Design and Operation of Work Zone Strategies to Improve Large Truck Safety

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Work Zone Safety Consortium

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Preface

Work zones can create special challenges for drivers of large vehicles, such as commercial motor vehicles, due to space restrictions. Road work must take place within highway rights-of-way and, often, within reduced numbers of lanes. Understanding how work zones can be designed to maintain the efficient movement of large freight transportation vehicles within the restricted right-of-way space and to ensure that DOT and public works staff and highway contractors' employees can safely work within work zones can provide significant benefits for all work zone users.

The U.S. Department of Transportation, Federal Highway Administration (FHWA), the Federal Motor Carrier Safety Administration (FMCSA), the National Highway Traffic Safety Administration (NHTSA), the American Trucking Association (ATA), State Departments of Transportation, local and State law enforcement agencies, academic researchers at the Texas A&M Transportation Institute, and others have worked to develop approaches to reduce the numbers of work zone crashes involving large trucks. This document on design and operation of work zones is a product of this ongoing effort.

Objectives

This document summarizes available methods for transportation agencies and road contractors to design and operate work zones to reduce the risk of large truck crashes.

In this document, large trucks include vehicles commonly referred to as commercial motor vehicles, semi-tractor trailers, 18-wheelers, or semis as well as single-unit trucks larger than 10,000 lbs gross vehicle weight.

This document is organized in the following sections:

1. How Significant Is the Large Truck Safety Issue in Work Zones?
2. Why Are Large Trucks Overrepresented in Work Zone Crashes?
3. Ways to Improve Large Truck Safety in Work Zones
   - 3.1 Work zone design practices to better accommodate large trucks
   - 3.2 Ways to help truck drivers better negotiate work zones

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Refer to http://www.workzonesafety.org for a copy of this document.

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Design and Operation of Work Zone Strategies To Improve Large Truck Safety

1. How Significant Is the Large Truck Safety Issue in Work Zones?

Many entities are concerned about the frequency and severity of large truck crashes that occur in work zones. These include state and local departments of transportation (DOTs), enforcement agencies, state highway safety offices (SHSOs), the U.S. Department of Transportation, Federal Highway Administration (FHWA), the Federal Motor Carrier Safety Administration (FMCSA), the National Highway Traffic Safety Administration (NHTSA), the American Trucking Association (ATA), and others. Annually, large trucks are involved in approximately 130 fatal crashes occurring in work zones. This is equivalent to about one-fourth of all fatal work zone crashes nationally (see Figure 1). In comparison, large trucks are only involved in about 9 to 12 percent of fatal crashes outside of work zones nationally each year.

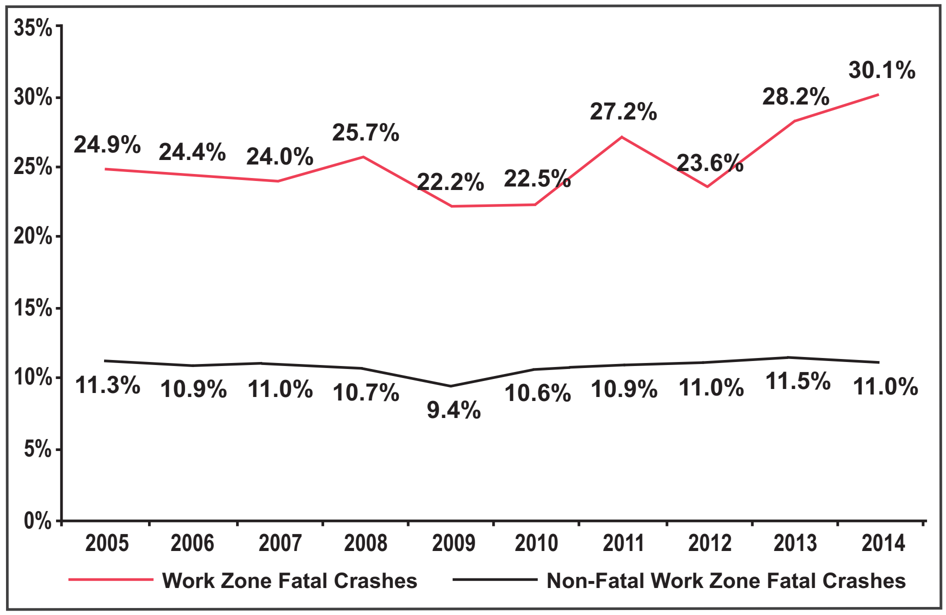


Figure 1. Percentage of fatal crashes nationally that involved at least one large truck *(Source: NHTSA Fatality Analysis Report System (FARS)).*

Many large truck-involved fatal work zone crashes occur on rural and urban high-speed facilities. On rural interstates, large trucks are involved in more than 50 percent of fatal work zone crashes that occur during the daytime (6 am to 7 pm) (see Figure 2). In urban areas, large trucks are involved in about one-third of fatal work zone crashes on interstates and freeways occurring during the nighttime (7 pm to 6 am). The frequency of nighttime incidents is likely due to the need to push most work activity to nighttime hours in urban areas. Although national statistics on injury and property-damage-only work zone crashes are not available, data from a sample of state DOTs suggest that large trucks are also overrepresented in these types of crashes.

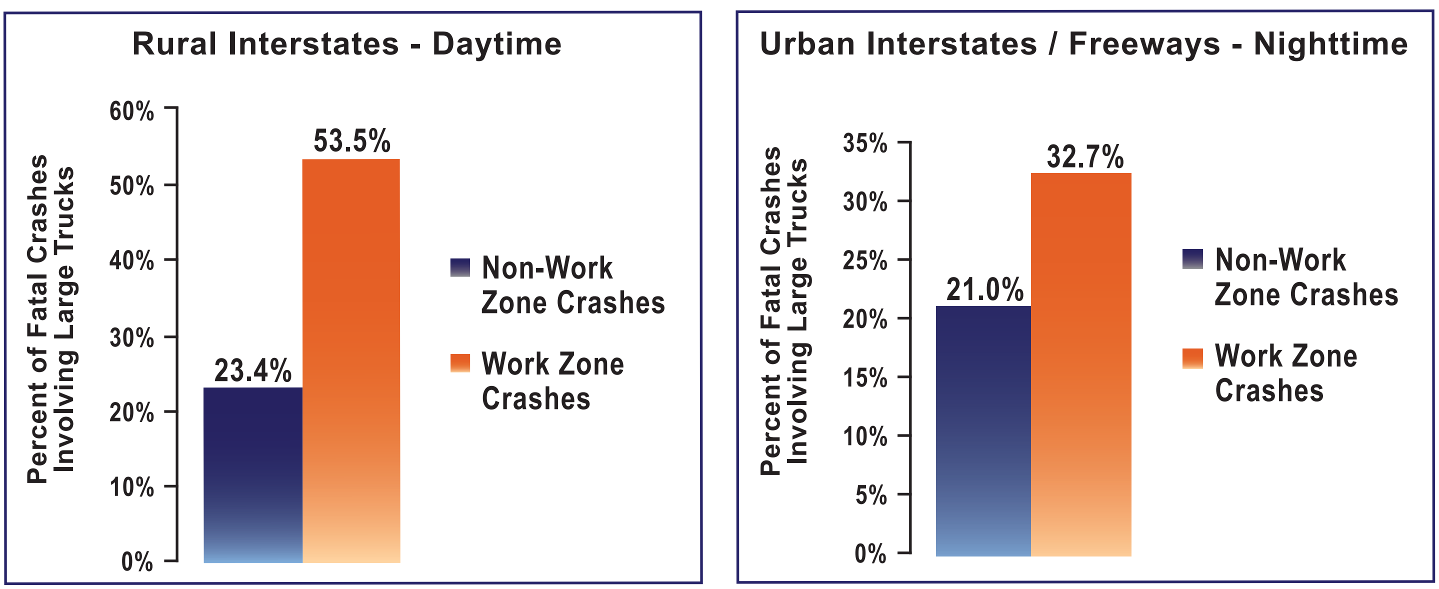


Figure 2. Large truck involvement in work zone and non-work zone fatal crashes on rural and urban interstates and freeways *(Source: 2010-2012 NHTSA FARS).*

Many work zones utilize large trucks for material and equipment deliveries, which some have theorized contribute to the higher crash involvement rates. However, based on the 2010-2012 FARS (NHTSA Fatality Analysis Report System) data, the contribution of these delivery trucks to large truck-involved work zone crashes has been fairly small. Specifically, large trucks that were parked or working inside work zones were involved in only three percent of all fatal work zone crashes nationally. Outside of work zones, the same FARS data shows that large trucks parked or working at the time of the crash comprised less than one percent of the fatal crashes that occurred.

Types of Crashes

Crashes that involve large trucks running into the rear of another vehicle at or upstream of a work zone are often very severe and usually receive a lot of media attention. However, large trucks are actually overrepresented in several types of work zone crashes, depending on the type of roadway where the work zone is located. As Table 1 shows, large trucks are overrepresented in rear-end collisions and also sideswipe crashes at work zones on high-speed controlled-access facilities such as interstates, freeways, and expressways. At work zones on other multi-lane roadways, large trucks are overrepresented in sideswipe collisions, angle collisions, and single-vehicle object impact collisions. Finally, work zones on two-lane, two-way highways experience an overrepresentation of large-truck rear-end collisions during daytime hours and head-on collisions during nighttime hours.

Table 1. Types of Work Zone Crashes Where Large Trucks Are Overrepresented, by Roadway Type
(Source: NHTSA Fatality Analysis Report System (FARS)).

Roadway Type	Types of Crashes Where Large Trucks Are Overrepresented
High-Speed Controlled Access Roadways	• Rear-End Collisions • Sideswipe Collisions
Other Multi-Lane Roadways	• Sideswipe Collisions • Collisions
Two-Lane Highways	• Impacts with Objects • Rear-End Collisions • Head-One Collisions

2. Why Are Large Trucks Overrepresented in Work Zone Crashes?

Table 2 on page 3 summarizes possible reasons why large trucks tend to be overrepresented in work zone crashes. Large truck size, mass, and center of gravity characteristics differ from those of personal vehicles (automobiles, sport utility vehicles, pickups, motorcycles, etc.). Trucks are also longer and wider than personal vehicles (see Figure 3 on page 3). In work zones, this means less lateral clearance and recovery area for large trucks when compared to other vehicles. Large trucks are also much heavier than personal vehicles and have more kinetic energy to dissipate, increasing the potential severity of a crash if one occurs. Finally, large trucks have a higher center-of-mass than most other vehicles, which can exaggerate the effects of changes in pavement cross-slope upon vehicle handling characteristics.

Large trucks also have more challenging operating characteristics than do personal vehicles, which may further contribute to the higher crash involvement in work zones. Certainly, large trucks have larger blind spots, and when coupled with the need to merge out of an upcoming closed lane at a work zone, this can contribute to the higher crash involvement levels. In addition, trucks accelerate and decelerate much differently from personal vehicles. These differences can sometimes create road rage stress for both truck drivers and drivers of personal vehicles trying to pass them. Ultimately, this stress can manifest itself in aggressive behavior (personal vehicles passing trucks improperly) as well as defensive behavior (truck drivers straddling lane lines or lining up together to restrict passing by personal vehicles).

Table 2. Large Truck Characteristics Relative to Other Vehicles

	Characteristics	Implications to Work Zone Designs
Physical	Longer and wider	Less lateral clearance and recovery area
	Heavier	More kinetic energy to dissipate, increasing crash severity
	Higher center-of-gravity	Pavement cross-slope changes, crossovers, and significant lane shifts increase chance for losing vehicle control (especially for liquid loads)
Operational	Larger blind spots	More difficult to merge out of a closed lane or see an automobile attempting to merge into the open lane
	Lower acceleration and deceleration rates	Increased frustration of drivers of personal vehicles following large trucks. More challenging for drivers of large trucks to stop in time.
	Greater distance between driver eye and vehicle headlights	Reduced brightness of retroreflective signs or visibility of vehicles ahead at night

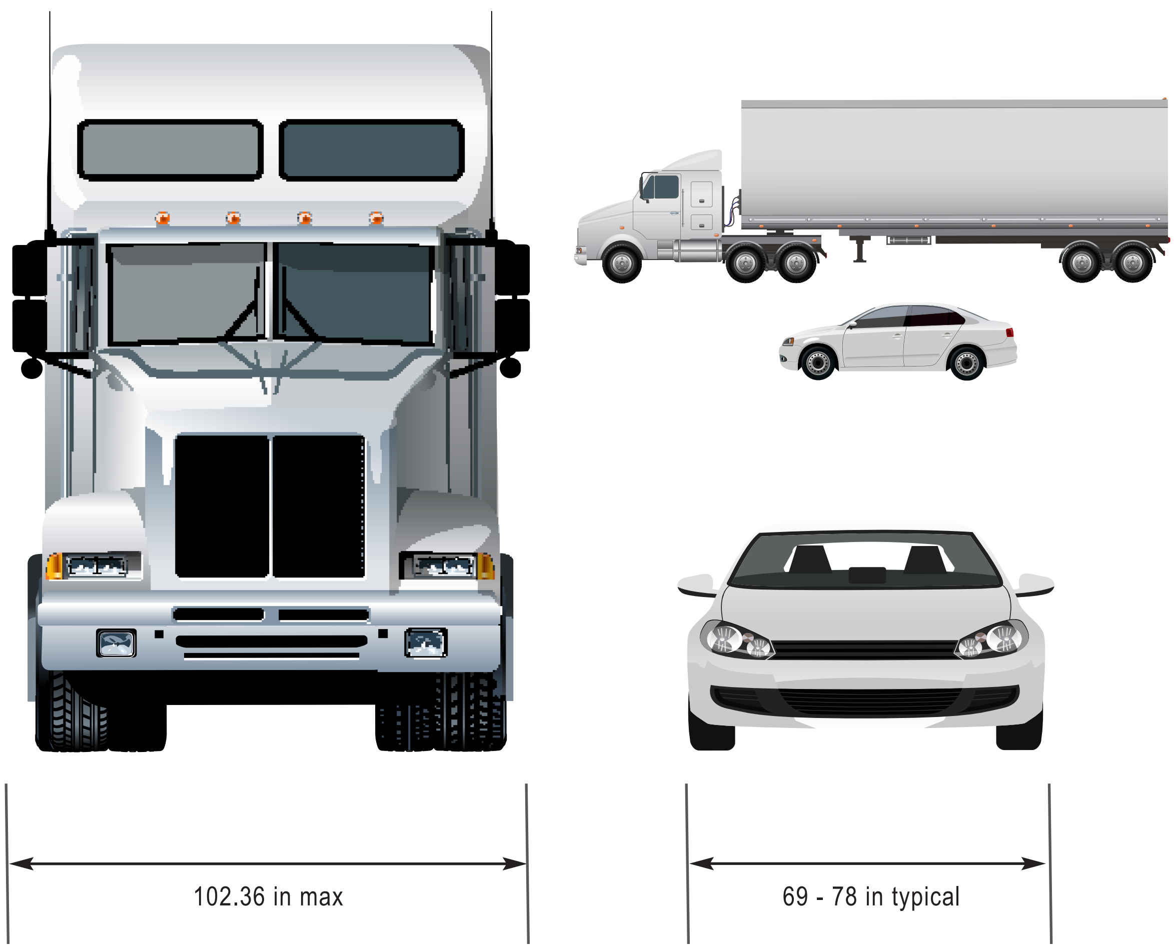


Figure 3. Typical lengths and widths of large trucks and automobiles *(Images: FOF)*.

Large truck designs also put the truck driver's line of sight much higher from their headlight beams than the line of sight is for personal vehicle drivers. Although truck drivers sit higher than passenger vehicles and so can typically see farther ahead, the increased distance between their eye and their vehicle headlights reduces the apparent brightness of retroreflective signs, channelizing devices, and pavement markings relative to what would be seen by automobile drivers, as Figure 4 shows. Under certain conditions, this lower brightness may reduce the legibility of signs and could potentially make it more difficult for truck drivers to detect, comprehend, and respond to those devices in time to react properly.

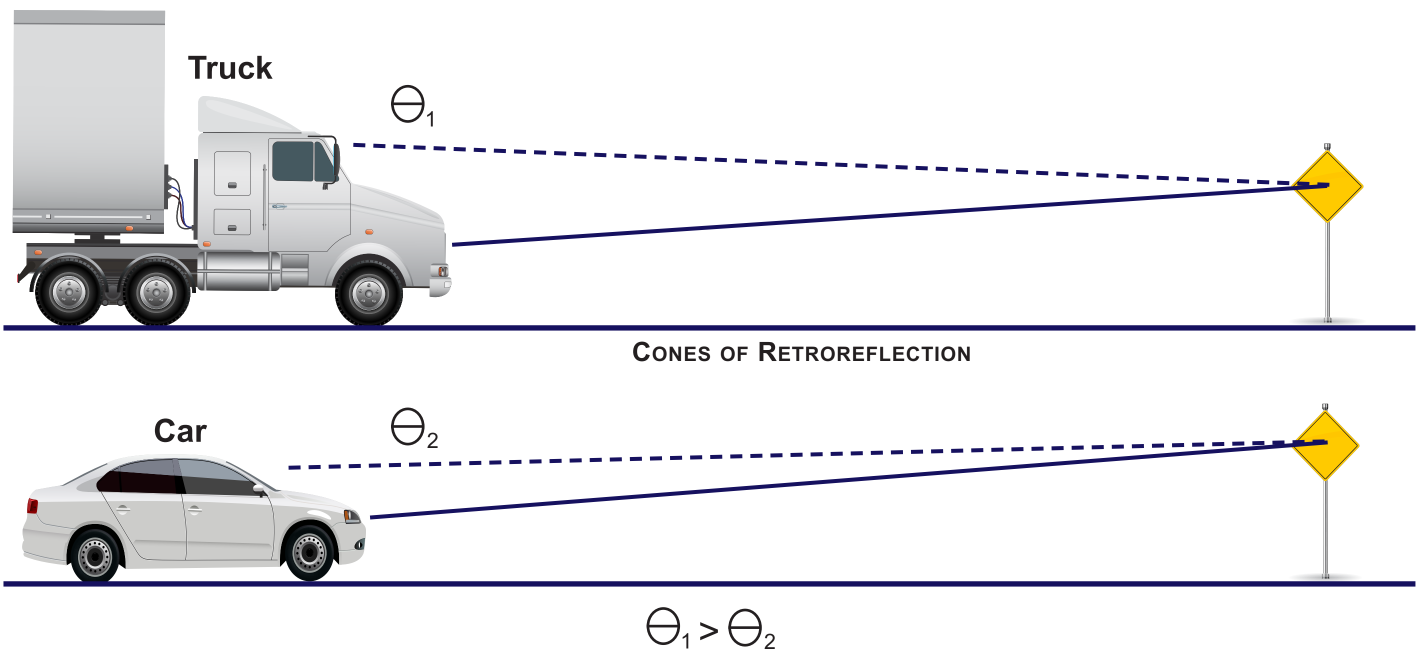


Figure 4. Increased cone of retroreflection reduces the apparent brightness of traffic signs and other devices for truck drivers *(Source: adapted http://www.atssa.com/Retroreflectivity/WhatisRetroreflectivity.aspx Images: FOF).*

3. Ways to Improve Large Truck Safety in Work Zones

Reducing large truck overrepresentation in work zone crashes is a focus area for many federal agencies, state DOTs, local municipalities, and the trucking industry. From the roadway infrastructure side, large truck safety in work zones can be improved through implementation of strategies in two main categories:

- Work zone design practices to better accommodate large trucks, and/or
- Ways to assist drivers of large trucks in better negotiating work zones.

Specific techniques within each of these categories are discussed in the sections that follow.

3.1 Work Zone Design Practices to Better Accommodate Large Trucks

Many work zones require temporary applications of reduced roadway design criteria in order to accomplish the work. Narrowed lanes, temporary shoulder closures, use of temporary barriers to separate work activities from traffic, crossovers, lane diversions, cross-street closures, reductions in posted speed limits, and other countermeasures may have to be used to fit the work required into the available right-of-way while still maintaining traffic flow. Depending on the work zone design, these types of changes to the normal roadway cross-section and alignment can be challenging for drivers of large trucks to negotiate. Table 3 on page 5 provides work zone design suggestions to better accommodate large trucks that may also generate positive safety benefits.

Table 3. Work Zone Design Practices to Better Accommodate Large Trucks and Enhance Safety

Roadway Type	Work Zone Design Practices to Better Accommodate Large Trucks
All	• Consider effects of large trucks upon capacity and operations during work zone impact analyses • Provide at least 11-foot lanes (plus a 1 foot buffer if a barrier is used) • Consider designating detour routes around work zones for oversize/overweight trucks • Consider encouraging alternative routes (and designating them as detour routes) for large trucks around work zones if the alternative routes can accommodate them • Consider establishing a truck-only lane through the work zone and diverting automobiles to a detour route around the work zone • Minimize large design speed reductions for lane shifts, crossovers, or other critical geometric features in the work zone • Avoid using rest area parking lots for staging construction equipment and materials • Use high performance sheeting on signs and channelizing devices for greater nighttime visibility to trucks • Incorporate regular cleaning of signs and channelizing devices into bid documents to maintain sufficient nighttime visibility for trucks • Incorporate minimum retroreflectivity specifications for signs and channelizing devices based on Table 2A-3 of the national *Manual on Uniform Traffic Control Devices* (MUTCD), into bid documents to maintain sufficient nighttime visibility • Consider adding a construction delivery work zone speed limit compliance requirement to construction bid documents • Consider using high-level (i.e. Manual for Assessing Safety Hardware [MASH] Test Level 3) crash attenuation devices for work zones
High-speed multi-lane roadways	• When narrower lane widths are needed during construction, consider maintaining one 12-foot lane that trucks can use, and take the lane width reduction from the other lanes that automobiles would still be able to use • Minimize capacity reductions (even for short durations) that will create unexpected queues • If queues are unavoidable, position lane closures so that that upstream end of queues that are expected are not located in areas of limited sight distance; or utilize queue warning systems to provide advance notification of stopped or slow traffic to drivers upstream; or utilize enforcement or maintenance/courtesy patrol vehicles (with lights activated) that try to maintain a position ¼ mile upstream of the queue • Avoid starting lane closures over hill crests, on or just past horizontal curves, or where bridges or other features limit sight distance to the closure • Consider closing entrance ramps if sufficient acceleration lane lengths cannot be maintained during construction or if work zone-induced congestion prevents smooth merging at design speed • Specify work space access points be designed to minimize speed differentials between delivery trucks and main lane traffic • Develop work zone-specific response plans if work zone is located on current hazmat route • Utilize speed display trailers to gain motorists attention when approaching and traveling through a work zone
Other multi-lane and two-lane highways	• Consider restricting left-turn egress by construction delivery vehicles into and/or out of work spaces • Consider creating temporary left turn bays at work space access points to avoid having large trucks for construction deliveries stopped in a through traffic lane • Consider using lower height channelizing devices or low-profile barriers around driveways and intersections to improve sight distance

Properly Incorporate Large Truck Effects into Work Zone Traffic Impact Analyses

Work zone traffic impact analyses are critical to the development of transportation management plans. Properly accounting for large truck effects upon analysis results can significantly improve agency ability to anticipate when and where mitigation strategies are needed, as well as better predict the effectiveness of those mitigation strategies.

In many locations, the time-of-day distribution of large truck travel does not correspond to that of passenger vehicles, and their effect upon work zone capacity can vary significantly over time. For example, expected work zone capacities for lane closures on Interstate 35 in central Texas differ by more than 200 vehicles per hour (vph) over the course of a 24-hour period, based on *Highway Capacity Manual 2010* procedures, due to the range in hourly truck percentages that occur (see Figure 5). Such changes in capacity may alter the results of impacts analysis and expectations regarding traffic queues.

Table 4 on page 7 shows the resulting estimate of queues expected of a nighttime lane closure using input-output analysis using either a single 24-hour average truck percentage versus an actual hour-by-hour truck percentage estimate during the hours of the closure. Using the single 24-hour truck percentage, the analysis suggests that only a very short (0.3-mile) queue will form during the first hour of the closure, but then quickly dissipate. However, using the hourly truck percentages, the analysis suggests that a much longer queue will form and will remain for several hours during the lane closure.

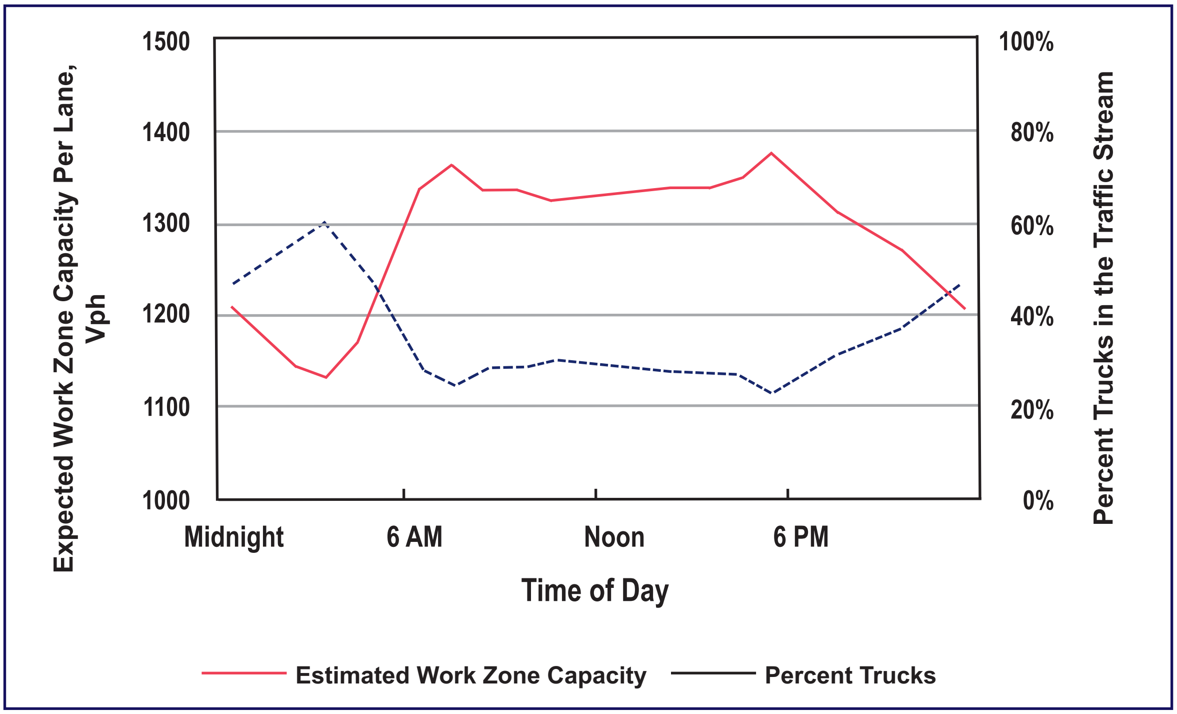


Figure 5. Effect of large truck time-of-day distribution upon expected work zone capacity on Interstate 35 in central Texas. *(Source: Texas A&M Transportation Institute).*

Table 4. Effect of Hourly Differences of Truck Percentage Upon Input-Output Analysis

Hour	Demand Volume, Vph	Actual Hourly Truck %	Estimated Work Zone Capacity, Vph		# of Vehicles Stored in Queue During Hour		Estimated Queue Length at End of Hour	
			Assuming 20% Trucks	Using Actual Hourly Truck %	Using a Constant Truck %	Using an Hourly Truck %	Using a Constant Truck %	Using an Hourly Truck %
7-8 pm	1477	27%	1404	1347	63	130	0.3	0.6
8-9 pm	1340	31%	1404	1312	0	158	0.0	0.7
9-10 pm	1309	34%	1404	1291	0	176	0.0	0.8
10-11 pm	1084	37%	1404	1271	0	0	0.0	0.0

Maintaining Sufficient Lane Widths

As noted above, large trucks are significantly wider than automobiles. As a result, maintaining sufficient lane widths in the work zone to accommodate large trucks is a key priority on any roadway where large trucks typically operate. The narrower the lane, the more attention drivers of large trucks must give to their side-to-side clearance, which may come at the expense of their ability to monitor conditions they are approaching. An 11-foot lane width is necessary, and 12-foot lanes are desirable. On high-speed multi-lane roadways it is usually preferable to maintain one lane at full width for trucks and allow narrower lanes (11 or even 10.5 foot) for personal vehicles, rather than reducing all lane widths uniformly. Signing to indicate that trucks are to use the lane must then be provided far enough upstream to allow truck drivers to move into that lane prior to reaching the laterally-constrained section of the work zone. If sufficient lane widths cannot be maintained, then signing to indicate the reduced lane width can be provided to warn drivers of large trucks so they can divert if they choose. An example of such signing is shown in Figure 6.

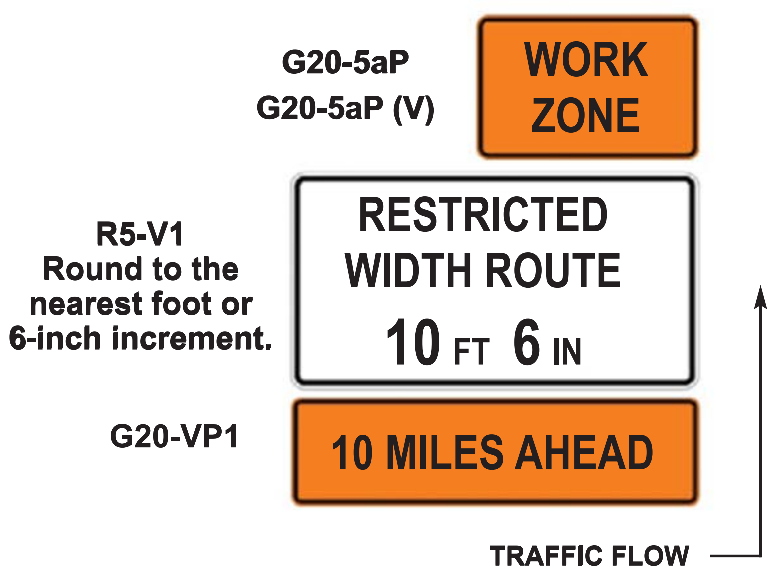


Figure 6. Work zone signing providing specific reduced lane width warning for large trucks
(Source: 2011 VA Work Area Protection Manual, http://www.virginiadot.org/Business/resources/Wrk_zone/Chapter6F_R1.pdf).

Encouraging Trucks to Use Alternative Routes (If Acceptable)

If widths or other temporary pavement conditions are constrained in the work zone, it may be prudent to establish and sign specific detours for large trucks around the work zone. Such detours should be able to accommodate oversize/overweight vehicles. For work zones that can accommodate large trucks, agencies may still want to encourage trucks to use alternative routes without work zones so that the impact of large trucks on work zone capacity and operations is reduced. It is important to ensure that the alternative routes are capable of accommodating these trucks, considering such factors as the expected volume of truck traffic that would use the route, the geometrics of the route, locations with height/width/weight restrictions, etc. Also, the alternative route should not be much longer than the original route, or else it will not be used extensively. Finally, good public outreach about the availability of the alternative route is needed to make this strategy successful.

Create a Truck-Only Lane through the Work Zone

In some situations, it may be more appropriate to keep large trucks on the facility and divert automobiles around the work zone as a way to manage congestion. This might be the case if the detour route could not accommodate large truck turning radii or heights, for example. This approach was successfully used in Virginia during a full-depth paving repair project on Interstate 81. Signing installed upstream of the project instructed large trucks to use the left lane and automobiles to use the right lane. Channelizing devices were then installed on the lane line upstream of the last exit ramp before the work zone to direct the traffic in the right lane off of the interstate and on to the detour route. Large trucks remained on I-81 in the left lane and passed through the work zone. Officials involved with the project indicate that this approach was very successful (see Figure 7).

Figure 7. Creating a truck-only lane through the work zone can be an effective congestion management strategy *(Source: https://farm7.staticflickr.com/6199/6124555951_9a402fe4b8_o.jpg).*

Use an Appropriate Design Speed

Another work zone design practice that benefits all vehicle types, including large trucks, is to avoid reducing the design speed and speed limit on critical work zone features such as crossovers and lane shifts more than 10 mph below the normal speed limit of the roadway. In fact, Section 6C.01 of the national *Manual on Uniform Traffic Control Devices* (MUTCD) recommends avoiding the need to reduce the speed limit through the work zone as much as possible. Even if such features are signed with reduced speed limits and warnings, it is often difficult to obtain good speed compliance without continuous law enforcement presence at those locations. As such, many vehicles may approach the feature at speeds in excess of posted work zone limits and may be surprised by the severity of the feature upon the vehicle's travel path.

Maintaining Sufficient Truck Parking at Rest Areas

At work zone locations where rest areas are located nearby, it can be tempting for agencies and contractors to propose using those areas for staging equipment and materials for the project. However, if this practice results in less space available for large trucks to park, it should be avoided. Truck drivers rely heavily on rest areas as places to take mandated sleep breaks. If construction equipment and/or materials occupy the truck parking spaces in a rest area, truck drivers may be compelled to bypass the rest area and park illegally on ramps or continue driving trying to find parking elsewhere, even though they could be exceeding their maximum hours of service.

Figure 8. Maintain sufficient truck parking at rest areas to permit mandated sleep breaks *(Source: FOF).*

Maintaining Good Sign, Device, and Pavement Marking Retroreflectivity

Agencies with work zones on facilities where significant truck traffic exists should also consider utilizing high intensity retroreflective sheeting on signs and channelizing devices, and should also strive to use higher performing pavement markings. Better nighttime retroreflectivity will help counteract the lower perceived brightness of devices and markings by truck drivers at night. Use of retroreflective devices on temporary concrete barrier can also assist truck traffic in determining the alignment, in particular in transition areas. Agencies should monitor and require regular cleaning and maintenance of the devices to remove accumulated dirt and grime and maintain adequate retroreflectivity throughout the project.

Establishing and Enforcing Work Vehicle Speed Limits

Establishing appropriate speed limits through the work zone is one of the most common strategies agencies use to promote safety for both workers and motorists, including drivers of large trucks. Achieving compliance with reduced speed limits can be challenging. At least one agency has incorporated a requirement specifically for construction delivery vehicles to comply with posted work zone speed limits into their construction bid specifications (see Figure 9 on page 10). This allows the agency to financially penalize the contractor if delivery trucks are found to be consistently exceeding the posted limit. Such a specification might require that detection and verification of speed limit violations occur. Automated speed enforcement technology currently available could be useful for this purpose. Care should be given in determining where it is safe for police officers to position themselves to enforce speeding violations in or near the work zone. Coordination with enforcement officials to determine when and where to position the automated enforcement technology will be helpful.

150.60 Construction Equipment Restrictions:
a) **Load and Speed Restrictions for Construction Vehicles and Equipment** - The Contractor shall comply with legal weight and speed restrictions when moving Materials or Equipment beyond the limits of the Project Site. The Contractor shall control vehicle and Equipment loads and speeds within the Project Site according to the following restrictions, unless the Special Provisions provide otherwise:

- The Contractor shall restrict loads and speeds as necessary to avoid displacement or loss of Materials on Subgrades and Aggregate Bases.
- The Contractor shall restrict weights to legal loads, and shall travel at speeds of no more than 45 mph or the posted construction speed, whichever is less, on treated Bases, Pavement, or wearing Courses.
- The Contractor shall not cross Bridges or other Structures with Equipment or vehicles exceeding the legal load limit without prior written permission of the Engineer. The Contractor shall make any such request in writing, describing the loading details and the arrangement, movement, and position of the Equipment on the Structure. The Contractor shall comply with any restrictions or conditions included in the Engineer's written permission.

Figure 9. Example of a Construction Equipment Speed Limit Compliance Requirement in a standard specification *(Source: Oregon Standard Specifications for Construction, Oregon Department of Transportation, Salem, OR, 2015).*

Avoiding the Creation of Traffic Queues

Lane closures on high-speed multi-lane roadways can create significant hazards for large trucks if traffic queues develop. Therefore, work zone crash risks for large trucks (and other vehicle types) can be reduced by efforts to avoid queue formation. Encouraging large trucks to divert to alternative routes, as mentioned previously, can assist in reducing demand and increasing work zone capacity. Scheduling short duration and short-term lane closures during hours when the reduced work zone capacity will not cause queues to form is another good practice to pursue. Unfortunately, in some locations it is not possible to avoid creating traffic queues during at least some portion of the day or night. In these cases, it is good practice to establish the start of the lane closure where the upstream end of the queue when it forms has good sight distance available and is not hidden over the crest of a vertical curve or just beyond an another area of limited sight distance (horizontal curves, bridge underpasses, etc.).

Crash risks due to queues can also be mitigated by utilizing queue warning systems that employ work zone intelligent transportation system (ITS) technology (additional detail on this technology is provided later in this document). Another effective technique in mitigating traffic queues is the use of enforcement presence patrols that strive to maintain a ¼ mile distance from the end of queue. It is also good practice to locate the beginning of lane closures in areas of good sight distance so that the closure is visible during periods when a queue is not present at the work zone. Portable rumble strips is another device that can be used to gain motorist attention upstream of where queues are anticipated. Additional details regarding their application are also found later in this document.

Avoiding Short or No Acceleration Lane Entrance Ramps

Due to significant blind spots, large trucks face challenges in entrance ramp merging maneuvers under high traffic volumes. If regular acceleration lane lengths at entrance ramps cannot be maintained in a work zone, consideration should be given to temporarily closing the ramp rather than allowing a very short or no acceleration lane to be used with stop or yield control. Large trucks simply cannot get up to speed from a stop condition in a short enough distance to merge into high-speed traffic. Likewise, a high number of large trucks in the right through lane makes it difficult for other drivers to find open gaps in which to merge from a stopped or slowed condition on the ramp. Some agencies use a **TRUCK USE LEFT LANE** sign near interchanges for this reason.

Providing Good Work Space Ingress and Egress Design and Warning

Figure 10. Example of a WORK VEHICLE sign on the rear of a construction vehicle *(Source: VA DOT).*

Although work space access from highway main lanes has traditionally been left up to the contractor to handle, the speed differentials between construction vehicles entering or exiting the work space and through traffic can contribute to increased crash risks. Some agencies have adopted standards for work space access points to minimize those speed differentials. An example of a standard work space access plan for freeways in Ohio is shown in Figure 11 on page 12. Work zone ITS technologies that provide work vehicle/equipment ingress and egress warnings to traffic approaching the work zone may also be beneficial.

Discouraging motorists from following work vehicles into the work space is another useful mitigation strategy at work space access points. Many agencies and contractors require a warning sign on the rear of their construction vehicles that enter and exit the work space delivering or hauling away materials. The recommended sign states **WORK VEHICLE / FREQUENT TURNS** or similar language (such as shown in Figure 10).

Incident Response Considerations for Work Zones on Hazardous Materials Routes

Work zone designs on roadways designated as hazardous material (hazmat) routes should consider the implications of the work activity upon any hazmat response that may be required should a crash occur. A key question to resolve is “from where would the response come?” In some cases, special efforts to ensure emergency vehicle access, or even supplement existing response capabilities with additional vehicles positioned to support hazmat response efforts, may be beneficial. It may also be beneficial to incorporate hazmat response considerations into a project incident management plan. For example, an agency and contractor may decide to establish specific procedures and contacts to ensure quick availability of response vehicles that are adequately equipped to clear incidents involving large trucks and/or hazmat.

Improving Work Zones on Non-Access-Controlled Facilities

Large trucks are overrepresented in work zone angle crashes on multi-lane roadways that are not access controlled. Eliminating conflicting movements within these work zones as much as possible could be beneficial in reducing these types of large truck angle crashes. For example, agencies might choose to prohibit left turns out of the work space as a special provision or specification in the contract. It might also be necessary to close or restrict large trucks from using existing U-turns if work zone geometrics do not allow those trucks to easily complete the turn. An agency might also choose to restripe the traffic space next to work space access points in order to create left-turn bays that provide a refuge area for delivery vehicles and make it easier to make turns into and out of the work space. In addition to reducing angle crashes, the strategy could also be useful in reducing rear-end collisions of passenger vehicles into the back of construction delivery vehicles waiting in a through travel lane to turn left into the work spacel.

For intersection and driveway right-angle conflicts, another practice that could be beneficial is to utilize lower height channelizing devices to delineate the driveway openings and intersections. Lower height devices (low-profile barrier, low-profile longitudinal channelizing devices, cones) make it easier for truck drivers to see other vehicles attempting to pull out into travel lanes, and do not block the vision of passenger vehicle drivers who are attempting to pull out into the travel lanes (see Figure 12 on page 13).

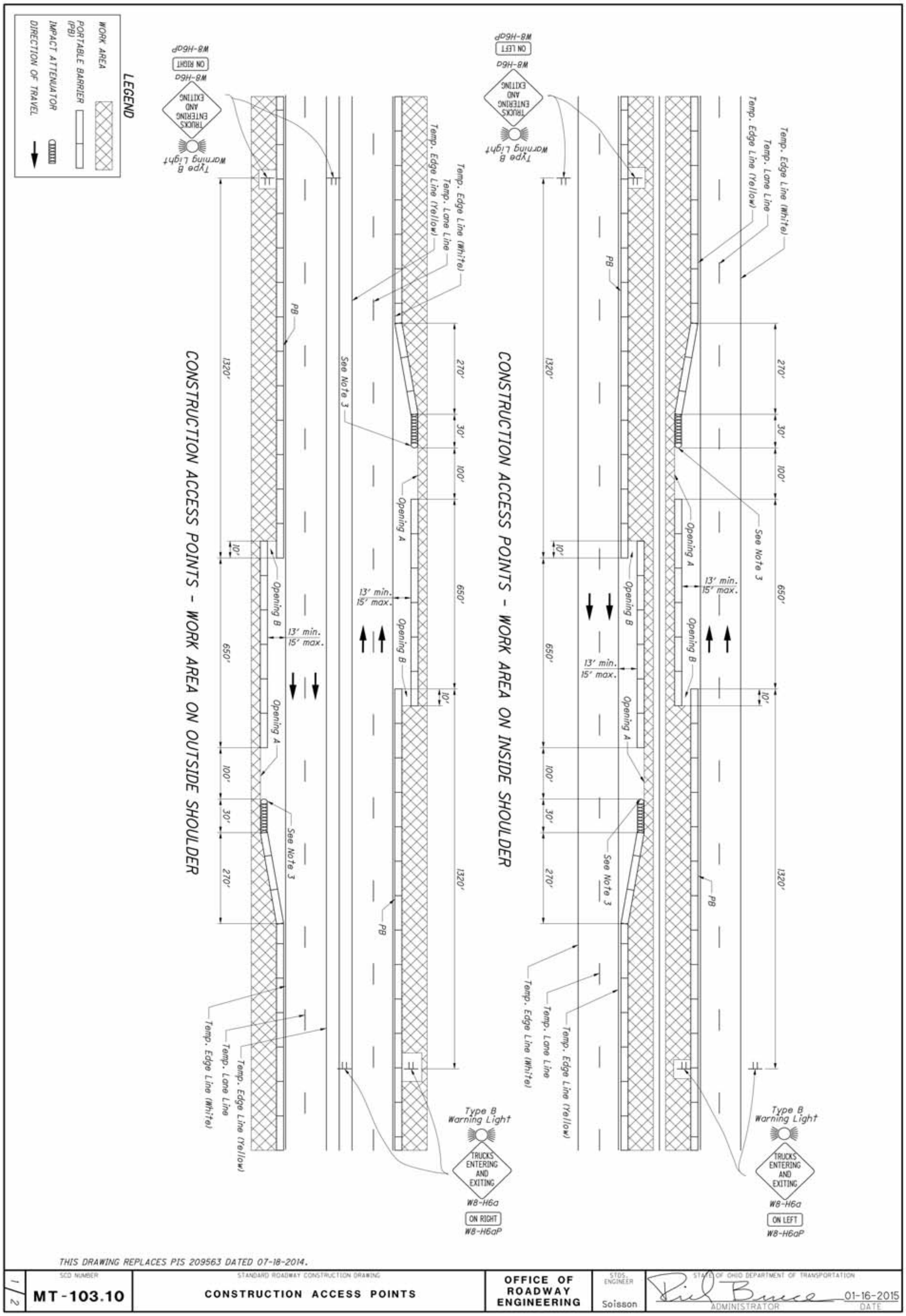


Figure 11. Standard plan for work space access design *(Source: Ohio Department of Transportation, 2015).*

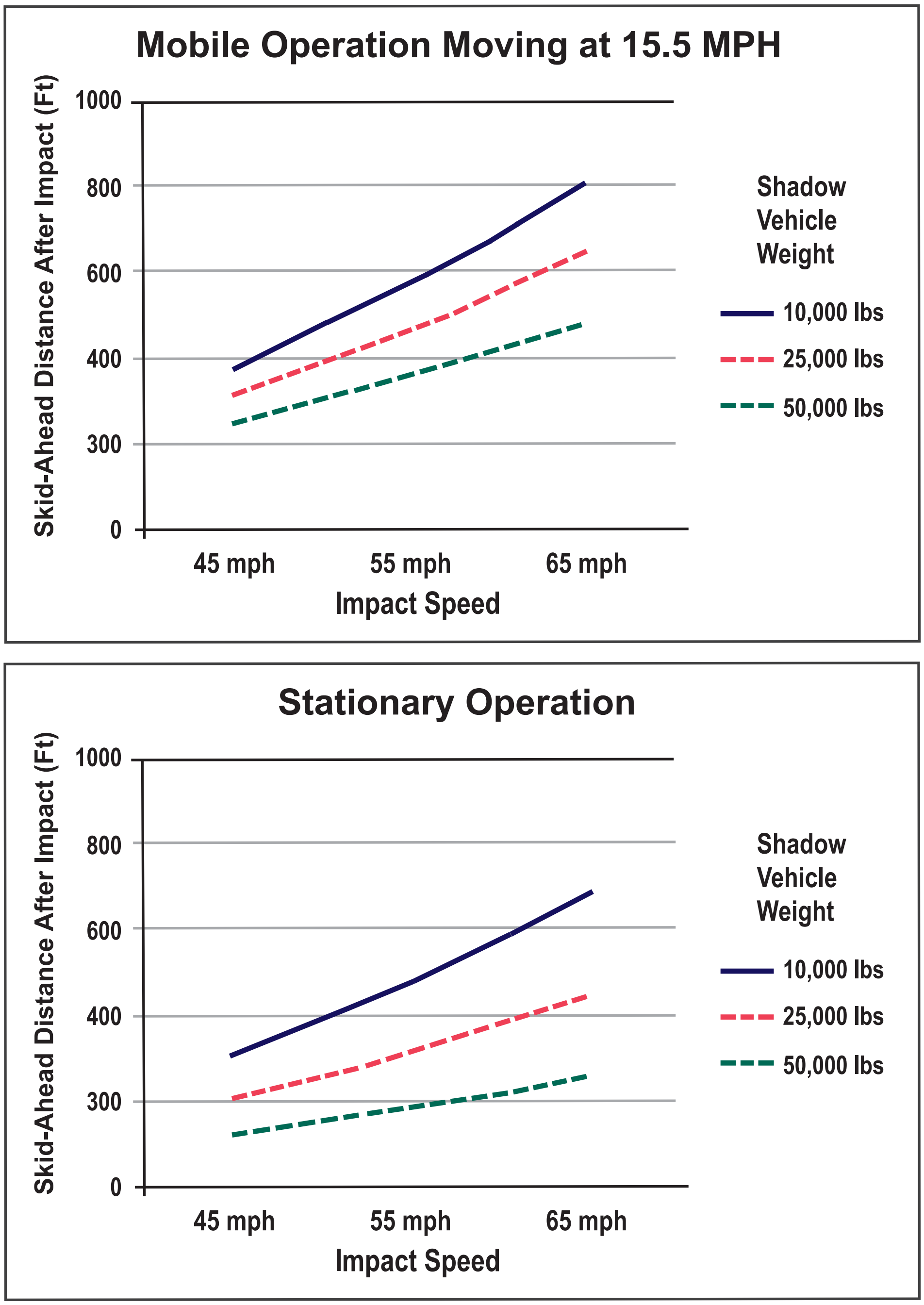
Figure 12. Use of shorter longitudinal channelizing devices to better delineate driveway access points in work zones *(Source: Texas A&M Transportation Institute).*

Improved Shadow Vehicle Size Selection, Attenuator Selection, and Spacing

A final practice suggested for adoption by agencies and contractors does not necessarily reduce the frequency of large truck crashes in work zones, but can significantly reduce the potential for injury to workers if one occurs. Specifically, existing advice on the use of shadow vehicles with truck-mounted attenuators (TMAs) in the *Roadside Design Guide 4th Edition* from the American Association of State Highway and Transportation Officials (AASHTO) provides shadow vehicle spacing recommendations for two shadow vehicle size ranges and operating conditions (stationary or moving at 15.5 mph). Depending on operating speeds on the facility and whether the work operation is stationary or moving, the recommendations suggest that roll-ahead/skid-ahead distances in the event of a rear-end crash with the shadow vehicle/TMA will be approximately 222 feet or less. These values were derived from crash test results performed with automobiles (4,400 lbs). It is assumed that maintaining these distances to the next vehicle in the convoy or to the work crew on the pavement will allow the shadow vehicle to come to a rest before running into the next vehicle or work crew in the event it is impacted from behind.

Today, however, many facilities serve a significant percentage of large trucks in the traffic stream. A rear-end collision by a fully-loaded large truck will likely result in roll-ahead/skid-ahead distances that are much greater than the current advice, increasing the risk of severe injury to both the shadow vehicle operator and any workers on foot in front of the shadow vehicle. For example, Figure 13 on page 14 presents an engineering analysis of the expected skid distance required to dissipate the kinetic energy of a large truck/shadow vehicle rear-end collision at different impact speeds. As the figure suggests, the only way to reduce these distances in the event of such a collision is to increase the size of the shadow vehicle used. On high-speed facilities with significant percentages of large trucks, agencies and contractors would be better protected by using shadow vehicles that weigh at least 50,000 pounds, such as a dump truck loaded with sand or gravel and a truck-mounted attenuator (TMA) attached to the back, and by increasing the spacing. For stationary operations where workers are out on the pavement, it may be necessary to include a second shadow vehicle closer to the work crew that helps keep drivers from attempting to enter the closed lane beyond the first shadow vehicle.

The decision to use a heavier shadow vehicle with a TMA does require proper attention to the type of TMA used with it so that the consequences of any smaller vehicles impacting the shadow vehicle are not adverse. In addition, care must be exercised to ensure that any weight added to the shadow vehicle is properly attached or will be otherwise contained within it so that proper energy dissipation occurs if it is impacted from behind by a large truck.



Notes:
- Assumes the shadow vehicle has a Test Level-3 rated TMA
- Assumes impacting vehicle is providing 25% braking force during impact ride-down
- Assumes shadow vehicle is proving 25% (moving) or 50% (stopped) braking force during impact ride-down

Figure 13. Estimated Skid-Ahead Distances of Shadow Vehicles with TMA Impacted by 80,000-Pound Large Truck
(Source: Texas A&M Transportation Institute).

3.2 Ways to Help Truck Drivers Better Negotiate Work Zones

In addition to making work zone design changes to improve the safety of large trucks in work zones, there are several crash countermeasure technologies that agencies can consider implementing to reduce work zone crash risks to large trucks. Figure 14 summarizes several of the major technologies and strategies available. Some of these also improve safety of passenger vehicles and so provide a dual benefit to agencies and contractors.

Strategies/Technologies Available to Help Truck Drivers Better Negotiate Work Zones
• Encourage truck drivers to activate emergency flashers whenever stopped or slowed at a work zone. An agency might also choose to encourage this behavior by drivers of personal vehicles as well.
• Provide outreach information about work zones and work zone challenges at truck stops, rest areas, dispatchers of major trucking companies, operators of on-board telematics systems, etc.
• Deploy smart work zone queue warning and/or dynamic lane merge warning systems when and where traffic queues are expected to develop
• Deploy temporary portable rumble strips (and optional signing warning of their presence) upstream of temporary lane closures to increase driver alertness and awareness
• Deploy sequential warning light systems on channelizing devices used in the taper of nighttime lane closures
• Utilize enforcement presence patrols maintaining ¼ mile distance from the end of the queue.

Figure 14. Technologies and Strategies Available to Help Truck Drivers Better Negotiate Work Zones
(Source: Texas A&M Transportation Institute).

Encouraging Safe Trucker Driving Behavior

The first two strategies listed involve agency outreach efforts to change truck driver behavior. The first strategy, activating emergency flashers when stopped or slowing rolling through the traffic queue and work, is a simple way for truck drivers to increase their warning to approaching drivers that they are stopped or slowed. The motion of the flashing lights attracts more attention than steady or no brake lights activated. Recent national crash statistics indicate that large trucks are hit from behind by vehicles in work zones as often as large trucks hit the back of other vehicles.

Encouraging driver adoption of this practice can be accomplished through various types of agency or trucking industry outreach efforts such as providing brochures and other outreach materials at truck stops, rest areas, major trucking employers, and elsewhere. Outreach efforts can also focus on specific corridor or route impacts from multiple projects by providing information on current and upcoming project locations, expected impacts, alternative route options, and other tips. An example of an outreach poster targeting truck drivers that was displayed at various truck stops and rest areas during widening of Interstate 35 in central Texas is shown in Figure 15 on page 16. A brochure, *Safe Trucking through Work Zones*, accessible at the National Work Zone Safety Information Clearinghouse, provides tips on how truck drivers can reduce their risks of being involved in a work zone crash.

Ideally, these outreach efforts would result from a comprehensive coordination effort among all stakeholders including the transportation agency, law enforcement, transit, large trucking associations, major trucking companies in the corridor, emergency response providers, and others. Coordination among the stakeholders should begin early in the project planning and design process and continue through to transportation management plan (TMP) development. In addition to the outreach materials that would be included in the public information and outreach component in the TMP, many of the truck considerations listed above would be incorporated into the temporary traffic control component and traffic operations component of the TMP as well. This coordination effort could also lead to the inclusion of special provisions in the contract language to address large truck accommodation needs or constraints that may be required.

Figure 15. Example of a work zone outreach poster
(Source: Texas A&M Transportation Institute).

Use of Work Zone Intelligent Transportation System Technology

Several commercial-off-the-shelf ITS for work zones are now currently available to improve safety and improve traffic flow. Two types of systems that may help improve large truck safety in work zones are queue warning systems and dynamic lane merge (DLM) systems. A queue warning system automatically displays a message on a portable changeable message sign (PCMS) indicating that traffic downstream is stopped or slowed whenever slower traffic speeds are detected near or in the work zone (see Figure 16). The approximate distance to the stopped or slowed traffic is displayed to help drivers gauge how close the congestion is downstream, and also to add credibility to the message that it is indeed current. A fact sheet *Innovative End-of-Queue Warning System Reduces Crashes Up to 45%*, available at the National Work Zone Safety Information Clearinghouse, describes how these systems can significantly reduce crashes when queues are present.

Figure 16. Message displayed on a queue warning system *(Source: Texas A&M Transportation Institute).*

As another example, static signs can be deployed and activated with flashingbeacons to indicate when traffic queues are present, as shown in Figure 17.

Figure 17. Stopped or slow traffic warning sign activated when queues are detected *(Source: Illinois DOT).*

At many work zones, most motorists will move out of the closed travel lane as soon as they see static advance warning signing for the lane closure. This creates a traffic queue in the open lane but leaves the closed lane mostly unused except for those few individuals who choose to remain in the closed lane right up to the lane closure merge point and try to force their way into the open lane. A DLM system is implemented to facilitate smoother traffic flow near the work zone bottleneck, to reduce the overall length of queue, and to reduce or eliminate queue-jumping behavior by some drivers. Whenever a traffic queue is detected near the lane closure, two PCMS are activated. One PCMS is positioned upstream of the maximum expected queue and displays a message to **USE BOTH LANES** (or all lanes if the roadway has more than two lanes per direction). The second PCMS is positioned just before the lane closure merge point. When activated, it displays a message that tells drivers to merge here and to take turns. Figure 18 on page 18 illustrates the messages used for this concept. Utilizing all lanes for storage when a queue is present reduces the total length of the queue. In addition, by eliminating the opportunity for some drivers to “jump” the queue, merging behaviors are smoother and less adversarial between vehicles in the open and closed lanes.

A few agencies (e.g., the Maryland State Highway Administration) are now considering the possibility of blending the queue warning and DLM systems together to provide a hybrid system. An example of the logic for such a proposed system is shown in Figure 19 of page 19.

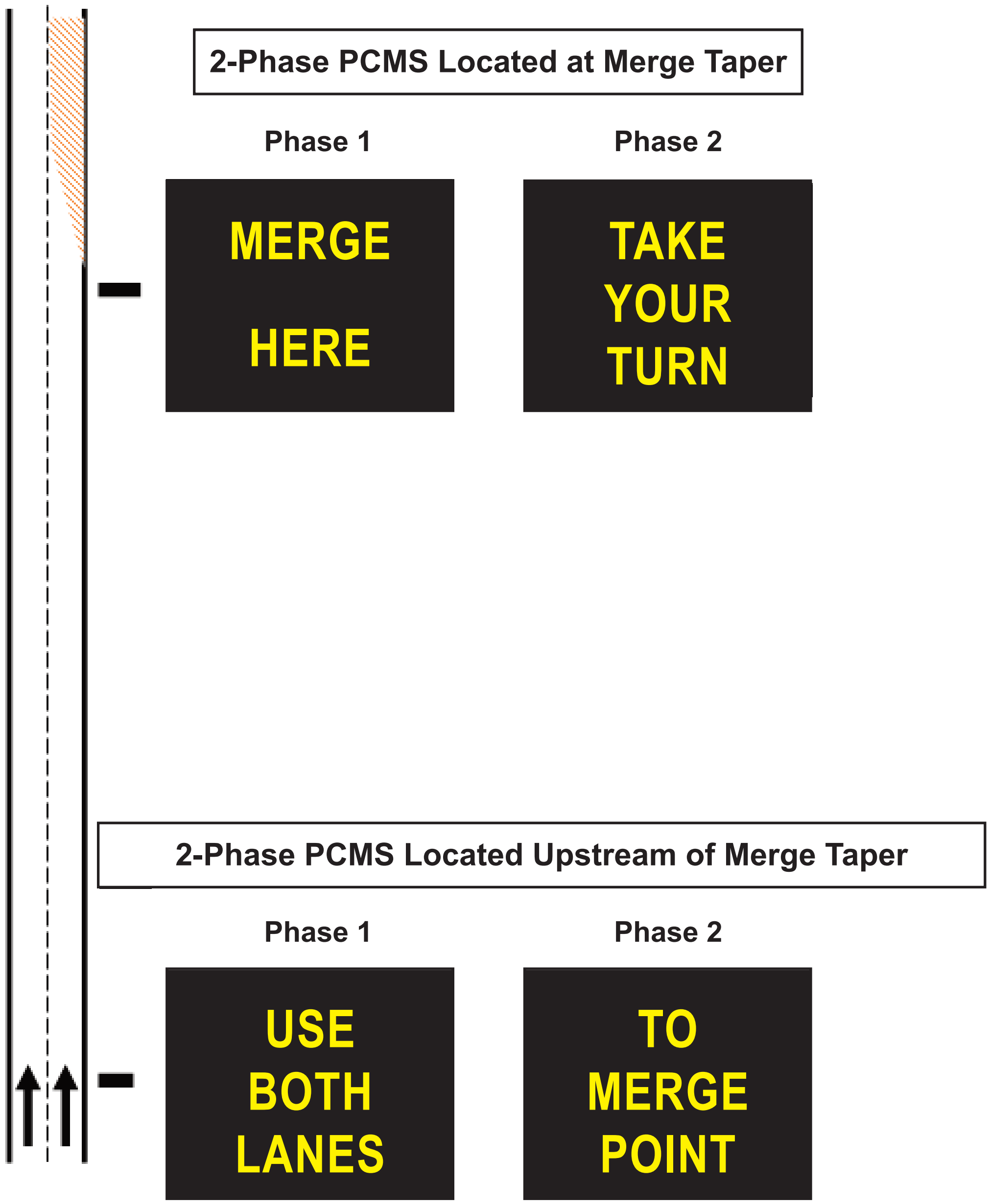
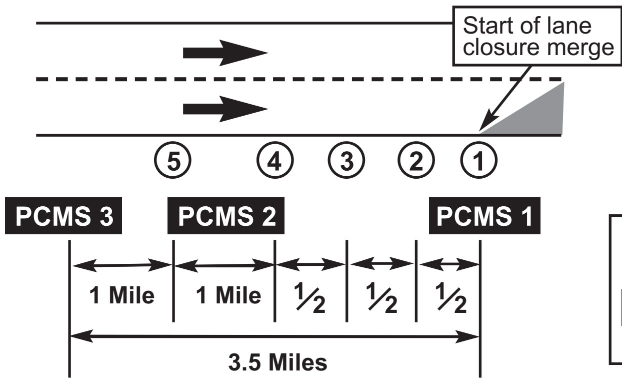


Figure 18. Messages typically used in a DLM (dynamic lane merge) system.



① iCone Traffic Sensor

PCMS Portable Changeable Message Sign

PCMS 3	PCMS 2	PCMS 1	Q	⑤	④	③	②	①
{BLANK}	ROAD WORK 2 MILES	{BLANK}	=0	F	F	F	F	F
{BLANK}	SLOW TRAFFIC 2 MILES	{BLANK}	=0.25	F	F	F	F	M
SLOW TRAFFIC 3 MILE	SLOW TRAFFIC 1 MILE	{BLANK}	=0.75	F	F	F	M	!S
{BLANK}	STOPPED TRAFFIC 2 MILES	{BLANK}	=0.25	F	F	F	F	S
STOPPED TRAFFIC 3 MILES	STOPPED TRAFFIC 1 MILE	{BLANK}	=0.75	F	F	F	!F / S	S / A
STOPPED TRAFFIC 2 MILES / USE BOTH LANES	STOPPED TRAFFIC AHEAD / USE BOTH LANES	MERGE HERE / TAKE TURNS	=1.25	F	F	!F	A	A
STOPPED TRAFFIC 1 MILE / USE BOTH LANES	ROAD WORK 2 MILES / USE BOTH LANES	MERGE HERE / TAKE TURNS	=2	F	!F	A	A	A
STOPPED TRAFFIC AHEAD / USE BOTH LANES	ROAD WORK 2 MILES / USE BOTH LANES	MERGE HERE / TAKE TURNS	>=3	!F	A	A	A	A

Symbol	Condition	Avg Speed (V)
F	Free Flow	40 mph <V
!F	Non Free Flow	V <=40 mph
M	Moderate / Slow	25 mph <=V <=40 mph
!S	Non Stopped	25 mph <=V
S	Stopped	V <25 mph
A	Any	0 <=V

iCone End Of Queue Warning With Dynamic Late-Lane Merge (Type 1 + DLM)

Notes

- Locations of the iCones and the PCMS can be adjusted based on site conditions (ramp locations, other static signing, overpasses, etc.)
- Free Flow/Slow/Stopped traffic trigger speeds are adjustable on a per iCone basis
- Displayed message text is configurable on a per PCMS basis
- "Q" is the calculated queue length from iCone-1, in miles, and resolves to the mid-points between iCones.
- **Condition tables may not cover all possible cases.** Please refer to the specific deployment's logic and settings for details.

Figure 19. A hybrid End of Queue + DLM system concept *(Source: iCone® Image recreated by FOF).*
Note:The U.S. Government does not endorse products or manufacturers.Trademarks or manufacturers' names appear in this report only because they are considered essential to the objective of the document.

Other Traffic Control Devices to Improve Truck Safety

Another fairly recent innovation being used by some agencies to improve safety of all vehicles (including large trucks) are portable transverse rumble strips. Rumble strips create both an audible and tactile alert when driven over by vehicles, and are believed to help increase attention and alertness of drivers. Rumble strips have now been developed that can be easily placed on the pavement when needed without adhesives and then simply picked up when no longer needed. The weight and design of the strips keep them from being moved significantly, even at high speeds (see Figure 20). Although these devices are most often utilized in conjunction with flagging operations on two-lane highways, several agencies have begun to utilize them successfully for short periods on high-speed interstate facilities to attract motorist attention and get them to focus on the upcoming work zone.

Care must be taken when deciding when and where to use these devices, though, as some agencies do have concerns about their effect on motorcycle stability. Several states have chosen to post advance warning signs notifying motorists where temporary rumble strips are deployed. Additional advice on portable rumble strip deployment in work zones is referenced at the end of this document.

Figure 20. Portable transverse rumble strips *(Source: Texas A&M Transportation Institute).*

A final innovation that is being used by some agencies to assist truck drivers approaching work zone lane closures at night is the sequential warning light system. The system consists of a series of wireless interconnected warning lights mounted on large channelizing devices used to close a travel lane. The warning lights flash in sequence repeatedly down the lane closure taper, supporting the message to move out of the closed lane and into the open lane that is being presented by the arrow panel at the merge taper (see Figure 21 on page 21). Past studies have shown the system capable of encouraging truck drivers to vacate the closed lane farther upstream, indicating that it is providing useful information and assisting drivers in recognizing sooner the need to change lanes.

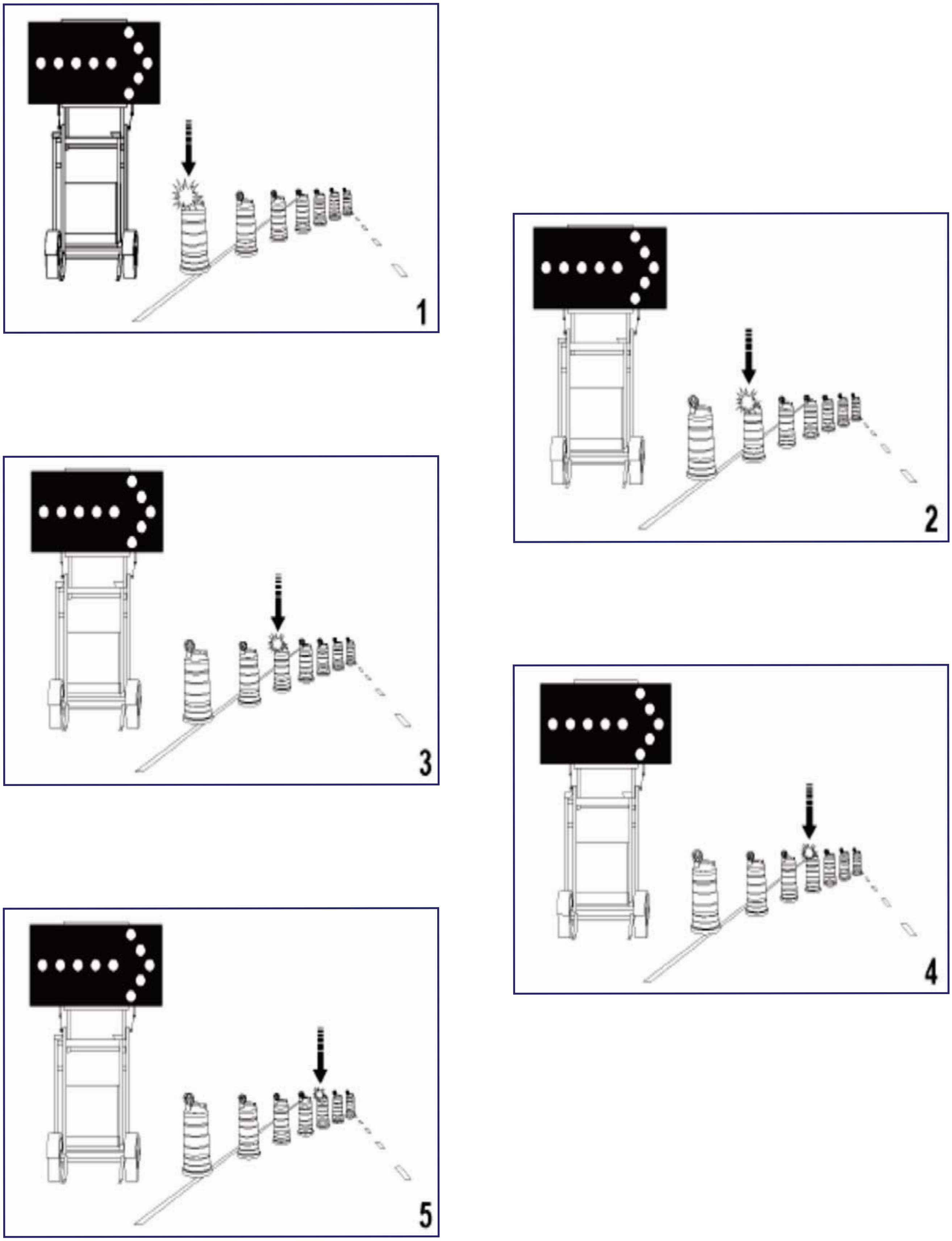


Figure 21. Sequential warning light systems at work zone lane closures
(Source: Report No. TX-00/3983-1, TTI, 1999).

Resources

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2. *Manual on Uniform Traffic Control Devices*. Federal Highway Administration (FHWA), U.S. Department of Transpor tation, Washington, DC. 2009. http://mutcd.fhwa.dot.gov

3. *Manual for Assessing Safety Hardware. American Associations of State Highway Transportation Officials*. (AASHTO), Washington, DC, 2009.Available at https://bookstore.transportation.org/collection_detail.aspx?ID=34

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10. *Smarter Work Zones Toolkit.* Accessible at http://www.workzonesafety.org/swz/

11. *Guidance for the Use of Temporary Rumble Strips in Work Zones. American Traffic Safety Services Association, Fredericksburg, VA, 2013. Accessible at https://www.workzonesafety.org/files/documents/training/fhwa_wz_grant/atssa_temporary_rumble_strips.pdf*

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Together, we represent all segments of the roadway construction industry.

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