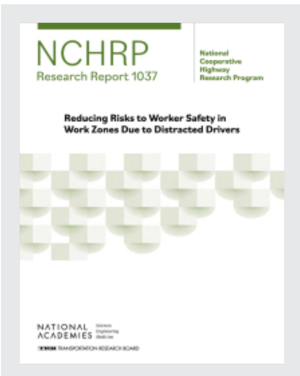

Reducing Risks to Worker Safety in Work Zones Due to Distracted Drivers (2023)

DETAILS

44 pages | 8.5 x 11 | PDF
ISBN 978-0-309-69830-6 | DOI 10.17226/27009

CONTRIBUTORS

LuAnn Theiss, Gerald L. Ullman; National Cooperative Highway Research Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

SUGGESTED CITATION

National Academies of Sciences, Engineering, and Medicine. 2023. *Reducing Risks to Worker Safety in Work Zones Due to Distracted Drivers*. Washington, DC: The National Academies Press. https://doi.org/10.17226/27009.

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) 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

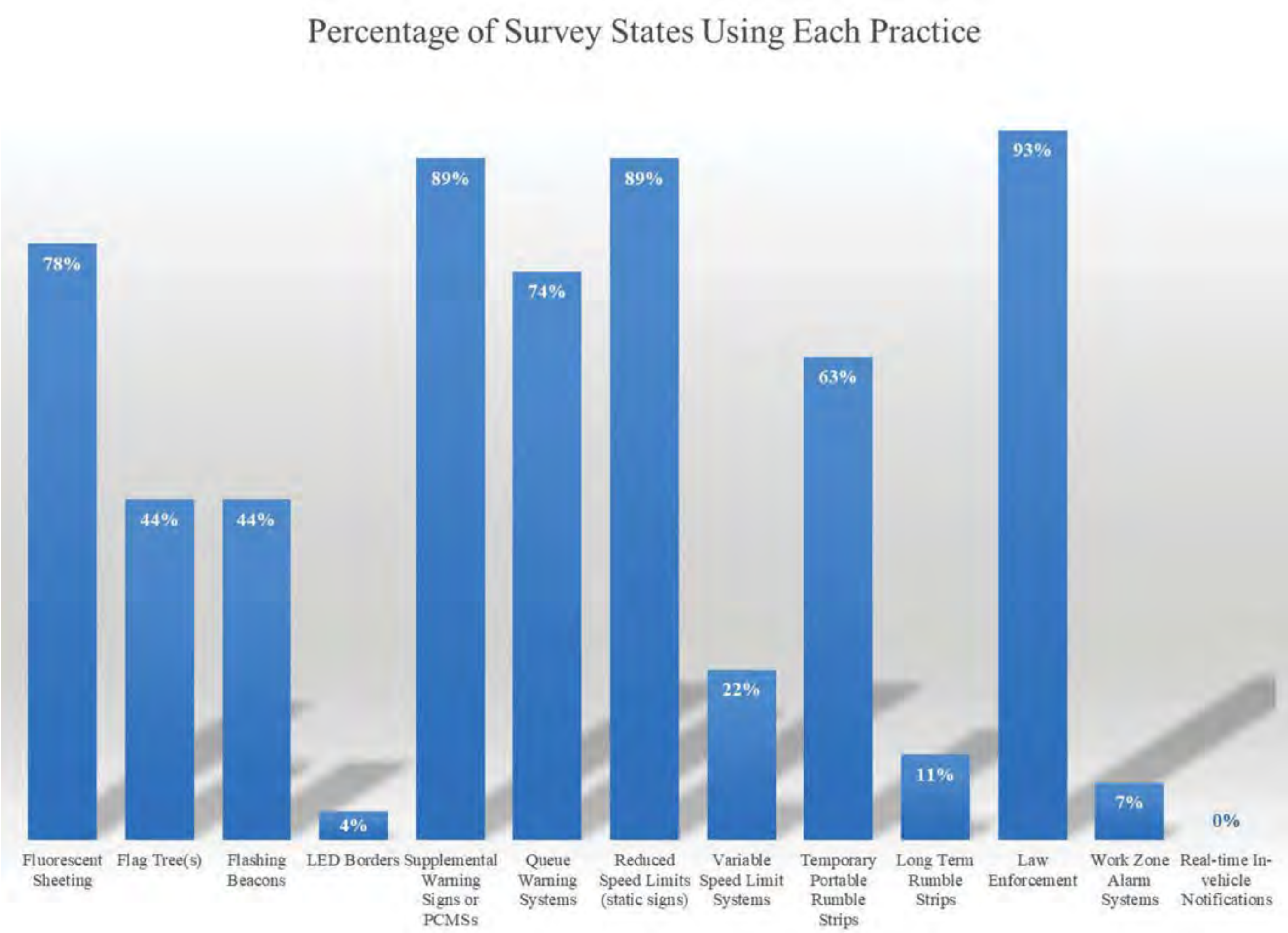

Figure 11. Utilization of various work-zone practices by survey states.

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.