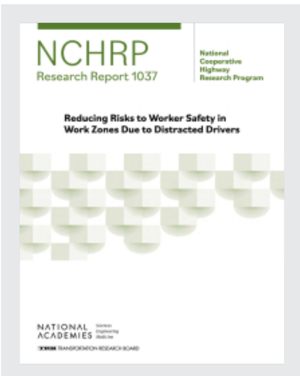

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP RESEARCH REPORT 1037

Reducing Risks to Worker Safety in Work Zones Due to Distracted Drivers

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2023

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By David M. Jared
Staff Officer
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NCHRP Research Report 1037: Reducing Risks to Worker Safety in Work Zones Due to Distracted Drivers presents proposals for temporary traffic control strategies aimed at reducing worker safety risks due to distracted driving in work zones. Development of these proposals was based on state-of-practice review and field evaluation of selected strategies. These proposals will be of interest to transportation agencies and contractors seeking to apply new technologies for promoting safety in work zones for both drivers and workers.

For highway construction and maintenance work zones, there is increasing concern about distracted drivers nearly and actually hitting pedestrians and/or equipment in work zones. While driver distraction is cited in 8 percent to 17 percent of fatal work zone crashes nationally, these figures may underestimate the role that distraction plays in work zone crashes. The advancement of new cell phone technologies now allows drivers to email, text, and make extended phone calls while driving, broadening the sources of potential distraction. Hence, an increasing need exists to determine what transportation agencies can do to minimize or mitigate the intrusion of distracted drivers into work zones. A significant amount of research has investigated how distracted driving can affect an individual's ability to drive or the impact of technology use on driver performance, with a focus on enforcement, education, and advocacy to reduce or eliminate use of technology while driving or operating a vehicle. Little research, however, has focused on distracted driving in work zones. *NCHRP Synthesis 587: Use of Smart Work Zone Technologies for Improving Work Zone Safety* summarized research on tools used to warn drivers about work zone conditions and the associated metrics for successful warnings, for example, vehicle speed reductions after encountering work zone notifications and diversion rates after delay notifications. The research summarized in *NCHRP Synthesis 587*, however, did not explore the effectiveness of distracted driving countermeasures in work zones.

Under NCHRP Project 20-07/Task 358, "Reducing Risks to Worker Safety in Work Zones Due to Distracted Drivers," Texas A&M Transportation Institute (TTI) was asked to develop a set of proposals on practices that can be used by transportation agencies and contractors to (1) alert distracted drivers to the presence of a work zone or maintenance moving operation and (2) prevent them from hitting a moving work vehicle or intruding into a work zone.

In addition to *NCHRP Research Report 1037*, a presentation introducing this report is available on the National Academies Press website (nap.nationalacademies.org) by searching for *NCHRP Research Report 1037*.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at nap.nationalacademies.org) retains the color versions.

SUMMARY

Reducing Risks to Worker Safety in Work Zones Due to Distracted Drivers

The purpose of this research was to identify and evaluate temporary traffic control (TTC) strategies aimed at reducing worker safety risks due to distracted driving in work zones. The research team first examined the state of the practice for deterring distracted driving behaviors in work zones. This information is in Chapter 2 and includes a review of available literature related to distracted driving in work zones, as well as a survey of state departments of transportation (DOTs) agency personnel and contractors to identify practices or countermeasures they were using to mitigate distracted driving intrusions into work zones. Countermeasures discussed included:

- Enhanced traffic control devices (primarily, advance warning signs).
- Queue warning systems.
- Speed limit reductions.
- Temporary portable rumble strips (TPRSs).
- Law enforcement.
- Intrusion alarm systems.
- Traveler real-time in-vehicle notifications.

Two countermeasures were selected for evaluation in real work zones, as Chapter 3 details. The research team used direct observations of driver attention to compare work zones with and without the countermeasures deployed.

TPRSs were evaluated at four different flagger stations on a two-lane road in Alabama. TPRSs appeared to have some effect on distraction, and the data indicate that transportation agencies and contractors should consider TPRSs for reducing distracted driving at flagger stations.

A "Watch for Workers When Flashing" warning sign was fabricated and evaluated at lane closures on multilane roads in Texas. Based on the evaluation outcomes, the research team concluded that the "Watch for Workers When Flashing" sign had a limited effect in terms of reducing distracted driving behaviors. This sign may also have other benefits not evaluated in this study, such as increased signing credibility.

The study's conclusions and proposals are in Chapter 4. For both countermeasures, only a limited number of work-zone conditions could be evaluated within the scope and budget of the research project. Additional research under a wider variety of conditions would be beneficial.

CHAPTER 1

Background

Work zones are complex and often hazardous places to work. Workers report an increasing concern of distracted drivers resulting in near misses and vehicles hitting pedestrians and/or equipment in work zones. While driver distraction is cited in 8 to 17 percent of fatal work-zone crashes nationally, these figures likely underestimate the role that distraction plays in work-zone crashes. In the past, driver distractions in the vehicle were generally limited to driver actions such as eating, reading a map, talking to passengers, applying makeup, or similar activities while operating the vehicle. The advancement of new cell phone technologies now allows drivers to email, text, and make extended phone calls while driving. An increasing need exists to determine what transportation agencies are doing to minimize or mitigate the intrusion of vehicles by distracted drivers into work zones and areas.

Distracted driving is defined as the "diversion of attention away from activities critical for safe driving toward a competing activity" (Regan et al. 2008). A significant amount of research has investigated how distracted driving can affect an individual's ability to drive, including the impact of technology use on driver performance. The primary focus, however, has been on enforcement, education, and advocacy to reduce or eliminate the use of technology while driving or operating a vehicle. Little research has been conducted to investigate what states are doing to alert workers or distracted drivers of approaching hazards prior to the distracted driver's vehicle entering work areas.

For this project, the research team first examined the state of the practice for deterring distracted driving behaviors in work zones. This was accomplished using two techniques to gather information about distracted driving in work zones. First, the research team reviewed the available literature to gather information on mitigating the intrusion of vehicles by distracted drivers into work zones and work areas. Second, the research team contacted the respective state departments of transportation (DOTs) agency personnel and highway construction and maintenance contractors to identify practices or countermeasures they may be using to mitigate distracted driving intrusions into work zones. Chapter 2 presents the state-of-the-practice findings.

Two countermeasures were selected for evaluation: a "Watch for Workers When Flashing" warning sign and temporary portable rumble strips (TPRSs). The research team worked with several transportation agencies and traffic control providers to identify the work zones for evaluating the countermeasures. Chapter 3 presents the details of the evaluation.

Based on the evaluation outcomes, the research team developed conclusions and proposals regarding the implementation of the two countermeasures. Chapter 4 provides this information.

CHAPTER 2

State of the Practice

This chapter provides information about the state of the practice for mitigating distracted driving in work zones. This includes a literature review and a survey of transportation agencies and contractors to better understand strategies they may be using to deter distracted driving behaviors.

Literature Review

Distracted Driving Crashes

The correlation between distracted driving and rear-end collisions is well documented in the literature (Strayer et al. 2006; Olson 2002; Lee et al. 2002; Neale et al. 2005; Stutts et al. 2001, 2005; Wang et al. 1996). Multiple analyses performed over the years have found that rear-end collisions are the predominant work-zone crash type that occurs. Moreover, they are the type of crash that most often experiences the largest increase relative to crashes normally occurring on that roadway segment prior to the initiation of the work zone (Rouphail et al. 1988; Hall and Lorenz 1989; Ullman and Krammes 1991; Ha and Nemeth 1995; Wang et al. 1995; Daniel et al. 2000; Raub et al. 2001; Garber and Zhao 2002; Salem et al. 2006; Mohan and Gautam 2002; Ullman et al. 2008). As one might expect, some studies have found that the biggest increase in rear-end crashes occurs in the advance warning area of the work zone (Garber and Zhao 2002). At least one study has shown that many of the rear-end collisions that occur at freeway and interstate work zones do so at locations where temporary lane closures are in place (Ullman et al. 2008). Situations of slowed or stopped traffic on facilities that normally do not experience queues appear to be especially problematic. Limited data from multiple Interstate Highway 35 reconstruction projects in Texas showed that when queues formed at nighttime lane closures with no safety countermeasures implemented, crash risks increased by nearly 500 percent (Ullman et al. 2018a).

The underlying reasons for the occurrence of crashes in work zones have also been the focus of multiple studies. As has been found for traffic crashes overall, driver error is by far the most common factor cited in work-zone crashes, particularly driver inattention and speeding (Akepati and Dissanayake 2011; Hargroves and Martin 1980; Pigman and Agent 1990; Bai and Li 2006; Hall and Rutman 2003; Swansen 2012). When researchers drill down into the crash report narratives, speed differentials caused by traffic queuing or by work vehicles entering and exiting the traffic stream at much slower speeds than the normal flow of traffic are commonly found to be contributing factors (Ha and Nemeth 1995; Ullman et al. 2011, 2018a; Hargroves and Martin 1980; Qin et al. 2007; Schrock et al. 2004).

Crashes in work zones occur despite the fact that roadways themselves are already designed to provide sufficient stopping sight distance to hazards, and that temporary traffic control (TTC)

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layout requirements themselves are based on fundamental principles of positive guidance (Alexander and Lunenfeld 1975; Hostetter et al. 1982). The logical conclusion is that driver distraction must play a significant role in many of the rear-end collisions that occur in work zones. Consequently, agencies continue to search for ways to enhance standard TTC in a way that reduces traffic crash risks in work zones.

While many specific driver behaviors contribute to distracted driving crashes, mind wandering is often overlooked as a significant cause. One analysis of data from the Fatal Analysis Reporting System (FARS) [National Highway Traffic Safety Administration (NHTSA) n.d.], summarized in Table 1, indicates that 61 percent of distracted drivers involved in fatal crash events reported they were "generally distracted" or "lost in thought" (i.e., mind wandering or highway hypnosis). The analysts recognized that FARS data on distraction are based largely on police officers' judgment at the time of the crash and that drivers may be reluctant to admit their distracted driving behaviors to police. Thus, the actual numbers are difficult to verify and may under-represent the seriousness and prevalence of driving distractions (Erie Insurance 2018).

Enhanced Traffic Control Devices in Work Zones

There have been various attempts at increasing driver attention and reducing speeds in work zones, with the overall goal of reducing crash risk and improving safety. Flags or flashing warning lights on advance warning signs are two ways of increasing the conspicuity and attention-getting value of these devices and have been in use for many years [Federal Highway Administration (FHWA) 2012]. Similarly, the specification of fluorescent orange sheeting for certain advance warning signs has been shown to increase driver detection of such signs (Zwahlen and Schnell 1997; Hummer and Scheffler 1998) and is in common use nationally.

Other efforts to increase driver attention/awareness and speed compliance in work zones include the use of electronic portable changeable message signs (PCMSs) (Ullman et al. 2005). PCMSs typically have high contrast values between the lighted message and the black background. Furthermore, the motion involved in switching between phases on two-phase messages also attracts driver attention (Huchingson 1981). In addition, the availability of PCMSs and space to deploy them can also be a challenge in some work zones.

Despite the common use of these types of attention-getting devices, work-zone crashes still occur. Driver distraction due to increased electronic device use in vehicles, daydreaming, or

Table 1. Erie Insurance analysis of FARS distracted driving crashes (Erie Insurance 2018).

Distraction Type	Percentage of Distracted Drivers
Generally distracted or "lost in thought" (daydreaming).	61%
Cell phone use (talking, listening, dialing, or texting).	14%
Outside person, object, or event, such as rubbernecking.	6%
Other occupants (talking with or looking at other people in car).	5%
Using or reaching for device brought into vehicle, such as navigational device or headphones.	2%
Adjusting audio or climate controls.	1%
Eating or drinking.	1%
Using other device/controls integral to vehicle, such as adjusting rear-view mirrors or seats, or using original equipment manufacturer navigation system.	1%
Moving object in vehicle, such as pet or insect.	<1%
Smoking related (includes smoking, lighting up, and putting ashes in ashtray).	<1%

highway hypnosis are thought to be key contributing factors. Therefore, efforts are being made to come up with new ways to *pull* drivers into a more alert state so that they can react more quickly and appropriately to work-zone conditions. At least one manufacturer is using trailer-mounted warning sign systems in Texas work zones to alert traffic about trucks entering and exiting the roadway (Figure 1). These systems have flashing light emitting diode (LED) lights in the sign border as well as flashing beacons that can be remotely activated when warranted by work truck movements. To date, no studies have been published that assess if and how effective such lighting could be in reducing crash risks at work zones where stopped traffic might be encountered.

Queue Warning Systems in Work Zones

End-of-queue warning systems are another example of innovative technology available to help reduce work-zone crash risks associated with stopped traffic. Figure 2 shows the use of this work-zone intelligent transportation system (ITS) technology for real-time queue warning. Sensors to detect when traffic speeds have dropped below a selected threshold are placed at one or more sensor locations where queuing is anticipated and an interconnected PCMS is activated when a queue is detected to warn approaching motorists of queue presence. Some systems simply display a "Stopped Traffic Ahead" message, whereas other systems calculate and display the approximate location to that queue as part of the message.

End-of-queue warning systems with and without TPRSs have been shown to reduce crashes. Overall, the use of these countermeasures appeared to reduce crashes during periods of queuing and congestion by 53 to 60 percent from what would have been expected if the countermeasures had not been used. In addition, the crashes that did occur were significantly less severe when the countermeasures were deployed, as compared to the no-countermeasure condition. Without

Figure 1. Example of warning sign with LED lights to increase driver attention (image courtesy of SAWS Inc.).

Figure 2. Example of work-zone ITS queue warning technology (Ullman et al. 2016a).

the countermeasures deployed, 50 percent of the crashes that occurred when queues were present involved injuries or fatalities; when the treatments were deployed, only 16 percent of the crashes involved injuries or fatalities (Ullman et al. 2016a, 2018a, 2018b). Many states, including Texas, are using end-of-queue warning systems at lane closures on multilane roadways [Texas Department of Transportation (TxDOT) 2019a, 2019b]. Of course, not all projects will benefit from the use of end-of-queue warning systems (for example, work zones that do not reduce roadway capacity and do not create queues from time to time). Consequently, the decision to use this technology should be based on a needs assessment of expected work activities and expected frequency of queue formation.

Speed Limit Reductions in Work Zones

Reduced Speed Limits

The *Manual on Uniform Traffic Control Devices* encourages agencies to design work zones such that drivers are not required to reduce their speed significantly. Nevertheless, reduced work-zone speed limits are perhaps the most common strategy used by agencies to try to prevent work-zone crashes. Conceptually, reduced speeds increase available response times by drivers to unexpected conditions and should lead to fewer crashes. The data do suggest that drivers reduce their speed when encountering work zones, and the magnitude of the reduction is dependent upon characteristics and conditions in the work zone (Finley et al. 2008, 2014). However, the reductions are typically much less than the amount by which the speed limit is lowered. Posting excessively low speed limits will not result in significant speed reductions without having continuous enforcement present. Since continuous enforcement is typically not attainable, speed limits posted far below are generally ignored by the motoring public and likely have little effect on distraction or crashes.

Variable Speed Limits

Variable speed limit (VSL) systems strive to harmonize speeds of vehicles approaching and within the work zone, calming traffic flow and warning of slowed or stopped traffic ahead. VSL systems can involve the display of either regulatory or advisory speed information to motorists. The systems themselves can be designed to automatically adjust to prevailing traffic speeds and environmental conditions or can be designed to reduce speed limits when work crews are present and then return to a higher speed limit when the crew has left for the day.

VSL systems have not been used extensively in work zones to date. However, limited testing does indicate that these systems can have moderate effects on driver speed choices if the system is properly designed (Kwon et al. 2007; Kuhn et al. 2015; Saito and Wilson 2011; Van Jura et al. 2018). Their specific effect on distracted drivers is unknown.

Temporary Portable Rumble Strips in Work Zones

Many drivers involved in work-zone crashes are reported to be completely unaware of the work zone. Distractions due to increased electronic device use in vehicles, daydreaming, or highway hypnosis are thought to be key contributing factors of many rear-end collisions. As a result, new ways are being sought to pull drivers into a more alert state so they can react more quickly and appropriately to work-zone conditions. To get the attention of those drivers who are not looking at the roadway scene due to in-vehicle distractions or who are experiencing highway hypnosis, some agencies deploy TPRSs in advance of flagger stations and multilane closures, as Figure 3 shows. These devices create vibratory (haptic) and auditory alerts designed to pull motorists out of a distracted state, so they concentrate on the driving task.

Whereas most studies of TPRS effectiveness have focused on operational measures such as speed changes (Ullman et al. 2018b; Welch et al. 2003; Hildebrand et al. 2003; El-Rayes et al. 2013; Ukkusure et al. 2016; Hawkins and Knickerbocker 2017; Sun et al. 2011; Wang et al. 2013), one study did look at the potential crash-reducing effects of these devices (Ullman et al. 2016a). The deployment conditions included nighttime lane closures on rural interstate roadways. During times when queues were not present at the lane closures, no statistically significant effect on crashes was detected. However, when queues had formed at the lane closures, the TPRSs achieved a 60 percent reduction in crashes that were estimated to have otherwise occurred. In addition, the severity of the remaining crashes that did occur when the TPRSs were present was significantly less than during periods of queuing at lane closures when TPRSs were not in use.

Various agencies use TPRSs during flagging operations on two-lane roads and lane closures on multilane roadways. They include the California Department of Transportation (Caltrans), Colorado Department of Transportation (CDOT), Illinois Department of Transportation (IDOT), Iowa Department of Transportation (Iowa DOT), Maine Department of Transportation (MaineDOT), Maryland State Highway Administration (Maryland SHA), TxDOT, and Virginia Department of Transportation (VDOT) (Caltrans 2014; CDOT 2019; IDOT 2017;

Figure 3. Example of TPRSs deployed upstream of an interstate lane closure (Ullman et al. 2018b).

Iowa DOT 2020; MaineDOT 2017; Maryland SHA 2005; TxDOT 2016; VDOT 2011, 2018). However, the effects of these devices on driver attention are not well documented in the body of research.

More recently, researchers at the Texas A&M Transportation Institute (TTI) completed a study to evaluate the impacts of TPRSs on distracted driving in work zones. Study sites included both flagging operations on two-lane highways and lane closures on multilane roadways. Researchers documented instances where drivers appeared visually distracted (looking at phones, looking at passengers, reading, adjusting the radio, etc.) as they passed the data collection observer. Researchers found the rate of visually distracted drivers, immediately prior to passing over the TPRSs, to be between 15 and 29 percent. These percentages appeared to depend on roadway type, land use, and the amount of traffic using the roadway. Researchers did note that several visually distracted motorists looked up immediately after passing over the TPRSs. Furthermore, data from one site, where data were collected at multiple points downstream of the TPRSs, suggested that their effect on driver distraction may be limited to about 1500 feet downstream (Ullman 2020). It should be noted that these devices do require workers to be out in travel lanes to deploy and then pick up the devices each work shift (unless specialized deployment and retrieval technology has been procured and is being used). As a result, not all agencies have embraced the use of TPRSs in all work zones.

Law Enforcement in Work Zones

The presence of an enforcement vehicle (with or without lights flashing) attracts driver attention and has been shown to affect driver speeds in some instances (Antonucci et al. 2006). At least one study has concluded that the presence of enforcement in a work zone significantly reduced crash risk (Chen and Tarko 2012). The California, Illinois, and Massachusetts DOTs frequently use law enforcement in maintenance work zones [Caltrans 2021; IDOT 2016; Massachusetts Department of Transportation (MassDOT) n.d.]. Of course, enforcement usage in work zones can be challenging due to constraints in available enforcement staffing, lack of adequate enforcement staging areas, and insufficient funding (Ullman et al. 2013; Ullman and Schrock 2001).

Intrusion Alarm Systems in Work Zones

Work-zone intrusion alarm systems can be used to alert drivers who may be on a path to crash into the end of a queue. Efforts to develop an effective means of detecting work-zone intrusions and warning workers with an audible alarm have existed since the late 1980s (Brown et al. 2015a). Early systems used pneumatic tubes or infrared beams placed along the edge of the work area that activated an alarm for workers if a vehicle crossed the tube or broke the beam (Benekohal and Linkenheld 1990). Another design attached the alarm to channelizing devices that activated if the device was knocked over (Graham et al. 1989). However, these systems all suffered from frequent false alarms and lacked sufficient alert volumes over the ambient work-zone noise to be effective (Krupa 2010; Kuta 2009). These systems were recently retested, and similar outcomes were documented (Gambatese et al. 2017; Khan et al. 2019). To address the insufficient sound levels of audible alarms, one study evaluated various directional sound broadcasting methods and found that an array of multiple ordinary loudspeakers was best for long-distance auditory warnings (Phanomchoeng et al. 2008). Directional audible system (DAS) technology was found to perform poorly in horizontal curve situations (Brown et al. 2015b). A survey of state transportation agencies also found frequent operational problems associated with some work-zone alarms, including false alarms, maintenance, and installation time (El-Rayes et al. 2014).

In California, researchers conducted an evaluation of several work-zone intrusion alarm systems in a closed-course setting and selected a few devices for further evaluation (Fyhrie 2016). Pilot testing in active work zones will occur over the next two years (Caltrans 2021).

In Georgia, researchers have attempted to use vision technology as part of an intruding vehicle awareness algorithm that includes a tire-based vehicle detection and tracking method. Preliminary testing in a simulated work zone showed that intruding vehicles were reliably detected. However, it does not appear that any type of alarm component that would alert workers has been included as part of the research (Tsai 2011).

In Michigan, researchers tested a privately developed prototype collision avoidance and mitigation system (CAMS) on two winter maintenance trucks. The CAMS, as Figure 4 shows, had a rear-facing radar, camera, warning light bar, cleaning/washing system (to keep the radar and camera surfaces clean), computer hardware, and in-cabin display. Despite the cleaning system, road spray continually blocked the detection system, and vehicles in adjacent lanes frequently triggered false alarms. Other than these issues, the system performed well, and the researchers noted moderate improvements in driver behavior (Zockaie et al. 2018).

In Missouri, researchers studied the use of two types of mobile work-zone alarm systems: a prototype alarm device and a DAS. Figure 5 and Figure 6 show these systems, respectively. Three modes of operation were tested: continuous, manual, and actuated. The research included an analysis of merging distances and speeds, as well as observations of driving behavior. All the configurations tested increased the merging distance of vehicles except for the alarm-actuated setup. The DAS continuous setup also reduced vehicle merging speeds and the standard deviation of merging distance. In some configurations, undesirable driving behaviors (such as severe braking and vehicle swerving) were observed, but it is unclear whether these driving behaviors were due to the presence of the mobile work-zone alarm device. Analysis of alarm activations

Figure 4. Michigan collision avoidance and mitigation system (Zockaie et al. 2018).

Figure 5. Missouri truck-mounted attenuator with alarm device (Brown et al. 2015b).

indicated that factors such as horizontal curves and movement of the truck-mounted attenuator vehicle created false alarms and false negatives. However, the research has demonstrated that mobile work-zone alarms have the potential to be an effective tool for improving safety by providing audible warnings (Brown et al. 2015b).

In North Carolina, researchers recently developed a work-zone intrusion detection and alert system prototype. Little is known about the system, but it is said to consist of a tripod-mounted mobile device that monitors a restricted area and runs a software application designed to alert workers when an intrusion occurs. The worker alerts include sounds and vibrations generated by their mobile devices. In a simulated test environment, the researchers found

Figure 6. Missouri DAS (Brown et al. 2015b).

Figure 7. Vehicle-mounted intrusion alarm system for lane closures (Theiss et al. 2017).

good potential for the device to improve work-zone safety (Ozan et al. 2020). Further testing is underway under a separate research project [North Carolina Department of Transportation (NCDOT) n.d.].

In Texas, researchers also evaluated an intelligent work-zone intrusion alarm system (AsphaltPro n.d.). Unlike previous intrusion alarm systems that rely on the detection of vehicles crossing a predetermined perimeter (typically identified with pneumatic tubes or infrared beams), this new system uses a target threat detection and tracking methodology to logically assess approaching vehicle speed, location, and possible trajectory. The truck-mounted alarm system (Figure 7) detects workspace intrusions in stationary lane closures, while a self-contained system (Figure 8) is used at flagger stations to detect vehicles passing by a flagger while traffic should be stopped. When errant or non-compliant vehicles are detected, an alarm sounds to alert the crew. In addition, the system includes small pagers (Figure 9) that can be worn by workers to

Figure 8. Self-contained intrusion alarm system for flagging operations (images courtesy of Oldcastle Materials).

Figure 9. Audible and haptic worker alarm system (Theiss et al. 2017).

provide individual audible and haptic alerts based on where the worker is positioned in the work zone (Theiss et al. 2017). A device reliability study found that the intrusion detection systems were 100 percent accurate for the scenarios evaluated and the worker alerting devices were 97 percent accurate for the scenarios evaluated (Theiss et al. 2017). A driver response assessment led to recommendations to modify the lighting and sound systems to improve motorist understanding (Ullman et al. 2016b). The practicality of the system was demonstrated during a recent Minnesota Department of Transportation (MnDOT) research project as well (Ullman and Theiss 2019).

Alarm systems that have automated detection have been shown to have various issues that have hampered further developmental efforts, such that none of them are yet commercially available. Distinguishing between a vehicle that truly is an intrusion threat from one whose driver plans to vacate a closed lane at the last second (and so is not a true intrusion threat) is difficult for automated radar-, camera-, or lidar-based systems. As a result, false alarms continue to plague these types of systems.

Based on the Missouri Department of Transportation (MoDOT) mobile work-zone alarm design concepts, the Iowa DOT has developed and fabricated a truck-mounted audible attenuator system that includes flashing lights and audible alerts when an errant motorist has been detected (Figure 10). The system is currently being used in mobile operations, such as applying pavement markings. It relies on a worker who must monitor all approaching vehicles and assess the risk of their speed and path posing a significant threat to the work operation. Because the alarm operator must view approaching vehicles through the truck's mirrors, the process of judging the vehicles' speed and path is likely more difficult. While manual alarms, such as simple handheld air horns, could be used in other (non-mobile) operations, some implementation challenges are associated with using these systems to try to prevent end-of-queue crashes, such as:

- Unavailability of the alarm operator to perform other work.
- Uncertainty about the proper location of the alarm relative to the work operation or end of the queue.
- Difficulty in judging the speed and path of approaching vehicles to identify real threats.

Figure 10. Iowa DOT truck-mounted audible attenuator system (image courtesy of Iowa DOT).

Traveler Real-Time In-Vehicle Notification of Work Zones

Conceptually, navigation apps that can provide real-time alerts of slowdowns, enforcement presence, and work zones (particularly those that provide such alerts in audio format) are another potential technology to help mitigate the effects of driver distraction on work-zone crashes. The effectiveness of this technology obviously depends on the percentage of distracted drivers who use such apps as well as on the characteristics of the work zone that create speed differentials or other unexpected changes to operating conditions that a distracted driver would otherwise miss. Although there have been efforts to assess the effect of having work-zone presence information automatically uploaded to third-party navigational aid platforms, studies to date have not yet correlated such efforts to reduced work-zone crashes or reductions in driver distraction approaching and passing through a work zone (Finley et al. 2020).

Survey of Transportation Professionals and Transportation Agencies

The research team developed and conducted a telephone survey of state DOTs to identify practices, beyond traditional work-zone signing, used to warn motorists of work-zone activities or moving operations. A telephone survey was used because it is a relatively efficient method of gathering the most recent information on DOT practices. Specific questions included in the survey were:

- Does your agency use and/or require any of the following enhancements to your standard advance warning signs?
  - Fluorescent sheeting.
  - Flag tree(s).
  - Flashing warning beacons.
  - LED lighting within or on the border of one or more signs.
  - Supplemental signs ("Be Prepared to Stop," work activity type, innovative messages, etc.).
  - Supplemental PCMS messages.
  - Other.

- Does your agency use or require the use of queue warning systems in work zones?
- Does your agency use or require the use of reduced or VSL systems in work zones?
- Does your agency use and/or require the use of rumble strips in the advance warning area?
- Does your agency use or require the use of law enforcement officers in work zones?
- Does your agency use and/or require the use of any type of work-zone alarm system?
- Does your agency attempt to broadcast in-vehicle notifications to motorists about work zones?
- Does your agency use any other innovative strategies to try to attract the attention of distracted drivers in work zones?

Twenty-seven state DOTs responded to the survey. Figure 11 shows utilization percentages for each practice, and details regarding the survey responses are described as follows.

Enhanced Traffic Control Devices in Work Zones

Most of the state DOTs require some type of enhancement of their work-zone advance warning signs in order to attract more driver attention to the signs. This includes 21 DOTs (78 percent) that use fluorescent sheeting for brighter signs, 12 DOTs (44 percent) that add flag trees to the sign, and 12 DOTs that add flashing beacons to the signs (44 percent). Only one, the Montana Department of Transportation (MDT), uses LED lights in the border of certain

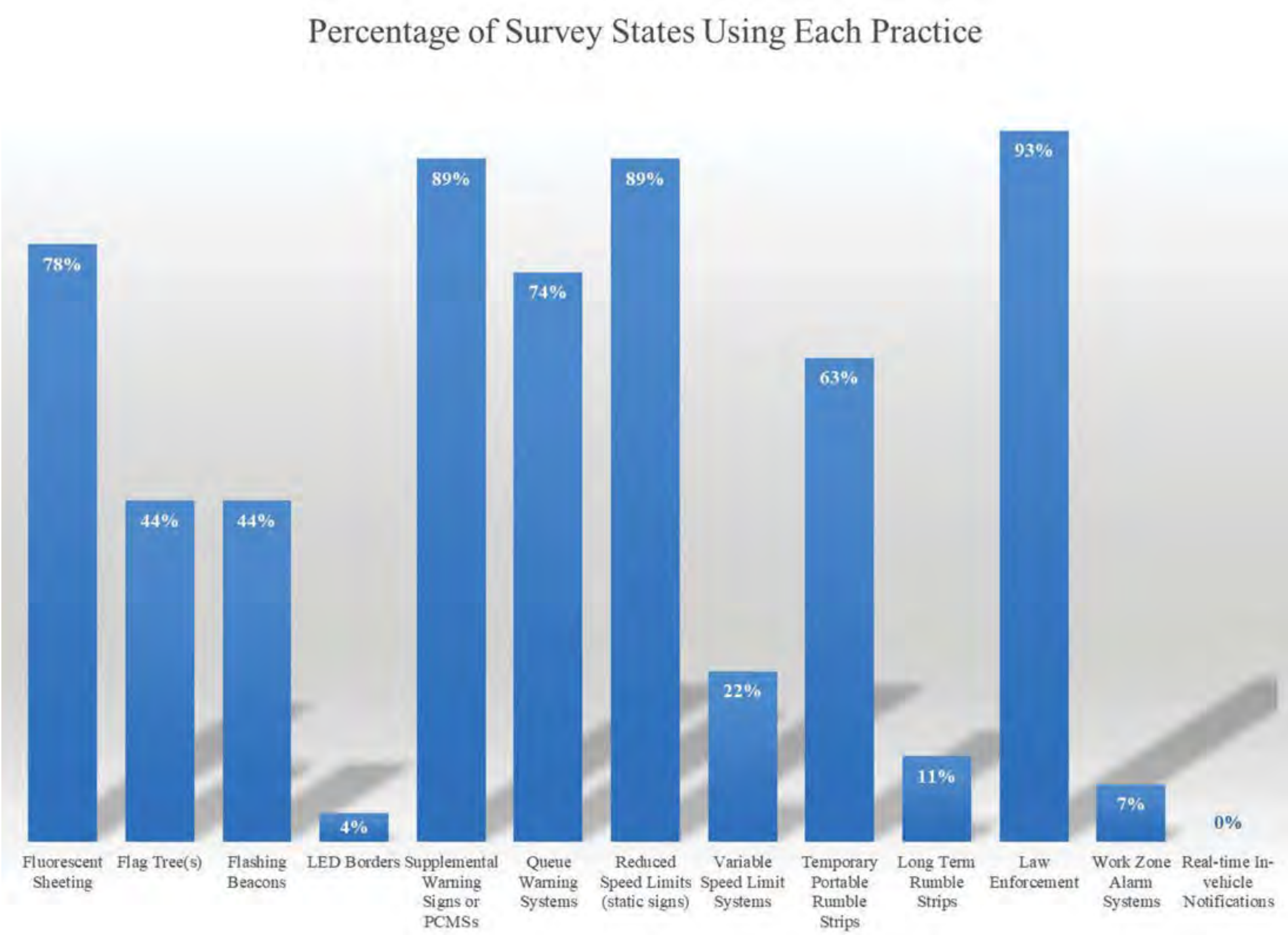

Figure 11. Utilization of various work-zone practices by survey states.

advance warning signs (see Figure 12). Only three (11 percent) of the 27 DOTs do not use at least one of these enhancements.

Twenty-four DOTs (89 percent) use supplemental signs and supplemental PCMS messages in their advance warning areas. Examples of extra signs include warnings about:

- Automated enforcement.
- Cellular phone use.
- Distance to road work (2 miles, 5 miles, etc.).
- Detours.
- Lane shifts.
- Merges.
- Motorcycle hazards.
- New traffic patterns.
- Pavement conditions.
- Stopped traffic.
- Worker presence.

Queue Warning Systems in Work Zones

Twenty DOTs (74 percent) use some type of automated queue warning system to alert motorists about slow or stopped traffic ahead. These systems include sensors that detect changing traffic conditions and communicate that information to motorists on upstream signs. The signs are primarily PCMSs but may also be static signs with flashing beacons. At least one state uses a queue truck, which is a DOT vehicle displaying a truck-mounted queue warning message. The queue truck is located on the shoulder upstream of the queued traffic. One of the challenges associated with using a queue truck is that the driver must try to maintain a position upstream of the queue to be effective. A recent study showed that hard-braking events were found to decrease by approximately 80 percent when queue warning trucks were used to alert motorists of impending queues (Sakhare et al. 2021).

Speed Limit Reductions in Work Zones

Twenty-four DOTs (89 percent) can use static signs to reduce the speed limit in their work zones. Six DOTs (22 percent) reported the use of VSL systems in long-term construction work zones. VSL systems may have increased attention-getting value over static speed limit signing due to the use of electronic numeral displays of the current speed limit. In addition, VSLs may

Figure 12. MDT warning sign with LED lights (image courtesy of Montana DOT).

result in improved compliance due to increased credibility with the motoring public that the speed limits reflect current conditions where reduced speeds are necessary (Van Jura et al. 2018).

Temporary Portable Rumble Strips in Work Zones

Seventeen DOTs (63 percent) use TPRSs but do not require them for all conditions. In most cases, specific work-zone and roadway conditions have been identified for their use (flagging stations on two-lane roads, dry pavement conditions, etc.). Three DOTs (11 percent) are currently experimenting with TPRSs, while five DOTs (19 percent) tried them and decided not to use them. Reasons cited for discontinuing their use included:

- Additional cost to obtain TPRSs.
- Vehicles using the shoulder to drive around them.
- Movement or "walking" of the TPRSs under interstate truck traffic.
- Increased worker exposure to frequently reset TPRSs.
- Noise complaints from nearby residents.
- Poor product quality of the TPRS devices used.

Many of the DOTs that use TPRSs have noted some of these same issues but continue to use them, presumably because the perceived benefits outweigh the cost. Four DOTs allow the use of pavement marking tape applied to the roadway surface to create rumble strips on long-term construction projects.

Law Enforcement in Work Zones

Twenty-five DOTs (93 percent) use law enforcement in their work zones. The project designer often determines the need for law enforcement on long-term construction projects. For maintenance work, maintenance supervisors typically make this decision. In most cases, law enforcement presence (with vehicle lights on) is the preferred deployment approach, and DOTs typically allow the law enforcement officers to select their own placement within the work zone.

Intrusion Alarm Systems in Work Zones

None of the DOTs require any type of work-zone intrusion alarm system. Only two DOTs (7 percent) reported the optional use of work-zone alarm systems by DOT staff: Missouri and Iowa. Figure 10 shows the Iowa system developed working cooperatively with Missouri, which has a similar system. Six DOTs (22 percent) indicated that they had experimented with at least one work-zone intrusion alarm system but discontinued that effort due to false alarms, etc. Two DOTs (7 percent) are currently sponsoring research to evaluate work-zone alarm systems: California (Caltrans 2021) and North Carolina (NCDOT n.d.). In addition, research to develop a connected, wearable alert system for construction workers was recently completed in Virginia (Roofigari-Esfahan et al. 2021).

Traveler Real-Time In-Vehicle Notification of Work Zones

Twelve DOTs are in the process of pursuing some types of real-time in-vehicle work-zone alerts, but their active use is not widespread. Nine of these DOTs mentioned that they have received funding from the U.S. Department of Transportation (U.S. DOT) Work Zone Data Exchange (WZDx) demonstration project (U.S. DOT 2022). The project was established to increase motorist and worker safety by producing consistent public work-zone data feeds across jurisdictions that could also be used by third-party traveler information and navigational systems. Several of these DOTs are using WZDx project grants to obtain smart arrow boards, which use cellular communications to send real-time data regarding arrow board location and display condition to app developers. The app developers can then push the work-zone location data out to vehicle navigation systems and mobile devices. Many of the navigational apps have the capability to provide real-time alerts of work zones and other incidents to motorists while driving via visual displays and/or audible messages. Conceptually, such alerts could help reduce distracted driving approaching a work zone. However, the effectiveness of this approach depends on the market penetration of navigation systems or app use by drivers while traveling (versus for pre-trip planning or routing purposes). This market penetration likely varies by region, type of trip, and driver characteristics. Urban areas (where traffic conditions change quickly) likely have higher utilization of real-time navigational aids than rural areas. Drivers are more likely to use navigational aids for unfamiliar trips or destinations than for regular or repeat trips. In addition, some drivers are less inclined in general to rely on navigational aids than others.

Other Ideas

Some of the survey respondents made suggestions for addressing distracted driving in work zones. Those suggestions are as follows:

- Add a flashing "Workers Present" sign.
- Use social media for work-zone awareness campaigns.
- Add a visual screen on a temporary barrier to reduce rubbernecking.
- Use temporary striping to visually narrow the lanes for a traffic-calming effect.
- Increase car-following gaps by using pavement dots and educating motorists to keep two dots between them and the car in front of them.
- Post alternate route travel times in real time.
- Use software during planning stages to better estimate anticipated delays.
- Use commercial third-party predictive analytics during project planning.
- Use geofencing technology to mark work zones and send notifications to drivers' phones when the geofence is penetrated.
- Use presence lighting in work zones.
- Cut cell phone signals.
- Use PCMSs on rollers to notify drivers of "Workers in Roadway/Slow to XX mph."
- Use automated speed enforcement.
- Add flashing lights or special colors to worker vests.

Summary

The researchers investigated the following countermeasures for distracted driving:

- Enhanced warning signs.
- Queue warning systems.
- Speed limit reductions.
- TPRSs.
- Law enforcement.
- Work-zone alarms.
- Real-time in-vehicle notifications.

Based on the review and survey of states, two countermeasures were selected for further evaluation:

- TPRSs.
- A lighted "Watch for Workers When Flashing" warning sign.

These treatments were believed to have significant distraction-reducing effects on drivers approaching a work zone. The potential benefit of the TPRS is that it provides visual, audible, and tactile/haptic feedback to motorists. Thus, motorists receive an alert (via the audible and tactile/haptic feedback) even if they are visually or cognitively distracted. Meanwhile, use of a lighted "Watch for Workers When Flashing" warning sign is designed to improve the credibility of the warning message with approaching motorists and lead to motorists increasing their situational awareness as they approach the work zone. Unlike the TPRS, this countermeasure does rely on an approaching motorist glancing up (if visually distracted) or detecting the movement of the flashing lights (if cognitively distracted) and increasing their attention because of the expectation of real work activity and worker presence downstream.

CHAPTER 3

Evaluation of the Countermeasures

Methodology

The evaluation of each countermeasure used a simple comparison of distracted driving behaviors with and without each treatment deployed. The measure of effectiveness was driver visual attention (i.e., where drivers were looking immediately after they passed the countermeasure). Drivers who were looking directly forward at the roadway ahead (and not talking on their phones) were considered to have "undistracted" visual attention. When drivers were looking in the rear-view mirror, out the side window, at passenger(s), at a cellular phone, or down into the cab of the vehicle, their visual attention was considered "distracted." While drivers' cognitive distraction per se could not be measured within the scope and budget of this project, any drivers that were holding their cellular phone near their face (in a talking position) were included with the cellular phone distracted drivers. This type of distraction is likely underrepresented in the data because the use of Bluetooth-connected devices could not be discerned. In addition, if the data collectors could not discern driver attention from passing vehicles, these drivers were not included in the data.

Temporary Portable Rumble Strips

The Alabama Department of Transportation (ALDOT) had interest in assisting with the TPRS evaluation. While ALDOT maintenance crews do not widely use TPRSs, ALDOT Special Project Detail 2002-A shows how TPRSs can be used in the advance warning area, as shown in Figure 13.

During the week of February 28, 2022, data were collected in four different flagging operations along State Route 22 (a rural two-lane road) with and without the TPRSs deployed. ALDOT was performing tree-trimming work, so the flaggers and work vehicles moved around between the sets of advance warning signs located at each end of the work zone. No channelizing devices were used. Figure 14 shows how the advance warning area was modified when the TPRSs were removed, while Figure 15 shows images from one work zone with and without the TPRSs.

At each site, a team of two researchers simultaneously recorded distracted driving data near the "Road Work Ahead" sign (the "upstream" location) and immediately after the rumble strips, or TPRS position (the "downstream" location). Table 2 summarizes the observations.

The researchers first looked at the data collected at the upstream location of each TPRS site. Table 3 summarizes these data.

Two-proportion Z-tests were used for the analysis of the distracted drivers. The purpose of this analysis was to determine if there were any statistically significant differences in driver distraction rates at the upstream location (after drivers entered the work zone but before their

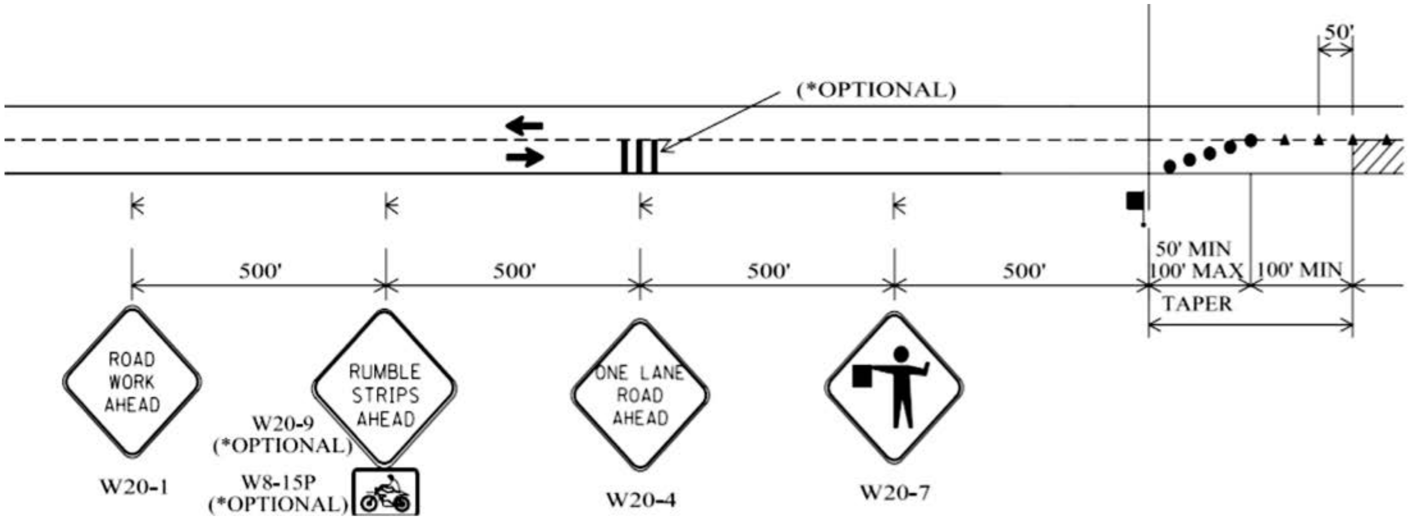

Figure 13. ALDOT Special Project Detail 2002-A (ALDOT 2018).

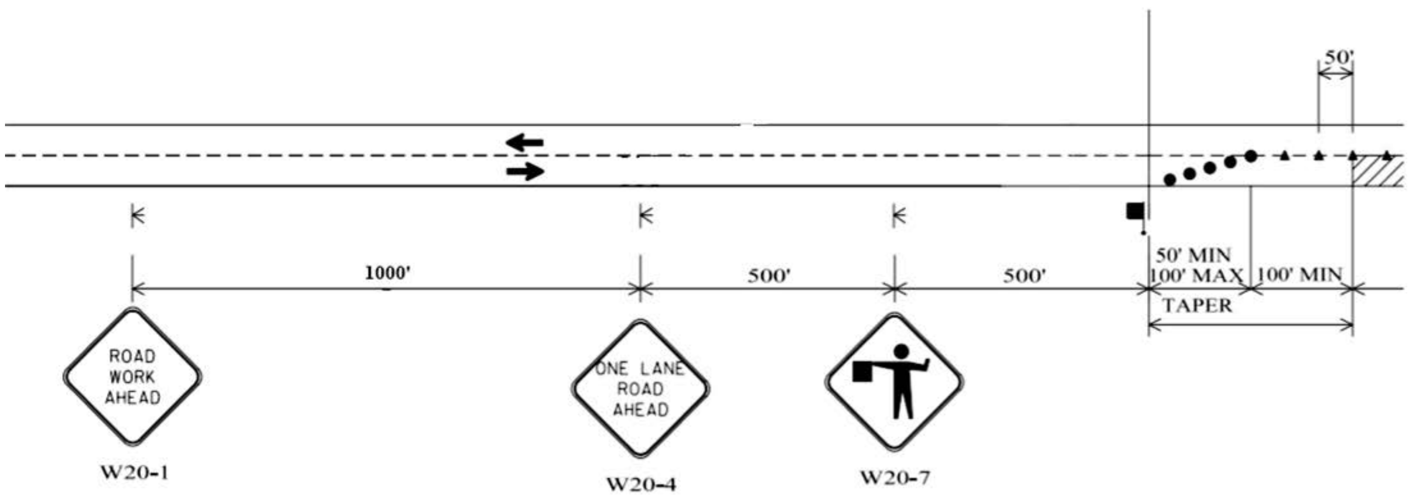

Figure 14. Modified advance warning area with TPRSs removed (ALDOT 2018, modified).

Figure 15. Site 1 with and without TPRSs.

Table 2. Data collection summary for the TPRS sites.

Site No.	Direction	Location Description	Posted Speed Limit (mph)	Number of Minutes of Data
1	Eastbound	West of County Road 100	55	251
2	Westbound	West of State Highway 49	45	250
3	Eastbound	East of County Road 17	55	264
4	Westbound	East of Georgia State Line	55	256

interaction with the TPRS). The hypothesis (H_0) was that the distracted driving percentages were the same at a 95 percent confidence interval ($\alpha = 0.05$). First, the pooled sample proportion ($\hat{p}$) for each site was calculated using the following formula for which x_1 = number of distracted drivers with treatment deployed, x_2 = number of distracted drivers without treatment deployed, n_1 = total number of drivers observed with treatment deployed, and n_2 = total number of drivers observed without treatment deployed:

$$\hat{p} = (x_1 + x_2)/(n_1 + n_2)$$

For site 1, $x_1 = 15$, $p_2 = 25$, $n_1 = 90$, $n_2 = 128$ and $\hat{p} = 0.183$ or 18.3 percent.

Next, the Z-test statistic (z) for each site was calculated by using the following formula:

$$z = (\hat{p}_1 - \hat{p}_2) \Big/ \sqrt{\hat{p} * (1 - \hat{p}) * \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

For site 1, $\hat{p}_1 = x_1/n_1 = 15/90$ and $\hat{p}_2 = x_2/n_2 = 25/128$. Thus, $z = 0.5380$.

Then the Z-test statistic was converted to a p-value using a normal distribution probability function. The p-value can then be compared to $\alpha = 0.05$. If the p-value is greater than 0.05, then we fail to reject the hypothesis and the upstream percentages are the same (i.e., there is no statistically significant difference). Table 4 provides the results of this analysis and demonstrates that no differences in the distraction rates were found in the upstream data.

The researchers then looked at the data collected at the downstream location of each site with and without the TPRSs deployed. The total number of drivers observed does not exactly match the upstream data in Table 3 because:

- Vehicles may have entered or exited the advance warning area of the work zone between the upstream and downstream locations.

Table 3. Summary of TPRS data collected at upstream locations.

Site No.	TPRSs Deployed Downstream	Total No. of Drivers Observed	Number and Percentage of Distracted Drivers
1	Yes	90	15 (17%)
	No	128	25 (20%)
2	Yes	134	15 (11%)
	No	113	15 (13%)
3	Yes	84	14 (17%)
	No	110	18 (18%)
4	Yes	101	21 (21%)
	No	98	22 (22%)

Table 4. Results of TPRS statistical analysis of distracted drivers at upstream locations.

Site No.	Pooled Sample Proportion, $\hat{p}$	Z-test statistic, z	p-value	Statistically Significant Difference
1	18.3%	0.5380	0.5906	No
2	12.1%	0.4986	0.6180	No
3	17.2%	0.1763	0.8601	No
4	21.6%	0.2839	0.7765	No

- Some vehicles may have been missed at either location due to coordinated start and stop times for data collection.
- Driver attention may not have been discernable by one or both data collectors.

The researchers also noted whether the work operation (i.e., flagger, work vehicles, or queue traffic at the flagger station) was visible from the downstream position. Table 5 summarizes downstream location data.

The researchers calculated the percent change in distraction rates for each site with and without the TPRSs deployed (Table 6).

Considering the sample sizes of the data used to calculate each percentage, which ranged from 84 to 141 observations, an error in researcher categorization of distraction by as few as one or two drivers could have an impact on the change in percentage (Δp). Thus, the small increases of 1 percent in Table 6 are essentially negligible.

At site 1, the changes in percentages were insignificant. Both the upstream and downstream locations were in areas of similar roadside development, and the work operation was not visible from the downstream location during either data collection period. Table 7 shows a breakdown of the distracted driving behaviors observed at site 1. Differences in driver attention with and without the TPRSs present were not apparent at this site.

At site 2, roadside development was similar at both the upstream and downstream locations, and the work operation was not visible from the downstream location during either data collection period. While collecting data without the TPRSs present, the researchers noted that many of the distracted drivers appeared to be glancing at a recreational facility situated near the downstream location. This behavior was not as prevalent when the TPRSs were deployed. After ALDOT removed the work zone at the end of the workday, the researchers stayed behind to gather additional data without the work zone present. Even with a very small amount of data,

Table 5. Summary of TPRS data collected at downstream locations.

Site No.	TPRSs Deployed	Total No. of Drivers Observed	Number and Percentage of Distracted Drivers	Work Operation Visible
1	Yes	103	18 (18%)	No
	No	125	26 (21%)	No
2	Yes	136	16 (12%)	No
	No	130	34 (26%)	No
3	Yes	85	9 (11%)	Yes
	No	102	25 (25%)	No
4	Yes	107	17 (16%)	No
	No	96	22 (23%)	No

Table 6. Comparison of upstream and downstream distracted driving at TPRS sites.

Site No.	TPRSs Deployed	Upstream Percentage, p_1	Downstream Percentage, p_2	Change in Percentage, Δp
1	Yes	17%	18%	+1%
	No	20%	21%	+1%
2	Yes	11%	12%	+1%
	No	13%	26%	+13%
3	Yes	17%	11%	–6%
	No	18%	25%	+7%
4	Yes	21%	16%	–5%
	No	22%	23%	+1%

Table 7. Site 1 downstream distracted driving behavior details.

Work Zone Present	TPRSs Deployed	Number and Percentage of Distracted Drivers					
		Looking Down	Looking Out Side Window	Looking in Mirror	Looking at Passenger	Using Cellular Phone[1]	Totals
Yes	Yes	4 (22%)	5 (27%)	1 (6%)	1 (6%)	7 (39%)	18 (100%)
Yes	No	8 (31%)	8 (31%)	2 (8%)	1 (4%)	7 (27%)	26 (100%)

[1] Includes those looking at or talking on a cellular phone.

the researchers noted that glances at the recreational facility accounted for half of the distracted behaviors with no work zone present. Thus, the TPRSs may have had an impact on the distraction by the recreational facility at this site. Table 8 shows the breakdown of distracted behaviors at the downstream location at site 2.

At site 3, the downstream location was near the crest of a vertical curve. The site was also at the end of a long (approximately 2-mile) section with limited sight distance due to horizontal and vertical roadway curvature. As drivers came over the hill, they entered a long, straight section of roadway where they could see a significant distance ahead. During the data collection period with the TPRSs deployed, the flagger, work vehicles, and any queued traffic at the flagger station were located near the downstream location and could easily be seen by approaching drivers. During the data collection period without the TPRSs deployed, the work operation was not visible from the downstream location. This likely impacted the distracted driving behaviors recorded at the downstream location of site 3. Table 9 shows the breakdown of distracted behaviors at the downstream location at site 3.

At site 4, drivers approaching the work zone were just crossing the Georgia state line into Alabama. For several miles upstream of the work zone, there was no commercial or retail

Table 8. Site 2 downstream distracted driving behavior details.

Work Zone Present	TPRSs Deployed	Number and Percentage of Distracted Drivers					
		Looking Down	Looking Out Side Window	Looking in Mirror	Looking at Passenger	Using Cellular Phone[1]	Totals
Yes	Yes	3 (19%)	6 (38%)	0 (0%)	1 (6%)	6 (38%)	16 (100%)
Yes	No	8 (24%)	17 (50%)	1 (3%)	2 (6%)	6 (18%)	34 (100%)
No	N/A	1 (14%)	4 (50%)	0 (0%)	1 (13%)	2 (25%)	8 (100%)

[1] Includes those looking at or talking on a cellular phone.

Table 9. Site 3 downstream distracted driving behavior details.

TPRSs Deployed	Number and Percentage of Distracted Drivers					
	Looking Down	Looking Out Side Window	Looking in Mirror	Looking at Passenger	Using Cellular Phone[1]	Totals
Yes	4 (44%)	2 (22%)	0 (0%)	1 (11%)	2 (22%)	9 (100%)
No	9 (36%)	12 (48%)	0 (0%)	2 (8%)	2 (8%)	25 (100%)

[1] Includes those looking at or talking on a cellular phone.

roadside development, the clear zone of the roadway was rather narrow, as Figure 16 shows. As drivers passed the rumble strips, they encountered a wider view and a busy convenience store, as Figure 17 shows. The work operation was not visible during either data collection period.

As with site 2, the researchers noticed that many drivers were distracted by the convenience store when the TPRSs were not present. Thus, a small amount of data was collected after ALDOT removed the work zone at the end of the workday. Table 10 shows the breakdown of distracted behaviors at the downstream location at site 4. It does appear that the TPRSs had an impact on the distraction by the convenience store located at this site.

Overall, the results show that TPRSs likely did reduce the visual distractions at two of the sites (i.e., the recreational facility at site 2 and the convenience store at site 4), but not at the other two sites. In addition, potential site-specific reasons for the lack of an effect of those sites have been presented.

Figure 16. Roadside development upstream of the work zone at site 4.

Figure 17. Roadside development near the downstream location at the site 4 work zone.

Table 10. Site 4 downstream distracted driving behavior details.

Work Zone Present	TPRSs Deployed	Number and Percentage of Distracted Drivers					
		Looking Down	Looking Out Side Window	Looking in Mirror	Looking at Passenger	Using Cellular Phone[1]	Totals
Yes	Yes	6 (35%)	6 (35%)	1 (6%)	0 (0%)	4 (24%)	17 (100%)
Yes	No	0 (24%)	20 (91%)	0 (0%)	0 (0%)	2 (9%)	22 (100%)
No	N/A	0 (14%)	5 (71%)	0 (0%)	0 (0%)	2 (29%)	7 (100%)

[1] Includes those looking at or talking on a cellular phone.

"Watch for Workers When Flashing" Warning Sign

The research team explored options for deploying a "Watch for Workers When Flashing" warning sign that included flashing lights indicating that the message was in effect. During past research efforts, the research team found that LED-style lights, which are very directional, may have reduced attention-getting capability when mounted on temporary portable sign stands such as those used with flexible roll-up signs, particularly in windy conditions (Theiss et al. 2022). Thus, for this research effort, the researchers pursued identification of rigid sign stands that are portable and already incorporate flashing lights, such as the sign shown in Figure 1. Researchers worked with a traffic control vendor to modify the sign, replacing the "Trucks Entering Roadway" warning sign with a "Watch for Workers" warning sign. The work truck detection system was disabled to allow the flashing lights to remain on continuously while researchers collected driver observation data.

During the week of March 14, 2022, data were collected in four different work zones located in the TxDOT Fort Worth District. All the work zones consisted of lane closures on multi-lane, divided highways, which used the TxDOT standard Traffic Control Plan (TCP) shown in Figure 18.

Distracted driving data were recorded with and without the "Watch for Workers When Flashing" sign deployed. Figure 19 shows how the advance warning area was modified when the sign was deployed. Figure 20 shows images from one work zone with and without the sign.

At each site, a team of two researchers simultaneously recorded distracted driving data near the "Road Work Ahead" sign (the upstream location) and immediately after the "Watch for Workers When Flashing" sign (the downstream location). Table 11 summarizes the observations.

At site 8, the researchers captured driver distraction data with the "Watch for Workers When Flashing" sign deployed. After the sign was removed, traffic congestion developed, and no data were collected without the sign deployed. Thus, site 8 data could not be used in the analysis. Table 12 summarizes the data collected at the upstream location of each of the remaining sites.

The two-proportion Z-tests were again used for the analysis of the distracted drivers at the upstream location for this treatment. Table 13 shows the results of this analysis, which demonstrates that no differences in the distraction rates were found in the upstream data.

The researchers then looked at the data collected at the downstream location of each site with and without the "Watch for Workers When Flashing" warning sign deployed. The researchers also noted whether the work operation (i.e., workers, work activity, or work vehicles) was visible from the downstream position. Table 14 summarizes the downstream location data.

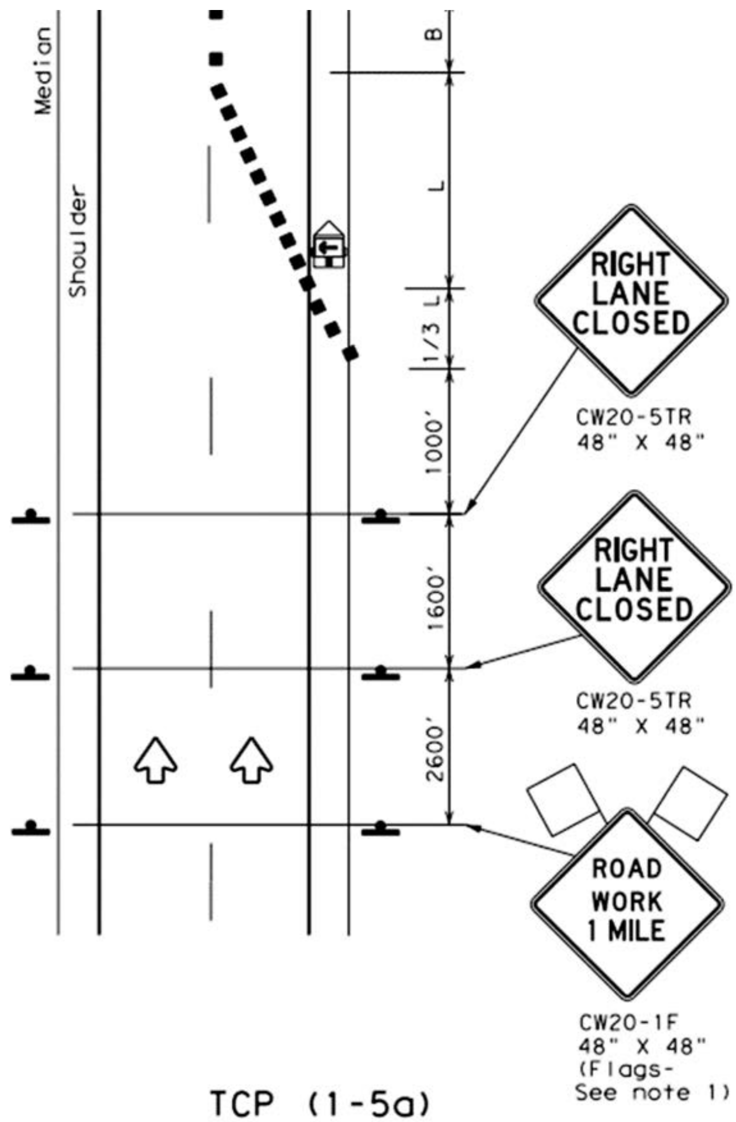

Figure 18. TxDOT TCP (1-5a) lane closure used at sites 6 and 7 (TxDOT 2018).

The researchers calculated the percent change in distraction rates for each site with and without the "Watch for Workers When Flashing" warning sign deployed (Table 15).

At site 5, the upstream location was near an entrance ramp on a freeway with three lanes in the direction of the single lane closure. Distracted driving data were recorded at the upstream location only for vehicles in the right lane (or third lane) since the "Watch for Workers When Flashing" warning sign was located on the right side of the road at the downstream location. When the "Watch for Workers When Flashing" warning sign was deployed, it was located between the first and second advance warning signs (see Figure 19). The work operation was not visible from the downstream location during either data collection period. The data in Table 15 appear to show slight increases in the percentage of distracted driving behaviors at the downstream location, although the increase was greater when the sign was not present. The researchers looked at the breakdown of distracted driving behaviors, which Table 16 shows. The distribution of the various behaviors appears to be very similar, regardless of the presence of the "Watch for Workers When Flashing" warning sign.

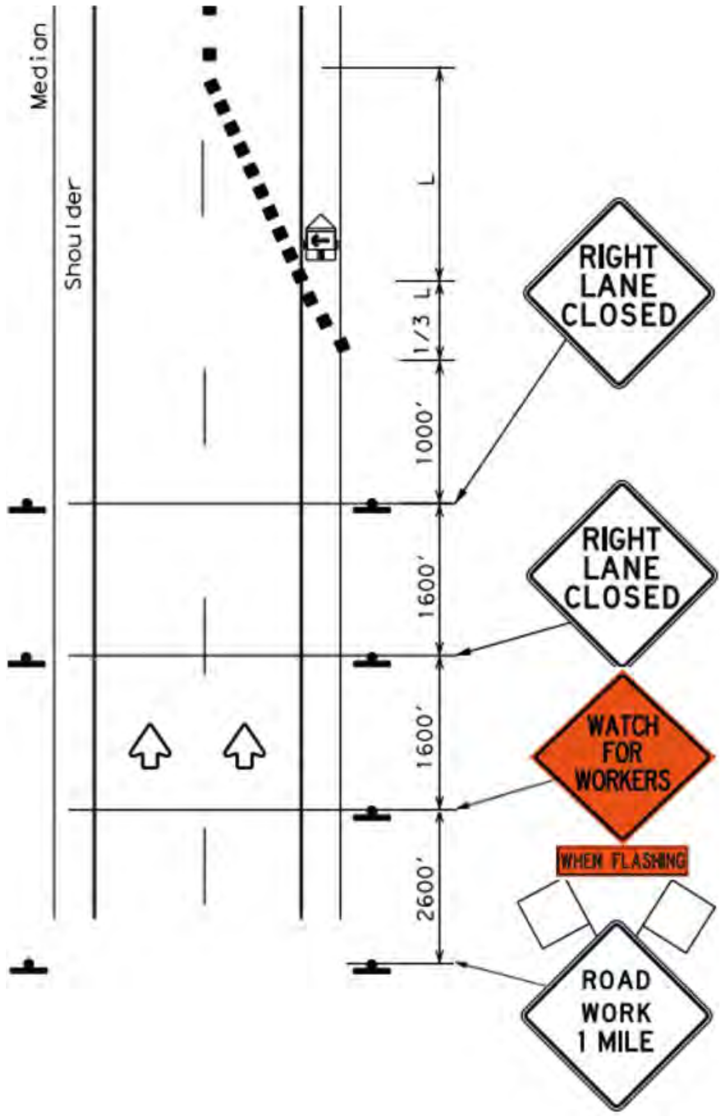

Figure 19. TxDOT TCP 1-5(a) lane closure on divided highways used at site 5 (TxDOT 2018, modified).

Figure 20. Site 6 with and without a "Watch for Workers When Flashing" sign.

Table 11. Data collection summary for the "Watch for Workers When Flashing" sign.

Site No.	Roadway	Direction	Location Description	Posted Speed Limit (mph)	Number of Minutes of Data
5	Interstate 30	Eastbound	East of Ridgmar Blvd.	65	60
6[1]	State Highway 303	Westbound	West of State Highway 161	45	74
7[1]	State Highway 303	Westbound	West of State Highway 161	45	65
8	Interstate 35	Northbound	South of US 67	70	47

[1] Site 6 was a double-right-lane closure, and site 7 was a double-left-lane closure at approximately the same location.

Table 12. Summary of "Watch for Workers When Flashing" warning sign data collected at upstream locations.

Site No.	WFWWF[1] Warning Sign Deployed Downstream	Total No. of Drivers Observed	Number and Percentage of Distracted Drivers
5	Yes	441	84 (19%)
	No	426	84 (20%)
6	Yes	352	82 (23%)
	No	289	67 (23%)
7	Yes	266	42 (15%)
	No	204	41 (20%)

[1] WFWWF = "Watch for Workers When Flashing."

Table 13. Results of "Watch for Workers When Flashing" warning sign statistical analysis of distracted drivers at upstream location.

Site No.	Pooled Sample Proportion, $\hat{p}$	Z-test statistic, z	p-value	Statistically Significant Difference
5	19.4%	0.2498	0.8028	No
6	23.2%	0.0334	0.9733	No
7	19.4%	0.3538	0.7235	No

Table 14. Summary of "Watch for Workers When Flashing" warning sign data collected at downstream locations.

Site No.	WFWWF[1] Warning Sign Deployed	Total No. of Drivers Observed	Number and Percentage of Distracted Drivers	Work Operation Visible
5	Yes	449	103 (23%)	No
	No	447	115 (26%)	No
6	Yes	344	82 (23%)	No
	No	287	67 (23%)	No
7	Yes	274	42 (15%)	Yes
	No	217	49 (23%)	Yes

[1] WFWWF = "Watch for Workers When Flashing."

Table 15. Comparison of upstream and downstream distracted driving at "Watch for Workers When Flashing" warning sign sites.

Site No.	WFWWF[1] Warning Sign Deployed	Upstream Percentage, p_1	Downstream Percentage, p_2	Change in Percentage, Δp
5	Yes	19%	23%	+4%
	No	20%	26%	+6%
6	Yes	23%	23%	0%
	No	23%	23%	0%
7	Yes	15%	15%	0%
	No	20%	23%	+3%

[1] WFWWF = "Watch for Workers When Flashing."

Table 16. Site 5 downstream distracted driving behavior details.

WFWWF[1] Warning Sign Deployed	Number and Percentage of Distracted Drivers					
	Looking Down	Looking Out Side Window	Looking in Mirror	Looking at Passenger	Using Cellular Phone[2]	Totals
Yes	26 (25%)	12 (12%)	8 (8%)	13 (13%)	44 (43%)	103 (100%)
No	24 (21%)	15 (13%)	7 (6%)	17 (15%)	52 (45%)	115 (100%)

[1] WFWWF = "Watch for Workers When Flashing."
[2] Includes those looking at or talking on a cellular phone.

At site 6, the upstream location was near an intersection with a tollway frontage road. Distracted driving data were recorded at the upstream location only for all vehicles, regardless of which of the three lanes they were using. The work zone consisted of a double-right-lane closure for milling work, so all traffic was in a single (left) lane upon reaching the downstream location. The "Watch for Workers When Flashing" warning sign was deployed close to the work area. On this day, the work operation was not visible from the downstream data collection location during the data collection. Table 15 shows no differences in distracted driving behaviors with or without the "Watch for Workers When Flashing" warning sign deployed.

Site 7 data were collected at the same upstream and downstream locations as site 6 on the following day, except the contractor was using a double-left-lane closure to continue the milling and begin the overlay work. When the "Watch for Workers When Flashing" warning sign was deployed, the milling equipment was visible from the downstream data collection location. After the sign was removed, the researchers began to collect data without the warning sign deployed. Before that effort could be completed, the contractor began unloading equipment near the downstream location. This likely impacted the distracted driving behaviors recorded at the downstream location, as Table 17 shows.

Overall, then, the challenges experienced at the sites when attempting to evaluate this particular treatment limits what can be confidently concluded. The data from sites 5 and 7 suggest that the sign may have a small positive effect on distraction in some cases.

Table 17. Site 7 downstream distracted driving behavior details.

WFWWF[1] Warning Sign Deployed	Number and Percentage of Distracted Drivers					
	Looking Down	Looking Out Side Window	Looking in Mirror	Looking at Passenger	Using Cellular Phone[2]	Totals
Yes	14 (33%)	12 (29%)	0 (0%)	1 (3%)	15 (36%)	42 (100%)
No	7 (14%)	17 (35%)	0 (0%)	3 (6%)	22 (45%)	49 (100%)

[1] WFWWF = "Watch for Workers When Flashing."
[2] Includes those looking at or talking on a cellular phone.

CHAPTER 4

Conclusions and Proposals

Conclusions

The researchers investigated the use of two countermeasures for distracted driving: TPRSs and a "Watch for Workers When Flashing" warning sign. The research findings can be summarized as follows:

- TPRSs tended to have a more consistent positive effect in reducing distracted driving than the "Watch for Workers When Flashing" warning sign.
- Although site conditions and activities may have affected the evaluations, the data collected with and without the "Watch for Workers When Flashing" warning sign suggest that the effect of this type of signing is limited in terms of its ability to reduce distracted driving behaviors. However, such signing may have other benefits not evaluated in this study, such as increased signing credibility.

Proposals

As a result of the evaluations, the researchers propose that:

- Transportation agencies and contractors should consider TPRSs as a reasonable countermeasure for reducing driver distraction approaching work zones.
- The "Watch for Workers When Flashing" signing should not be implemented strictly for the purpose of reducing driver distraction approaching work zones. However, based on the data collected, such signing does not appear to increase such distraction and may offer other possible benefits (i.e., improved credibility of work-zone signing).

Suggested Research

The TPRS evaluations were short-term lane closure deployments. It is unknown whether semi-permanent rumble strips deployed upstream of long-term lane closures or other work zones will have similar distraction-reducing effects or whether the effectiveness will decrease over time due to increased local driver familiarity with the work zone. Additional research is needed to evaluate semi-permanent deployments as well as repeated short-term deployments of TPRSs on sequential days (e.g., for daily paving operations).

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GHSA	Governors Highway Safety Association
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

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