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A Case Study Approach to Understand Heavy Truck Safety-critical Events in Work Zones

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EXECUTIVE SUMMARY

Large trucks are overrepresented in work zone crashes. Data from the Federal Motor Carrier Safety Administration's Large Truck and Bus Crash Facts show that, in 2017, 30% of work zone fatal crashes and 12% of work zone injury crashes involved at least one large truck, which was more than double the percentage of all crashes that occurred outside of work zones, where 12% of fatal crashes and 5% of injury crashes involved at least one truck. This study used data from four major truck naturalistic driving studies to investigate the risk associated with a variety of work zone roadway, environmental, and safety features. The vast majority of the work zone observations occurred with no adverse weather conditions present, dry road conditions, straight roadway alignment, and light traffic, with roughly three-quarters of commercial motor vehicle (CMV) drivers wearing a seatbelt. The most common features observed in work zones were warning signs, barrel barriers, and lane closures, which were used in various combinations. Traffic cones were associated with an increase of safety-critical event (SCE) risk, likely as a result of their small size and being less visible to CMV drivers. Reflective signs, barrels, and concrete barriers, however, reduced the SCE risk for CMV drivers in work zones by 40%–60%. There was a small decrease in SCE risk associated with light traffic in a work zone compared to moderate and heavy traffic. There was also a nearly 3-times greater risk of a CMV driver being involved in an SCE in work zones on single-lane roadways versus four-lane roadways. Active work zones had nearly twice the SCE risk for CMV drivers compared to inactive work zones. In active work zones, non-driving-related distractions, internal distractions, and external distractions all resulted in an almost three-fold increase in SCE risk for CMV drivers. When planning smaller, more temporary work zones, it may be beneficial for worker and road user safety if planners employ larger, more visible safety barriers such as barrels and reflective signage.

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LIST OF ABBREVIATIONS AND SYMBOLS

CI	confidence interval
CMV	commercial motor vehicle
C/VIS	camera/video imaging system
DDWS FOT	Drowsy Driver Warning System Field Operational Test
DMS	dynamic messaging signs
DOT	Department of Transportation
FAST DASH	Federal Motor Carrier Safety Administration's Advanced System utilizing a Data Acquisition System on the Highways
FMCSA	Federal Motor Carrier Safety Administration
ND	naturalistic driving
NHTSA	National Highway Traffic Safety Administration
NTDS	Naturalistic Truck Driving Study
OR	odds ratio
SCE	safety-critical event

CHAPTER 1. INTRODUCTION

WORK ZONE INJURIES AND CRASHES

Roadwork has largely shifted from new construction to maintenance and rehabilitation since the completion of the interstate highway system. As traffic volumes on the nation's roadways continue to increase, it is not practical to close long stretches of roadways during periods of road maintenance and rehabilitation. This results in a significant increase in the number of work zones and the associated need to improve safety in and around these areas. It is widely recognized that highway work zones present increased risks to both highway users and workers. The National Highway Traffic Safety Administration (NHTSA) estimates that over 95,000 work zone crashes occurred in 2017, resulting in over 40,000 injuries and 754 fatalities. Unfortunately, these numbers are on the rise nationally, with a 30% increase in work zone crash fatalities since 2013.

Work zones are complicated driving environments that often present unexpected situations that differ from normal driving conditions. Hall and Lorenz (1989) found that crashes in work zones increased by 26% compared to the same area in the same period during the previous year when no construction was underway. Additionally, there is minimal consistency in the design and characteristics of work zones, including the types of traffic control devices used (e.g., signage, barriers), which may add to a driver's uncertainty of appropriate work zone driving actions and behavior (Antonucci et al., 2005). Studies found that the type of traffic control device used in work zones influences safety behaviors and crash rates (e.g., Garber & Woo, 1990; Pigman & Agent, 1990; Hill, 2003; Bai & Li, 2006; Carlson et al., 2000). For example, a combination of cones, flashing arrows, and flaggers on multilane highway work zones resulted in the fewest crashes, whereas flaggers were most effective in urban work zones (Garber & Woo, 1990). In rural high-speed work zones, fluorescent signage and worker vests, radar drones (i.e., devices used to make drivers with radar detectors think there is a police presence in the area), and speed display trailers were effective in reducing speed and improving worker and work zone visibility (Carlson et al., 2000).

A variety of driver, vehicle, road, and environmental factors may influence the occurrence and severity of work zone crashes. Driver factors include risky behaviors, such as engaging in distracting tasks, yielding to signage, and not wearing a seatbelt. Vehicle factors include speed and vehicle condition (i.e. quality of tires, brakes, etc.). Road factors include number of lanes, lane closure design, road alignment, and road type and condition. Environmental factors include light conditions, adequate and proper signage, safety cones and barriers, etc. Gaining a better understanding of these factors and how they interact to influence work zone crashes will inform countermeasures to improve work zone safety.

COMMERCIAL MOTOR VEHICLES AND WORK ZONE CRASHES

Work zones can create particularly challenging environments for drivers of large vehicles such as commercial motor vehicles (CMV). Truck characteristics, such as large blind spots, the extra length and width of the truck compared to a regular vehicle, and the increased distance required to stop, make lane closures and space restrictions typically associated with work zones difficult to maneuver safely. Statistics indicate that large trucks are overrepresented in work zone crashes, which likely results from both their physical and operational characteristics. The size, mass, and center of gravity characteristics of large trucks differ from those of smaller vehicles. The length and width of large trucks result in less lateral clearance and recovery area compared to other vehicles. The weight of large trucks increases the potential severity of a crash, and the higher center of gravity can affect vehicle handling characteristics (Work Zone Safety Consortium, 2016). The challenging operating characteristics of large trucks may further contribute to their higher crash involvement in work zones. Trucks have larger blind spots, which, in congested areas such as work zones, can amplify crash risk. Slower acceleration and deceleration compared to light vehicles also present challenges, creating stress for both truck and passenger vehicle drivers, which may manifest in aggressive driving behavior. Finally, line of sight differences between large trucks and passenger vehicles may make it difficult for truck drivers to detect, comprehend, and respond to retroreflective signs, channelizing devices, and pavement markings in low light conditions relative to what is visible to passenger vehicle drivers (Work Zone Safety Consortium, 2016).

Large Truck and Bus Crash Facts, released annually by the Federal Motor Carrier Safety Administration (FMCSA), compiles data from a variety of sources to present descriptive statistics about fatal, injury, and property-damage-only crashes involving large trucks and buses. As shown in Figure 1, in 2017, 30% of work zone fatal crashes and 12% of work zone injury crashes involved at least one large truck. That was more than double the percentage of all crashes that occurred outside of work zones (i.e., non-work zone crashes), where 12% of fatal crashes and 5% of injury crashes involved at least one truck. It is concerning that the fatal crash numbers have increased over the previous 3 years from 2015, when 27% of work zone fatal crashes involved at least one large truck (FMCSA, 2019). As these numbers indicate, not only are large trucks overrepresented in work zone crashes, but the problem of large truck involvement in work zone crashes is worsening (see Figure 1). According to the National Work Zone Safety Information Clearinghouse, there were approximately 18,000 truck-involved work zone crashes nationwide in 2017. This is a drastic increase from 2012, when there were approximately 10,000 work zone crashes involving at least one truck (https://www.workzonesafety.org/crash-information/work-zone-injuries-injury-property-damage-crashes/).

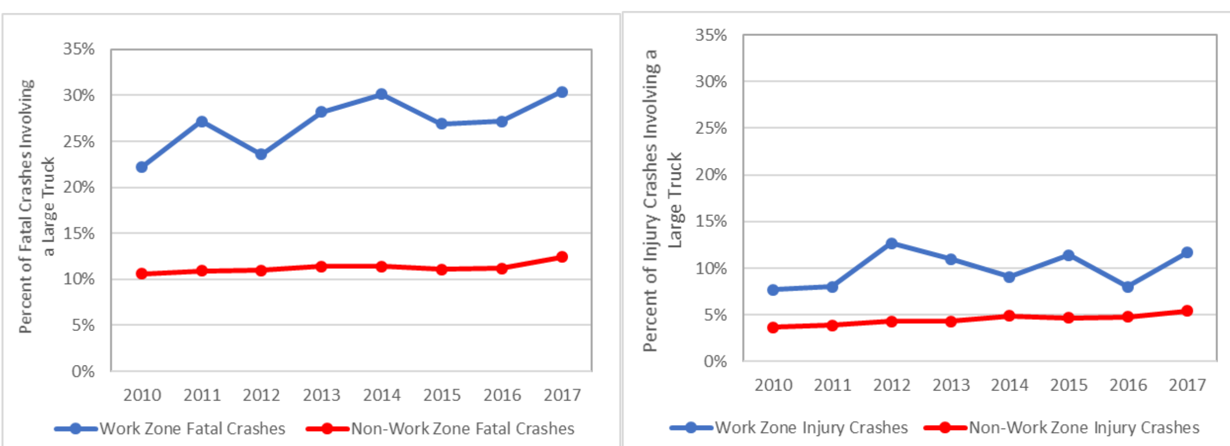

Figure 1. Graphs. Percentage of fatal and injury crashes involving at least one truck that occurred in work zones compared to non-work zones for the years 2010 to 2017.

Although large trucks are often used in work zones to deliver materials and equipment, 2010–2012 NHTSA Fatality Analysis Reporting System data shows that these delivery trucks, either parked or working inside work zones, contributed to only 3% of all fatal work zone crashes nationally (Work Zone Safety Consortium, 2016). The overwhelming majority of large trucks involved in work zone injury and fatality crashes are those that are driving through work zones as part of their route. Factors such as road type (e.g., two-lane highway vs. interstate), locality (e.g., urban vs. rural), time of day (e.g., daytime vs. nighttime), and day of the week (e.g., weekday vs. weekend), all impact the likelihood of a large truck being involved in a fatal work zone crash. Additionally, a number of these factors also influence the type of crashes large trucks are involved in. For instance, in work zones on two-lane highways, large trucks are overrepresented in rear-end collisions during daytime hours and head-on collisions during nighttime hours (Work Zone Safety Consortium, 2016).

WAYS TO IMPROVE LARGE TRUCK SAFETY IN WORK ZONES

An array of transportation-related entities are focusing on initiatives to reduce large truck crashes in work zones, including Federal agencies (e.g., FMCSA, Federal Highway Administration, NHTSA), state and local departments of transportation (DOTs), state highway safety offices, and trucking industry associations (e.g., American Trucking Associations). One area of focus to improve large truck safety in work zones is the implementation of targeted roadway infrastructure strategies. Redesigning work zone practices to better accommodate large trucks and to assist truck drivers in negotiating work zones would have positive safety benefits. One of the most important, and relatively simple, elements is maintaining good retroreflectivity on all signage, devices, and pavement markings. This helps truck drivers negotiate work zones safely, especially under low light conditions and in transition areas. A simple technique that may often be overlooked is regular cleaning and maintenance of signage and devices to remove dirt accumulation and maintain good retroreflectivity (Work Zone Safety Consortium, 2016).

In addition to infrastructure changes, influencing driver behavior is a crucial strategy to reduce work zone crash risks for large trucks. Outreach efforts to encourage truck drivers to practice safe driving behaviors are ongoing and supported by FMCSA's Our Roads, Our Safety partnership (2019). Shareable social media posts, graphics, and postcards include messages such as Stay Focused; Keep Your Distance; Merge Early; Protect Workers; Go Slow; Plan Ahead; and Add a Margin of Safety (see example in Figure 2). Additional outreach efforts, such as the Tips for Sharing the Road with CMVs website (www.cmvroadsharing.org), are aimed at drivers of passenger vehicles and cover key areas for sharing the road safely with trucks.

Figure 2. Illustration. Example of shareable outreach material.
(*www.fmcsa.dot.gov/ourroads/tips-traveling-safely-work-zones*)

Other efforts targeting specific routes or corridors that are impacted by roadwork may also be effective for reminding drivers of safe work zone practices. Dynamic message signs (DMS) have been shown to effectively influence driver behavior. Rahman and colleagues (2017) showed that while sign content and placement did not impact speed reduction and compliance in work zones, the refresh rate of DMS did have a significant effect on drivers' initial speed reduction approaching the work zone. In regard to speed reduction on approach to a work zone, DMS were also found to be most effective at night, rather than during the day (Rahman et al., 2017). Harder and colleagues (2017) used a simulator study followed by a field test evaluation to determine the effectiveness of roadway elements in capturing driver attention and fostering compliance in work zones. They found a combination of a speed trailer and horn barrel to be the most effective for reducing the speed of vehicles approaching a work zone (Harder et al., 2017).

Innovative technologies are also available to aid truck drivers in work zones. Intelligent Transportation System tools, such as a queue-warning system, give drivers real-time advanced warning of impending congestion. A portable changeable message sign displays the approximate distance to the traffic congestion to help drivers gauge their proximity to the areas impacted by work zones. Other examples of innovative technologies for work zone safety include dynamic lane merge systems, which are designed for use in work zones incorporating lane closures to facilitate smoother traffic flow near work zone bottlenecks. Reducing both the distance of congestion and drivers' queue-jumping behavior results in smoother merging behaviors and smoother and more efficient traffic movement. Variable speed limit systems dynamically manage traffic in a work zone based on real-time conditions, such as weather and congestion. Portable rumble strips are designed for temporary use and provide drivers with tactile, audible, and visual alerts on approach to lane closures. The effectiveness of technologies in reducing crashes in work zones is illustrated by a Texas DOT project to widen 96 miles of Interstate 35. The dangers of unexpected nighttime lane closures on a high-speed road heavily used by trucks were recognized and a hybrid queue warning system was implemented, comprising a queue detection and warning system, as well as portable rumble strips. The Texas DOT estimates the use of the system reduced crashes by up to 45%, with fewer rear-end collisions and severe crashes at work zones where the system was deployed compared to similar work zones not using the system (Work Zone Safety Consortium, 2015).

To measure the effectiveness of strategies for improving work zone safety, it is important to assess safety performance measures over time. Unfortunately, existing traffic safety databases have a number of limitations that prohibit the calculation of ideal rate-based performance measures. Using direct safety metrics, such as number of fatalities and injuries in work zone crashes, does not reflect differences in work zone exposure measures, such as number of work zones. For example, it can be difficult to discern whether an increase in work zone crashes is due to safety problems or simply a result of the overall increase in the amount of road work being conducted. A recent effort by the Virginia Transportation Research Council sought to address these challenges by combining two database sources to assess work zone safety performance: (1) the Virginia DOT crash database, which contains information from police crash reports and provides count measures, such as number of fatal work zone crashes; and (2) the Virginia Traffic Information Management System (VaTraffic), which contains information on work zones and was the source for exposure measures, such as work zone hours (Kweon et al., 2016). Combining the two datasets allowed researchers to come up with a rate measure, such as the number of fatal work zone crashes per 1,000 work zone hours. One of the study's more important findings was that including a measure of exposure was critical for accurately assessing safety performance. The authors also recommended using performance metrics, such as crashes per work zone-hour-mile and fatal and injury crashes per work zone-hour-mile, to evaluate safety performance (Kweon et al., 2016).

Naturalistic driving data provides researchers with a method to gain insight into the characteristics of work zones, roadways, vehicles, or environments that may be associated with a truck driver being involved in a safety-critical event (SCE). Continuous video and kinematic data pertaining to the vehicle itself, the driver of the vehicle, the location of the vehicle, and its surroundings provides a unique opportunity to achieve a better understanding of the circumstances and possible reasons for work zone crashes involving large trucks. While it is known that trucks are overrepresented in work zone crashes (i.e., when compared to light passenger vehicles), little is known about why these crashes occur. Understanding the circumstances surrounding truck-involved SCEs that occur in work zones will inform countermeasures and increase the safety of all road users, including road work crews.

CHAPTER 2. METHODS

APPROACH

This study is a secondary analysis of four major truck naturalistic data (ND) studies to identify SCEs and baseline events that occurred in work zones. Baseline events refer to periods of "normal" driving that are not characterized by the occurrence of an SCE. Work zones were identified in previously sampled and coded events (i.e., SCEs and baselines) from the following data sets.

OVERVIEW OF THE DATA SETS USED IN THE CURRENT STUDY

Drowsy Driver Warning System Field Operational Test (DDWS FOT)

The Drowsy Driver Warning System Field Operational Test (DDWS FOT) was the largest ND CMV study ever conducted by the U.S. Department of Transportation, with more than 12 terabytes of kinematic and video data collected. Data were collected for 18 months from 103 drivers of 46 instrumented trucks. The resulting database contains approximately 2.3 million miles traveled. See Blanco et al. (2009) for a complete description of the DDWS FOT.

Naturalistic Truck Driving Study (NTDS)

The Naturalistic Truck Driving Study (NTDS) was another ND truck study that collected more than 4 terabytes of kinematic and video data. The NTDS collected continuous driving data from 100 drivers of nine instrumented trucks, with each driver being observed for approximately 4 consecutive workweeks. The resulting database contains approximately 735,000 miles of driving data. See Blanco et al. (2011) for a complete description of the NTDS.

Field Demonstration of Heavy Vehicle Camera/Video Imaging Systems (C/VIS)

The Field Demonstration of Heavy Vehicle Camera/Video Imaging Systems (C/VIS) study was conducted to evaluate the benefits and disbenefits of implementing C/VISs in real-world trucking operations. A total of 3.62 terabytes of data were collected over a 12-month period from 12 CMV drivers of six instrumented trucks, with each driver being observed for 4 months. The resulting database contains approximately 278,000 miles of driving data. See Fitch et al. (2011) for a complete description of the C/VIS study.

FMCSA's Advanced System Utilizing a Data Acquisition System on the Highways (FAST DASH)

The purpose of the FMCSA's Advanced System utilizing a Data Acquisition System on the Highways (FAST DASH) study was to evaluate safety technologies aimed at improving CMV operations. Data from Phase I were collected over an 11-month period from 21 drivers of 20 instrumented trucks, with each driver being observed for 6 months. The resulting database contains approximately 722,000 miles of driving data. See Schaudt et al. (2014) for a complete description of FAST DASH.

DATA SET FORMATTING

Prior to any analyses, the data were formatted and merged into one data set, which comprised different types of SCEs, defined as follows:

- *Crash:* Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off the roadway, pedestrians, cyclists, or animals.
- *Near-Crash:* Any circumstance requiring a rapid, evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal, to avoid a crash, or any circumstance that results in extraordinarily close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrian(s), cyclist(s), or animal(s), there is no avoidance maneuver or response. A rapid evasive maneuver is defined as steering, braking, accelerating, or any other combination of control inputs that approaches the limits of the vehicle's capabilities.
- *Crash-Relevant Conflict:* Any circumstance that requires a crash-avoidance response on the part of the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal, that is less severe than a rapid evasive maneuver (as defined above) but greater in severity than a "normal maneuver" to avoid a crash, or any circumstance that results in close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrian(s), cyclist(s), or animal(s), there is no avoidance maneuver or response. A crash-avoidance response can include braking, steering, accelerating, or any combination of control inputs.

Given that the data were compiled from multiple studies, a number of variables needed to be recoded in order to be consistent. Additionally, coding options on a number of variables were combined for the purpose of analysis. Table 1 lists the existing variables compiled in the final data set, the coding options for each variable, and a short description of the variable.

Table 1. Recoded variables from existing truck ND studies.

Variable	Coding Options	Definition
SCE vs. Baseline	SCE	Was the event an SCE or baseline?
	Baseline	
Event Severity	Crash	Outcome of each event
	Near-crash	
	Crash-relevant conflict	
Safety Belt	Yes	Safety belt worn?
	No	
Light Condition	Daylight	Combined to indicate if the event occurred during daylight or low light conditions
	Dark/dawn/dusk	
Weather	No adverse conditions	Weather at the time of the event
	Rain	
	Fog	
Roadway Surface	Dry	Surface condition at the time of the event
	Wet	
Number of Lanes	1 – 6	Total number of travel lanes
Roadway Alignment	Straight	Combined to indicate if the event occurred on a straight or curved road
	Curve	
Traffic Density	Light traffic	Free flow traffic vs. stable flow/restricted maneuverability/high density traffic
	Moderate/heavy traffic	
Distracted	No distraction	Eyes on the forward roadway
	Driving-related distraction	Eyes off the roadway for driving-related task; e.g., check mirrors
	External distraction	Looking at something outside the vehicle
	Internal distraction	Distracted by something in the vehicle; e.g., talking on phone

DATA REDUCTION

The data reduction used in the four existing data sets was leveraged in the current study to compare and contrast driver, road, environmental, and work zone variables in the SCEs with the baseline events. Driver factors include safety behaviors, such as seatbelt use and distraction; road variables include alignment and number of lanes; and environmental factors include light condition and weather.

In addition to the existing variables of interest, data reduction was conducted to acquire the necessary information specific to the aims of the current study. More in-depth information was required to evaluate the characteristics of the work zone. Data analysts went back to the original video data from each of the existing truck-based ND studies, selected the event of interest using the required data reduction tool (i.e., DART or Hawkeye), and coded the new variables of interest. Table 2 lists the new work-zone-related variables, the coding options for each variable, and a short explanation of each. The data reduction protocol can be found in Appendix A. The existing and new data reduction variables were used to compare and contrast the driver, road, environment, and work zone variables in the SCEs with the baseline events.

Table 2. New work zone-related variables.

Variable	Coding Options	Definition
Warning Sign	Yes	Was there any work zone warning signage?
	No	
Reflective Signage	Yes	Was there reflective signage?
	No	
Portable Dynamic Signage	Yes	Was there portable dynamic signage?
	No	
Barrier Type	Cones	What barrier types are in use?
	Barrels	
	Plastic Barrier	
	Concrete Jersey Barrier	
	Other: Describe	
Active Work	Yes	Is the work zone active?
	No	
Lane Closure	Yes	Are there any lanes closed in the work zone?
	No	

DATA ANALYSIS

ND epochs that included observed work zones were investigated for presence of various work zone, roadway, and environmental features. The coding approach for observed work zone features covered the entire work zone from start to finish (i.e., from the first identifiable work zone feature to the final one). Work zone features included presence of reflective signage, portable dynamic signage, or warning signs; type of barriers observed, such as cones, barrels, plastic, and/or concrete barriers; and the use of lane closures. The frequency of multiple features in one work zone was also examined, with percentage of observations calculated as the count of work zone observations with feature combinations over total number of work zone observations in the data.

Work zones observations were also evaluated for roadway and environmental conditions. These variables included weather, light conditions, roadway alignment, roadway surface conditions, traffic density, and number of lanes in roadway. In addition, driver seatbelt use was noted during work zone observations. Work zones were deemed active or inactive by reductionists using cues from the video, such as visible workers and/or machinery in use. The descriptive analysis presents the frequency counts of active and inactive work zones in the data.

Chi-squared tests of independence were used to assess the association between work-zone-related variables. The test compares two variables using a contingency table like that shown in Figure 3.

		Variable B	
		Level 1	***Level 2***
Variable A	***Level 1***	O_{11}	O_{12}
	Level 2	O_{21}	O_{22}

Figure 3. Contingency table. Frequency counts for two work zone-related variables.

The chi-squared test statistic is calculated as:

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij}-E_{ij})^2}{Eij}$$

where r is the row number in the contingency table, c is the column number in the table, O_{ij} is the observed frequency count for row i and column j, and E_{ij} is the expected frequency count for row i and column j. The expected frequency for a contingency table cell is calculated as:

$$E_{ij} = [(\text{total sum for } i^{th} \text{ row})(\text{total sum for } j^{th} \text{ column})] / [\text{total sum for table}]$$

Degrees of freedom must be determined to calculate the p-value of the chi-square test statistic. The number of degrees of freedom for the table is calculated as:

$$df = (R-1)(C-1)$$

where R is the total number of rows and C is the total number of columns in the contingency table. If the test is statistically significant, there is a significant relationship between the two variables being compared.

RISK OF SCE INVOLVEMENT IN WORK ZONES

The risk of SCE involvement when driving in a work zone was assessed separately by determining the presence of work zone features and between levels of roadway and environmental variables. Distraction during work zone driving and the risk of distraction were also analyzed. Since the data set only included observations in work zones, the risk analyses evaluated if risk while driving in a work zone significantly differed for certain variable levels and did not measure how risk while driving in a work zone compared to non-work zone driving.

Risk analyses were performed using an odds ratio (OR) calculation with confidence interval, CI. The OR is calculated as:

OR = (SCE Odds for Variable Level 1) / (SCE Odds for Variable Level 2)

Using the example contingency table structure illustrated below, the OR value comparing one variable level to another was calculated as:

OR = (A/C) / (B/D)

where the values A, B, C, and D are the frequency counts from a contingency table like the following in Figure 4:

<table>
<tr><td colspan="2"></td><td colspan="2">Variable of Interest</td></tr>
<tr><td colspan="2"></td><td>Variable Level 1</td><td>Variable Level 2</td></tr>
<tr><td rowspan="2">Work Zone Event Type</td><td>SCEs</td><td>A</td><td>C</td></tr>
<tr><td>BLs</td><td>B</td><td>D</td></tr>
</table>

Figure 4. Contingency table. Frequency counts by work zone event type (SCE or baseline) and variable of interest (variable levels 1 and 2).

The variable of interest could vary. For example, in the analysis of work zone features, the variable of interest might have been the presence of a work zone feature. Level 1 in the contingency table could mean that the work zone feature was present in the observation, while Level 2 could mean that the work zone feature was not present in the observation. In the analysis of environmental conditions, an example variable of interest would be traffic density in the work zone. In this example, Level 1 would be light traffic density and Level 2 would be moderate/heavy traffic density. In comparing work zone status, active work zone would be Level 1 and inactive work zone would be Level 2. ORs were also used to measure the risk of distraction in work zone observations by certain work zone features.

CHAPTER 3. RESULTS

DESCRIPTIVES

Combining the four truck NDSs resulted in a total of 466 SCEs and baselines that occurred in a work zone. The following section includes frequency counts of work zone observations by work zone features, combinations of features, roadway and environmental conditions, and event types. These tables were used to guide the risk analysis.

Work Zone Features

Work zone features included in the analyses are highlighted in Figure 5, which shows the percentage of observations with the work zone feature present among all work zones. Work zones could have more than one feature present, resulting in a total of 1,769 work zone features observed among 457 unique work zones. More than two-thirds of work zone observations had a warning sign present or lane closures associated with the work zone. The most commonly observed barrier type was the barrel, which was present in over 80% of work zones, followed by concrete barriers in over half of the work zones, then cones in approximately 20%, and a very small number of work zones with plastic barriers. Reflective signage was observed in nearly 50% of work zones and portable dynamic signage was observed in just over 45% of work zones. The plastic barrier work zone feature was excluded from additional analysis due to low counts.

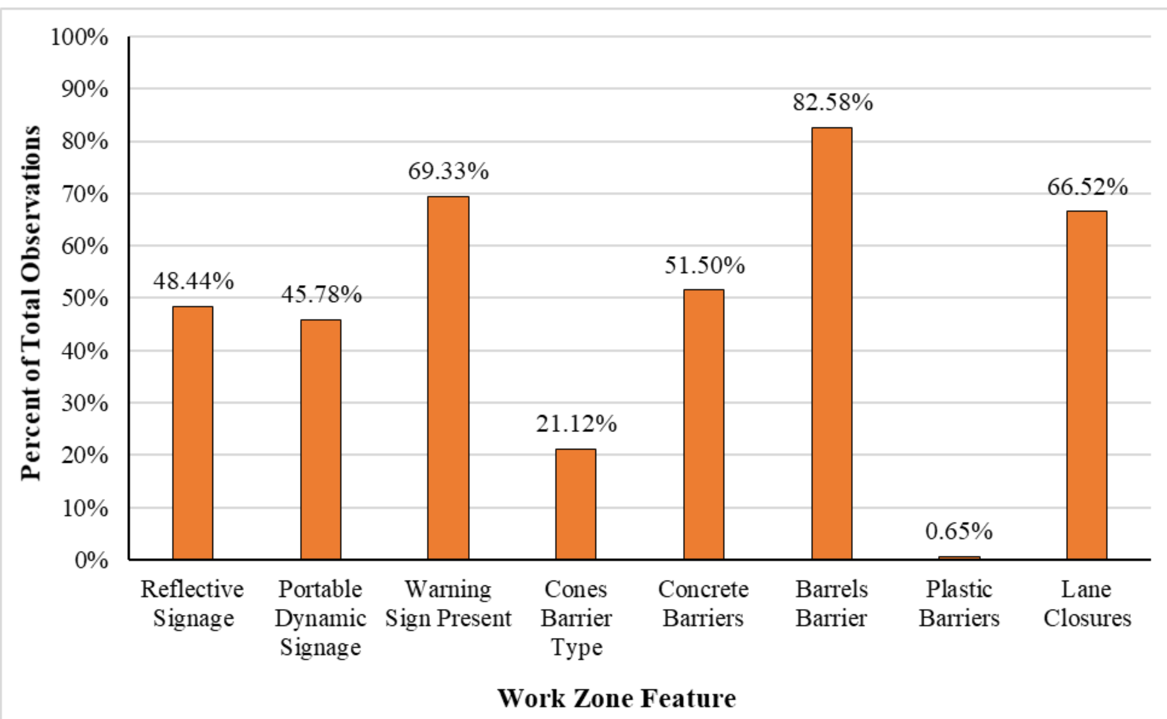

Figure 5. Graph. Percent of observations with work zone features present.

The number of work zone features in a single work zone ranged from one feature to seven features. Table 3 includes the counts of ND observations by number of work zone features.

Approximately one quarter of all work zone observations had five of the work zone features, followed by slightly less than 20% with four work zone features present.

Table 3. Number of work zone features in each observation.

Number of Work Zone Features	Number of Observations	Percent of Total Observations
1 Feature	48	10.50%
2 Features	76	16.64%
3 Features	51	11.16%
4 Features	85	18.60%
5 Features	123	26.91%
6 Features	60	13.13%
7 Features	14	3.06%
Total	**457**	**100.00%**

Table 4 shows the frequency of combined work zone features, with combinations shown in descending order of frequency counts. The most common combinations included warning signs and barrels, which were both present in nearly 60% of work zone observations. Similarly, lane closures and barrels were both present in 57% of observations, followed closely by lane closures with warning signs found in 55% of observations. The least frequent work zone feature combination was traffic cones and concrete barriers, which may be due to the nature of the barriers themselves (i.e., traffic cones are temporary whereas concrete barriers are presumably more long term).

Table 4. Frequency of work zone feature combinations, in descending order by number of observations.

Work Zone Feature 1	Work Zone Feature 2	Frequency of Both Features Present	Percent of Total Observations
Barrels Barrier Type	Warning Sign Present	261	58.13%
Barrels Barrier Type	Lane Closures	265	57.24%
Warning Sign Present	Lane Closures	249	55.58%
Concrete Barrier Type	Barrels Barrier Type	217	46.67%
Reflective Sign Present	Barrels Barrier Type	187	41.65%
Portable Dynamic Signage	Lane Closures	180	40.18%
Reflective Sign Present	Lane Closures	171	38.17%
Warning Sign Present	Concrete Barrier Type	171	38.00%

Work Zone Feature 1	Work Zone Feature 2	Frequency of Both Features Present	Percent of Total Observations
Portable Dynamic Signage	Barrels Barrier Type	168	37.42%
Concrete Barrier Type	Lane Closures	162	34.99%
Reflective Sign Present	Concrete Barrier Type	131	29.11%
Portable Dynamic Signage	Concrete Barrier Type	100	22.22%
Warning Sign Present	Cones Barrier Type	78	17.41%
Cones Barrier Type	Lane Closures	79	17.10%
Portable Dynamic Signage	Cones Barrier Type	58	12.95%
Cones Barrier Type	Barrels Barrier Type	55	11.85%
Reflective Sign Present	Cones Barrier Type	53	11.83%
Cones Barrier Type	Concrete Barrier Type	42	9.05%

Roadway and Environmental Conditions in Work Zones

The work zone observations were also reduced for several roadway and environmental conditions. The roadway and environmental conditions, with observation frequency, are presented in Table 5. Drivers were observed wearing their safety belt in just over 70% of work zone observations. Roughly 90% of work zone observations occurred with no adverse weather conditions present, dry road conditions, straight roadway alignment, and light traffic. The work zone observations were split almost evenly between daylight and dark/dawn/dusk light conditions. The majority of work zone observations occurred on two-lane roads (45%), followed by single-lane roads (28%), three-lane roads (20%), and four- or five-lane roads (6%).

Table 5. Roadway and environmental conditions observed in work zones.

Condition in Work Zone	Levels	Number of Work Zone Observations with Condition Level Present (% of Total)
Safety Belt	Yes	332 (71.24%)
	No	134 (28.76%)
Weather	No adverse conditions	430 (92.27%)
	Fog	4 (0.86%)
	Rain	32 (6.87%)
Light Condition	Daylight	250 (53.65%)

Condition in Work Zone	Levels	Number of Work Zone Observations with Condition Level Present (% of Total)
	Dark/Dawn/Dusk	216 (46.35%)
Roadway Surface Condition	Dry	424 (90.99%)
	Wet	42 (9.01%)
Number of Lanes	1	133 (28.54%)
	2	210 (45.06%)
	3	92 (19.74%)
	4	27 (5.79%)
	5	4 (0.86%)
Roadway Alignment	Curve	58 (12.45%)
	Straight	408 (87.55%)
Traffic Density	Light	425 (91.20%)
	Moderate/Heavy	41 (8.80%)

Roadway characteristics, such as straight or curved roadway alignment, play a role in the type of safety features used in a work zone. Table 6 lists the observation counts of work zone features in curved and straight roadway alignments. Warning signs were observed at higher proportions on curved roadways than on straight roads, with warning signs present in nearly 75% of observations, reflective signs in just under 60%, and portable dynamic signage in roughly 45% of observations (compared to 68%, 47%, and 45%, respectively). Cones were used similarly in just over 20% of work zones on both curved and straight roadway alignments. In curved roadways, concrete barriers were used in approximately 67% of work zone observations and barrels were used in nearly 90% of observations. This dropped to roughly half with concrete barriers and 80% with barrel barriers in work zones on straight roadways. Additionally, lane closures were observed less frequently in work zones on curved roadways compared to straight alignment (55% and 68% of observations, respectively).

Table 6. Observations of roadway alignment by presence of work zone features.

Work Zone Feature	Counts of Curve Alignment with Work Zone Feature Present (% of Curve)	Counts of Straight Alignment Condition with Work Zone Feature Present (% of Straight)
Warning Sign Present	40 (74.07%)	272 (68.69%)
Reflective Sign Present	31 (57.41%)	187 (47.22%)
Portable Dynamic Signage	25 (46.30%)	181 (45.71%)

Work Zone Feature	Counts of Curve Alignment with Work Zone Feature Present (% of Curve)	Counts of Straight Alignment Condition with Work Zone Feature Present (% of Straight)
Cones Barrier Type	12 (20.69%)	86 (21.18%)
Concrete Barrier Type	39 (67.24%)	201 (49.26%)
Barrels Barrier Type	51 (87.93%)	333 (81.82%)
Lane Closures	32 (55.17%)	276 (68.15%)

In addition to roadway alignment, number of lanes is another roadway characteristic that impacts the safety features used in a work zone. Table 7 shows the proportion of work zone features in number of traffic lanes, from one to five lanes. Warning signs, reflective signs, portable dynamic signs, barrels, and lane closures were observed more frequently in work zones on roadways with one traffic lane, compared to work zones on roadways with two or more traffic lanes. Cones and concrete barriers were used more frequently in work zones on roadways with four lanes compared to roads with all other numbers of lanes.

Table 7. Observations of numbers of traffic lanes by presence of work zone features.

Work Zone Feature	Counts of One Lane with Work Zone Feature Present (% of One Lane)	Counts of Two Lanes with Work Zone Feature Present (% of Two Lane)	Counts of Three Lanes with Work Zone Feature Present (% of Three Lane)	Counts of Four Lanes with Work Zone Feature Present (% of Four Lane)
Warning Sign Present	115 (88.46%)	133 (66.17%)	45 (50.56%)	16 (61.54%)
Reflective Sign Present	71 (54.62%)	99 (49.25%)	33 (37.08%)	14 (53.85%)
Portable Dynamic Signage	91 (70.00%)	77 (38.31%)	26 (29.21%)	10 (38.46%)
Cones Barrier Type	32 (24.24%)	42 (20.10%)	14 (15.22%)	9 (33.33%)
Concrete Barrier Type	57 (42.86%)	115 (54.76%)	51 (55.43%)	16 (59.26%)
Barrels Barrier Type	112 (84.85%)	171 (81.43%)	78 (84.78%)	21 (77.78%)
Lane Closures	120 (90.91%)	115 (55.02%)	51 (56.04%)	19 (70.37%)

Active and Inactive Work Zones

Work zones were classified as active or inactive based on the level of activity, or lack thereof, during the video observation. These data included 167 active work zones and 260 inactive work zones. Table 8 shows the work zone feature counts in active and inactive work zones. Chi-square tests of independence were used to test if a significant relationship existed between work zone status and presence of a work zone feature. Active work zones showed higher use of warning signs ($\chi^2 = 31.76$, $p < 0.0001$), reflective signage ($\chi^2 = 9.29$, $p = 0.0023$), and/or portable dynamic signage ($\chi^2 = 48.36$, $p < 0.0001$). Active work zones also showed higher use of cones as a barrier type ($\chi^2 = 58.99$, $p < 0.0001$), and lane closures were observed more frequently in active compared to inactive work zones ($\chi^2 = 48.67$, $p < 0.0001$). Concrete barriers and barrels were more common in inactive work zones ($\chi^2 = 10.18$, $p = 0.0014$; $\chi^2 = 8.59$, $p = 0.0034$, respectively) compared to active work zones; however, since these types of safety features are deployed for longer duration and larger work zones, there is much more opportunity for observation of inactive periods in these work zones.

Table 8. Work zone features in active and inactive work zones comparing feature presence by work zone status.

Work Zone Feature	Active Work Zone Frequency (% of Active Obs.)	Inactive Work Zone Frequency (% of Inactive Obs.)	χ^2 Statistic	*p*-value
Reflective Signage	95 (57.93%)	107 (42.63%)	9.29*	0.0023
Portable Dynamic Signage	110 (67.07%)	81 (32.27%)	48.36*	<.0001
Warning Sign Present	129 (84.76%)	147 (58.57%)	31.76*	<.0001
Cones Barrier Type	68 (40.72%)	24 (9.30%)	58.99*	<.0001
Concrete Barriers	68 (40.72%)	147 (56.54%)	10.18*	0.0014
Barrels Barrier	125 (74.85%)	223 (86.10%)	8.59*	0.0034
Lane Closures	144 (86.23%)	23 (13.77%)	48.67*	<.0001

** denotes significant finding*

DRIVER SAFETY AND WORK ZONES

The data set included 359 baselines and 107 SCEs. Table 9 shows the breakdown of SCEs and baselines by event classification.

Table 9. SCE and baseline frequency counts in work zone data set.

Event Classification	Frequency	Percent of All Observations
SCEs (all)	**107**	**22.96%**
Crash	4	0.86%
Near-Crash	16	3.43%
Crash-Relevant Conflict	87	18.67%
Baselines	**359**	**77.04%**
Total	**466**	**100.00%**

Safety Risk of Work Zone Features

The safety risk of each work zone feature was tested by calculating the number of SCEs and baselines observed when that particular feature was present and when it was not present. The data were compared using OR tests and 95% CIs. As shown in Table 10, the presence of cones in a work zone was associated with an increased risk (OR = 4.99) of being involved in an SCE. Use of reflective signage in a work zone was associated with a decrease in SCE risk (OR = 0.53), as was the use of barrel and concrete barrier types (OR = 0.43 and 0.64, respectively). Since the barrel and concrete barrier types were found to be strongly associated with an inactive work zone, these findings may be confounded with work zone status-associated risk (i.e., active vs. inactive) and care must be taken when interpreting these results.

Table 10. SCE risk associated with work zone features.

Work Zone Feature	SCE Count (% SCEs)	Baseline Count (% Baselines)	OR	95% CI
Warning Signs (Yes)	68 (65.38%)	244 (70.52%)	0.79	(0.50, 1.26)
Reflective Signage (Yes)	38 (36.54%)	180 (52.02%)	0.53*	(0.34, 0.83)
Portable Dynamic Signage (Yes)	48 (46.15%)	158 (45.66%)	1.02	(0.66, 1.58)
Barrier Type Cones (Yes)	48 (44.86%)	50 (14.01%)	5.00*	(3.08, 8.11)
Barrier Type Barrels (Yes)	77 (71.96%)	307 (85.75%)	0.43*	(0.25, 0.71)
Barrier Type Concrete (Yes)	46 (42.99%)	194 (54.04%)	0.64*	(0.42, 0.99)
Lane Closures (Yes)	74 (69.16%)	234 (65.73%)	1.17	(0.73, 1.86)

** denotes significant finding*

Additional analyses were performed to assess the safety risk of work zone features in active work zones only. As shown in Table 11, in active work zones, cones were again associated with an increased risk of being involved in an SCE (OR = 5.19). No other work zone features showed an association with risk in active work zones.

Table 11. Risk of work zone features in active work zones.

Work Zone Feature	SCE Count (% SCEs)	Baseline Count (% Baselines)	OR	95% CI
Warning Signs	40 (81.63%)	99 (86.09%)	0.72	(0.29, 1.76)
Reflective Signage	26 (53.06%)	69 (60.00%)	0.75	(0.38, 1.48)
Portable Dynamic Signage	28 (57.14%)	82 (71.30%)	0.54	(0.27, 1.08)
Barrier Type Cones	34 (68.00%)	34 (29.06%)	5.19*	(2.54, 10.61)

Work Zone Feature	SCE Count (% SCEs)	Baseline Count (% Baselines)	OR	95% CI
Barrier Type Barrels	34 (68.00%)	91 (77.78%)	0.61	(0.29, 1.27)
Barrier Type Concrete	20 (40.00%)	48 (41.03%)	0.96	(0.49, 1.88)
Lane Closures	46 (92.00%)	98 (83.76%)	2.23	(0.72, 6.93)

** denotes significant finding*

In Table 12, the OR and 95% CI are shown for combinations of two work zone features in active work zones. Increased risk of an SCE in active work zones was observed for work zones combining cone barriers with reflective signage (OR = 4.81), portable dynamic signage (OR = 5.38), warning signage (OR = 4.35), and concrete barriers (OR = 6.25). However, when cone and barrel barriers were observed together in active work zones, there was no increased risk of an SCE, OR = 1.62, CI = (0.62, 4.24). The use of reflective signage and portable dynamic signage together in an active work zone was associated with decreased risk of an SCE (OR = 0.38).

Table 12. Safety risk of work zone feature combinations in active work zones.

Work Zone Feature #1	Work Zone Feature #2	OR	95% CI
Reflective Signage	Concrete Barriers	1.43	(0.58, 3.54)
Reflective Signage	Cones	4.81*	(1.81, 12.74)
Reflective Signage	Barrels	0.77	(0.26, 2.31)
Reflective Signage	Portable Dynamic Signage	0.38*	(0.15, 0.98)
Reflective Signage	Lane Closures	0.74	(0.13, 4.30)
Portable Dynamic Signage	Concrete Barriers	0.87	(0.36, 2.12)
Portable Dynamic Signage	Cones	5.38*	(2.10, 13.82)
Portable Dynamic Signage	Barrels	0.51	(0.20, 1.29)
Portable Dynamic Signage	Lane Closures	1.08†	(1.02, 1.15)
Warning Signage	Concrete Barriers	1.00	(0.48, 2.11)
Warning Signage	Cones	4.35*	(1.98, 9.53)
Warning Signage	Barrels	0.56	(0.25, 1.27)
Warning Signage	Lane Closures	1.10	(0.39, 9.21)
Concrete Barriers	Cones	6.25*	(2.00, 19.51)
Concrete Barriers	Barrels	0.38	(0.07, 2.06)
Concrete Barriers	Lane Closures	1.29	(0.24, 7.00)

Work Zone Feature #1	Work Zone Feature #2	OR	95% CI
Cones	Barrels	1.62	(0.62, 4.24)
Cones	Lane Closures	2.76	(0.5, 15.33)
Barrels	Lane Closures	1.14	(0.34, 3.81)

** denotes significant finding*
† denotes calculation of risk ratio in place of OR

Safety Risk of Roadway and Environmental Conditions in Work Zones

The risk of SCEs was calculated for each of the different roadway and environmental conditions. This analysis provides insight into how risk changes depending on levels of roadway and environmental conditions using a sample of work-zone-only observations. By using events from work zones, the results can be compared to other studies with different samples to understand how risk of a roadway or environmental condition might be different in work zones.

In Table 13, the number of SCEs and baselines were calculated for each roadway and environmental condition and corresponding condition level. Seatbelts were observed in use in almost two-thirds of SCEs and three-quarters of baselines. Just over two-thirds of SCEs occurred in light traffic, and the remaining third occurred in moderate or heavy traffic. The proportion of baselines that occurred in light traffic was close to 98%, with the remaining 2% occurring in moderate or heavy traffic. The counts and proportions for weather, light condition, roadway surface condition, and number of lanes are listed in Table 13.

Table 13. Work zone SCE and baseline counts in various roadway and environmental conditions.

Environmental Conditions	Level	Number of SCEs (% of SCE Total)	Number of Baselines (% of Baseline Total)
Seatbelt Usage	Yes	69 (64.49%)	263 (73.26%)
	No	38 (35.51%)	96 (26.74%)
Weather	Fog/Rain	6 (5.61%)	30 (8.36%)
	No adverse conditions	101 (94.39%)	329 (91.64%)
Light Condition	Daylight	77 (71.96%)	173 (48.19%)
	Dark/dawn/dusk	30 (28.04%)	186 (51.81%)
Roadway Surface Condition	Dry	101 (94.39%)	323 (89.97%)
	Wet	6 (5.61%)	36 (10.03%)
Number of Lanes	1 Lane	23 (21.50%)	110 (30.64%)

Environmental Conditions	Level	Number of SCEs (% of SCE Total)	Number of Baselines (% of Baseline Total)
	2 Lanes	50 (46.73%)	160 (44.57%)
	3 Lanes	21 (19.63%)	71 (19.78%)
	4 Lanes	10 (9.35%)	17 (4.74%)
	5 Lanes	3 (2.80%)	1 (0.28%)
Roadway Alignment	Curve	14 (13.08%)	44 (12.26%)
	Straight	93 (86.92%)	315 (87.74%)
Traffic Density	Light Traffic	74 (69.16%)	351 (97.77%)
	Moderate/Heavy Traffic	33 (30.84%)	8 (2.23%)

Table 14 lists the ORs and 95% CIs for safety risk comparisons by roadway and environmental condition. Daylight work zone observations were associated with greater risk of an SCE when compared to dark/dawn/dusk work zone observations (OR = 2.76, CI = [1.73, 4.42]). Work zone observations occurring on a single-lane roadway showed greater risk compared to work zone observations of four-lane roadways (OR = 2.81, CI = [1.14, 6.93]) and five-lane roadways (OR = 14.35, CI = [1.43, 144.16]). Work zone observations from roadways with three lanes were associated with greater risk when compared to work zones on roadways with five lanes, although the CI is very wide due to low counts of five-lane work zone observations (OR = 10.14, CI = [1.00, 102.69]). A lower safety risk was observed in work zones with light traffic density when compared to moderate or heavy traffic density (OR = 0.05, CI = [0.02, 0.12]). All other comparisons showed no significant differences.

Table 14. ORs and 95% CIs for risk of SCE across different levels of roadway and environmental conditions.

Environmental Condition Comparison	OR	95% CI
Seatbelt Usage (Yes vs. No)	0.66	(0.42, 1.05)
Weather (Fog/Rain vs. No adverse)	0.65	(0.26, 1.61)
Light Condition (Daylight vs. Dark/dawn/dusk)	2.76*	(1.73, 4.42)
Roadway Surface Condition (Dry vs. Wet)	1.88	(0.77, 4.58)
Number of Lanes: 1 vs. 2 Lanes	1.50	(0.86, 2.59)
Number of Lanes: 1 vs. 3 Lanes	1.42	(0.73, 2.74)
Number of Lanes: 1 vs. 4 Lanes	2.81*	(1.14, 6.93)

Environmental Condition Comparison	OR	95% CI
Number of Lanes: 1 vs. 5 Lanes	14.35*	(1.43, 144.16)
Number of Lanes: 2 vs. 3 Lanes	0.95	(0.53, 1.69)
Number of Lanes: 2 vs. 4 Lanes	1.88	(0.81, 4.37)
Number of Lanes: 2 vs. 5 Lanes	9.60	(0.98, 94.36)
Number of Lanes: 3 vs. 4 Lanes	1.99	(0.79, 4.99)
Number of Lanes: 3 vs. 5 Lanes	10.14*	(1.00, 102.69)
Number of Lanes: 4 vs. 5 Lanes	5.10	(0.47, 55.89)
Roadway Alignment (Curve vs. Straight)	1.08	(0.57, 2.05)
Traffic Density (Light vs. Moderate/Heavy)	0.05*	(0.02, 0.12)

** denotes significant finding*

Safety Risk and Work Zone Status

Table 15 shows the counts of SCEs and baselines in active and inactive work zones. These data included 50 SCEs and 117 baselines in active work zones. Inactive work zone data included 48 SCEs and 212 baselines. Active work zones were associated with a 1.89 times higher risk of involvement in an SCE than inactive work zones (OR = 1.89, 95% CI = [1.20, 2.98]).

Table 15. SCEs and baselines in active and inactive work zones.

Work Zone Status	SCE Frequency Count	Baseline Frequency Count
Active	50 (51.02%)	117 (35.56%)
Not Active	48 (48.98%)	212 (64.44%)

DISTRACTION AND WORK ZONE FEATURES

Work zone observations were also reduced and analyzed for driver distraction. Driver distraction types included (1) driving-related distraction, where the driver has their eyes off the forward roadway for a driving-related task (e.g., checking mirrors); (2) external distraction, where the driver has their eyes off the forward roadway and is looking at something outside the vehicle; and (3) internal distraction, where the driver is distracted by something in the vehicle (e.g., talking on a cell phone). Internal and external distractions are subsets of non-driving-related distractions and electronic device distractions are a subset of internal distractions. Distraction types are not mutually exclusive and each work zone observation could comprise multiple distractions (e.g., checking mirrors while talking on a hands-free cell phone). The frequency counts for the distraction types are listed in Table 16. The data set included 163 work zone observations with driving-related distractions, 229 observations with non-driving-related distractions, 161 observations with internal distractions, and 97 observations with external distractions. Electronic device distraction, which included talking or listening to handheld phones, hands-free phones, or CB microphones, was present in 50 work zone observations (i.e., 25 observations of handheld devices and 25 observations of hands-free devices).

Table 16. Frequency counts and percentage of driver distraction types in work zone observations.

Distraction Type	Number of Events with Distraction Type	Proportion of Events with Distraction Type
No distraction	120	28.30%
Driving-related distraction	163	34.98%
Non-driving-related distraction	229	49.14%
Internal distraction	161	34.55%
External distraction	97	20.82%
Electronic device distraction	50	10.73%
Handheld electronic device	*25*	*5.36%*
Hands-free electronic device	*25*	*5.36%*

Table 17 provides a breakdown of event classification frequency and proportion by distraction type. No distraction was observed in nearly a quarter of SCEs and just over a quarter of baselines. Non-driving-related distractions were observed in a higher proportion of baselines than SCEs (49% vs. 41%, respectively), while the opposite was true for driving-related distractions, which were observed in higher proportions of SCEs than baselines (44% vs. 35%, respectively). Internal distractions were observed slightly more in SCEs than baselines, and external distractions were roughly the same in SCEs and baselines. Finally, SCEs had a higher proportion of electronic device distractions compared to baselines (14% vs. 11%, respectively).

Table 17. Frequency counts and percentage of driver distraction types in SCEs and baselines.

Distraction Type (Not mutually exclusive)	Number of SCEs with Distraction Type	SCE Proportion of Distraction Type	Number of Baselines with Distraction Type	Baseline Proportion of Distraction Type
No distraction	24	22.43%	96	28.30%
Driving-related distraction	47	43.93%	116	34.98%
Non-driving-related distraction	44	41.12%	185	49.14%
Internal distraction	41	38.32%	120	34.55%
External distraction	21	19.63%	76	20.82%

Distraction Type (Not mutually exclusive)	Number of SCEs with Distraction Type	SCE Proportion of Distraction Type	Number of Baselines with Distraction Type	Baseline Proportion of Distraction Type
Electronic device distraction	15	14.02%	35	10.73%
Handheld electronic device	*9*	*36.00%*	*16*	*64.00%*
Hands-free electronic device	*6*	*24.00%*	*19*	*76.00%*

The safety risk associated with each distraction type in work zone observations was evaluated using ORs and 95% CIs. As shown in Table 18, driving-related distraction was 1.64 times more likely to be present in SCEs than baselines. All other distraction types showed no significant difference in risk.

Table 18. ORs and 95% CIs for risk of an SCE across different distraction types.

Distraction Type	OR	95% CI
Driving-related distraction	1.64*	(1.06, 2.55)
Non-driving-related distraction	0.66	(0.42, 1.02)
Internal distraction	1.24	(0.79, 1.94)
External distraction	0.91	(0.53, 1.56)
Electronic device distraction	1.51	(0.79, 2.88)
Handheld electronic device	*1.97*	*(0.84, 4.59)*
Hands-free electronic device	*1.06*	*(0.41, 2.73)*

** denotes significant finding*

Work zone features were compared to see if any were associated with differences in driving-related distraction, internal distractions, and/or external distractions. Only one work zone feature was associated with a significant difference in distraction type. The occurrence of internal distractions was lower when reflective signs were used in the work zone (work zones with reflective signs included 40.47% of observations with internal distractions and 50.16% of observations without internal distraction; $\chi^2 = 4.06$, *p*-value = 0.0440). The table with all results is included in Appendix B.

An additional analysis estimated how SCE risk changed with work zone status for drivers who were distracted. The analysis identified, for each distraction type, the number of distracted SCEs and baselines in active and inactive work zones. Table 19 shows the number of SCEs in active work zones and inactive work zones, with the corresponding proportion of events in the work zone status and driver distraction type. In work zone observations of driving with non-driving-related distraction, active work zones were associated with higher risk of SCE involvement than inactive work zones (OR = 2.80, CI = [1.39, 5.67]). In work zone observations of driving with internal distraction, active work zones were associated with a higher SCE risk than driving in an inactive work zone (OR = 2.83, CI = [1.32, 6.05]). Similarly, driving with external distractions also had a higher SCE risk in active work zones compared to inactive work zones (OR = 2.95, CI = [1.03, 8.46]).

Table 19. SCE risk in active and inactive work zones by distraction type.

Distraction Type	Count of Distracted SCEs in Active Work Zones (% of Total Distracted Active Work Zone Obs.)	Count of Distracted SCEs in Inactive Work Zones (% of Total Distracted Inactive Work Zones Obs.)	OR	95% CI
Driver not distracted	11 (21.15%)	11 (18.03%)	1.22	(0.48, 3.10)
Non-driving-related distraction	22 (30.14%)	18 (13.33%)	2.80*	(1.39, 5.67)
Driving-related distraction	22 (36.67%)	21 (23.86%)	1.85	(0.90, 3.79)
Internal distraction	22 (38.60%)	16 (18.18%)	2.83*	(1.32, 6.05)
External distraction	12 (32.43%)	7 (14.00%)	2.95*	(1.03, 8.46)

** denotes significant finding*

CHAPTER 4. DISCUSSION

Work zones create risky scenarios for both workers and road users, but they present additional challenges for CMV drivers. The size and weight of a truck affect stopping distance, visibility of other vehicles, and maneuverability, all of which are vital for safely navigating a work zone. The present study investigated features of work zones and the risk associated with a variety of their roadway, environmental, and safety features. The vast majority of the work zone observations occurred with no adverse weather conditions present, dry road conditions, straight roadway alignment, and light traffic, with roughly three-quarters of CMV drivers wearing a seatbelt. The most common features observed in work zones were warning signs, barrel barriers, and lane closures, which were used in various combinations (e.g., warning sign and lane closures; barrels and warning signs, etc.).

It is important to note that the types of safety features used in a work zone are largely dictated by the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD; FHWA, 2009) based on the characteristics of the work and the surrounding roadway environment. There are different requirements for night work versus day work, short-term work versus long-term work, and high-speed multi-lane road versus low-speed single-lane roadway. For example, according to the MUTCD (FHWA, 2009), in the state of Virginia, traffic cones can only be used for short-duration daylight operations, while barrels must be used after dark for longer duration work zones. Concrete barriers are essentially a semi-permanent deployment for large extensive work zones requiring a higher standard of safety feature implementation (e.g., lane closures, higher speed roads). Although this does create some potential confounds in these analyses, the findings provide a clear indication that some work zone features were associated with increased risk of an SCE (i.e., traffic cones), which highlights the danger associated with these temporary work zones. The portability and ease of movement associated with traffic cones is beneficial for workers when placing traffic cones; however, these results suggest that traffic cones are not an ideal safety feature, particularly when focusing on CMV driver risk. This may be due to their small size, relatively speaking, resulting in their being less visible than other types of safety barriers, such as barrels. The light weight of traffic cones means they may be easily knocked over, or run over, and once they are knocked down, they may be even less visible to other vehicles, especially trucks that sit much higher off the road. Unlike traffic cones, reflective signs, barrels, and concrete barriers reduced the SCE risk for CMV drivers in work zones by 40%–60%, meaning these safety features had a protective effect for CMV drivers. The improved visibility of reflective signs and barrels and the semi-permanent nature of the concrete barriers mean these safety features are more effective and make the work zones safer for CMV drivers and the other vehicles sharing the road with them.

When broken down into active versus inactive work zones, based on visible activity by workers and machinery in the work zone, active work zones were associated with higher use of warning signs, reflective signs, and portable dynamic signs, as well as lane closures and traffic cones. Inactive work zones, on the other hand, were more likely to have concrete barriers and barrel barrier types present. This may be due to the nature of the barrier types themselves, as concrete barriers are heavy and difficult to move; as such, they would likely be used on larger road improvement projects which may become inactive for periods of time due to weather, lighting, or even lack of funds to complete the work. The concrete barriers may become a semi-permanent feature until the road improvement project is complete. Signage, traffic cones, and lane closures may be more indicative of current active work due to the fact that these features may be easily changed by workers on a daily basis if needed, and thus may be considered more temporary in nature than concrete barriers or barrels.

In addition to work zone safety features, a small number of roadway and environmental features were linked to SCE risk for CMV drivers. The results of the analyses show there was a small decrease in SCE risk associated with light traffic in a work zone compared to moderate and heavy traffic. There was also a nearly 3-times greater risk of a CMV driver being involved in an SCE in work zones on single-lane roadways versus a four-lane roadway. Due to the disruption to traffic flow caused by work zones on single-lane roads, this result is not entirely surprising. Furthermore, active work zones had nearly twice the SCE risk for CMV drivers compared to inactive work zones. The increased risk associated with work zones located on single-lane roads combined with the potential use of traffic cones as safety features in a smaller, more temporary type of work zone (i.e., compared to larger road improvement efforts on four-lane highways) highlights the critical interaction of various elements of a work zone that may have a detrimental impact on work zone safety.

The present study also investigated the risk associated with different types of driver distraction in work zones. The most common type of CMV driver distraction found in work zones was non-driving-related distraction, which refers to any additional activity engaged in by the driver that was not relevant to the driving task, such as using a cell phone or other electronic device. When comparing SCEs with baselines, CMV drivers were 1.6-times more likely to be engaged in a driving-related distraction, such as checking mirrors, during an SCE in a work zone. Given the more demanding nature of driving in a work zone, CMV drivers will likely be engaging in these driving-related distraction tasks more frequently. Checking mirrors and monitoring speed are necessary elements to safely negotiating a potentially crowded work zone, but these tasks, even when done safely, still require the driver's eyes to be off the forward roadway for a short amount of time. Unfortunately, traffic flow can change drastically in a work zone in a short amount of time, which may inadvertently result in the CMV driver becoming involved in an SCE. In active work zones, non-driving-related distractions, internal distractions (i.e., distractions inside the vehicle), and external distractions (i.e., distractions outside the vehicle) all resulted in an almost three-fold increase in SCE risk for CMV drivers.

Limitations of the study include the age of some of the ND study datasets. Although useable, the ND instrumentation and resulting video footage lacked the resolution available in more recent ND studies. The videos were difficult to see at times so there were missing data in an already relatively small dataset. In addition, SCE and baseline observations were taken from work zones only, not from general everyday roadway driving. As a result, comparisons could only be made between instances in a work zone that resulted in an SCE and instances in a work zone where nothing happened (i.e., baselines). Work zone driving could not be compared to regular everyday driving with no work zones present. Although this study is based on a relatively small number of work zone observations, the results are striking enough to warrant further investigation. Traffic cones, active work zones, and single-lane roads appear to be features that are associated with an increased SCE risk for CMV drivers. When planning smaller, more temporary work zones, it may be beneficial for worker and road user safety if planners employ larger, more visible safety barriers such as barrels and reflective signage.

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APPENDIX A. DATA REDUCTION PROTOCOL

STUDY ID

- 34TRUCK
- 8TRUCK
- IVS
- FASTDASH

EVENT ID (Enter the Event ID number)

FILE ID (Enter the File ID number)

WARNING SIGN (is there any work zone warning signage?)

- YES or NO
    - **IF YES, THEN:**

      REFLECTIVE SIGNAGE (see photo example)
    - YES or NO

      PORTABLE DYNAMIC SIGNAGE (see photo example)
    - YES or NO

POSTED SPEED (what is the posted speed in the work zone?)

ACTIVE WORK (is there active work occurring at the time the video was captured?)

- YES or NO
    - **IF YES, THEN:**

      # OF WORK TRUCKS (if yes, how many work trucks are visible?)

      # OF CREW (if yes, how many crew are visible?)

LANE CLOSURE (are there any lanes closed in the work zone?)

- YES or NO
    - **IF YES, THEN:**

      # OF CLOSED LANES (if yes, how many lanes are closed?)

      BARRIER TYPE (if yes, what barrier types are in use? Options are: **cones; barrels; plastic barrier; concrete jersey barrier; other – describe if possible.** See photo example for different barrier types)

EXAMPLE OF WORK ZONE REFLECTIVE SIGNAGE

EXAMPLE OF PORTABLE DYNAMIC SIGNAGE

EXAMPLE OF LANE CLOSURE USING TRAFFIC CONES

EXAMPLE OF LANE CLOSURE USING BARRELS

EXAMPLE OF LANE CLOSURE USING PLASTIC BARRIERS

EXAMPLE OF LANE CLOSURE USING CONCRETE JERSEY BARRIERS

APPENDIX B. PROPORTION OF WORK ZONE OBSERVATIONS WITH DISTRACTION, BY WORK ZONE FEATURE

Work zones with a feature were compared to work zones without that feature for differences in distraction behavior and evaluated using a chi-square test, which is included in the table.

Table 20. Distraction in work zones evaluated by work zone features.

Work Zone Feature	Distraction Type	Distracted Event Count with Work Zone Feature (% Distracted)	Distracted Event Count without Work Zone Feature (% Distracted)	χ^2 Statistic	*p*-value
Warning Sign	Driving-related distraction	105 (33.65%)	58 (37.66%)	0.73	0.3934
Warning Sign	Non-driving-related distraction	147 (47.12%)	82 (53.25%)	1.55	0.2130
Warning Sign	Internal distraction	102 (32.69%)	59 (38.31%)	1.44	0.2302
Warning Sign	External distraction	59 (18.91%)	38 (24.68%)	2.08	0.1493
Reflective Sign	Driving-related distraction	79 (36.24%)	84 (33.87%)	0.29	0.5928
Reflective Sign	Non-driving-related distraction	105 (48.17%)	124 (50.00%)	0.16	0.6926
Reflective Sign	Internal distraction	65 (29.82%)	65 (38.71%)	4.06*	0.0440
Reflective Sign	External distraction	42 (19.27%)	55 (22.18%)	0.60	0.4399
Portable Dynamic Sign	Driving-related distraction	67 (32.52%)	96 (36.92%)	0.98	0.3227
Portable Dynamic Sign	Non-driving-related distraction	93 (45.15%)	136 (52.31%)	2.36	0.1246
Portable Dynamic Sign	Internal distraction	72 (34.95%)	89 (34.23%)	0.03	0.8709
Portable Dynamic Sign	External distraction	39 (18.93%)	58 (22.31%)	0.79	0.3727
Cones	Driving-related distraction	41 (41.84%)	122 (33.15%)	2.57	0.1092
Cones	Non-driving-related distraction	44 (44.90%)	185 (50.27%)	0.89	0.3443
Cones	Internal distraction	31 (31.63%)	130 (35.33%)	0.47	0.4944
Cones	External distraction	22 (22.45%)	75 (20.38%)	0.20	0.6540
Concrete Barriers	Driving-related distraction	89 (37.08%)	74 (32.74%)	0.96	0.3262
Concrete Barriers	Non-driving-related distraction	123 (51.25%)	106 (46.90%)	0.88	0.3482

Work Zone Feature	Distraction Type	Distracted Event Count with Work Zone Feature (% Distracted)	Distracted Event Count without Work Zone Feature (% Distracted)	χ^2 Statistic	*p*-value
Concrete Barriers	Internal distraction	81 (33.75%)	80 (35.40%)	0.14	0.7084
Concrete Barriers	External distraction	50 (20.83%)	47 (20.80%)	<0.01	0.9922
Barrels	Driving-related distraction	131 (34.11%)	32 (39.02%)	0.72	0.3974
Barrels	Non-driving-related distraction	191 (49.74%)	38 (46.34%)	0.31	0.5763
Barrels	Internal distraction	136 (35.42%)	25 (30.49%)	0.73	0.3942
Barrels	External distraction	75 (19.53%)	22 (26.83%)	2.18	0.1395
Lane Closures	Driving-related distraction	101 (32.79%)	62 (39.24%)	1.91	0.1671
Lane Closures	Non-driving-related distraction	148 (48.05%)	81 (51.27%)	0.43	0.5112
Lane Closures	Internal distraction	103 (33.44%)	58 (36.71%)	0.49	0.4826
Lane Closures	External distraction	61 (19.81%)	36 (22.78%)	0.56	0.4533
** denotes significant finding*					