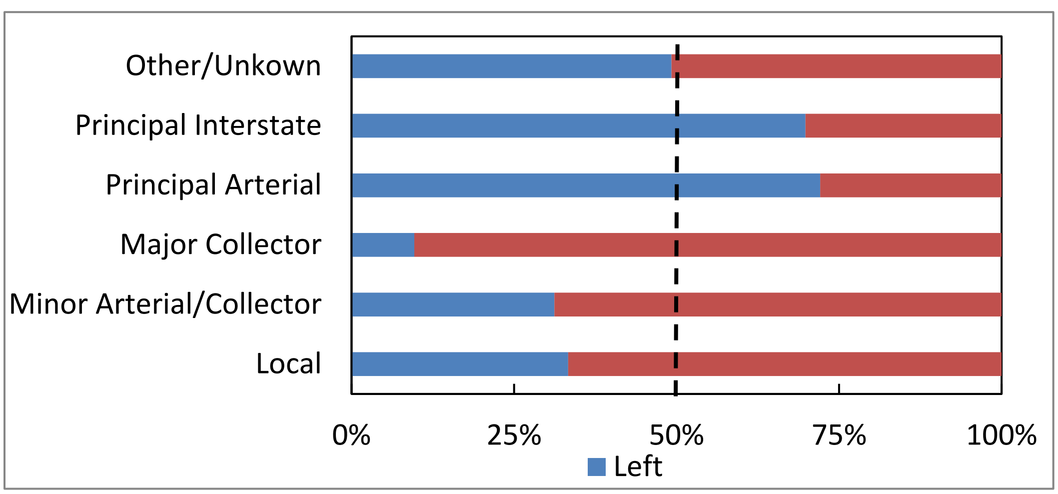
Figure 12. Geographical Distribution of Encroachment-Related Crash Events

ROADWAY CONDITIONS

The research team explored the roadway characteristics of locations where the work zone encroachments occurred using both NDS and crash databases. Figure 13 shows the association of the roadway facility with encroachment direction. About 60 percent of the encroachments on the one-way and two-way with left lane roads were toward the right side of the road (Figure 13[a]). Almost 70 percent of the encroachments on the undivided two-way roads were toward the right side. On the other hand, most of the encroachments on two-way roads with medians were toward the left side of the road. As observed in Figure 13(b), interstate and principal arterials (high-speed roadways) were associated with left-side encroachments, while lower classes such as collector and local roads were associated with right-side encroachments. This finding indicates that in high-speed roadways, most of the work zone encroachments happen toward the median barriers, while in low-speed roadways, work zone encroachments happen toward the shoulder.



a) Travel Lanes and Median Characteristics

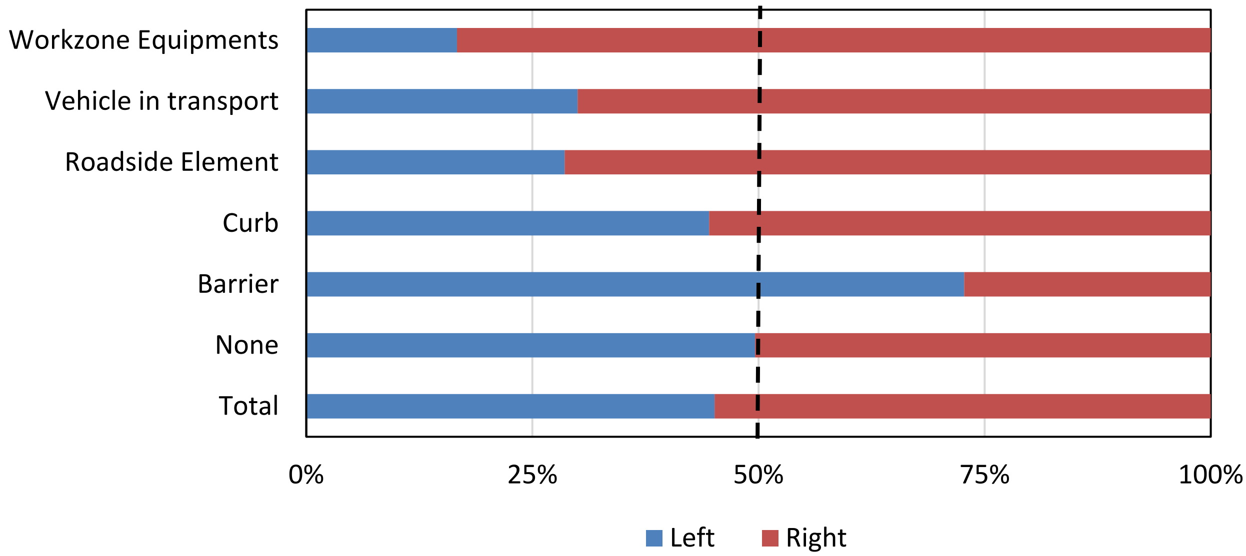


b) Roadway Functional Class

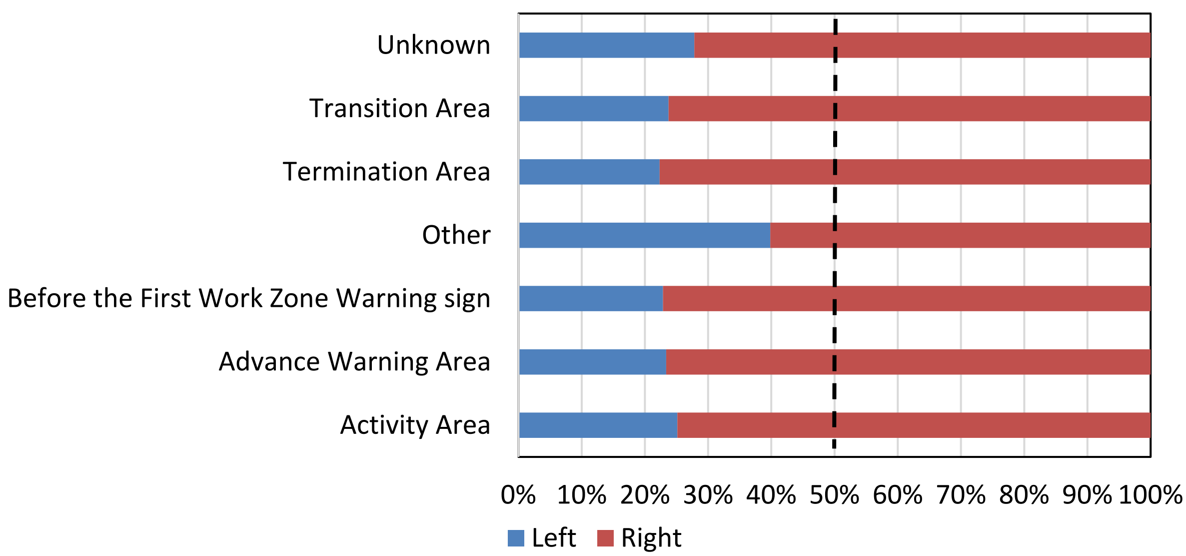
Figure 13. Roadway Facility Type in Encroachment Events

ROADSIDE AND WORK ZONE CONDITIONS

Figure 14 depicts the roadside object and work zone location where the encroachment occurred. As observed in Figure 14(a) majority of encroachments involved fixed objects on the right side of the road, except for barriers. Figure 14(b) depicts the percentage of encroachments per work zone location. As observed in work zone areas, majority of encroachments are to the right side of the road.



a) Roadside Object

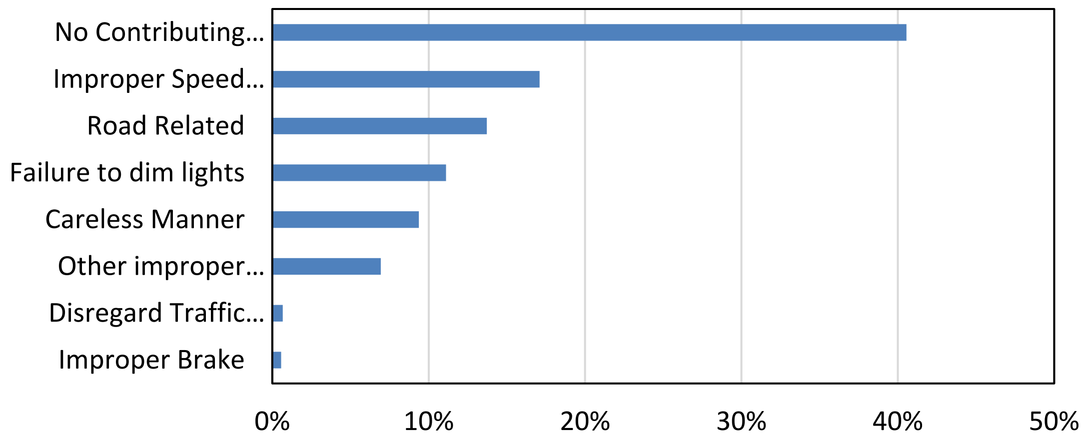


b) Work Zone Location

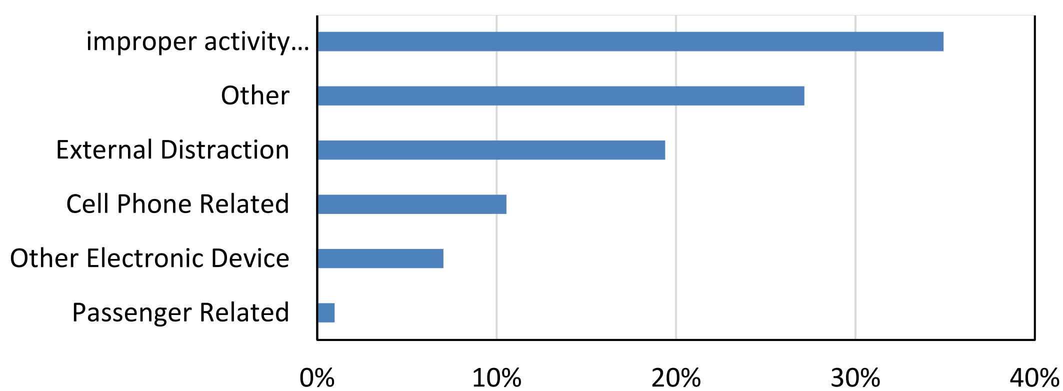
Figure 14. Roadside and Work Zone Conditions in Encroachment Events

DRIVER BEHAVIOR CHARACTERISTICS

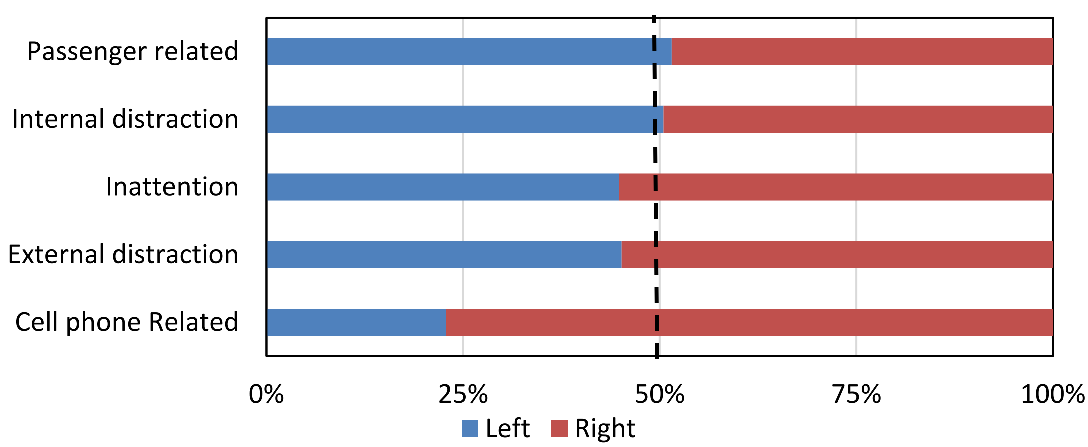
Figure 15 depicts the reported driver behavior where the encroachment occurred.



a) Driver Contributing Actions



b) Driver Distraction Factors



c) Driver Distraction vs. Departure Direction

Figure 15. Reported Driver Behavior during Encroachment Events

Among the driver contributing actions (Figure 15[a]), improper speed was observed in 15 percent of encroachments. This contributing factor had more weight than road-related factors. Other contributing factors found in the crash data included failure to dim lights, carelessness, disregard for traffic, and improper braking.

Figure 15(b) depicts driver distraction factors observed in work zone encroachment events. As observed, most driver distractions were related to improper driving activity (e.g., improper speed, improper lane change, etc.), external distraction (likely due to the built environment), cellphone and other electronic device use, and passenger.

Figure 15(c) depicts the reported driver distraction associated with the encroachment direction. Both right- and left-side encroachments involved distraction due to the passenger and internal distractions. Inattention and external distractions were mainly observed in right-side encroachment events. Among the distraction factors, cellphone use was found to be significantly associated with right-side encroachments, indicating that drivers using a cellphone are more likely to encroach on the right side of the road, which could result in fixed-object crashes.

CHAPTER 7. WORK ZONE ENCROACHMENT CRASHES

EXPLORATORY ANALYSIS

This chapter presents the exploratory analysis of the work zone crash data based on some of the key factors. Approximately 60 percent of the encroachment crashes in work zones that were obtained from state DOT databases did not result in any injury, 1 percent of crashes resulted in a fatality (F), 4 percent resulted in incapacitating injuries (A), 14 percent resulted in non-incapacitating injuries (B), 16 percent resulted in possible injuries (C), and 60 percent resulted in property damage only (PDO) (Figure 16).

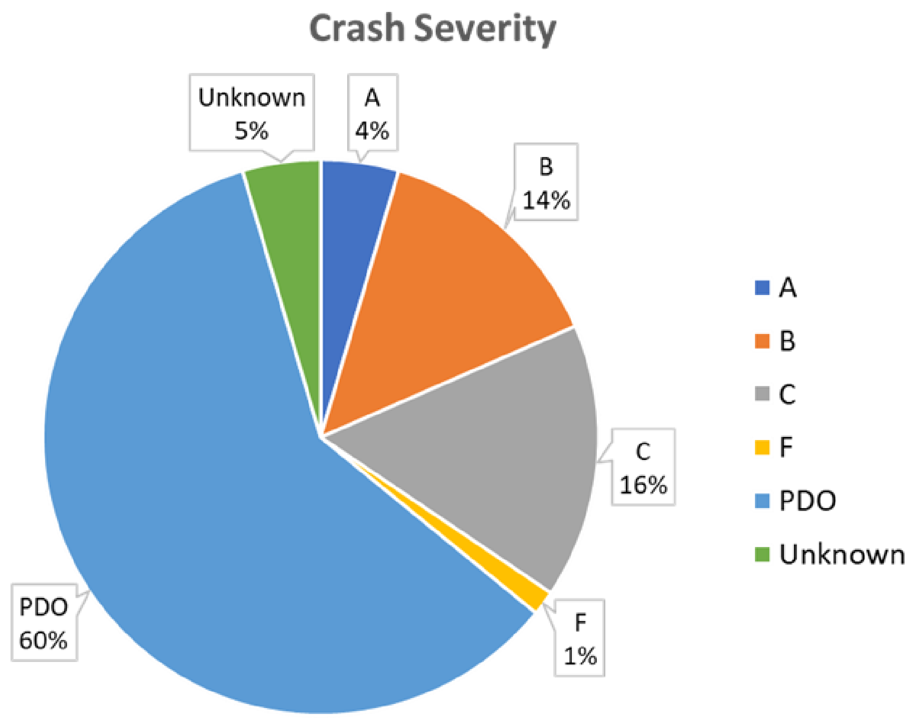


Figure 16. Crash Severity Distribution

Figure 17 depicts the work zone crash severity per encroachment directions based on the NDS database. As observed, right encroachments resulted in near-crash and minor crashes (i.e., encroachment to the shoulder). In contrast, left-side encroachments mostly resulted in police-reportable and severe crashes. Such encroachments included median barriers.

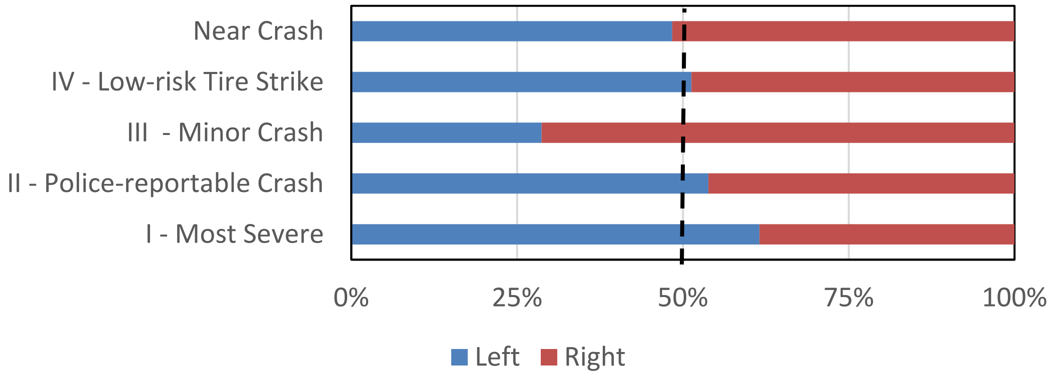


Figure 17. Crash Severity vs. Encroachment Direction

Table 27 depicts the descriptive statistics of crashes per severity. For qualitative variables, the research team included the number of crashes per category, while for quantitative variables, researchers included the mean and standard deviation of the variables.

Table 27. Descriptive Statistics of Variables per Crash Severity

Variable	Category	A	B	C	K	PDO	Unknown
		n=811	n=2,466	n=2,897	n=261	n=10,617	n=789
Qualitative Variables							
Year	2010	3	16	33	1	73	5
	2011	60	143	145	9	296	19
	2012	42	98	117	13	309	13
	2013	40	110	91	16	348	16
	2014	39	81	121	6	387	17
	2015	43	112	141	15	540	20
	2016	140	482	537	52	2,017	136
	2017	184	568	589	52	2,466	191
	2018	124	443	561	43	2,133	178
	2019	136	413	562	54	2,048	194
Encroachment Direction	Left	362	1,184	1,405	103	5,087	283
	Right	280	775	892	97	3,381	285
	Unknown	186	581	625	62	2,404	261
Manner of Collision	Angle	25	94	43	4	328	31
	Head-on	12	14	23	8	39	3
	Sideswipe	4	7	6	4	59	0
	Single Vehicle	5	39	23	1	212	7
	Other	243	501	480	75	1,789	91
	Unknown	520	1,848	2,314	167	8,281	694
Speed Limit (mph)	Mean	58.48	57.73	56.99	57.77	56.18	49.72
	S.D.	11.6	11.72	11.95	12.13	13.22	12.85
Driver Age (years old)	Mean	38.19	36.53	36.26	40.65	35.81	37.49
	S.D.	16.41	16.28	15.69	18.1	15.5	15.71
Lane Width (ft)	Mean	3.58	3.93	3.75		3.64	3.66
	S.D.	0.14	0.12	0.78		0.76	0.21
Left Shoulder Width (ft)	Mean	3.15	4.73	4.61	4.24	4.69	
	S.D.	3.72	3.91	3.54	4.67	3.61	
Rt Shoulder Width (ft)	Mean	8.49	9.16	9.3	8.06	9.34	
	S.D.	2.78	2.48	2.45	3.51	2.58	
Median Width (ft)	Mean	56.53	49.19	42.95	55.22	45.89	36.59
	S.D.	73.83	79.04	56.98	66.61	63.8	41.68

Note: S.D. = standard deviation.

WORK ZONE VERSUS NON-WORK ZONE CRASHES IN TEXAS

The research team obtained the non-work zone crashes only from Texas. Data mining analyses were performed to identify the patterns in work zone versus non-work zone crashes. For this purpose, the researchers used cluster correspondence analysis. Table 28 presents the description of data on encroachment-related work zone crashes, including no-injury and fatal and injury categories. From 2016 to 2019, there were a total of 10,677 encroachment-related work zone crashes in Texas. Out of these, 3,678 resulted in a fatality or injury (34 percent), while 6,998 resulted in no injuries (PDO). The rows provide the odds ratio (OR) of each category of attributes included in the dataset. The measure p.ratio provides a p-value, which indicates significance of attribute (for example, curve is an attribute of alignment) level OR measures. The measure p-overall provides the p-value of the variables.

Table 28. Percentage Distribution of Key Attributes by Crash Severity

Variable Category	No Injury (N=6,998)	Fatal and Injury (N=3678)	OR	p.ratio	p.overall
FIRST_DEP_DIR (Direction of Departure)					0.072
Left	3,154 (45.1%)	1,583 (43.0%)	Ref.[1]	Ref.	
Right	1,644 (23.5%)	865 (23.5%)	1.05 [0.95;1.16]	0.365	
Unknown	2,200 (31.4%)	1,230 (33.4%)	1.11 [1.02;1.22]	0.022	
RDWY_ALIGN (Alignment)					0.066
Curve	1,326 (18.9%)	766 (20.8%)	Ref.	Ref.	
Other	46 (0.66%)	25 (0.68%)	0.94 [0.57;1.54]	0.818	
Straight	5,626 (80.4%)	2,887 (78.5%)	0.89 [0.80;0.98]	0.020	
FRST_HARM_LOC (Location of First Harmful Event)					0.112
Median	1,904 (27.2%)	1,011 (27.5%)	Ref.	Ref.	
Off Roadway	4,227 (60.4%)	2,270 (61.7%)	1.01 [0.92;1.11]	0.810	
On Roadway	832 (11.9%)	382 (10.4%)	0.86 [0.75;1.00]	0.046	
Other	35 (0.50%)	15 (0.41%)	0.81 [0.43;1.47]	0.500	
RDWY_GRADE (Grade)					0.630
Grade	1,312 (18.7%)	725 (19.7%)	Ref.	Ref.	
Hillcrest/Uphill/Downhill	358 (5.12%)	194 (5.27%)	0.98 [0.80;1.19]	0.848	
Level	5282 (75.5%)	2,734 (74.3%)	0.94 [0.85;1.04]	0.208	
Other	46 (0.66%)	25 (0.68%)	0.99 [0.59;1.61]	0.957	
TRAF_CTRL (Traffic Control)					0.017
Controlled	635 (9.07%)	324 (8.81%)	Ref.	Ref.	
No Control	1,320 (18.9%)	615 (16.7%)	0.91 [0.77;1.08]	0.279	
Other	5,043 (72.1%)	2,739 (74.5%)	1.06 [0.92;1.23]	0.388	
SUR_TYPE (Surface Type)					<0.001
Asphalt	2,253 (32.2%)	1,257 (34.2%)	Ref.	Ref.	
Concrete	3,039 (43.4%)	1,654 (45.0%)	0.98 [0.89;1.07]	0.595	
Unknown	1,706 (24.4%)	767 (20.9%)	0.81 [0.72;0.90]	<0.001	
TRAF_WAY (Traffic Way)					
Other	11 (0.16%)	2 (0.05%)	Ref.	Ref.	.
Two-Way, Divided, Unprotected Median	4319 (61.7%)	2299 (62.5%)	2.76 [0.73;19.5]	0.148	
Two-Way, Not Divided	704 (10.1%)	500 (13.6%)	3.68 [0.97;26.0]	0.057	
Two-Way, Not Divided, with TWLTL	258 (3.69%)	110 (2.99%)	2.21 [0.57;15.8]	0.277	
Unknown	1706 (24.4%)	767 (20.9%)	2.33 [0.61;16.5]	0.237	
SEC_T_ADTC (AADT)					<0.001
1,001–4,000 vehicles per day (vpd)	237 (4.48%)	189 (6.49%)	Ref.	Ref.	
4,001–40,000 vpd	64 (1.21%)	50 (1.72%)	0.98 [0.64;1.49]	0.925	
401–1,000 vpd	3476 (65.7%)	1807 (62.1%)	0.65 [0.53;0.80]	<0.001	
GT 40,000 vpd	26 (0.49%)	19 (0.65%)	0.92 [0.49;1.71]	0.789	
LT 400 vpd	64 (1.21%)	50 (1.72%)	0.98 [0.64;1.49]	0.925	
MED_WIDTHC (Median Width)					0.392
11–20 ft	338 (7.82%)	194 (8.43%)	Ref.	Ref.	
GT 20 ft	2809 (65.0%)	1450 (63.0%)	0.90 [0.75;1.09]	0.268	

Variable Category	No Injury (N=6,998)	Fatal and Injury (N=3678)	OR	p.ratio	p.overall
LT 10 ft	1172 (27.1%)	655 (28.5%)	0.97 [0.80;1.19]	0.793	
No median	4 (0.09%)	1 (0.04%)	0.48 [0.02;3.50]	0.506	
RD_SRFC_COND (Road Surface Condition)					<0.001
Dry	5011 (71.6%)	2828 (76.9%)	Ref.	Ref.	
Not Dry	1987 (28.4%)	850 (23.1%)	0.76 [0.69;0.83]	<0.001	
LIGHT_COND (Lighting Condition)					<0.001
Dark–Lighted	1743 (24.9%)	814 (22.1%)	Ref.	Ref.	
Dark–Not Lighted	1724 (24.6%)	900 (24.5%)	1.12 [1.00;1.26]	0.060	
Daylight	3233 (46.2%)	1842 (50.1%)	1.22 [1.10;1.35]	<0.001	
Other	298 (4.26%)	122 (3.32%)	0.88 [0.70;1.10]	0.254	
EVNT_WTHR_COND (Weather Condition)					<0.001
Clear	4418 (63.1%)	2426 (66.0%)	Ref.	Ref.	
Other	1194 (17.1%)	698 (19.0%)	1.06 [0.96;1.18]	0.246	
Rain/Snow	1345 (19.2%)	550 (15.0%)	0.74 [0.67;0.83]	<0.001	
Unknown	41 (0.59%)	4 (0.11%)	0.18 [0.05;0.46]	<0.001	
D1_DR_COND (Driver 1 Condition)					<0.001
Apparently Normal	5832 (83.3%)	2972 (80.8%)	Ref.	Ref.	
Not Normal	788 (11.3%)	562 (15.3%)	1.40 [1.24;1.57]	<0.001	
Unknown	378 (5.40%)	144 (3.92%)	0.75 [0.61;0.91]	0.003	
D1_SEX (Driver 1 Gender)					<0.001
F	2019 (28.9%)	1420 (38.6%)	Ref.	Ref.	
M	4448 (63.6%)	2246 (61.1%)	0.72 [0.66;0.78]	<0.001	
Unknown	531 (7.59%)	12 (0.33%)	0.03 [0.02;0.06]	0.000	
D1_SEX (Driver 1 Gender)					<0.001
F	2019 (28.9%)	1420 (38.6%)	Ref.	Ref.	
M	4448 (63.6%)	2246 (61.1%)	0.72 [0.66;0.78]	<0.001	
Unknown	531 (7.59%)	12 (0.33%)	0.03 [0.02;0.06]	0.000	
D1_DR_DSTR (Driver 1 Distraction)					<0.001
Distracted	3822 (54.6%)	1846 (50.2%)	Ref.	Ref.	
Not Distracted	1804 (25.8%)	958 (26.0%)	1.10 [1.00;1.21]	0.053	
Unknown	967 (13.8%)	393 (10.7%)	0.84 [0.74;0.96]	0.009	
V1_FRST_DR_ACTN (Vehicle 1 Action)					0.001
Improper Driving	1148 (16.4%)	642 (17.5%)	Ref.	Ref.	
No Contributing Action	2963 (42.3%)	1521 (41.4%)	0.92 [0.82;1.03]	0.144	
Other	201 (2.87%)	77 (2.09%)	0.69 [0.52;0.90]	0.007	
Unknown	364 (5.20%)	139 (3.78%)	0.68 [0.55;0.85]	0.001	
Violation	2322 (33.2%)	1299 (35.3%)	1.00 [0.89;1.13]	0.996	
V1_POINT_IMP (Vehicle 1 Important Point)					<0.001
Back	298 (4.26%)	75 (2.04%)	Ref.	Ref.	
Front	4042 (57.8%)	2083 (56.6%)	2.04 [1.59;2.67]	<0.001	
Left	807 (11.5%)	355 (9.65%)	1.75 [1.32;2.33]	<0.001	
Other	154 (2.20%)	63 (1.71%)	1.62 [1.10;2.39]	0.015	
Overturn	482 (6.89%)	747 (20.3%)	6.14 [4.67;8.16]	0.000	
Right	924 (13.2%)	322 (8.75%)	1.38 [1.05;1.85]	0.022	
Unknown	291 (4.16%)	33 (0.90%)	0.45 [0.29;0.70]	<0.001	

[1] Ref. indicates the variable on the left is considered the base or reference.
Note: TWLTL = two-way left-turn lane.

With respect to the left-side encroachments, the OR is greater than 1 for right-side encroachments and unknown encroachments in these crashes. The unknown encroachments are also marginally significant (p-value < 0.05). For the first harmful event, the OR for off-roadway is greater than 1 when compared to the median. However, it is not statistically significant. The OR is less than 1 for work zones with no control (TRAF_CTRL), indicating that the odds of being involved in a crash decrease at work zones with no control. which might be counterintuitive. Under "traffic way," the ORs for two-way divided, two-way undivided, two-way undivided with continuous left-turn lane, and unknown are higher than 1 when compared to other. Of these, only two-way undivided is statistically significant. The finding is in line with many other studies. Under "lighting conditions," the ORs for dark–not lighted and daylight are higher than 1 when compared with dark–lighted. These two attributes are both statistically significant. Under "weather condition," the OR for other is greater than 1 when compared to clear, but it is not statistically significant. Under "driver 1 condition," the OR for not normal is greater than 1 when compared with apparently normal. It is statistically significant, and this finding is intuitive. Under "driver 1 distraction," the OR for not distracted is greater than 1 when compared to distracted. It is statistically significant. Under "vehicle 1 action," the OR for violation is equal to 1 when compared to improper driving, but it is not statistically significant. Under "vehicle 1 important point," the ORs for front, left, other, overturn, and right are greater than 1 when compared to back. These attributes are all statistically significant.

Cluster Correspondence Analysis

Cluster correspondence analysis (CA) is one of the approaches that has been developed for categorical data analysis (Velden et al., 2017). The research team conducted a categorical data analysis on crash data using the cluster CA. The cluster CA is an excellent tool for analyzing complex crash data by providing the co-occurrence patterns. Since crash data are complex in nature, it is important to identify the critical factors and their association patterns. This section provides a brief overview of the theory.

In the first step, a normal data matrix $\boldsymbol{X}$ with *n* observations containing *q* number of categorical variables needs to be converted to a new matrix $\boldsymbol{Z}$ named as a super indicator matrix. This matrix will be generated through a one-hot encoding process that transforms each categorical variable to a binary matrix, i.e., $\boldsymbol{Z} = [\boldsymbol{Z_1}, \boldsymbol{Z_2}, \ldots, \boldsymbol{Z_q}]$, where $\boldsymbol{Z_j}$ is an $n \times p_j$ matrix of the encoded *j*-categorical variable with $\boldsymbol{p_j}$ number of categories. The indicator matrix $\boldsymbol{Z}$ has the same *n* number of rows and $Q = \sum_{j=1}^{q} Pj$ number of columns. One can define $\boldsymbol{Z_k}$ as a $n \times K$ binary matrix indicating the memberships of each observation into the *K* number of clusters. To take into account the clusters' relationship with categorical variables, cross-tabulation of the indicator matrix and the membership matrix will be constructed as a $K \times p_j$ matrix, i.e., $\boldsymbol{F} = \boldsymbol{Z_K^{\mathrm{T}}}\boldsymbol{Z}$. By applying CA to the contingency matrix $\boldsymbol{F}$, scaling values corresponding to clusters and categories that maximize the inter-group variances will be optimized (Velden et al., 2017). In the optimal condition, the clusters separating the observations in a way that maximum variances from distributions over categorical variables, and simultaneously distributions of categories in each variable, will be obtained.

The process of cluster CA can be briefly described as:

- Randomly assigning observations to clusters and creating an initial membership matrix $\boldsymbol{Z_k}$ and contingency matrix $\boldsymbol{F}$.
- Applying the corresponding analysis to $\boldsymbol{F}$ and finding the category quantifications matrix $\boldsymbol{B}$.
- Calculating object coordinate matrix $\boldsymbol{Y} = \frac{1}{q}\left(\boldsymbol{I_n} - \frac{\boldsymbol{1_n 1_n'}}{n}\right)\boldsymbol{ZB}$.
- Applying k-means clustering to $\boldsymbol{Y}$ and updating $\boldsymbol{Z_k}$.
- Repeating the process until $\boldsymbol{Z_k}$ values converge to a fixed number.

The resulting $\boldsymbol{Z_k}$ gives the optimum cluster centroid matrix $\boldsymbol{G}$ and category quantification matrix $\boldsymbol{B}$. The coordinate matrix $\boldsymbol{G}, \boldsymbol{B}$ can be used to present a biplot of the clusters and categories. However, to facilitate the interpretation of the biplots, the two matrixes will be scaled by a constant value of $\gamma = \left(\frac{K}{Q} \cdot \frac{TrB^TB}{TrG^TG}\right)^{1/4}$. The new coordinate matrixes, $\boldsymbol{G_s} = \gamma\boldsymbol{G}$ and $\boldsymbol{B_s} = \frac{1}{\gamma}\boldsymbol{B}$, have the same average squared deviation from the origin that will be used for biplot presentations of analysis.

Data Mining Results

The categorical data analysis shows evidence of analyzing the data by crash injury types. Cluster CA was applied to the no-injury crash data and the fatal and injury crash data separately. Determination of the optimal clusters was conducted based on the convergence properties. Finally, four clusters for each of the datasets were developed. Table 29 shows the locations of the centroids and relevant cluster-based properties (size of the clusters and within-cluster sum of squares). The first two clusters of each of the datasets contain 70 percent or above of the data used for analysis. Since the contributing factors are displayed in the two-dimensional space, the relative distances between the contributing factors can be seen. The closer the factors, the higher the co-occurrence. The centroid of the clusters and their relative locations indicate the similarity or dissimilarity between the clusters.

Table 29. Centroids and Size of the Clusters

Cluster	No-Injury Crashes				Fatal and Injury Crashes			
	Dim 1	Dim 2	Within-cluster sum of squares	Size	Dim 1	Dim 2	Within-cluster sum of squares	Size
Cluster 1	−0.0080	−0.0025	0.0198	3114	−0.0117	−0.0013	0.0197	1548
Cluster 2	0.0138	−0.0077	0.0156	1706	−0.0010	−0.0060	0.0193	869
Cluster 3	−0.0031	0.0034	0.0176	1464	0.0102	0.0200	0.0152	767
Cluster 4	0.0084	0.0225	0.0127	714	0.0226	−0.0166	0.0137	494

Note: Dim = dimension or axis.

No-Injury Crash Data

The no-injury crash data from encroachment-related work zone crashes were used to develop clusters, which are illustrated in Figure 18 as a two-dimensional biplot. The locations of the centroids of the clusters are shown in blue ellipses. Because the biplot shows the locations of all attributes, it is difficult to explore individual attributes. This plot is provided to show the nature of attribute presence and locations in a two-dimensional space. Additional cluster-level bar plots are shown later and explained in detail. Cluster 1, which explains 44.5 percent of the data, primarily includes AADT greater than 4,000 vpd, concrete surface type, two-way divided, unprotected median as the traffic way, six lanes, median width of less than 10 ft or greater than 20 ft, left departure direction, median being the location of the first harmful event, and first harmful event being a collision with a barrier as the crash-contributing factors. This cluster is located mostly in quadrant three and partially in quadrant two. Cluster 2 (24.4 percent of the data) primarily includes the first harmful location being on a roadway, along with several other positively associated but unknown categories such as surface type, traffic way, total lane count, crash severity, and injury severity. This cluster is mostly located in quadrant four. Cluster 3 (20.9 percent of the data), which primarily relates to an AADT of 4,001–40,000 vpd, four lanes, a two-way undivided with continuous left-turn lane traffic way or a two-way divided with unprotected median traffic way, asphalt surface type, median width of greater than 20 ft, non-collision or collision with another fixed object as the first harmful event, and overturning, is located mostly in quadrants one and two, and partially in quadrant three. Cluster 4 (10.2 percent of the data), which primarily relates to two-way undivided roads as the traffic type, total lane count of two, surface type of asphalt, AADT less than 40,000 vpd, controlled traffic, non-collision being the first harmful event, and an important point of vehicle 1 being overturn, is located mostly in the first quadrant. Cluster 3 is the closest to the center of the biplot.

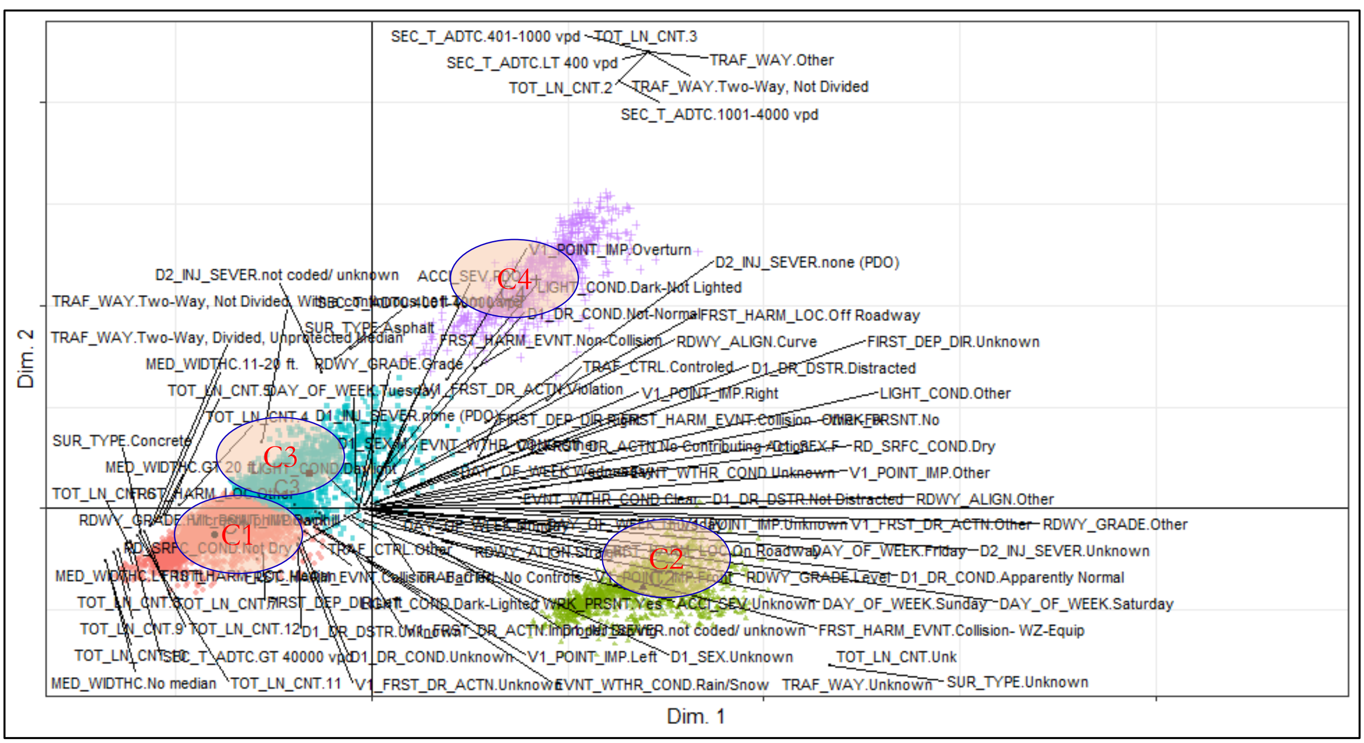


Figure 18. Clusters Developed from No-Injury Crash Data

Cluster 1 (C1)—Median-Related Crashes on High-Volume Two-Lane Divided Roadways

In C1 (representing 44.5 percent of the data) of the encroachment-related no-injury work zone crash data, AADT greater than 40,000 vpd has the longest bar on the positive side (see Figure 19). This indicates that it has the strongest association with the other categories in this cluster, including concrete surface type, two-way divided with unprotected median as the traffic way, six lanes, median width of less than 10 ft or greater than 20 ft, left departure direction, median being the location of the first harmful event, and first harmful event being a collision with a barrier. This cluster indicates patterns of median or barrier encroachment-related crashes in a work zone area. The crashes mostly occur on high-volume two-lane divided (unprotected median) roadways with concrete pavement. Thus, this cluster is defined as median-related crashes on high-volume two-lane highways.

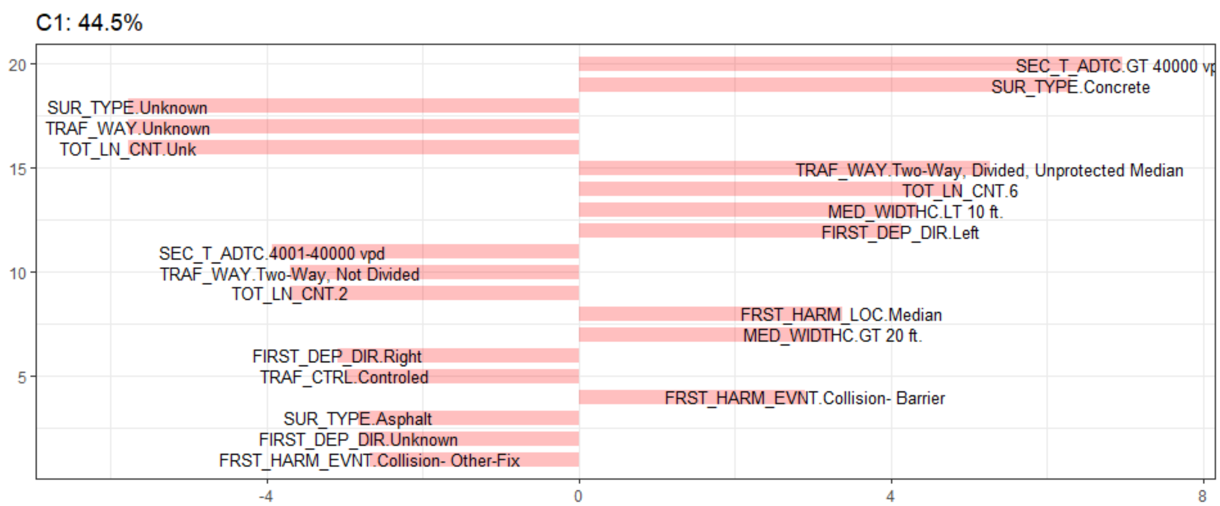


Figure 19. Cluster 1 (C1), No-Injury Crashes

Cluster 2 (C2)—Encroachment on Roadway

In C2 of the encroachment-related no-injury work zone crash data, many of the attributes are listed as unknown (see Figure 20). This indicates that around 25 percent of the work zone related no-injury data have missing information. One of the features that stands out in this cluster is "on roadway." As indicated earlier, encroachments usually take place outside of the travel lane; thus, one can assume that this cluster represents a special case where the encroachment occurs on the roadway but where the vehicle is not running off the road.

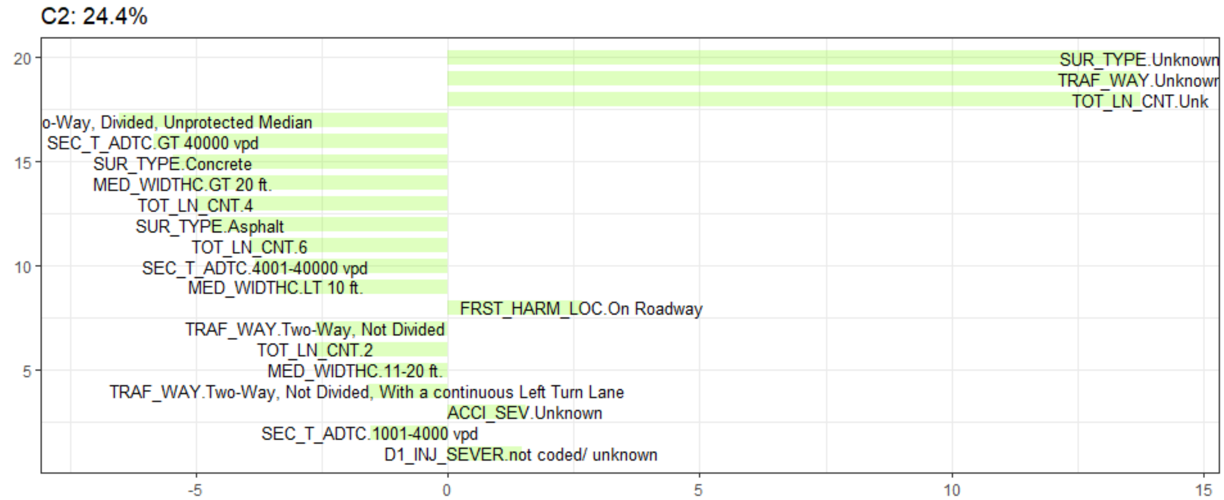


Figure 20. Cluster 2 (C2), No-Injury Crashes

Cluster 3 (C3)—Single-Vehicle Overturning Collisions on Two-Way Divided Roadways with Unprotected Median

In C3 of the encroachment-related work zone no-injury crash data, the longest bar on the positive side is AADT of 4,001–40,000 vpd (see Figure 21). The other key category in this cluster includes four lanes, two-way undivided with continuous left-turn lane or two-way divided with unprotected median traffic way, asphalt surface type, median width of greater than 20 ft, non-collision or collision–other–fix as the first harmful event, and overturning. The first departure direction also has a positive association, but the direction type is unknown. This cluster also indicates median-related collisions on two-lane divided roadways with low to moderate traffic volume. Safety barriers are the prospective countermeasure to reduce these crashes.

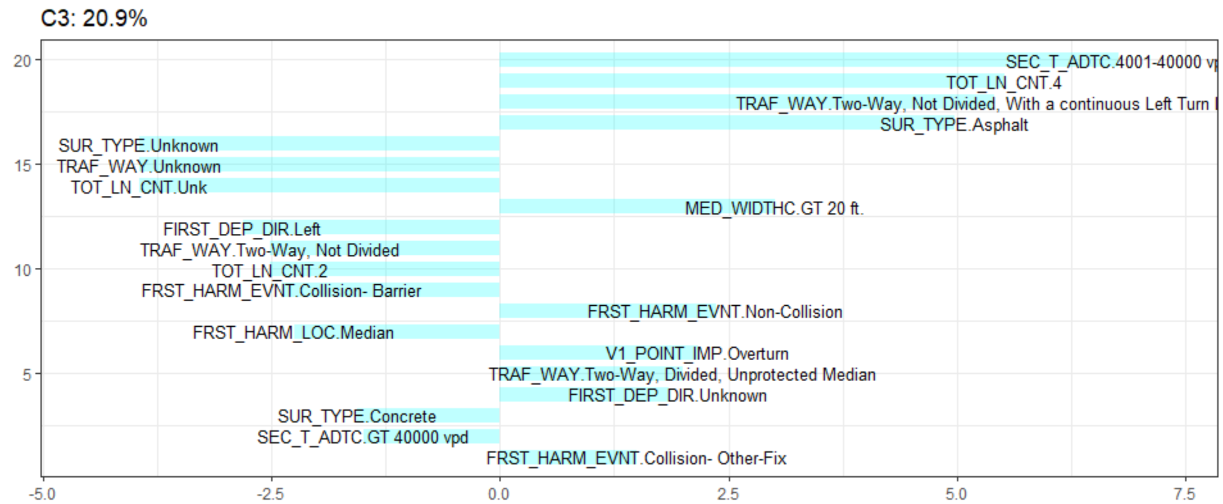


Figure 21. Cluster 3 (C3), No-Injury Crashes

Cluster 4 (C4)—Overturning Crashes on Two-Lane Undivided Roadways in Controlled Traffic

In C4 of the encroachment-related work zone no-injury crash data, the longest bar on the positive side is two-way undivided roads as the traffic type, meaning that it has the highest association with other categories within this cluster (see Figure 22). This includes two lanes, asphalt pavement, AADT less than 40,000 vpd, controlled traffic, non-collision being the first harmful event, and overturning. This cluster indicates encroachment-related work zone crashes on two-lane undivided roadways with different traffic volumes (ranging from less than 400 to 40,000 vpd). The surface type is asphalt in this cluster.

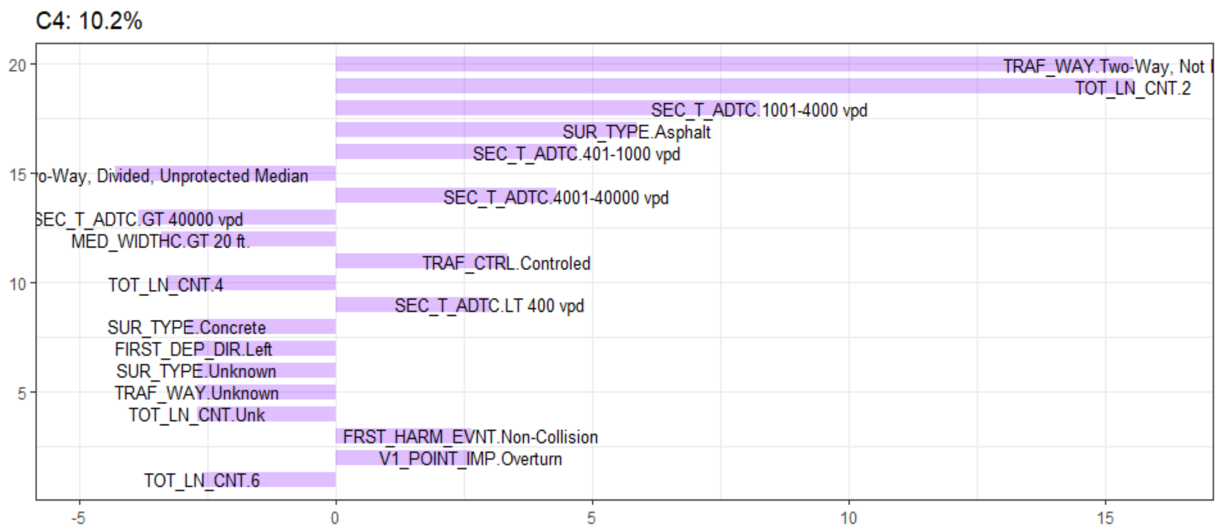


Figure 22. Cluster 4 (C4), No-Injury Crashes

Fatal and Injury Crash Data

The fatal and injury crash data from encroachment-related work zone crashes were used to develop clusters, which are portrayed in Figure 23. The locations of the centroids of the clusters are shown in blue ellipses. As mentioned earlier, the biplot is a difficult visual representation for exploring individual attributes. This plot is provided to show the nature of attribute presence and locations in a two-dimensional space. Additional cluster-level bar plots are shown later and explained in detail. Cluster 1 (42.1 percent) primarily relates to roadways with AADT greater than 40,000 vpd, concrete surface type, six lanes, first departure direction being left, traffic way being a two-way divided with unprotected median, median width of less than 10 ft, first harmful location being the median, and first harmful event being collision into a barrier. It is located mostly in quadrants two and three. Cluster 2 (23.6 percent), which primarily relates to an AADT of 4,001–40,000 vpd, four lanes, traffic way either being two-way undivided with a continuous left-turn lane or two-way divided with an unprotected median, median width of greater than 20 ft, asphalt surface type, first harmful event being non-collision with other vehicles, overturning, fatality, and first departure direction being right or unknown, is mostly located in quadrants three and four. Cluster 3 (20.9 percent), which has several unknowns but includes positive associations with a collision with other fixed objects as the first harmful event, first harmful location being on the roadway, first departure direction being right, and lighting conditions being dark but lighted, as well as the unknown categories of surface type, traffic way, and total lane count, is mostly located in quadrant one. Cluster 4 (13.4 percent), which primarily relates to a traffic way of two-way undivided, two-lane, AADT of less than 40,000 vpd, asphalt surface type, controlled traffic, and important point of vehicle one being overturned, is located mostly in quadrant four. Cluster 2 is located the closest to the center of the graph.

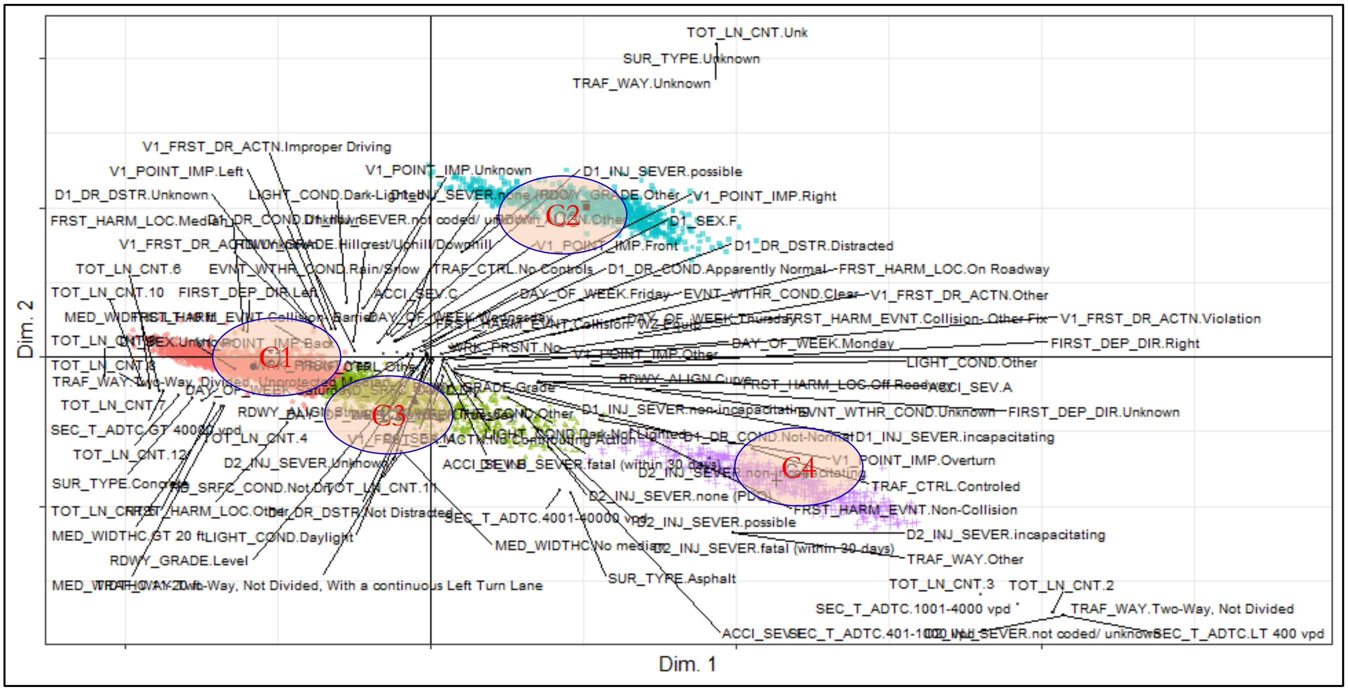


Figure 23. Clusters Developed from Fatal and Injury Crash Data

Cluster 1 (C1)—Median-Related Crashes on High-Volume Two-Lane Divided Roadways

In C1 of the encroachment-related work zone fatal and injury crash data, the longest bar on the positive side is an AADT greater than 40,000, meaning it has the highest association with other categories within this cluster (see Figure 24). These include a surface type of concrete, six lanes, first departure direction being left, traffic way being a two-way divided with unprotected median, median width of less than 10 ft, first harmful location being the median, and first harmful event being collision into a barrier.

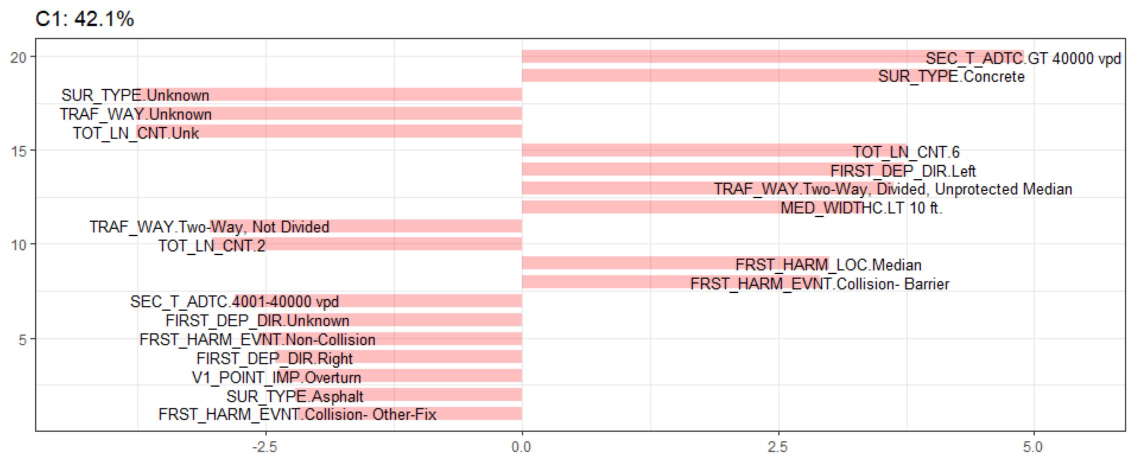


Figure 24. Cluster 1 (C1), Fatal and Injury Crashes

Cluster 2 (C2)—Single-Vehicle Overturning Collisions on Two-Way Divided Roadways with Unprotected Median

In C2 of the encroachment-related work zone fatal and injury crash data, the longest bar on the positive side is an AADT of 4,001–40,000 vpd, meaning it has the highest association with other categories within this cluster (see Figure 25). These include four lanes, traffic way being either two-way undivided with a continuous left-turn lane or two-way divided with an unprotected median, median width of greater than 20 ft, asphalt surface type, first harmful event being non-collision, important point about vehicle 1 being overturned, crash severity of F, and first departure direction being right or unknown.

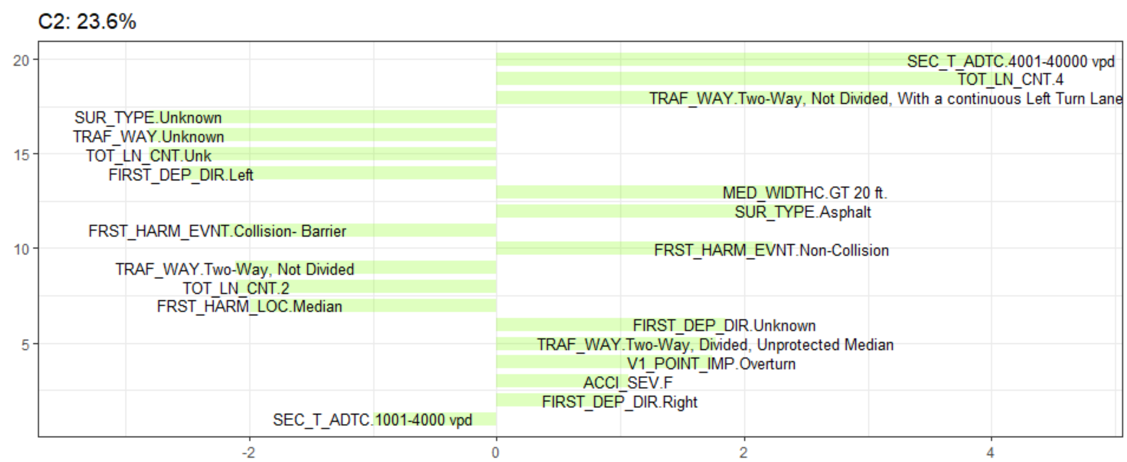


Figure 25. Cluster 2 (C2), Fatal and Injury Crashes

Cluster 3 (C3)—Crashes on Roadways with Dark–Lighted Condition

C3 of the encroachment-related work zone fatal and injury crash data has several unknowns (see Figure 26). However, the longest bar on the positive side that is known is the first harmful event, which is collision–other–fix. This means that it has strong positive associations with the other categories in this cluster, including the first harmful location being on roadway, first departure direction being right, and lighting conditions being dark but lighted. Other categories that are unknown but associated with it include surface type, traffic way, and total lane count. Although several key variable categories are unknown, the cluster indicates work zone crashes where the vehicle is encroaching to the right side of the road at dark (lighted condition). This cluster also shows that crashes took place on the main lane instead of the shoulder or beyond.

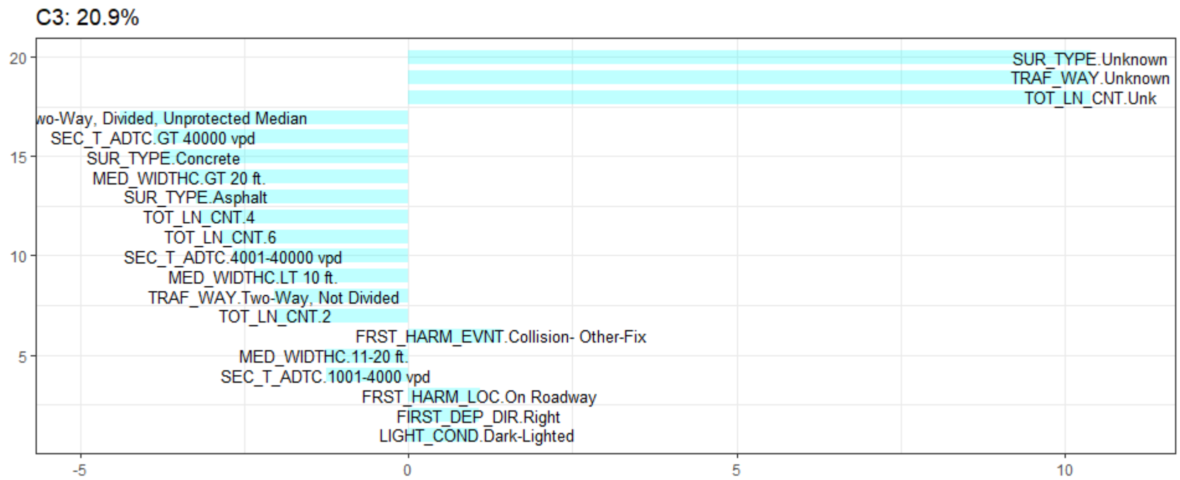


Figure 26. Cluster 3 (C3), Fatal and Injury Crashes

Cluster 4 (C4)—Overturning Crashes on Two-Lane Undivided Roadways with Controlled Traffic

In C4 of the encroachment-related work zone fatal and injury crash data, the longest bar on the positive side is traffic way of two-way undivided (see Figure 27). This means that it has the highest association with other categories within this cluster, including two lanes, AADT less than 40,000 vpd, asphalt surface type, controlled traffic, and overturning. Cluster 4 represents 14 percent of encroachment-related work zone fatal and injury data. The attributes in this cluster are similar to cluster 4 of the encroachment-related work zone no-injury data

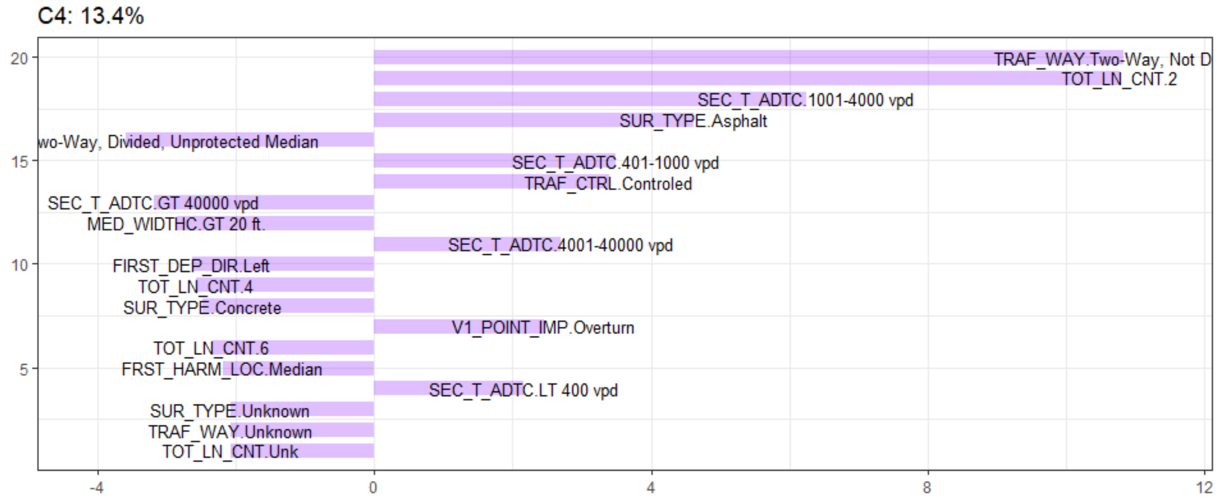


Figure 27. Cluster 4 (C4), Fatal and Injury Crashes

Key findings from the conducted cluster CA can be summarized as follows:

- The clusters and attributes in each cluster do not widely vary in the two datasets based on crash injury type.
- Encroachment-related work zone no-injury data have a cluster that represents 25 percent of data, and some critical variable categories of this cluster are unknown. For fatal and injury data, a similar cluster covers around 21 percent of the data. This indicates that police reports often contain less information if the crash involves no injury.
- The three major clusters of both datasets are median-related crashes on two-lane divided high-volume roadways, single-vehicle overturning collisions on two-way divided roadways with unprotected median, and overturning crashes on two-lane undivided roadways in controlled traffic. The coverages by clusters vary in the two datasets. The results indicate there is a need for median protection to reduce encroachment-related work zone crashes, as the results show that undivided roadway is a key risk factor. Overturning crashes need to be examined in depth to see the roadway geometry, posted speed limit, and curvature information. While installation of median safety barriers could potentially increase the probability of errant vehicle crashes, implementation of such crashworthy systems will help with limiting the severity of such crashes.
- Since the datasets were analyzed based on injury types, individual injury type attributes are only seen in one cluster (cluster 2 of fatal and injury crash data).
- Although median-related crashes dominate in both datasets, overturning and right-encroachment crashes also need careful attention from safety engineers.

CHAPTER 8. PEER EXCHANGE WORKSHOP

The objective of the PEW was multifaceted: (a) debrief the participants on the purpose of the project and the tasks involved, (b) introduce and provide a brief overview of the draft products, and (c) engage the participants in discussions and solicit feedback for potential inclusion in the final guidance document.

PEW LOGISTICS

The PEW was held virtually, spanning across two half-days, strategically chosen one week apart from each other to allow for the research team to address any potential suggested logistic/agenda change as a result of the outcome from the first day of the workshop. The proposed scheduling facilitated mitigation of time commitment for attendees, considering the various time zones that are involved, since the PEW was a virtual event. The two-day schedule was also strategically proposed to allow the participants adequate time to reflect on the results from the first day and be best prepared to address group discussions on the second day.

The workshop was conducted through use of the Webex platform. This platform allowed for use of several features during the meeting, such as the ability to create private groups for participants to take part in more detailed discussions based on the workshop requests.

PEW PARTICIPANTS

The project team surveyed the DOTs and requested feedback on their interest and ability to participate in the virtual workshop. Table 30 shows the agencies that were represented during the PEW, which included 16 participants from DOTs as well as NCHRP 03-134 project panel members.

Table 30. PEW Participant Representation

State DOT Representatives	Caltrans	Oregon DOT
	Hawaii DOT	Pennsylvania DOT
	Indiana DOT	South Dakota DOT
	Massachusetts DOT	Texas DOT
	Michigan DOT	Vermont DOT
	Minnesota DOT	Virginia DOT
	Missouri DOT	Wisconsin DOT
Project Panel Representatives	Illinois DOT	
	Maine DOT	
	AECOM	
	Safe Roads Engineering	
	TRB	
	FHWA	

PEW AGENDA

The final agenda for the two-day PEW is displayed in Table 31. The project team also delivered important project material to attendees prior to the peer exchange workshop. The PEW was strategically coordinated to allow for overview of the project objectives and documented material, explanation of the format and content of the proposed guidance, and identification and discussion of research needs within the scope of the topic.

Table 31. PEW Agenda

Day 1 (11:00 a.m.– 3:45 p.m. CT)	
11:00 am	Welcome and Introductions
11:15 am	Revision of Workshop Agenda and Workshop Expectations
11:20 am	NCHRP 03-134 General Project Overview (Objectives, Tasks, Products)
11:30 am	Overview of Database Analysis Results
12:00 pm	Discussion of Database Analysis Results
1:00 pm	Break
1:45 pm	Overview Project Draft Products (Guidance—MASH)
2:00 pm	*Breakout Session*—Results Discussion on Guidance—MASH
3:00 pm	15-Minute Break
3:15 pm	Reconvene Meeting from Breakout Session—Discussion of MASH Breakout Session Outcomes
3:45 pm	Adjourn

Day 2 (11:00 a.m.–3:30 p.m. CT)	
11:00 am	Welcome and Introductions
11:10 am	Day 1 Workshop Meeting Recap & Comments
11:40 am	Minnesota WZ Intrusion App
12:00 pm	WZ Intrusion App Discussion
12:15 pm	Break
1:00 pm	Overview Project Draft Products (Guidance—RDG)
1:15 pm	Overview Project Draft Products (Guidance—MUTCD)
1:30 pm	*Breakout Session*—Results Discussion on Guidance—RDG and MUTCD
2:30 pm	Break
2:45 pm	Reconvene Meeting from Breakout Session—Discussion of RDG and MUTCD Breakout Session Results
3:15 pm	General Comments
3:30 pm	Adjourn

During the first day, the workshop opened with an introduction to the project team and panel members, followed by revision of the proposed agenda and clarification on the workshop expectations. Next, a session was conducted with the objective to describe the purpose of the project and the different tasks involved, including a general overview of the anticipated project products. This introduction was followed by a general session to provide a detailed overview of the database that was developed as one of the project products, leading to a group discussion where comments were solicited from the participants. During the second part of the first day of the PEW, the researchers presented details of potential guidance modification suggestions with respect to MASH standards. The workshop attendees were then separated into two smaller groups to allow for deeper discussions on what was presented, and comments were sought from these breakout sessions on the shared material. Each breakout group was asked to actively discuss the shared material and engage in discussion in their own group, to ultimately provide summary comments to be discussed when the general meeting reconvened. Each session was facilitated by a moderator and a note taker.

During the second day, the workshop began with a general summary of the main activities and conclusions from Day 1, followed by a requested presentation on the development of the Work Zone Intrusion app developed by Minnesota DOT and a group discussion on the potential application of the app. During the second part of the second day of the PEW, the researchers presented details of potential guidance modification suggestions with respect to RDG and MUTCD criteria. Following the same methodology from Day 1, the workshop attendees were then separated into two smaller groups to allow for deeper discussions on what was presented, and comments were sought from these breakout sessions on the shared material. Each breakout group was asked to actively discuss the shared material and engage in discussion in their own group, to ultimately provide summary comments to be discussed when the general meeting reconvened. Each session was facilitated by a moderator and a note taker. The second and final day of the workshop concluded with some general remarks and takeaways from the conducted peer exchange.

PEW OUTCOME—DISCUSSION AND NEEDS

After reviewing the PEW discussion notes, and based on participants' common feedback, several common themes emerged, along with several research project ideas for future exploration. Below is a summary of the identified research needs, complemented by notes collected during the PEW. Chapter 10 also summarizes recommendations for additional research.

- Potential use of video data as a source for future complementing studies on encroachments in work zones.
  - Current setback experienced by some DOTs is that implemented ITS cameras are not set to record potential encroachments.
  - Other DOTs record their camera data, but there is also a specific retention schedule; otherwise, the data are continuously captured, and the data are overwritten.
  - Cameras are also currently implemented on the back of truck-mounted attenuators (TMAs), continuously recording, as both stationary and moving applications.

- Industry has worked on developing small sensors that can be implemented on roadside safety systems to notify of a vehicle hit.
- Need for tracking TMA hits as encroachments in work zones.
    - Virginia DOT has created an online training course for law enforcement personnel for better collection of crash information. Also, traffic operations centers around the state are being notified when a TMA crash occurs, and an in-depth investigation is conducted when a fatality occurs. The TMA hits are placed into a separate database, and a current study is investigating how to reduce future TMA crashes.
- Minnesota DOT developed an intrusion reporting interface to develop a standardized way of reporting a work zone incident (crash, encroachment, near-miss).
- Need to investigate the crashworthiness and implementation of temporary barrier walls.
    - Illinois DOT currently tracks every time a barrier wall has been hit and how much it moves, whether it is permanent or temporary.
    - State DOTs might have their own barrier wall shape.
- Illinois DOT has a specific form for work zones for the police to use.
- Need to develop a synthesis study regarding expected future DOT plans to address work zone encroachments/impacts.
- State DOT experience with respect to vehicle impacts/encroachments in work zones (vs. non-work zones). Any tangible/recorded indication that roadside safety devices are hit differently (in a significant statistical way) in work zone vs. non-work zone?
    - Some state DOTs do not have a formal process to track.
    - In California, there is procedure in place following an incident in work zones: the inspector is supposed to provide a summary report every month to management. Work is in progress with California Highway Patrol. Interestingly, Caltrans considers "intrusion" only if the incident is close to either a worker or machinery.
    - The implementation and expansion of the Work Zone Intrusion App (in Minnesota) may potentially assist with tracking work zone intrusions, especially those that do not result in a crash that will be recorded in a crash report.
- Need to investigate reasons that lead to encroachments in work zones: are they a consequence of driver behavior or are they related to the need for safer DOT implementation procedures that should be developed and applied?
    - Several DOTs commented that speed appears to be a relevant factor of incidents in work zones (significant number of fatalities during the pandemic period, and not just in work zones).
    - State DOTs commented on the fact that enforcing speed limits appears not to be a solid solution, and other alternatives need to be explored to address high-speed driving.
    - One state DOT experienced a change in driver behavior in work zones that have automated speed enforcement (overall speeds decreased by 20 percent, excessive

    speeding (<11 mph over posted speed) down 3 percent, crashes down 19 percent, fatalities down 8 percent in work zones that have automated speed enforcement).
  - One state DOT experience included development of a report in response to automated speed enforcement measures; in that study, it was found that in work zones where barriers are implemented closer to the travel lane, drivers seem to slow down, and crashes appear to be less severe due to a lower angle of approach. Overall, the implementation of the barrier close to the travel lane reduced encroachment of barriers into work areas.
  - Illinois DOT commented on the implementation of rumble strips on approach to work zones with the objective to gain driver attention as approaching. Also, off-duty officers are being hired to monitor work zones; they may be posing as a flagger and catching drivers on cell phones.
- Need to investigate the longevity of safety devices implemented in work zones—comparing the risk for a system to be hit based on the limited exposure in work zones to that of systems that are deployed for much longer (outside work zones).
- Need to collect/analyze data with the objective to investigate how to safely deploy barrier systems in work zones based on their offset.
- Need to conduct an in-service performance evaluation of Category 2 and 3 NCHRP 350-approved devices to understand whether there is any issue related to their crashworthiness.
  - Developing (MASH) systems for these categories of devices may be very costly and might not be the most cost-effective solution for a DOT if NCHRP 350-approved systems still adequately perform on roadways.
- Need to develop work zone Category 4 safety devices whose crashworthiness meets MASH testing and evaluation criteria.
- Need to investigate which types of devices are getting hit when in proximity to the lane of travel.
  - Are safety devices implemented in work zones being hit harder (full speed) due to their close proximity to the travel lanes? A comment followed recalling potentially a shorter driver reaction time due to the closer implementation to the travel lane; however, crash IS depends on impacting speed and angle, and the current study did not have enough data to support a need for different impact conditions than those used currently in MASH.
  - One DOT intern investigated work zone crashes and related them to the types of devices reportedly being hit: traffic control drums being hit in one of four crashes. Delineator hits are not being captured.
  - It would be interesting to gather information on those devices hit on the edge of work zones but not being reported because of the lower damage severity they caused. It would be hard to collect this type of information in a consistent way.
- Suggestion to include a written restriction in contract to limit workers taking a lane after a certain time of the day; this might ease vehicle backups due to contractors staging on shoulders, even without lane closures. However, the DOT that included that clause in

contracts still had issues with staff members not obeying that time constraint in regard to lane closure.

- Need for additional information from NDS available data/data collection.
  - Lack of information related to posted speed limit and roadway classifications in NDS data. Understanding the roadway classifications from available NDS data would allow for a significant and robust data result comparison.
  - Work zone configuration information would make a difference in comparing collected data and information.
  - Need to include information related to lane versus shoulder closure (left closure = lane closure; right closure = either lane or shoulder closure). Driver behavior is different depending on whether it is a right or left closure.
- Discussion on shy distance for barrier placement in work zones.
  - One state DOT commented on using barrier placement directions reported by the RDG: minimum of 2 ft from edge of roadway.
  - Iowa DOT investigated and compared configurations with concrete barriers and large channelizing devices: large trucks did move farther away when a concrete barrier was used.
  - Barrier offset in work zones is a balancing act: if the barrier is placed farther away from the lane, there is a chance that it gets closer to the workers. Also, does barrier offset increase equate to driver disregard increase?
  - One state DOT experience was as follows: when shy distance is ~2–4 ft, drivers' speeds seem not to increase that much; when shy distance is 6 ft, drivers might start using that space as a shoulder. It is preferable to use ~2 ft of shy distance; however, during the winter months, snowplowing might become a challenge.
  - Another state DOT reported the following experience: when some sort of a physical barrier (curb neckdown) or a roundabout (drunk catchers) is implemented, drivers seem to react to that, and those barriers seem to be self-enforcing. However, use of cones seems to be less self-enforcing.
- Discussion on DOT use of the RDG guidance and its implementation, as well as future needs.
  - Comments regarding the message board placement in clear zones being not practical: It is important to invest in developing message board equipment that is crashworthy.
  - Discussion on clear zone section within the RDG: In real-life applications, it seems that at times there is no consistency in applying the required clear zone distance.
  - Understanding dynamic barrier deflections in temporary work zones is important.
  - Need to include within the RDG more guidance related to steel barrier types and Category 4 devices, as well as minimum recommended lateral barrier widths and lateral deflection distance behind barrier.
  - Need for crashworthy Category 4 device development and testing.
  - Need to develop crash reduction factors for different work zone scenarios.

    - There are situations where traffic is directed between two sets of concrete barriers for long lengths. Need guidance to define maximum distance allowed.
- Discussion on implementation of higher differences in posted speed limits in transition areas: It seems to promote smooth transition.

CHAPTER 9. IDENTIFIED AND PROPOSED GUIDANCE REVISIONS

In line with the efforts performed to investigate vehicle encroachment conditions associated with work zone locations, one of the project objectives was to support potential updates to MASH, the RDG, and the MUTCD. Researchers developed related guidance for state DOTs and research practitioners to improve safety for workers and the traveling public in roadway work zones. This chapter presents the proposed guidance revisions.

MANUAL FOR ASSESSING SAFETY HARDWARE

The NCHRP 17-43 database was analyzed to investigate impact and encroachment conditions. There were only eight work zone crashes in the database, and five of these included a value for the impact speed. All but one of these had an impact speed below the 85th percentile of the 17-43 data. The comparison of the reconstructed impact angles from the eight work zone crashes to the 85th percentile of the 17-43 impact angle data (from all crashes) was inconclusive due to the limited available data. Encroachment conditions associated with the crashes in the 17-43 database were also investigated. Although MASH is based on impact conditions rather than encroachment conditions, encroachment conditions will have more correlation than other types of roadside safety devices to impact conditions for work zone barriers and traffic control devices. This is based on the restricted nature of work zones and the proximity of work zone barriers and traffic control devices to the edge of travel lanes

Of the eight cases identified in the NCHRP 17-43 database, six contained reconstructed impact and departure speeds (Table 32). Of these eight cases, only two impacted a temporary work zone sign and one impacted a concrete barrier protecting the work zone. This latter case involved a 2012 Ford Explorer that departed the road to the left within a work zone. The vehicle impacted the barrier at approximately 11 degrees and 53.7 mph. The vehicle was successfully redirected, and the barrier performed as intended.

There were not enough cases to statistically determine if any differences existed in the frequency or magnitude of encroachments between different roadside devices. Four of these cases had very similar departure speeds and impact speeds because the impact occurred very close to the road edge. One case had a difference of more than 58 mph between departure and impact speeds due to the vehicle traveling over 300 ft through a work zone and up a large embankment. In work zone areas preventing large lateral encroachments, the impact speed remained similar to the departure speed.

Studies conducted under NCHRP Project 17-43 indicated that the reconstructed speed at the first departure (i.e., encroachment speed) was similar between the NCHRP 17-43 database and older NCHRP 17-22 database. The median departure speeds for all roadway departure crashes were 39.3 mph in the NCHRP 17-43 dataset and 40.7 mph in the NCHRP 17-22 dataset. The 85th percentile departure speeds were also similar, with a value of 57.8 mph in the NCHRP 17-43 dataset and 57.0 mph in the NCHRP 17-22 dataset.

Table 32. Summary of Work Zone Crash Cases Identified in the 17-43 Database

Case Number	Speed Limit (mph)	Impact Speed (mph)	Departure Speed (mph)
126014659	30	40.7	40.8
717016292	45	Unknown	Unknown
779014928	45	Unknown	Unknown
501014875	Unknown	41.9	42.3
510015803	40	Unknown	Unknown
877015332	45	53.7	53.7
554017111	40	20.3	78.5
554017572	35	42.1	53.7

The departure angle distribution was also similar between the datasets. In general, right-side departures tended to have a smaller departure angle than left-side departures. For left-side departures, the 85th percentile angle was 31 degrees in the NCHRP 17-43 database and 29 degrees in the NCHRP 17-22 database. For right-side departures, the 85th percentile angle was 18 degrees in the NCHRP 17-43 database and 23 degrees in the NCHRP 17-22 database. An additional analysis of the NCHRP 17-43 database indicated that the 85th percentile of the departure angle was 22 degrees when considering right- and left-side encroachments collectively.

An in-depth analysis of encroachment speed and angle was also conducted using the available NDS data. The encroachment data were not collected as part of the NDSs (e.g., impact or departure angle), and some of the data were manually collected from videos. No difference was observed in the 85th percentile encroachment speed when comparing work zone and non-work zone related encroachments happening on the right side (51 mph in both cases). When left- and right-side encroachments were combined, the 85th percentile speeds were 50.4 mph and 55.4 mph for work zone and non-work zone related encroachments, respectively.

When comparing encroachment angles for right-side encroachments in the NDS dataset, the 85th percentile encroachment angles were 29.6 degrees and 31 degrees for work zone and non-work zone related encroachments, respectively. The difference between these values is less than the 1.5-degree tolerance for impact angle in MASH. When left- and right-side encroachments were combined, the 85th percentile angle was 30.6 degrees for both work zone and non-work zone related encroachments.

A summary of the encroachment conditions (speed and angle) obtained from analysis of the 17-43 database and the NDS data is reported in Table 33. Some accuracy limitations associated with the angle data manually collected from videos as part of the NDS data investigation may exist. The 85th percentile encroachment speeds from the NCHRP 17-43 and 17-22 databases (57.8 mph and

57 mph, respectively) are similar to the 85th percentile speed calculated from the NDS data for non-work zone encroachments (55.4 mph). These three values are not significantly different from a barrier testing perspective when considering that the MASH tolerance for impact speed is 2.5 mph. The NDS data indicate that the 85th percentile speed for combined left- and right-side encroachments in a work zone is 50.4 mph, which is a 10 percent drop from the 55.4 mph representing the 85th percentile of the overall encroachment speeds in non-work zone areas.

Table 33. Summary of Encroachment Results from 17-43 Database and NDS Data

Source	Encroachment	85th Percentile (right+left side)	85th Percentile (right side only)
17-43	Speed (mph)	57.8	—
	Angle (deg)	22	18
17-22	Speed (mph)	57	—
	Angle (deg)	—	23
NDS WZ	Speed (mph)	50.4	51
	Angle (deg)	30.6	29.6
NDS No WZ	Speed (mph)	55.4	51
	Angle (deg)	30.6	31

Note: WZ = work zone; No WZ = no work zone.

As mentioned, the encroachment speeds obtained from 17-43, 17-22, and NDS data are comparable, with differences in the range of 3–4 percent. The differences in encroachment angle are considerably greater, with the NDS data having larger encroachment angles than both the 17-43 and 17-22 databases. This difference might be the result of the manual technique utilized to extract the encroachment angle values directly from videos as part of the NDS data effort. The differences that exist among these datasets may be due to several factors. For example, the NDS data are encroachment based, whereas the 17-43 and 17-22 databases are crash based. In other words, the encroachment conditions extracted from the 17-43 and 17-22 databases are based on run-off-road crashes, while the NDS data are based on encroachments, most of which did not result in a crash. Further, the posted speed limits for roadways on which the encroachments occurred in the NDS data are not available. There may also be differences associated with the different data collection periods of these datasets and the relative contribution of advancing vehicle safety technologies in each.

From the perspective of the impact/encroachment speed, the general conclusions are:

- **Impact speed in work zones:** There are not enough data to support the need for a change in MASH impact conditions for testing and evaluating roadside safety hardware implemented in work zone locations (source is only five work zone related crashes with reconstructed impact speed).
- **Encroachment speed in work zones:** The NDS data indicate that the 85th percentile encroachment speed in work zones is 10 percent less than the 85th percentile encroachment speed in non-work zone areas. However, the functional classification and posted speed limits

for the roadways on which these encroachments occurred is not available, so it is difficult to conclude that a reduction in MASH test speed is clearly indicated.

From the perspective of the impact/encroachment angle, the general conclusions are:

- **Impact angle in work zones:** There are not enough data to support the need for a change in MASH impact conditions for testing and evaluating roadside safety hardware implemented in work zone locations (source is only eight work zone related crashes with reconstructed impact angle).
- **Encroachment angle in work zones:** The NDS data indicate that there is no difference in the 85th percentile of the overall encroachment angles for work zone and non-work zone locations (30.6 degrees in both cases). The 85th percentile of the 17-43 overall encroachment angle is 22 degrees, which is very similar to the current MASH nominal impact angle of 25 degrees used for testing and evaluating roadside safety devices. The discrepancy between the NDS and 17-43 encroachment angles is not fully understood, so there is not a strong basis for change of the MASH impact angle as this time.

Encroachment angles were also explored per encroachment speed bins in work zones to determine if there is a correlation between encroachment angle and encroachment speed. The mean value of departure angle remained stable across the different speed ranges, meaning that the encroachment angle is not correlated with encroachment speed.

Guidance Recommendation

There were insufficient results to support the need to revise current guidance pertaining to impact conditions in MASH.

ROADSIDE DESIGN GUIDE

The lateral distance to the first impact for the eight crashes in work zones was compared to all crashes in the NCHRP 17-43 database. The lateral distance to the first impact in a work zone was not smaller than in the rest of the NCHRP 17-43 database.

An in-depth analysis of encroachment lateral extensions was also conducted using the available NDS data. There was not a considerable difference in encroachment lateral extension when comparing work zone and non-work zone related encroachments happening on the right side (8.5 ft vs. 8.2 ft, respectively). Also, when combining the values for the left and right encroachment sides, the 85th percentile resulted in 7.1 ft and 8.7 ft for work zone and non-work zone related encroachments, respectively.

The average speed for right-side work zone encroachments (mean = 36.8 mph) was slightly lower than for left-side work zone encroachments (mean = 38.6 mph), but the 85th percentile was higher for right-side work zone encroachments (85th percentile = 51.0 mph) than for left-side work zone encroachments (85th percentile = 49.7 mph). In the case of non-work zones, right-side encroachments were higher (max = 83.3 mph; mean = 34.2 mph) compared to left-side encroachments (max = 83.3 mph; mean = 31.7 mph).

These data provide a better understanding of the speed of vehicles at the moment of encroachment, showing that left/right-side encroachments are reasonably similar.

Guidance Recommendation

The current guidance from the RDG on clear zone requirements seems to be appropriate considering the recorded lateral extensions of encroachments in work zone locations.

The collected and analyzed data provide a better understanding of the speed of vehicles at the moment of encroachment, showing that left/right-side encroachments are reasonably similar. The speed difference between left- and right-side encroachments is fairly minimal and not statistically significant enough to support different barrier recommendations based on the lane side implementation (left vs. right).

MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES

Several of the analyses resulted in information that could be used to develop guidance for incorporation into the MUTCD.

An in-depth analysis of encroachment lateral extensions was conducted using the available NDS data. The 85th percentile lateral encroachment to the right in work zones was 8.5 ft compared to 8.2 ft in non-work zones. The 85th percentile left-side encroachment in work zones was 5.2 ft compared to 9.2 ft in non-work zones.

The average speed for right-side work zone encroachments (mean = 36.8 mph) was slightly lower than for left-side work zone encroachments (mean = 38.6 mph), but the 85th percentile was higher for right-side work zone encroachments (85th percentile = 51.0 mph) than for left-side work zone encroachments (85th percentile = 49.7 mph). In the case of non-work zones, right-side encroachments were higher (max = 83.3 mph; mean = 34.2 mph) compared to left-side encroachments (max = 83.3 mph; mean = 31.7 mph).

These data provide a better understanding of the speed of vehicles at the moment of encroachment, showing that left/right-side encroachments are reasonably similar.

Speed was noted as the highest contributing factor (17 percent), which was second to no contributing factor (41 percent) in work zone encroachment crashes. External distraction accounted for 18 percent of work zone crashes, which may be due to drivers paying attention to work zone traffic control devices. Additionally, interaction with electronic devices or cell phones accounted for about 18 percent of work zone crashes.

As noted in Figure 28, evaluation of crash data indicated that a curb was the most typical object struck in work zone crashes involving an encroachment. The next most common objects struck were work zone equipment (8 percent) and barriers (7 percent). Barriers were more likely to be struck during left-side encroachments than right side.

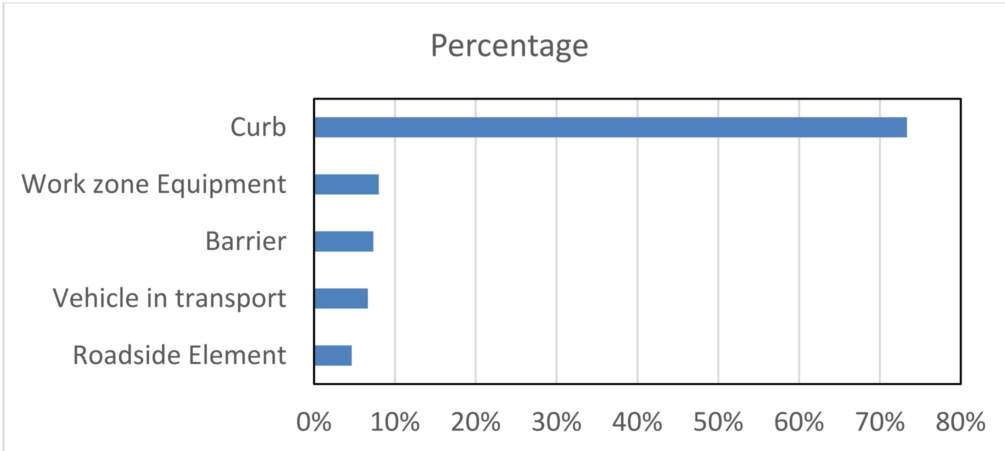


Figure 28. Objects Struck in Work Zone Crashes Involving an Encroachment

Evaluation of crash data also indicated that the majority of work zone encroachments occur in the activity area of the work zone (72 percent) versus the transition area (13 percent) or advance warning area (9 percent), as shown in Figure 29.

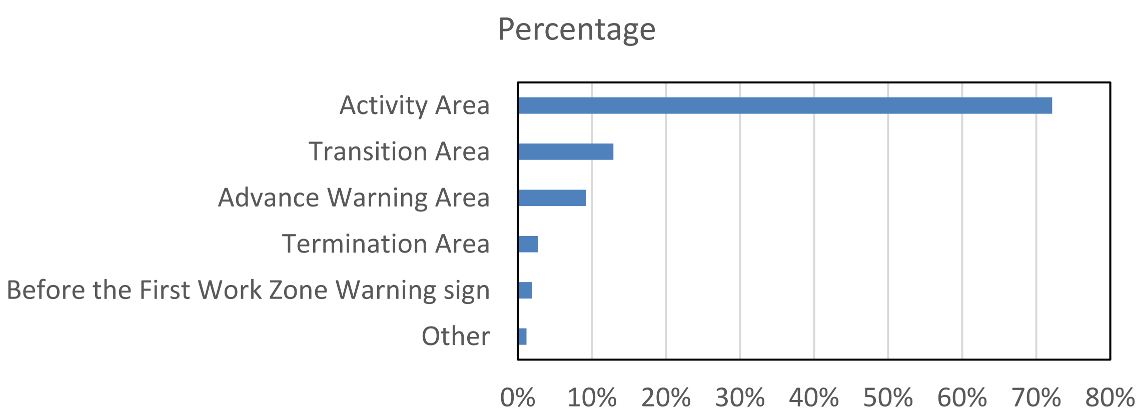


Figure 29. Location of Work Zone Crashes Involving an Encroachment

Guidance Recommendation

The project findings and potential guidance implications for the MUTCD include the following:

- Section 6C.04. Advance Warning Area: This section discusses traffic control devices for the advance warning area. The findings suggest that around 9 percent of work zone encroachment-related crashes occur in the advance warning area. However, no other information was available to suggest additional guidance needs to be provided.
- Section 6D.03. Worker Safety Considerations: This section discusses use of temporary traffic barriers, which is based on factors such a lateral clearance of workers from adjacent traffic and speed reduction. The findings suggest encroachment speeds are 49.7 mph for left-side encroachment and 51.0 mph for right-side encroachment. Additionally, 8 percent of encroachment crashes in work zones strike work zone equipment. The suggested

recommendations in this section could be examined to determine whether they are sufficient given likely lateral clearance when a vehicle encroaches into the work zone environment.

- Section 6F. Temporary Traffic Control Devices: This section outlines considerations for traffic devices in work zones. The findings suggest right-side encroachments are higher than left-side encroachments in work zones (8.5 vs. 5.2 ft). Section 6F could offer guidance on the amount of lateral clearance that should be provided with use of traffic control devices placed on the left or right shoulder.

CONSIDERATIONS AND LIMITATIONS

One of the conclusions reached by the research team was that there is not sufficient evidence to support the need to revise current guidance pertaining to impact conditions in MASH. As largely explained above and in previous sections, this conclusion was supported by a variety of observations, some of which related to lack of data and/or differences in data collection. For example:

- There are not enough data to support the need for a change in MASH speed impact conditions for testing and evaluating roadside safety hardware implemented in work zone locations.
    - Only five work zone related crashes with reconstructed impact speed were identified in the 17-43 database.
    - The posted speed limits and the functional classification for the roadways on which these encroachments occurred are not available in the NDS data.
    - There may be differences associated with the different data collection periods of the utilized datasets and the relative contribution of advancing vehicle safety technologies in each.
- There are not enough data to support the need for a change in MASH angle impact conditions for testing and evaluating roadside safety hardware implemented in work zone locations.
    - Only eight work zone related crashes with reconstructed impact angle were found.
    - The encroachment angles obtained from 17-43, 17-22, and NDS data were fairly different, potentially due to the manual technique utilized to extract the encroachment angle values directly from videos as part of the NDS data effort.
- The encroachment conditions extracted from the 17-43 and 17-22 databases are based on run-off-road crashes, while the NDS data are based on encroachments, most of which did not result in a crash.

CHAPTER 10. CONCLUSIONS AND RESEARCH NEEDS

The research team collected and investigated available data from vehicle encroachment conditions associated with work zone locations. Data were mainly collected from available and applicable NDSs, shared state crash databases, and NMVCCS and NCHRP 17-43 project databases. Exploratory data analysis and cluster CA were conducted to investigate encroachment, roadway, roadside, work zone, and driver behavior conditions.

A PEW was conducted with the objectives to provide an overview of the project draft products, engage agency participants in related discussions, solicit feedback for potential inclusion in the final guidance document, and identify future research needs. Based on participant feedback, several common themes emerged, along with various research project ideas for future exploration (Table 34).

In line with the efforts performed to investigate vehicle encroachment conditions associated with work zone locations, one of the project objectives was to support potential updates to MASH, the RDG, and the MUTCD. Researchers developed related guidance for state DOTs and research practitioners to improve safety for workers and the traveling public in roadway work zones. This chapter presents the proposed guidance revisions.

The researchers concluded that there is not sufficient evidence to support the need to revise current guidance pertaining to impact conditions in MASH—a conclusion supported by a variety of observations, some of which related to lack of data and/or differences in data collection. Also, the current guidance from the RDG on clear zone requirements seems to be appropriate considering the recorded lateral extensions of encroachments in work zone locations. The project findings and potential guidance implications for the MUTCD, however, include the following:

- <u>Section 6C.04. Advance Warning Area</u>: This section discusses traffic control devices for the advance warning area. The findings suggest that around 9 percent of work zone encroachment-related crashes occur in the advance warning area. However, no other information was available to suggest additional guidance needs to be provided.
- <u>Section 6D.03. Worker Safety Considerations</u>: This section discusses use of temporary traffic barriers, which is based on factors such a lateral clearance of workers from adjacent traffic and speed reduction. The findings suggest encroachment speeds are 49.7 mph for left-side encroachment and 51.0 mph for right-side encroachment. Additionally, 8 percent of encroachment crashes in work zones strike work zone equipment. The suggested recommendations in this section may be examined to determine whether they are sufficient given likely lateral clearance when a vehicle encroaches into the work zone environment.
- <u>Section 6F. Temporary Traffic Control Devices</u>: This section outlines considerations for traffic devices in work zones. The findings suggest right-side encroachments are higher than left-side encroachments in work zones (8.5 vs. 5.2 ft). Section 6F could offer guidance on the amount of lateral clearance that should be provided with use of traffic control devices placed on the left or right shoulder.

Table 34. Future Research Needs

#	Description
1	Investigation of the use of video data as a source for collecting encroachment data in work zones.
2	Continuous collection of work zone encroachment and impact conditions.
3	Collection and analysis of TMA hits to complement encroachment data in work zones.
4	Crashworthiness investigation and implementation guidance of barrier walls (temporary and permanent).
5	Synthesis study of existing best practices and expected future DOT plans to address work zone encroachments/impacts.
6	Development of a formal process to collect and analyze vehicle impacts/encroachments in both work zone and non-work zone locations for direct comparison of impact modes and severity.
7	Investigation of encroachments in work zones to determine predominant causes: are they driver behavior related or are they tied to the need for safer DOT implementation procedure development and application?
8	Investigation of longevity of roadside safety devices when implemented in work zones: does their limited exposure when implemented in work zones have an effect on the overall risk of being impacted by encroaching vehicles?
9	Data collection and analysis to support the safe deployment of roadside safety barrier systems in work zones based on their offset implementation.
10	In-service performance evaluation of NCHRP 350-approved Category 2 and 3 devices.
11	Development of MASH crashworthy work zone Category 4 safety devices.
12	Data collection and analysis to support the identification of hit device types when implemented in proximity to work zone travel lanes.
13	Best practices and challenges of implementing shy distances for barrier placement in work zones: what are the observed driver effects?

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APPENDIX A. SURVEY QUESTIONS

<u>Question 1:</u> Contact information

1. Name
2. Position Title
3. Agency
4. Email or Phone Number

<u>Question 2:</u> How does your agency determine when to require positive protection in a work zone? Please feel free to either include a link below or attach the file directly to this survey response.

<u>Question 3:</u> Does your agency's positive protection requirements vary by work zone conditions (duration, roadway classification, speed limit, etc.)? Please feel free to either include a link below or attach the file directly to this survey response.

1. Yes
2. No

<u>Question 4:</u> Does your Agency have a work zone management practice to help keeping track whether a work zone was present on a given day, as well as to identify specific areas where work is being actively conducted on it? Please feel free to either include a link below or attach the file directly to this survey response.

1. Yes
2. No

<u>Question 5:</u> Can you please describe the type of work zone safety data that your agency is collecting? (Select all that apply)

1. Date and Location of Work Zone
2. Work Zone Crash Reports
3. Archived video of crashes, conflicts, or queues
4. Maintenance records of "hits" or encroachments on barriers or other work zone devices
5. Forensic or roadside investigations of crashes or encroachments
6. Log of work zone intrusions
7. Other (please specify)
8. None

<u>Question 6:</u> Would your Agency be able to share any of the work zone safety data you mentioned in Question 5 with the NCHRP 03-134 team?

1. Yes, contact me
2. Yes, other contact (please provide name, email/phone number for alternate contact from your agency)
3. We are not able to share data

<u>Question 7:</u> Does your Agency have any additional needs for work zone encroachments and intrusions data collection that is not currently addressed by your Agency data collection method?

*The project team identifies a **"work zone"** as the following, based on definition provided by the FHWA:*
"A work zone is an area of roadway with construction, maintenance, or utility work activities. A work zone is typically marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign (...) to the "end Road Work Sign" or the last TTC device"

*The project team identifies a **"work zone encroachment"** as*
"The vehicle travel condition when such a vehicle inadvertently traverses across the boundaries of a work zone. Considering the different zone areas defined by the MUTCD, encroachments occurring in the advance warning area might be defined as departures across the edgeline of the travel way, whereas those in the transition and activity areas could be either across a lane line or an edge line".

*The project team identifies an **"intrusion crash"** as:*
"a vehicle or object which penetrates the actual work space within the work zone and strikes workers, construction vehicles and equipment, or construction materials and debris"

1. Yes
2. No

<u>Question 8:</u> Does your agency have any needs for Work Zone guidance that are not currently being met?

1. Yes
2. No

<u>Question 9:</u> How does your agency use encroachment data? (Not necessarily specifically just from work zones) (Select all that apply)

1. RSAP
2. Work Zone Positive Protection Program
3. Roadside Design Decision
4. Safety Analyses
5. Other (please describe)
6. None

<u>Question 10:</u> Is there any additional information that you would like to share with the project team regarding your needs/constraints related to this project? If yes, please feel free to comment below or drop an attachment below.

<u>Question 11:</u> As part of this National NCHRP research project, a 2-day peer exchange will be conducted for state attendees to review a draft guidance document which will enhance the importance of encroachment conditions in work zones. Attendee experience and possible adaptation strategies for the guidance will also be solicited. Would your Agency like an invitation to this peer exchange Workshop? Please indicate a preferred Agency personnel contact to follow up on this request at a later date.

1. Yes
2. No
3. Not sure at this moment

APPENDIX B. SURVEY RESPONSES

Q2. How does your agency determine when to require positive protection in a work zone? Please feel free to either include a link below or attach the file directly to this survey response.

Fifty-two percent of the states follow the guidelines given in the MUTCD to determine the need for positive protection in work zones. The considerations are:

- Project scope and duration: duration more than 2 weeks requires positive protection.
- Anticipated traffic speeds through the work zone.
- Anticipated traffic volume.
- Vehicle mix.
- Type of work (related to worker exposure).
- Distance between traffic and workers, and extent of worker exposure.
- Limited escape paths.
- Time of day.
- Consequences to road users resulting from roadway departure.
- Potential hazard to workers and road users presented by the device itself and during placement and removal.
- Geometrics and/or work area restrictions that may increase crash risk.
- Access to/from work space.
- Roadway classification.
- Impacts on project duration and cost.

Other considerations used by the states include the following:

- Arizona uses positive protection for:
  - Freeway widening.
  - Existing positive protection improvement/construction.
  - Shifting traffic out of freeway or to separate two-way traffic on crossover.
  - Concrete structure extension or box culvert extension.
  - Directing traffic on high-volume roadway.
- California and Kansas determine the need based on edge drop-off, shoulder width, and roadway type.
- Colorado gives special consideration to closeness of workers to traffic and travel speed.
- Connecticut uses positive protection if the proposed work cannot be completed or the roadway cannot be satisfactorily opened to traffic after a single work shift. TPCBC is also used if there are potential hazards within the clear zone, such as the storage construction equipment or sudden drop-offs.
- Delaware considers edge drop-offs, depth of excavation, clear zone issues with the proposed construction, long-term MOT condition, and speed of roadway.

- Massachusetts requires the use of temporary barriers when the work zone creates a situation where traffic is exposed to a new drop-off condition, non-recoverable slope, or the work puts non-crashworthy equipment and/or materials within the clear zone.
- Along with the MUTCD considerations, Michigan also considers unprotected features like walls, piers, foundations, etc., and the type of work zone equipment.
- Mississippi also considers potential barrier deflection relative to workers' positions when determining barrier location along with the guidance from MUTCD.
- Missouri uses positive protective based primarily on the type and location of the work area.
- Nebraska considers proximity of drop-off/obstacle, depth of drop-off, traffic volume, duration of work, and worker exposure.
- Oklahoma uses positive protection where head-to-head traffic on interstates, edge drop-off greater than 2 inches without treatment, not being able to meet construction clear zone, bridge construction, and shoo-fly with steep slope.
- Pennsylvania uses positive protection wherever drop-offs within less than 12 ft of the roadway are anticipated.
- Tennessee uses positive protection on interstate shoulder and lane closure work.
- Texas considers positive protection only when there are edge drop-offs in work zones.
- Along with the guidelines in MUTCD, Virginia considers a run-off-road frequency chart to determine the need for positive protection.

Q3. Does your agency's positive protection requirements vary by work zone conditions (duration, roadway classification, speed limit, etc.)? Please feel free to either include a link below or attach the file directly to this survey response.

1. Yes
2. No

All the survey responses indicate that positive requirements vary by work zone conditions (see Figure B-1). The requirements are mainly based on roadway characteristics like roadway classification, shoulder width, travel speed, anticipated edge drop-off, adverse geometrics that may increase the likelihood of run-off-the-road vehicles, two-way traffic on one roadway of a divided highway, and volume of traffic. They are also based on work zone characteristics like length of need, duration, type of work, proximity of workers, clear zone, nature of potential conflict, transition areas at crossovers, and lane closures or lane transitions.

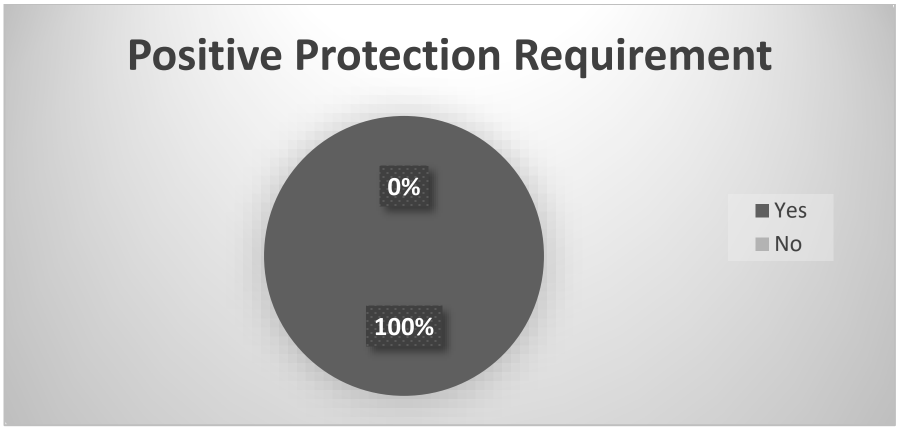

Figure B-1. Agency Variation of Positive Protection Requirements

Q4. Does your agency have a work zone management practice to help keeping track whether a work zone was present on a given day, as well as to identify specific areas where work is being actively conducted on it? Please feel free to either include a link below or attach the file directly to this survey response.

1. Yes
2. No

Seventy-nine percent of responses answered yes to this question (Figure B-2). Most of the states maintain a daily diary that describes the work performed each day. The states that follow a different method of keeping track include:

- California, Virginia, and Wisconsin use a lane closure system (LCS).
- Indiana uses a system called CARS.
- Iowa and Washington are still developing a work zone database.
- Prior to starting work for each day, contractors in Massachusetts are required to fill out Roadway Work Notification forms that are filed with both the MassDOT District Construction Office and the Highway Operations Center.
- Missouri DOT has a traveler information map that documents almost all its lane closures. Each work zone has information in a database where the project information can be uploaded. The work zone time period is part of the data.
- In New York, all work zone activity is reported in advance to the appropriate regional traffic management center using a Road Work Notification form. Any work impacting traffic is entered into the 511NY system (511ny.org). Road Work Notification records are archived and can be retrieved later to determine whether a work zone was present on a given day. Active work zones can be retrieved directly from 511NY.
- Texas DOT uses SiteManager to determine all active work zones at any given time.

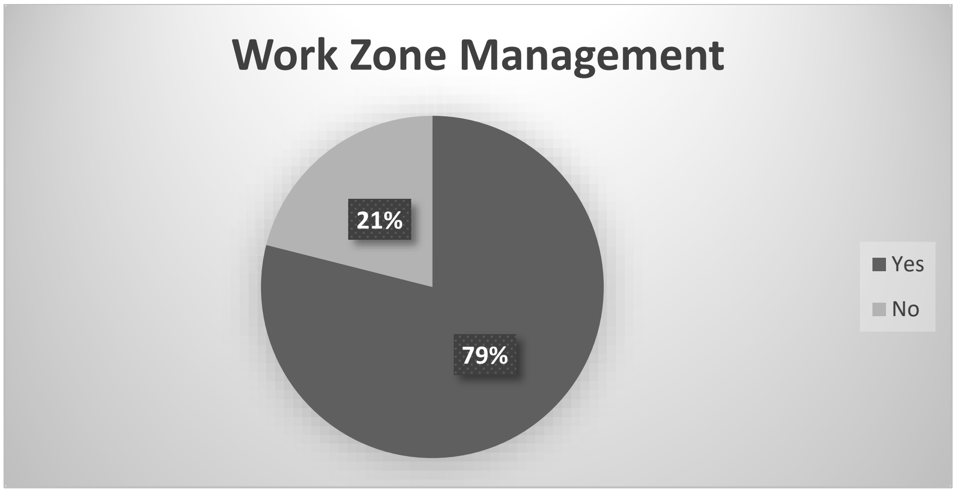

Figure B-2. Work Zone Management Practices of Agencies

Q5. Can you please describe the type of work zone safety data that your agency is collecting? (Select all that apply)

1. Date and Location of Work Zone
2. Work Zone Crash Reports
3. Archived video of crashes, conflicts, or queues
4. Maintenance records of "hits" or encroachments on barriers or other work zone devices
5. Forensic or roadside investigations of crashes or encroachments
6. Log of work zone intrusions
7. Other (please specify)
8. None

Figure B-3 shows the breakdown of responses. Out of the 38 responses:

- 36 collect work zone crash reports and data.
- 24 states collect location of work zones.
- 12 states collect maintenance records of hits or encroachments on barriers or other work zone devices.
- 9 collect forensic or roadside investigations of crashes or encroachments.
- 5 states collect archived videos of crashes, conflicts, or queues.
- 5 collect logs of work zone intrusions.
- 11 states collect other data, which include:
    - Arizona collects speeds within advance work zone areas to infer queue length, queue speed, and travel delay.
    - Connecticut collects smart work zone related data like continuous speed, volume, and delay data that are used to provide real-time information to the public, as well as historical data that can be used in the future.
    - Indiana tracks queuing through INRIX data. Date and location of work zone are collected through CARS. Indiana also performs work zone reviews and tabulates the occurrence rates of work zone issues related to TTC devices.

- Minnesota will soon begin to log work zone intrusions through a WZ Intrusion form developed by a human factors expert in maintenance projects.

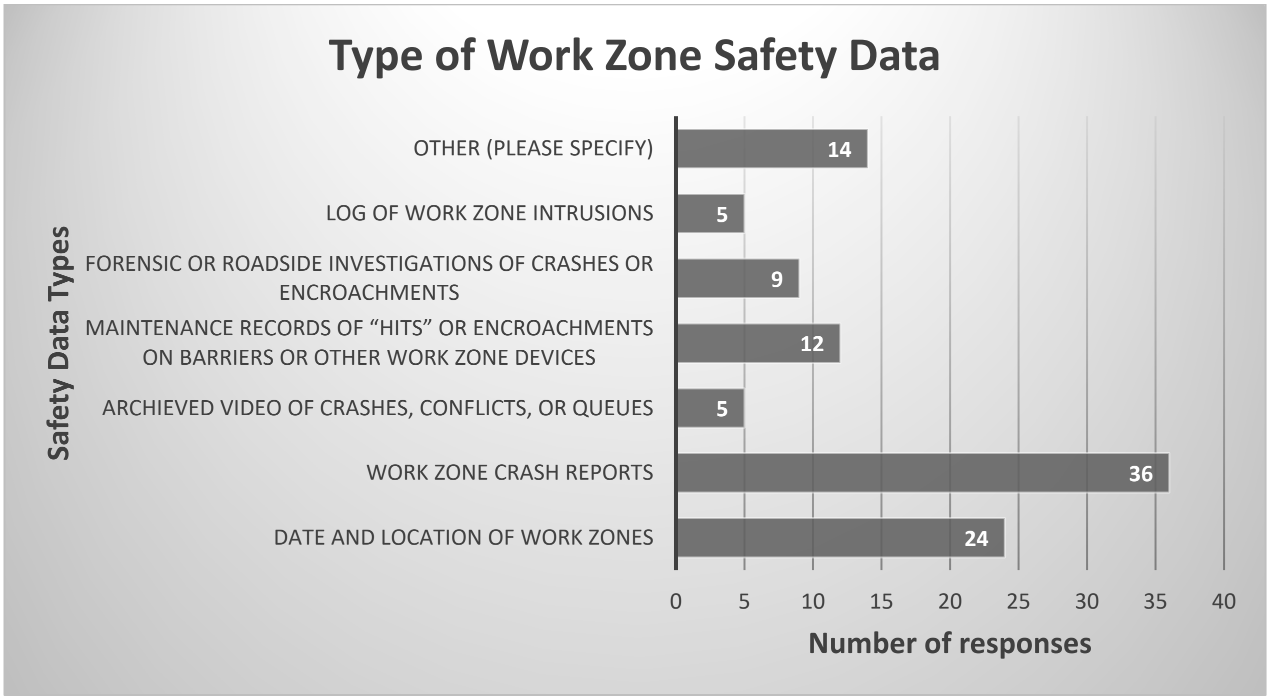

Figure B-3. Types of Work Zone Safety Data Collected by Agencies

Q6. Would your agency be able to share any of the work zone safety data you mentioned in Question 5 with the NCHRP 03-134 team?

1. Yes, contact me
2. Yes, other contact (please provide name, email/phone number for alternate contact from your agency)
3. We are not able to share data

Out of the 40 responses received, 76 percent said they are willing to share the work zone safety data, and the remaining 24 percent said they could not share data (Figure B-4).

Figure B-4. Agencies' Willingness to Share Work Zone Safety Data

Q7. Does your agency have any additional needs for work zone encroachments and intrusions data collection that is not currently addressed by your agency data collection method?

1. Yes
2. No

Out of the 38 responses to this question, 37 percent of the states responded that they do not have any additional needs for work zone encroachments and intrusions since encroachment events are rare and can be identified from the work zone crash reports (Figure B-5). The states that need additional work zone encroachment data include:

- Arizona wants to know the corrective actions taken by other DOTs to manage mobility and safety based on criteria such as travel delay, queue length, and crash occurrences.
- Florida wants additional guidance on work zone clear zones and crash testing requirements for temporary roadside safety devices.
- Iowa needs additional guidance on barrier impacts (speed, angle, encroachment, performance) and audible attenuators on maintenance vehicles.
- Massachusetts wants accurate determination about what is effective at reducing the number and severity of crashes.
- Michigan would like to know what type of work and traffic control device layout were in place when intrusions occur and where within the project limits they occur. This could give some insight as to when the motorists may relax or lower their guard in the work zone, thus increasing the likelihood of a crash. Is a narrow lane actually better because the driver becomes more alert?
- Tennessee wants to look at work zone crashes within advance warning areas.
- Texas would like to collect information on work zone encroachments if there is no collision.

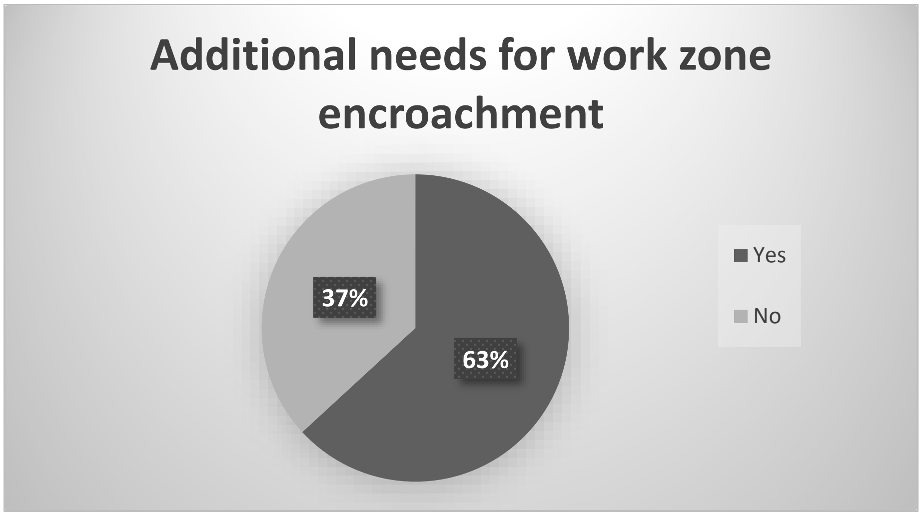

Figure B-5. Agencies' Additional Needs for Work Zone Encroachment Data

Q8. Does your agency have any needs for work zone guidance that are not currently being met?

1. Yes
2. No

Out of 37 responses to this question, 68 percent said they need additional work zone guidance (Figure B-6). These include:

- California and Idaho need more guidance on work zone speed limit reduction.
- Iowa would like:
  - Guidance on use of temporary barriers to separate opposing traffic on rural, high-speed two-lane, two-way operations.
  - Better guidance on drop-off protection (warrants and mitigation).
- Michigan, Nevada, and Washington need smart devices and real-time location of work zone signs.
- Minnesota would like to know:
  - How to effectively slow traffic down in work zones without adding hazards.
  - Useful performance measures for work zones.
  - How to improve effectiveness of merging behavior.
- Montana could use better work zone guidance on the use of positive protection versus the use of crossovers.
- Ohio would like guidance on determination of when to anchor portable barriers where there is a drop-off, as well as protection methods for corners where portable barriers cannot effectively wrap and facilities with multiple driveways requiring repeated breaks in the portable barrier.
- Oregon is interested in:
  - Methodology to compare TTC alternatives using the *Highway Safety Manual* and crash modification factors.

   - Acceptable practices around using a number of AFAD operators, maintaining line of sight (electronically), and best practices.
   - ITS devices in work zones for connected and automated vehicles.
- Pennsylvania is interested in utilization of moveable barrier systems (i.e., zipper barriers) and communicating with commercial motor vehicles approaching work zones.
- Texas designers have expressed an interest in guidance on when to use positive protection based on factors other than drop-off like geometry, ADT, speed, traffic mix, etc.
- Washington is interested in temporary rumble strip testing and guidance on effectiveness.
- Wisconsin is interested in the following:
   - At what point does anchoring a barrier versus allowing a barrier to be freestanding make sense?
   - How should the agency deal with the damage from anchoring temporary barriers into the pavement or deck?
   - What degradation to the pavement happens when anchoring to pavement or deck?
   - Is length of need different for work zones?

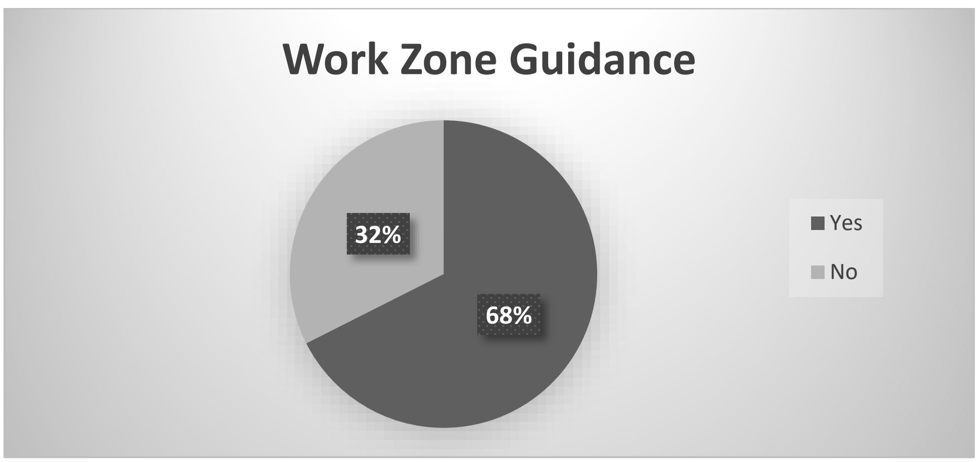

Figure B-6. Agencies' Work Zone Guidance Requirement

Q9. How does your agency use encroachment data? (Not necessarily specifically just from work zones) (Select all that apply)

1. RSAP
2. Work Zone Positive Protection Program
3. Roadside Design Decision
4. Safety Analyses
5. Other (please describe)
6. None

Figure B-7 shows the breakdown of responses. Out of the 36 states that answered this question:

- 16 states do not collect or use encroachment data.
- 9 states said that they use the encroachment data for safety analyses.

- 7 states use the data for the RSAP.
- 4 states use the data for the Work Zone Positive Protection Program.
- New York and Maryland use the encroachment data for four areas—RSAP, Work Zone Positive Protection Program, roadside design decisions, and safety analyses.
- Oregon DOT uses crash data to highlight high accident locations, which are then used to perform safety analyses, implement program safety projects, and inform work zone decisions.
- Minnesota DOT uses intrusion data to determine modifications to typical applications for various work zone operations. It also uses the data for the Work Zone Positive Protection Program. For non-work zone applications, Minnesota DOT would likely use the data to determine where roadside safety needs to be improved by either improving the clear zone or adding a barrier.

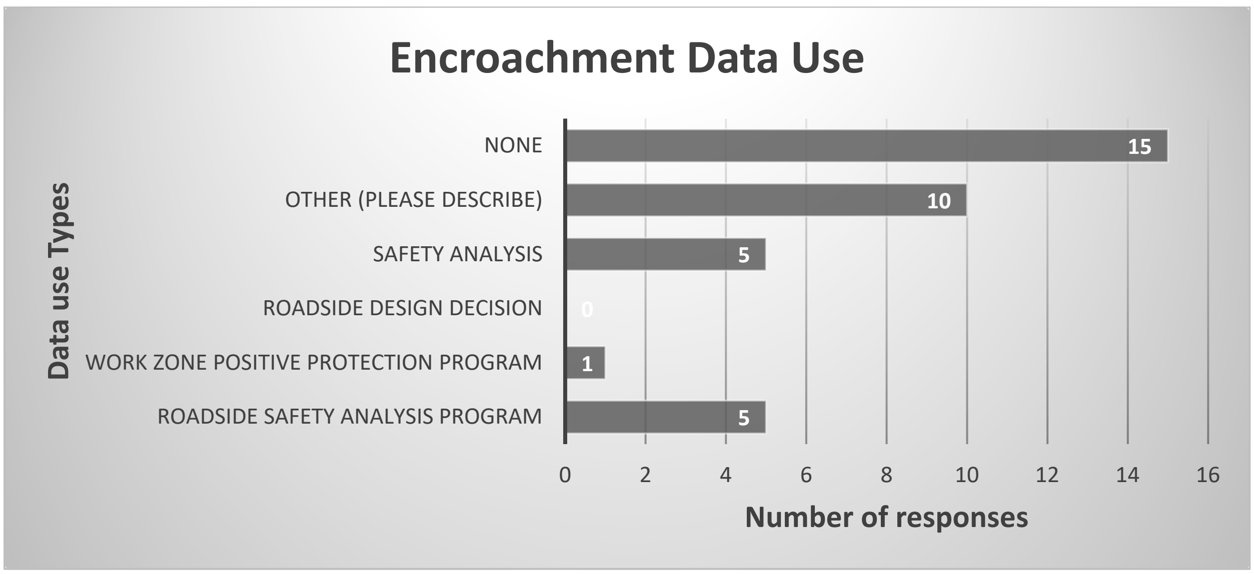

Figure B-7. Agencies' Type of Usage of Encroachment Data

Q10. Is there any additional information that you would like to share with the project team regarding your needs/constraints related to this project? If yes, please feel free to comment below or drop an attachment below.

The additional information given by the states is as follows:

- Arizona DOT suggested possible actions to improve safety and mobility, which include a place to enter data such as travel delay, queue length, and crash occurrences.
- Delaware suggested possible guidance on lowering the barrier deflection distance when traffic cannot hit the barrier at 20 degrees.
- Along with the crash test performance data, Iowa recommended practical work zone deployment data.

- Michigan mentioned when looking at the location and offset, a key factor is the roadway and joint line. In case of a runoff, the soft slopes often pull the vehicles in. Therefore, the location of the joint line and the material of the shoulder are important.

Q11. As part of this National NCHRP research project, a 2-day peer exchange will be conducted for state attendees to review a draft guidance document which will enhance the importance of encroachment conditions in work zones. Attendee experience and possible adaptation strategies for the guidance will also be solicited. Would your agency like an invitation to this peer exchange workshop? Please indicate a preferred agency personnel contact to follow up on this request at a later date.

1. Yes
2. No
3. Not sure at this moment

Out of the 38 states that responded to this question, 68 percent said that they would like to attend the peer exchange workshop, and 29 percent were not sure at the moment (Figure B-8).

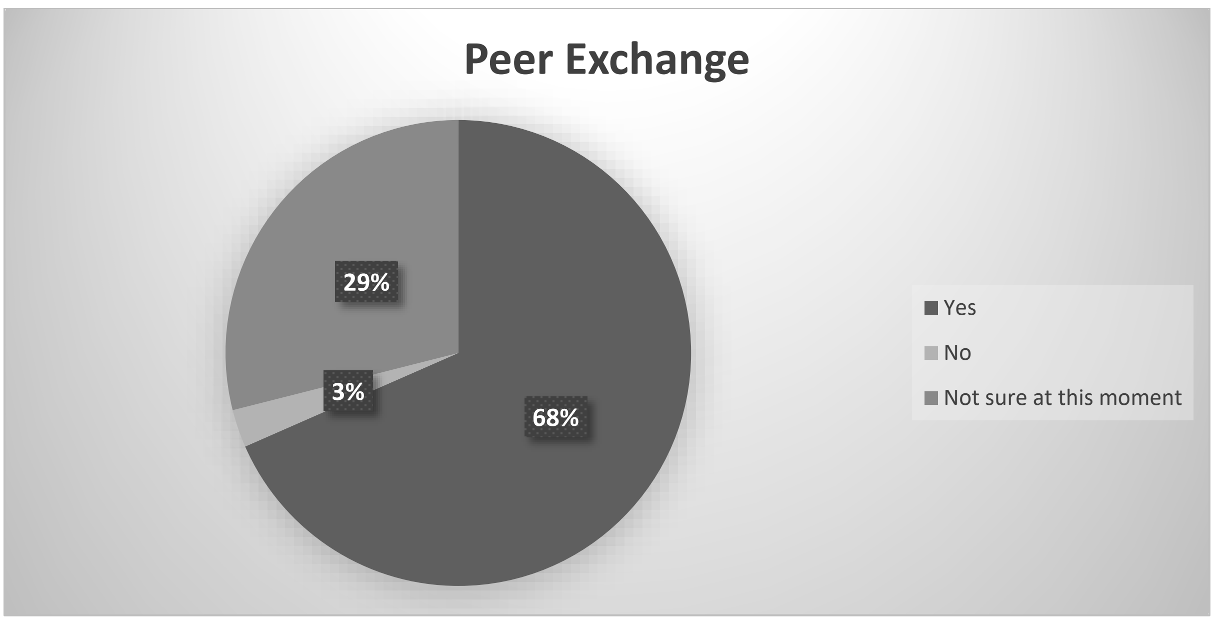

Figure B-8. Agencies' Willingness to Attend Peer Exchange Workshop

APPENDIX C. INDIVIDUAL STATE RESPONSES

Q2. How does your agency determine when to require positive protection in a work zone? Please feel free to either include a link below or attach the file directly to this survey response.

Table C-1 includes the verbatim responses to Question 2. The attachments provided by the survey respondents are not included in this document for brevity but were used for the research study.

Table C-1. Individual Responses for Question 2

State	Response
Alabama	ALDOT has a Guideline for Operation (GFO) in its determination of when to use positive protection. The GFO is attached.
Alaska	Alaska DOT&PF - Policy and Procedure 05.05.015 Highway Work Zone Safety and Mobility (http://www.dot.state.ak.us/edocs_code/edocs_document_ relay_ nativefile_bydocname.cfm?inline=1&ddocname=DOT-JNU_123033).
Arizona	Engineering judgment. In practice For freeway widening For existing positive protection improvement/construction For shifting traffic out of freeway or to separate two-way traffic on crossover For concrete structure extension or box culvert extension On high-volume roadway to direct traffic
Arkansas	
California	If there is enough shoulder width before using an impact attenuator vehicle(s) for placement and removal of TTC components on two-lane, two-way highways.
Colorado	Lot of this is up to the project, but anytime workers could be in the path of traffic and as the speed increases, our S-standards give some guidance
Connecticut	Positive protection, such as temporary precast concrete barrier curb, is used if the proposed work cannot be completed or the roadway cannot be satisfactorily opened to traffic after a single work shift. TPCBC is also be used if there are potential hazards within the clear zone, such as the storage construction equipment or sudden drop-offs. Short-term work zones, such as lane closures during off peak periods or mobile operations, can be performed using traffic drums, cones, and crash trucks. The CTDOT Highway Design Manual provides guidance on when TPCBC should be considered for a work zone. The Manual can be found on the CTDOT website at the following link: https://portal.ct.gov/-/media/DOT/documents/dpublications/highway/coverpdf.pdf?la=en
Delaware	Edge drop-offs, depth of excavation, clear zone issues with the proposed construction, long-term MOT condition, speed of roadway. It really depends on the condition.

State	Response
Florida	Temporary barrier is used for drop-off conditions, above ground hazards that are present when work is not active, and to separate high-speed traffic on multilane facilities that would otherwise be divided under permanent conditions. FDOT Standard Plans, Index 102-000, Sheet 2 of 8, provides the Drop-Conditions (see link below). https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/design/standardplans/2021/idx/102-000.pdf?sfvrsn=857da2ed_6
Georgia	
Hawaii	Positive protection is generally determined by predicted motorists speeds through the work zone and potential run-off-the-road risk, such as in the case of divergent roads for new bridge construction (MUTCD, TA-7).
Idaho	The Idaho Transportation Department does not "require" positive protection, but offers a tool to assist with an engineering study per 23 CFR 630, subpart K. The tool was developed by Jerry Ulman at TTI through a research project with ITD (see the attachment). The ITD Work Zone Safety and Mobility Program provides some guidance (see the attachment).
Illinois	
Indiana	Indiana Design Manual 503-3.05(01) Positive Protection https://www.in.gov/indot/design_manual/files/Ch503_2013.pdf
Iowa	You will need to copy these links and paste in your browser: https://iowadot.gov/design/dmanual/09b-09.pdf https://iowadot.gov/design/dmanual/09c-02.pdf
Kansas	This is usually determined by the Design squad in charge of the project. Positive protection is usually require only when there is an edge drop-off along the edge of the traveled way in close proximity to the traffic. Thomas Rhoads [KDOT] <Thomas.Rhoads@ks.gov> with KDOT Road Design would be the contact for specific information.
Kentucky	
Louisiana	It varies based on the project site limitations and work zone requirements. When the requirements for positive protection are known ahead of time, they can be specified in the plans. Otherwise, the need for positive protection can be discussed when the contractor submits his TTC plan prior to starting work.
Maine	
Maryland	Using the Guidelines, policy based on type of work, duration, time, proximity to traffic, lateral hazard etc. see link http://shawwwstage/OOTS/WorkZoneTemporaryTrafficBarrierPolicies.pdf
Massachusetts	MassDOT requires the use of temporary barrier when the work zone creates a situation where traffic is exposed to a new drop-off condition, non-recoverable slope, or the work puts non-crashworthy equipment and/or materials within the clear zone.
Michigan	table 6-9 of the WZSMM. section 6.01.07 temporary barriers

State	Response
	https://www.michigan.gov/documents/mdot/2018_WZSM__Manual_627313_7.pdf
Minnesota	It is primarily a decision by the traffic engineer working with the construction Project Engineer. They will generally take volume of traffic, traffic type, and proximity of workers into consideration. Many projects in the Twin Cities Metro Area will have positive protection, and less so in our rural districts. More common in Minnesota are temporary full closures and detours. The MnDOT's Metro District will close roads and detour traffic over weekends or overnight - this past construction season, most weekends had some sort of closure on the state highway system to accommodate construction. Our rural districts will often detour traffic. We've found the public to be more receptive to closures over the past decade. The above paragraphs are generally using the term 'positive protection' primarily for worker safety. MnDOT also uses temporary barrier for protecting drivers from hazards that may be in the clear zone. For more detail, see MnDOT's Temporary Barrier Guidance Manual at: http://www.dot.state.mn.us/trafficeng/workzone/doc/Temporary%20Barrier%20Guidance%20Manual%20181129.pdf
Mississippi	MDOT Traffic Engineering Division does not manage work zones nor keep crash data for such. We do provide in-house guidance on utilizing traffic barriers for maintenance operations 3) Temporary Traffic Barriers – Temporary traffic barriers should be placed along the work space depending on factors such as lateral clearance of workers from adjacent traffic, speed of traffic, duration and type of operations, time of day, and volume of traffic. Potential barrier deflection relative to worker's positions should be considered when determining barrier location. While all barriers can provide effective channelization, not all barrier types behave in the same manner. Deflection varies depending on the type of barrier and the manufacturer's procedures must be followed when worker protection is the desired outcome of the barrier. This guidance comes from our Traffic Control for Maintenance Operations which is an abridgement of Part 6 of the MUTCD.
Missouri	The use of positive is based predominately on the type and location of the work area. I have linked our Guidance. Within the article are links to pertinent drawings and specifications for positive protection. http://epg.modot.org/index.php/617.1_Temporary_Traffic_Barriers
Montana	During the planning and design of a project, give careful consideration to traffic control plan alternatives that do not require the use of temporary barriers. This can often be accomplished by using detours, constructing temporary roadways, minimizing exposure time, and maximizing the separation between traffic and workers. Even with proper project planning and design, there will still be instances where positive protection should be considered. Because each site should be designed individually, MDT has no specific warrants for providing positive protection in construction zones. The design team should coordinate with the Construction Bureau and field construction personnel to make the determination whether to provide positive protection in construction zones and

State	Response
	capture the decision in the TCP. The MDT Standard Specifications for Road and Bridge Construction can be used as a reference to assist in the decision process.
Nebraska	Proximity of drop-off/obstacle (large hole excavated, hole in bridge deck, barrier removal) Depth of drop-off Traffic Volume Duration of workworker protection District Preference
Nevada	The department has typical details per the 2017 Standard Plans for Road and Bridge Construction for certain positive protection devices. Most applicable are the temporary impact attenuators and PCBs. Most recently the department will be updating the Standard Plans for Road and Bridge Construction to include typical for TMAs within TTC for multilane closure, exit ramp and shoulder work. That has not been finalized for production. Follow this link to the department's 2017 Standard Plans for Road and Bridge Construction: https://www.nevadadot.com/doing-business/contractors-construction/contract-services/standard-specifications-and-plans In addition, the department has incorporated a matrix for temporary speed reduction in the work zone that is incorporated within the department's 2019 Work Zone Safety & Mobility Implementation Guide. Follow this link to the department's 2019 Work Zone Safety & Mobility Implementation Guide https://www.nevadadot.com/doing-business/about-ndot/ndot-divisions/operations/traffic-operations/signs-striping-traffic-control
New Hampshire	Depending on the work activity and proximity to traffic In combination with the Posted Speed Limit and traffic volume we will determine whether or not positive protection is required.
New Jersey	See chapter 9 and chapter 14 of the NJDOT Roadway Design Manual. https://www.state.nj.us/transportation/eng/documents/RDM/documents/2015RoadwayDesignManual20191010.pdf
New Mexico	Our design directive on TTC devices Subpart K provides guidance
New York	For capital construction projects, the determination to require positive protection in a work zone is made as part of the design process. See attached Section 16.3 Safety Devices and Barriers from the NYSDOT Highway Design Manual. For maintenance and operations, guidance on the use of positive protection is contained in the NYSDOT Work Zone Safety Manual.
North Carolina	
North Dakota	Engineering Standard
Ohio	Ohio DOT Traffic Engineering Manual (TEM) Section 603-3 Worker Considerations http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/TEM/Documents/Part_06_Complete_071919Revision_bookmarked_051719.pdf#page=25

State	Response
	Section 605-14 Temporary Traffic Barriers http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/TEM/Documents/Part_06_Complete_071919Revision_bookmarked_051719.pdf#page=47 Section 640-6 Work Zone Drop-Offs http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/TEM/Documents/Part_06_Complete_071919Revision_bookmarked_051719.pdf#page=88 Section 641-25 Drop-Offs in Work Zones (MT-101.90) http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/TEM/Documents/Part_06_Complete_071919Revision_bookmarked_051719.pdf#page=129 Maintaining Traffic Standard Construction Drawing MT-101.90 Drop-Offs in Work Zones http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/SCD/Documents/MT_10190_2017-07-21.pdf
Oklahoma	We do not have a set of rule that define the use of positive protection so we leave the decision to use positive protection to the Design Engineer. We are trying to come up with guidelines for the use of positive protection along with law enforcement; however it is difficult due to the complexity and the different situation in work zones. Situation where use of positive protection is common: Head-to-Head traffic on interstates Edge drop-off greater than 2 inches without treatment Not being able to meet construction clear zone Bridge construction Shoo-fly with steep slope Some of the challenges that we face: Not enough space in the roadway lanes to use positive protection Construction clear zone are hard to meet Pinning barrier wall to new pavement without damage MUTCD Definition of Short-term duration definition
Oregon	ODOT TCP Design Manual Chapter 3.3.1 Policies and Practices - Positive Protection https://www.oregon.gov/ODOT/Engineering/Pages/TCP-Manual.aspx#page=73
Pennsylvania	Positive protection needs are determined on a project-by-project basis. Wherever drop-offs within less than 12 feet of the roadway are anticipated, positive protection is utilized.
Rhode Island	
South Carolina	

State	Response
South Dakota	We do not have formal criteria or specific thresholds for when to use positive protection. It is included as a consideration under the Traffic Operations Component of the Transportation Management Plan in our Work Zone Safety and Mobility Plan. Currently, our DOT project and traffic personnel determine whether positive protection is appropriate for a situation on a case-by-case basis using their experience and engineering judgment.
Tennessee	Interstate shoulder and lane closure work. Other state route maintenance used when needed.
Texas	As far as I know the only guidance given for when to use positive protection are when there are edge drop-offs in work zones. I have included the link to the portion of the Roadway Design Manual that discusses it. http://gsd-ultraseek/txdotmanuals/rdw/treatment_pavement_drop_offs_in_work_zones.htm
Utah	UDOT Standard Drawing TC-3B uses work zone conditions to help determine when positive protection is required.
Vermont	Based on designers need and the RDG
Virginia	Please see Appendix A of the 2011 Virginia Work Area Protection Manual: http://www.virginiadot.org/business/resources/traffic_engineering/workzone/2011_WAPM_Rev_2.pdf
Washington	See our Design Manual section 1010.09 https://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1010.pdf
West Virginia	
Wisconsin	We have guidance in our Facilities Development Manual 11-50-35 on when we require temporary concrete barrier.
Wyoming	

Q3. Does your agency's positive protection requirements vary by work zone conditions (duration, roadway classification, speed limit, etc.…)? Please feel free to either include a link below or attach the file directly to this survey response.

Table C-2 includes the verbatim responses to Question 3. Again, the attachments provided by the survey respondents are not included but were used for the research study.

Table C-2. Individual Responses for Question 3

State	Response	Comments
Alabama	Yes	
Alaska	Yes	The evaluation of the conditions outlined in the P&P are subject to interpretation by the Project Engineer and work Zone Traffic Control Coordinators. There is no hard requirement to implement positive protection for a given condition. However recommended conditions are listed in the P&P.
Arizona		Using engineering judgment. Mainly based on roadway classification such as freeways.

State	Response	Comments
Arkansas		
California	Yes	Yes. Same as response to Q2 - If there is enough shoulder width before using an impact attenuator vehicle(s) for placement and removal of TTC components on two-lane, two-way highways.
Colorado	Yes	It can also be modded by the project.
Connecticut	Yes	Different conditions, such as roadway type and travel speed, can impact the use of TPCBC, including the length of need and how blunt ends are protected.
Delaware	Yes	Duration, Speed Limit, type of work, anticipated edge drop-off condition,
Florida	Yes	Temporary barrier may be omitted for drop-off conditions with a duration of one day or less.
Georgia		
Hawaii	Yes	See previous response.
Idaho	Yes	See the positive protection worksheet attached to Question 2.
Illinois		
Indiana	Yes	Indiana Design Manual 503-3.05(03) Design Considerations for Use of Positive Protection https://www.in.gov/indot/design_manual/files/Ch503_2013.pdf
Iowa	Yes	See policies sent for previous question.
Kansas	Yes	Those could all be factors in the decision. Another good question for KDOT Road Design.
Kentucky		
Louisiana	Yes	
Maine		
Maryland	Yes	http://shawwwstage/OOTS/WorkZoneTemporaryTrafficBarrierPolicies.pdf
Massachusetts	Yes	Speed, but only as it pertains to the size of the clear zone.
Michigan	Yes	See sections in work zone manual and tables in section 6.01.07.
Minnesota	Yes	Engineering judgment is used by the TTC designer working with the construction Project Engineer taking the type of work, duration, volume, and proximity of workers into consideration.
Mississippi		
Missouri	Yes	I provided the link in Question 2.
Montana	Yes	The following provides a list of factors that should be considered: Duration of construction activity, Clear zone for the construction zone design speed, Traffic volumes (including seasonal fluctuations), Nature of potential conflict, Design speed, Highway functional class, Length of hazard, Proximity between traffic and construction workers—consider dynamic deflection of barrier, Proximity between traffic and construction equipment, Adverse geometrics which may increase the likelihood of run-off-the-road vehicles, Two-way traffic on one roadway of a divided highway, and Transition areas at crossovers, and/or lane closures or lane transitions.

State	Response	Comments
Nebraska	Yes	
Nevada	Yes	Same as previous question. See links provided.
New Hampshire	Yes	Proximity to traffic in combination with posted speed limit and ADT.
New Jersey	Yes	
New Mexico	Yes	
New York	Yes	Work zone conditions such as duration, roadway classification or speed limit are all factors in the determination to require positive protection in work zones.
North Carolina		
North Dakota	Yes	
Ohio	Yes	See same links as provided in Q2.
Oklahoma	Yes	Duration, Speed Limit, edge drop-off, construction clear zone, roadway classification, slopes, ADT.
Oregon	Yes	See TCP Design Manual Chapter 3.3.1 Determination to use positive protection is on a project-by-project basis, including a project specific work zone decision tree to document decision.
Pennsylvania	Yes	
Rhode Island		
South Carolina		
South Dakota	Yes	Again, no formal guidelines (though we are working toward this), however, positive protection type and use do vary depending on the facility type/speed and the duration of work.
Tennessee	Yes	Interstate work has positive protection.
Texas	Yes	The only guidance TxDOT provides for when to use positive protection is when there is edge drop-off conditions (edge height, lateral clearance).
Utah	Yes	
Vermont	Yes	
Virginia	Yes	http://www.virginiadot.org/business/resources/traffic_engineering/workzone/2011_WAPM_Rev_2.pdf
Washington	Yes	Other than what is described in the DM 1010.09 it would be determined project by project based on an impact assessment described in DM section 1010.05(2) For short duration work zones, TMAs are required on high-speed high-volume roads. https://www.wsdot.wa.gov/Design/Standards/PlanSheet/Work-Zone-Typical-TCPs.htm
West Virginia		
Wisconsin	Yes	Yes, https://wisconsindot.gov/rdwy/fdm/fd-11-50.pdf#fd11-50-35
Wyoming		

Q4. Does your agency have a work zone management practice to help keeping track whether a work zone was present on a given day, as well as to identify specific areas where work is being actively conducted on it? Please feel free to either include a link below or attach the file directly to this survey response.

Table C-3 includes the verbatim responses to Question 4. Provided attachments are not included herein but were used for the research study..

Table C-3. Individual Responses for Question 4

State	Response	Comments
Alabama	No	
Alaska	No	NO, if the question focuses on a department-wide system for logging presence of WZ by route and mile point, or another means. YES, if recordkeeping on a project-by-project basis, such as tracking approved Traffic Control Plans in effect, and numbers of devices installed.
Arizona	Yes	Department construction inspectors complete daily diaries per ADOT Construction Manual Section 701. Subsection "Traffic Control Documentation" addresses the specific documentation requirements.
Arkansas		
California	Yes	LCS Mobile web page.
Colorado	No	We depend on daily diaries for the most part as well as payment records.
Connecticut	Yes	Each project in construction maintains a daily activity log that describes the work performed on each day. This process is not available on an agency wide basis, but is performed separately by each project and overseen by each of the District offices for the projects within each district. Projects on limited access highways are also required to call in to the Highway Operations Unit, which oversees the operation of the permanent VMS on each limited access highway.
Delaware	Yes	When a lane closure is taken, typically the inspection staff will call in the lane closure to our TMC. Also, inspection records will note the work performed and MOT used.
Florida	Yes	To an extent. See https://data.fdot.gov/road/projects/.
Georgia		
Hawaii	Yes	Construction project daily diaries. However, there currently is no database for collecting this data.
Idaho	Yes	Inspectors on highway construction projects keep a construction diary.
Illinois		
Indiana	Yes	Yes, somewhat. We use a software system called CARS. However, it is dependent on construction project and maintenance staff keeping it current. I believe the CARS data is stored, but I am not aware of a way to access the stored data. http://indot.carsprogram.org/#roadReports?timeFrame=TODAY&layers=roadReports%2CwinterDriving%2CweatherWarnings%2Cflooding%2CallReports

State	Response	Comments
Iowa	Yes	We are developing a work zone database that can be easily searched. We are still a few years from implementation.
Kansas	Yes	
Kentucky		
Louisiana	Yes	See Section 713 in the attached document for our requirements.
Maine		
Maryland	Yes	https://onemdot/mdotsha/SOC/Pages/SID.aspx This monitor and keep data on permits for lane closure schedule in work zones.
Massachusetts	Yes	Prior to starting work for the day, Contractors are required to fill out Roadway Work Notification Forms that are filed both with the MassDOT District Construction Office and the Highway Operations Center.
Michigan	No	We keep track of this at a project level in the daily reports but it is not searchable. we do post closures to the public but these are general times and aren't updated in real time on site conditions.
Minnesota	Yes	On a per project basis with the construction project staff. This information is not currently stored centrally. MnDOT does not have a mechanism for doing so at this time.
Mississippi		
Missouri	Yes	MoDOT has a traveler information map which documents almost all of MoDOT's lane closures. Each work zone has information in a database which the project information can be uploaded. The work zone time period is part of the data. http://traveler.modot.org/map/
Montana	No	
Nebraska	Yes	District manages this and records dates and area of work.
Nevada	Yes	Follow this link to the department's work zone management practices:https://www.nevadadot.com/home/showdocument?id=9278
New Hampshire	No	
New Jersey	Yes	The project Traffic control coordinator is responsible to oversee and inspect the traffic control operation, maintaining or replacing traffic control devices to ensure traffic control devices are in an acceptable condition and good working order.
New Mexico		
New York	Yes	All work zone activity is reported in advance to the appropriate regional traffic management center using a Road Work Notification form. Any work impacting traffic is entered into the 511NY system (511ny.org). Road Work Notification records are archived and can be retrieved at a later date to determine whether a work zone was present on a given day. Active work zones can be retrieved directly from 511NY.
North Carolina		
North Dakota	Yes	

State	Response	Comments
Ohio	Yes	We do have daily diaries that are completed on projects that would indicate what was active on a given day and where; however, this is more for records. Our PIOs and project staff do submit information that is applied through our TMC to show on our public facing mapping (ohgo.com). The detail of the information can vary (some posts are general for ongoing work and others are detailed for specific impacts for a specific shorter duration).
Oklahoma	Yes	Not Sure. Field division keep daily logs of the work performed in there division. inspectors keep daily logs of construction work zones. the agency as a whole does not have a process to track/manage work zones.
Oregon	Yes	ODOT does submit look ahead schedules to our Tripcheck ITS platform, but the tracking of the work zone is not live, based upon the submitted schedule. On a project level, the Construction Resident Engineers track whether a work zone is present and where it is located but that data is maintained locally and shared globally. https://www.tripcheck.com/ On a programmatic level, No ODOT does not have a system to track whether or not work zone was present or to identify specific areas.
Pennsylvania	Yes	PennDOT has a Road Condition Reporting System utilized for planned and unplanned TTC. The contractor and/or maintenance forces are required to report lane closures and/or road closures prior to installing the work zone and once again when the patterns are removed.
Rhode Island		
South Carolina		
South Dakota	No	
Tennessee	No	We do not.
Texas	Yes	TxDOT has SiteManager which we can use to determine all active work zones at any given time. That is not the purpose of SiteManager and it is not really intuitive to this task, but it can be used for that.
Utah	Yes	UDOT Standard Specification 01554 states that traffic control must be inspected/documented daily. See 01554 1.9 D.6.
Vermont	Yes	Daily work reports.
Virginia	Yes	We have a system called LCAMs, which stands for lane closure access management system.
Washington	Yes	We are currently developing a statewide "work zone database" that will be used to log all construction, maintenance, utility... work zones. Now it is done region by region. We are working to be in line with the national database effort...
West Virginia		
Wisconsin	Yes	We have our Wisconsin LCS (WisLCS), however it does have limitations and does not report the specific location of work within a lane closure. http://transportal.cee.wisc.edu/closures/

State	Response	Comments
Wyoming	No	

Q5. Can you please describe the type of work zone safety data that your agency is collecting? (Select all that apply)

1. Data and Location of Work Zones
2. Work Zone Crash Reports
3. Archived video of crashes, conflicts, or queues
4. Maintenance records of "hits" or encroachments on barriers or other work zone devices
5. Forensic or roadside investigations of crashes or encroachments
6. Log of work zone intrusions
7. Other (please specify)
8. None

Table C-4 includes the verbatim responses to Question 5.

Table C-4. Individual Responses for Question 5

State	Response	Comments
Alabama	Work Zone Crash Reports, Maintenance records of "hits" or encroachments on barriers or other work zone devices, Forensic or roadside investigations of crashes or encroachments, Other (please specify)	Only do the forensic investigations if there is a death in the crash.
Alaska	Work Zone Crash Reports, Forensic or roadside investigations of crashes or encroachments, Other (please specify)	Work Zone Crash reports are tracked, with associated evaluation of Traffic Control Plans in effect at the time, for revision if necessary.
Arizona	Date and Location of Work Zone Work Zone Crash Reports Other (please specify)	Speed within advance work zone area to infer queue length, queue speed, and travel delay. We also collect crash occurrences related to work zones.
Arkansas		
California	Date and Location of Work Zone	
Colorado	Work Zone Crash Reports, Maintenance records of "hits" or encroachments on barriers or other work zone devices, Other (please specify)	We have a person would know all this exact data.

State	Response	Comments
Connecticut	Date and Location of Work Zone, Work Zone Crash Reports, Maintenance records of "hits" or encroachments on barriers or other work zone devices, Log of work zone intrusions, Other (please specify)	Smart work zones are also implemented on a project-by-project basis. Those identified as benefiting from a smart work zone also collect continuous speed, volume, and delay data that is used to provide real-time information to the public, as well as historical data that can be used in the future.
Delaware	Date and Location of Work Zone, Work Zone Crash Reports, Maintenance records of "hits" or encroachments on barriers or other work zone devices	
Florida	Work Zone Crash Reports	
Georgia		
Hawaii	Work Zone Crash Reports	
Idaho	Work Zone Crash Reports	
Illinois		
Indiana	Date and Location of Work Zone, Work Zone Crash Reports, Maintenance records of "hits" or encroachments on barriers or other work zone devices, Other (please specify)	We track queuing through INRIX data. We have live video of urban areas, but do not record video. Date and location of work zone is thru CARS. We also perform work zone reviews and tabulate the occurrence rates of work zone issues related to TTC devices.
Iowa	Date and Location of Work Zone, Work Zone Crash Reports, Archived video of crashes, conflicts, or queues, Maintenance records of hits or encroachments on barriers or other work zone devices, Forensic or roadside investigations of crashes or encroachments, Other (please specify)	There are limitations on the data we are collecting.
Kansas	Date and Location of Work Zone, Work Zone Crash Reports, Archived video of crashes, conflicts, or queues, Maintenance records of "hits" or encroachments on barriers or other work zone devices, Other (please specify)	Most of this Data exists here at KDOT but to my knowledge there is no active effort here to compile it and mine it for information.
Kentucky		
Louisiana	Date and Location of Work Zone,	

State	Response	Comments
	Work Zone Crash Reports	
Maine		
Maryland	Date and Location of Work Zone, Work Zone Crash Reports Maintenance records of "hits" or encroachments on barriers or other work zone devices, Forensic or roadside investigations of crashes or encroachments	
Massachusetts	Work Zone Crash Reports	
Michigan	Work Zone Crash Reports, Other (please specify)	we only have the police report that is filled out by the officer and they are required to check the work zone box for it to be counted as a work zone crash.
Minnesota	Date and Location of Work Zone, Work Zone Crash Reports, Log of work zone intrusions, Other (please specify)	Some districts are logging work zone intrusions, but it's not consistent statewide. On a statewide basis, MnDOT will be starting to log work zone intrusions through a WZ Intrusion form developed by a human factors expert in maintenance projects starting next year. It is expected to be added to construction projects in the future. See the following website for the Work Zone Intrusion Report Interface Design Study - http://www.dot.state.mn.us/research/reports/2018/201809.pdf
Mississippi		
Missouri	Date and Location of Work Zone, Work Zone Crash Reports	
Montana	Work Zone Crash Reports	
Nebraska	Date and Location of Work Zone, Work Zone Crash Reports, Forensic or roadside investigations of crashes or encroachments, Log of work zone intrusions	
Nevada	Date and Location of Work Zone, Other (please specify)	This is logged under the department's construction section using NDOT Form 040-056B.
New Hampshire	Work Zone Crash Reports	
New Jersey		

State	Response	Comments
New Mexico	Forensic or roadside investigations of crashes or encroachments	
New York	Date and Location of Work Zone Work Zone Crash Reports Log of Work Zone Intrusions	
North Carolina		
North Dakota	Date and Location of Work Zone, Work Zone Crash Reports, Maintenance records of hits or encroachments on barriers or other work zone devices, Forensic or roadside investigations of crashes or encroachments	
Ohio	Date and Location of Work Zone, Work Zone Crash Reports, Archived video of crashes, conflicts, or queues, Other (please specify)	Date and Location of Work Zone - This is through daily diaries and if logged into Ohgo.com. Work Zone Crash Reports - We have access to all crash reports and we regularly monitor crashes on a select set of projects. Archived video of crashes, conflicts, or queues - we have access to record down videos of these items but sometimes screen captures work just as well. We also avoid recording any crashes and must go through the TMC for recording in these cases if we feel it is necessary to document. More common that we only use this for documenting operational or queuing issues. This is only on an as needed basis.
Oklahoma	Date and Location of Work Zone, Work Zone Crash Reports, Other (please specify)	We receive police reports of all crashes on state highways. the date and location is available in project reports, inspection report, etc., however it is not compiled in one location. for the rest of the data, I am not sure.
Oregon	Work Zone Crash Reports, Other (please specify)	Answering this question holistically. As an organization ODOT collects work zone crash reports, including forensics for major encroachments. ODOT collects date and location of work zones locally. ODOT does not collect video, maintenance records of encroachments, forensic investigations of minor encroachments, or logs of work zone intrusions.

State	Response	Comments
Pennsylvania	Date and Location of Work Zone, Work Zone Crash Reports, Archived video of crashes, conflicts, or queues, Maintenance records of hits or encroachments on barriers or other work zone devices, Log of work zone intrusions	
Rhode Island		
South Carolina		
South Dakota	Work Zone Crash Reports	
Tennessee	Work Zone Crash Reports	
Texas	Date and Location of Work Zone, Work Zone Crash Reports, Maintenance records of "hits" or encroachments on barriers or other work zone devices	
Utah	Date and Location of Work Zone, Work Zone Crash Reports	
Vermont	Date and Location of Work Zone, Work Zone Crash Reports	
Virginia	Date and Location of Work Zone, Work Zone Crash Reports	
Washington	Date and Location of Work Zone, Work Zone Crash Reports, Maintenance records of hits or encroachments on barriers or other work zone devices, Forensic or roadside investigations of crashes or encroachments	
West Virginia		
Wisconsin	Date and Location of Work Zone, Work Zone Crash Reports, Archived video of crashes, conflicts, or queues, Forensic or roadside investigations of crashes or encroachments	
Wyoming		

Q6. Would your agency be able to share any of the work zone safety data you mentioned in Question 5 with the NCHRP 03-134 team?

1. Yes, contact me
2. Yes, other contact (please provide name, email/phone number for alternate contact from your agency)
3. We are not able to share data

Table C-5 includes the verbatim responses to Question 6.

Table C-5. Individual Responses for Question 6

State	Response	Comments
Alabama	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	Waymon Benifield 334-353-6404 benifieldw@dot.state.al.us
Alaska	We are not able to share data	
Arizona	Yes, contact me	Adam Carreon/ACarreon@azdot.gov/ 6027122212
Arkansas		
California	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	Refer to LCS Mobile web page
Colorado	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	I will provide you the person if you reach out to me
Connecticut	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	It isn't clear exactly what data can be shared at this time. Please contact Joseph Cristalli (Joseph.Cristalli@ct.gov) in CTDOT Policy and Planning. The Office of Construction (Anthony Kwentoh, Anthony.Kwentoh@ct.gov) may also be contacted.
Delaware	We are not able to share data	
Florida	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	FDOT.CrashData@dot.state.fl.us
Georgia		
Hawaii	Yes, contact me	
Idaho	Yes, contact me	
Illinois		
Indiana	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	I will be the contact. However, we are short-staffed and may not have data for this year as this requires manual data entry. We do have some years past.
Iowa	Yes, contact me	

State	Response	Comments
Kansas	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	Not Sure. I would have to check with our legal staff to know how much is available through the open records act.
Kentucky		
Louisiana	We are not able to share data	
Maine		
Maryland	We are not able to share data	
Massachusetts	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	Bonnie Polin, Manager of Highway Safety Programs, bonnie.polin@dot.state.ma.us
Michigan	Yes, contact me	
Minnesota	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	We can provide some summaries of the data collected. Start with me and I'll bring in the appropriate MnDOT Traffic Engineering Safety folks.
Mississippi		
Missouri	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	I will be able to get the team to the proper personnel.
Montana	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	Patricia Burke pburke@mt.gov (406) 444-9420
Nebraska	We are not able to share data	
Nevada	Yes, contact me	
New Hampshire	Yes, contact me	
New Jersey	We are not able to share data	
New Mexico	We are not able to share data	
New York	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	Md Haque MD.Haque@dot.ny.gov 518-457-7784
North Carolina		
North Dakota	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	I would not be the contact person but could possibly link you to the correct person.
Ohio	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	Yes, Contact me. Additional comments below. Ohgo.com can be viewed online and the construction notices can be viewed there. Work Zone Crash Reports - While it may be difficult to share the reports we can share an example of the monitoring reports that we have for projects that we

State	Response	Comments
		have selected to monitor. Videos/screen captures are only done on an as needed basis. If there is something specific you are looking for I can get with our TMC and inquire if we can send it.
Oklahoma	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	Please contact David Glabas 405-521-4157 Dglabas@odot.org
Oregon	Yes, contact me	
Pennsylvania	Yes, contact me	
Rhode Island		
South Carolina		
South Dakota	Yes, contact me	
Tennessee	We are not able to share data	
Texas	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	Eduardo Acosta - Eduardo.acosta@txdot.gov 512-416-4554 I think Eduardo can provide some information, but if not I can be contacted to find the right person
Utah	We are not able to share data	
Vermont	Yes, other contact (please provide name, email/phone number for alternate contact from your agency)	Crash Data Mandy White mandy.white @vermont.gov 802-595-9341
Virginia	Yes, contact me	
Washington	Yes, contact me	
West Virginia		
Wisconsin	Yes, contact me	
Wyoming		

Q7. Does your agency have any additional needs for work zone encroachments and intrusions data collection that is not currently addressed by your agency data collection method?

The project team identifies a "work zone" as the following, based on definition provided by the FHWA:

"A work zone is an area of roadway with construction, maintenance, or utility work activities. A work zone is typically marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign (...) to the "end Road Work Sign" or the last TTC device."

The project team identifies a "work zone encroachment" as
"The vehicle travel condition when such a vehicle inadvertently traverses across the boundaries of a work zone. Considering the different zone areas defined by the MUTCD, encroachments occurring in the advance warning area might be defined as departures across the edgeline of the travel way, whereas those in the transition and activity areas could be either across a lane line or an edge line."

The project team identifies an "intrusion crash" as:
"a vehicle or object which penetrates the actual work space within the work zone and strikes workers, construction vehicles and equipment, or construction materials and debris."

1. Yes
2. No

Table C-6 includes the verbatim responses to Question 7.

Table C-6. Individual Responses for Question 7

State	Response	Comments
Alabama	Yes	I would say yes, but I am not sure what all the department does collect.
Alaska	No	Encroachment events are rare. Such events that can be identified are logged among work zone crash reports.
Arizona	Yes	What are corrective actions taken by other DOTs to manage mobility and safety based on criteria such as travel delay, queue length, and crash occurrences.
Arkansas		
California	Yes	
Colorado	Yes	I am not the best person to answer this.
Connecticut	Yes	The department is continuously working to improve its data collection processes. Crash reports completed by law enforcement personnel after an incident are validated to provide better location data and crash information, as well as improving smart work zones and inspection record keeping and reporting requirements.
Delaware	Yes	
Florida	Yes	To the extent that we believe additional data could help improve guidance for Work Zone Clear Zones and crash testing requirements for temporary roadside safety devices.
Georgia		
Hawaii	No	

State	Response	Comments
Idaho	No	I answer no, but the agency does have a policy to use median crossovers on divided highways based on an agreement with the Idaho Association of General Contractors. The agreement and policy are not based on data.
Illinois		
Indiana	Yes	We are currently not tracking.
Iowa	Yes	Barrier impacts (speed, angle, encroachment, performance). Work are intrusion awareness would be nice. Iowa DOT has deployed over 24 audible attenuators on maintenance vehicles. More research would benefit nationwide deployment.
Kansas	Yes	I am not sure.
Kentucky		
Louisiana	Yes	
Maine		
Maryland	Yes	Including Police report.
Massachusetts	Yes	Other than when we summarize all crash types for a year, there is no other investigation after the fact of work-zone related crashes unless there is a fatality or serious injury. Most of our work zone setups are based upon the MUTCD, but given there are many optional devices it is difficult to accurately determine what is effective at reducing the number and severity of crashes.
Michigan	Yes	it would be good to know what type of work and traffic control device layout was in place when intrusions occur and where within the project limits do they occur. 2 miles in versus 5 miles? This could give us some insight as to when the motorist may relax or lower there guard in the work zone increasing the likely hood of a crash. Is a narrow lane actually better because the driver becomes more alert? these would be interesting things to look at for patterns.
Minnesota	Yes	As mentioned previously, MnDOT has not had a statewide accepted way to collect WZ encroachment (we use the term 'intrusion') data. However, we are starting the implementation of this data collection. The concern was overloading staff with collecting the data. It was felt that workers would not stop their work and take the time to fill out a form if the WZ Intrusion happened in such a way that no one felt at risk. Thus the data would be incomplete. More information can be found in the Work Zone Intrusion Report Interface Design Study at http://www.dot.state.mn.us/research/reports/2018/201809.pdf.
Mississippi		
Missouri	No	At this time, five crash items on Question 5 would provide great knowledge to MoDOT.

State	Response	Comments
Montana	No	
Nebraska	No	
Nevada	No	
New Hampshire	No	
New Jersey	No	
New Mexico	No	
New York	None at this time	
North Carolina		
North Dakota		
Ohio	Yes	I can't think of anything specific at this time but we are open to thoughts on this and ways to continue to make improvements.
Oklahoma	Yes	We currently don't collect encroachments and intrusions data.
Oregon	Yes	
Pennsylvania	Yes	
Rhode Island		
South Carolina		
South Dakota	No	
Tennessee	Yes	We look at work zone crashes within advance warning area.
Texas	Yes	I don't believe that we currently collect information on work zone encroachments if there is no collision. I believe it would be useful to be able to study encroachments.
Utah	No	
Vermont	No	
Virginia	Yes	
Washington	Yes	Non-active work zone crashes on long-term stationary projects may not be reported as work zone related.
West Virginia		
Wisconsin	Yes	
Wyoming		

Q8. Does your agency have any needs for work zone guidance that are not currently being met?

1. Yes
2. No

Table C-7 includes the verbatim responses to Question 8.

Table C-7. Individual Responses for Question 8

State	Response	Comments
Alabama	No	
Alaska	Yes	Always interested in guidance for good practices. However, with a low incidence of WZ encroachments or intrusion crashes, the current approach to positive protection seems appropriate to Construction staff.
Arizona		
Arkansas		
California	Yes	Work Zone Speed Limit Reduction.
Colorado	Yes	
Connecticut	Yes	The department is always looking for additional information, including best practices, standards, and guidelines, from other departments and agencies to determine ways to improve work zones and safety.
Delaware	Yes	I think that MASH is causing some questions regarding compliance issues since the FHWA sunset dates are not able to be met in some areas.
Florida	No	This question is pretty broad there a various areas where more guidance would be helpful (e.g., metrics for when positive protection should be used solely for the protection of workers).
Georgia		
Hawaii	No	
Idaho	Yes	We would like updated guidance on work zone speed limits. The research summarized in Research Results Digest Number 192 (NCHRP Project 3-41) is dated and we wonder how relevant it still is.
Illinois		
Indiana	Yes	Always open to additional guidance.
Iowa	Yes	1) Use of temporary barriers to separate opposing traffic on rural, high-speed two-lane, two-way operations. 2) Better guidance on drop-off protection. (warrants and mitigation).
Kansas	No	Not as far as I know but I would need more information on what is meant by "Guidance."
Kentucky		
Louisiana	Yes	
Maine		
Maryland	Yes	
Massachusetts	No	

State	Response	Comments
Michigan	No	At this time we are pretty good but in the future smart devices and real-time location of work zone signs is something that CAVs will need, just not sure when that date is.
Minnesota	Yes	There are perennial questions that many states struggle with that MnDOT struggles with as well: - How to effectively slow traffic down in work zones without adding hazards? - What are useful performance measures for work zones? - Improve effectiveness of merging behavior. - There are more...
Mississippi		
Missouri	Yes	
Montana	Yes	We could use better Work Zone guidance on the use of positive protection vs the use of crossovers.
Nebraska	No	
Nevada	Yes	More on the performance metrics and regarding smart work zone initiatives.
New Hampshire	No	
New Jersey	No	
New Mexico	Yes	A process review identified many needs.
New York	None at this time	
North Carolina		
North Dakota		
Ohio	Yes	Determination of when to anchor portable barrier where there is a drop-off. Example, for depth D or more where barrier is x or less from the edge. How deep is too deep and needs anchored. We have standards for when to provide bridge mounted barrier but for areas where it is not a bridge condition but is still a significant drop. Barrier is provided but when to anchor. We can all seem to reach an agreement when depth gets to a certain point but don't all agree on the minimum that still kicks it into an anchoring requirement. Also, protection methods for corners where portable barrier can't effectively wrap and facilities with multiple driveways requiring repeated breaks in the portable barrier.
Oklahoma	Yes	we are always looking to improve our work zone practices.
Oregon	Yes	ODOT is interested in methodology to compare TTC alternatives using the Highway Safety Manual and crash modification factors. Unfortunately the database of work zone crash modification factors in minimal. AFAD technology is advancing quickly, using camera's to monitor

State	Response	Comments
		traffic/work zone. Acceptable practices around using number of AFAD operators, maintaining line of sight(electronically), and best practices. ITS devices in work zones for connected and automated vehicles.
Pennsylvania	Yes	Utilization of Moveable Barrier Systems (i.e. Zipper Barrier) and Communicating with Commercial Motor Vehicles approaching work zones.
Rhode Island		
South Carolina		
South Dakota	Yes	A synthesis of what other states are using for criteria on when to install temporary barriers in a work zone would be very helpful.
Tennessee	Yes	more training for designers.
Texas	Yes	We don't currently provide guidance on when to use positive protection based on anything other than edge conditions. Designers have expressed an interest in guidance on when to use positive protection based on other factors like geometry, ADT, speed, traffic mix, etc.
Utah	No	
Vermont	Yes	We need better speed management and more uniformity of practices throughout the state.
Virginia	No	
Washington	Yes	Temporary rumble strip testing and guidance on effectiveness Smart work zone systems application.
West Virginia		
Wisconsin	Yes	Some of the hazards that exist in work zones do not have well established severities. Theses hazards may not be typical for a normal roadside (e.g. equipment, workers). Work zone durations are shorter than the normal roadside and severity may need to be adjusted for this difference. At reality low speeds severity for hitting people is very high. But workers are not on site 24 hours a day and every day of the year. Balancing the time it takes to install barriers (a known hazard and additional risk for workers) versus the risk of the hazard to traveling public during construction. At what point, does anchoring a barrier versus allowing a barrier to be freestanding make sense. How to deal with the damage anchoring temporary barrier into pavement or deck? What degradation to the pavement happens when we anchor to pavement or deck? Is length-of-need different for work zone?
Wyoming		

Q9. How does your agency use encroachment data? (Not necessarily specifically just from work zones) (Select all that apply).

1. RSAP
2. Work Zone Positive Protection Program
3. Roadside Design Decision
4. Safety Analyses
5. Other (please describe)

Table C-8 includes the verbatim responses to Question 9.

Table C-8. Individual Responses for Question 9

State	Response	Comments
Alabama	Safety Analyses	
Alaska	Other (please describe)	Not sure how Data is used. Project-by-project staff experience and consideration of the conditions described in the P&P is presumably implemented when/as Traffic Control Plans are developed/approved.
Arizona	Other (please describe)	Do not collect encroachment data.
Arkansas		
California	Other (please describe)	Unsure.
Colorado	Other (please describe)	Does not allow multiple selection.
Connecticut	None	
Delaware	None	
Florida	RSAP	
Georgia		
Hawaii	None	
Idaho	None	
Illinois		
Indiana	None	
Iowa	Other (please describe)	Our only encroachment data comes from crash reports. They are not easily searchable for different types or locations of encroachment data.
Kansas	Other (please describe)	Not to my knowledge but possibly through our safety section.
Kentucky		
Louisiana	None	
Maine		
Maryland	Other (please describe)	All selected except the last row.
Massachusetts	None	
Michigan	None	
Minnesota	Other (please describe)	If we had good intrusion data, MnDOT would use it to determine modifications to typical applications for various work zone operations. This page wouldn't let me also highlight Work Zone Positive

State	Response	Comments
		Protection Program, but we'd use this data for that as well. For non-work zone applications, if we could collect this data, MnDOT would likely use it to determine where roadside safety needs to be improved by either improving the clear zone or barrier needs to be added.
Mississippi		
Missouri	None	
Montana	Safety Analyses	
Nebraska	RSAP	
Nevada	Safety Analyses	
New Hampshire	None	
New Jersey		
New Mexico	Safety Analyses	
New York	RSAP Work Zone Positive Protection Program Roadside Design Decision Safety Analyses	
North Carolina		
North Dakota		
Ohio	None	
Oklahoma	None	
Oregon	Other (please describe)	Survey won't let me pick more than one option. ODOT uses crash data to highlight high accident locations, which are then used to perform safety analyses, program safety projects, inform work zone decisions. https://www.oregon.gov/ODOT/Engineering/Pages/SPIS-Reports-On-State.aspx
Pennsylvania	RSAP	
Rhode Island		
South Carolina		
South Dakota	Other (please describe)	I am not sure what other types of encroachments are meant or how they might be used by our DOT. As far as work zone encroachments go, currently we are collecting work zone crash reports.
Tennessee	None	
Texas	None	
Utah		
Vermont	None	
Virginia	Work Zone Positive Protection Program	

State	Response	Comments
Washington	Safety Analyses	
West Virginia		
Wisconsin	RSAP	
Wyoming		

Q10. Is there any additional information that you would like to share with the project team regarding your needs/constraints related to this project? If yes, please feel free to comment below or drop an attachment below.

Table C-9 includes the verbatim responses to Question 10.

Table C-9. Individual Responses for Question 10

State	Response
Alabama	
Alaska	
Arizona	A place to enter data such as travel delay, queue length, and crash occurrences that suggests possible actions to take to improve safety and mobility.
Arkansas	
California	None at this time.
Colorado	
Connecticut	Not at this time.
Delaware	Not sure this has anything to do with the goal of this project, but temporary barrier wall deflection causes some issues with tight constraints. If traffic is in a cattle chute condition, they are not able to strike the barrier at 20 degrees. Possibly guidance on lowering the deflection distance when traffic cannot hit the barrier at 20 degrees.
Florida	
Georgia	
Hawaii	
Idaho	
Illinois	
Indiana	
Iowa	We need practical work zone deployment data and not just 'crash test" performance data.
Kansas	
Kentucky	
Louisiana	I do not get involved with work zones or data collection so I answered the questions to the best of my ability given my limited experience with these issues.
Maine	
Maryland	N/A
Massachusetts	
Michigan	when looking at the location and offset a key factor in this is the roadway and where the joint line is. We had a project were the widening put the joint in the wheel path and we also had a very soft shoulder which didn't allow for a recovery. I think this is something that could be looked at as to if there is run offs as the soft slope would often times pull

State	Response
	the vehicles in. we now use safety edge and a higher compacted material when widening shoulders in work zones. See 6.05.07.D - relocating traffic - D. shoulder conditions https://www.michigan.gov/documents/mdot/2018_WZSM__Manual_627313_7.pdf
Minnesota	
Mississippi	
Missouri	
Montana	
Nebraska	
Nevada	Not at this time.
New Hampshire	
New Jersey	
New Mexico	
New York	None at this time
North Carolina	
North Dakota	
Ohio	N/A
Oklahoma	Except for police reports, ODOT does not collect encroachments and intrusion data.
Oregon	
Pennsylvania	
Rhode Island	
South Carolina	
South Dakota	
Tennessee	
Texas	
Utah	
Vermont	
Virginia	
Washington	
West Virginia	
Wisconsin	
Wyoming	

Q11. As part of this National NCHRP research project, a 2-day peer exchange will be conducted for state attendees to review a draft guidance document which will enhance the importance of encroachment conditions in work zones. Attendee experience and possible adaptation strategies for the guidance will also be solicited. Would your agency like an invitation to this peer exchange workshop? Please indicate a preferred agency personnel contact to follow up on this request at a later date.

1. Yes
2. No
3. Not sure at this moment

Table C-10 includes the responses to Question 11. Respondents also provided the contact details of the agency personnel to follow up with for the peer exchange program. Those details are removed from the individual responses for confidentiality reasons. The information is available from the research agency upon special request.

Table C-10. Individual Responses for Question 11

State	**Response**
Alabama	Yes
Alaska	No
Arizona	
Arkansas	
California	Not sure at this moment
Colorado	Yes
Connecticut	Yes
Delaware	Yes
Florida	Not sure at this moment
Georgia	
Hawaii	Not sure at this moment
Idaho	Yes
Illinois	
Indiana	Yes
Iowa	Yes
Kansas	Yes
Kentucky	
Louisiana	Not sure at this moment
Maine	
Maryland	Yes
Massachusetts	Yes
Michigan	Yes
Minnesota	Yes
Mississippi	
Missouri	Yes
Montana	Yes

State	Response
Nebraska	No
Nevada	Yes
New Hampshire	Not sure at this moment
New Jersey	Yes
New Mexico	Not sure at this moment
New York	Yes
North Carolina	
North Dakota	Not sure at this moment
Ohio	Not sure at this moment
Oklahoma	Yes
Oregon	Yes
Pennsylvania	Yes
Rhode Island	
South Carolina	
South Dakota	Yes
Tennessee	Yes
Texas	Yes
Utah	Not sure at this moment
Vermont	Not sure at this moment
Virginia	Yes
Washington	Yes
West Virginia	
Wisconsin	Yes
Wyoming	