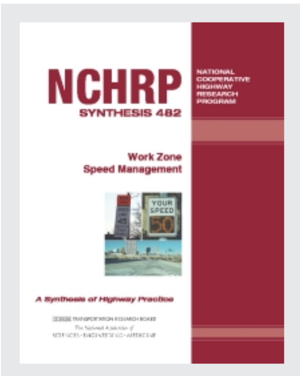

Work Zone Speed Management

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 482

Work Zone Speed Management

A Synthesis of Highway Practice

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Cover figure: Three speed management techniques used in 2014 on the I-794 Hoan Bridge re-decking project in Milwaukee, Wisconsin. (Upper left) Reduced speed limit signs. (Upper right) Dynamic speed feedback display. (Lower) Converging chevron pavement markings (Photos: John Shaw).

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FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Tanya M. Zwahlen
Consultant
Transportation
Research Board

This synthesis documents information regarding the current state of practice for work zone speed management. The report compiles data, procedures, techniques, and technical issues related to observing and comparing work zone speeds. The speed management measures have been organized into four categories: engineering, operational, enforcement, and public education and outreach.

Information included in this study was acquired through a review of the literature, two surveys of state department of transportation representatives in all states, a compilation of state agency public information campaigns, and follow-up interviews with select survey respondents from several U.S. states and one Canadian province.

Madhav V. Chitturi, John W. Shaw, William Bremer, and David A. Noyce, the University of Wisconsin–Madison, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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 www.trb.org) retains the color versions.

WORK ZONE SPEED MANAGEMENT

SUMMARY

Highway work zone safety is of paramount importance to state departments of transportation (DOTs) and other transportation agencies. Contractors, construction and maintenance workers, highway engineers, law enforcement personnel, and road users are important both as stakeholders and as influencers of work zone safety. *Toward Zero Deaths: A National Strategy on Highway Safety* identified six work zone-related strategies for improving highway safety including "improving speed management and enforcement in work zones to reduce the risk of work zone fatalities."

This Synthesis of Practice focuses on speed management for work zones on roadways with ordinary (pre-construction) speed limits of 45 mph and above such as freeways, tollways, multilane divided rural highways, and many two-lane and multilane undivided rural highways. The speed management measures have been organized into four categories: engineering, operational, enforcement, and public education and outreach.

This report presents data and case examples regarding the effectiveness of various speed management techniques, reviews typical agency work zone speed limit setting procedures, provides examples of agency speed management practices and public outreach efforts, discusses some combination techniques, and addresses technical issues related to observing and comparing work zone speeds. Institutional arrangements for implementing work zone speed management are beyond the scope of this synthesis report; however, some resources are listed in chapter one.

Table 25, located at the end of chapter twelve, provides an overview of 28 work zone speed management techniques identified by this synthesis report and summarizes the available information about each technique's effectiveness. Information was gathered through a review of relevant research literature, and from selected U.S. and international highway agency design manuals. Two surveys of state DOT officials were completed: one focused on engineering and enforcement techniques (50 respondents) and the other on public outreach (42 respondents). Information was also acquired through follow-up telephone interviews with selected survey participants and publicly available data about work zone public outreach.

Work zones are complicated driving environments: the cognitive workload for drivers is high and police speed enforcement can be difficult because of space constraints. Transportation professionals are required to balance the need for mobility with work zone safety and the unique characteristics of each site. This balancing can be challenging because of complicated relationships between work zone traffic speeds and overall safety. For example, high-speed traffic may be perceived as dangerous by road workers, whereas stop-and-go traffic can increase the risk of back-of-queue crashes and sideswipes. Nevertheless, driver safety and worker safety are closely linked: as a Canadian study observed, "traffic crashes . . . often spill over into the work areas and put workers at risk."

In 2012, as reported by NHTSA, there were 547 fatalities in work zones in the United States and speeding was cited as a contributing factor in 192 (35.1%). Focusing more narrowly on worker safety, an analysis by the Bureau of Labor Statistics found that during the

years 2003 through 2010, an average of 19 highway workers were killed per year by traffic in U.S. work zones. These fatalities represent a small portion of all work zone crashes. The individual stories behind these statistics sometimes spark efforts to improve work zone safety.

The World Health Organization (WHO) regards speeding as a leading cause of preventable deaths and injuries. A joint WHO/World Bank report observed that higher speed reduces the time available for stopping and crash avoidance, magnifies driver error, and increases crash risk. As impact speed increases, disproportionately more kinetic energy is transferred from vehicles to humans. Consequently, speed reduces crash survivability for bicyclists, pedestrians, and unprotected workers. For example, pedestrians have a 90% chance of survival when struck by a car travelling at 20 mph, but less than a 50% chance of surviving a 30-mph impact. A person on foot has almost no chance of surviving a 50-mph impact.

The surveys and interviews conducted for this study indicate that work zone speed management decisions are generally made on a project-by-project basis, and it is necessary for engineering and enforcement tactics to reflect site conditions. The SHRP 2 Organizational Capability–Maturity model suggests that traffic management effectiveness is strategically enhanced when project-level techniques are integrated into an overall framework that transcends organizational and jurisdictional boundaries.

For example, after a 2012 worker fatality in Saskatchewan (discussed in Case Example 1), reducing work zone speeding became a shared goal uniting contractors, police and highway agency personnel, political leaders, and the public. For Saskatchewan, public outreach now sets the tone and site-specific work zone speed reduction techniques have become part of an ongoing effort to address work zone speeding. In this way, each new highway construction project contributes to what the Toward Zero Deaths National Strategy calls a “long-term process that involves all levels . . . to pursue and sustain the [safety] transformation.”

Most state DOTs have guidelines for setting work zone speed limits. The guidelines are usually based on a combination of agency experience and recommendations from the U.S. *Manual on Uniform Traffic Control Devices* (*MUTCD*). Typical influencing factors include the road type, pre-construction speed limit, presence of workers, worker proximity to traffic, work duration, and physical length of the work zone. The type of separation between workers and traffic (e.g., drums versus a concrete barrier) and state-specific statutory provisions (such as lower limits when workers are present) are also considerations.

Since the 1990s, work zone speed reductions of 10 mph or less have generally been recommended to help ensure that all vehicles in the traffic stream travel at about the same speed. Two newer studies (one in 2008 by Porter and Mason and a second in 2011 by Hou et al.) suggest more complex interactions between posted reductions, work zone site conditions, and speed variance. When reductions of greater than 10 mph are necessary, a stepped reduction (in increments of 5 or 10 mph) is generally considered the most effective practice. Interviews conducted for this project indicate that reinforcing speed-related messages by placing signs on both the left and right sides of the roadway appears to be an increasingly common practice, especially on multilane divided highways.

Many agencies combine multiple speed reduction techniques. To some extent, each treatment deals with a different part of the work zone driving process:

- **Public outreach** (such as radio work zone safety campaigns or project-specific press releases) provides pre-trip information that explains why speed reduction is necessary and requests the public’s cooperation. To be effective, the message must reach a sufficient number of drivers.
- **Upstream treatments** (such as gateway assemblies, transverse rumble strips, speed feedback displays, and police vehicles at the work zone approach) remind drivers that they are approaching an area where speed reduction is required.

- **Buffer area and activity area treatments** (such as automated enforcement using the average speed method, reduced lane width, or pace vehicles) help ensure that drivers continue their speed reduction throughout the work zone.
- **Downstream enforcement** intercepts speed violators observed in the work zone at a location where there is sufficient space for police operations to be carried out safely.
- **Post-work zone treatments** could potentially provide positive feedback to drivers who complied with the work zone speed limit (e.g., thanking drivers for their patience and cooperation). Although these strategies have seldom been attempted, they would be consistent with psychological research findings and elements of the Toward Zero Deaths National Strategy.

Some work zones operate primarily in stable conditions (unsaturated flow), whereas others experience both stable flow and stop-and-go traffic. As a result, it may be necessary to adjust speed management tactics in real time. For example, during stable flow some agencies deploy law enforcement near the activity area to encourage respect for the speed limit as drivers pass by the workforce. When traffic is backed up, it may be more effective to move the enforcement upstream to encourage drivers to slow down as they approach the back of queue.

Some engineering and operational strategies were reviewed for this synthesis report. The use of standard regulatory signs notifying drivers about increased fines in the work zone has *not* proven to be an effective speeding deterrent, except perhaps when combined with a high level of enforcement. Manually operated electronic changeable speed limit signs have emerged as an efficient way to change speed limits based on the presence or absence of workers, but appear to have only a slight effect on speeds compared with conventional signs displaying the same speed limit. Variable speed limits are sophisticated systems that adjust the work zone speed limit based on real-time traffic conditions; however, field results have been inconclusive.

Several radar-based systems have been developed to display targeted messages to speeders. Examples include speed feedback trailers, portable changeable message signs (PCMS) with anti-speeding text, and systems that display the license plate number and speed of an individual vehicle. Typically, these electronic systems have been shown to reduce speeds by 1 to 8 mph; however, the effect appears to diminish as the devices become familiar to drivers, especially if they are not associated with increased enforcement. Similarly, emission of decoy radar signals intended to slow drivers with radar detectors showed good results in early studies; however, interviews with practitioners suggest that effectiveness has declined and drivers quickly become aware of the ruse.

Narrowing the travel lanes has been shown to reduce traffic speeds, but negatively impacts work zone capacity. Temporary transverse rumble strips have been shown to increase driver awareness of flagger stations on two-lane highways, but their effect on deceleration profiles has proven difficult to measure. Mobile barrier systems provide worker protection for short-duration projects, with moderate increases in the speeds of vehicles passing the barrier vehicle. The Emergency Flasher Traffic Control Device simply involves asking drivers to turn on their four-way flashers (hazard lights) to increase visibility of the back-of-queue at flagger stations on two-way, one-lane work zones; small-scale testing in rural highway work zones showed promising results.

Gateway treatments have been used in two Canadian prairie provinces to give drivers the impression of approaching a constrained environment; however, their effect on speeds is unknown. Perceptual devices such as optical speed bars and chevron pavement markings have produced inconclusive results in field studies. Sequential warning lights are primarily intended to draw attention to merging tapers at night; a slight speed reduction may occur as a secondary effect. The use of human flaggers making hand signals to tell drivers to slow down has been shown to reduce speeds if implemented correctly; however, use of this technique appears to be declining owing to worker safety concerns.

State DOTs and their partner law enforcement agencies apply a wide range of policing philosophies and methods for work zone speed enforcement, which are addressed in detail in *NCHRP Report 746: Traffic Enforcement Strategies for Work Zones.* In some states, the view is that the police should be actively patrolling the work zone and issuing as many citations as possible. In other states, the goal is a very visible presence of police vehicles with their lights flashing, and citations are seldom issued except to extreme violators.

A Global Road Safety Partnership report emphasizes the value of enforcement methods based on an anywhere, anytime approach to deter all speeding on the roadway network. The goal is to send a clear message that speeding is illegal and unacceptable behavior, and at odds with the interests of the community. The report says, "Unpredictability of where and when speed enforcement operations take place [encourages] drivers to drive within the speed limit no matter where or when they are travelling."

- **Single-vehicle enforcement techniques.** Work zone speed enforcement is often hampered by lack of space for traffic stops. Some agencies use enforcement techniques similar to those used on ordinary highway segments (such as a patrol that circulates through the work zone and pulls over speeders wherever there is sufficient space). Interviews conducted for this synthesis report indicate that an increasingly used method focuses on slowing traffic upstream of the work zone. In this configuration, the police vehicle is typically positioned at the work zone approach, often with its lights flashing. From this position the officer generally cannot issue tickets, but the police presence reminds drivers to reduce speed. Agencies such as the Pennsylvania State Patrol apply this tactic when there is queued traffic. As the queue grows the police vehicle moves upstream to provide advance warning of the location where drivers need to begin reducing speed.
- **Multi-vehicle enforcement techniques.** The use of two or more police vehicles allows agencies to address space constraints by separating the tasks of identifying and intercepting speeders. One officer observes the traffic and identifies speeders; typically, this officer is positioned at the work zone approach, within the work zone, or on an overpass. The observer communicates by radio with other officer(s) who intercept violators, typically at a location downstream of the work zone. This gives the enforcement team more flexibility to pull over violators in locations where it is easier to re-enter the traffic stream safely after traffic stops are completed. If the observer is dressed as a highway worker and positioned on work equipment, the technique is sometimes publicized as Operation Hardhat or Operation Yellow Jacket.

Automated speed enforcement (ASE) (also called speed photo enforcement or speed cameras) has been shown to be one of the most effective methods for reducing work zone speeding. Although the technique can be controversial (and is statutorily prohibited in some states), statewide work zone ASE programs are ongoing in Illinois and Maryland. Oregon and Washington have also implemented work zone ASE on a limited basis. These programs are discussed in Case Examples 3, 4 and 5.

There are two ASE methods. In the single-point method, citations are based on the vehicle's speed as it passes a single camera. The point-to-point or average speed method uses two or more cameras spaced a known distance apart; citations are based on the travel time between two sites. European experience indicates that the point-to-point method is well-suited to work zones, because it requires the driver to comply with the speed limit throughout the work zone (not just while passing the camera or enforcement vehicle). The point-to-point method also benefits work zone capacity by reducing abrupt speed changes near the camera.

A decade of experience in Europe indicates that comprehensive use of automated enforcement can dramatically reduce crash rates and fatalities. Experience in the United States and the United Kingdom suggests that public outreach is an essential aspect of implementing ASE, to ensure that drivers are fully aware that the system is about to be deployed and understand that it serves a legitimate work zone safety purpose.

Field studies suggest that drivers typically reduce their speeds a little at work zones, but often not enough to achieve compliance with work zone speed limits:

- In a 1990 survey of drivers at a rural freeway work zone in central Illinois, 79% of respondents said the posted 45 mph speed limit was about right, but more than a third admitted to speeding through the work zone.
- A 1999 study found an average decrease in mean speeds of 5.1 mph in work zones where the posted speed limit remained unchanged from the ordinary limit.
- A 2006 Kentucky study found that most freeway drivers were already speeding upstream of the work zone. Although the drivers slowed by 5 to 10 mph, speeds in the work zone usually remained above the limit. The degree of speed reduction depended on whether there was visible work activity. Motorists observed the work zone speed limit only when law enforcement was present.

Toward Zero Deaths: A National Strategy on Highway Safety emphasizes the importance of integrating social sciences research with traditional highway safety approaches. Public outreach campaigns are direct attempts to address the social and psychological influences that contribute to work zone speeding.

Many DOTs develop work zone safety public service announcements (PSAs) on an annual basis, but there have been very few assessments of their effectiveness. To gain a better understanding of current agency practices, 43 PSAs posted by transportation agencies on YouTube were reviewed. Overall view rates were quite low, with a median of 0.96 views per day; however, two videos achieved approximately 100 views per day. Videos featuring workers explaining the hazards of their job and asking drivers to "help keep all of us safe" tended to receive the highest view rates. In comparison, over a 4½-year period, a 1½-minute PSA, *Embrace Life—Always Wear Your Seat Belt* averaged 10,960 views per day (https://www.youtube.com/watch?v=h-8PBx7isoM).

The viewing rate analysis suggests that a positive tone appeals to YouTube viewers. Certainly this is the case in the *Embrace Life* seatbelt video, which makes a deeply emotional appeal to the benefits of safety, rather than showing the consequences of failing to be safe. Many of the 43 work zone PSAs compressed five to six messages (such as speeding, texting, expecting delays, and courtesy) into timeframes as short as 30 seconds. Conversely, most other transportation PSAs focus on a single issue. Many of the PSAs say slow down in work zones; however, none provided a specific numerical speed reduction target. As a result, many viewers may believe that they already comply with the work zone speed reduction message, when actually they routinely exceed work zone speed limits.

Responses to the public outreach survey indicated that work zone safety outreach is hampered by limited budgets for paid advertising in nearly all states. Instead, most state DOTs relied on low-cost media strategies such as press releases, social media, and unpaid PSAs.

Currently, some documented work zone speeding countermeasures are infrequently used in the United States:

- **Pilot and pace vehicles.** Pilot cars are sometimes used to control speeds and guide traffic through flagging operations on two-lane highways, especially in rugged terrain. Pace vehicles are occasionally used for short duration rolling closures on freeways. More routine use of pace vehicles to control freeway work zone speeds has not received much attention from U.S. highway agencies; however, the technique is used in Canada and Australia. A Canadian study recommended using pace vehicles for situations where portable barriers are not feasible and workers must be positioned very close to high-speed traffic.
- **Chicanes.** Chicanes force vehicles to slow down as they negotiate a series of lane shifts. Four U.S. states reported the successful use of a chicane design known as the "Iowa

Weave" to reduce speeds as traffic approaches work zones on lower-volume freeways. Use of this technique is less common in other states. Chicanes are standard practice in some European countries, where they have been used to reduce freeway traffic speeds to as little as 30 mph.

A small number of studies have looked at the effectiveness of combining various techniques. Some combinations shown to be more effective than individual techniques include:

- Florida's Motorist Awareness System, a series of signs and feedback displays at the work zone approach.
- Police enforcement combined with a speed feedback display.
- Police enforcement combined with a variable message sign (VMS) displaying an enforcement message.
- PCMS mounted on equipment displaying work zone safety messages, combined with speed feedback displays.
- Chicanes combined with electronic signage.

There is no universal solution to the work zone speed management problem. At a strategic level, highway agencies must look for engineering, operational, enforcement, and public outreach techniques that can be combined to achieve the desired speed reduction. Individual highway construction projects can be viewed as the means to implement a long-term, agency-wide or regionwide work zone speed reduction strategy aimed at overcoming entrenched driver behaviors that compromise safety for both workers and road users. Within this overall strategy, work zone speed limit selection and associated speed reduction techniques would reflect each project's site conditions (which can change rapidly).

After realistic work zone speed limits have been determined, a combination of project-level speed reduction tactics can be implemented to address different parts of the work zone driving experience. Public outreach can provide pre-trip information that establishes the need for speed reductions greater than what drivers would make voluntarily. Engineering and/or enforcement techniques deployed at the work zone approach can alert drivers and remind them to slow down. Operational speed reduction measures and enforcement within the work zone (potentially including automated enforcement) can help ensure that drivers sustain the desired speed throughout the entire work zone. The area immediately downstream of the work zone is often the best place to pull over speeders. Although it has received very little research attention, methods could potentially be developed to reinforce good behavior by providing positive feedback to drivers who complied with the work zone speed restrictions, perhaps through electronic displays downstream of the work zone or post-construction public outreach.

CHAPTER ONE

INTRODUCTION

Highway work zone safety is of paramount importance to state departments of transportation (DOTs), toll highway authorities, and other transportation agencies. Contractors, construction and maintenance workers, law enforcement personnel, engineers, and road users are also important both as stakeholders and as influencers of work zone safety. *Toward Zero Deaths: A National Strategy on Highway Safety* (TZD Steering Committee 2014) identifies six work zone-related strategies for improving highway safety:

1. Improve speed management and enforcement in work zones to reduce the risk of work zone fatalities.
2. Improve work zone design and operations to reduce the risk of work zone fatalities.
3. Educate drivers on safer driving practices in work zones.
4. Educate workers on safety practices in work zones.
5. Educate judges, prosecutors, and law enforcement on . . . risks related to work zones.
6. Enact legislation and implement automated traffic enforcement—including pervasive automated speed enforcement and applications for school and work zones.

Work zones affect both safety and mobility, and there are complicated relationships between work zone traffic speeds and overall safety. For example, high-speed traffic may be perceived as dangerous by road workers, while unstable stop-and-go traffic conditions in the work zone can increase speed differentials and the risk of a driver being involved in a back-of-queue crash or sideswipe.

Generally speaking, two categories of speeding have been defined (Howard 2008):

1. Excessive speed: exceeding the posted or statutory legal speed limit.
2. Inappropriate speed: driving too fast for the prevailing road and traffic conditions, but within the posted or statutory limits.

Work zone speed management serves three primary objectives:

1. Reducing collision risks for drivers and other road users;
2. Protecting the transportation workforce, including law enforcement personnel operating in the work zone; and
3. Providing effective movement of traffic.

PROBLEM STATEMENT SUMMARY AND SCOPE OF THIS SYNTHESIS REPORT

This Synthesis of Practice focuses on speed management for work zones on roadways with ordinary (preconstruction) speed limits of 45 mph (70 km/h) and above. Such facilities include freeways, tollways, multilane divided rural highways, and many two-lane and multilane undivided rural highways. Work zone speed management for streets and highways with ordinary speed limits below 45 mph is beyond the scope of this report. For this synthesis, speed management techniques have been organized into several categories:

- Engineering Technologies (speed management devices)
- Engineering Techniques (changes in the physical or perceptual driving environment)
- Operational Techniques (using lead vehicles or field personnel to limit traffic speeds)
- Traditional "Human" Enforcement Techniques (police officers in cars)
- Automated Speed Enforcement
- Education and Outreach
- Combinations of the above.

The purpose of this synthesis report is to identify and compile strategies, practices, and technologies that transportation agencies have used to manage speeds and reduce speed-related risks in highway work zones. The information presented in this document has been assembled through:

- A review of the research literature on work zone speed management devices.
- Evaluation of selected portions of design and policy manuals published by U.S., Canadian, and European highway agencies.
- Two surveys of state DOTs. The first survey focused on engineering- and enforcement-related techniques. The second focused on public outreach related to work zone speed management.
- Follow-up interviews with selected survey respondents from several U.S. states and one Canadian province.
- Compilation of information on state agency work zone public information campaigns and associated metrics.

Information discussed includes:

- Available data regarding the effectiveness of various methods and devices for managing speed in work zones.

- Summaries of the methods DOTs and their partner law enforcement agencies have utilized to enforce work zone speed, including automated enforcement.
- An overview of recent work zone safety public outreach materials produced by or on behalf of state DOTs.
- Examples of combination techniques that have been used by highway agencies.
- Case examples illustrating some of the techniques deployed by transportation agencies.

To address the report objectives, this document summarizes current research about the effectiveness of various work zone speed management techniques. As such, it is intended to assist transportation agencies in selecting techniques that are appropriate for each specific work zone, as well as assisting practitioners in selecting statewide or programmatic work zone safety techniques (such as public information campaigns) that reflect what is known about why drivers choose unsafe speeds in work zones. The report also discusses some cases where speed management is unlikely to be effective; in such situations agencies must consider other methods for protecting road users and workers, such as diverting traffic to alternate routes or using barriers to isolate the workforce from live traffic. Although they have a secondary effect on speeds, systems for managing work zone queuing (such as dynamic late merge systems) are beyond the scope of this report. Similarly, this report does not address intrusion alarms or other systems for alerting workers to the approach of errant vehicles.

Although some speed management techniques (such as public outreach campaigns) are programmatic in nature, engineering- and enforcement-related work zone speed management techniques are often implemented at the highway project level. A detailed discussion of all safety-related elements of the work zone planning and design process is beyond the scope of this report; however, it can be recognized that the initial selection of speed management techniques usually begins fairly early in the project planning and design process, often as part of the Transportation Management Plan (TMP) or Maintenance of Traffic (MOT) plan. As each project progresses, its speed management techniques may require adjustment and refinement based on actual field conditions and experience.

While the need to manage work zone speeds exists worldwide, U.S. readers may wish to note that under current (2015) policies, FHWA generally allows highway improvement funds to be used to implement work zone speed management (including law enforcement) on federal-aid projects. Moreover, the speed management process for federal-aid projects does not end when construction is done: Federal Work Zone Safety & Mobility Rule (23 CFR 630) requires states to conduct ongoing work zone performance assessment and process reviews by analyzing crash and operational data from multiple projects and reviewing randomly selected projects. FHWA states that the assessment results are to be used to improve processes and procedures, data and information resources, and training programs for work zones (FHWA 2005).

Appropriate institutional arrangements are required for implementation of work zone speed management techniques and can be particularly challenging for some of the enforcement-related techniques discussed in chapter six. As Hyman has noted (2012):

> Effective work zone management within a transportation agency cuts across organizational boundaries and involves construction, maintenance, safety, and operations personnel. More significantly, many operational strategies . . . require strong cooperation from many different organizations, such as transportation departments, police, fire, emergency medical services, and towing and recovery.

Readers seeking additional information about work zone speed management strategy implementation may find the following resources to be of interest:

- *NCHRP Report 746: Traffic Enforcement Strategies for Work Zones* provides information about the administration of work zone speed enforcement, along with related issues such as determining how much enforcement is required and where to position police vehicles (Ullman et al. 2013).
- *Institutional Architectures to Improve Systems Operations and Management* (SHRP 2 Report S2-L06-RR-1) provides guidance to assess and increase organizational readiness to take on traffic management techniques that require higher levels of internal business process integration and external coordination (Tarnoff et al. 2012).
- ISO Standard 39001 Road Traffic Safety (RTS) Management Systems establishes benchmarks that an organization (such as a work zone oversight agency, highway maintenance department, or construction contractor) can use to establish and certify ongoing efforts to improve work zone safety or other aspects of roadway safety that the organization is able to influence (ISO 2012).
- *Toward Zero Deaths: A National Strategy on Highway Safety* establishes a shared vision for safer roadways that encourages professional collaboration across organizational, jurisdictional, and ideological boundaries (TZD Steering Committee 2014).
- British *Traffic Signs Manual*, Chapter 8 describes techniques for limiting roadworks (work zone) speeds to as little as 10 mph; these techniques may be particularly relevant for urban streets and minor roads (DfT 2013a–c).

OBJECTIVES OF WORK ZONE SPEED MANAGEMENT

A report prepared for the Transportation Association of Canada identified 11 interrelated work zone speed management issues and objectives (Harmelink and Edwards 2005):

1. Work zone speed management philosophy.
2. Extent to which it is desirable and feasible to reduce work zone speeds.

3. Determining where to apply work zone speed limit reductions.
4. Division of work zone safety responsibilities.
5. Roadway type (urban or rural, high or low speed, freeway or nonfreeway).
6. Driver attitudes to work zone speed reductions.
7. Work zone design.
8. Provision of work zone information to the public, including locations, duration, effects, etc.
9. Credibility of work zone signing and posted work zone speeds.
10. Work zone speed reduction techniques.
11. Work zone speed enforcement.

In recent decades there has been gradual change in the approach toward speed management, with increasing emphasis on persuading drivers to select speeds that offer mobility without compromising safety. Human factors and the interaction between road users, vehicles, and the roadway environment have become a greater consideration, with recognition of the need for systems that anticipate and allow for human error while minimizing the risk of casualties (World Health Organization 2008). These considerations are particularly important in work zones because:

- The work zone driving environment usually increases the overall cognitive workload for the driver (owing to narrow lanes, temporary traffic control devices, visual distractions, work zone activities, etc.).
- The enforceability of the speed limit is often hampered by a lack of physical space suitable for issuing citations and safely re-entering the traffic stream.

SPEED AND SAFETY

Because of the wide range of traffic conditions found in work zones, the relationships between operating speed and safety are somewhat complicated. A distinction must be made between work zones that are operating under stable traffic flow conditions and those where the flow is unstable ("stop-and-go" traffic):

- In general, reducing speeds can be expected to improve safety when the traffic flow is stable.
- When conditions become unstable average speeds may decline sharply, but crash rates may increase as a result of abrupt fluctuations in the running speed.

It is also important to recognize that some speed reduction techniques can reduce *average* running speeds while increasing speed variation (differences between the fastest and slowest vehicles), and this can increase crash frequency. Large speed differentials between the fastest and slowest vehicles are associated with rear-end collision risks. Large differences between the speeds in adjacent lanes (unless they are separated by barriers) are also undesirable, as are situations that are likely to provoke a breakdown into unstable flow (or oscillation between stable and unstable flow). Such situations can be exacerbated by other adverse factors that are common in work zones, such as limited sight distance, poor visibility, excessive glare from natural or artificial lighting (e.g., during night work), or work operations that are distracting to the driver.

Khattak and Targa (2004) explored relationships between work zone speeds and crash severity. Their statistical analysis included nearly 3,400 North Carolina work zone crashes that occurred in 2000. As shown in Figure 1, the study modeled the relationship between posted work zone speed limits and the probability that the crash resulted in a casualty (injury or death). Casualty probability increased substantially with higher speeds, given a crash. The study's authors calculated that every 10 mph increase in the authorized speed limit increases the chances that a crash will result in injury by 8% and increases the economic costs of the crash by 15%.

Stable Traffic Flow Conditions

Stable flow generally occurs under low-to-moderate traffic volumes, making it the most frequently observed operational regime in rural work zones (during most hours of the day), and in urban work zones during off-peak hours. Inappropriately high speed is almost certainly a contributing factor in driver and worker casualties in work zones with freely flowing traffic.

In 2004, WHO and the World Bank co-developed a *World Report on Road Traffic Injury Prevention* (Peden et al. 2004). The report takes the perspective that highway crashes caused

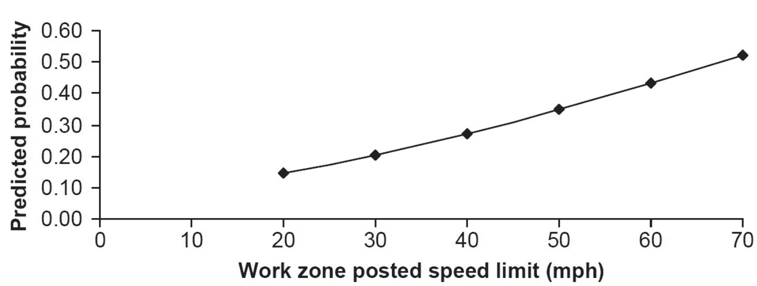


FIGURE 1 Predicted probability of a work zone crash resulting in a casualty (injury or death) for various posted speed limits (Khattak and Targa 2004).

by excessive and inappropriate speed are a preventable public health problem that has become one of the leading causes of injury and death worldwide. The report makes a number of general observations about speed-safety relationships:

- *Higher speed reduces the time available for stopping and crash avoidance.* For example, a car proceeding at 30 mph typically requires approximately 43 ft to stop, whereas one traveling at 25 mph can generally stop in less than 30 ft. Stated somewhat differently, in this instance the 25% increase in speed results in about a 50% longer stopping distance.
- *Speed magnifies driver error and increases crash risk.* An increase in average speed of 1 km/h (0.6 mph) typically results in a 3% higher risk of a crash involving injury, with a 4% to 5% increase for crashes that result in fatalities. Conversely, a 1 km/h decrease in travelling speed can be expected to reduce crashes by 2% to 3%.
- *Speed increases impact severity when a collision does occur.* For car occupants involved in a crash with an impact speed of 50 mph, the likelihood of death is approximately 20 times what it would have been at an impact speed of 20 mph.
- *Speed reduces crash survivability for pedestrians, bicyclists, and unprotected workers.* As shown in Figure 2, pedestrians have been shown to have a 90% chance of survival when struck by a car travelling at 20 mph, but less than a 50% chance of surviving an impact at 30 mph. Pedestrians and unprotected road workers have almost no chance of surviving an impact at 50 mph.

A closely related point is raised in a 2006 report from the Organization for Economic Cooperation & Development:

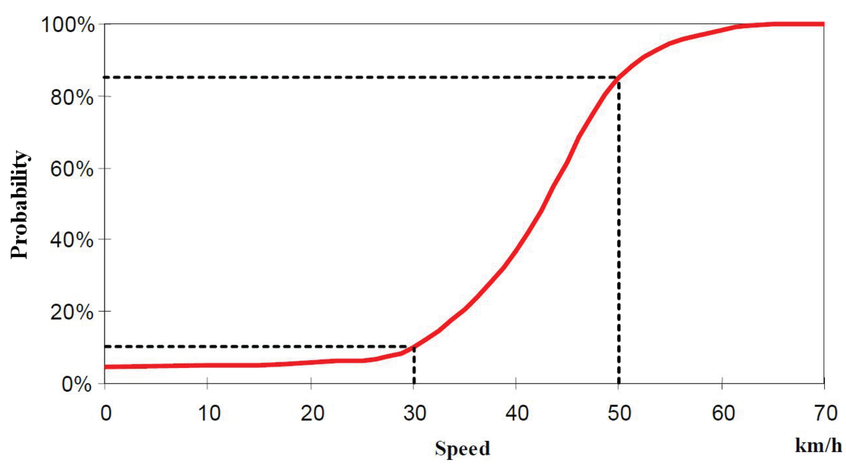
- *Speed reduces a driver's effective field of vision.* As vehicle speed increases, so does the amount of visual information presented to the driver. At higher speeds drivers do not have time to process all of the information that is being gathered visually; the human brain compensates by analyzing only the central part of the image (OECD 2006). As a result, high-speed drivers are less likely to notice objects on the side of the roadway such as workers, work vehicles, or construction debris.

Unstable Traffic Flow Conditions

Unstable traffic flow (stop-and-go traffic) occurs frequently in work zones when the traffic demand exceeds the available capacity. As a result, unstable flow is often associated with urban work zones, especially during peak hours. Unstable flow can also occur in rural work zones, particularly during periods of high demand such as holiday weekends or hours with peak tourist and recreational traffic demand. In both cases, transitions from freely flowing traffic upstream to stop-and-go conditions in the work zone can be hazardous, particularly if the speed change is abrupt, inconsistent with driver expectations, or occurs under conditions that limit visibility.

While excessive speed (exceeding the speed limit) is often the main concern in work zones that are operating under stable traffic flow conditions, inappropriate speed (driving too fast for prevailing conditions) contributes to crashes and near-misses in work zones with stop-and-go traffic. Unstable flow (or oscillation between free-flow and unstable traffic operations) is likely to increase the risk of rear-end crashes and same-direction sideswipes. Two fairly common crash scenarios are:

- When traffic becomes congested, running speeds within a lane can change rapidly. Some drivers overaccelerate as speeds increase, and then brake sharply when the



Source: Interdisciplinary Working Group for Accident Mechanics (1986); Walz et al. (1983); Swedish Ministry of Transport (2002).

FIGURE 2 Probability of fatal injury for a pedestrian colliding with a vehicle (OECD/ECMT 2006; Speed Management: http://www.internationaltransportforum.org/Pub/pdf/06Speed.pdf).

speed drops (Kemer 2009). A driver who misperceives the required deceleration has an increased risk of hitting the rear end of the vehicle ahead.

- In work zones on multilane roadways, highly aggressive drivers may attempt to exceed the prevailing speed by making frequent, abrupt lane changes into the fastest moving lanes. If an aggressive driver misjudges the headway or the traffic speed in the destination lane (or someone fails to yield to the aggressive driver owing to inattention or a blind spot), same-direction sideswipe may occur.

There is a difference between objective safety (the actual number of crashes) and subjective safety (peoples' perception of traffic crash risks). An unintended consequence of unstable traffic flow is that workers may perceive an improvement in their personal safety (owing to lower speeds in the adjacent lanes), while drivers are probably less safe than they would be under stable flow conditions. Anecdotal evidence from the work zone engineering community suggests that contractors occasionally attempt to destabilize the traffic flow (e.g., by unnecessarily narrowing the travel lanes) to achieve this perceived benefit. Such actions by contractors may be based on flawed logic: "the problem is that if motorist safety is reduced in work zones, worker safety is also reduced, because the traffic crashes that occur often spill over into the work areas and put workers at risk" (Harmelink and Edwards 2005).

DRIVER SPEEDING AND SAFETY IN WORK ZONES

Work zone crashes are a significant problem in the United States and worldwide, and speed is often cited as a contributing factor. In 2012, the Fatality Analysis Reporting System (FARS), maintained by the NHTSA, recorded 30,800 fatal motor vehicle crashes in the United States, of which 547 (1.7%) were reported to have occurred in work zones. Among the work zone fatalities, speeding was indicated as a contributing factor in 192 (35.1%).

While FARS tracks only fatal crashes, fatalities represent only a small proportion of all work zone crashes. For example, in Wisconsin 1,675 work zone crashes were reported in 2012, of which only 6 (0.35%) resulted in a fatality (WisDOT 2014a). FHWA has reported that, for work zone crashes that occurred in the United States in 2010, 0.6% were fatal crashes, 30% were injury crashes, and 69% were property damage only crashes (FHWA 2012).

It is important that data from state and national databases be interpreted carefully, because reporting errors potentially bias both the number and severity of reported work zone crashes. Both academic research and investigative journalism (McIntire and Orr 2009) suggest that work zone crashes are underreported, in part because many police agencies do not consider crashes that occur upstream of the ROAD WORK AHEAD signage to be work zone crashes, even when queues caused by the road work extend upstream of the signs. The accuracy of the information reported by law enforcement on the "check the box" sections of crash report forms has also been questioned; for example, comparison of detailed Illinois crash narratives with statistical crash abstracts found that 65% of work zone crashes were miscoded (Raub et al. 2001). Minor crashes were less likely to be correctly attributed to the work zone than severe ones. Crash location was a factor: in general, crashes occurring in the work activity area were correctly identified as construction zone crashes, but those occurring in the approach, transition, or exit were less likely to be properly coded. Based on the narratives, approximately 40% of all crashes occurred in the approach or taper, which is also where speed-related crashes were most prevalent. Taken as a whole, these results suggest that property-damage-only and minor-injury crashes are probably underrepresented in statistical summaries for most U.S. states, making the total number of work zone crashes appear to be lower than what is reported and the severity of a "typical" work zone crash appear to be worse than it is.

In 1998, ARROWS, a European work zone safety study completed an international review of accident studies (Dimitropoulos et al. 1998). The study concluded that work zones typically have higher crash rates than equivalent sections without roadwork. They went on to note that "studies on road user behavior in work zones reveal that speeding, abrupt deceleration and inadequate distances from preceding vehicles occur frequently in road work zones. Such behavior is reasonably characterized as high-risk behavior and assumed to influence traffic safety negatively." Citing German and British studies, the researchers noted that approximately 60% of daytime work zone crashes were rear-end collisions, with the remainder comprised primarily of sideswipes (both collision types are likely to be exacerbated by unstable traffic flow conditions: abrupt speed changes can result in rear-end collisions and speed differentials between lanes can encourage abrupt lane changing maneuvers and the temptation to attempt to merge into small gaps). At night, collisions with fixed objects were of particular concern and were typically associated with inappropriate vehicle speeds. Crash rates were generally higher for short-duration work zones and those utilizing full (rather than partial) contraflow. The ARROWS report also found that:

> A cause of real concern regarding driver behavior at road work zones is the fact that drivers *believe* they take sufficient caution, choose the right speed and decelerate properly. Experimental studies have shown that the majority of drivers in fact approach road work zones driving too fast for the circumstances, and usually well above the posted speed limit. Moreover, they do not decelerate until just before an abrupt change in the conditions (for example, a crossover point), and then in an extremely abrupt manner.

A 2006 study at 23 locations in Kentucky supports the ARROWS conclusions: drivers *do* reduce their speeds in work zones, but not to the extent desired by transportation

TABLE 1
OBSERVED TRAFFIC SPEEDS ON KENTUCKY FREEWAYS WITH AND WITHOUT WORK ZONES

Situation	Speed Limit (mph)	Observed Speed (MPH)	
		50th percentile	85th percentile
Not in Work Zone	65	67.8	71.6
Work Zone: No Activity	55	62.7	67.7
Work Zone: Active, Typical Signs	55	57.5	62.8
Work Zone: Active, Double Fine Signs Only	55	57.8	62.2
Work Zone: Active, Double Fine Signs, Police	55	53.8	57.3
Work Zone: Active, Double Fine Signs, Radar Box, Police	55	54.8	56.2

Source: Pigman et al. (2006).

agencies. As indicated in Table 1, at the control sites without work zones the 85th percentile speed was 6.6 mph above the 65 mph posted limits. Although typical work zone signage resulted in an 8.8 mph speed reduction, the 85th percentile speed remained 7.8 mph above the posted 55 mph work zone speed limit. In the Kentucky study, full compliance occurred only when police were present (Pigman et al. 2006).

This finding has implications for many aspects of work zone speed management; for example, work zone public information campaigns often ask drivers to "reduce speed in work zones"; however, it is quite likely that a large majority of drivers believe they already comply with this instruction and, as a result, the campaign may not provoke the intended behavioral change. Additional numerical examples of potential voluntary speed reductions can be found in Table 13 in chapter eight.

WORKER SAFETY

Collisions with road workers were noted as being "of special importance" by the ARROWS report. Vehicles that strike road workers have a high public profile and are often mentioned in the public outreach materials published by state DOTs. Records of on-the-job fatalities at the California DOT (Caltrans) show that "errant drivers" caused 49 of the 91 Caltrans employee deaths (54%) that occurred from 1971–2013 (contractor employees are not included) (Caltrans).

Highway worker casualties sometimes serve as a call to action for improving work zone safety. As discussed in more detail in Case Example 1, Saskatchewan's Ministry of Highways & Infrastructure came under pressure to improve work zone safety after a speeding driver killed a young highway worker in the summer of 2012. The province is now implementing many of the recommendations developed in response to the crash, including "simplified" work zone signage to clarify when workers are present, installation of temporary rumble strips and gateway treatments at work zone approaches, increased fines for work zone speeding, increased police enforcement, and automated speed enforcement.

In 2013, the U.S. Bureau of Labor Statistics (BLS) published an analysis of fatal occupational injuries at road construction sites, based on 2003–2010 data (Pegula 2013). The study focused on fatalities that occurred within the formal limits of the temporary traffic control zone [as defined by the U.S. *Manual on Uniform Traffic Control Devices* (*MUTCD*)]. It concluded that during that during that 8-year period, 962 workers were killed at road construction sites, representing approximately 2.2% of all fatal occupational injuries in the United States. Not all of these "occupational" deaths were highway construction workers, 13% were truck drivers who were just passing through the site.

Construction work has many hazards; a significant portion of the deaths occurred when workers were hit by construction equipment, struck by materials that were being moved, or became involved in incidents directly related to the construction such as trench collapses, falls, contact with live electrical wires, or similar hazards. Nevertheless, the BLS analysis shows that over the 8-year period 153 workers were hit at least once by a car, van, tractor-trailer, bus, or motorcycle. In other words, from 2003–2010, an average 19 highway workers per year were killed each year by traffic in work zones in the United States.

Workers were flagging or performing other traffic control duties in 92 cases. Of these, 20 workers were reported as wearing reflective or brightly colored clothing (such as vests) to increase visibility. Only 32 of the workers were employed as flaggers; the remaining 60 worked in other occupations such as laborers, maintenance workers, and operating engineers.

BLS noted the following other transportation-related deaths incurred by road construction workers:

- Five workers were killed when a bucket truck they were in was struck by another vehicle. In each case, the worker fell from the bucket truck.
- Five workers were killed when they fell from a truck while setting up or removing traffic control devices such as signs and cones.
- Three workers were killed when the mobile equipment being used by the worker was struck by a train.

Case Example 1: Agency and Legislative Response to Highway Worker Fatality in Saskatchewan

Saskatchewan is a predominantly rural Canadian province that borders the U.S. states of North Dakota and Montana. On Friday, August 23, 2012, Ashley Richards was working as a flag person on a road construction crew on Highway 39 about 5 miles north of Midale, a small town about an hour north of the U.S. border. According to media reports, it was Richards' first full day on the job; the day before she had taken a flagperson training course and also had some supervised training on the jobsite. At 5:30 p.m., about 45 minutes into her shift, the 18-year-old was struck from behind and killed by an SUV.

The story received extensive media attention and sparked public outcry: Richards and her fiancé Ben Diprose had recently moved to Saskatchewan to get a fresh start; Diprose was working on the site as an asphalt truck driver and witnessed the crash, and Richards was pregnant with the couple's child. In a radio interview Diprose said, "She was bleeding to death in my arms and there was nothing I could do." The SUV driver, 44-year-old Keith Dunford of Regina, was arrested at the scene. In October 2012, following an investigation by the RCMP (Royal Canadian Mounted Police, Canada's national police force), Dunford was charged with two offences (criminal negligence causing death and dangerous operation of a motor vehicle causing death); however, a series of legal actions resulted in the postponement of a trial until August 2015.

Although details of the crash were not released by the police prior to the trial, in a radio interview Diprose said that Dunford hit Richards while attempting to pass a line of vehicles that were stopped by the flagging operation. According to Diprose, Dunford told him he did not see Richards because he was looking for a paper he dropped. Although Dunford did not testify, a police interview recorded 2 hours after the crash was played at the trial. "I wasn't paying attention, I must admit," Dunford said on the tape. "I was looking at my paperwork." Witnesses also testified that prior to the crash Dunford passed two semi-trucks in the work zone, despite the presence of two no-passing signs. Prosecutors noted that Dunford had driven through the work zone previously and a police officer testified that there was no indication Dunford was intoxicated or high. Cpl. Jeff Burnett, a collision analyst, testified that Richards' body was found 54 m (177 ft) from the estimated point of impact, and that Dunford was going 82 to 99 km/h (51 to 62 mph). The work zone speed limit was 60 km/h (35 mph).

Although the legal process took more than 3 years, Saskatchewan's political and administrative leadership responded to the incident quickly. On the Wednesday following the crash, Saskatchewan Premier Brad Wall (equivalent to a Governor in the United States) posted two Twitter messages that were soon relayed by other media outlets:

> 12:29 p.m.: "Angry to learn from owner of constr co. where Ashley worked that drivers are still not obeying orange zone laws. SLOW DOWN. NO PASSING."
>
> 12:32 p.m.: "Have asked Hwys and Justice Ministers to work with police, stakeholders to canvass any and all ideas to improve orange zone safety."

In coordination with the RCMP, the Saskatchewan Ministry of Justice announced that patrols and ticketing in work zones would be stepped up immediately. In September 2012, the RCMP launched a provincewide safety blitz to catch speeders in construction zones, which involved officers dressed as construction workers observing drivers in the work zone and communicating with downstream officers to intercept speeders. In September and October RCMP officers issued more than 400 work zone speeding tickets according to media reports.

With an existing statutory work zone speed limit of 60 km/h (approximately 35 mph) for all sites where workers are present (including freeways and mobile operations) reducing speed limits was not an option; however, by late October the Saskatchewan government announced plans for three statutory changes:

1. Work zone speeding fines were increased to triple the ordinary fine. A work zone violation at 70 km/h (approximately 45 mph) now results in a fine of CAD $300 (about U.S. $280). Speeding at 120 km/h (approximately 75 mph) results in a fine of CAD $798 (about U.S. $740).
2. Highway Transport Patrol officers who previously enforced only truck safety and weight regulations were authorized to issue work zone speeding tickets.
3. A 5-year pilot program for automated speed enforcement was put in place. The system began operation in July 2013 and makes it possible to issue speeding citations by mail, without having to intercept speeders in the work zone.

The province's Ministry of Highways and Infrastructure also responded with several engineering measures in preparation for the 2013 construction season:

- Signage was modified to indicate more clearly when workers are present (which activates the statutory triple-fines provision). A new sign was also added to make it easier for drivers to see where the construction area ends. (In a November 2013 online survey of 804 drivers conducted for the Ministry of Highways & Infrastructure by a private firm, 86% of respondents agreed that "there has been an improvement in clarity for work zone signing on provincial highways.")
- Certain signs at approaches to long-term work zones were doubled-up to improve their visibility. Specifically, on all four-lane roadways (divided and undivided) the ROADWORK AHEAD, speed limit, and FLAGGER AHEAD signs are now placed on both the left and right sides of the roadway approaching the work zone.
- Temporary rumble strips were specified contractually for the approaches to most projects lasting 5 days or more (79% of respondents to the November 2013 survey agreed that "rumble strips alerted me to important information.")
- Recognizing that Saskatchewan is a prairie province where wide-open spaces encourage fast driving, a gateway treatment based on a Manitoba design was implemented at work zone approaches on rural freeways, as shown in Figure 3 The barricade-like design is used on higher-volume highways for projects lasting 5 days or

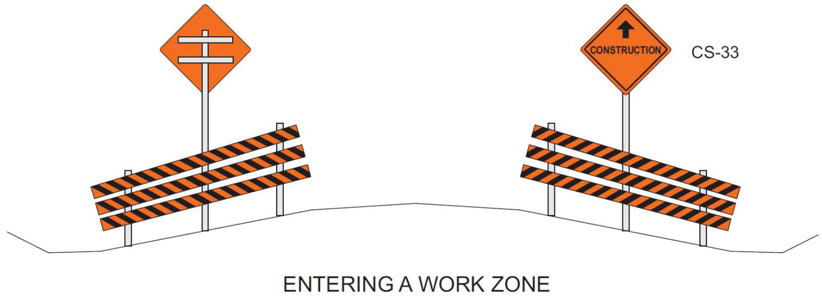


FIGURE 3 Gateway treatment for entrance to Saskatchewan rural highway work zone (Saskatchewan MHI 2013).

more. It consists of three horizontal boards, positioned starting at the break point of the shoulder and extending 12 ft down the sideslope on each side of the roadway. The spacing of the boards converges to create an exaggerated sense of perspective and heighten the sense that the roadway is narrowing. Each bar has orange and black stripes facing traffic approaching the work zone and reflective white and black stripes facing traffic leaving the work zone.

- Contractual provisions were strengthened to ensure that contractors promptly remove work zone speed limit signs when they are not needed. According to Marla Muhr of the Ministry of Highways & Infrastructure, "Often contractor compliance with taking down signs when workers were not present was not good, so the public does not feel the signs are meaningful; the public is skeptical and may not slow down until they are immediately in the vicinity of the workers."

Saskatchewan's 2014 work zone safety public information campaign featured a television advertisement that appears to be loosely based on the Ashley Richards crash. In the video, a woman, late for work, is seen kissing her adolescent son at the breakfast table. In the next scene she is approaching a work zone at 110 km/h, impatiently tapping her fingers on the steering wheel. She sees the 60 km/h speed limit sign, but only slows to 80. When she looks at the flagger, it is her son. She cringes and brakes abruptly, then realizes that the flagger is actually an adult man. He waves at her, and she waves back sheepishly. The ad closes with the tag line, "Imagine how fast you would drive in a work zone if someone you loved was there."

The full results of Saskatchewan's experience with these work zone speed management techniques were not available prior to the preparation of this synthesis report, and it may ultimately be difficult to separate the effects of the individual components of this combination strategy. Saskatchewan's situation has inherent challenges: with a small number of law enforcement personnel spread across more than 16,000 miles of provincial highways it is not possible to have police present at all work zones. Although automated speed enforcement augments the traditional patrols, the province's three automated speed enforcement devices are shared among numerous construction projects. The statutory speed limit is 60 km/h (approximately 35 mph), but achieving full compliance is difficult; according to Muhr, observed work zone speeds are closer to 80 km/h (50 mph) for most projects and around 70 km/h (45 mph) for bridge projects. Nevertheless, the public appears to be accepting the changes implemented in response to the death of Ashley Richards and press coverage continues to be pro-safety. After attending a speech where officials announced the implementation of automated speed enforcement, Diprose was quoted as saying, "It means quite a bit because I wouldn't want anybody else to go through the same thing I went through. I wouldn't wish this on my worst enemy."

References: (CBC News 2012a-e; CTV 2121; Saskatchewan MOJ 2012; SGI 2010 CBC News 2013; Insightrix 2013; Saskatchewan MHI 2013, 2014a,b; *Global News* 2014; Government of Saskatchewan 2014; M. Muhr, Saskatchewan Ministry of Highways & Infrastructure 2014; Wilson 2014; Discover Weyburn.com 2015; CBC News 2015a, b).

SOCIAL, PSYCHOLOGICAL, AND CULTURAL FACTORS AFFECTING SPEEDING

The Global Road Safety Partnership developed a comprehensive speed management handbook on behalf of WHO (Howard et al. 2008). The document discusses several social and psychological factors that contribute to speeding:

- Travelling at higher speeds offers the immediate "reward" of a faster trip. This benefit is reinforced each time a driver exceeds the speed limit without apparent consequences.
- Although speed is a factor in a very high percentage of serious and fatal crashes, many drivers underestimate these risks. As a result, drivers tend to think more about the risk of being penalized for speeding than about the risk of being involved in a speed-related crash.
- Most drivers consider themselves to be above average in terms of skill. A number of surveys conducted in various countries around the world demonstrate that up to 90% of drivers believe they are an above-average, low-risk driver.
- Many drivers regard speed limits as arbitrary and do not fully understand the greater risks associated with even small increases in speed.
- In some cases, commercial drivers feel pressure to drive faster to increase their income or meet company productivity goals. Some large U.S. trucking companies are aware of this issue and equip their vehicles with speed limiters; however, this is often not the case for other fleets such as taxis, shuttle vans, small trucking companies, or independent truck drivers.

Toward Zero Deaths: A National Strategy on Highway Safety (TZD Steering Committee 2014) emphasizes the importance of integrating knowledge gained through the social sciences with the more traditional approaches to highway safety. As illustrated in Figure 4, the report developed a new Traffic Safety Culture Model (TSC) that augments the long-standing focus on engineering, enforcement, and education. The report states:

> The TSC model focuses on how social factors in a culture influence how people prioritize traffic safety and accept traffic safety strategies. That is, the TSC model assumes that behaviors related to traffic safety performance are . . . influenced by our culture. Therefore, it is difficult to achieve sustainable improvements in traffic safety until we understand these processes and create a culture in which everyone values traffic safety and works to enhance it. By operating and integrating TSC programs across multiple levels [we can] achieve effective and sustainable improvements in road user behavior.

One example of the cultural dimension of speeding is raised by the Global Road Safety Partnership report (Howard et al. 2008):

> Very small increments of speed in excess of speed limits are a major factor in increasing crash risk on the network, especially if it is a behavior that is widely practiced by the driving population. Over time, low-level speeding can become the accepted behavior of drivers and they will expect to drive at a higher level until or unless they encounter some enforcement.
>
> If low level speeding is widespread and is more than 2 or 3 km/h (1 to 2 mph) above a posted speed limit, there may be the need to apply tougher standards to speed enforcement than those that currently exist. For example, some jurisdictions allow drivers to travel up to 15 km/h (10 mph) over the limit before being given an infringement notice. This results in the de facto speed limit becoming 15 km/h over the posted limit. The increase in crash risk as a consequence can be large.

Responses to the Engineering and Enforcement survey conducted for this report indicate that speeding tolerance in the

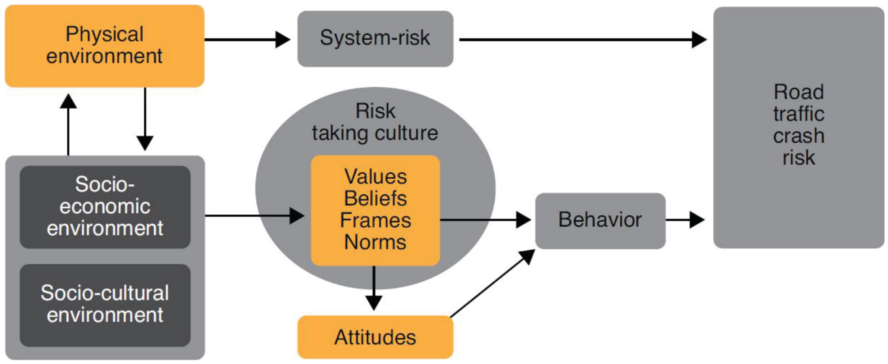


FIGURE 4 Descriptive and predictive model of key concepts that define traffic safety culture (TSC) and their relationship with behavior and crash risk (TZD Steering Committee 2014).

United States varies from state to state, ranging from less than 5 mph to more than 10 mph above the posted speed limit. Consequently, a posted work zone speed limit of 55 mph is actually enforced as 60 to 65 mph (or more) depending on the locality.

Another indicator of the variability of public attitudes toward speeding is the state-to-state differences in the statutory fines leveled for speed infractions. According to a NHTSA summary (NHTSA 2011), as of February 2010 the maximum fine for speeding ranged from $50 in Tennessee to $2,500 in Virginia. The maximum jail time imposed by the states for speed law violations varies dramatically, from 15 days to one year. Some states impose additional penalties if the incident results in a worker casualty. Comparatively, as of February 2013, France levied uniform national fines that range from €68 to €3750 (approximately U.S. $120 to $5,250) depending on the severity of the infraction; in addition to these fines, drivers who exceed the speed limit in France by more than 50 km/h (30 mph) are subject to a prison sentence of up to 3 months, a 3-year driving license suspension, and confiscation of their vehicle.

Frustration with entrenched behaviors that negatively impact work zone safety is evident in many of the information sources identified for this synthesis report. For example, the authors of a Canadian work zone speed management report wrote that, "Drivers are unwilling to slow down and seem to resent construction and maintenance delays" (Harmelink and Edwards 2005). Similarly, in an interview conducted for this project, Virginia DOT's (VDOT's) David Rush noted that, "[Often] work zone speed limit compliance only occurs when police are present" (D. Rush, VDOT, personal communication, 2014). Research supports this point of view: A 1990 survey of drivers at a rural work zone on I-57 in central Illinois found that although 79% said the posted 45 mph speed limit was about right, only 59% reported that they drove at or below this limit. More than one-third of the drivers admitted to speeding through the work zone (Benekohal et al. 1990). A 2001 Swedish survey of drivers who were cited for work zone speed violations found that very few reported that they had been in a rush; most believed they had not done anything major wrong by exceeding the work zone speed limit (Bolling and Nilsson 2001).

In an interview conducted for this synthesis report, a Saskatchewan official identified an interaction between contractor and driver attitudes that has had the effect of promoting work zone speeding in the past. The province's statutes establish a mandatory 60 km/h (approximately 35 mph) work zone speed limit when workers are present. Marla Muhr of the Saskatchewan Ministry of Highways & Infrastructure expressed concern that the credibility of this limit was undermined by contractors' ongoing failure to remove or cover the signs when the workforce leaves the site. Citing the need for contractor cooperation and compliance Muhr said, "For too many years, the [work zone speed limit] signs did not mean anything" (M. Muhr, Saskatchewan Ministry of Highway & Infrastructure, personal communication, 2014).

The TSC model suggests that anti-safety behaviors such as those cited by Rush and Muhr are linked to personal and organizational values, beliefs, frames-of-mind, norms, and attitudes. The TZD report notes that the term safety culture has "a long history in organizations in which safe operations are critical, such as in nuclear power plants, commercial aviation, and healthcare." It asserts that long-term internal and external improvement in safety outcomes is achievable through a systematic approach that emphasizes shared values, "cohesion, trust, and willingness to engage with the community" (TZD Steering Committee 2014).

Social science research suggests that punishments and rewards have equal value in promoting socially cooperative behavior, as long as they are administered equitably and are seen as promoting collective interests (rather than the self-interests of the administrator) (Balliet et al. 2011). The *Toward Zero Deaths* report suggests that, where feasible, positive approaches to safety improvement are more likely to be accepted than negative or punitive approaches. Examples cited in the report include rewarding good choices and using humor to demonstrate the value of safety. "Rather than having agencies dictate appropriate behaviors, the intent is to create the motivation within the driving population to partner with highway safety agencies to achieve mutual goals" (TZD Steering Committee 2014). An unconventional example of a positive approach toward preventing speeding comes from an automated enforcement pilot project in Sweden, which rewarded drivers who did *not* speed through a business district with a portion of the fines collected from the violators (Volkswagen 2010). During the brief experiment, average speeds went down 22% according to a video produced by the project sponsor. The video quotes a driver as saying, "This is a really positive thing. Drive legally and earn money. Perfect."

ELEMENTS OF A WORK ZONE

The *MUTCD* (FHWA 2009) divides work zones into four areas, as shown in Figure 5:

- Advance Warning Area (including shoulder taper) where traffic is told what to expect ahead.
- Transition Area (including upstream taper) where traffic moves out of its normal path.
- Activity Area where work takes place.
- Termination Area (including downstream taper) where traffic resumes normal operations.

Slightly different terminology is used in other countries to describe these four areas.

There is a general consensus that improving compliance with speed limits and reducing inappropriate driving speeds are not easy tasks, that speed management remains one of the biggest challenges facing safety practitioners, and that a concerted, long-term, multidisciplinary approach is necessary (Peden et al. 2004). These challenges are compounded by the differing conditions in various parts of a work zone:

- In Advance Warning and Transition areas the goal is generally to encourage drivers to slow to the work zone speed limit or make a gradual reduction to the speed associated with a lateral shift, lane drop, or queue. One study found that approximately 40% of crashes occur in advance warning and transition areas, primarily as a result of drivers approaching lane drops and queued traffic at high speeds (Raub et al. 2001). Based on video observations, the same study found that approximately 5% of drivers approached at speeds that were high relative to the queue.
- After entering the Activity Area drivers often attempt to increase their speeds; therefore, a separate set of techniques may be necessary to achieve sustained speed reduction throughout the entire work zone (especially for longer work zones). Raub et al. (2001) found that approximately 60% of crashes occur in Activity and Exit areas, caused mainly by sudden driver maneuvers, inappropriate following distance, and driver distraction. Although speed-related crashes are less common in these areas compared with the upstream portions of the work zone, sudden slowing can occur, particularly if there are merges within the Activity Area. Multiple-vehicle involvement can be high because of a lack of escape routes (especially if lane width is constrained by temporary concrete barriers).

MEASUREMENT OF WORK ZONE SPEEDS AND SPEED REDUCTIONS

It is important that the numerical values of work zone speed reductions reported for techniques discussed in this synthesis report be interpreted with some caution. Many variables affect work zone speeds, even when special speed management techniques are not in use. Variations in free-flow speed, time of day, traffic volume, and truck percentage can complicate work zone speed studies (Chen et al. 2007). Traffic volumes influence the extent to which the speeds of individual vehicles are independent or result from car-following phenomena (Porter and Mason 2008). Characteristics of the work zone itself [such as the number of available lanes, surface condition, vertical and horizontal geometry, and type of delineation (e.g., concrete barrier vs. drums)] also influence work zone speeds and can change rapidly as construction progresses. As a result, researchers face inherent challenges in ensuring that observed work zone speed changes are attributable to the devices and techniques under study, and not to external factors.

One consideration when interpreting reported speed reductions is that the magnitude of the observed speed reduction is likely to depend on the severity of the speeding upstream. For example, an Illinois study comparing automated speed enforcement at two sites found greater reductions in the Chicago area than in the St. Louis area, primarily because speeding was more prevalent at the Chicago site (Benekohal et al. 2010).

Work zone speed reductions have been measured in a number of ways by various researchers depending on the characteristics of the work zone, the type of speed management technique that is being studied, and the available observational equipment and personnel. Many studies focus on the average speed of the vehicles in the traffic stream, while others emphasize 85th percentile speeds or speed variation (often reported as the standard deviation of the speeds of individual vehicles). Relationships between these measures are not always well-established or consistent, and may differ for cars and heavy trucks (Porter and Mason 2008). Some studies compute speed reductions using simple methods, whereas others use sophisticated statistical analysis. These methodological differences can make it difficult to make direct comparisons of the effectiveness of speed management techniques. Examples of some methods that have been used to evaluate work zone speeding countermeasures include:

- The difference between the speed upstream of the work zone and the speed within the work zone where the countermeasure was deployed.

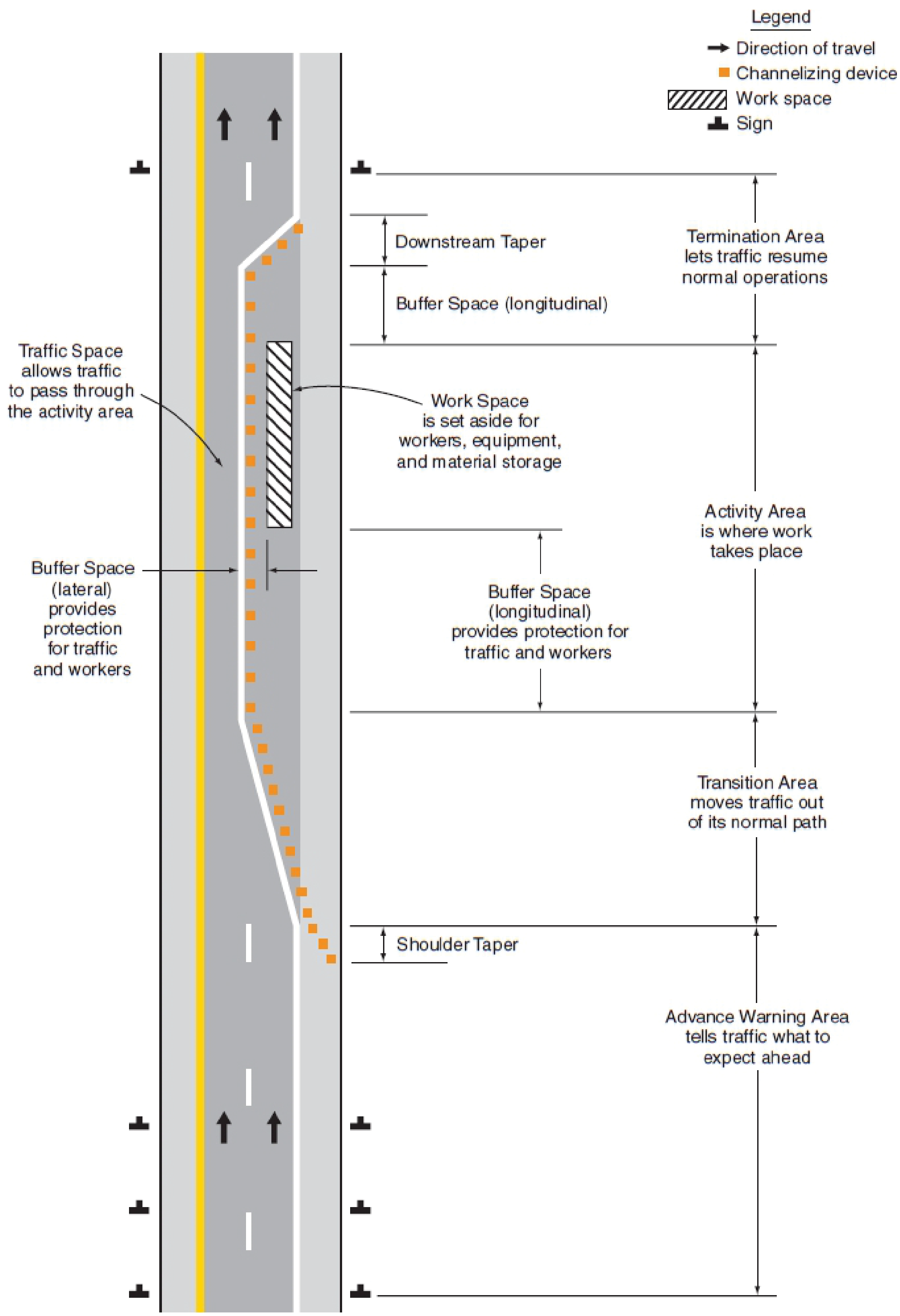


FIGURE 5 Elements of a work zone as defined in the U.S. *Manual on Uniform Traffic Control Devices* (*MUTCD*) (FHWA 2009).

- The difference between the speed within the work zone with and without the countermeasure.
- Spot speed observations at several locations in and adjacent to the work zone.
- Speeds a predetermined distance upstream of a flagger station during two-way one-lane operations.

The location where speeds are measured is another consideration: some speed management measures have only a localized effect, while others are effective over a longer distance. When comparing the results of work zone speed studies it is also necessary to consider the observational methods and equipment used to compute the speeds. Measurement accuracy is particularly important when the speed management technique under study is expected to yield fairly small speed reductions (i.e., 2 to 3 mph).

Four of the most frequently used methods for work zone speed measurement are:

1. Point speed observations. Typically, in this method an observer is stationed near the roadway with a police-type portable Doppler radar or Lidar device. The observer points the device at individual vehicles (parallel or at a slight angle to oncoming traffic) and records their speeds. This method is considered highly accurate, but has some limitations: it is labor-intensive, so the number of samples that can be obtained is usually limited, and it is not always feasible to have observers on-site during the full range of work zone traffic conditions. In high-volume, multilane situations it may be necessary to position observers on an overpass to obtain data from all lanes.
2. Pneumatic counters. Single-hose pneumatic traffic counters were developed for traffic volume studies nearly a century ago (Hogentogler 1923). Some modern pneumatic counters are also capable of gathering traffic speed data, which requires installing two air hoses (or "tubes") across the roadway. Counters that support this function typically incorporate a digital controller that records time-stamped observations for each axle hit; if the hose spacing is known, the speed of individual vehicles can be imputed from the time differential between hits on the two hoses.

   The accuracy of the speed computation from pneumatic counters is dependent on correct installation of the hoses and proper selection of detector settings. Systematic errors can occur if the hoses are not precisely parallel to each other or are not perpendicular to the vehicle path. Excessive hose slack, bends, and kinks can also affect results. It is important that the hose spacing used in the speed computation software match the actual field spacing very closely; for example, if the expected hose spacing is 36 in. and the actual spacing is 37.5 in., a speed of 48 mph would be attributed to a vehicle whose actual speed is 50 mph (a –4% error). An Australian study found that increasing the hose spacing to 4 m (13.1 ft) "increased accuracy of the speed and axle spacing calculations (owing to the decrease in the significance of any error in tube length or tube spacing)" (Mendigorin et al. 2003a, b). A spacing of 1 m (39 in.) had historically been used in the study area. Quadrupling the spacing required changes in the processing software. The study also found poor speed accuracy in congested traffic conditions (a frequent occurrence in some work zones). The study noted that in addition to previously documented issues with high-speed vehicles causing "reflections" (false pulses potentially interpreted as axle hits), "quite surprisingly . . . vehicles at very low speed were generating reflections."
3. Side-fired radar. Permanent or semi-permanent radar units mounted at the roadside have been used for a number of work zone speed studies. The term "side-fire" indicates that the units are positioned with the radar beam perpendicular to the traffic stream, an unfavorable vantage point for gathering speed data. Table 2 shows the manufacturer-claimed speed accuracy for three common side-fire radar units.
4. Bluetooth Vehicle Re-Identification. Bluetooth is a short-range wireless telecommunications technology that is widely used in mobile phones, headsets, electronic games, and other consumer devices. Each Bluetooth device is capable of emitting a unique serial number called the media access control (MAC) address. Traffic speed data can be collected using detectors that scan for MAC addresses; these detectors are typically mounted at the roadside or in the median. When a Bluetooth device is observed, the detector records the MAC address and a timestamp. Addresses presumed to be associated with vehicles are then matched (re-identified) with data from other locations. If the distance between the Bluetooth detectors is known, travel time can be imputed from the time difference between the observations. In principle, similar information can be gleaned from other types of wireless devices such as WiFi; however, as of 2014 most commercially available detection products are based on Bluetooth (Chitturi et al. 2014). When appropriate filtering settings are used Bluetooth "is capable of providing reliable and high-quality ground truth travel time data on highways" (Haghani et al. 2010).

TABLE 2
SPEED MEASUREMENT ACCURACY OF SIDE-FIRE RADAR UNITS AS STATED BY THE MANUFACTURERS

Product	Per-Direction Average Speed Accuracy	Per-Lane Average Speed Accuracy	Per Vehicle Average Speed Accuracy
Autoscope RTMS G4	Not stated	Not stated	±10%
Wavetronix SmartSensor HD	±3 mph	±3 mph	±5 mph for 90% of measurements
Wavetronix SmartSensor V	±5 mph	±10 mph	Not stated

Sources: Image Sensing Systems (2012); Wavetronix LLC (2014).

In contrast to the point-speed data gathered by pneumatic and radar-based speed data collection devices, each individual Bluetooth observation represents a vehicle's average speed between a pair of detectors. Therefore, if one detector is installed at the approach to a work zone and another is placed at the work zone's termination, data indicative of the overall speeds in the work zone can be gathered. Consequently, Bluetooth is well-suited to evaluation of techniques intended to influence speed throughout the work zone.

Finally, it is necessary to note that some of the speed management techniques included in this synthesis report have been tested only on a limited basis (e.g., small sample size, small number of sites, limited diversity of sites), resulting in some uncertainty. Site-specific field conditions can also affect the observed speed reduction; for example, a Kansas test of optical speed bars was hampered by lack of contrast between the bar markings and the pavement (Meyer 2004). Similarly, geometric design details (such as the lateral shift rate of chicanes) are likely to affect the observed speed reduction.

CHAPTER TWO

WORK ZONE SPEED LIMITS

INTRODUCTION

This chapter discusses criteria and policies for setting work zone speed limits, penalties for exceeding the limits, and several devices and technologies that are intended to reduce work zone speeding by enhancing driver awareness of speed limits.

SETTING WORK ZONE SPEED LIMITS

Several factors deserve consideration when selecting an appropriate work zone speed limit. Although most U.S. state DOTs have policy guidance on speed limit selection, it can be difficult to create guidelines that are responsive to all project-specific situations. The 2009 *MUTCD* includes several recommendations that form the basis of most state guidelines (FHWA 2009):

- Reduced speed limits should be used only in the specific portion of the Temporary Traffic Control (TTC) zone where conditions or restrictive features are present. However, frequent changes in the speed limit should be avoided. A TTC plan should be designed so that vehicles can travel through the TTC zone with a speed limit reduction of no more than 10 mph.
- A reduction of more than 10 mph in the speed limit should be used only when required by restrictive features in the TTC zone. Where restrictive features justify a speed reduction of more than 10 mph, additional driver notification should be provided. The speed limit should be stepped down in advance of the location requiring the lowest speed, and additional TTC warning devices should be used.
- Reduced speed zoning (lowering the regulatory speed limit) should be avoided as much as practical because drivers will reduce their speeds only if they clearly perceive a need to do so.

The *MUTCD* section on Worker Safety Considerations offers a counterpoint:

> Reducing the speed of vehicular traffic, mainly through regulatory speed zoning, funneling, lane reduction, or the use of uniformed law enforcement officers or flaggers, should be considered [to improve worker safety].

Imposing a work zone speed limit that drivers perceive to be unreasonably low has been shown to increase speed variation: conservative drivers tend to observe the work zone limit, whereas aggressive drivers may attempt to operate speeds closer to the ordinary limit (without road work). The *MUTCD* frames the issue as follows:

> Research has demonstrated that large reductions in the speed limit, such as a 30 mph reduction, increase speed variance and the potential for crashes. Smaller reductions in the speed limit of up to 10 mph cause smaller changes in speed variance and lessen the potential for increased crashes. A reduction in the regulatory speed limit of only up to 10 mph from the normal speed limit has been shown to be more effective.

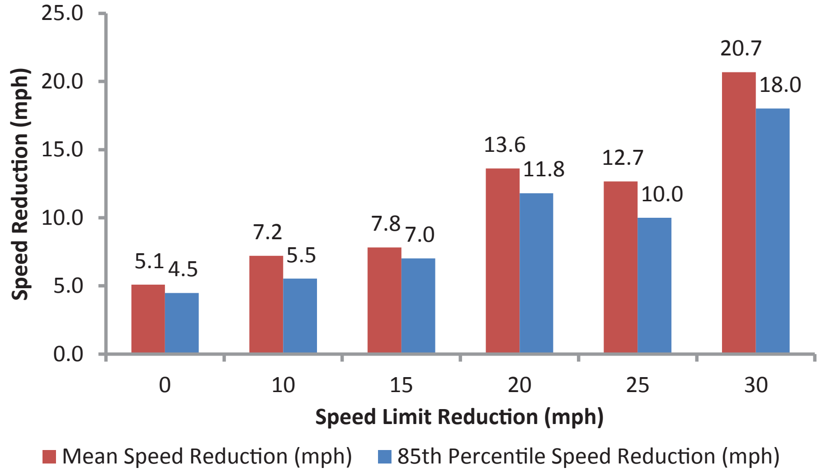
More emphatic advice is offered in a 1989 work zone design standard published by MOPU, Spain's Ministry of Public Works & Urbanism:

> The most frequent issue is that as the result of routine, laziness, or fear of liability, abnormally low values are set. The attempt to limit speed with signs alone to a value that is not realistic and easily understood by the user not only fails to achieve the intended effect; the limit will be ignored or perceived as a speed trap, causing proper traffic control to be disregarded and reducing its general credibility.

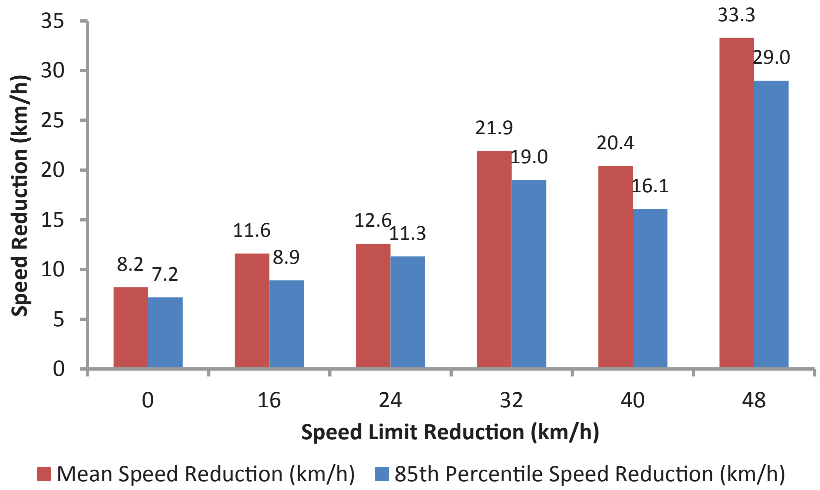
The *MUTCD* and MOPU advice is supported by a late 1990s study that examined the relationships between work zone speed limits and crash rates (Migletz et al. 1999). As shown in Figure 6*a* and *b*, the study found that in work zones where the speed limit was *not* reduced there was an average decrease of 8.2 km/h (5.1 mph) in mean speed and a reduction of 7.2 km/h (4.5 mph) in 85th percentile speed. Compliance with work zone speed limits was generally most effective when the work zone speed limit was not reduced, and compliance decreased where the speed limit was reduced by more than 10 mph. Conversely, when the work zone limit was set 20 mph below the ordinary limit, the mean reduction in actual speeds was only 13.6 mph and the 85th percentile speed went down by just 11.8 mph.

Speed variance, a potentially useful surrogate measure for safety, had an important relationship with the speed limit reduction in the Migletz study. The study's authors asserted that the safest work zones are those with the smallest increase in the upstream-to-work-zone speed variance, and found that the speed limit variance was minimized for a speed limit reduction of 10 mph as shown in Figure 7. These results were developed into a work zone speed limit setting procedure in NCHRP Projects 3-41 and 3-41(2), which have influenced state practices and the *MUTCD.* Migletz et al. noted:

> None of the differences between the percentage increases in speed variance . . . were statistically significant. Although disappointing, this finding reflects the diversity of conditions inherent in work zones. Given motorist responses that are so highly variable, it is unlikely that statistically significant differences can be found. Despite the lack of statistical significance, rational policies for setting work zone speed limits must be developed. It was con-



(a)



(b)

FIGURE 6 Mean and 85th percentile speed reductions from upstream to work zone locations: (*a*) mph, (*b*) km/h (Migletz et al. 1999).

sidered reasonable to use the speed variance results . . . as a basis for policy [because] accident analysis provided similar findings and . . . engineering judgment suggested that these findings were reasonable.

Two more recent study results differ from *MUTCD*/Migletz findings and suggest more complex relationships between work zone speed limits, speed variation, and compliance rates. A study of speed profiles along 17 freeway work zones in Pennsylvania and Texas found that “speed deviations were lower in work zones with a posted speed reduction of 16 or 24 km/h [10 or 15 mph] than in work zones with no speed reduction” and concluded that “at least some magnitude of speed reduction is recommended if lowering speed deviation is a design objective” (Porter and Mason 2008). In addition to the work zone speed limit, the upstream traffic speeds, work zone geometry, and type of work zone delineation (e.g., concrete barrier vs. drums) were found to influence the speed variance. Similarly, a study of three short-term work zones on rural Kansas freeways that had ordinary (nonconstruction) speed limits of 70 mph found a reduction in speed variance when the work zones were posted at 50 or 60 mph instead of 70 mph (Hou et al. 2011). When the Kansas maintenance work zones operated under a 70 mph work zone speed limit, only 51% of the traffic complied with the limit; when the limit was reduced to 60 mph the compliance rate was 74%, and under a 50 mph limit the compliance rate reached almost 90%.

Among the agencies that responded to a survey conducted for this synthesis report, 64% reported that they have a formal policy or guideline for determining when to reduce speed limits in work zones (Table 3). In most cases, these documents also establish an administrative process for approving reductions that is specific to the agency’s organizational hierarchy. In general, the original posted speed limit and road type are important factors, as are the presence of workers, their proximity to traffic, and the duration or physical length of the work zone (Thomson et al. 2014). The type of separation between workers and traffic (e.g., drums vs. concrete barrier) is also

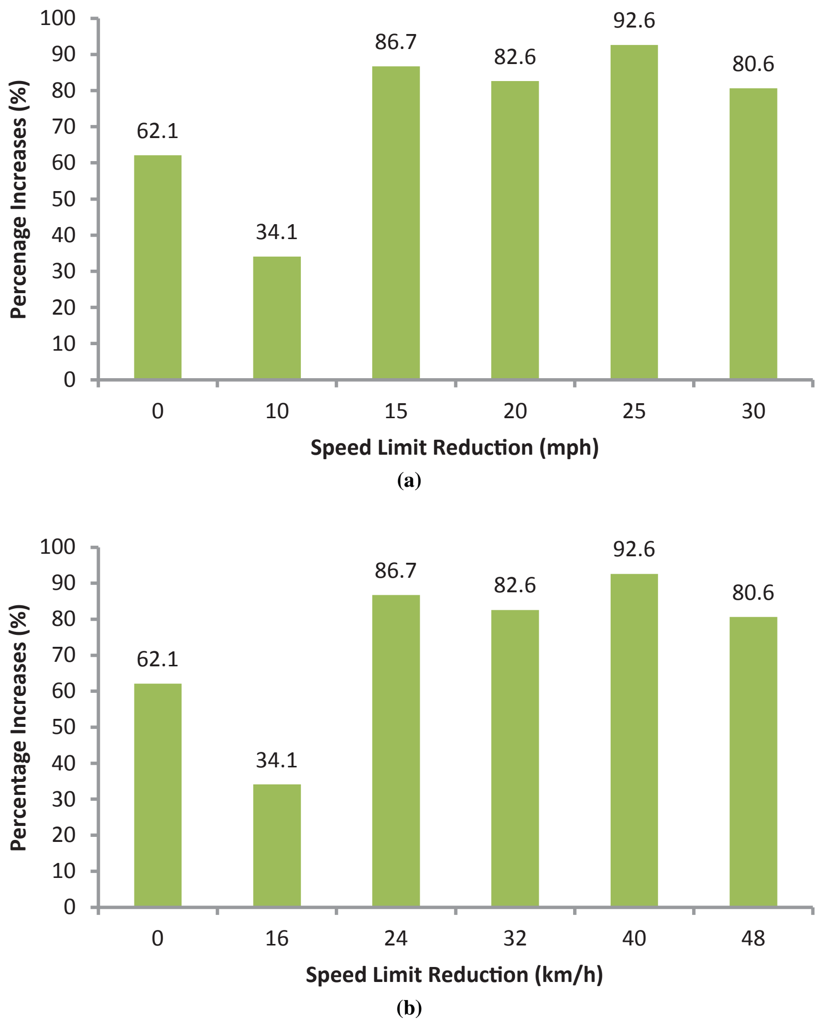


FIGURE 7 Percentage increase in speed variance from upstream to work zone locations: (*a*) mph, (*b*) km/h (Migletz et al. 1999).

frequently mentioned. Statutory work zone speed limits are also a consideration, particularly in states that have lower speed limits when workers are present.

In most cases, the technical content of the state guidelines is based on a combination of the *MUTCD* recommendations, results of the Migletz study, local experience, and factors such as those listed in Table 4. For example, a Wisconsin DOT guideline (WisDOT 2013) provides criteria that could result in a reduction of 5 or 10 mph from the ordinary speed limit; the criteria include narrow lane width, narrow shoulder width, lateral shifting of the lanes, work operations close to an open lane, and traffic operating on shoulders, temporary pavement, or gravel. A simplified flowchart for setting work zone speed limits published by the Roadway Safety Consortium in 2010 is reproduced as Figure 8.

The exact criteria used in setting work zone speed limits (and the extent to which the limits can be modified based on engineering judgment) vary jurisdictionally. Table 5, produced

TABLE 3
AGENCY POLICIES ON SETTING WORK ZONE SPEED LIMITS

Agency Policies on Work Zone Speed Limit Setting	Yes	No	No Response	Total
Formal Policy or Guideline Exists	64%	32%	4%	100%
Policy Implemented Uniformly	52%	8%	40%	100%
Policy Posted on Organization's Website	34%	26%	40%	100%

TABLE 4
GENERAL FACTORS TO CONSIDER WHEN SETTING SPEED LIMITS

• Traffic mix and vulnerable road users	• Type of intersections and traffic control
• Crash history	• Traffic volume and traffic flow
• Road shoulder width and pavement quality	• Types of vehicles allowed
• Road delineation	• Access
• Road and lane widths	• Free-flow speed
• Abutting land development	• Ability to overtake [pass] safely (within sight distance) at posted speed

Source: Howard et al. (2008).

for the Conference of European Directors of Roads (CEDR), summarizes the work zone speed limit setting criteria mentioned in official guidelines from 17 countries (including four U.S. states and the U.S. *MUTCD*). As of 2014, CEDR's ASAP project was attempting to build on the Migletz research to develop unified criteria for use throughout the European Union (Thomson 2014).

As of this writing, the January 2014 edition of Book 7 of the *Ontario Traffic Manual* (MTO 2014) provides one of the most recently updated sets of guidelines for determining when to reduce speed limits in construction zones:

> The travelled way through a work zone should be designed for a speed that is equal to or as close as possible to the design speed of the approaches to the work zone. If a speed limit reduction is deemed necessary, road authorities have the option of using advisory signs or reducing the regulatory speed limit, either temporarily or continuously through a construction zone.
>
> [Table 6] provides examples of the appropriate uses of each method. Both regulatory and advisory speed limit signs can be used on different portions of the same contract for severe work zone conditions. The road and police authorities should discuss logistics of enforcement and speed control.
>
> Regulatory and advisory speed reductions should not be more than 20 km/h (10 mph) below the normal posted speed. Speed limit reductions that are up to 20 km/h have been shown to be the most effective for keeping traffic in compliance, and increasing public and worker safety and mobility.
>
> Both advisory and regulatory speed reductions must move with the active operation and there must be visible signs of work activity. When reduced speed limit signs are used for worker safety, the signs must be covered or removed when not required.
>
> Speed reductions are more likely to be obeyed by motorists if they are perceived as necessary. If there is a good reason for reducing speed which may not be readily apparent to motorists, then the reason for the speed reduction should be provided

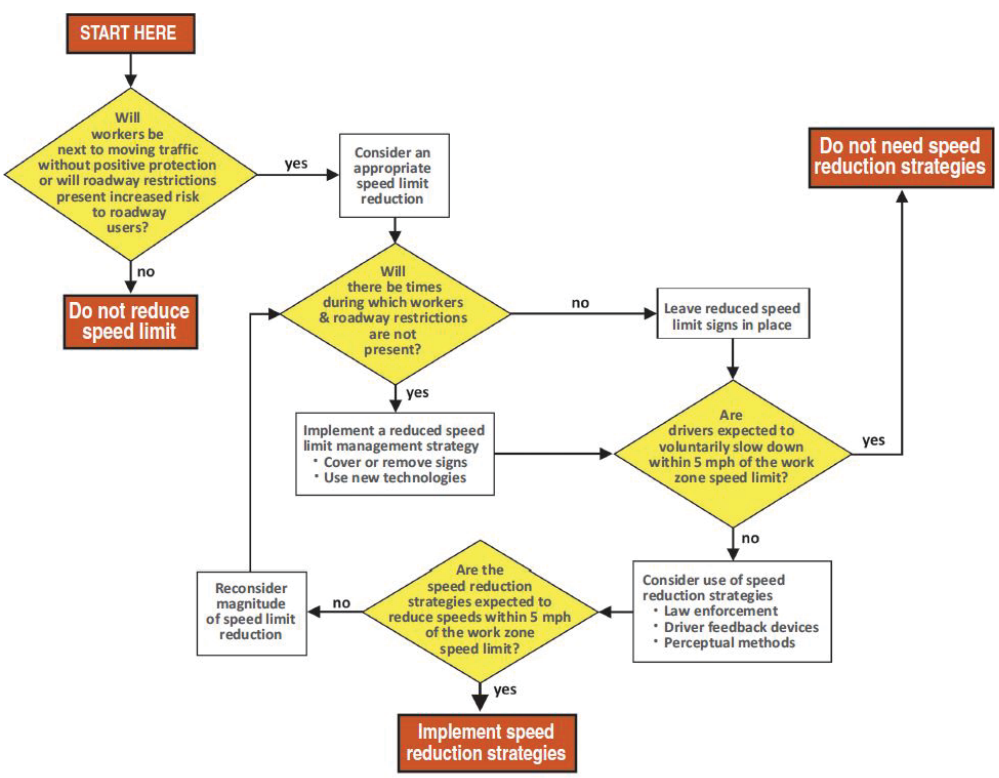


FIGURE 8 Simplified flowchart for setting work zone speed limits (Roadway Safety Consortium 2010).

TABLE 5
INTERNATIONAL SUMMARY OF PARAMETERS USED TO ASSIGN SPEED LIMITS IN WORK ZONES

	Original Posted Speed	Road Type	Lane Width	Duration or Length of Construction	Workers Present	Proximity of Workers to Traffic	Impact on Traffic	Change-overs and Cross-overs	Change in Road Surface Properties
Australia									
New South Wales		X		X					X
Queensland		X			X	X			X
Austria		X	X		X		X	X	
Belgium	X	X	X				X	X	
Canada									
Quebec	X	X	X						
Czech Republic		X							
Denmark	X	X		X	X	X			
France	X	X			X		X	X	
Germany		X	X						X
Ireland	X	X		X	X	X			
Italy	X	X						X	
Luxembourg	X	X	X				X		
Netherlands	X	X		X	X	X			
Norway	X	X		X	X	X	X	X	X
Sweden	X		X	X	X	X			
Switzerland			X		X	X			
United Kingdom	X	X		X	X	X			
United States									
MUTCD				X	X	X			X
Michigan	X			X	X	X			
Minnesota	X	X							
New York				X	X				
Washington		X	X			X			

Source: Thomson et al. (2014).

TABLE 6
APPROPRIATE USE OF ADVISORY OR REGULATORY SIGN LIMITS FROM ONTARIO TRAFFIC MANUAL BOOK 7 (TEMPORARY CONDITIONS)

Method	Examples Where Speed Limit Reductions May Be Used
Advisory speed limits Used whenever an unexpected change in geometrics is caused by the work activity	▪ Bumps ▪ Low shoulders ▪ Drop-offs ▪ Limited but not substandard sight lines or stopping sight distance ▪ Limited but not substandard horizontal or vertical alignment ▪ Gravel surfaces (length less than 500 m) ▪ Temporary lane closures ▪ Milled surfaces
Regulatory Speed Limits Used for temporary worker safety Only to be used when workers present.	Workers on a freeway within 3 m (10 ft) of a travelled lane open to traffic where no barrier is used.
Regulatory speed limits Used for continuous, public and worker safety on long duration construction with continuous hazards or where uninterrupted flow cannot be designed at or above the normal regulatory posted speed (substandard geometrics). Used 24 hours a day	▪ Lane width less than 3.5 m (12 ft) on freeways or less than 3.0 m (10 ft) on non-freeways ▪ Shoulder width or offset to barriers less than 0.5 m (1½ ft), one or both sides ▪ Sudden lane narrowing ▪ Substandard sight lines or stopping sight distance ▪ Multiple lane shifts, detours or transition designed at less than the normal posted speed limit or those with no illumination ▪ Substandard horizontal or vertical alignment ▪ Gravel surfaces [length greater than 500 m (¼ mile)] ▪ Multiple lane shifts with overlapping/confusing pavement markings ▪ Partial lane shifts onto a surface texture different from the main roadway.

Source: Ministry of Transportation–Ontario (2014).

through advance signage, repeated as necessary. Regulatory speed limit signs shall only be installed when approved by the road authority. Once approved the appropriate police authority must be notified of the regulatory speed change prior to installation. Otherwise, only advisory signs should be used and all existing regulatory speed limit signs within the limits of the speed reduction must be covered or removed for the duration of the construction project.

A regulatory speed reduction should be implemented for a minimum road length of 300 m (0.2 miles) or more, even if the work zone is less than 300 m. Speed reductions can be implemented in stages. On a divided highway, the road authority may permit different speed limits for each direction of travel. In the case of an express/collector freeway, the speed limit may be lowered on one roadway, but not on another.

There are some philosophical and policy differences about appropriate work zone speed limits. For example, as with Ontario, VDOT prefers to design work zones so as to maintain normal speed limits where possible, but will reduce the speed limit by 10 mph if conditions warrant (D. Rush, VDOT, personal communication, 2014). Pennsylvania DOT (PennDOT) also tries to maintain normal speed limits on freeways, but only if workers are separated from traffic by a barrier. If workers are near live freeway lanes, PennDOT reduces the speed limit based on engineering judgment and experience; agency policy allows a 10 mph reduction without a formal study; however, a 15 mph reduction requires study and documentation (M. Briggs, PennDOT, personal communication, 2014). Although many other U.S. jurisdictions follow speed limit setting procedures that take site conditions and prior experience into consideration, in some cases statutory work zone speed limit provisions limit the discretion of the highway agency or project engineer. A Canadian work zone speed management guide suggests a pragmatic approach: "to assure a high level of compliance, speed limits have to be set at levels that are largely self-enforcing, or at the lowest speed the police are able to enforce" (Harmelink and Edwards 2005).

Although the *MUTCD* discourages setting speed limits more than 10 mph lower than the ordinary speed limit, there are some situations where the nature of the work, the close proximity of workers to live traffic, statutory requirements, or political considerations require a greater reduction. In these instances stepped reduction in increments of 5 mph or 10 mph is generally considered a most effective practice. For example, Virginia has occasionally applied 20 mph reductions (stepped down in 10 mph increments) for bridge deck closures with severe width constraints (D. Rush, VDOT, personal communication, 2014). As of 2014, Oregon DOT occasionally approves 35 mph work zone speed limits in situations such as night paving on low-volume freeways; a mandatory limit can be approved if at least two law enforcement officers will be present at the site (a stationary officer at the work zone approach to slow traffic and identify violators, and a mobile officer to intercept violators), otherwise the 35 mph limit is advisory. In these situations Oregon typically steps down the speed in 15 mph increments (65–50–35) (R. Pappe, personal communication, 2014).

FIGURE 9 *MUTCD* W3-5 sign.

The use of advance warning signs such as those shown in Figure 9 is generally considered a most effective practice to provide drivers with additional notice, particularly if the reduction is 10 mph or more. "The addition of advisory speed panels to work zone warning signs may also help in conveying to drivers appropriate speeds through specific portions of the project" (Bryden and Mace 2002). Interviews conducted for this project indicate that reinforcing the speed reduction message by placing the speed limit and advance speed reduction signs on both the left and right sides of the road appears to be an increasingly common practice, especially on multilane divided highways.

INCREASED FINES FOR WORK ZONE SPEEDING

According to the Governors Highway Safety Association (GHSA 2014) nearly all U.S. states have increased penalties for speeding or other violations in work zones. The higher penalties are implemented in several ways:

- In 33 states and the District of Columbia the fine for work zone speeding is twice the amount for nonwork zone speeding.
- In some cases the penalty is a higher fixed amount or range.
- In some cases the penalty depends on whether it is a first or subsequent offence.

In spite of the relatively widespread implementation of increased penalties, the evidence from field studies indicates that higher penalties have relatively little effect on compliance with the work zone speed limit.

In many states increased penalties are applicable only when workers are present and/or if suitable signs notifying drivers of increased fines are posted. Twenty-four states and the District of Columbia require workers to be present in the work zones as a condition for imposing the higher penalty. In 40 states and the District of Columbia highway agencies are required to install signs notifying drivers of the higher fines as they approach work zones (GHSA 2014). State-specific statutory provisions and case law affect the enforceability of increased fines for work zone speeding. For example, in Virginia work zone speeding fines can be increased to $500, but signs notifying drivers of the increased penalty must be installed and accompanied by flashing lights indicating that workers are present. Contractors are also required to maintain a log of the times when the lights were activated and deactivated. VDOT officials report that many contractors view the light activation and recordkeeping as burdensome, resulting in limited use of the enhanced fines provision (D. Rush, VDOT, personal communication, 2014). In Wisconsin, project managers are instructed that the courts might not enforce the state's double-fines law if an END ROAD WORK sign was not in place when the violation occurred (Shaw et al. 2014).

A 1997 report to the California Legislature reviewed the safety effectiveness of double-fine legislation (Khorashadi 1997). Crash and enforcement data for three pilot projects in California were used. Based on analysis of one year's data the report suggested that double-fine zones may help in reducing crash rates.

A study published in 2000 examined the short-term effect of a double-fine law that was implemented in Texas on January 1, 1998 (Ullman et al. 2000). Field studies of traffic speeds in several work zones were conducted before and after the implementation of the law. In addition, traffic citation information was collected for these work zones. Analyses suggested that the speeds before and 4 to 6 months after the law came into effect were essentially unchanged. Similarly, citation frequency and fines levied were not significantly higher than they were before the law became effective.

A 2002 study evaluated the effectiveness of double fines as a speed control measure in safety corridors in Oregon (Jones et al. 2002). The research was based on a telephone survey of 651 adult drivers in Oregon about their decision to speed in a variety of conditions. Survey analysis was used to infer indirectly the effectiveness of double fines on the driver's judgment. Most people were aware of double fines in work zones. Jones et al. concluded that effectiveness of double fines is weak, inconsistent, and generally not very conclusive. However, there are indications of a beneficial effect as a result of double fines. The study found that awareness of double fines elevates the perception of the risk of traffic fines, traffic citations, and higher insurance costs in school zones and to a lesser extent in work zones.

CHAPTER THREE

ENGINEERING TECHNOLOGIES

INTRODUCTION

This chapter discusses technologies—predominantly electronic technologies—intended to enhance driver awareness and/or compliance with work zone speed limits.

CHANGEABLE SPEED LIMIT SIGNS FOR WORK ZONES

Changeable speed limit (CSL) signs, such as those shown in Figure 10, appear to be gaining popularity in jurisdictions where work zone speed limits are based on criteria that change frequently, such as the presence or absence of workers. CSL systems typically combine an ordinary sign with a digital display panel that can be toggled between two or more values, such as a workers-present and a workers-not-present speed limit. Some systems allow the change to be made remotely. (Similar equipment is sometimes used at school zones to change the speed limit when children are present.) Some examples of the use of this type of equipment are as follows:

- VDOT reports the use of permanently mounted CSL signage at tunnel approaches near Hampton Roads (D. Rush, VDOT, personal communication, 2014). The ordinary speed limit in this section is 45 mph; however, a CSL system is activated (along with other pretunnel signage) to reduce the speed limit to 25 mph during recurring tunnel cleaning and maintenance.
- In 2008, Minnesota DOT (MnDOT) issued a *Guideline for Intelligent Work Zone System Selection*, which provides operational notes for the use of CSL signs (MnDOT 2008).
- In 1999–2000, MnDOT conducted a small-scale demonstration project intended to make it easier to change work zone speed limits on high-volume urban freeways (FHWA 2002). Portable speed limit signs mounted on U-channel supports were used for the project. Each sign was equipped with a two-digit digital display panel. When construction workers were not present, a 65 mph the speed limit was displayed; when construction workers arrived at the site, a designated worker changed the speed limit to 45 mph.

Only two studies were found comparing driver compliance with CSL to compliance with ordinary fixed work zone speed limit signs:

1. A study of CSL-type signage displaying mandatory work zone speed limits on I-80 near the Wyoming–Utah border concluded that at night under uncongested conditions and a 65 mph speed limit, the CSL-type signs resulted in hourly average speeds that were somewhat lower than the standard static speed limits signs previously used at the site. Speed variation was also reduced. The digital signs were highly conspicuous at night. During daylight hours the travel speeds appeared to be more consistent when the digital signs were used, but the results were difficult to interpret because of work zone congestion, traffic volume fluctuations, and other factors (Rifkin et al. 2008; McMurtry et al. 2009).
2. A study of advisory CSL-type signage at three Missouri work zones found that average traffic speeds were generally 1.5 to 2.0 mph lower with the digital signs than with static signs; 85th percentile speeds and speed variance were also reduced (Edara et al. 2013).

Additional evaluations may be necessary to understand more fully whether the differences found in these two studies are attributable to the greater conspicuity of the digital signs or simply novelty effects that will diminish with more widespread use of CSL.

VARIABLE SPEED LIMITS

In contrast to the relative simplicity of CSL signs, large-scale variable speed limit (VSL) systems modify the speed limit in response to real-time changes in traffic conditions. VSL systems typically involve corridor-level deployment of a series of speed sensors, digital signs, and automated control algorithms. A significant level of planning, system engineering, and system integration may be required. The requirements vary with the VSL system design and the extent of existing Intelligent Transportation System (ITS) infrastructure at the site. Administrative procedures for approving the system-recommended speed limit and communicating it to law enforcement are also a consideration, particularly if the limit is mandatory rather than advisory.

Typically the objective of VSL is to delay the onset of congestion by slowing traffic gradually as it approaches a bottleneck. Consequently, the goal is usually to improve the temporal and spatial uniformity of traffic speeds, rather than simply reducing speeds. This characteristic makes assessment of VSL systems more difficult than evaluation of most other work zone speed management techniques. Some of

FIGURE 10 Trailer-mounted changeable speed limit (CSL) sign (MinnDOT 2008).

these challenges are discussed in Case Example 2, which describes a large-scale Virginia deployment.

A number of relatively theoretical research papers have explored the speed harmonization and capacity benefits of work zone VSL systems; however, the primary field application for VSL in the United States has been to reduce the risk of back-of-queue crashes at work zone approaches. These queue management applications are beyond the scope of this synthesis report. The theoretical papers often assume low latency (short time lags between selection of a new speed limit and its display to traffic) and high levels of driver compliance, which have not always been the case in U.S. field deployments.

A few field studies have examined the speed management aspects of work zone VSL systems. The small number of studies, technical differences between the systems, variations in site conditions, and diversity of results make it difficult to generalize about the systems' effectiveness. Reported results include the following:

- A study of VSL deployment on I-96 near Lansing, Michigan, found increased average speeds in the freeway work zone when the system was operational, primarily because during uncongested conditions the VSL was higher than the fixed work zone speed limits that had been in place before the system was activated. Effects on the estimated 85th percentile speed and speed variance were either undetectable or inconsistent (Lyles et al. 2004).
- A study of a Variable Advisory Speed Limit (VASL) system deployed on I-494 in the Twin Cities (Minnesota) found that the system was effective in reducing the longitudinal speed differences along the work zone area during the weekday morning peak period. Traffic throughput also increased (Kwon et al. 2007).
- As discussed in Case Example 2, effects of the 2008–2010 VSL deployment on the Capitol Beltway in Virginia were inconclusive, in part because of driver noncompliance with the variable speed limits.
- A 2013 Missouri study of a VASL system deployed at an uncongested site on I-270 on the outskirts of St. Louis found that average freeway speeds were reduced by 2.2 mph, but the standard deviation of speeds increased by 4.4 mph, most likely because some drivers complied with the advisory limits and others did not. Compliance rates at the uncongested site were much higher with the VASL system than without it. Results at a nearby congested site were mixed (Edara et al. 2013).

Case Example 2: Variable Speed Limit Pilot Project on the Woodrow Wilson Bridge**

The Capital Beltway (I-95/495) encircles the Washington, D.C., area. The Woodrow Wilson Bridge (WWB) carries the Beltway across the Potomac River at the Virginia/Maryland border near Alexandria. In late July 2008, VDOT introduced a Variable Speed Limits (VSL) test program as part of a mega-project to reconstruct the bridge. The initial deployment was intended to assist drivers approaching the reconstruction of the Telegraph Road Interchange near the western approach to the bridge. The Telegraph Road project was a $240 million element of the larger WWB mega-project. The cost of deploying the temporary VSL system was $3.2 million.

Three to six travel lanes were available in each direction through the work area, and the work zone was approximately five miles long in each direction. To minimize impact on the already heavily congested roadway the lane closures were done during overnight hours, typically with one or two lanes closed. Given the high traffic volumes and the complexity of the work zone, VSL was deployed as a congestion management tool. The intent was to enable more vehicles to pass safely through the constricted area by gradually regulating the speed of vehicles approaching a reduction in lane capacity. Other ITS applications were also incorporated into the transportation management plan, including closed-circuit television cameras to monitor traffic conditions and Portable Changeable Message Signs (PCMS) to provide real-time travel delay information to motorists and enable drivers to modify travel routes, times, and modes.

The VSL deployment was intended to increase throughput traffic flow in a safe manner by reducing driver speed variation. Specially trained VSL officers housed at the project field office oversaw the system using roadway sensors and the other ITS hardware and systems on the project. The officers developed optimal speed limits using a vendor-supplied control algorithm that would attempt to keep traffic flowing by setting the range of speed limits from a minimum speed of 35 mph to a maximum speed of 55 mph. Drivers were informed of the varying speed limits, which changed in 5 to 10 mph increments, through the VMS along a seven-mile portion of I-95 between the Springfield Interchange and the Maryland shore. To allow sufficient time for law enforcement to be notified, the speed limit was not changed more than once every 20 minutes.

The VSL system was initially deployed in July 2008, but only activated during temporary lane closures that occurred at night and weekends, and under certain "restricted" conditions that resulted in very limited use. In May 2009, the VSL was expanded to "full-time" use: the system was activated in a traffic-responsive mode during all peak congested periods, regardless of construction activity. The pilot program officially ended February 21, 2010; all VSL equipment was removed from the area and a fixed 55 mph speed limit was restored throughout the project corridor.

A preliminary evaluation, done in 2009 by the Virginia Transportation Research Council (VTRC), studied the initial 10-month restricted activation period. The evaluation produced inconclusive results, including no large changes in speed or queue length. Therefore, in May 2009, significant changes were made by extending the system to full-time use and the system vendor made changes in the control logic.

After the VSL system operation changes were made, the VTRC researchers concluded it was not prudent to conduct a thorough empirical analysis of the system performance of the final system operation. Significant variations in the lane closure locations, demand volumes, and work activity made it difficult to perform before-and-after comparisons under similar conditions. In addition, construction activities changed enough that there was never a clear one-to-one match between lane closures before and after the VSL was activated. Because of the inconclusive preliminary results of the field deployment of VSLs on the project, the researchers concentrated their efforts on using simulation modeling to gain a better understanding of the significance VSL system design has on operations. Using data collected during the second half of the deployment period, an in-depth report was prepared using a calibrated VISSIM microsimulation model of the project area. The simulation provided an opportunity to examine a number of system configurations to assess how changes in system design and driver behavior might affect a variety of performance measures. The results indicated that VSL could provide substantial improvements in traffic operations, but only if demand did not exceed capacity by too large a margin, such as only reducing four lanes to two lanes versus four lanes to one lane. The simulation also demonstrated that algorithm design, driver compliance with the limits, and the location of the VSL signs all play important roles in operational performance. A cost–benefit analysis was also conducted, which showed that VSL was most appropriate only for long-term work zone applications, because of the high cost of establishing the VSL system.

The construction project team (including the VSL project manager) conducted a before-and-after study of the full-time VSL phase. Various measures of effectiveness (MOEs) were examined including speed, travel time, capacity, queues, and delays. Three months of baseline before data (February through April 2009) and 9 months of after data (May 2009 through January 2010) were used for this study. As a result of cost limitations, travel time for each segment was estimated by multiplying the average speed at each detector by the distance between detectors. Results were as follows:

- Overall, there were no statistically significant changes in the various speed or capacity MOEs; however, some positive impact was indicated in the capacity of the roadway.
- Travel times increased in the area upstream of the beginning of the bottleneck and significantly decreased for the remainder of the work zone for the north/east direction of travel. An insignificant change in travel time was detected for the south/west direction of travel.
- Anecdotal observations of queue lengths and associated delay time appeared slightly reduced from normal patterns.
- Qualitative measures such as public outreach and community feedback were also assessed, but little feedback was received about VSL after the initial deployment. The deployment and methods of use of PCMS received very positive feedback.

The project study team reported several lessons learned:

- The system performance and ability to evaluate the system would have been improved by using speed detectors that could record individual vehicle speeds instead of averaging all vehicle speeds over a period of time.
- The speed detectors should be verified with other traffic data sources, such as speed radar guns, and system software calibrated regularly to account for changing roadway configurations.
- Automated speed enforcement could have enhanced system performance by substantially reducing the number of high speed drivers.
- PCMS at key locations are important to help drivers make diversion decisions.

The project construction team evaluation concluded that successful VSL deployment as a work zone management tool would be viable if motorists are informed of real-time work zone conditions, automated speed limit enforcement is used, and if drivers have adequate time to use alternate routes.

References: (Fudala and Fontaine 2010a, b; Nicholson et al. 2010; VDOT 2010).

DYNAMIC SPEED FEEDBACK SIGNS

Dynamic speed feedback signs (also known as dynamic speed signs, speed monitoring displays, speed indicator boards, radar speed reader boards, or radar speed display units), such as those shown in Figure 11, combine a static sign showing the regulatory or advisory speed limit with an adjacent digital panel that displays the observed speed of the nearest vehicle. Displaying actual speed to motorists as they approach a work zone (or proceed through the work zone) has become a useful speed management practice. The technique has been successfully implemented using several different types of hardware. Although the topic has been extensively researched, a wide range of speed reduction results has been found in the field.

FIGURE 11 Dynamic speed feedback trailer. (Photo: Wikimedia Commons).

Work zone dynamic speed feedback systems typically utilize a trailer-mounted display panel for ease of installation and portability. Alternatively, a post-mounted system can be used, or the speed can be displayed on a multipurpose PCMS. The speed data are typically collected using a radar device. Depending on the design details of the system, observed speeds that exceed the speed limit are sometimes displayed in red or using flashing amber digits. A limitation of the system is that in multilane applications with moderate to heavy traffic it may be unclear which vehicle's speed is being displayed.

Although some automated speed enforcement systems incorporate a dynamic speed feedback display, standalone dynamic speed feedback signs are generally not used to enforce speed limits. Such signs serve solely as a reminder to the driver by displaying his or her actual speed in comparison with the posted speed limit. Unlike automated speed enforcement systems, no photographs are taken, nor are individual vehicles identified. Nevertheless, summary speed data are often recorded to assist law enforcement and the highway authority in determining whether additional speed management measures (such as additional active law enforcement patrols) are needed.

Dynamic speed feedback can modestly reduce the vehicle speeds in the immediate vicinity of the display, with various research studies showing a range of speed reductions of approximately 1 to 8 mph in the area approaching lane reduction tapers and 3 to 6 mph within the work zone, compared with conventional work zone treatments used in the before condition. The treatment was evaluated and found effective for both short-term work zones (maintenance operations) as well as long-term projects (Carlson et al. 2000; Maze et al. 2000; McCoy and Pesti 2002; Brewer et al. 2006; Hajbabaie et al. 2011). Speed reductions of 8 mph were reported when a radar-equipped portable changeable message board was used (Wang et al. 2003).

There is no consensus on the long-term speed reduction from using the technique based on different studies. The research done by Wang et al. (2003) concluded that the effects remained valid three weeks after the installation. Conversely, a study by Meyer (2004) concluded there was a novelty effect. A somewhat more recent study concluded that, "After a long-term implementation, the DSD [dynamic speed display] had a slight impact on the daytime speed but significantly decreased both the average speed and percentage of speeding drivers during nighttime hours. The significant speed reduction by the DSD presented in previous studies was likely the result of a novelty effect. As observed in this study, the overall speed reduction lapsed with time" (Chen et al. 2007).

Field experience indicates some potential limitations of the signs. For example, PennDOT prefers to display a SLOW DOWN message instead of a numerical speed reading because some drivers attempt to see how large a number they can register on the sign (M. Briggs, PennDOT, personal communication, 2014). In 2014, the authors of this synthesis report routinely observed readings in the 59 to 63 mph range on dynamic speed feedback signs at a work zone on I-94 in Milwaukee County, Wisconsin, which had a speed limit of 50 mph and is used mainly by commuters. In the multilane Milwaukee application it was often difficult to tell which vehicle's speed was being displayed.

Surveys and interviews with state DOT officials indicate varying levels of utilization of speed monitoring displays in the United States. In 2014, Illinois DOT began requiring contractors to furnish a dynamic speed feedback sign whenever workers are present and lanes are restricted by construction (IDOT 2014a).

PORTABLE CHANGEABLE MESSAGE SIGNS WITH VEHICLE-ACTIVATED SPEED MESSAGES

Trailer-mounted PCMS can be equipped with radar-activated changeable message displays that warn motorists they are traveling at an unsafe or undesired speed in a work zone.

Typically, the unit is programmed to display an anti-speeding message when a vehicle exceeding a threshold speed (typically 3 mph above the speed limit) approaches. Common messages that are displayed when the threshold speed is exceeded include:

- YOU ARE SPEEDING, SLOW DOWN
- HIGH SPEED, SLOW DOWN
- REDUCE SPEED IN WORK ZONE
- EXCESSIVE SPEED, SLOW DOWN.

Several studies have been conducted on the effectiveness of these four sign messages and all were found to reduce the number of vehicles speeding adjacent to the PCMS, with a speed reduction of 7 mph near the sign reported in a Georgia study (Fitzsimmons et al. 2009). The reduction in speed did not extend into the work area itself, perhaps owing to the site conditions and distance to the active work site.

A more advanced version of this concept was tested on a four-lane divided highway in Arizona that had a 35 mph work zone speed limit (Roberts and Smaglik 2012). On the PCMS, a YOUR SPEED IS XX MPH message was displayed to all vehicles. For vehicles traveling 46 mph or more, the speed feedback message alternated with a second message: POSSIBLE FINE $XXX. The dollar amount varied from $155 to $480 based on the severity of the speeding. Reductions in mean speeds were modest (about 4 mph); however, the number of severe speeders was reduced by up to 50%.

PORTABLE CHANGEABLE MESSAGE SIGNS WITH GENERAL SPEED SAFETY MESSAGES

In the 1990s, as PCMS technology became widely available, PCMS units were added to supplement static work zone signs and traditional traffic control devices. In general, the intent is to draw attention to the changed road condition and the need for drivers to reduce speeds. PCMS used in this application are typically programmed with general work zone safety messages and speed limit information. They became a staple speed reduction device on many large freeway and high-speed roadway projects. Starting in the 1990s, a number of studies found that this technique resulted in a speed reduction for all types of vehicles; however, in more recent studies only 1 to 4 mph reductions were typically observed (Garber and Srinivasan 1998a, b; Fontaine and Carlson 2001; Brewer et al. 2006; Bai et al. 2010).

PORTABLE CHANGEABLE MESSAGE SIGNS SPEED FEEDBACK TRAILER WITH "POLICE" LIGHTS

In 2011, small-scale field tests of a PCMS trailer augmented with experimental flashing "police" lights were performed at moderate-volume freeway maintenance work zones near Stockton in north-central California (Ravani et al. 2012).

FIGURE 12 PCMS augmented with flashing "police" lights (Ravani 2012).

The units combined a standard PCMS, a radar speed data collection unit, and a set of blue and amber flashing lights—colors are associated with the California Highway Patrol. The flashing lights and a SLOW DOWN message were activated when a vehicle traveling 5 mph or 10 mph over the speed limit was detected (Figure 12). The lane closure alone without the trailer resulted in a reduction of average traffic speed by approximately 5 to 5.5 mph. The use of the light-augmented speed trailer by itself resulted in approximately 3 to 7 mph further reduction of the average traffic speed in the work zone beyond what was observed with the closure alone. Use of a highway patrol officer in a police vehicle in addition to the speed trailer resulted in approximately 5 to 9 mph further reduction of the average traffic speed in the work zone beyond what was observed with the closure alone. Some of the reductions associated with the device may have been novelty effects.

AUGMENTED ENFORCEMENT SYSTEM

An experimental augmented enforcement system was tested on a multilane divided rural highway in central California in 2012 (Chan et al. 2013). The system utilized Automated License Plate Recognition similar to the technology discussed in chapter seven to go beyond the capabilities of traditional speed feedback displays. As shown in Figures 13 and 14, the system combined the license plate recognition capabilities of a speed camera with a PCMS to display the speed and plate number of each vehicle that was exceeding the work zone speed limit. In addition, the system demonstrated the feasibility of using Dedicated Short Range Communications (DSRC) to relay the plate number and observed speed to a California Highway Patrol officer or workers downstream. The research prototype did not include any automated functions related to issuing citations. Speed data were collected using iCone drums—proprietary radar and telecommunication devices concealed inside ordinary orange traffic control drums. Results from an 8-week field test showed a 10%

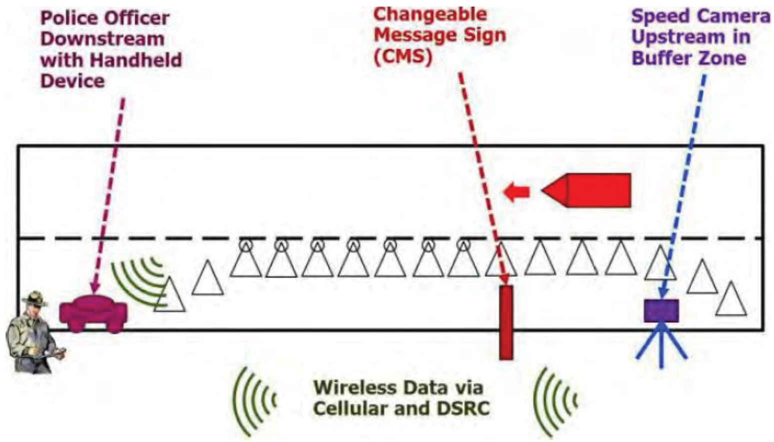


FIGURE 13 Concept of operation for augmented enforcement system (Chan et al. 2013).

reduction in the percentage of vehicles travelling through the work zone at speeds above 65 mph and approximately 6% more vehicles traveling at less than 60 mph. The accuracy of the Automated License Plate Recognition system in the speed camera declined under certain lighting conditions.

DECOY RADAR

Decoy or "drone" radar refers to unattended systems that emit a decoy radar signal. Decoy radar units are relatively inexpensive and can be mounted on a variety of roadside objects including signs, guardrails, arrow panels, traffic control drums, and vehicles. The tactic is primarily used to catch the attention of drivers with radar detectors.

An August 1991 directive from U.S.DOT and NHTSA authorized the use of decoy radars (Eckenrode et al. 2007). The intent is that vehicles equipped with radar detectors will perceive the presence of decoy radar as the presence of police enforcement and reduce speeds. In general, decoy radar is expected to affect speeding vehicles more than general traffic, because it is anticipated that drivers who intend to exceed the speed limit are more likely to have radar detectors. Consequently, the effectiveness of decoy radar depends on the number of radar detectors in the traffic stream. In February 1995, U.S.DOT issued a directive banning the use of radar detectors in all commercial vehicles. Nevertheless, it is likely that some commercial vehicles still use radar detectors. As of 2007, radar detector usage in passenger vehicles was legal except in the District of Columbia, Virginia, and U.S. military installations (Eckenrode et al. 2007).

Several studies have been undertaken on the effectiveness of decoy radar in work zones since the mid-1980s. Table 7, based on Eckenrode et al. (2007), summarizes the evaluations of decoy radar in work zones. The same authors performed the most recent evaluation of decoy radar using information gathered in South Carolina work zones. Data were collected at five sites including interstate highways, state routes, and rural routes. Results showed mean speed

FIGURE 14 Messages displayed to speeders by the augmented enforcement system (Chan et al. 2013).

TABLE 7
SUMMARY OF DECOY RADAR STUDIES

Date	Study	Description	Configuration	Results
1986	Northern Kentucky (Pigman et al. 1987)	Used X-band decoy radar in 6-lane Interstate work zones	Speed collected at 2 locations for several days for both night and day	Radar detectors (42% tractor-trailers and 11% cars) mean and 85th percentile speed decreased
1990	Texas Transportation Institute (Ullman 1991)	Used low output radar transmissions in 8 Interstate work zones	Station 1: 3,000 ft upstream from work zone Station 2: 1,200 ft upstream from decoy Station 3: 2,000 ft downstream of Station 2	Speeds decreased 2 mph and standard deviations increased
1992	South Dakota DOT (Fors 1999)	Used 500 of Kustom Signal Pro 65 X-band decoys	Decoys were placed in 500 of the 602 state vehicles	21.1% decrease in statewide crashes
1992	Champaign, Illinois (Benekohal et al. 1993)	Used a radar gun that acts as decoy on rural Interstates, CB radio	Experiment 1: immediate effect of decoy Experiment 2: short-term effect Experiment 3: use multiple radar guns	Experiment 1 (8 to 10 mph decrease) Experiment 2 (no effect) Experiment 3 (3 to 6 mph decrease)
1993	Maryland (Teed et al. 1993)	Used multiple police radar devices on Interstates	Radar placed every few miles. Tested radar detector use by looking for braking and 5 mph speed reductions	Both experiments showed police radar has short-term effects on speed, radar detector usage was 30%
1994	Missouri (Freedman et al. 1994)	Placed decoys on pavement edge of roads of long-term work zones	Station 1: 0.4 mi from work zone Station 2: 0.2 to 0.8 mi in work zone Station 3: 0.4 mi from decoy	3.4 to 1.8 mph speed decreases (passenger cars), 3.6 to 2.0 mph decrease (tractor trailers)
1995	New Mexico and Texas (Fors 1999)	Placed decoys on arrow boards and barrels	Monitored CB radio and collected speeds for 40 consecutive hours	3 to 4 mph decrease (tractor-trailers), 2 mph reduction in speeds (cars)
1995	University of Michigan (Streff et al. 1995)	Used decoy radar and police enforcement in two major Interstates	Station 1: upstream from decoy detection Station 2: detection distance from decoy Station 3: downstream of decoy	2 mph decrease in speeds, radar detector usage days (5% cars), (19% tractor-trailers day, 28% night)
1997	Virginia Polytechnic Institute and State Univ. (Turochy 1997)	Used the decoy radar checkpoint model 2A by PM design lab of NC	Station 1: upstream into decoy Station 2: 500 to 1,000 ft from decoy detection	Mean speeds decreased 0.8 to 2.3 mph, standard deviations reduced in half with decoy on
2000	Midwest Smart Work Zone Deployment Initiative (Fors et al. 2000)	Placed decoy on either end of 1-mi segment of work zone	Speeds were collected 4 h before decoy deployment and 4 h after	No significant changes in speeds, but may reduce 85th percentile speeds
2001	Georgia Institute of Technology (de Oliveira et al. 2002)	Tested safety warning system and basic decoy radar on Interstates	Station 1: collected volume using road tubes Station 2: pictures of radar detector users Station 3: decoy unit	No decrease in speeds, decelerated more with SWS in place

reductions of about 2 mph for the entire traffic stream. Speed reductions of vehicles equipped with radar detectors ranged from 5 to 8 mph. Decoy radar also caused 85th percentile speeds to decrease between 1 and 5 mph, and a 20% speed reduction was shown in vehicles exceeding the speed limit. Another important finding from this study is the prevalence of radar detectors in the traffic stream. For passenger cars it varied from 2.2% to 5% and for tractor-trailers it ranged from 7.1% to 7.5%, which helps explain the relatively modest impact decoy radar has on speeds. Collectively, these studies suggest that decoy radar can have minor impacts on speeds within the detection distance of radar transmissions.

Prolonged use of decoy radar limits its effectiveness. A 2005 Maryland State Highway Administration report (MSHA 2005) recommends periodic police enforcement in conjunction with decoy radar operation to maintain its effectiveness over the long term.

A 1991 Texas study reported that severe braking and last minute lane changing increased when decoy radar was in operation (Ullman 1991); however, one could expect that a similar response would be elicited by the presence of law enforcement.

State DOTs interviewed for this project reported mixed results with the use of these systems. For example, VDOT experimented with a portable decoy radar system that could be attached to a guard rail, but stopped using the system after one construction season because of “disappointing” speed reduction results and because users found the system cumbersome to move and recharge (D. Rush, VDOT, personal communication, 2014).

CHAPTER FOUR

ENGINEERING TECHNIQUES

INTRODUCTION

How a work zone is designed and organized can help create an environment that encourages drivers to select an appropriate speed. Typically, this involves providing visual or tactile cues (in addition to speed limit signs) that let drivers know they are entering a stretch of road where driving conditions are more difficult and speeds need to be reduced. A number of engineering measures have been proposed to help reduce speeds in work zones. Researchers and transportation professionals in some regions of the United States use the term "work zone traffic calming" to refer to such methods. In other regions, the term "traffic calming" is strongly associated with residential streets and other low-speed environments, and the use of the term traffic calming may require clarification if applied in the context of speed reduction on freeways and other principal highways.

Broadly speaking, engineering techniques can be classified as either physical or perceptual. Typically, physical measures involve reducing lane width or changing vertical or horizontal geometry so as to provoke a reduction in motor vehicle speeds. Perceptual measures generally involve creating the illusion that the roadway is narrower or the driving environment is becoming more difficult, and hence speed must be reduced.

PHYSICAL REDUCTION OF LANE WIDTH

Generally speaking, roads with wide lanes are easier to drive than roads with narrow lanes. As lane width increases there is an increased margin for error, so drivers will tend to increase their speeds. The physical width of travel lanes in work zones appears to have a moderate effect on traffic speeds: narrowing the lanes appears to reduce both speed and the capacity of the work zone.

Right-of-way constraints often require lane width to be reduced to provide sufficient space for work operations. In some instances, lane width has also been deliberately reduced to achieve a speed reduction effect. From a human factors perspective, reduced lane width means less lateral maneuvering distance and a reduction in the distance between the vehicle and roadside obstacles such as traffic control drums or barriers; this requires more driver attention, and drivers often compensate by reducing speeds. The 2010 *Highway Capacity Manual* (HCM) (TRB 2010) considers 12-ft lane width as the base case and provides values for reduction in free-flow speed because of narrow lanes on basic freeway sections and multilane highways. No guidance is provided on the impact of narrow lanes on speed reduction in work zones.

Kemper et al. (1984) studied the safety effects of narrow lanes in construction zones. The study was conducted during the 17-month before and after period during the reconstruction of bridge decks on the George Washington Memorial Parkway near Washington, D.C. The study found that the use of 9-ft lanes in Stage 1 of the reconstruction increased the crash rate, although crash severity decreased. Lower speeds were observed but the speed reduction was not quantified.

Two 1980s studies evaluated the speed change effects of narrow lanes in two work zones (Richards et al. 1982; Kuo and Mounce 1985). At one location mean speeds were reduced by 3 to 8 mph, whereas there was only a slight reduction at the other. The study did not control for the influence of other factors on speeds and, therefore, the reductions may not be fully attributable to reduced lane width.

Another mid-1980s study evaluated the effect of lane width reductions at six work zones on rural and urban freeways in Texas (Richards et al. 1985a, b). Cones were used to reduce the lane widths to 11.5 and 12.5 ft in the work zones. The effect of the lane-width reduction varied widely across the different sites, from 0 to 8 mph. In other words, the effect varied from none to a 16% speed reduction. The study suggested that using drums or concrete barriers might result in greater reductions.

A more recent study explored reductions in free-flow speed resulting from reduced lane widths and lateral clearances in work zones (Chitturi and Benekohal 2005). Traffic data were collected at 11 work zones on interstate highways in Illinois that normally had two lanes and were reduced to one open lane (Table 8). Four work zones had a period of time during which there was no work activity, police presence, flagger presence, or the presence of a flashing speed limit of 45 mph. All four sites were long-term work zone sites with a posted speed limit of 55 mph in the work zone and 65 mph outside the work zone, had no lateral clearance on either side of the travel lane, and were located in level terrain. The lane widths in the four work zones were 16, 12, 11, and 10.5 ft. The reductions in vehicular free-flow speed in the work zones were found to be greater than the reductions given in the HCM for basic freeway sections. The data also showed greater speed reduction for greater reductions in lane width. In addition, the reduction in the free-flow speeds of heavy vehicles was greater than the

TABLE 8
RELATIONSHIP BETWEEN SPEED AND LANE WIDTH PROPOSED BY CHITTURI AND BENEKOHAL

Lane Width (feet)	Free-Flow Speed Reduction (mph)
10	10.0
10.5	7.0
11	4.4
11.5	2.1

Source: Chitturi and Benekohal (2005).

reduction in the free-flow speeds of passenger cars. As shown in Figure 15, the study recommended that 10.0, 7.0, 4.4, and 2.1 mph be used for speed reduction in work zones for lane widths of 10, 10.5, 11, and 11.5 ft, respectively.

A 1989 design manual published by Spain's MOPU discusses the use of "lateral obstacles" to control work zone speed by reducing the effective lane width (MOPU 1989). It appears that typical Spanish practice is to channelize the traffic using vertical panels arranged in pairs on each side of the roadway to create a "gateway" effect; longitudinal panels and temporary barriers are also suggested for this purpose (Figure 16). As shown in Table 9, the manual suggests a nearly linear relationship between lane width and the target traffic speed, but does not discuss relationships with the design standard, traffic environment, or ordinary speed of the roadway; as a result, it is unlikely that the effect of lane width alone is as strong as the MOPU manual suggests.

Lane width reductions may require additional administrative coordination for the routing and permitting of overwidth trucks. In some cases it is necessary to move drums or other temporary traffic control devices while a wide load passes though the work zone (Shaw et al. 2014).

Occasionally, there are work zone situations where a lane closure results in the remaining lane being very wide.

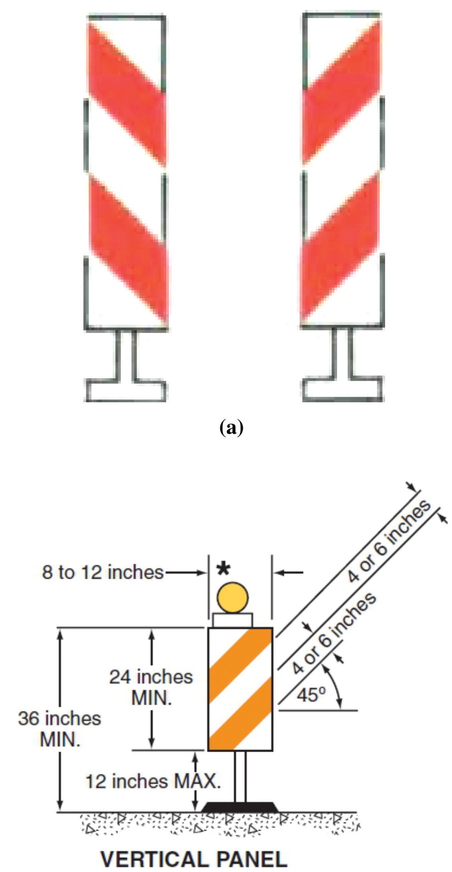


FIGURE 16 Vertical panels: (*a*) Vertical panels used for channelization and lane narrowing in Spain (MOPU 1989), (*b*) U.S. *MUTCD* vertical panel (FHWA 2009).

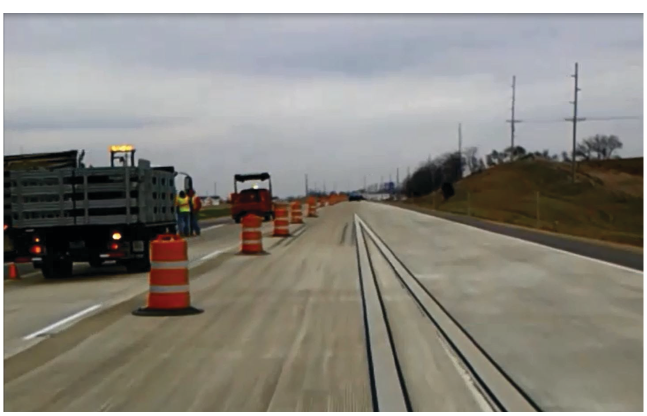


FIGURE 15 Restriction of expressway lane width, possibly initiated by a contractor attempting to reduce speeds adjacent to the activity area (Rizos 2014).

NCHRP Report 476 cautions against this situation (Bryden and Mace 2002):

> It is often necessary to use two or more longitudinal rows of channelizing devices to define both sides of a travel lane or for exit and entrance lanes. In these locations, it is essential to control the width between rows of devices to restrict traffic to the intended number of lanes while providing adequate width to accomplish turning

TABLE 9
RELATIONSHIP BETWEEN SPEED AND LANE WIDTH PROPOSED IN WORK ZONE DESIGN GUIDANCE ISSUED BY THE MINISTRY OF PUBLIC WORKS AND URBANISM IN SPAIN

Desired Speed		Width for	Width for
km/h	mph	One Lane (feet)	Two Lanes (feet)
100	62	12.6	24.6
90	56	12.1	23.8
80	50	11.6	23.0
70	43	11.2	22.1
60	37	10.8	21.3
50	31	10.5	20.5

Source: MOPU (1989).

maneuvers required by the traffic pattern. Where excessive width is available, aggressive drivers may attempt to pass slower traffic, creating confusion and a potential conflict when the lane again narrows. Typical problem areas are locations where a single open lane shifts from one side of the roadway to the other, at on- and off-ramps. For tangent sections and flat curves, the normal lane width of 4 m (12 ft) is normally sufficient to permit smooth flow while discouraging high speeds. In shifts and other locations where some turning is necessary, especially if articulated vehicles are present, increasing the width between devices to 4.3 m or 4.9 m (14 ft or 16 ft) will smooth flow and reduce abrupt driver reactions. Except where severe alignment necessitates, more width, greater than 4.9 m (16 ft) between devices, may encourage drivers to form two lanes or attempt to pass.

CHICANES

In the absence of superelevation, vehicles must reduce speed when they encounter a horizontal deflection in the travelled way. Any roadway configuration that adds horizontal curves for the purpose of reducing traffic speeds can be referred to as a chicane. One example of the use of permanent chicanes is to reduce traffic speeds as a high-speed, two-lane highway enters a village, as shown in Figure 17.

Various highway agencies have explored the use of chicanes to reduce speed in the upstream portions of work zones. In the United States, the most common technique is the Iowa Weave or switchback, which typically consists of a lane closure with traffic merging into the left lane followed by a lane shift to the right, as shown in Figure 18.

FIGURE 17 Permanent chicane intended to reduce speeds on highway D29 on a downgrade entrance to the village of Ernée, Mayenne, France (CERTU 2006, 2007).

According to Lorscheider and Dixon (1995), "this type of closure has [also] been successfully performed on three lane, one-way sections, although this use is limited because of its complexity. To perform this technique, two lanes are closed and the open lane is weaved across the center lane to the far side." An example is illustrated in Figure 19.

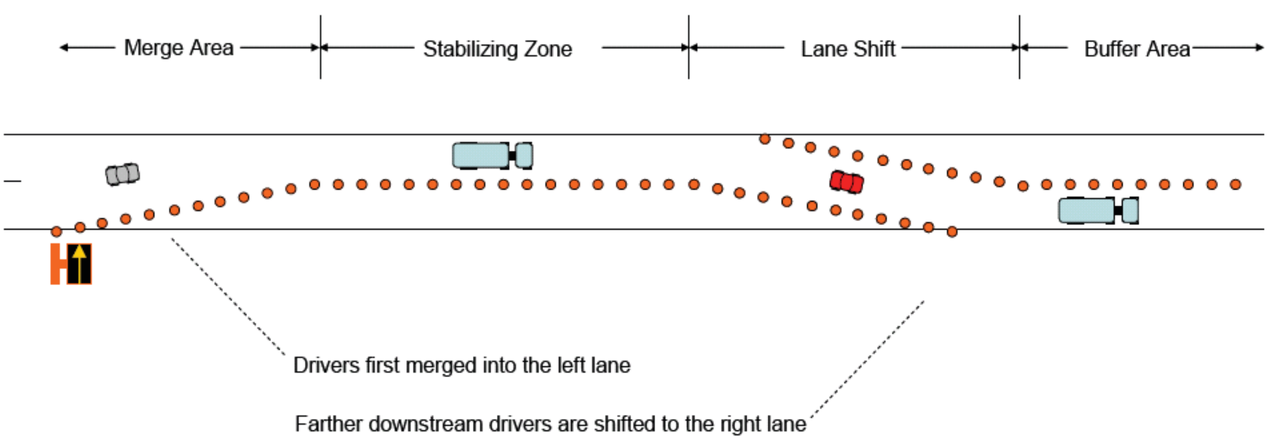


FIGURE 18 Iowa Weave for 2:1 closure with downstream left lane closed (Schrock et al. 2008).

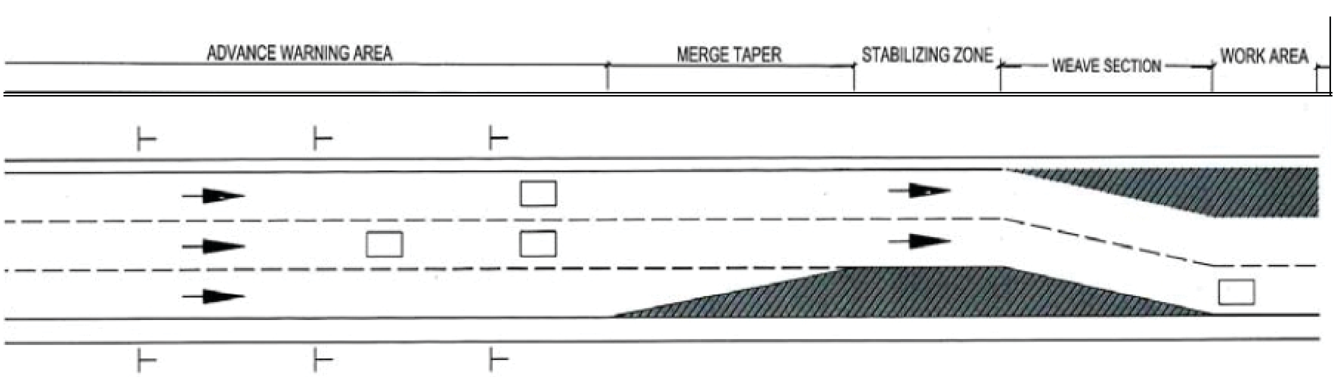


FIGURE 19 Iowa Weave for 3:2 closure with downstream left lane closed (See 2008).

The Iowa Weave was developed in the 1960s by the Iowa State Highway Commission (now Iowa DOT) for use in the transition area of work zones on multilane roads and streets. It was originally designed as a method to reduce speeds prior to entering a work area where workers were present and is typically implemented using traffic control drums or cones. An early 1970s study on an arterial street found it highly effective, with more than 50% of all sampled vehicles traveling below the 30 mph posted temporary speed limit, compared with less than 20% in construction sites where the Iowa Weave was not used (Brewer 1972). Brewer concluded that there was no excessive driver confusion in the use of this pattern, although three drivers were found performing unusual maneuvers in the advance warning area.

A mid-1990s study examined the effect of the Iowa Weave by evaluating the speeds at the advance of warning, end of taper, and weave and lane closure areas on both rural and urban freeways (Lorscheider and Dixon 1995). The research showed that the pattern is effective in reducing work zone speeds, but increases driver confusion in urban settings. The study therefore advised that the use of this chicane pattern be limited to rural freeways. In addition, Lorscheider and Dixon found that the speed reduction resulting from the chicane dissipated within 0.75 mile. The study's authors also pointed to time-saving advantages for contractors, because the switching from a right-lane Iowa Weave closure to a left-lane conventional closure can be accomplished quickly.

A 2008 study reported on the use of the Iowa Weave for freeway projects in Arkansas, Iowa, North Carolina, and Tennessee (Schrock et al. 2008). The authors reported that the Tennessee Department of Transportation requires all interstate construction and maintenance projects to review and include the use of the merge left where lane closure is applicable. The following criteria are used to determine its use:

- Projects on rural interstates should include the merge left concept.
- Projects on urban interstates will be reviewed for merge left concept considering factors such as number of lanes, interchange spacing, and proximity to major splits.
- Other controlled access facilities will be considered on a case-by-case basis.

Another 2008 study evaluated the crash performance of 10 Arkansas work zones, with and without Iowa Weaves (see Schrock et al. 2008). Based on a paired comparison, the author found a 30% reduction in the crash rate when the Iowa Weave configuration was used, but a logistic regression model found that the crash severity differences between the Iowa Weaves and conventional right-lane closures were not statistically significant.

Chicane designs are also used internationally to slow traffic at work zone approaches. As shown in Figure 20, a Spanish work zone design manual illustrates several designs for different situations, including two that are similar to the Iowa Weave (Direccion General de Carreteras 1997). In typical applications the speed limit is reduced from 100 km/h (62 mph) upstream to 80 km/h (50 mph) downstream. Older, more general, Spanish guidance cautions that, "to be safe and effective it is essential that [the chicane] is easily perceived and understood by the driver, and coordinated with signs and signals. At night, when traffic flow is low, it must also be clearly visible" (MOPU 1989).

A Swedish study explored new methods for marking work zone closures. Figures 21 and 22 show the "conventional" double-chicane design that served as the study's baseline (Nygårdhs 2007). Typical of current European practice, vertical panels with chevron markings are used for delineation. Considerable speed reduction is intended in the Swedish design: the posted limit is stepped down in 20-km/h (12-mph) increments to 50 km/h (approximately 30 mph) in the chicane, rising to 70 km/h (approximately 45 mph) downstream of the median crossover. According to Nygårdhs, observed speeds at point M3 of Figure 22 were approximately 65 km/h (40 mph), and were at or below the posted limit of 50 km/h (30 mph) at point M4.

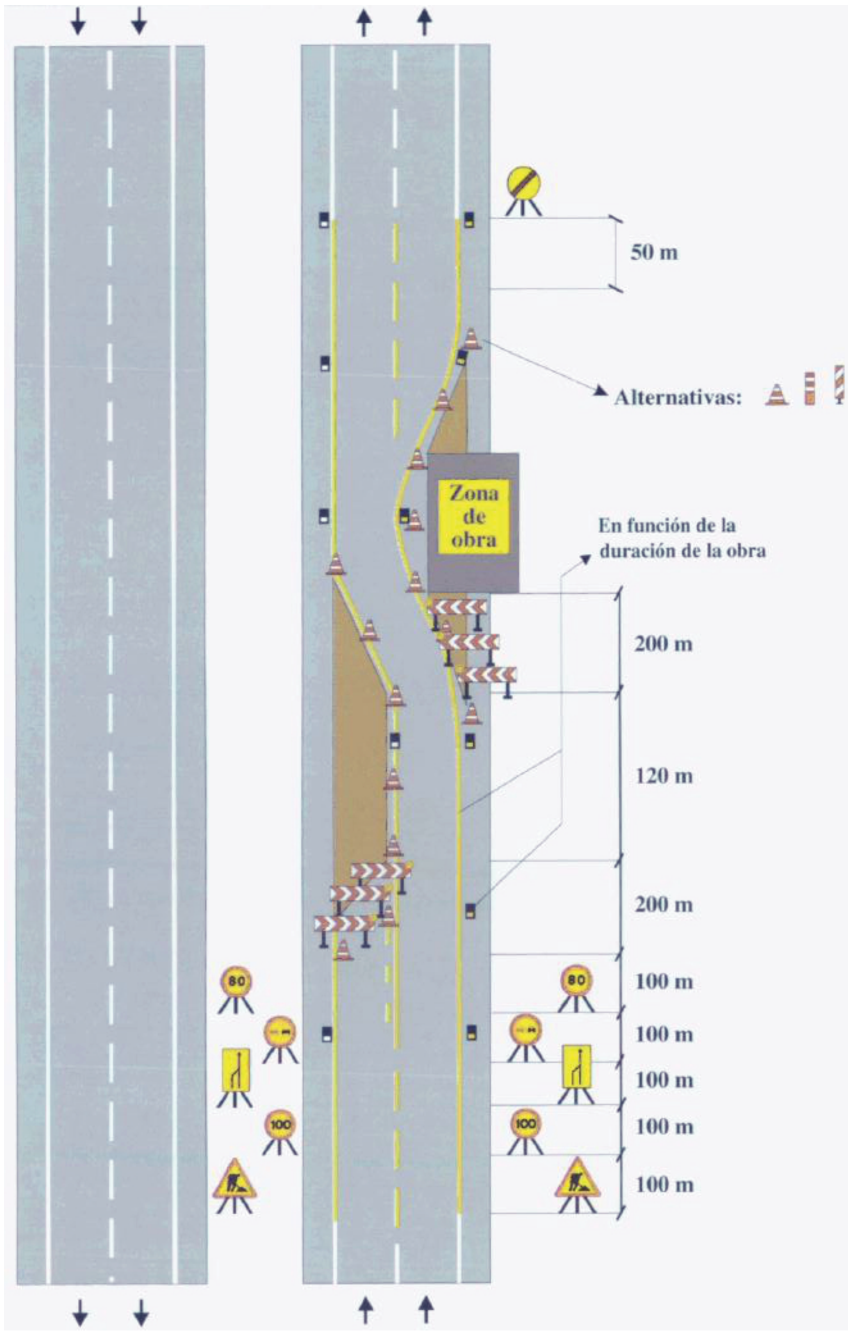
Additional research on the capacity and safety of chicanes may be desirable to provide practitioners with guidance on their appropriate use.

TEMPORARY TRANSVERSE RUMBLE STRIPS

Rumble strips provide drivers with tactile and audible warning in advance of a speed reduction. Proponents advocate the use of temporary transverse rumble strips for a wide variety of work zone applications, such as approaches to intersections, temporary traffic signals, and flagger stations. Interviews conducted for this project suggest that currently the primary field use of temporary rumble strips is for the approach to flagger stations on two-lane rural highways.

Kansas DOT requires the use of rumble strips on state routes when work requires the closure of a lane on a two-lane highway (Meyer 2000). An experimental freeway application has also been attempted on I-35 in Texas. A study by Hallmark recommended that to increase effectiveness, signing and other traffic control devices should be used in conjunction with the rumble strip to give drivers an indication of the reason for the required speed reduction (Hallmark et al. 2007).

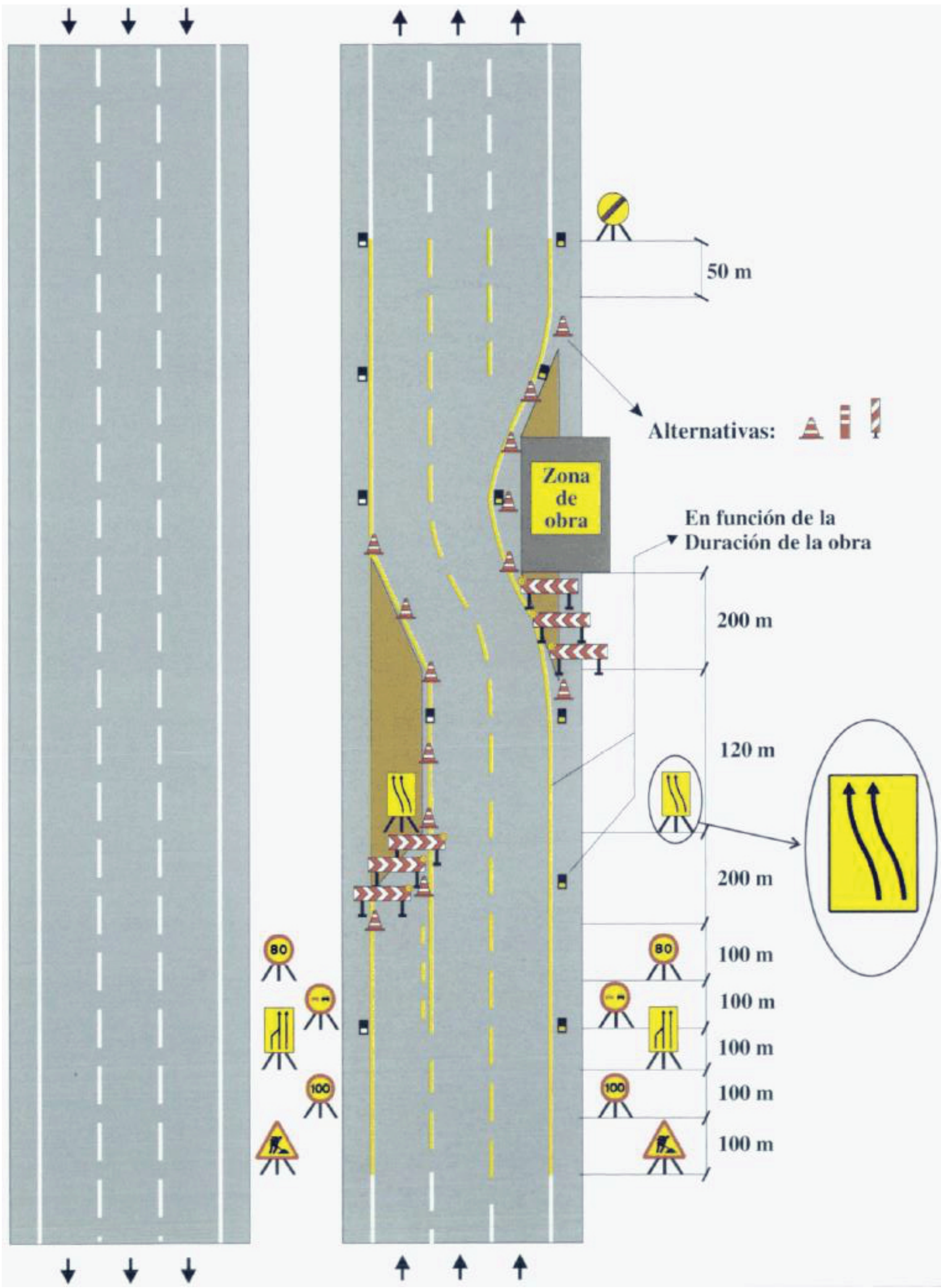
Researchers have explored a number of temporary transverse rumble strip configurations (Figure 23). Various materials have been used including formed asphalt, exposed aggregate, thermoplastic, rubber, and multiple layers of pavement marking tape. Studies have examined various combinations of number, thicknesses, and color of the strips (Harwood 1993; Shaik et al. 2000; Morgan 2003). Typical rumble strip dimensions ranged from 4 to 8 in. wide and from ⅛ to 1½ in. high. Several colors have been tested including black, white, yellow, and orange. These design differences (along with differences in the



(a)

FIGURE 20 Two-lane and three-lane chicane designs from a work zone design manual published by Spain's Ministry of Public Works (speeds in kilometers/hour and distances in meters) (Dirección General de Carreteras 1997).

(*continued on next page*)



(b)

FIGURE 20 (*Continued*).

FIGURE 21 Approach to chicane at a rural freeway work zone in Sweden (Nygårdhs 2007).

highway context, site conditions, and the upstream pavement surface condition) probably contribute to the wide variation in the results of field studies.

Nearly all of the rumble strip research reported an increase in driver awareness; however, most of the studies did not report quantitative changes in average speed. As one research group explained, "tests indicate that there may be positive benefits from temporary rumble strips, but a behavioral response from drivers is not necessarily observable through objective observations of vehicular speeds" (Horowitz and Notbohm 2005).

The following are some of the findings:

- An evaluation at four work zones on two-lane roads in New Brunswick reported that rumble strips reduced the mean speed by 6.9 km/h (4.3 mph) and the 85th percentile speeds by 9.5 km/h (5.9 mph). Variation of speeds was also improved by rumble strips. Specifically, the number of vehicles in the 15 km/h (9.3 mph) pace increased by an average of 6.4% and the standard deviation of operating speeds was reduced by an average of 0.86 km/h (0.53 mph) (Copeland 1998; Hildebrand et al. 2003).
- A study evaluated orange removable rumble strips and compared them with "standard" cold mix asphalt rumble strips (Meyer 2000). The orange removable strips were reported to have a significant effect on vehicle speeds (about 2 mph) as a result of their higher visibility.
- A 2001 report focused primarily on rumble strip applications for low-volume, two-lane roads in Texas with a 70 mph regulatory speed limit (Fontaine and Carlson 2001). The study's authors stated that results for portable rumble strips were mixed, with passenger cars experiencing less than a 2 mph reduction in mean speed approaching the temporary traffic control zone. The impact of the rumble strips on trucks was more

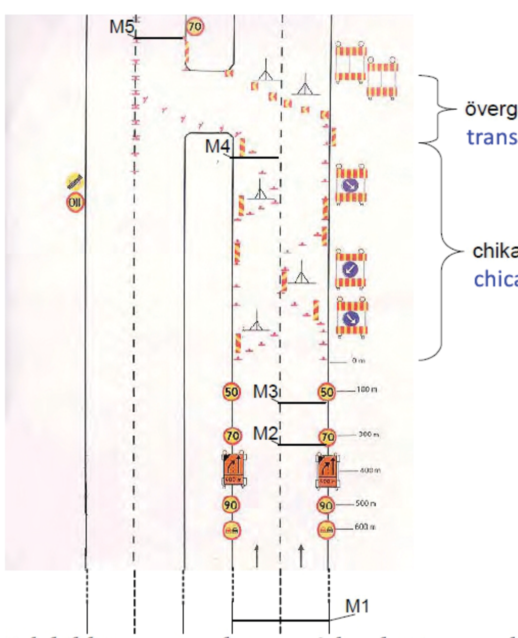


FIGURE 22 "Conventional" chicane design from Swedish study (Nygårdhs 2007).

(a)

(b)

FIGURE 23 Temporary transverse rumble strips (Pappe 2014).

pronounced, with mean speed reductions approaching the temporary traffic control zone of up to 7.2 mph lower than normal traffic control. The percentage of vehicles exceeding the speed limit in the advance warning area was also reduced when the rumble strips were used. Erratic maneuvers near the rumble strips were observed, perhaps because the strips used for the study were bright orange that contrasted sharply with the asphaltic pavement.

- A 2002 before and after study evaluated the performance of a proprietary product designed to be "quieter than a conventional rumble strip" at the approach to a work zone on a rural two-lane highway in Wisconsin (Horowitz and Notbohm 2002). The quality of sound was reported to be "distinctly different from a conventional rumble strip." The combination of warning signs and the rumble strips resulted in a small (less than 1 mph) but statistically significant slowing of vehicles.
- A 2005 report described results as "minor" (Lessner 2005).
- An evaluation of two proprietary rumble strip products conducted in Wisconsin in 2005 concluded that speed was an important determinant of the amount of sound coming from a work zone rumble strip (Horowitz and Notbohm 2005). The 0.25-in.-thick product was "effective" at 55 mph, but not at 40 mph. The 0.75-in.-thick product was effective for vehicle speeds of 10 to 40 mph.
- A 2009 Iowa report quantified the mean speed reductions as being in the range of 1 to 2 mph (Fitzsimmons et al. 2009).
- A Florida study evaluated removable rumble strips at construction work zones on a state route (McAvoy et al. 2009). Speed studies were conducted 600 ft and 5,500 ft upstream of work zones. At 5,500 ft upstream speeds were similar regardless of the presence of rumble strips. At 600 ft upstream rumble strips produced a speed reduction of 8 mph when compared with locations without rumble strips. The authors suggest that placing rumble strips closer to the work zone and using several sets in succession might have contributed to the greater reduction compared with previous studies.
- A 2010 study tested portable rumble strips on a closed roadway in Kansas City and in a closed Park & Ride facility in Lawrence, Kansas (Heaslip et al. 2010). Portable temporary rumble strips made out of steel with a rubber bottom and four generations of plastic rumble strips were tested. The most effective solution for most short-term work zones was found to be the fourth generation of plastic rumble strips. Steel rumble strips were also found to be promising; however, their structural integrity needs to be addressed.
- A Missouri study evaluated a nonadhesive temporary rumble strip near a two-way, one-lane operation on a low-volume road (Sun et al. 2011a). More than 10% of vehicles braked because of the rumble strips. Of the vehicles that braked, the average decease in speed was 3.7 mph and speed compliance increased by 2.9%. The average speed of all vehicles deceased by 1 mph; nevertheless, the number of adjacent lane encroachments increased by 8.8%.
- A Kansas study evaluated the effect of portable plastic rumble strips (PPRS) at three short-term maintenance work zones (Wang et al. 2011). The PPRS were placed in sets of four at 36 in., with two or three sets installed in advance of the flagger controlled work zones. Data were collected when no work activity or traffic control were present, when standard flagger traffic control was present and with PPRS in place. PPRS reduced car speeds by 4.6 to 11.4 mph. PPRS also reduced truck speeds by 5 to 11.7 mph on average, but only at two sites. About 5% of car and truck drivers swerved around the PPRS. The authors suggested that additional signing might be required.

As with the academic studies, practitioners reported a range of experiences with temporary rumble strips.

- VDOT recently established a typical application drawing for temporary rumble strips (D. Rush, VDOT, personal communication, 2014). The Virginia design calls for one set of three rumble strips to be placed 1,000 ft in advance of the flagger station; it is based on a proprietary product consisting of interlocking 36-in.-wide self-weighted rumble strip sections, black in color. The product vendor recommended using two sets of three strips; however, Virginia eliminated the second set after observing motorists attempting to drive around them. VDOT reports satisfactory performance, with the strips typically moving longitudinally approximately 3 in. during a typical workday. No difficulties with motorcycle safety have been reported. A gap in the strips allows bicycles to avoid driving over the rumble strips.
- Saskatchewan's Ministry of Infrastructure & Transportation reports difficulties keeping rumble strips in the correct location, possibly because of incorrect installation by contractors (M. Muhr, Saskatchewan MHI personal communication, 2014). A new, easier-to-install version of the proprietary product is expected to resolve the problem. Driver acceptance has been high, with 79% of drivers who responded to an online panel survey conducted for the Ministry stating that they agree that "Rumble strips alerted me to important information." The survey was conducted in December 2013 following the first construction season that the product was used in Saskatchewan (Insightrix 2013).

EMERGENCY FLASHER TRAFFIC CONTROL DEVICE

The Emergency Flasher Traffic Control Device (EFTCD) is intended to reduce traffic speeds on the approach to flagger stations at sites with two-way, one-lane operation. In a test at rural work zones in Kansas the technique was implemented as follows: as the first vehicle reached the flagger station and came to a stop, a research assistant asked the driver to turn on the vehicle's emergency flashers, thus increasing the conspicuity of the flagger station. The same request was made as each subsequent vehicle stopped at the back-of-queue, further augmenting the visibility of the flagging operation and the location of the back-of-queue. Ideally, the drivers of all vehicles would consecutively illuminate their flashers until they reached the end of the work zone.

An evaluation of the technique was conducted at three work zones on two-lane rural highways in Kansas (Bai and Li 2009, 2011). The sites had ordinary (nonconstruction) speed limits of 55 to 65 mph and traffic volumes of 750 to 5,000 vehicles per day. For all three sites combined, speeds were observed for a total of 110 vehicles with EFTCD in operation and 118 vehicles without EFTCD. At the 65 mph site, the average speed reduction measured 500 ft upstream of the flagger station was 5 mph; using combined data from the two 55 mph sites the average speed reduction measured 400 ft upstream of the flagger station was 2.5 mph compared with the speeds at the same locations when EFTCD was not used. Based on driver surveys, the EFTCD captured the attention of 84% of the drivers and 60% of the drivers thought that the EFTCD signified a need for speed reduction.

As currently conceptualized the EFTCD requires the presence of a second traffic control person at the flagger station, whose duty is to ask drivers to activate their flashers. Further research on this technique may be desirable to compliment the small-scale Kansas study and evaluate the EFTCD in other driving environments.

TRACTOR-TRAILER-TYPE MOBILE BARRIER SYSTEMS

Mobile barrier systems are intended to protect workers by isolating short-duration work zones from live traffic. As of 2014, two tractor-trailer-type mobile barrier systems were in use in the United States, the Balsi Beam developed by California DOT (Caltrans) and the MBT-1 system developed by Mobile Barriers, LLC (only the MBT-1 was in commercial production). Both systems are shown in Figure 24. They are typically used for freeway maintenance projects such as shoulder repair, guardrail replacement, bridge deck repairs, bridge joint maintenance, and pavement patching. A 2013 Oregon study found that compared with a standard closure using traffic cones, deployment of the MBT-1 during night work generally *increased* traffic speeds passing the work zone, but workers were on the opposite side of the crash-tested barrier; the study's authors concluded that this benefitted driver mobility (Gambatese and Zhang 2013).

- **Balsi Beam.** The tractor-trailer Mobile Worker Protection Device was developed by Caltrans in 2001–2003 (Caltrans 2004, 2007). The trailer consists of two telescoping steel beams whose width can be extended to 12 ft. Using hydraulic power, each beam can rotate to the left or right side as needed; with both beams stacked on the same side, the wall height is 3 ft. The trailer can be extended to provide a work area up to 30 ft long. In 2003, Caltrans conducted crash testing based on NCHRP 350 Test Level 2 procedures (43 mph).
- **MBT-1.** The MBT-1 barrier consists of a 5-ft-tall smooth steel wall to protect the work zone from the side, combined with an impact attenuator and Portable Changeable Message Sign (PCMS) at the rear (Mobile Barriers LLC 2014). Wall sections can be added to increase the length of the work area from 42 to 102 ft. The device can be reconfigured for left or right side of road placement by swapping the positions of the semi-tractor and the rear wheels. In 2008, the system was certified as compliant with MASH/NCHRP 350 Test Level 3 (62 mph).

GATEWAY ASSEMBLIES

Gateway assemblies are intended to serve as a perceptual speed reduction measure, heightening the sense that the driver is approaching a constrained driving environment. At least two Canadian provinces (Manitoba and Saskatchewan) use the assemblies at work zone approaches and terminations

FIGURE 24 Balsi beam (*left*) and MBT-1 (*right*) (Caltrans 2004, Mobile Barriers LLC 2014).

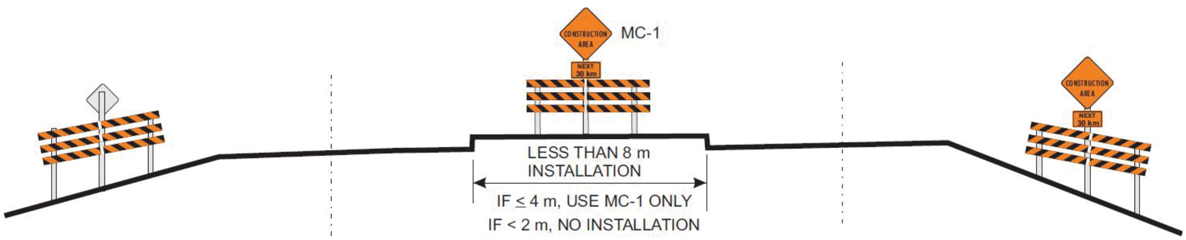


FIGURE 25 Manitoba gateway assembly for freeway applications (approaching work zone) (Manitoba Infrastructure and Transportation 2013).

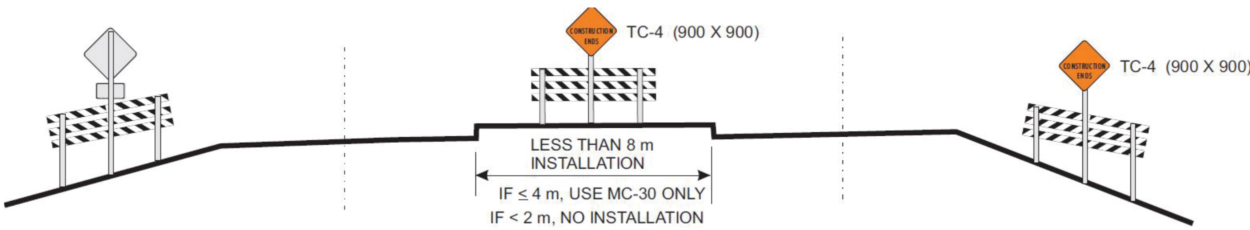


FIGURE 26 Manitoba gateway assembly for freeway applications (leaving work zone). Sign dimensions are in millimeters (Manitoba Infrastructure and Transportation 2013).

for long-term projects. Both provinces have large expanses of prairie terrain where the sense of wide-open space fosters high-speed driving. The assemblies also serve an advance-warning function, providing greater visibility at the work zone approach. The Manitoba and Saskatchewan designs use orange and black stripes on the approach side of the assembly (entering the work zone) and white and black stripes on the termination side (leaving the work zone). Figures 25 and 26 illustrate the freeway gateway (two center barricades are used on roadways with wide medians). Figure 27 illustrates the two-lane rural highway version (Manitoba Infrastructure and Transportation 2013). No information about the effectiveness of this treatment was found.

CONVERGING OPTICAL DEVICES: OPTICAL SPEED BARS, CHEVRON PAVEMENT MARKINGS, AND RELATED TECHNIQUES

Optical speed bars are specialized pavement markings intended to reduce vehicle running speeds. A number of marking patterns, such as transverse stripes and transverse chevrons, have been investigated as potential techniques for this purpose, but work zone applications have been rare.

The concept of optical speed bars is perhaps most-effectively illustrated by Figure 28 from the British *Traffic Signs Manual*, which authorizes the use of a series of transverse bars at approaches to roundabouts. A series of 90 bars is used on main highways and 45 bars on exit ramps; each bar is 600 mm (24 in.) wide. The spacing of the bars decreases as the driver approaches the hazard, on the premise that the converging pattern will give the driver an increased perception of speed and a corresponding inclination to slow down. For example, at the upstream end of the 45 bar configuration the specified spacing between bars is 7.7 m and this decreases progressively to 2.75 m at the downstream end. In the United Kingdom, all ordinary pavement markings are white; however, yellow is used in this application used to draw attention.

A variety of optical speed bar patterns have been evaluated in permanent (nonwork zone) applications. Although most of the work on this topic has been done in Europe and Japan, two very different marking patterns have been tested in the United States:

- A 2001–2003 study reported a 17 mph reduction in 85th percentile speeds on an urban freeway-to-freeway ramp in Milwaukee, Wisconsin, where a complex chevron pattern was deployed experimentally (Drakopoulos and Vergou 2003). The pattern, originally used in Japan, combines converging chevrons in the middle of the roadway with transverse bars straddling the wheel tracks, as shown in Figure 29. The study estimated that 3 mph of the reduction was the result of increased traffic volume and the remainder was attributable to the effectiveness of the device. The Milwaukee findings were contradicted by a 2012 evaluation of a similar treatment in Atlanta, which showed that the chevrons had a minimal long-term effect on vehicle speeds, with drivers adjusting back to their previous speeds as they acclimated to the treatment (Hunter et al. 2010). Although there was an initial reduction in speeds, by the ninth month after implementation the speed reduction dropped to less than 1 to 2 mph for the mean speed and most vehicle speed percentiles in the Atlanta study.

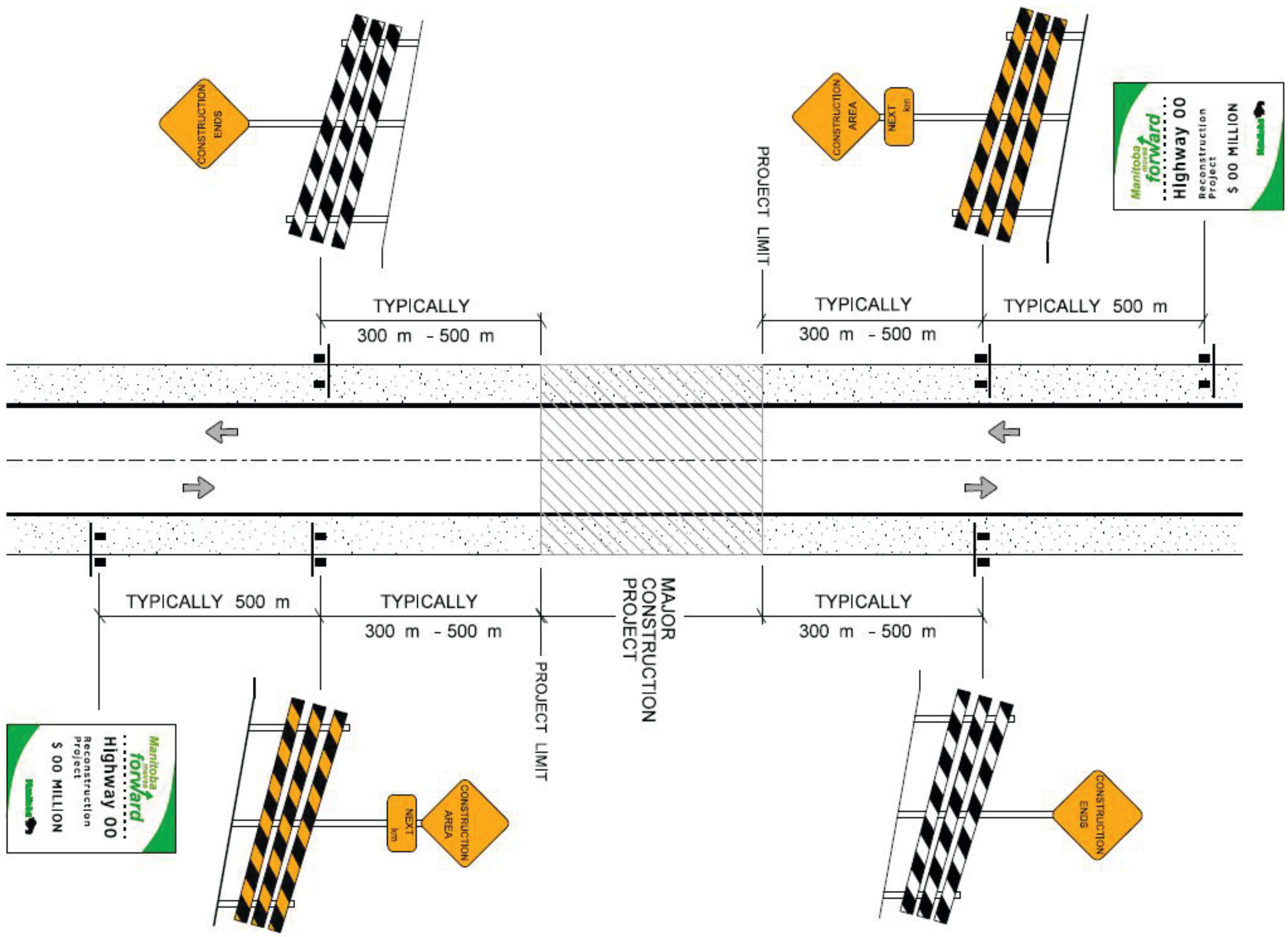
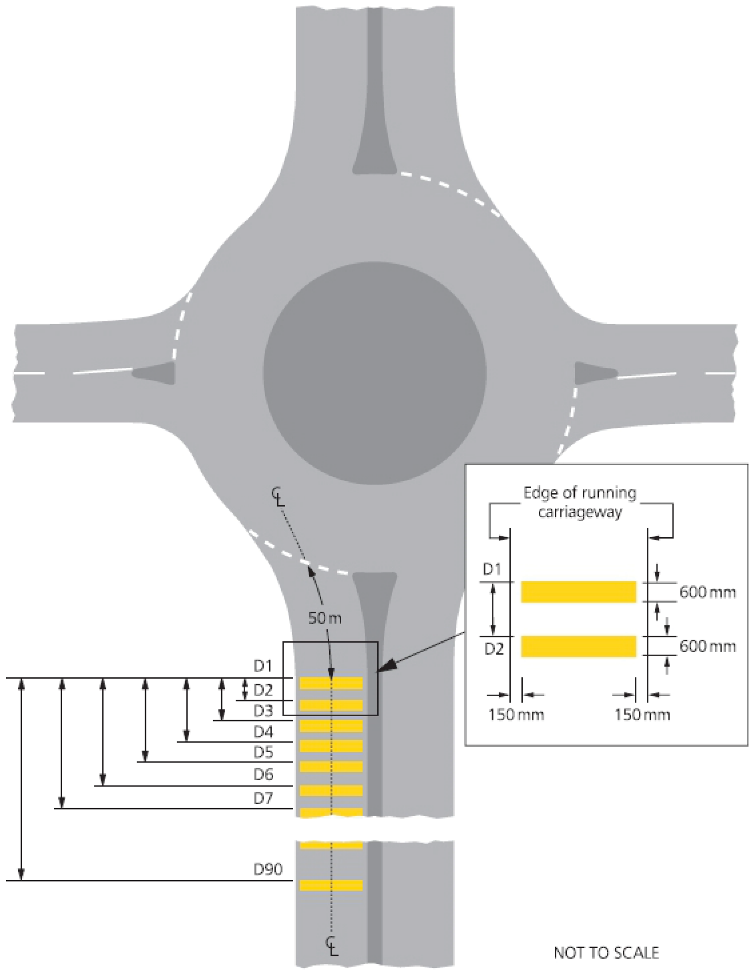


FIGURE 27 Manitoba gateway assembly for undivided highways (Manitoba Infrastructure and Transportation 2013).

- A 2006 study explored the use of converging peripheral transverse bars at three sites (Rakha et al. 2006). This *MUTCD*-approved marking consists of relatively small bars (12 × 18 in.) that straddle the wheel tracks, as shown in Figure 30. The study's authors found reductions of 5 mph in 85th percentile speeds at an exit ramp near Syracuse, New York. Results on two-lane rural highways were mixed, with a 1 mph reduction at a site in Mississippi, but a speed increase at a site in Texas. A 2008 study evaluated the use of peripheral transverse bar markings in a three-lane urban freeway curve located in Milwaukee near the site studied by Drakopoulos and Vergou (Gates et al. 2008). The study's authors found lane-specific, short-term 85th percentile speed reductions of 0 to 3 mph; after 6 months, a small additional reduction was observed in one travel direction but not the other.

Only one study was identified that explored the use of optical speed bars for work zone applications. It was conducted at a moderate-volume rural freeway site on I-70 in Kansas that had an ordinary speed limit of 70 mph and a work zone limit of 60 mph (Meyer 1999, 2004). A bar pattern was selected for the field deployment, although driver opinion surveys based on a visual simulation suggested that a chevron pattern was perceived as being more effective.

- Within the study area three areas were identified, a "leading pattern" with uniformly spaced bars, a "primary pattern" of converging bars, and a "work zone pattern" with intermittent uniformly spaced bars. Reductions in mean and 85th percentile speeds were observed by comparing speeds upstream of the pattern with speeds in the pattern; the magnitudes were small (about 1 mph), but statistically significant. There was no noticeable diminution of the speed reduction effect over the three-month project duration. Insufficient contrast between the bars and the pavement surface may have contributed to the relatively low reduction in speeds. Speed variance was also reduced.
- Both a warning effect and a perceptual effect were observed; that is, both the presence of the bars and the decreasing spacing (in the primary pattern area) contributed to the speed reduction, but it was not possible to separate the two effects. The intermittent work zone pattern was not effective in sustaining the speed reductions downstream of the initial speed reduction. As a



NOTE: The 150 mm gap between the edge of the running carriageway and the bar edges can be increased on the left hand side to a maximum of 750 mm at sites where there are particular problems with surface water drainage or where there is a significant number of cyclists.

FIGURE 28 Optical bar markings for permanent hazard marking from the British *Traffic Signs Manual* (driving on left) (DfT 2003).

result, the author concluded that the treatment was best suited for locations where a point-speed reduction is desirable. Examples of such locations could include the approaches to ramp terminals, sharp curves, or temporary median crossovers.

Three potential concerns have inhibited more widespread use of optical speed bars in the United States. For designs that span the full width of pavement, the possibility that the markings will wear off in the wheel tracks is sometimes cited as a potential issue, although maintenance of the markings is not always necessary for short-term work zone deployments. A related objection is the potential for the markings to be scraped off by snow removal operations; in the work zone context this would apply only to long-duration projects in areas that receive snowfall. Skid resistance is also a concern. In general, these issues can be addressed through proper materials selection and application. For example, the British *Traffic Signs Manual* stipulates that the skid resistance of the bars should not be less than 55 (DfT 2003).

Another study exploring the perceptual effects of converging visual devices was conducted in a New Zealand work zone (Allpress and Leland 2010). The study involved placing a series of 36-in.-tall traffic cones at a work zone approach, with either uniform or converging cone spacing. The work zone was on a two-lane rural highway with a traffic volume of more than 10,000 vehicles per day. The ordinarily posted speed limit was 100 km/h (62 mph); during construction, the speed limit was reduced to 50 km/h (30 mph). As shown in Figure 31, the work zone was hidden from approaching vehicles by a curve. At the work zone approach (just downstream of the curve) a total of 16 cones were placed: eight on each side of the lane. In the uniform configuration the cone spacing was 2 m (6.6 ft), whereas in the converging configuration the spacing ranged from 3.5 m (11.5 ft) at the upstream end

FIGURE 29 Converging chevron pattern at a 2014 Wisconsin work zone.

to 0.5 m (1.6 ft) at the downstream end. The presence of the cones reduced speeds by 7.8 to 9.5 km/h (4.9 to 5.9 mph) compared with the without-cones condition. With the converging arrangement, speeds measured at the downstream end of the cone array were 1.6 km/h (1.0 mph) lower than with the uniform arrangement. Conversely, near the middle of the work zone at a distance 150 m (490 ft) beyond the end of the cone array, the speed with the converging arrangement was 1.5 km/h (0.9 mph) *higher* than with the uniform arrangement. Although the authors concluded that the results were statistically significant, the speed difference between the converging and uniformly spaced cone patterns may have been smaller than the measurement tolerances for the pneumatic counters used to gather the speed data.

SEQUENTIAL AND SYNCHRONIZED WARNING LIGHTS

The illusion of motion can be created when discrete stationary lights are flashed sequentially. A small number of studies have investigated the potential for deploying a series of lights along the roadway shoulder that flash at predetermined rates, with the intent of encouraging drivers to reduce speed. Evaluations of the effect on speeds have shown mixed results.

Section 6F.63 of the 2009 U.S. *MUTCD* permits the use of a series of sequential flashing warning lights that may be placed on channelizing devices that form a merging taper in order to increase driver detection and recognition of the merging taper. The manual stipulates that successive flashing of the sequential warning lights shall occur from the upstream end of the merging taper to the downstream end of the merging taper and specifies a flash rate of 55 to 75 times per minute (0.92 to 1.25 Hz) (FHWA 2009). Flash rates in the range of 16–25 Hz must be avoided because of the potential for adverse health and safety effects on persons with photosensitive epilepsy; some individuals may be sensitive to rates as low as 3 Hz and as high as 60 Hz (Epilepsy Action 2014).

A 2001 study tested a prototype warning-light system composed of a series of interconnected, synchronized individual flashing warning lights attached to the channelizing drums forming a lane-closure taper (Finley et al. 2001). The lights were timed to produce the perception of a light that "moves" repeatedly in a sequential manner from the beginning of the taper to the end of the taper. Two field tests were conducted, one on a low-volume, rural, farm-to-market road with a 65 mph night speed limit (which had already had a lane closure for 6 months) and one on I-10 West, an urban freeway near Houston with a 65 mph speed limit for cars and a 55 mph limit for trucks. In the nighttime field studies, the prototype warning-light system did not significantly affect the speed of vehicles at either test site, but the system encouraged earlier merging at the I-10 site. The study's authors reported that the flashing warning-light system was perceived positively and was not confusing to the motoring public.

A 2010 driving simulator study explored various light patterns: asynchronous, moving, and static. Random or steady lights were found to have little effect on driver speed, and

FIGURE 30 Peripheral transverse bar markings application diagram from the U.S. *MUTCD* (FHWA 2009).

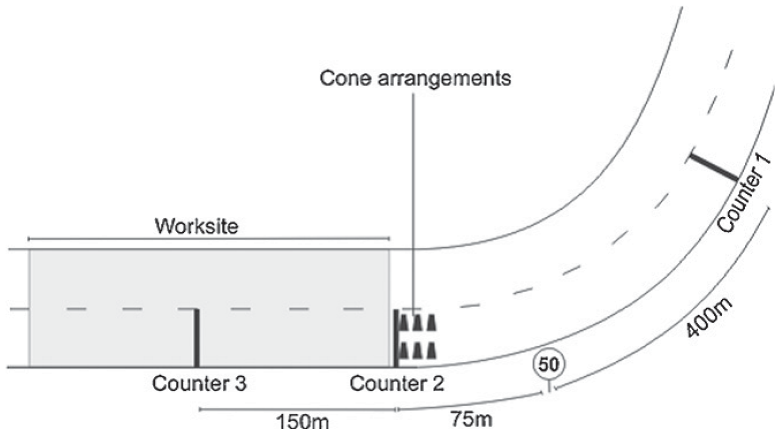


FIGURE 31 Layout of work zone in New Zealand study (driving on left side of road) (Allpress and Leland 2010).

synchronized lights did not show statistical significance in reducing driver speed (Khan 2010).

A 2011 field study evaluated the lane taper approach speeds with and without sequential warning lights at three Missouri sites with 60 mph work zone speed limits (Sun et al. 2011b). With the sequential lights the mean speed decreased by 2.2 mph and the 85th percentile speed decreased by 1.0 mph; however, the speed standard deviation (a measure of speed variation) increased by 0.91 mph. The study's authors reported an improvement in overall speed limit compliance. With the lights the number of vehicles merging earlier (in the vicinity of the upstream end of the taper) increased at two rural work zones, but decreased at the urban site.

CHAPTER FIVE

OPERATIONAL SPEED MANAGEMENT TECHNIQUES

INTRODUCTION

Operational speed management techniques utilize strategically placed speed control vehicles (operated by or on behalf of the highway agency) to limit work zone traffic speeds. Three fairly distinct operational techniques were identified: pilot vehicles, pace vehicles, and rolling closures. A brief discussion of the use of flag persons to limit vehicle speeds is also included in this chapter.

PILOT VEHICLES

Pilot car or pilot vehicle operations (also called convoy working in some countries) involve stopping traffic in advance of a work zone and then using an appropriately signed work vehicle to lead traffic through the site. The use of pilot vehicles is mentioned in the 2009 *MUTCD* as a method for guiding a queue of vehicles through a temporary traffic control zone or detour. In the United States, the method is typically applied to special situations such as two-way, one-lane operations in mountainous areas. For example, PennDOT reports the use of pilot vehicles for work zones on two-lane highways, especially in areas where it is difficult for flaggers to communicate with each other because of the length of the work zone or because mountainous terrain inhibits radio communication (M. Briggs, PennDOT, personal communication, 2014). Similarly, VDOT reports the use of pilot vehicles for two-way, one-lane operations that are more than two miles long or where flaggers cannot see each other because of sharp curves (D. Rush, VDOT, personal communication, 2014). Pilot vehicles also provide an affirmative method for limiting work zone speeds, because vehicles in the convoy are normally prohibited from overtaking (passing) the pilot vehicle. VDOT uses pilot vehicles for this purpose when it is necessary to maintain low-speed traffic on poor running surfaces.

Some countries appear to make greater use of pilot vehicles than the United States. For example, the *MUTCD* for Queensland state in Australia identifies four situations where a pilot vehicle may be used:

1. Part of the length of the work site is out of view of the supervisor, work crew, and the flagger.
2. The hazard to workers described requires the traffic speed to be reduced to less than 40 km/h (25 mph).
3. The traffic speed is required to be kept low to minimize damage to the work.
4. Traffic is to follow a particular path through the site, which may not be obvious unless a pilot vehicle is used.

In the United Kingdom, the *Traffic Signs Manual* (DfT 2013a) provides detailed advice on the use of pilot vehicles for situations where “normal traffic management arrangements are not feasible because of restricted highway width, and diversion is impracticable.” The manual allows speeds to be reduced to 10 mph or less when the convoy is passing an especially hazardous location such as a work area with “little or no safety zone clearance.” The manual also suggests using pilot vehicles during preventative maintenance operations “when it is considered necessary to ensure compliance with speed limits which have been implemented to protect newly laid surface dressing.” The British guidance does not allow pilot vehicles to be used on freeways; however, they are allowed day and night on other divided and undivided highways when traffic is reduced to a single lane in either or both directions.

Relatively little academic research has been conducted on the use of pilot vehicles; however, a recent study evaluated their effectiveness for speed reduction at a long-term, rural highway work zone in Queensland, Australia (Debnath et al. 2014). In contrast to typical U.S. practice, the 2.5-mile-study segment was straight and mostly flat with good sight distance. The ordinary speed limit was 80 to 100 km/h (50 to 62 mph). Analysis of data covering a 5-day period showed that a pilot vehicle reduced the average speeds at the treatment location. There was no “halo effect” downstream of the work zone. The portion of vehicles speeding through the activity area was also reduced, particularly those traveling at 10 km/h (6 mph) or more above the posted limit. Drivers were less likely to speed when the proportion of large (medium and heavy) vehicles in the traffic stream was greater. Medium vehicles (two- and three-axle buses or trucks, four-axle trucks) were less likely to speed in the presence of a pilot car than light vehicles. When a pilot car was present, the mean speed of all vehicles under a posted speed limit of 40 km/h dropped from 52.0 to 46.1 km/h (32.3 to 28.6 mph), a reduction of 5.9 km/h (3.7 mph). Despite these reductions, the mean speed of all vehicles remained 6.1 km/h (3.8 mph) above the posted limit when the pilot car was in operation, primarily because in many instances the pilot vehicle was itself speeding. To realize the full benefit of pilot vehicle operations, the pilot vehicles must observe the speed limit.

TABLE 10
PERCEIVED EFFECTIVENESS OF PACE VEHICLES AND PILOT VEHICLES AMONG CANADIAN PROVINCIAL MINISTRIES OF TRANSPORTATION

Rating	Number of Agencies	Percent of Agencies
High	14	67
Medium	5	24
Low	2	10
Not Effective	0	0

Source: Harmelink and Edwards (2005).

A survey and interview of Canadian provincial transportation ministries requested information about the perceived effectiveness of pace vehicles and pilot vehicles (Harmelink and Edwards 2005). As shown in Table 10, 90% of the agencies rated the effectiveness as "high" or "medium." Only police enforcement received similarly high scores. Harmelink and Edwards concluded that pilot vehicles are "very effective methods of controlling motorist speeds in work zones, without requiring police enforcement" when used together with flaggers on a two-lane road to guide a queue of vehicles through a one-lane section of a temporary traffic control zone or detour, or to control the speed of vehicles through the construction site, especially immediately adjacent to areas where workers are present.

Oregon DOT reports stipulating the maximum speeds of vehicles that are making materials deliveries to work zones on rural, low-volume facilities (Pappe 2014). The effectiveness of this less formal type of speed-controlling operation probably depends on the frequency and uniformity of the deliveries (and the extent to which delivery drivers comply with the stipulations). Such methods can potentially be used to augment more formal speed pacing.

PACE VEHICLES

Pace vehicles are conceptually similar to pilot vehicles; however, the term pace vehicles typically refers to speed control for freeways and other multilane divided highways. The phrase appears to have been borrowed from automobile racing, where pace cars have long been used to limit speeds during adverse track conditions. In the work zone context, Harmelink and Edwards (2005) provide the following definition:

> One or more pace vehicles are used on freeways, one pace vehicle per open lane of traffic, to constrain and control the speed of vehicles traveling through the work zone, where reduced speed is necessary but it is difficult to achieve speed reductions by other means.

Currently, the use of pace vehicles in freeway situations is uncommon in the United States. A 2005 Canadian study advocated their use (Harmelink and Edwards 2005). The authors of that report suggest the use of pace vehicles (subject to approval by the road authority) to control speeds in long-duration freeway construction work zones in situations, such as freeway paving operations, where temporary concrete barriers cannot be provided, and yet workers must work within 5 to 10 ft of a live lane of traffic. The *Ontario Traffic Manual* devotes several pages to the topic of pace vehicles and stipulates that either police or pace vehicles must be used to support an 80 km/h (50 mph) speed limit during freeway paving operations, unless the traffic volume is sufficient to keep speeds below that threshold (Ministry of Transportation–Ontario 2014).

For continuous pacing of the work zone (e.g., throughout a work shift), the pace vehicles are dispatched at a predetermined rate in pairs (for a two-lane work zone) or trios (for a three-lane work zone) (Figure 32). Typically, the vehicles enter the roadway at an upstream interchange. As they approach the work zone the pace vehicles begin traveling side-by-side to prevent other traffic from overtaking (passing) them. The pace vehicles gradually reduce speed as they approach the work zone and proceed through the work zone at a predetermined speed (e.g., the work zone speed limit). Downstream of the work zone the vehicles gradually accelerate to the ordinary speed limit and prepare to exit the roadway. If the roadway is being paced in both directions, the vehicles then repeat the operation for the opposite direction; if only one direction is being paced, the vehicles return to their starting point and prepare to lead another platoon of traffic through the work zone. Thus, the total number of vehicles required is a function of the number of lanes that are open to traffic, the round-trip travel time, and the desired headway (time interval) between pace vehicles. In some cases, a dispatcher or monitor may be used to ensure that the headway remains reasonably uniform, and a reserve driver may assist the primary drivers during their meals and breaks.

Although there appears to be little doubt about the potential for pace vehicles to limit traffic speeds to very low values (or bring the traffic to a complete stop if necessary), little formal research has been conducted on their use and little

FIGURE 32 Although not typically intended as a speed control measure, snow removal operations often result in situations where traffic is "paced" by maintenance vehicles (Viking-Cives 2014).

guidance has been developed for multilane applications other than rolling closures (which are discussed in the next section). Additional research may be desirable to:

- Identify a more complete set of work zone situations that are amenable to the use of pace vehicles.
- Determine the minimum practical speed for the pacing operation and its relationship to traffic volume.
- Determine the optimal headway for the pace vehicles in relation to the length of the work zone.
- Determine the vehicle markings that are most desirable for the construction and maintenance vehicles used for this application.
- Determine whether controlled acceleration and deceleration by the pace vehicles can delay the onset of work zone congestion.

ROLLING CLOSURES

A special case of the use of pace vehicles is the rolling closure, also called a rolling roadblock, rolling slowdown, slow roll, or mobile carriageway closure. This procedure is used to create a time window when the road downstream of the lead vehicles is effectively clear of vehicles (traffic volumes must be low to avoid creating an excessively long bottleneck). A number of DOTs use this procedure for very short-duration work operations on freeways and other multilane divided highways. Examples of such work include:

- Installing or removing a sign bridge,
- Setting a bridge girder,
- Stringing electrical lines across the roadway,
- Switching a freeway lane closure from a right-side closure to a left-side closure,
- Changing lane shifts in multiphased projects, and
- Removing debris from the roadway.

As illustrated in Figure 33, in a rolling closure a group of designated pace vehicles (at least one per lane and possibly including one for each drivable shoulder) enters the traffic stream. After synchronizing their positions across all lanes to eliminate all opportunities for being overtaken by other traffic, the pace vehicles gradually reduce their speeds to create an interval of approximately 5 to 10 minutes where the travelled way will be clear of all traffic upstream of the work site. The speed differential between downstream traffic moving away from the work site and the reduced-speed convoy approaching the site creates the working window. Consequently, work cannot commence until a monitor has verified that all downstream traffic has cleared the work site. In addition, all personnel and equipment must clear the travelled way before the convoy can pass through the site. In the unfavorable case that the work is incomplete when the pace vehicles reach the work site, the pace vehicles bring the convoy to a complete stop upstream of the site. In the normal case where the work has been completed on time, the pace vehicles continue past the work site, allow the convoy to resume normal speed gradually, and exit the roadway downstream. Advance signage and other details of this operation are critical to its safety, and have been documented in some detail by Harmelink, America Traffic Safety Services Association (ATSSA), and in the British *Traffic Signs Manual* (DfT 2013b), among others.

The specific type of pace vehicles used for rolling closures varies by state. In some jurisdictions the vehicles are operated only by police, whereas in others maintenance or contractor vehicles are also considered acceptable, provided that they are equipped with appropriate signage and flashing lights or beacons or arrow boards. Harmelink and Edwards (2005) and ATSSA (2013) both assert that driver compliance is likely to be higher when the closure is paced by a police vehicle than when paced by a contractor vehicle. Some jurisdictions use a combination of police and contractor vehicles; for example, a March 2012 policy drawing by the Kentucky Transportation Cabinet shows the use of at least four vehicles, of which two must be police (KYTC 2012). VDOT uses one police vehicle and two to three contractor vehicles depending on the number of lanes to be closed (D. Rush, VDOT, personal communication, 2014). The *Ontario Traffic Manual* stipulates that the back of each pace vehicle must be equipped with "do not pass" signage (Ministry of Transportation–Ontario 2014).

Complete closure of the entrance ramps in the rolling closure area is particularly important to the safety of the operation, since any vehicle that enters the freeway downstream of the paced platoon has the potential to arrive at the work site at full freeway speed. Some agencies assert that a police presence is helpful in ensuring that drivers respect the ramp closures; for example, South Carolina DOT requires the ramp closure to be done by uniformed law enforcement personnel in police vehicles with lights flashing (J. Sease, personal communication, 2014). Conversely, Kentucky allows contractor vehicles to be used for this purpose (KYTC 2012).

Little formal research appears to have been conducted on the desirable minimum speed the pace vehicles would use in rolling closures. Kentucky Transportation Cabinet calls for a minimum speed of 10 mph (KYTC 2012). ATSSA suggests a minimum speed of 10 mph, with preferred speeds of 20 to 30 mph (ATSSA 2013). The *Traffic Signs Manual* for the United Kingdom requires a pace vehicle speed in the 20 to 30 mph range (DfT 2013a). The *Ontario Traffic Manual* takes a more conservative approach, stipulating that on rural low-volume freeways the pace vehicle should lead at a speed of no less than 15 to 20 km/h (9–12 mph) below the normal posted regulatory speed (Ministry of Transportation–Ontario 2014); this would correspond to a pacing speed of 50 to 55 mph on a freeway that normally operates at 65 mph (the *Ontario Traffic Manual* is less prescriptive in the case of urban freeways, on the premise that urban drivers are more accustomed to congestion). Presumably, the maximum safe reduction in the running speed also depends on the driving environment and the type of signage that is provided in advance of the closure,

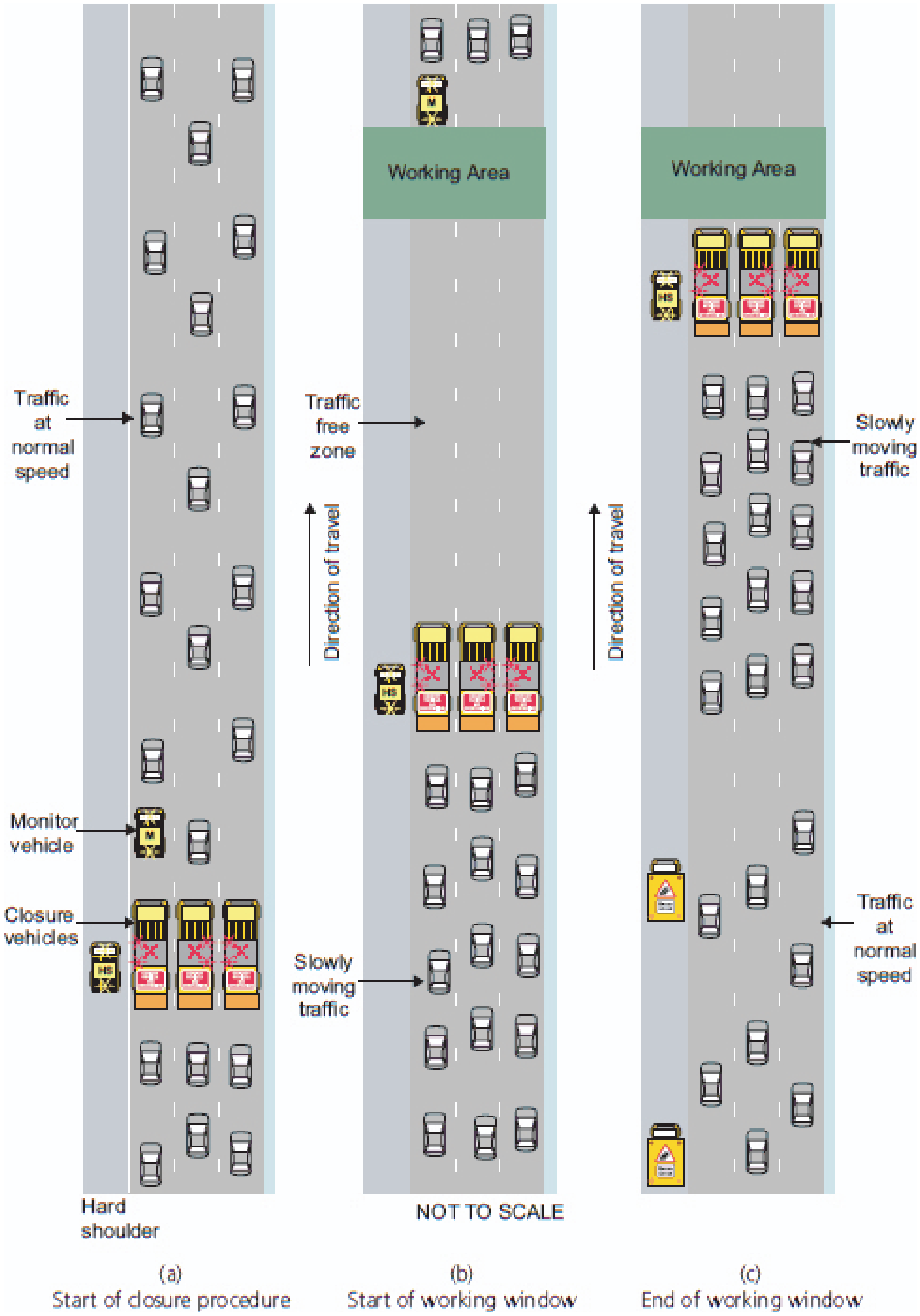


FIGURE 33 Rolling roadblock diagram from British *Traffic Signs Manual* (DfT 2013b).

but neither topic appears to have been researched in detail. Further work to clarify this parameter may be desirable, because the rolling closure may need to start 10 to 15 miles upstream of the work site under the more conservative rural Ontario speed reduction assumptions.

Interviews with state DOT officials conducted for this project indicate that in many states the availability of police resources is a constraint on implementation of work zone speed management techniques. Therefore, further research may also be desirable to determine whether specially marked (highly conspicuous) pace vehicles operated by contractors or maintenance personnel could achieve compliance levels similar to those that occur when police vehicles lead the pace.

SPEED LIMITERS

It is important that pilot, pace, and rolling closure lead vehicles conform to the intended speed profile to ensure the effectiveness of the operation. Vehicles used in operational speed management applications can potentially benefit from the use of road speed limiters, which allow drivers to adhere to a specified maximum speed without having to constantly monitor their speed. The devices are widely used to limit the top speed of heavy trucks and other fleet vehicles. Various vendors offer fixed and adjustable limiters, both as original equipment and as retrofit kits for existing vehicles (VDO 2008; AutoKontrol 2011; InterMotive 2014; SCT 2014). Speed limiters are also increasingly being offered as a factory-installed option for cars and light-duty trucks, particularly in countries where the use of automated speed enforcement is widespread (Lingeman 2012). In contrast to cruise control (which maintains a constant speed), a speed limiter prevents the driver from accelerating above a set speed; if the driver releases the accelerator the vehicle will slow down (Ford Motor Company 2010). Some speed limiter systems are advisory, activating a warning light or chime if the vehicle exceeds the desired speed; other systems restrict fuel flow if the vehicle begins to exceed the desired speed.

FLAGGING FOR SPEED REDUCTION

Flaggers (also called flag persons or traffic control persons) are often utilized for two-way, one-lane operations on undivided rural highways and urban streets. A second type of flagging involves slowing freeway traffic. For example, Figure 46 (in chapter eight) illustrates intermittent flagging to assist construction vehicles with re-entering the general traffic stream as they leave a freeway work activity area. Flagging to reduce work zone speeds is generally considered to be a supplemental (rather than a primary) method of encouraging drivers to slow down. The technique is perhaps most applicable to situations where a flagger is already present on the site (e.g., as a spotter). Concerns over worker safety and labor cost appear to be diminishing the use of this technique in the United States, especially on high-speed roadways and at night.

Mid-1980s research suggested that a properly trained flagger simultaneously displaying the *MUTCD* SLOW sign, making the slow-down hand gesture, and positioned adjacent to a speed limit sign, could reduce average speeds (Richards et al. 1984; Bryden and Mace 2002). The technique also included having the flagger point at a reduced speed limit sign with his or her free hand. Work zone speeds were reported to have been reduced by 4 to 5 mph on urban interstates, 7 to 13 mph on rural interstates, 13 mph on urban arterials, and 10 to 16 mph on rural, two-lane highways.

An early 1990s study evaluated the effect of flaggers on traffic speed along a rural Illinois work zone (Benekohal and Kastei 1991). The effects of flagger training on their effectiveness were also studied by collecting data before and after the flaggers received training. Training included recommendations in the *MUTCD* on proper posturing, motions, assertiveness of flaggers, and making eye contact with motorists. The average speeds of cars and trucks were reduced by 11.7 and 9.1 mph before a flagger received training and were reduced by 14.9 and 11.9 mph, respectively, after they received training.

A mid-1990s study evaluated traditional and new flagging procedures (McCoy and Bonneson 1993). The new flagging procedure included larger flagger signs and new yellow–green flagger apparel. New and traditional approaches reduced mean speeds by 9.2 and 11.1 mph, respectively.

The 2009 *MUTCD* allows for the use of remotely operated Automated Flagger Assistance Devices (AFADs) for short-term and intermediate-term work activities at sites where there is only one lane of approaching traffic (FHWA 2009). In addition to the safety benefit of removing the flagger from exposure to traffic, the devices offer the potential for a one-person operation in some situations (Pigman et al. 2006). Studies have evaluated several proprietary AFAD products to determine operational effectiveness and quantify failure-to-stop violations, but relatively little research has been conducted to identify any differences in the deceleration speed profiles for vehicles approaching AFADs as compared with conventional flagging operations.

CHAPTER SIX

TRADITIONAL "HUMAN" WORK ZONE SPEED ENFORCEMENT

INTRODUCTION

This chapter discusses non-automated work zone enforcement techniques; that is, policing by humans. Automated and semi-automated enforcement technologies are discussed in chapter seven.

State DOTs and their partner law enforcement agencies apply a wide range of policing philosophies and methods for work zone speed enforcement, which are summarized in Table 11. In some states, such as South Carolina, the view is that the police should be actively patrolling the work zone and issuing as many citations as possible (J. Sease, personal communication, 2014). In other states, such as Pennsylvania, Vermont, and Virginia, the goal is a very visible presence of police cars in the work zone with their lights flashing, and citations are seldom issued except to extreme violators (M. Briggs, personal communication, PennDOT, 2014; B. Nyquist, Vermont Agency of Transportation, personal communication, 2014; D. Rush, VDOT, personal communication, 2014). Although law enforcement agencies often suggest that the number of citations issued is a measure of the effectiveness of work zone speed enforcement, a Canadian work zone speed management report notes that, "decreasing numbers of citations may indicate improved safety conditions in the work zone, provided the posted speed limit is realistic for the conditions" (Harmelink and Edwards 2005).

A report from the Global Road Safety Partnership emphasizes the value of enforcement methods based on an anywhere, anytime approach to deter all speeding on the roadway network (Howard et al. 2008). The goal is to send a clear message that speeding is illegal and unacceptable behavior, and at odds with the interests of the community. Although the report does not focus on work zones, the following text appears to be particularly relevant to work zone enforcement techniques:

> How speed enforcement is done determines whether its principal effect is through specific or general deterrence.
>
> - Operating highly visible (police or fixed-camera) speed enforcement in the same areas all the time is likely to result in drivers being deterred from speeding only in those specific areas.
> - Operating a mix of highly visible and strategically directed police patrols or speed cameras increases public perception that speed enforcement can happen anywhere and at any time. The unpredictability of where and when speed enforcement operations take place will have a more general deterrent effect by encouraging drivers to drive within the speed limit no matter where or when they are travelling.

Many work zones lack sufficient physical space for intercepting speeders and issuing citations; as a result, some jurisdictions such as Virginia use multiple-officer techniques, with one officer positioned in the work zone as an observer and one or more police vehicles downstream of the work zone to pull over speeders and issue citations (D. Rush, personal communication, 2014). To provide a wider field of view, a variation of this tactic is to position the observer on an overpass, a practice widely used in Texas. South Carolina typically uses four troopers in a work zone to issue citations and saturate a work zone with enforcement presence (J. Sease, South Carolina DOT, personal communications, 2014).

Obtaining sufficient police resources for work zone enforcement remains an ongoing concern in many states, and is a limiting factor for many types of work zone enforcement. This issue has many dimensions: budget and finance, human resources and labor relations, and organizational and jurisdictional factors. To a large extent each state's situation is a unique reflection of its state laws, collective bargaining agreements, and the established degree of cooperation or competition between state, county, and local law enforcement agencies. As Pigman et al. (2006) noted:

> The state . . . does not have enough police to be at all work zones. The commissioner noted that [the state] needs to use *local* police officers for work zone enforcement even on state highways and interstates. (emphasis added).

In recent years there have been increased efforts to train law enforcement personnel on work zone enforcement techniques. For example, the National Highway Institute (NHI) offers a two-hour, web-based training course *Safe and Effective Use of Law Enforcement Personnel in Work Zones* (NHI 2014).

POLICE ENFORCEMENT

Police enforcement has repeatedly been shown to be one of the most effective speed management techniques in work zones. Law enforcement presence has also been shown to

TABLE 11
OVERVIEW OF WORK ZONE ENFORCEMENT TECHNIQUES

Tactic	Description	Advantages	Disadvantages
Active Enforcement	Officers actively identify, pursue, and cite violators in a manner similar to ordinary highway patrols.	• Maintains the potential threat of citation	• Loss of effect of enforcement once the officer pursues or is engaged with a violator
Circulating Enforcement	Officers circulate the work zone in vehicles	• A circulating patrol at the speed limit can serve as a "pilot car" and reduce speed throughout the work zone. • Does not limit the effectiveness of enforcement to a specific location • Can simultaneously serve roadway monitoring and incident detection/response role	• Loss of speed reduction at certain locations such as work activity area
Stationary Enforcement	Officer and vehicle parked in or upstream of work zones; not pursuing violators. Some have flashing lights on, while some do not.	• Sustained effect on speeds of vehicles	• Loss of potential threat of citation and consequent lack of driver response
Police Traffic Controller	Officer positioned outside vehicle for reducing speeds, not traffic control duties	• Visibility of officer can increase speed reductions.	• Increased risk for officer • Officer cannot easily pursue a violator
Enforcement Pack	One officer identifies violators and notifies another officer(s) downstream of the work zone to cite them. Some agencies use covert officers for identifying violators.	• Safer as it eliminates the pursuit of violators through work zones • Speed reduction effect at the upstream location remains • Citation downstream ensures credibility of enforcement is not lost • Multiple officers are available in case of incidents in work zone.	• Increased costs • Greater requirement of law enforcement resources • Violators are not pulled out of traffic stream till they exit the work zone
Aerial Enforcement	Aircraft or helicopter used to monitor speeds. Violators are identified and an officer on the ground is notified to stop and cite violators	• Does not require officers in work zone and has benefit of covert enforcement.	• Requires roadway to be marked for measuring speeds. Maintaining the markings through different stages of work activity can be difficult. Relatively expensive and rarely used.

reduce speed variation and undesirable driving behaviors such as tailgating and unsafe lane changing. Additional benefits include greater motorist alertness, quicker response to incidents and crashes in a work zone, and the ability to perform traffic control, if necessary. Some of the disadvantages and limitations of using police enforcement in work zones include reduced availability of officers for other law enforcement duties, officer safety in the work zone environment, enforcement-related costs, and cooperation and coordination between law enforcement, the contractor, and the highway agency. Another potential disadvantage is reduced work zone traffic throughput, for example Avrenli et al. (2012) reported that police presence can decrease free-flow speed by 6.3 mph and capacity by 50 passenger cars per hour per lane (50 pcu/ln). A typical constraint for active enforcement by police is the lack of space for maneuvering and apprehending speeders in work zones. This can be mitigated to some degree by providing enforcement pads or pullouts (also called pullovers or lay-bys) in the work zone; Ullman and Schrock (2011) developed design recommendations for the length and spacing of such areas.

Although federal regulations do not require law enforcement in all work zones, federal regulation 23 CFR 630 Subpart K does require all state agencies to have a policy for the use of enforcement in work zones on federal-aid projects. *Guidelines on the Use of Law Enforcement in Work Zones* developed by the Roadway Safety Consortium, summarizes the available guidance on the use of law enforcement in work zones (Roadway Safety Consortium 2011). *NCHRP Report 746: Traffic Enforcement Strategies for Work Zones* published in 2013 provides guidance on safe and effective deployment of traffic enforcement techniques in work zones on highways with speed limits of 45 mph or greater (Ullman et al. 2013). To avoid duplication, readers are referred to *NCHRP Report 746* for guidance on planning, design, and operation of traffic enforcement techniques, as well as administrative issues (the scope of this synthesis report is limited to discussion of the effectiveness of various police enforcement techniques).

A variety of enforcement techniques have been used in work zones. Technique selection is influenced by site conditions, the nature of the work operations, physical constraints such as the availability of enforcement pads or pullouts, staffing and budgetary constraints, and institutional and organizational factors. Table 11 lists several common techniques and summarizes strengths and weaknesses that have been reported in the transportation literature.

ENFORCEMENT EFFECTIVENESS RESEARCH FINDINGS

A number of studies have examined the speed reduction effects associated with various enforcement techniques. It is important to recognize that these observations are influenced by the methods used to collect the speed data, the location where the speeds were measured (e.g., immediately adjacent to the police vehicle or further downstream), the work zone site conditions, and the severity of the speeding in the absence of enforcement, which in some cases is related to the traffic volume through the site.

MnDOT examined the effectiveness of stationary police enforcement at work zones on a rural interstate, an urban freeway, and a metro location (Maze et al. 2000). The 85th percentile speeds were reduced from 51 to 43 mph, 66 to 58 mph, and 58 to 47 mph, respectively, at the three locations. Researchers from Illinois evaluated the effectiveness of stationary enforcement at two work zones in Illinois (Benekohal et al. 2010; Hajbabaie et al. 2011). Stationary enforcement reduced the mean speeds significantly by 5 to 7 mph, for the general traffic stream as well as free-flowing vehicles. Lodes and Benekohal (2013) compared the speeds of individual drivers near stationary enforcement and 1.5 miles downstream. The paired data were used to quantify the speed change behavior and spatial effect of the treatments. The vast majority of drivers (92%) sped up after passing the treatment location, indicating that spatial effectiveness of stationary enforcement is limited.

Oregon DOT used three stationary law enforcement vehicles in a pilot evaluation to reduce the speed limit from 65 mph to 35 mph in two stages of 15 mph each (Gambatese and Zhang 2013). Figure 34 shows the traffic control plan used for this purpose. The 85th percentile speeds for passenger cars and trucks were 36 mph with standard deviations of 4 mph and 3 mph, respectively.

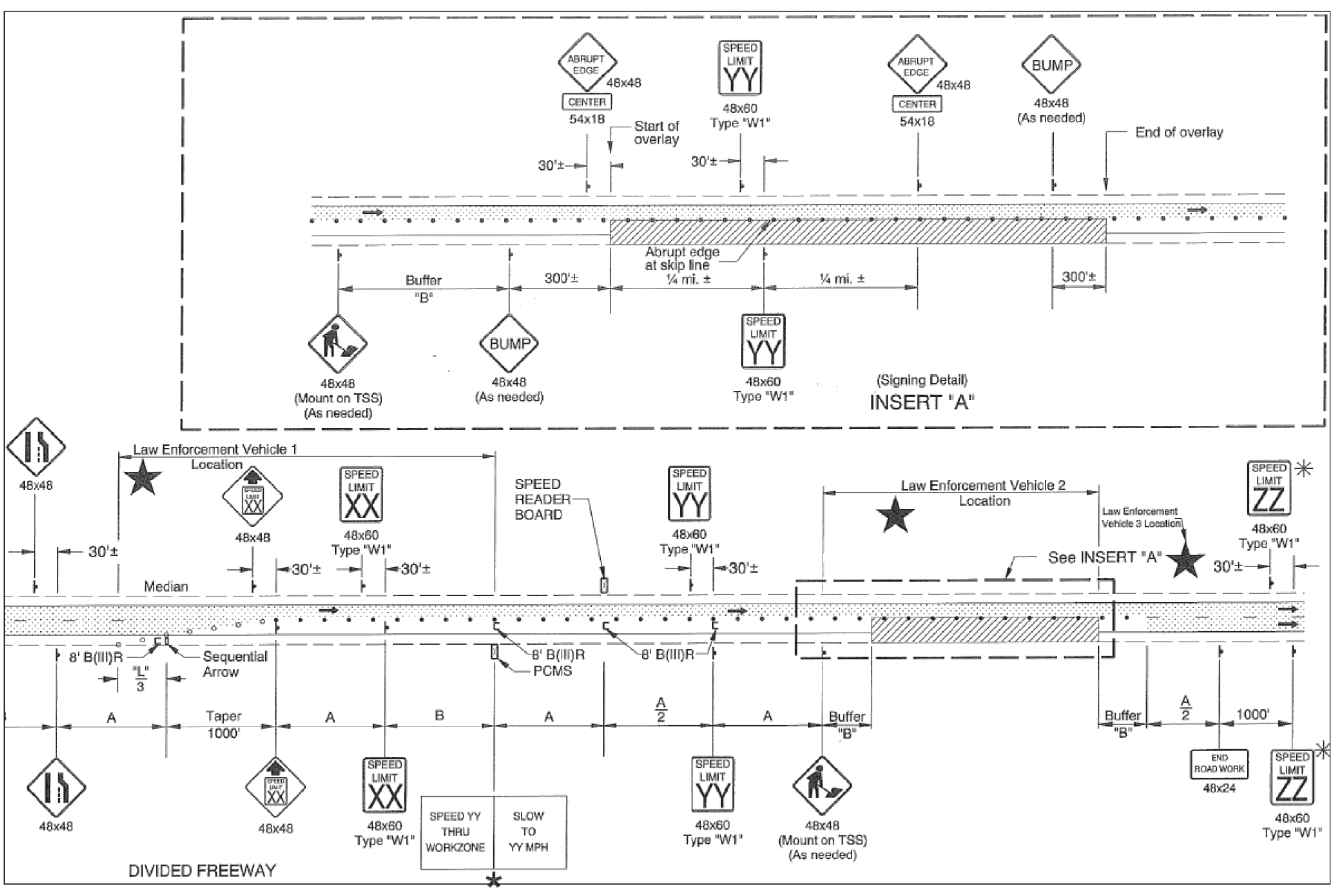


FIGURE 34 Traffic control plan for 30 mph reduction in Oregon (Gambatese and Zhang 2013).

Noel et al. evaluated stationary enforcement with active radar and police traffic controller techniques on a six-lane freeway in Delaware (Noel 1987; Noel et al. 1988). Data were collected under one-lane and two-lane closure conditions and short-term and long-term data collections. Mean speeds were reduced by 2.4 and 5.1 mph for one-lane closure under stationary and police traffic controller approaches, respectively. For a two-lane closure, speeds decreased further by 6.3 mph for police traffic controller and counterintuitively increased by 3.6 mph for stationary enforcement.

Circulating enforcement is reported to be less effective than stationary enforcement. Ullman et al. (2013) reported that stationary enforcement results in a speed reduction of about 5 to 7 mph and circulating enforcement results in a reduction of 2 to 4 mph. Benekohal et al. (1992) reported that average speeds of cars and trucks were 4.3 to 4.4 and 4.3 to 5.0 mph lower with circulating enforcement. Richards et al. (1985a, b) evaluated the effectiveness of stationary and circulating enforcement at six work zones on rural and urban highways in Texas. Stationary enforcement resulted in reduction of mean speeds by 4 to 12 mph and circulating enforcement resulted in a reduction of 2 to 3 mph.

California uses the Augmented Construction Zone Enhanced Enforcement Program (ACOZEEP), which is essentially an enforcement pack tactic with one enforcement vehicle visible near the beginning of the work zone and one or more downstream for citing the violators. Caltrans compared ACOZEEP with their typical approach (stationary enforcement) of using only one enforcement vehicle parked near the beginning of a work zone. Results indicate that ACOZEEP resulted in a higher average speed reduction of 9.6 mph compared with 8.8 mph from the traditional approach (Carpenter et al. 2012). ACOZEEP also resulted in vehicles maintaining lower speeds for a longer distance. ACOZEEP was recommended in moderate-to-lengthy work zones where there is an uninhibited field of view. ACOZEEP is less recommended if the field of view is inhibited or when there are natural features that result in speed reduction in the work zone. Washington State's *Traffic Manual* (Washington State DOT 2009) calls for two or more stationary patrol vehicles for work zones with a work area greater than 1,000 ft in length. Texas and South Carolina also use enforcement pack techniques in work zones.

DOTs and law enforcement agencies in Florida, Illinois, New York, and Pennsylvania have reported the use of the stealth work zone speed enforcement tactic illustrated in Figure 35. In this technique, an upstream officer (sometimes dressed as a worker) is positioned inconspicuously in the work activity area to identify violators using a radar or Lidar unit. A downstream officer(s) intercepts and tickets the violators. Several names have been used to describe and publicize this tactic, including Operation Hard Hat, Operation Yellow Jacket, and Operation Orange Squeeze. The latter term is used on the Pennsylvania Turnpike, where patrol commander Captain Gregory Bacher describes the objective as follows: "Motorists won't know where or when troopers will be in construction vehicles, so they need to always obey the posted speed limit and travel with headlights on in active work zones" (PTC 2014). Local media reported that 28 tickets were issued in 90 minutes in one such operation in Delaware County, Pennsylvania, in 2012 (Scharr 2012), but no formal data on the speed reduction effectiveness of this tactic have been published. Similarly, no data on the effectiveness of aerial enforcement have been reported in the literature.

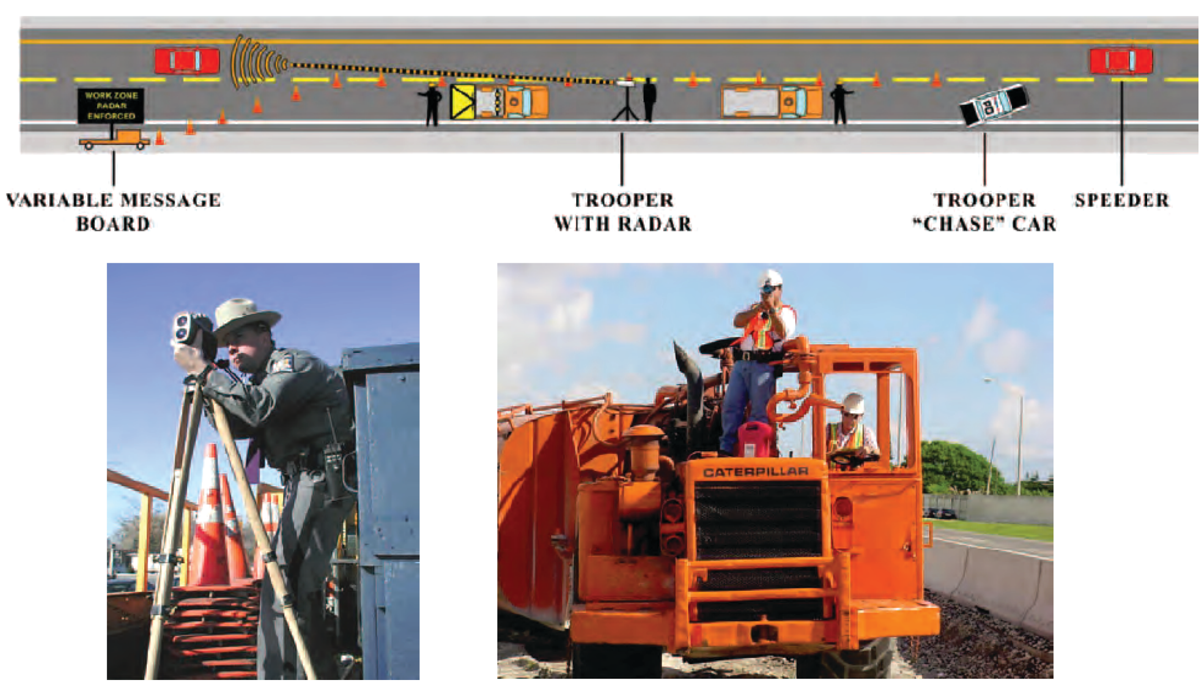


FIGURE 35 Operation Hardhat tactic described in *NCHRP Report 746* (Ullman 2013).

CHAPTER SEVEN

AUTOMATED WORK ZONE SPEED ENFORCEMENT

INTRODUCTION

Automated speed enforcement (ASE) is also known as photo speed enforcement, photo radar speed enforcement, speed photo enforcement, or simply speed cameras. In the United Kingdom, the acronym TASCAR (Temporary Automatic Speed Camera at Roadworks) is used specifically in the context of work zones. Automated enforcement has been in use since at least 1973, when it was deployed to address excessive speeds on a downgrade section of an autobahn near Elzer Mountain, Germany (Lamm and Kloeckner 1984). The technique involves the use of permanent or temporary equipment that determines vehicle speeds, photographs the vehicle license plate, and mails an infraction notice to the registered owner of the vehicle.

Although automation assists with the enforcement process, automated enforcement is generally not robotic. Commercially available systems vary in the degree to which humans oversee the ticketing process. State statutes and collective bargaining agreements also influence the amount of oversight required and whether it must be done by police officers; for example, the system used in Illinois checks the speeds of all vehicles, but a police officer in the enforcement vehicle must verify several details and approve issuance of a citation (Benekohal et al. 2009, 2010; Chitturi et al. 2010). In Saskatchewan, a private security contractor (typically a retired police officer) decides which vehicles are potential violators and activates the system to check the speeds of those individual vehicles; if a violation is observed the automation handles the process of sending a violation notice to the registered owner of the vehicle (Saskatchewan MOJ 2012; M. Muhr, Saskatchewan MOJ, personal communications, 2014). In most systems, a human operator verifies the license plate number determined by the automated system, which minimizes the risk of mis-reads of similar looking characters on the plate (such as B-8, D-O-0, I-1, and S-5). In some jurisdictions, the operator or officer also compares an image of the vehicle driver with the license photo for the vehicle's registered owner and issues a citation only if they match. What is clearly different from human enforcement is that violation notices are sent by mail, so there is no need to chase or intercept speeders.

AUTOMATED ENFORCEMENT TECHNOLOGIES

Currently two technical approaches are in use for automated speed enforcement:

1. Single-point method. This method is based on an observation of the vehicle's speed at a single location. Radar units or similar speed detectors are integrated with the license plate recognition camera and the vehicle's speed at the precise location of the camera is used to determine whether to issue a citation (or warning).
2. Point-to-point (average speed) method. This method uses two (or more) cameras spaced a known distance apart (Figure 36). A vehicle's license plate is identified at the first camera (e.g., at the beginning of a work zone) and the plate is then re-identified downstream (e.g., at the end of a work zone). The time differential between the observations allows the computation of the vehicle's average speed over the monitored segment. Consequently, each driver is required to observe the speed limit throughout the entire segment, not just in the immediate vicinity of the cameras. Another characteristic of this method is that minor exceedances [such as briefly exceeding the speed limit while overtaking (passing) a slow vehicle] are not likely to generate a citation if the overall average speed remains below the limit.

ASE, using the point-to-point (average speed) method, has been found to be one of the most effective ways to reduce speeds in work zones and on ordinary highway segments. An in-depth 2012 study conducted for Austroads (the Australian equivalent of AASHTO) reviewed the use of point-to-point ASE in Australia and internationally and made the following statements (Soole et al. 2012):

> In England, point-to-point speed enforcement . . . is now widely used. The first full implementation of the technology occurred in Nottinghamshire in July 2000. The program has expanded into urban areas more recently. Over 210 temporary systems have been operated in major road work schemes as well as 36 permanent installations by one provider and up to 40 temporary systems at road work sites by another provider.
>
> Evaluations of point-to-point systems have typically reported substantial reductions in mean and 85th percentile speeds associated with the introduction of the technology. Moreover, average (and often even 85th percentile) speeds are reduced to at or below the posted speed limit. Such impacts have been reported in association with both permanent and temporary systems employed in various countries throughout the world. Exceptional rates of Point-to-Point Speed Enforcement compliance with posted speed limits are also noted, with offence rates typically reported to be less than 1%, even when daily traffic volume is high. Further, the proportion of vehicles exceeding the speed limit is often found to be drastically reduced (upwards of a 90% reduction) and the approach has been noted as particularly effective in reducing excessive speeding behavior. Reductions in all crash types, particularly fatal and serious injury crashes, have been reported.

The single-point ASE method has been shown to be advantageous in terms of speed limit compliance and safety. As with

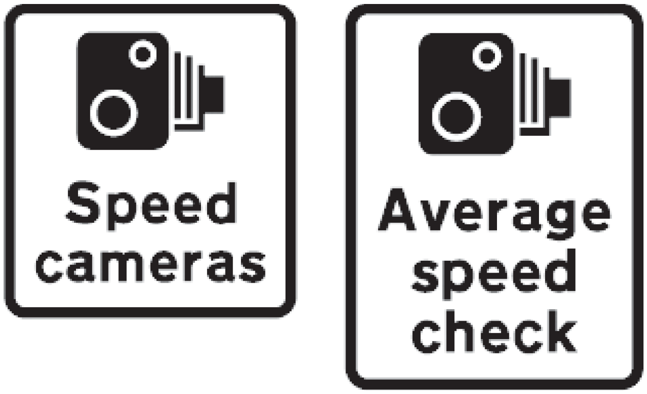


FIGURE 36 British standard signs notifying drivers of point-speed (*left*) and average-speed (*right*) photo enforcement (Highways Agency 2006).

traditional "human" enforcement, single-point ASE results in a moderate reduction in work zone capacity; for example, using a four-regime traffic flow model, an Illinois study found that single-point ASE reduced work zone capacity by 100 passenger cars per hour per lane (pce/h/ln) (Avrenli et al. 2012).

European experience indicates that ASE using the point-to-point method (average speed) is beneficial in terms of speed limit compliance, crash reduction, work zone capacity, and fuel consumption and emissions (Soole et al. 2012):

> [International] evaluation results generally indicate a decreasing trend in KSI (killed or serious injury) crashes after the installation of point-to-point speed enforcement in the order of between 33 [and] 85%. Reductions in minor injury crashes were also noted. However, statistical significance testing, the control of confounding factors (including regression-to-the-mean) and the use of control/comparison areas, were absent from all these evaluations.
>
> An additional benefit associated with point-to-point speed enforcement is more homogenized traffic flow and increased traffic capacity resulting from reduced vehicle speed variability and subsequent increased headway. . . . [Single-point enforcement] cameras have been found to be associated with a stop-start motion created by acceleration and braking close to camera sites and this has been shown to have a detrimental impact on traffic flow. . . . A number of . . . studies conducted in England, Scotland, the Netherlands and France [provide] evidence of improved traffic flow [with point-to-point enforcement], generally as a result of reductions in the standard deviation in vehicle speed variation . . . Reduced congestion resulting from improved traffic flow due to less speed variation equates to higher volumes of traffic being able to travel through a stretch of road before traffic flow breakdown occurs. This increases the capacity of the existing road.

HUMAN AND AUTOMATED ENFORCEMENT COMPARED

Traditional traffic stops are labor-intensive: a police officer must identify a violator, pull the violator over, check the violator's driving record, and issue a warning or a citation. Although this one-on-one approach (one police officer working on one violator) is effective, its scope is inherently limited by the available police human resources.

In work zones there are additional constraints on traditional enforcement techniques, which sometimes render active enforcement infeasible:

- Physical space to park the police vehicle while waiting for violators may be limited.
- Acceleration distance may be insufficient for the police vehicle to enter the traffic stream safely after a violator has been detected.
- The vehicle that is being stopped for speeding may have difficulty finding an appropriate place to pull over.
- Deceleration distance may be limited, resulting in reduced traffic flow as the speeder searches for a place to pull over. This is especially likely in work zones where only one lane is open to traffic.
- Roadway and shoulder width may be insufficient to park the two vehicles while investigating the violation and preparing the citation. In some cases, this may pose a safety hazard; for example, the investigating officer may be required to stand very close to live traffic.
- After the citation process is completed, acceleration distance for the vehicles to re-enter the traffic stream may be problematic from a safety and/or capacity perspective.

Interviews with the state DOT officials revealed concerns that the effectiveness of police presence diminishes once an officer has initiated a traffic stop, because little or no action can be taken against other speeders. As a result, some jurisdictions have transitioned from traditional one-on-one enforcement to multi-officer techniques, which require still more labor.

ASE addresses many of the limitations described earlier. Its legal status varies widely from state to state; in some states, it is expressly permitted through a statutory provision, in others it is expressly prohibited. Some states allow automated enforcement in certain situations, such as work zones or school zones, or when authorized by a municipal ordinance. In some cases, no statutory provision exists, yet case law indicates that ASE is being used. Finally, several states have no legislation addressing this topic, leaving the status of automated enforcement unclear. According to information compiled by NHTSA, as of February 1, 2010, 13 states, the District of Columbia, and Puerto Rico have legislation permitting the use of ASE to some degree (NHTSA 2011). An additional three states utilize ASE without explicit legislation or case law. Sixteen states explicitly prohibit the use of ASE, whereas 18 states do not address this issue legislatively. Arizona legislation repealed the statute establishing the Photo Enforcement Fund, effective July 2012 (CTC & Associates 2011). According to information compiled by the Insurance Institute for Highway Safety, 132 localities in the United States had ASE programs and four states were using speed cameras statewide in work zones as of May 2014 (IIHS 2014). The Province of Quebec appears poised to become the first North American jurisdiction to make widespread use of ASE, with 24 photo radar units to be acquired in 2014 and a "larger number" in 2015 (MTQ 2014).

AUTOMATED ENFORCEMENT AS A HIGHWAY SAFETY METHOD

Although no U.S. research has been found evaluating the safety benefits of ASE in work zones, other research has shown that in general ASE has safety benefits. Thomas et al. (2008) performed a critical review of 90 studies from 16 countries and identified 13 that satisfied the methodological review criteria. They estimated that injury crash reduction in the range of 20% to 25% is reasonable for site-specific safety benefit from conspicuous fixed-camera ASE locations. A similar meta-analysis prepared in 2005 found that all 14 observational studies meeting the study's inclusion criteria reported a reduction in road traffic collisions and casualties (Pilkington and Kinra 2005). The reduction in adverse outcomes in the immediate vicinity of camera sites varied considerably across studies, with ranges of 5% to 69% for collisions, 12% to 65% for injuries, and 17% to 71% for deaths at camera sites. Smaller reductions in adverse outcomes were seen over a wider area.

Increased vehicle headway (i.e., greater spacing between vehicles) is a surrogate measure for improved safety: longer headway reduces the likelihood of rear-end crashes. A recent U.S. study examined headway and distributions of platooning traffic with and without the presence of ASE in two work zones. Mean headways of cars in the median lane and trucks in the shoulder lane significantly increased when ASE was present (Wang et al. 2010).

Although not specific to work zones, experience in France associates considerable safety benefits with ASE. In November 2003, the first speed cameras were installed across the country. At the end of 2004, there were 400 speed cameras (232 fixed and 168 mobile), and by the late 2000s well over 2,000 devices were in operation (including fixed and mobile cameras). The penalty system was modified, with minor offences having fixed fines and more serious offences having greater fines. The enforcement process is now fully automated: a citation is sent automatically to the vehicle owner who must pay it within 45 days. After paying the fine it is possible to designate another driver as the offender, which has reduced the appeal rate to less than 1%. Overall detection rates have increased and sanctions are more severe for repeat offenders. The average speed on French roads decreased by 5 km/h (3 mph) over three years. The rate of "excessive speeding" [defined as more than 30 km/h (18.6 mph) over the limit] was reduced by a factor of five. Very favorable safety outcomes have been reported, including a 40% to 65% decrease in fatal crashes in the vicinity (6 km, approximately 3.7 miles) of fixed cameras. Between 2002 and 2005, fatalities decreased by more than 30% in France—an unprecedented result. These substantial decreases are not entirely the result of the implementation of automatic speed controls; however, it is estimated that the decrease in speed, in which automatic speed control played the major role, accounted for roughly 75% of this decrease (OECD 2006; Howard et al. 2008; Zarei et al. 2009).

WORK ZONE AUTOMATED ENFORCEMENT IN THE UNITED STATES

Illinois, Maryland, Oregon, and Washington State currently use automated work zone speed enforcement. Case Examples 3, 4, and 5 elaborate on the use of ASE in each of the states and summarize findings about effectiveness. In most cases the point speed method is used. Typically, the system is based on a self-contained vehicle that has been equipped to identify vehicles traveling at a speed above a certain threshold, capture image(s) of the vehicle's license plate, and in some cases capture an image of the driver. The images usually include date, time, location, and speed information. Typically, the vehicles are manned by police officers and the decision to issue citations is made by the police officers.

Research has shown that ASE has limited spatial effect at locations downstream of the ASE vehicle (Medina et al. 2009; Lodes and Benekohal 2013). Medina et al. compared the average speeds of vehicles at the ASE location and 1.5 miles downstream. ASE reduced the average speed of free-flowing vehicles by 2 to 3.8 mph for cars and by 0.8 to 5.3 mph for trucks. Lodes and Benekohal (2013) also compared the speeds of individual drivers near ASE and 1.5 miles downstream; paired data were used to quantify the speed change behavior and spatial effect of the treatments. Approximately 85% of drivers sped up after passing the ASE vehicle, indicating that the spatial effectiveness of point-speed-based ASE is limited.

ESTABLISHING AUTOMATED SPEED ENFORCEMENT PROGRAMS

A British document, *Speed Limit Enforcement at Road Works: Guidance and Best Practice*, published in 2006 by the Highways Agency addresses site selection, design, implementation, and maintenance of automated work zone speed enforcement sites, as well as decommissioning of the site when the road work is complete (Highways Agency 2006). A flowchart for deciding when to use automated work zone enforcement is reproduced in Figure 37. The document recommends publicizing the planned use of speed cameras starting 4 weeks before deployment at each project site and notes that the "publicity campaign should emphasize that cameras are there to protect [the] workforce." The project manager is also advised to prepare an "evidence pack" documenting the site layout, signage, and daily equipment checks, which can be used if a driver challenges a citation issued through the system.

Although political opposition to automated enforcement can be "vociferous" (Pilkington and Kinra 2005), polls repeatedly show that a majority of the public responds positively to ASE. The extent of support varies widely, from 77% in Scottsdale, Arizona, to 51% in Washington D.C. (CTC & Associates 2011). A 1998 NHTSA survey identified invasion of privacy (26%), preference for in-person contact with an officer (14%), and camera errors (12%) as the primary public objections. International research suggests that

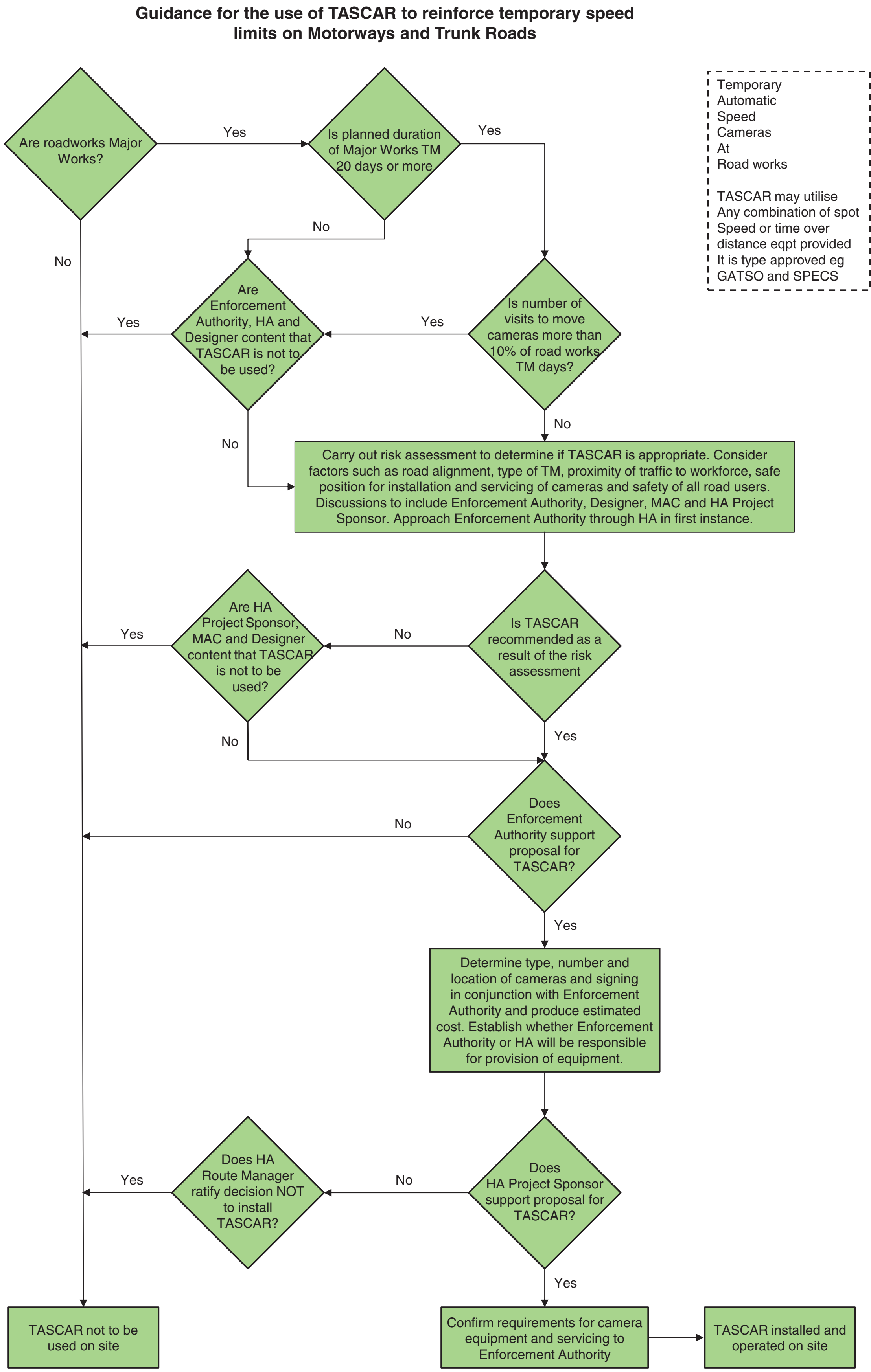


FIGURE 37 Decision-making flowchart for *Temporary Speed Cameras at Roadworks* (TASCAR) published by the British Highways Agency in the context of overall traffic management (Highways Agency 2006).

point-to-point ASE is perceived to be fairer than single-point techniques because drivers are less likely to be cited for instantaneous, inadvertent speeding (Soole et al. 2012).

General guidance on establishing automated speed enforcement programs has been published by NHTSA (2008) and in *NCHRP Report 729* (Eccles et al. 2012); the latter also addresses the start-up of automated systems to reduce red light running. Detailed case examples for four cities with successful automated enforcement programs are included in the NCHRP report, along with a comprehensive review of ongoing and terminated programs.

The *NCHRP Report 729* guidelines recommend that for a program to be successful it should be open to the public, be motivated by safety concerns, have strong enabling legislation, and be repeatable. Similarly, a report prepared by the Organization for Economic Co-operation & Development (OECD) states that, "A crucial element for the success of the speed camera program is to have a transparent communication on the allocation of the revenues [from fines] which are mainly invested on road safety improvements" (OECD 2006). This is consistent with social science research suggesting that cooperation decreases if a punishment is seen as simply serving the self-interest of the punisher, and cooperation increases if incentives are seen as genuine tools to promote collective interests (Balliet et al. 2011).

Case Example 3: Automated Speed Enforcement in Illinois

In 2006, Illinois became the first U.S. state to implement ASE in work zones. The state's deployment has been evaluated in depth and described in considerable detail in the academic literature. The implementation of ASE was prompted by work zone safety concerns: fatalities in Illinois work zones increased to 46 in 2003 from 31 in 2002. Illinois introduced double work zone fines for speeding and enacted the Automated Traffic Control Systems in Construction or Maintenance Zones Act, which authorized the use of cameras by the state police to enforce speed limits. The Act requires that construction workers be present when ASE is in use. It allows ASE to be used day or night, even if the workers are behind temporary concrete barriers. The law also requires special signs (Figure 38*a*) to be posted to inform motorists of ASE in the work zones.

ASE began with a pilot program of two vans; as of May 2014, five vans were in use during the construction season (usually April–October), with deployment limited to freeway work zones. Each DOT district was allocated a budget for automated enforcement, with the enforcement locations subject to approval by the agency's central office (P. Lorton, personal communication, 2014).

Illinois DOT uses a self-contained ASE van (shown in Figure 38*b*) provided by a private vendor. As shown in Figures 38*b* and *c*, each ASE van is equipped with two radar units that monitor the speed of approaching vehicles. One unit is called the down-the-road radar and the other across-the-road radar.

- The speed obtained using the down-the-road radar is displayed on a large LED sign mounted on top of the van, providing

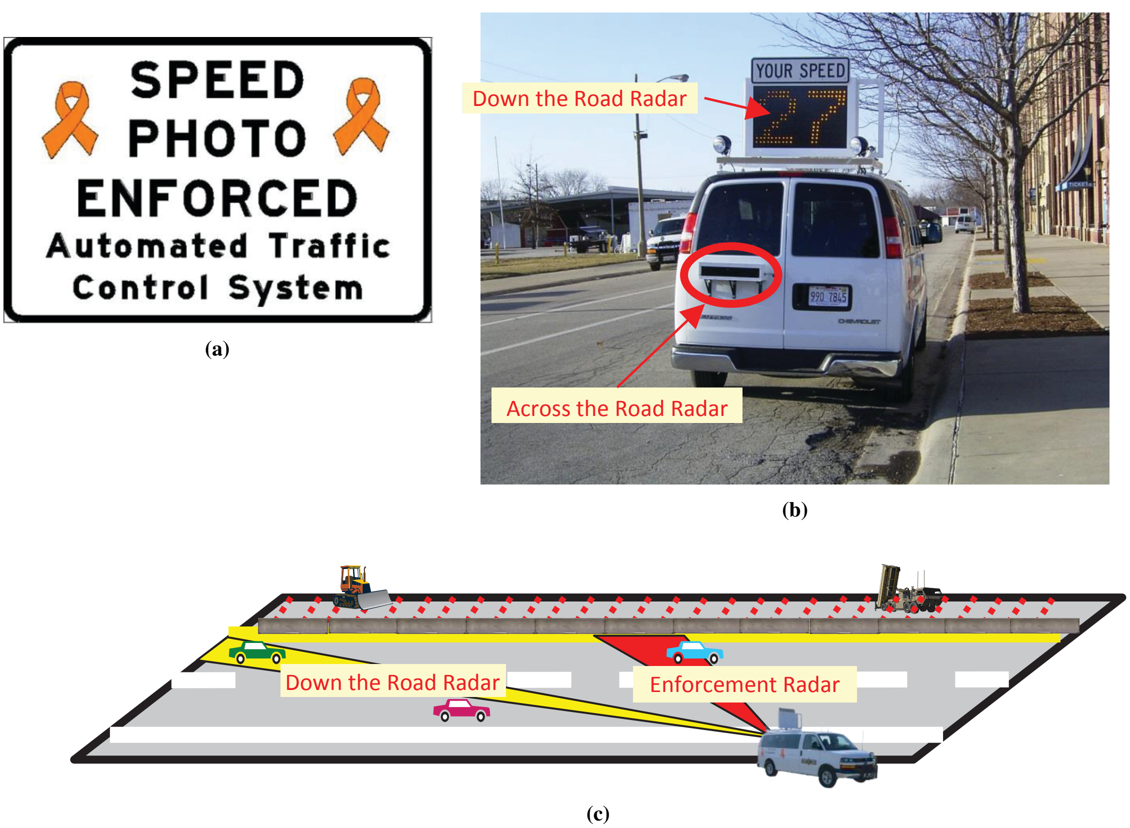


FIGURE 38 Illinois ASE signs, vehicle, and operation: (*a*) special signs to be posted in work zones when ASE is deployed, (*b*) ASE vehicle, and (*c*) operation of ASE.

speeding drivers with a last chance to reduce speed and comply with the speed limit. The range of the down-the-road radar is approximately ¼ to ½ mile.

- The across-the-road radar measures the speeds of vehicles when they are approximately 150 ft upstream of the van. The across-the-road radar operates at a specified angle to the path of vehicles and accounts for the angle effect.

The operation of this ASE van is shown in Figure 38c. If the vehicle speed measured by the across-the-road radar is greater than a specified value, the radar activates the two on-board cameras to photograph the vehicle. The rear camera (Figure 39*a*) captures the driver's face, while the front camera (Figure 39*b*) captures the violator's rear license plate. Each image is overlaid with the date and time of the violation. For night operation, the rear of the van is equipped with a flash unit (Figure 39*d*) to illuminate the car and driver; the van's headlights provide sufficient light to identify the violator's license plate.

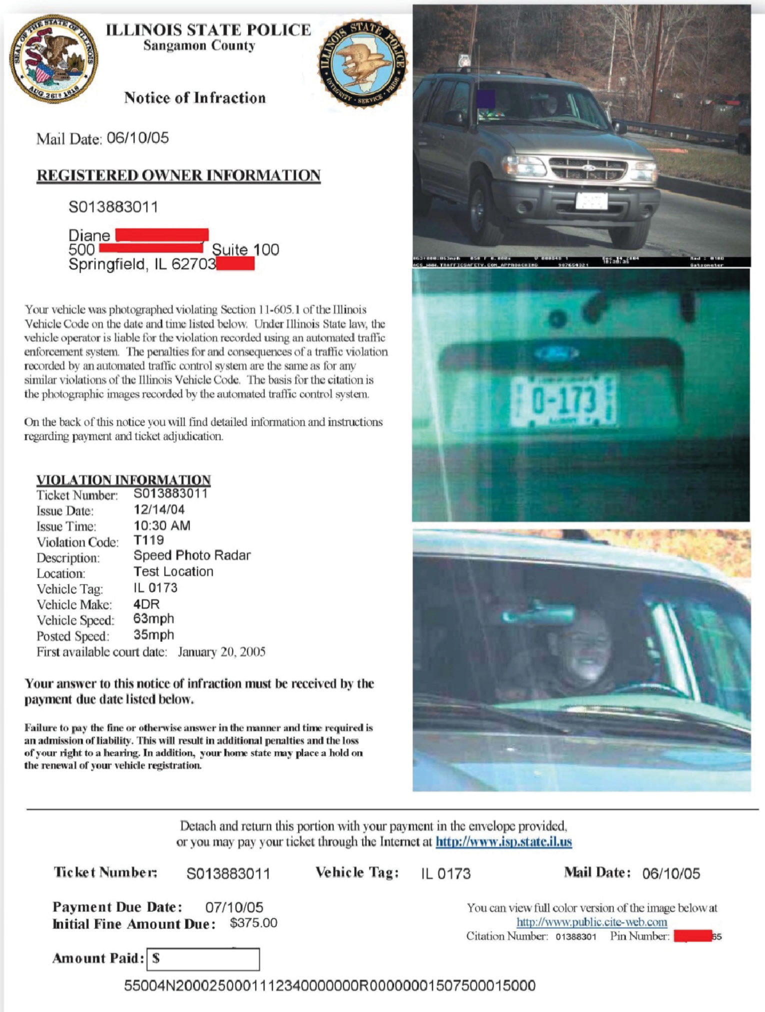
The vans are staffed by specially trained Illinois State Police officers. The officers at the deployment station (Figure 39*c*) receive an audible alert of an approaching speeder and can see the speeding vehicle on a computer monitor. The officer can activate a warning system (if installed) to warn the workers in the work area of an arriving speeding vehicle. Issuance of a speeding citation is at the discretion of the officer in the van and is generally limited to clear cases of excessive speed.

A sample citation is shown in Figure 40. Currently, the violation is tied to the driver of the vehicle. The vehicle's owner is identified based on the speeding vehicle's license plate, and the image of the person driving the speeding vehicle is compared with the vehicle owner's photo from the driver's license database. The ticket is approved by the police officer if the two images match. The vendor processes the approved citation and mails it to the registered owner of the vehicle within 14 days. Local stakeholders are proposing legislative changes so that citations can be issued even when the registered owner is not the speeding driver. Car rental companies are sent an Affidavit of Non-Liability and are required to respond within 30 days.

Illinois fines for speeding in a construction or maintenance work zone are the same regardless of method of enforcement. As of May 2014, the minimum fine was $375 for the first offense and $1,000 for the second offense; if the second offense is within two years of the first offense, the driver's license is suspended

(a) (b) (c) (d)

FIGURE 39 Inside and outside ASE van: (*a*) rear camera, (*b*) front camera, (*c*) deployment station, and (*d*) flash unit at rear of van.



ILLINOIS STATE POLICE
Sangamon County

Notice of Infraction

Mail Date: 06/10/05

REGISTERED OWNER INFORMATION

S013883011

Diane [redacted]
500 [redacted] Suite 100
Springfield, IL 62703[redacted]

Your vehicle was photographed violating Section 11-605.1 of the Illinois Vehicle Code on the date and time listed below. Under Illinois State law, the vehicle operator is liable for the violation recorded using an automated traffic enforcement system. The penalties for and consequences of a traffic violation recorded by an automated traffic control system are the same as for any similar violations of the Illinois Vehicle Code. The basis for the citation is the photographic images recorded by the automated traffic control system.

On the back of this notice you will find detailed information and instructions regarding payment and ticket adjudication.

VIOLATION INFORMATION
Ticket Number: S013883011
Issue Date: 12/14/04
Issue Time: 10:30 AM
Violation Code: T119
Description: Speed Photo Radar
Location: Test Location
Vehicle Tag: IL 0173
Vehicle Make: 4DR
Vehicle Speed: 63mph
Posted Speed: 35mph
First available court date: January 20, 2005

Your answer to this notice of infraction must be received by the payment due date listed below.

Failure to pay the fine or otherwise answer in the manner and time required is an admission of liability. This will result in additional penalties and the loss of your right to a hearing. In addition, your home state may place a hold on the renewal of your vehicle registration.

Detach and return this portion with your payment in the envelope provided, or you may pay your ticket through the Internet at http://www.isp.state.il.us

Ticket Number: S013883011 **Vehicle Tag:** IL 0173 **Mail Date:** 06/10/05

Payment Due Date: 07/10/05
Initial Fine Amount Due: $375.00

You can view full color version of the image below at http://www.public.cite-web.com
Citation Number: 01388301 Pin Number: [redacted]65

Amount Paid: $

55004N2000250001112340000000R00000001507500015000

FIGURE 40 Sample citation.

for 90 days (IDOT 2014b). A portion of the revenue collected from the fines is used to pay off-duty state troopers who provide additional enforcement in work zones. The equipment vendor receives a processing fee of $15 per ticket in addition to contractual fees of $2,950 per month per van for provisioning and maintenance of the van, associated equipment, and police officer training.

ASE in Illinois work zones has been extensively evaluated by university researchers. Three speed datasets were collected at two work zones in Illinois to study their effectiveness. In all but one scenario, the average speed was significantly lower than the work zone speed limit of 55 mph when ASE was present in the work zone. ASE reduced the work zone speeds of cars and heavy vehicles by 3 to 8 mph. The percentage of vehicles exceeding the speed limit was drastically reduced; after treatment, the vast majority of speeding vehicles exceeded the speed limit by fewer than 5 mph. In one work zone, only about 2% of cars exceeded the speed limit by more than 10 mph. As with cars, most of the speeding heavy vehicles were within 5 mph of the work zone speed limit; only a small percentage exceeded the speed limit by 5 to 10 mph and only one heavy vehicle exceeded it by more than 10 mph. ASE had limited spatial effect downstream of the ASE vehicle. Overall, the Illinois studies show that ASE is very effective in improving speed limit compliance in work zones. References: (Benekohal et al. 2008, 2009a, b, 2010; Hajbabaie et al. 2008, 2011; Chitturi et al. 2010; Wang et al. 2011; Lodes and Benekohal 2013).

Case Example 4: Automated Speed Enforcement in Maryland

In October 2009, the Maryland State Highway Administration began a work zone ASE pilot called Maryland SafeZones. It has since become a permanent part of the state's work zone enforcement activities. Speed cameras are mounted on sport utility vehicles (SUVs) and can be located in work zones on expressways and controlled access highways with a speed limit of 45 mph or greater. The system uses Lidar to ensure that the speeds measured are of individual vehicles. Maryland does not require workers to be present for citations to be issued. As in Illinois, special signs (see Figure 41) informing drivers of ASE are required. Trailer-mounted speed display signs are used to notify drivers of their speed. The SUVs are operated by trained operators; however, the Maryland State Police review all violations (exceeding the speed limit by 12 mph or more) before citations are issued. Civil infraction fines are $40 and no points are

FIGURE 41 Signs notifying drivers of ASE in Maryland (Maryland State Highway Administration).

assessed against the driver's license. As of July 2011, Maryland had seven ASE units that rotate through a series of work zones. Several factors such as work zone characteristics, speed limit, and availability of traditional enforcement are considered in deciding where to deploy ASE. The Maryland SafeZones website (www.safezones.maryland.gov) provides the public with a regularly updated list of the work zones that are using ASE; as of May 2014, the system was potentially present at 17 sites.

Franz and Chang (2011) studied the spatial and temporal effects of ASE on motorists' speed behavior in Maryland. Data were collected at three work zones before, during, and after ASE at up to four locations: 2 miles upstream of ASE, at ASE, 0.5 to 1 mile downstream, and 1 to 2 miles downstream of ASE. ASE was found to reduce speeds of aggressive motorists and it created a more stable spatial speed distribution through the work zone. The data also suggest that motorists may learn the location of the ASEs and adjust their speeds accordingly. As illustrated in Figure 42, Maryland is not secretive about the locations of the ASE: the sites where it is in use are posted on an official website.

Case Example 5: Automated Speed Enforcement in Washington State and Oregon

In 2007, the state of Washington authorized a pilot program to use ASE in work zones when workers are present. Following the pilot evaluations, the state's legislature authorized the use of ASE

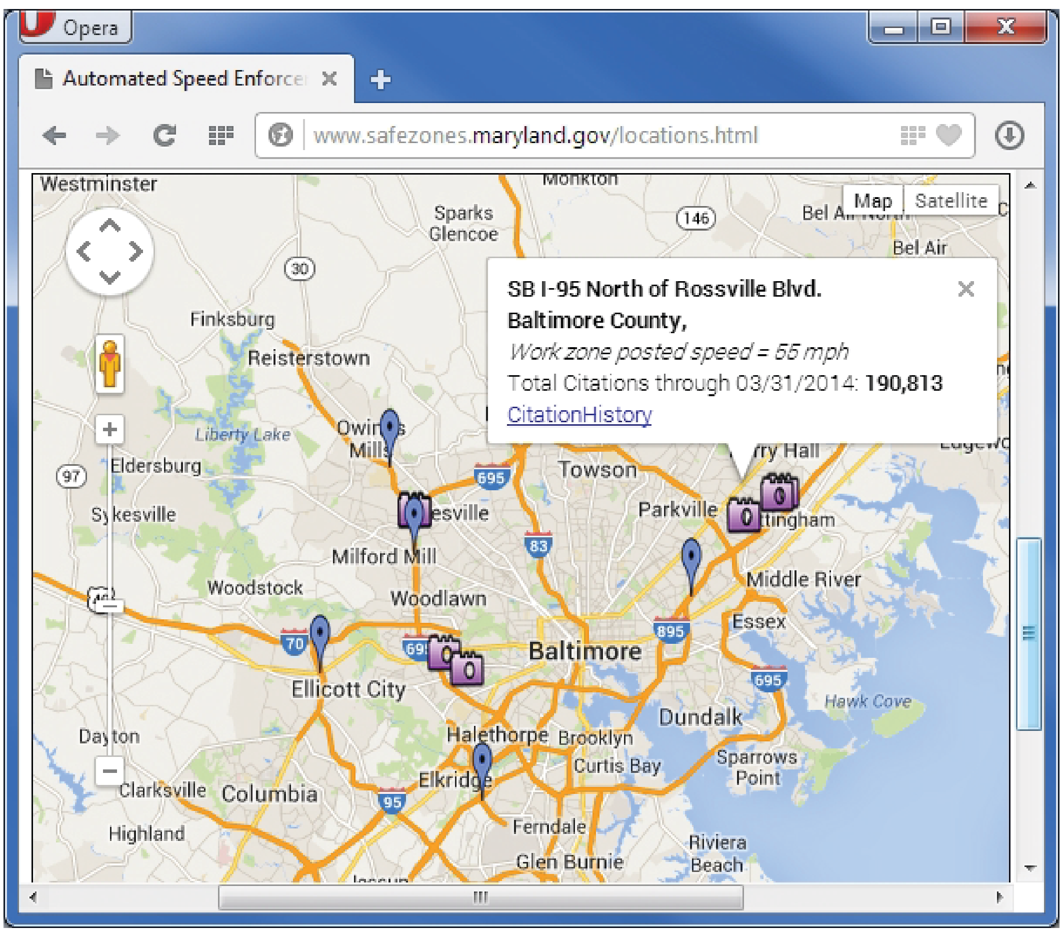


FIGURE 42 Screenshot of Maryland SafeZones website showing current locations of ASE.

FIGURE 43 Signs notifying drivers of ASE in Washington.

in work zones permanently beginning in 2011. As in Illinois, signs notifying the use of ASE (see Figure 43) need to be present in work zones. Washington uses radar to measure vehicle speeds and a camera unit records the rear license plate of any speeding vehicles. The entire system is housed in a SUV as shown in Figure 44. Trained operators monitor the system and forward the violator information to the Washington State Patrol, which checks the vehicle registration. The registered owner of the vehicle receives a $137 citation within 14 days of the violation. Revenue from the fine is shared, with $32 going to the Patrol's highway account and the remainder deposited with the county where the violation occurred.

Washington State DOT launched a pilot project in September 2008 to test the use of ASE in highway work zones; data were collected at two work zones. At one of the work zones, the number of drivers exceeding speed limit by more than 10 mph was reduced from 18% to between 8% and 13%. The number of drivers complying with the 60 mph work zone speed limit increased when ASE was present. The average speed was reduced by 2 to 3 mph (from 62 mph to 59–60 mph) for the northbound and southbound traffic, respectively.

In 2007, Oregon's legislature authorized the use of ASE in work zones on non-interstate state highways when workers are present. Signs notify drivers of the use of ASE. Normally citations are $160 or more depending on the violation, but double in work zones. The first project to use ASE in work zones in Oregon was in northwest Portland in 2009 at a site with a 40 mph posted speed limit. A substantial impact of ASE on speeding was found: the average reduction was 23.7% in vehicles traveling faster than 45 mph (Joerger 2010). Since then, ASE has only been used in one other project, in east Portland in 2013. The limited use of ASE in Oregon is in part attributable to cost considerations arising from public employee labor contracts.

FIGURE 44 Washington ASE implementation (Washington State DOT 2009).

CHAPTER EIGHT

WORK ZONE SPEEDING PUBLIC EDUCATION AND OUTREACH

INTRODUCTION

Many state transportation departments and other agencies engage in public education and outreach aimed at increasing compliance with work zone speed limits and improving work zone safety in general. To date there have been very few assessments of the effectiveness of these campaigns. To gain a better understanding of current agency practices, 43 public service announcements (PSAs) and other outreach materials posted by transportation agencies on YouTube were reviewed. In addition, state DOTs were surveyed to learn more about their work zone public outreach and education efforts; the survey findings are discussed in chapter eleven.

Founded in 2005, YouTube is an advertising-supported online service that allows "billions of people" to watch and share videos (YouTube 2014). As of July 2014, the Internet ratings service Alexa ranked youtube.com number 3 globally among all websites (Alexa 2014). YouTube was also ranked number 3 in the United States (behind search engine Google and social media site Facebook). Alexa estimated that 19.2% of all YouTube views originated in the United States. Reportedly, the average YouTube visitor viewed 9.41 web pages and spent 19 minutes on the site. Alexa also estimated that 3.56 million other websites have links to YouTube.

State DOTs conduct at least two types of work zone public outreach campaigns:

- Programmatic campaigns typically address general work zone safety issues. Their intent appears to be to encourage drivers to reduce speeds, respect workers, drive attentively, and practice other good driving habits in work zones.
- Project-specific campaigns are typically aimed at notifying the public about the anticipated traffic impacts of an individual highway project (or phase of a project). Perhaps the most famous example of a project-specific campaign was launched approximately six weeks in advance of the 53-hour full closure of more than 10 miles of I-405 in Los Angeles over a weekend in July 2011. Dubbed Carmageddon by local media, the project received nationwide publicity before and after the closure, in part because "warnings of catastrophic congestion had been so dire and so relentless that people in the region drastically reduced their driving" (Kandel 2011; Winer et al. 2014).

A handful of studies have evaluated project-specific work zone awareness campaigns. For example, Choi et al. (2009) evaluated public perceptions of an earlier extended closure of a 2.8-mile segment of I-405 east of Los Angeles and found that "the outreach program effectively reduced traffic demand." Similarly, an evaluation of the 2003 "Hyperfix" full freeway closure on I-65/70 in Indianapolis, Indiana, explored the media outlets that individuals and businesses used to get information about the project (Sinha et al. 2004). In spite of the ongoing nature of programmatic work zone public outreach campaigns, formal evaluations are rare. Therefore, publicly available information was used to learn more about the content of programmatic DOT work zone safety campaigns, the extent to which they focus on work zone speeding, and their view rates.

There are at least four dimensions to be considered when evaluating mass media effectiveness:

- Coverage (who is exposed to a communication),
- Response (reactions to the communication's content),
- Impact (determinable impacts on the audience), and
- Process (the manner by which communications influence the audience) (Wright 1955).

This research focused solely on content and coverage: What are the themes of the work zone safety videos on YouTube? How frequently are they viewed?

METHODOLOGY

To ensure inclusion of as many relevant work zone safety campaigns as possible, the research team began by searching YouTube for work zone safety PSAs. Search terms such as "work zone safety" were applied using YouTube's search function. When relevant videos were located, automated links were followed to identify similar material. Also all U.S. state DOT websites were checked to find links to videos the agencies had posted. The review focused on agency-produced road-user safety materials posted as of early April 2014. (Road worker instructional materials and materials produced by individuals were not included in the analysis.)

The videos were evaluated to identify common themes. Every video on YouTube is accompanied by the date it was posted and the cumulative number of views; the team used this information to compute view rates by dividing the number of reported views by the number of days the video had been online. A summary can be found in Table 12.

TABLE 12
INVENTORY OF DOT WORK ZONE PUBLIC SERVICE ANNOUNCEMENTS ON YOUTUBE AS OF APRIL 2014
(listed in decreasing order of views per day)

Views/ Day	Views	Date Published	Length (min:sec)	Sponsor	Title	Theme	Description
116.02	77,150	11-Jun-12	0:32	Vermont DOT	AOT Summer Work Zone Safety	Be considerate of workers	Clips of workers asking people to respect them and slow down and be safe.
108.95	68,312	19-Jul-12	2:43	Quebec Ministry of Transport	Un Chantier Dans Tous Ses États (A work zone in all conditions)	Worker's perspective of the work zone	TV personality Pierre-Yves Lord visits a work site to see what it looks like on the other side of the orange drums.
8.24	2,940	15-Apr-13	1:02	Virginia DOT	Work Zone Safety Awareness Week Safety Video	Be considerate of workers	Highway workers being extremely disruptive and rude in an office. Respect workers office. We're all in this together.
7.78	2,871	3-Apr-13	0:32	AASHTO	2013 Nat. Work Zone Awareness PSA	Work Zone Tips	Stats on work zone fatalities. Tips on staying safe. Announcement of Work Zone Awareness Week.
6.04	13,132	23-Apr-08	0:30	Wisconsin DOT	What Have I Done?	Worker Fatalities	Shows man looking scared in a vehicle involved in a crash. Then looking very sad looking over the body of a dead worker as emergency crews rush in.
4.76	10,525	20-Mar-08	6:06	New York State DOT	A Family's Grief—Your Car Is Like a Weapon	Interviews with people affected by a specific highway crash.	Interviews with multiple people affected by a fatality in a work zone. Multiple people asking motorists to slow down.
4.03	5,949	23-Mar-10	0:40	AASHTO	National Work Zone Awareness Week	Work zone deaths don't need to happen	Stats on work zone fatalities. Anecdote from a widow. Raise awareness of work awareness week.
3.15	5,205	27-Sep-09	6:12	Texas DOT	Work Zone Safety	Fatalities in Work Zones. Increasing Awareness.	Started with statistics on work zone fatalities and collisions. Offered general safety tips and anecdotes.
2.85	2,028	25-Apr-12	4:07	Washington DOT	Workzone Safety 2012	Drive safely so everyone comes home	Man in a hurry runs a work zone stop sign, injures worker. Meets the worker later, feels guilty, apologizes.
2.15	775	12-Apr-13	2:26	Missouri DOT St. Louis	Work Zone Safety: I survived	Pay Attention in work zones	Anecdote from highway worker hit by a truck asking people to pay attention and move over.
1.99	376	30-Sep-13	0:36	Georgia DOT	Work Zone Safety	Drivers have to be aware how dangerous it is	Short clip of interview with state safety manager on how dangerous it is.
1.84	1,324	19-Apr-12	0:30	Kansas DOT	Work Zone Safety—It's for Everybody	Safety is Important for driver too	Short PSA showing highway worker asking people to slow down "for me, and for you."
1.82	2,014	29-Mar-11	1:39	Kansas DOT	Workzone Safety	Be safe when you see orange on the roadway	Images of people wearing orange, showing support for highway workers. General work zone safety tips.
1.29	449	24-Apr-13	7:31	Pennsylvania DOT	Just Drive—Work Zone Smart	Personal responsibility	Starts with the focus on an incident where a driver caused three fatalities under the influence of prescribed drugs. Second half is tips and consequences relating to work zone safety.

TABLE 12
(*continued*)

Views/ Day	Views	Date Published	Length (min:sec)	Sponsor	Title	Theme	Description
1.15	15	25-Mar-14	3:57	Oklahoma DOT	Workzone Awareness	Respect and awareness for highway workers	Anecdotes from two workers involved in a work zone crash.
1.11	1,552	15-Jun-10	0:42	Kentucky Transportation	KY Hwy Improve-ments Underscore Importance Of WZ Safety	General safety instruction	Clips of workers working and narration on work zone safety.
1.09	1,196	1-Apr-11	2:07	New York City DOT	The Importance of Work Zone Awareness	Anecdote from widow	Anecdote from a widow of highway worker. Periodic flashing of fatality statistics. Short interview with highway worker.
1.08	1,187	1-Apr-11	2:06	Virginia DOT	Work Zone Safety—Faces Behind the Numbers	Family of killed worker	Anecdote from a family struggling to recover after the loss of a loved one in a work zone.
1.07	508	18-Dec-12	0:38	Texas DOT	Work Zone Safety: We're All in This Together	General safety instruction	Message from deputy executive director of TxDOT.
1.07	1,549	16-Apr-10	2:02	Missouri DOT	WorkZone Safety Week with MoDOT and the Highway Patrol	Ride along with MO State Patrol enforcing work zones	Interview with police enforcing work zones and safety officials as part of work zone awareness week
1.04	1,508	13-Apr-10	0:30	Texas DOT	What One Thing?	Things to do to stay safe in work zones	Clips of workers answering what one thing people should do to stay safe in work zones.
0.96	355	1-Apr-13	0:33	Indiana DOT	Work Zone Awareness Week is April 15–19, 2013	Deaths in Indiana work zones	Stats posted on signs. No dialogue. Sign asking "Will you slow down?"
0.96	220	20-Aug-13	2:16	Illinois DOT	Work Zone Safety/ National Work Zone Memorial Wall	Work zone memorial wall	Interviews with worker who was severely injured in a crash and safety officials.
0.9	307	2-May-13	0:32	Wisconsin DOT	Inconvenience—Work Zone Safety	Move Over, Slow Down	Animated clip of unsafe driver getting pulled over in a work zone. Mention of fines doubling in work zones.
0.69	759	31-Mar-11	2:15	Missouri DOT SE Region	Work Zone Awareness 2011	Workers want to go home to their families	Interviews with workers and their families talking about the dangers of work zones and how they want to get home safe to their families. Short mention of Work zone Awareness Week.
0.66	1,165	11-Jun-09	0:30	North Carolina DOT	At the Office—Work Zone Safety PSA	Don't drive through someone's workplace at 65 mph	Paid actor on an office set with a short monologue about dangers of not slowing down in work zones. Car then crashes through work zone with people screaming.
0.66	1,163	11-Jun-09	0:31	North Carolina DOT	In the Elevator—Work Zone Safety PSA	Imagine what it's like to be a worker	Office setting, man complains about a work zone. Elevator opens onto a highway. "How would you like it if someone drove through your office at 65 mph?"
0.39	421	11-Apr-11	4:45	Maryland State Hwy. Admin	Maryland leads the nation in work zone safety awareness kick-off	General work zone safety awareness	Clips from speeches from the kick-off press conference.

(*continued on next page*)

TABLE 12
(*continued*)

Views/ Day	Views	Date Published	Length (min:sec)	Sponsor	Title	Theme	Description
0.38	142	25-Mar-13	5:32	Iowa DOT	The Work Zone	"Twilight Zone" theme	Over-achieving driver with license plate GOGETR is so impatient she hits a flagger, then suddenly finds she *is* the flagger.
0.36	638	11-Jun-09	0:31	North Carolina DOT	Applesauce—Work Zone Safety PSA	One bad apple can spoil it for the rest of us	Humorous commercial modeling apples as drivers. "It's bad enough they make applesauce out of themselves, they can hurt you and workers too."
0.34	247	13-Apr-12	0:30	Missouri DOT	Work Zone Awareness PSA 2012	Distracted Driving	Man shown crashing into people with his cart at the super market. Ends with clip of workers saying "No one likes a distracted driver."
0.32	466	9-Apr-10	0:30	Texas DOT	Don't be a statistic	Drivers are more at risk	More drivers are killed than workers. Text slides with dramatic music.
0.31	446	13-Apr-10	0:29	Kentucky Highway Safety	Work Zone Safety	Orange and black signs mean construction	Animated sign explaining construction signs and safety.
0.3	332	14-Apr-11	1:59	Ohio DOT	Work Zone Safety	General safety instruction	Clips from a press conference on why and how to be safe.
0.28	310	29-Mar-11	0:30	Kentucky Highway Safety	My Daddy Works Here	Be considerate of workers	Daughter of killed worker asking drivers to slow down.
0.21	301	20-Apr-10	2:28	Idaho ITD	In Motion—Work Zone Safety	General safety instruction	Interviews with officials and workers on why/how to be safe.
0.21	435	1-Jul-08	1:39	Oregon DOT	Work Zone Safety Message	Reasons for delay and tools and tips to stay safe	Short message from Oregon Director of Transportation on construction for summer 2008 and tools and tips you should use to travel safe and efficiently.
0.19	113	10-Aug-12	0:15	Michigan DOT	Don't Barrel Through Work Zones	Drivers are at risk	The life you save could be your own.
0.13	47	19-Apr-13	1:06	Wyoming DOT	Work Zone Safety	Safety Tips in Work Zone	Wyoming officials giving tips and safety measures for driving in work zones.
0.13	45	26-Apr-13	1:58	Mississippi DOT	Work Zone Safety Awareness Press Conference	Work Zone Safety awareness	Short narration followed by short clips of speech given at press conference.
0.12	86	23-Apr-12	0:38	Nevada DOT	Work Zone Safety	Be considerate of workers	Workers are people too. Slow down.
0.11	81	25-Apr-12	2:22	Ohio DOT	Do Not Barrel Through Work Zones	Slow Down, Be Alert, Save Lives	Video of press conference for work zone awareness with some added clips and editing.
0.09	152	27-Jul-09	0:43	North Carolina DOT	Under Construction: Trucking in the Work Zone	Trucking in work zones	Various scenes of truckers talking about how and why to be safe in work zones.
0.96	**573**			**Median**			

GENERAL FINDINGS

A number of observations emerged from this process:

- In general, agencies produce work zone safety videos in two formats: short PSAs (typically 30 seconds in duration) and longer videos probably intended for use in driver education classes (typically about 5 minutes long).
- Generally, speed reduction is just one of several work zone safety messages embedded in each video. Other common themes include expecting delays, being patient, avoiding texting and cell phone use, and respecting workers and other drivers.
- Overall viewing rates for the work zone videos posted on YouTube were quite low, with a median value of 0.96 views per day. In general, videos that focused on workers doing their jobs received the most views. Press conferences and specialized videos (such as those directed toward truck drivers) received the fewest views.
- The number of videos and frequency of posting suggest that individual state agencies appear to be devoting substantial resources to video production, but very little of the content is specific to individual states or localities.
- Agency efforts are often intermittent. New videos are typically posted in the spring around the time of National Work Zone Safety Awareness Week. Follow-ups later in the construction season are rare.

VIEWING RATES AND EXCEPTIONAL CASES

As detailed in Table 12, YouTube viewing rates for the work zone safety videos are low; most of the videos ranged from 0.09 to 8.24 views per day. In comparison, a 1½-minute PSA, *Embrace Life—Always Wear Your Seat Belt* (Sussex Safer Roads Partnership and Alexander 2010) averaged 10,960 views per day: more than 18 million YouTube views over the 4½ year period from January 2010 to July 2014.

Two work zone safety videos had more than 100 views per day. The reasons for these outliers are unclear, but their content is similar:

- The highest view rate (116 views per day) was obtained by *AOT Summer Work Zone Safety*, a 33-second PSA produced by the Vermont Agency of Transportation. Figure 45 provides a screen capture from the video, which is comprised of short clips where actual road workers (not actors) say they have seen co-workers hit by cars, ask the viewer to help keep them safe, and close by saying, “Your safe driving makes the work zone safer—for everyone.”
- The second-highest view rate (106 views per day) was achieved by *Un Chantier Dans Tous Ses États* (A Work Zone in All Conditions), a 2¾-minute video produced by the Quebec Ministry of Transport. Figure 46 shows an image from the video. The view rate is notable given that the video is entirely in French, a minority language in North America. In the video, Quebec TV commentator Pierre-Yves Lord puts on a hardhat, takes a look at the work zone from the workers’ point of view, works as a flagger, talks with a traffic control technician, and asks the viewer to look out for workers’ safety. Lord’s video has similar view rates and is thematically similar to a series of employee recruitment videos produced for the Quebec ministry, where employees in various occupations (such as bridge inspector, snow plow operator, engineer, environmental specialist, and surveyor) discuss their work and its challenges.

FIGURE 45 The highest YouTube viewing rate was achieved by a 33-second Vermont Agency of Transportation video where highway workers address the viewer, “Please: watch out for me when you’re driving through a work zone.”

YouTube viewership is subject to self-selection, but collectively these results suggest that an effective strategy (at least in terms of viewing rates) may be quite straightforward: show viewers what it is like to work on the “other side of the barrels” and have the workers themselves ask the driver to “help keep everyone safe.” A similar worker-focused strategy was utilized in a recent Swiss work zone safety campaign, illustrated in Figure 47.

In the safety psychology research literature there is considerable debate about whether health and safety messages are more effective when they evoke a positive tone (such as humor,

FIGURE 46 TV commentator Pierre-Yves Lord puts on a safety vest as he prepares to find out what it is like to be a flagger in a video for the Quebec Ministry of Transport.

FIGURE 47 A Swiss work zone public information website puts the emphasis on protecting the safety of individual workers (Wir arbeiten für Sie 2014). This is one of a series of images that display workers' first names on overhead sign gantries (in this case Roger and Heiri/Harry). The tag line translates, "We work for you. Look out for our safety."

et al. 2010). The viewing rate analysis suggests that videos with a positive tone tend to appeal to YouTube viewers. Certainly, this is the case in the *Embrace Life* seatbelt video, which makes a deeply emotional appeal to the benefits of safety, rather than showing the consequences of failing to be safe.

ARE DRIVERS GETTING THE MESSAGE?

Although an in-depth investigation of the relationship between work zone safety messages and changes in driver behavior is beyond the scope of this synthesis report, it is important to recognize even in the absence of public information campaigns, that most drivers reduce their speeds *somewhat* when they are in work zones:

- Table 13 summarizes some recent findings on potential voluntary speed reductions associated with various types of roadwork (Roadway Safety Consortium 2010).
- As detailed in Table 1, a 2006 Kentucky study examined locations where freeways upstream of a work zone had 65 mph posted speed limits (Pigman et al. 2006). The actual speeds upstream were 68 to 72 mph (50th and 85th percentiles, respectively). After entering work zones posted at 55 mph, drivers typically reduced their speed by approximately 5 mph and travelled through the work zone at speeds in the mid-60s if there was no visible work activity. When there was activity, drivers slowed by about 10 mph and went through the work zone at speeds in the upper 50s to low 60s—still above the work zone limit. Similarly, a recent Ohio study using simulated work zone driving environments found that the factors that most strongly influenced speed were worker presence, construction vehicle presence, and enforcement (Sommers and McAvoy 2013).
- A 1999 study found an average decrease in mean speeds of 5.1 mph in work zones where the posted speed limit remained unchanged from the ordinary limit (Migletz et al. 1999).

In spite of these voluntary speed reductions, it is likely that a substantial proportion of the drivers in most work zones are still well above the work zone speed limit. For example, in many states a fairly typical practice is to post a work zone speed limit of 55 mph or 60 mph on a freeway where the speed limit is ordinarily 65 mph. In such a scenario, the actual traffic speed upstream of the work zone might be closer to 72 mph. If drivers voluntarily reduce their speeds by 5 mph, they will be proceeding through the work zone at about 67 mph, which is 7 to 12 mph above the work zone speed limit.

The content of the state DOT work zone public service announcements posted on YouTube were reviewed. Although some campaigns tell drivers to observe the work zone speed limit, none of the campaigns suggested a specific numerical speed reduction target. Therefore, it is possible that the majority of viewers believe their driving already conforms with the campaigns' goals, when actually their speed reductions fall short of the levels desired by the sponsoring agencies.

While not focused specifically on work zones, a 2000 British survey about attitudes toward speeding offers additional insights (Silcock et al. 2000):

> Speeding is not seen as a crime. Whilst "serious speeding" is accepted as dangerous, "moderate speeding" is not. There is a widespread view that the stereotypical images of the "boy racer" and the "company car driver" are the problem, not "me." Until there is a general acceptance of the breadth and depth of the

TABLE 13
POTENTIAL VOLUNTARY SPEED REDUCTIONS FOR VARIOUS WORK ZONE CONDITIONS

Work Zone Condition	Potential Voluntary Speed Reduction*
Work Zone Reduced Speed Limit Sign	0 to 3 mph
Barrier Near Inside Travel Lane	0 to 3 mph
Lane Encroachment	1 to 5 mph
Lane Closure	1 to 7 mph
Construction Vehicle Access/Egress Location	5 to 6 mph
Temporary Crossover	4 to 9 mph
Two-Lane, Two-Way Barrier Separated Traffic	7 to 9 mph

Source: Roadway Safety Consortium (2010).
* The speed reductions listed are based on a study conducted in Texas. Operating speeds upstream of the work zones ranged from 60 mph to 77 mph.

problem it is unlikely that attitudes will change. Indeed it may be that the targeted campaigns have inadvertently offered the excuse to many (who do not identify with the target group) that the problem lies with limited groups of drivers.

Whilst . . . surveys support the view that some categories of driver are more likely to speed, and to have more serious crashes as a result, speeding is not restricted to such groups. An important message to get across is that we all speed, and we all cause increased risk as a result.

Current campaigns to persuade drivers to observe speed limits seem to reinforce the view held by some drivers that they are able to speed safely as they do not identify with the drivers in the advertisements, even when targeted at drivers like themselves. Drivers in general feel that radio advertisements are more effective than TV, primarily because they listen to the radio whilst driving whereas TV adverts are remote from the driving task.

Most transportation-related PSAs have a focused message such as "wear your seatbelt" or "drive sober." Conversely, many work zone safety campaigns include five to six work zone driving safety messages, often compressed into a short (e.g., 30-second) time frame. For example, an Illinois DOT work zone safety website (IDOT 2014c) urges drivers to make the following "pledge":

- I won't:
  - Text and drive
  - Talk on my phone in a work zone.
- I will:
  - Obey posted work zone speed limits—24/7
  - Pay attention to changing conditions when approaching a work zone
  - Be courteous to other motorists.

Additional research may be necessary to determine the optimal number of messages to include in individual work zone PSAs. An example of a more focused message would be, "Take off 12: in work zones reduce your speed by twelve miles per hour."

To date, very little information has been published about the extent to which work zone PSAs influence driver behavior. In 2013, Saskatchewan conducted an online panel survey as a follow-up to the highly publicized worker fatality described in Case Example 1. For those circumstances and that set of advertisements, among those who recalled seeing a work zone safety television ad or hearing a radio ad, 70% agreed that it had changed their driving behavior, as shown in Figure 48 (Insightrix 2013).

DRIVER EDUCATION

The driver manuals produced by state departments of motor vehicles (DMVs) currently vary in the extent to which they address work zone speed. For example, the *New Mexico Driver Manual* primarily focuses on the shape and color of work zone signs, along with a reminder not to park in construction areas if it will block traffic (New Mexico MVD 2014). In addition to those items, Wisconsin's *Motorist Handbook* instructs drivers to move over or slow down when approaching a construction vehicle (but does not specify how much speed reduction is expected). The Wisconsin manual also reminds drivers to avoid being distracted in work zones and to be alert for distracted workers (WisDOT 2014b). California's *Driver Handbook* addresses work zone safety in greater detail: "Reduce your speed and be prepared to slow down or stop for highway equipment. Merge as soon as it is safe to do so and without crossing the cones or drums. . . . Watch for work zone speed limit and reduced speed limit warning signs. . . . The most common cause of deaths and injuries in work zones is rear end collisions. . . . Do not stop or slow down to watch the road work. . . . Remember to 'Slow for the Cone Zone' " (California DMV 2014).

In 2005, FHWA, the American Road & Transportation Builders Association (ARTBA), the AAA Foundation for

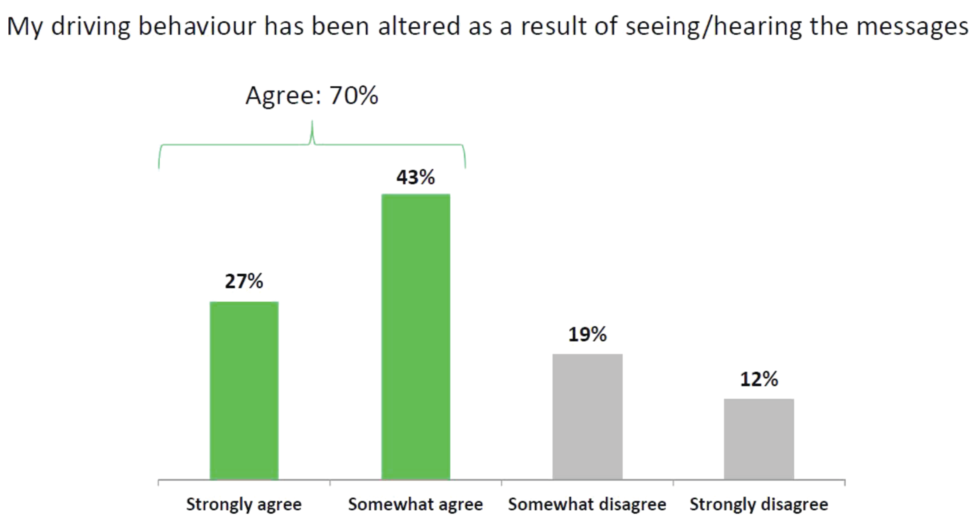


FIGURE 48 Self-reported behavioral responses of Saskatchewan survey respondents who had seen or heard the province's work zone safety PSAs (Insightrix 2013).

Traffic Safety, and the National Safety Council co-developed workzonedriver.org, a teen-oriented website titled *Turning Point: Roadway Work Zone Safety for New Drivers.* The website includes several resources for teens, parents, and driving instructors; however, the centerpiece (an 11-minute video titled *Turning Point: Some Decisions Last a Lifetime*) cannot be viewed or downloaded from the site (the video is available for purchase from ATRBA). As of July 2014 the website ranking service Alexa was unable to compute a ranking for workzonedriver.org, which is indicative of low traffic to the website (Alexa 2014).

In 2008, Iowa DOT took an unconventional approach toward promoting teen driver work zone safety by sponsoring a new car giveaway. Teens who viewed a work zone safety video could register to win a 2008 Ford Fusion, with one winner selected at random. "Nearly 12,000 unique visitors logged on the site from August 2007 to March 2008, and more than 18,000 views of the safety video were recorded" according to an Iowa DOT press release. The DOT collaborated with a car dealership, a television station, and high schools to promote the contest (Bramble 2008; Fitzsimmons et al. 2009).

Canadian guidance on work zone speed management recommended that the following information be considered for inclusion in driver instruction manuals (Harmelink and Edwards 2005):

- The importance of safety for both motorists and workers.
- Explanation of orange warning signs for work activities on the road.
- The depiction and description of the most important work zone signs and traffic control devices, such as cones, barrels, barriers, and barricades.
- The need to slow down for work zones where indicated (by ROAD WORK signs, by signs indicating the speed limit when workers are present, by signs indicating reduced speed when lights are flashing, and/or by PCMS).
- The need to stop (or proceed slowly) as indicated by traffic control persons.
- Recommended driver action when encountering mobile work operations.

Harmelink and Edwards also note that "experienced drivers should be provided periodic summaries or updates of such information; for example, as inclusions in notices of their driver license renewal."

CHAPTER NINE

COMBINATION TECHNIQUES FOR MANAGING WORK ZONE SPEED

INTRODUCTION

Law enforcement has been shown to be one of the most effective methods for increasing speed limit compliance in work zones; however, research has also shown that the spatial and temporal effectiveness of law enforcement is limited (except in the case of automated enforcement using the point-to-point method). Several states (e.g., California, Pennsylvania, South Carolina, Texas, and Washington) use multi-officer techniques (sometimes called enforcement packs) to enhance law enforcement effectiveness, especially in extended work zones. Nevertheless, deploying large numbers of law enforcement officers at work zones is subject to staffing and budgetary constraints, and may conflict with other policing priorities. In addition, enforcement for rural work zones may require police personnel to travel considerable distances from their usual work locations. As a result, a number of state DOTs and researchers have searched for possible combinations of work zone speed reduction tactics whose effectiveness would be similar to what is achieved through enforcement. Many of these combinations have arisen purely through practitioners' field experience and are not well documented. A few studies have formally evaluated combination treatments; these studies are summarized in this chapter.

FLORIDA: MOTORIST AWARENESS SYSTEM

In 2005, the Florida DOT (FDOT) developed a combination of traffic control techniques called the Motorist Awareness System (MAS) (Reddy et al. 2008). In addition to traffic control and warning devices that are part of standard MOT plans, the MAS uses PCMS, radar speed feedback signs, and regulatory speed limit signs with flashers, as shown Figure 49. Active enforcement is also a critical element of the MAS. The system is implemented on multilane facilities with posted speed limits of 55 mph or higher when work operations require a closure and workers are present.

FDOT conducted a public information campaign to notify the public of the change and the need to reduce speeds in work zones. The MAS was evaluated on two segments of I-10 and I-95 in Florida. Both are four-lane divided facilities with 70 mph posted speed limits, although I-95 has three lanes in one direction at some locations. Speed studies were conducted at three locations within each work zone: prior to, in the middle, and at the end of the work zone. Speed data were collected for three scenarios: traditional MOT, MAS without police enforcement, and MAS with police enforcement. Data were collected for various times of the day and days of the week. Mean speed, 85th percentile speed, and characteristics of speed distribution were used in the evaluation.

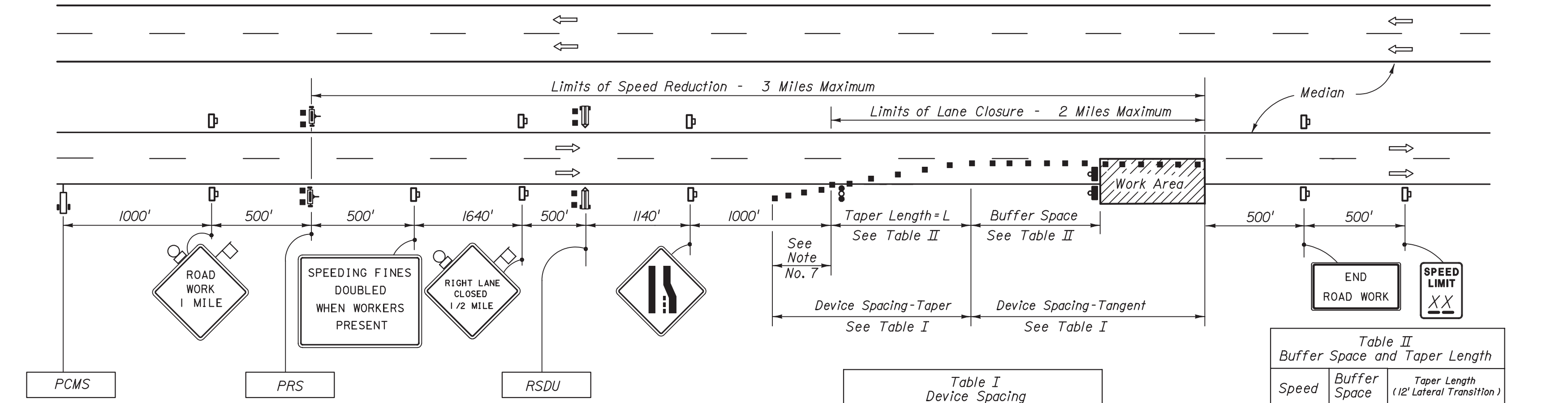
Mean and 85th percentile speeds were lower when MAS was used when compared with standard MOT. MAS alone reduced the average speeds by approximately 1.5 mph. MAS coupled with enforcement reduced the average speeds by about 4 to 5 mph. Variability of travel speeds was decreased with MAS at one location. Proportions of drivers exceeding the speed limit within and near the end of the work zone were substantially reduced by MAS. Augmenting MAS with enforcement further reduced the proportion of speeders. Overall, MAS was found to be effective in reducing vehicular speeds in work zones.

ILLINOIS: ENFORCEMENT WITH SPEED FEEDBACK DISPLAYS

Researchers from Illinois evaluated the effectiveness of multiple speed reduction measures at two work zones in Illinois (Benekohal et al. 2010; Hajbabaie et al. 2011). The speed reduction measures studied included:

- Speed feedback trailer,
- Passive law enforcement,
- Passive law enforcement in conjunction with speed feedback trailer, and
- ASE.

One work zone had moderate speeding, whereas the other had extensive speeding. Data were collected without any treatment and served as the basis for the comparisons. For the three datasets analyzed, ASE, passive law enforcement, and passive law enforcement with speed feedback trailer, reduced the mean speeds significantly (5 to 7 mph) for the general traffic stream as well as free-flowing vehicles. The three enforcement treatments also reduced the degree of speeding: speeding by more than 10 mph was almost reduced to zero and speeding by up to 10 mph was significantly reduced. At one location, the combination treatment was more effective than ASE and law enforcement alone, whereas at the second location, ASE and combination were similar and both were better than law enforcement alone. Limited effects were found for the speed feedback trailer.



Typical PCMS Display

With speed reduction:
- Message 1: WORKERS PRESENT AHEAD
- Message 2: SPEED REDUCED NEXT 3MI

Without speed reduction:
- Message 1: WORKERS PRESENT AHEAD
- Message 2: NEXT 3 MILES

Table I
Device Spacing

Speed (mph)	Max. Distance Between Devices (ft.)			
	Cones or Tubular Markers		Type I or Type II Barricades or Vertical Panels or Drums	
	Taper	Tangent	Taper	Tangent
25	25	50	25	50
30 to 45	25	50	30	50
50 to 70	25	50	50	100

Table II
Buffer Space and Taper Length

Speed (mph)	Buffer Space Dist. (ft.)	Taper Length (12' Lateral Transition) L (ft.)	Notes (Merge)
25	155	125	$L = \frac{WS^2}{60}$
30	200	180	
35	250	245	
40	305	320	
45	360	540	L = WS
50	425	600	
55	495	660	
60	570	720	
65	645	780	
70	730	840	

When Buffer Space cannot be attained due to geometric constraints, the greatest attainable length shall be used, but not less than 200 ft.

For lateral transitions other than 12', use formula for L shown in the notes column.
Where:
L = Length of taper in feet
W = Width of lateral transition in feet
S = Posted speed limit (mph)

SYMBOLS

- Work Area
- Sign With 18"x 18" (Min.) Orange Flag And Type B Light
- Channelizing Device (See Index No. 600)
- Type I, Type II Or Type III Barricade Or Vertical Panel Or Drum (With Flashing Light)
- Work Zone Sign
- Advance Warning Arrow Panel
- Lane Identification + Direction of Traffic
- (1) PCMS = Portable Changeable (Variable) Message Sign
- (2) PRS = Portable Regulatory Sign - Speed Limit When Flashing
- (2) RSDU = Radar Speed Display Unit

GENERAL NOTES

1. At lane closures where workers are present, reduce the posted speed limit (speed limit that existed prior to construction) by 10 MPH using the Portable Regulatory Sign (PRS), but not less than 55 MPH or to a speed warranted by geometric condition, whichever is lower. Taper lengths, buffer space and device spacing shall be selected using the posted speed, not the reduced speed.
2. All Arrow Panels, Portable Changeable Message Signs, Portable Regulatory Signs and Radar Speed Display Trailers, shall be turned off and moved outside the clear zone or be shielded by a barrier or crash cushion when not in use.
3. Work operations shall be confined to one traffic lane, leaving the adjacent lane(s) open to traffic.
4. When work is performed in the median lane on divided highways, the barricading plan is inverted and left lane closed and lane reduction signs substituted for the right lane closed and lane reduction signs.
5. When work is being performed on a multilane undivided roadway, the signs and traffic control devices normally placed in the median (as shown) shall be omitted.
6. When paved shoulders having a width of 8 ft. or more are closed, channelizing devices shall be used to close the shoulder in advance of the merging taper to direct vehicular traffic to remain within the travel way. See Index No. 612 for shoulder taper formulas.
7. For general TCZ requirements and additional information, refer to Index No. 600.

CONDITIONS

The MAS shall be used if all the following conditions exists:

- Multilane facility
- Posted speed limit is 55 MPH or greater
- Work activity requires a lane closure for more than 5 days (consecutive or not)
- Workers are present

2008 FDOT Design Standards	Last Revision	Sheet No.
MOTORIST AWARENESS SYSTEM	07/01/07	1 of 1
	Index No.	670

FIGURE 49 Standard detail drawing for Florida Motorist Awareness System (Florida DOT).

VERMONT: ENFORCEMENT WITH SPEED FEEDBACK DISPLAYS

In Vermont work zones, law enforcement is typically used for presence rather than active enforcement (Lee et al. 2014). Uniformed traffic officers (UTO) are police officers contracted for work zones and stationed in marked police vehicles with the blue lights flashing. The study evaluated the effectiveness of the following four treatments on interstate highways:

- UTO,
- Targeted police enforcement,
- Radar speed feedbacks signs (RSFS), and
- Combination of UTO and RSFS when work zones are active.

For all the scenarios, traffic speeds were measured for at least 1 week before, during, and after their implementation, allowing statistical testing of mean speeds as well as proportions of vehicles speeding. The least effective treatment was found to be targeted police enforcement. Although the mean speeds and percentage of speeders decreased with targeted enforcement, they remained high. UTO and RSFS were similarly effective in lowering mean speeds and percentage speeders. Both treatments reduced the average speed to below the speed limit. When used in combination, UTO and RSFS had more impact on speeds of travelers than when only one of them was used; the proportion of speeders was small and the number exceeding the speed limit by greater than 5 mph was close to zero.

OREGON: COMBINATION STRATEGIES

A recent study evaluated combinations of SPEED LIMIT 50 signs, PCMS, and RSFS at two work zones in Oregon (Gambatese and Zhang 2013) (Figure 50). The combination of PCMS with RSFS recorded the lowest 85th percentile speed of all the treatments at the end of the taper. The reduction in 85th percentile speed was about 6 mph at the end of the taper. No similar significant effect was observed when the treatments were used individually. The study recommends that a PCMS be used in conjunction with a RSFS just downstream from the end of the taper, in the buffer area, and just upstream of work activity area (Figure 51). The suggested messages included: "Slow for Workers," "Workers on Roadway," and "Narrow Lane" (Figure 52). The spatial effect of the combination was found to be limited. Therefore, to help maintain lower speeds next to the work activity area, the study recommends using PCMS mounted on work equipment such as pavement rollers, which ordinarily remain in or just upstream of the work activity area while in use. If roller-mounted PCMS are unavailable, and if sufficient space is available in the median or shoulder, Gambatese and Zhang recommend placing PCMS and RSFS at multiple locations within the work zone, such as every 0.5 mile.

INDIANA: ENFORCEMENT WITH VARIABLE MESSAGE SIGN

Researchers evaluated police enforcement with and without VMS displaying an enforcement message (Chen and Tarko 2013). Stationary enforcement was found to be effective. VMS used in conjunction with stationary enforcement increased the speed reduction by an additional 3.6 mph for cars and 2.7 mph for trucks. VMS with police had a significant effect on speed up to one mile downstream as opposed to one-half mile for police enforcement. The study concluded that the most cost-effective enforcement tactic consists of one stationary police vehicle at the beginning of a work zone with a VMS placed closely upstream, displaying an enforcement message.

SWEDEN: CHICANES WITH ELECTRONIC SIGNAGE AND ENHANCED LANE DELINEATION

A 2007 study by Nygårdhs for the Swedish National Road and Transport Research Institute explored the effects of signage and delineation enhancements at a rural freeway work zone. A double-chicane design was taken as the "conventional" equipment base case. Three enhanced versions of the chicane were explored (Nygårdhs 2007):

- The same physical layout as the standard chicane, but substituting VMS for the following fixed signs: NO PASSING, SPEED LIMIT, and LEFT LANE ENDS. The LEFT LANE ENDS sign was supplemented with a VMS panel displaying an exclamation point inside a triangle, which is a standard method of highlighting miscellaneous hazards in Sweden and many other countries. The speed limit sign flashed for speeding vehicles (flashing activated at 50 km/h) (Figure 53).
- Like the previous version; however, the vertical panels delineating the chicane had arrow patterns showing which way to turn, instead of using ordinary diagonal stripes on the panels (Figure 54).
- Like the previous version, but supplemented by white plastic barriers in the chicane.

The two arrangements using VMS without a barrier reduced speed most effectively. In a comparison test of photographs of the different arrangements, the arrangement using a white barrier was considered clearer than the others. Nevertheless, the high clarity also appeared to lead to higher speeds. Some of the speed reduction may have been attributable to novelty effects.

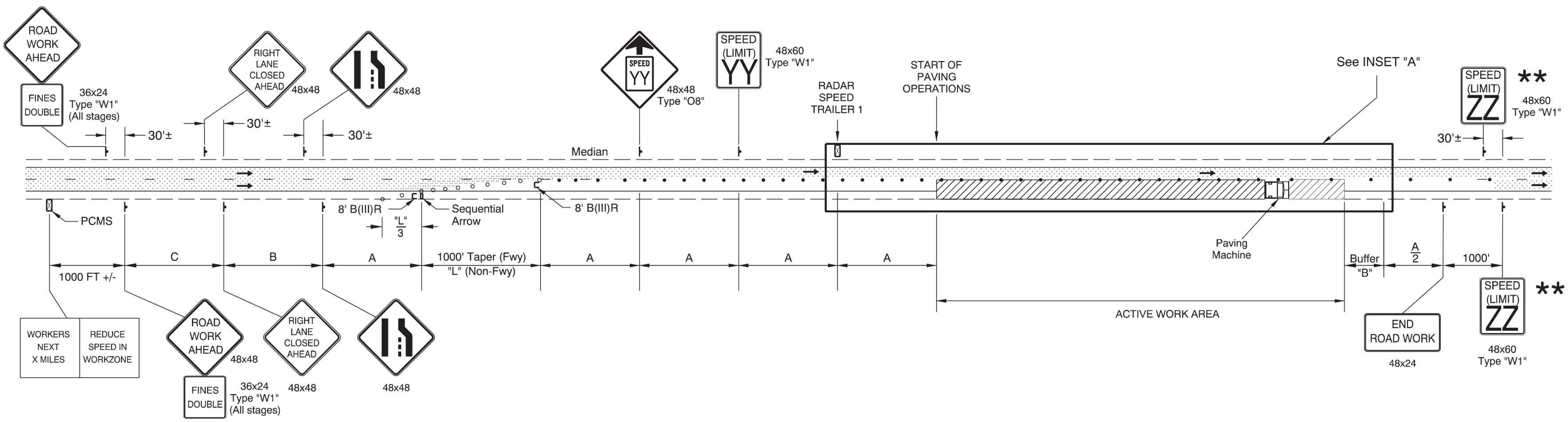


FIGURE 50 Oregon DOT Standard Drawing TM 880 (Pappe 2014).

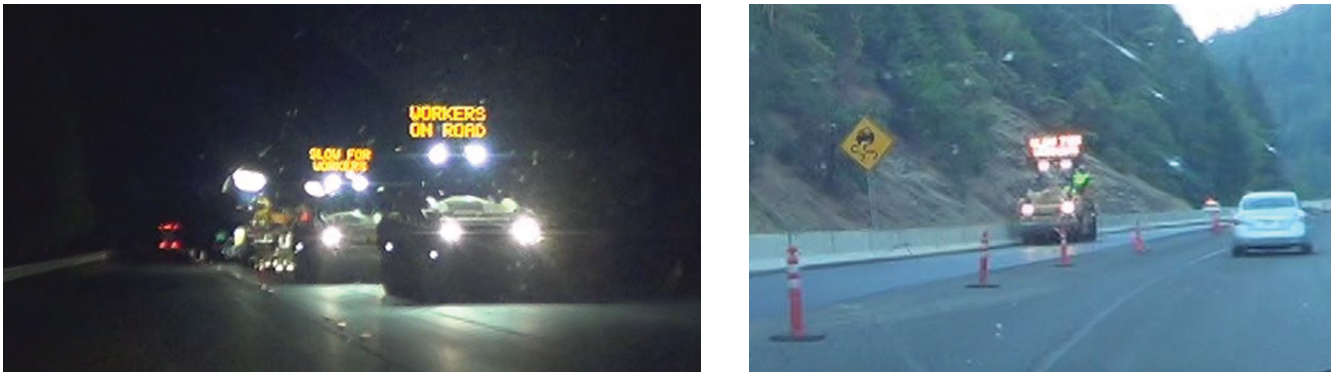


FIGURE 51 PCMS mounted on work vehicles: night (*left*) and day (*right*) (Pappe 2014).

FIGURE 52 PCMS mounted on pavement roller: night (*left*) and day (*right*) (Pappe 2014).

FIGURE 53 "Conventional" upstream chicane marking from Swedish study (Nygårdhs 2007).

FIGURE 54 Swedish upstream chicane marking enhanced with LED/VMS signage (Nygårdhs 2007).

CHAPTER TEN

SURVEY OF WORK ZONE ENGINEERING AND ENFORCEMENT PRACTICES

INTRODUCTION

Two online surveys were conducted to gain an understanding of the current state of practice regarding work zone speed management by highway agencies. This chapter summarizes the findings of the Engineering and Enforcement survey. An invitation to participate in the survey was distributed to members of the AASHTO Standing Committee on Traffic Engineering. The invitation list was further augmented by inviting members of the FHWA Work Zone Safety Peer Exchange and work zone engineering professionals from Canadian provincial MOTs. In all, 50 responses were received, including four Canadian MOTs. In addition, four DOTs in the United States provided more than one response, typically one response from the agency's headquarters and a response from a regional or district office. The U.S. respondents are shown in Figure 55 and the survey instrument is attached as Appendix A.

KEY FINDINGS

As indicated in Table 3 (located in chapter two), approximately two-thirds of the agencies that responded to the survey reported that they have a written speed limit setting procedure or policy in place. Just over half of the respondents indicated that the policy is uniformly implemented; however, 40% did not respond to this question.

Agencies were asked about several signing and marking techniques that have the potential to reduce traffic speeds in work zones. The results are tabulated in Tables 14 and 15 and can be summarized as follows:

- Dynamic work zone speed limit signage is rarely used; however, when it is applied, it is used primarily for freeway projects that involve unusual situations.
- About half of all respondents indicated the use of mandatory reduced speed limits when workers are present. According to the survey responses, the signs were more commonly used on two-lane rural highway projects than on freeways.
- On freeway projects, the vast majority of responding agencies frequently use FINES DOUBLED IN WORK ZONES signs or analogous signage indicating the higher penalties authorized under their respective laws. In some jurisdictions this type of signage is mandatory or must be in place for the higher fines to be enforceable. Most respondents noted that such signs were used only in special situations on two-lane rural highway projects.
- By and large the use of dynamic speed feedback signs appears to be limited to special situations.
- Currently, there is limited use of transverse rumble strips at work zones. Although the survey responses indicated occasional use for freeway work zones, interviews with DOT personnel suggest that the primary use is to encourage drivers to decelerate in advance of flagger stations at two-way, one-lane work zones.
- Currently, the use of optical bar markings at work zones is uncommon.
- Agencies occasionally use narrowed lanes as a speed management measure. The use of modified cone or barrel spacing to encourage speed reduction is more common.
- The use of pace cars and pilot vehicles is fairly common, with 44% of respondents indicating their use on freeway projects (presumably for rolling closures) and 76% of respondents indicating their use on two-lane, rural highway projects (presumably as pilot vehicles in work zones that are long, traverse rugged terrain, or involve bringing live traffic very close to workers).
- Advance warning signs indicating a speed reduction ahead are widely used on freeway projects, but seldom used on two-lane, rural highway projects.
- Wide edgelines are rarely used as a work zone speed management measure.

The survey responses regarding enforcement techniques are detailed in Tables 16 and 17 and can be summarized as follows:

- Standard active enforcement remains the most common tactic for work zones.
- About one-third of the respondents reported frequent use of police officers in work zones who have their flashing lights on to indicate presence, but do not issue tickets. About one-quarter of the respondents use the same tactic, but with lights off.
- Decoy police vehicles and aerial enforcement are seldom used in work zones.
- Stealth enforcement, such as radar spotters on an overpass, is used by about one-quarter of the agencies in special situations.
- Automated issuance of warnings (not citations) is rare.
- By and large decoy radar is used only in special situations.

As shown in Figure 56, most agencies tolerate speeding to some degree. The most frequently reported tolerance range was 4 to 6 mph, and the second most frequently reported range was 9 to 10 mph.

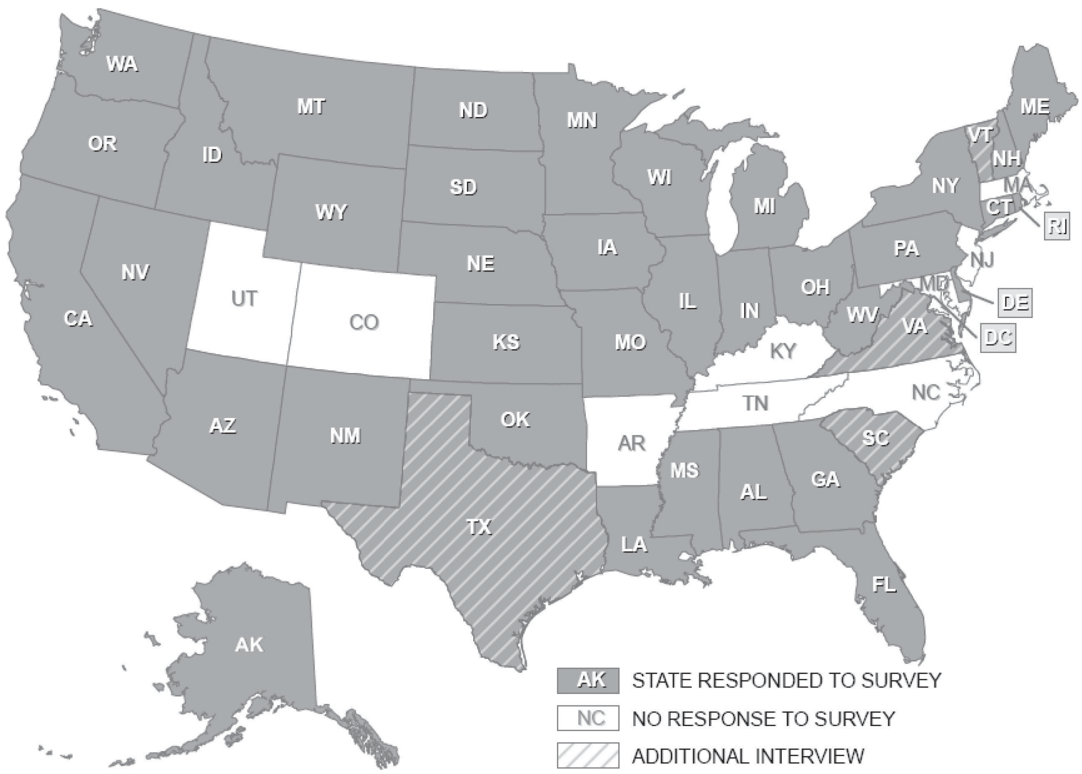


FIGURE 55 U.S. respondents to engineering and enforcement survey.

TABLE 14
ENGINEERING MEASURES USED BY SURVEY RESPONDENTS ON FREEWAY AND OTHER MULTILANE DIVIDED HIGHWAY WORK ZONES IN THE PREVIOUS THREE YEARS

Engineering Techniques for Freeway Work Zones	All Work Zones	Most Work Zones	Some Work Zones	Occasional/ Unique Situations	Never	No Response	Total
Dynamic Work Zone Speed Limit Signs	2%	0%	8%	32%	58%	0%	100%
Mandatory Reduced Speed Limit only When Workers Present	18%	14%	14%	8%	44%	2%	100%
"Fines Doubled in Work Zones" Signage	50%	28%	16%	0%	4%	2%	100%
Dynamic Speed Feedback Signs	2%	4%	18%	56%	18%	2%	100%
Transverse Rumble Strips at Approach to Work Zone	0%	0%	8%	50%	42%	0%	100%
Converging Bar Pavement Markings (optical speed bars)	0%	0%	0%	10%	90%	0%	100%
Reduction of Lane Width to Encourage Slower Driving	0%	2%	14%	36%	44%	4%	100%
Modified Cone/Barrel Spacing to Encourage Slower Driving	0%	6%	20%	22%	52%	0%	100%
Pace Cars/Pilot Vehicles	0%	2%	42%	24%	32%	0%	100%
Speed Reduction Warning Signs	14%	40%	34%	8%	4%	0%	100%
Wide (10 in.) Edgelines	2%	0%	4%	18%	74%	2%	100%

TABLE 15
ENGINEERING MEASURES USED BY SURVEY RESPONDENTS ON HIGH-SPEED, TWO-LANE, HIGHWAY WORK ZONES IN THE PREVIOUS THREE YEARS

Engineering Techniques for Two-Lane Highway Work Zones	All Work Zones	Most Work Zones	Some Work Zones	Occasional/ Unique Situations	Never	No Response	Total
Dynamic Work Zone Speed Limit Signs	0%	0%	6%	22%	70%	2%	100%
Mandatory Reduced Speed Limit only When Workers Present	48%	18%	20%	4%	6%	4%	100%
"Fines Doubled in Work Zones" Signage	0%	2%	12%	60%	24%	2%	100%
Dynamic Speed Feedback Signs	0%	2%	18%	38%	40%	2%	100%
Transverse Rumble Strips at Approach to Work Zone	0%	0%	0%	6%	92%	2%	100%
Converging Bar Pavement Markings (optical speed bars)	0%	0%	12%	44%	42%	2%	100%
Reduction of Lane Width to Encourage Slower Driving	0%	6%	12%	32%	48%	2%	100%
Modified Cone/Barrel Spacing to Encourage Slower Driving	0%	2%	56%	24%	16%	2%	100%
Pace Cars/Pilot Vehicles	10%	32%	34%	14%	8%	2%	100%
Speed Reduction Warning Signs	0%	0%	4%	10%	84%	2%	100%
Wide (10 in.) Edgelines	16%	8%	16%	6%	52%	2%	100%

TABLE 16
ENFORCEMENT MEASURES USED BY SURVEY RESPONDENTS ON FREEWAY AND OTHER MULTILANE DIVIDED HIGHWAY WORK ZONES IN THE PREVIOUS THREE YEARS

Freeway Work Zone Enforcement Techniques	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never	No Response	Count
Police Vehicles in Work Zone—Active Enforcement	2%	16%	52%	26%	0%	4%	100%
Police Vehicles (flashing lights OFF) Present in Work Zone, but Not Issuing Tickets	0%	2%	22%	28%	44%	4%	100%
Police Vehicles (flashing lights ON) Present in Work Zone, but Not Issuing Tickets	2%	12%	24%	24%	34%	4%	100%
Decoy Police Vehicles	0%	0%	0%	18%	78%	4%	100%
Aerial Enforcement	0%	0%	4%	16%	76%	4%	100%
Enhanced/Stealth Enforcement (spotters on overpass or shoulder)	0%	0%	8%	24%	64%	4%	100%
Automated Enforcement/Speed Cameras	0%	0%	6%	6%	84%	4%	100%
Decoy Speed Cameras	0%	0%	0%	2%	94%	4%	100%
Automated Issuance of Written Warnings (non-citation)	0%	0%	2%	4%	90%	4%	100%
Decoy Radar	0%	0%	4%	10%	82%	4%	100%

TABLE 17
ENFORCEMENT MEASURES USED BY SURVEY RESPONDENTS ON TWO-LANE RURAL HIGHWAY WORK ZONES IN THE PREVIOUS THREE YEARS

Two-Lane Rural Highway Work Zone Enforcement Techniques	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never	No Response	Count
Police Vehicles in Work Zone—Active Enforcement	0%	10%	40%	32%	14%	4%	100%
Police Vehicles (flashing lights OFF) Present in Work Zone, but Not Issuing Tickets	0%	2%	18%	24%	52%	4%	100%
Police Vehicles (flashing lights ON) Present in Work Zone, but Not Issuing Tickets	0%	4%	22%	16%	54%	4%	100%
Decoy Police Vehicles	0%	0%	0%	12%	84%	4%	100%
Aerial Enforcement	0%	0%	4%	10%	80%	6%	100%
Enhanced/Stealth Enforcement (spotters on overpass or shoulder)	0%	0%	0%	20%	76%	4%	100%
Automated Enforcement/Speed Cameras	0%	0%	2%	4%	90%	4%	100%
Decoy Speed Cameras	0%	0%	0%	2%	94%	4%	100%
Automated Issuance of Written Warnings (non-citation)	0%	0%	2%	0%	94%	4%	100%
Decoy Radar	0%	0%	4%	2%	90%	4%	100%

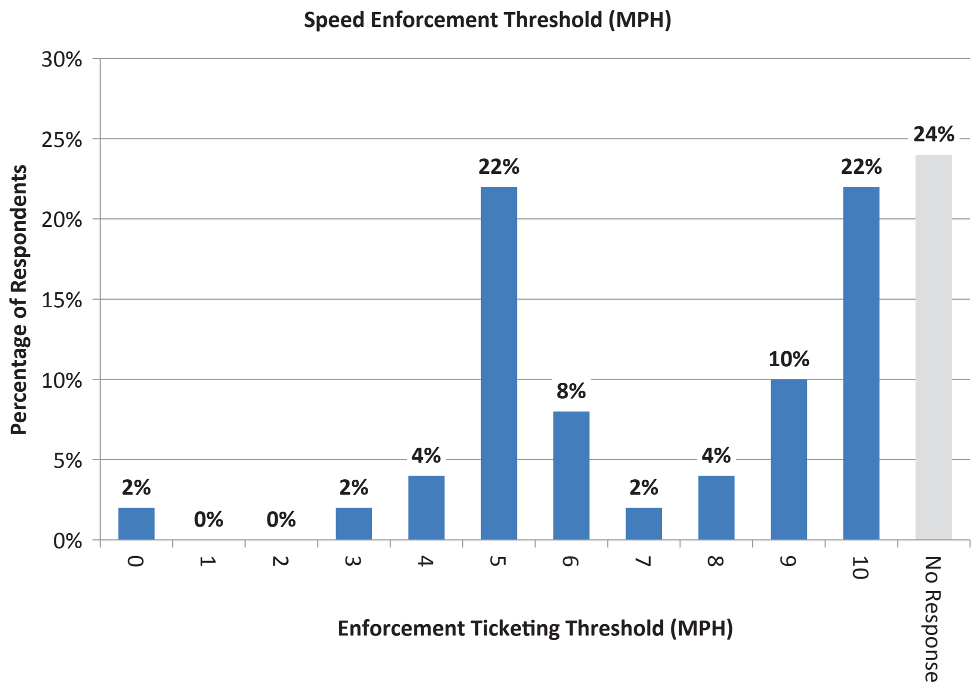


FIGURE 56 Reported law enforcement speeding tolerance/ticketing thresholds.

CHAPTER ELEVEN

SURVEY ON STATE DOT WORK ZONE PUBLIC OUTREACH EFFORTS

In addition to the Engineering and Enforcement survey discussed in chapter ten, an online survey was undertaken to gain an understanding of how U.S. state DOTs are conducting public outreach related to work zone speeding and general work zone safety. An invitation to participate in the survey was distributed to members of the AASHTO Standing Committee on Public Information. Supplemental invitations were made to FHWA Work Zone Peer Exchange participants if their state did not respond to the initial AASHTO survey invitation. Responses were received from DOT officials in 42 U.S. states. The survey instrument is attached as Appendix C and the responses to open-ended questions are tabulated in Appendix D.

The respondents to the Public Information Survey were generally not the same individuals who responded to the Engineering and Enforcement Survey. Typically, the Public Information survey respondents were DOT public information officers or members of their staff.

Most DOTs conduct public outreach on a number of safety-related themes. As indicated in Table 18, the majority of survey respondents indicated that they believe work zone safety is one of the most important safety-related public outreach messages. This contrasts to some degree with the main themes of current traffic safety marketing by NHTSA, which include campaigns on bicycle safety, child car seats, distracted driving, drunk driving, motorcycle safety, older drivers, pedestrian safety, school bus safety, seat belts, speed prevention (not specific to work zones), and teen safety (NHTSA 2015).

As detailed in Table 19, respondents indicated that general statewide work zone safety campaigns are the most frequently used approach. Work zone safety outreach campaigns are also sometimes conducted in conjunction with major construction projects; however, campaigns targeted toward sites with a history of work zone crashes appear to be relatively rare.

Table 20 summarizes the responses regarding the types of media used to communicate work zone public outreach messages. Press releases were mentioned most often, followed by social media such as Twitter and Facebook. Respondents indicated that their agencies make moderate use of radio and television PSAs, driver education materials, and videos posted on the agency's website or YouTube. Paid advertising for work zone safety messages (including television, radio, online, and print advertisements) appears to be relatively rare, and many agencies commented that they have little or no budget for purchasing advertising. Other communication methods mentioned by participants included media events, billboards, transit advertisements (advertisements on the interior or exterior of buses and trains), pump-top placards at gas stations, table tents at restaurants, posters or video displays at highway rest areas, and moving billboards on tractor-trailers.

Most agencies noted that they use similar strategies for small and large media markets, although Arizona DOT reported that they focus on newspapers and websites in the smaller markets, and television and radio in the larger markets. Some respondents commented that their agencies typically schedule news conferences around major construction projects, which typically occur in larger urban areas.

As indicated in Table 21, formal evaluations of the effectiveness of work zone safety campaigns appear to be quite rare, with only two of the 42 respondents indicating that their agency has done an evaluation.

Taken as a whole, the survey response data suggest that agencies are attempting to spread the word about work zone safety through low-cost and no-cost media, and generally lack the resources necessary to conduct work zone safety campaigns on a larger scale. This interpretation is supported by a number of survey comments describing funding constraints. For example, a Missouri DOT respondent observed, "The more a message is seen or heard, the better it is remembered. If a larger advertising budget existed, we could reach more markets with a more frequent message." An Iowa DOT respondent commented, "With budget restrictions our staff and dollars are stretched pretty thin. We have to balance work zone campaigns with all other safety campaigns as well as normal day-to-day communications." Similarly, a Tennessee DOT respondent commented, "One of the biggest challenges is that . . . we do not spend money on advertising. Since there is no dedicated safety funding that would allow us to reach a broader audience through advertising, we must rely on social media, YouTube and our own website, press releases, etc."

By definition, PSAs are unpaid advertisements aired by television and radio stations on behalf of government agencies and nonprofit organizations (FCC 2007). Stations typically air PSAs during unsold advertising time spots. Table 22 summarizes the survey respondents' satisfaction with the quality and quantity of PSA airtime provided by television and radio stations.

Most agencies reported that their work zone safety outreach efforts are primarily scheduled to occur in April during

TABLE 18
PERCEIVED IMPORTANCE OF WORK ZONE SAFETY RELATIVE TO OTHER DOT PUBLIC OUTREACH SUCH AS IMPAIRED DRIVING, MOTORCYCLE SAFETY, PEDESTRIAN SAFETY, AND RAILROAD CROSSING SAFETY

Level	Percent
Very High	36
High	38
Medium	26
Low	0
Very Low	0
No Response	0

National Work Zone Awareness Week, an annual event sponsored by FHWA. Several respondents mentioned the need for continued reminders throughout the construction season. Some agencies based in colder climates noted that in the late fall they conduct additional safety campaigns focusing on winter road maintenance.

Survey participants were asked to rate their perceptions of the overall level of compliance with work zone speed limits in their respective areas. As shown in Table 23, the majority of respondents rated compliance only “good” or “fair” and 14% of respondents described compliance as “poor.”

Survey respondents had definite views about the themes that would be included when creating new work zone safety outreach campaigns. As shown in Table 24, protecting worker safety was by far the most highly ranked theme, followed by driver safety and reducing distractions. Some respondents commented on the importance of telling the stories of individual workers, drivers, and passengers involved in work zone casualties. Some participants also commented on the difficulties of selecting work zone messages that are appropriate for all types of work zones. For example, a New Hampshire DOT respondent commented, “Work zones come in many different sizes and complexity. [It is] difficult to come up with a solution that can equally be applicable to all work zones. Interstate speed requirement and safety is vastly different than on a local two lane roadway.” A related perspective is evident in an Oregon DOT respondent’s comment, “Everyone knows they should slow down and be alert in work zones, most people intend to do the right thing, but they still don’t do it consistently. People just tend to be very self-involved when they are in their cars.” Another perspective was offered by an Indiana DOT respondent, “Our focus has moved away from speeding to behaviors that crash statistics have shown lead to work zone crashes and fatalities. These include following too closely, failure to yield, and improper lane change.”

In summary, the survey findings indicate that all or nearly all state DOTs are engaged in work zone safety outreach efforts. Protecting worker and driver safety were viewed as the most important messages. Because of staffing and funding constraints, agencies generally rely on low-cost or no-cost

TABLE 19
RESPONSES TO “WHAT KINDS OF WORK ZONE SAFETY CAMPAIGNS DO YOU CONDUCT?” (multiple responses allowed)

Campaigns	Percent
General statewide campaigns	94
Campaigns targeted toward specific major construction projects	58
Campaigns targeted toward specific smaller construction projects	11
Campaigns targeted toward geographic areas with a history of work zone crashes	11
Other	11

TABLE 20
MEDIA TYPICALLY USED BY STATE DOTS FOR WORK ZONE PUBLIC OUTREACH

Type of Media	Very Often	Often	Occasionally	Rarely	Never	No Response
Press Releases	52%	33%	12%	0%	0%	2%
Twitter	29%	33%	10%	14%	5%	10%
Facebook	31%	29%	12%	12%	7%	10%
Driver Education Materials and Handbooks	12%	29%	19%	24%	2%	14%
Radio PSAs	10%	29%	26%	12%	7%	17%
Videos on YouTube	10%	29%	21%	14%	10%	17%
TV Public Service Announcements (PSAs)	5%	31%	29%	14%	10%	12%
Videos on Agency Website	7%	26%	21%	17%	7%	21%
Paid Advertising on Radio	10%	17%	26%	24%	12%	12%
Print PSAs	10%	14%	31%	21%	7%	17%
Paid Advertising on TV	2%	14%	17%	29%	24%	14%
Paid Web Advertising	5%	10%	10%	29%	26%	21%
Paid Print Advertising	0%	7%	14%	45%	17%	17%

TABLE 21
PROPORTION OF AGENCIES THAT HAVE CONDUCTED FORMAL EVALUATIONS OF THE EFFECTIVENESS OF THEIR WORK ZONE PUBLIC INFORMATION CAMPAIGNS

Effectiveness Evaluated	Number	%
Yes	2	5
No	37	88
No Response	3	7

TABLE 22
RESPONDENT PERCEPTIONS REGARDING THE QUALITY AND QUANTITY OF PSA AIRTIME PROVIDED BY TELEVISION AND RADIO STATIONS

Quality and Quantity of PSA Airtime	TV	Radio
Excellent	2%	10%
Very Good	33%	24%
Good	38%	48%
Fair	10%	7%
Poor	5%	5%
No Response	12%	7%

TABLE 23
RESPONSES TO "OVERALL, HOW GOOD IS PUBLIC COMPLIANCE WITH WORK ZONE SPEED LIMITS IN YOUR AREA, IN YOUR OPINION?"

Public Compliance	Percent
Excellent	0
Very Good	5
Good	40
Fair	36
Poor	14
No Response	5

techniques such as press releases, social media, unpaid PSAs, and their own websites. Only two of the 42 respondents reported that their agencies have conducted an evaluation of their campaigns' effectiveness. Respondents often expressed doubt about the adequacy of the scope of these efforts and commented on the difficulty of changing driver behavior in the absence of additional funding for advertising purchases. Some officials expressed interest in establishing a coordinated national work zone safety campaign.

TABLE 24
IMPORTANCE OF VARIOUS THEMES WHEN CREATING NEW WORK ZONE SAFETY OUTREACH CAMPAIGNS

Theme	Very High	High	Medium	Low	Very Low	No Response
Protecting the Safety of Workers	74%	17%	2%	0%	0%	7%
Protecting the Safety of Drivers	57%	33%	2%	0%	0%	7%
Reducing Distractions While in Work Zone	60%	26%	7%	0%	0%	7%
How Often Work Zone Fatalities Occur	43%	43%	5%	2%	0%	7%
Paying Attention to Flaggers	40%	43%	7%	2%	0%	7%
Reducing Speed While in Work Zone	50%	31%	12%	0%	0%	7%
How Often Work Zone Crashes Occur	31%	48%	12%	2%	0%	7%
Paying Attention to Work Zone Signs	43%	36%	12%	2%	0%	7%
Protecting the Safety of Passengers	43%	33%	12%	2%	0%	10%
Expecting Delays/Being Patient	36%	36%	21%	0%	0%	7%
Penalties For Work Zone Traffic Violations	19%	36%	29%	10%	0%	7%

CHAPTER TWELVE

CONCLUSIONS

Work zone crashes are a serious problem in the United States and globally. In 2012, there were 547 reported fatalities in work zones in the United States, and speeding was cited as a contributing factor in 35% of them. An average of 19 highway workers per year was killed by traffic in U.S. work zones in the period from 2003 to 2010. For each fatality there are many more injury and property-damage crashes. In addition, it is likely that work zone crashes are underreported in the United States owing to coding errors on police reports and (in some states) exclusion of back-of-queue crashes that occur upstream of the ROAD WORK AHEAD sign. The individual stories behind these statistics sometimes spark efforts to improve work zone safety. For example, the speeding-related death of a pregnant 18-year-old traffic control person in Saskatchewan received extensive media coverage that resulted in significant technical, contractual, and statutory changes aimed at improving work zone speed management and safety (Case Example 1 provides more details).

Although there is some general agreement about the engineering factors to be considered when setting work zone speed limits, entrenched attitudes about speeding can cause difficulty in achieving compliance. In most U.S. jurisdictions, the de facto speed limit is higher than the number posted on regulatory signs. An agency survey conducted for this synthesis report indicates that using a 5-point scale from "excellent" to "poor," most state DOTs rated compliance with work zone speed limits only "good" or "fair." A second survey indicated that most states tolerate speeding of at least 5 mph above the posted limit; in many states, speeding of 10 mph or more is tolerated. Decades of leniency by police and the courts have resulted in a situation where drivers expect that small-to-moderate exceedances are unlikely to result in a citation (excessive speeding is generally perceived more negatively; however, this term is often used imprecisely).

A number of studies have found that in the absence of concentrated enforcement or special speed management devices, drivers voluntarily reduce their speeds by about 5 mph when they encounter a work zone. This raises several issues:

- In many cases, the majority of drivers are speeding by more than 5 mph upstream of the work zone and, as a result, the difference between the speed limit and the actual running speed will increase if the speed limit posted in the work zone drops by more than 5 mph compared with the upstream speed limit.
- Interviews conducted for this synthesis report and a review of the content of work zone public service announcements produced by highway agencies indicate that in many cases agencies (and construction personnel) want drivers to slow down considerably more than 5 mph. This implies a desire for drivers to adhere to speed limits more strictly in work zones than is customary in non-construction situations.
- Many highway agencies are concerned that artificially-low work zone speed limits could increase the speed difference between the slowest (most compliant) drivers and the fastest (least compliant) drivers, potentially increasing crashes. This concern is supported by the U.S. *Manual on Uniform Traffic Control Devices* (*MUTCD*) and 1990s field research. Two recent studies suggest more complicated interactions between posted reductions, work zone site conditions, and speed variation. Further research on relationships between speed limit reductions and speed variation in work zones may be necessary to clarify this issue.
- The effect of "voluntary" reduction needs to be considered when developing public outreach campaigns, to make it clear to viewers and listeners that "slow down in work zones" means slowing down to (approximately) the speed limit, not just slowing down by about 5 mph.

A number of speed management techniques and devices have been tested in the field as part of ongoing efforts to improve work zone speed limit compliance. Table 25 summarizes the characteristics of 28 techniques and summarizes the available information about each technique's effectiveness in reducing traffic speeds (as an isolated, single measure). Some are widely used, whereas others have been deployed only in small-scale tests. Several newer techniques (such as the Emergency Flasher Traffic Control Device) show promising results that likely warrant further research and field evaluation.

Interviews with practitioners and formal field evaluations both indicate that traditional "human" law enforcement is reasonably effective at achieving compliance with work zone speed limits—especially in close proximity to a conspicuous enforcement vehicle—but the cost and scarcity of law enforcement resources appears to be a limiting factor in nearly all jurisdictions. Other highly-effective techniques tend to be controversial. For example, experience in a handful of states including Illinois and Maryland indicates that automated

TABLE 25
OVERVIEW OF WORK ZONE SPEED MANAGEMENT TECHNIQUES

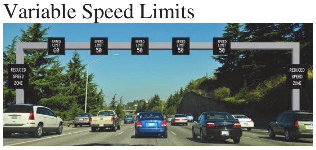
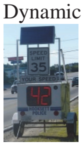
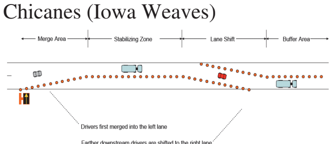
METHOD	SPEED REDUCTION	NOTES
Engineering Technologies		
Increased Fines for Work Zone Speeding  	Low (See notes)	Although most U.S. jurisdictions increase (or double) the traffic fine if the violation occurs in a work zone, there is little evidence that this is an effective deterrent to work zone speeding, except perhaps when combined with a high level of enforcement.
Changeable Speed Limit Signs  Photo: Michigan DOT	See notes	In jurisdictions that reduce the speed limit when workers are present, it is more convenient to change the speed limit if a two-digit electronic panel is used in place of the usual speed limit digits. Only two studies have explored compliance rates. Under free-flowing traffic conditions, CSL compliance was slightly better than with ordinary signage, perhaps due to greater conspicuity of the CSL signs at night.
Variable Speed Limits 	Site-Specific (See notes)	Systems that modify the speed limit in response to work zone traffic conditions have been used in a small number of locations, mainly to reduce the risk of back-of-queue crashes. The overall effectiveness of these systems in limiting speed through the work zone is dependent on a number of factors, making assessment difficult.
Dynamic Speed Feedback Signs  Photo: Wikimedia Commons	Low to Moderate (1 to 8 mph)	Studies of the effectiveness of dynamic speed feedback signs have reported speed reduction results ranging from 1 to 8 mph. Field experience suggests that drivers begin to disregard the signs if they are not accompanied by enforcement.
Portable Changeable Message Signs (PCMS) with Vehicle-Activated Speed Messages  	Low to Moderate (Up to 7 mph)	This technique involves equipping a standard PCMS with a radar unit programmed to display anti-speeding text when drivers approach the sign at a speed exceeding a pre-set threshold (typically 3 mph). Speed reduction of 7 mph near the sign was reported in a 2009 study, but the reduction did not extend into the work area itself, perhaps due to site conditions and the distance to the active work site.
PCMS with General Speed Safety Messages  	Low to Moderate (1 to 4 mph)	1990s studies found that this technique resulted in a speed reduction for all types of vehicles, but in more recent studies relatively small (1 to 4 mph) reductions were typically observed.
Augmented Enforcement System  	Perhaps Moderate (See notes)	Experimental system combined speed camera and PCMS to provide driver feedback with plate number and speed (if over speed limit). System could also provide remote speeder alerts to nearby police or workers. Significant reductions in percent of speeding vehicles were found in tests at a rural California site, but some reduction may be due to novelty effect. May not be suitable for high-volume freeways. Potentially adaptable to provide positive feedback to non-speeders.
Decoy Radar (also called Drone Radar) 	Low to Moderate (See notes)	Unattended systems can emit a decoy radar signal intended to slow drivers who have a radar detector. In early studies, average speed change was about 2 mph for the traffic stream as a whole, with reductions of up to 8 mph for vehicles with radar-detectors. If the unit is left in one place too long, people who drive the route regularly soon realize it is not a police vehicle. Interviews with practitioners suggest effectiveness may be declining.

TABLE 25
(*continued*)

METHOD	SPEED REDUCTION	NOTES
Engineering Techniques		
Physical Reduction of Lane Width 	Varies (See notes)	Observed speed reductions associated with lane width reduction vary depending on site conditions. A 2005 study suggested that reducing freeway lane width from 12 feet to 11 feet would decrease free-flow speed by 4.4 mph, while a reduction to 10 feet would reduce free-flow speed by 10 mph. Effects on safety are unclear; a 1984 study of 9-foot lanes on a parkway near Washington, DC showed an increase in crash rates but a decrease in crash severity. Lane narrowing may require additional coordination for routing over-width trucks.
Temporary Transverse Rumble Strips 	Varies (See notes)	Most frequently used at approach to flagger stations during two-way one-lane operations, but Texas DOT is experimenting with their use at freeway work zone approaches. Academic studies and practitioner experiences point to a wide range of results from temporary transverse rumble strip applications, in part because there are many possible combinations of dimensions, colors, materials, and spacing. Generally reductions in speeds at approaches to flagger stations have been around 2 mph, but speed reductions of as much as 8 mph have been reported in exceptional cases. Appears to have more effect on trucks than on passenger vehicles. Most practitioners view the strips primarily as a method for alerting inattentive drivers to the approaching work zone. A 2013 Saskatchewan survey found high driver acceptance.
Emergency Flasher Traffic Control Device (EFTCD) 	Moderate to High (Perhaps 2 to 5 mph)	The EFTCD simply involves asking drivers to turn on their four-way flashers (hazard lights) to increase visibility of the back-of-queue as they stop at flagger stations on two-way one-lane work zones. This requires an additional traffic control person at each flagger station. Testing at 3 rural highway work zones in Kansas showed promising results with 2.5 to 5 mph speed reductions compared to the without-EFTCD condition, measured 400-500 feet upstream of the flagger station. Sample sizes were small and additional field evaluation may be necessary to generalize these results.
Chicanes (Iowa Weaves)  	High (Varies depending on geometry)	Chicane designs force a reduction in speed by requiring drivers to make two or more lateral shifts as they approach the work zone. Currently this technique is used in 4 U.S. states (primarily for low-volume rural freeways). Application appears to be more widespread in Europe. The amount of speed reduction is a function of the geometry, for example a Swedish double-chicane design was shown to achieve stepped reduction to a 30 mph running speed at a critical point in the chicane. Design details including night visibility are important for the chicane's safety.
Mobile Barrier Systems  Photo: Caltrans	Possible speed increase (See Notes)	Tractor-trailer mounted mobile barrier systems provide lateral protection to isolate workers from live lanes. Work activity area length is limited to 40-100 feet, but some models allow the barrier vehicle to move as work progresses. A recent Oregon study showed *increased* speeds in the lane adjacent to the work operation (compared to standard work zones delineated with cones); authors of the study concluded mobility was improved while protecting maintenance workers from live traffic.

(*continued on next page*)

TABLE 25
(*continued*)

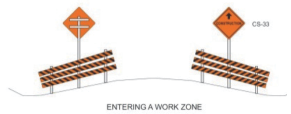
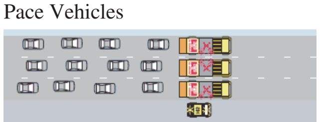
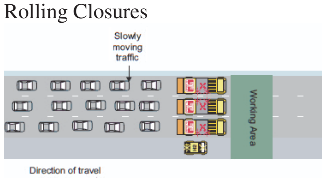
METHOD	SPEED REDUCTION	NOTES
Gateway Assemblies  Drawing: Saskatchewan Ministry of Highways & Infrastructure	Unknown	Gateway assemblies use barricade-like signage mounted on roadway side-slopes to increase the visibility of the work zone approach. They are also said to create a sense that the driver is entering a more constrained environment. No studies have been found that evaluate this relatively new low-cost technique.
Optical Speed Bars and Chevron Pavement Markings 	Inconclusive	Optical speed bars and chevron pavement markings are specialized pavement marking treatments that consist of a series of transverse marking whose distance decreases progressively to create the illusion that the driver is speeding up. Only one study has examined their application in work zones; speed reduction was small, possibly due to poor contrast with the pavement surface. Studies of *permanent* installations show conflicting results.
Sequential Warning Lights  https://www.youtube.com/watch?v=C5-9eWeeRSo	Very Low	Primarily intended to draw attention to merging tapers during night driving. Possible slight speed reduction as a secondary effect.
Operational Techniques		
Pilot Vehicles 	High (Varies depending on pilot vehicle speed)	In the U.S., pilot vehicle operations are typically used for two-way, one-lane operations in locations where flaggers cannot see each other. In other countries, notably Australia, they are also used as a speed management technique. Vehicles at the head of the platoon cannot exceed the speed of the pace vehicle; late-arriving vehicles may go faster as they catch up with the rest of the platoon.
Pace Vehicles  Drawing: British Traffic Signs Manual	High (Varies depending on pilot vehicle speed)	Pace vehicles can be used to control traffic speeds on multilane facilities. A minimum of one vehicle per lane is required for each platoon, and platoons must be dispatched frequently enough that high-speed vehicles arrive at the back of the platoon before it reaches the work zone. A 2005 Canadian study recommended the use of pace vehicles in situations where workers must be very close to freeway traffic and barriers cannot be provided.
Rolling Closures  Drawing: British Traffic Signs Manual	High (Varies depending on pilot vehicle speed)	Rolling closures are a special case of the use of pace vehicles. They are typically used to create a “working window” when a freeway is clear of all traffic for very short duration operations such as setting girders or clearing debris. Details of the operation are critical to safety. In addition to the pace vehicles for the traffic lanes, one or more vehicles may be required to prevent traffic from passing on the shoulder. A monitor vehicle is also required. Some sources contemplate freeway speed reductions to as little as 10 mph; others suggest 50 mph as a more realistic target in rural situations.
Flagging for Speed Reduction  Photo: Transports Québec	Moderate to High (5 to 10 mph)	A study in the 1980s indicated that flaggers who were displaying the SLOW sign, making the slow-down hand gesture, *and positioned near a speed limit sign* could reduce speeds by 5 to 10 mph. Concerns about worker safety and labor costs appear to have resulted in reduced use of this technique in recent years.

TABLE 25
(*continued*)

METHOD	SPEED REDUCTION	NOTES
Traditional "Human" Enforcement Techniques		
Single-Vehicle Roving Patrols	Moderate (2 to 5 mph)	Limited space within the work zone may result in difficulty finding locations where it is safe to intercept violators and then get back into traffic, especially in long work zones.
Single-Vehicle Visible Upstream Presence	High (4 to 12 mph)	Police vehicle positioned at work zone approach reminds drivers to slow down as they reach the back of queue or enter the work zone. From this position it is generally not possible to intercept speeders (except perhaps to go after extreme violators). Speed reductions may not be sustained throughout the work zone.
Multi-Vehicle Enforcement (Enforcement Packs)	Uncertain, presumed high.	One officer observes traffic, others pull speeders over downstream of the work zone. In some cases the observer also provides upstream presence to encourage slowing at the back of queue or work zone approach. In other cases the observer is hidden on a work vehicle or overpass. No studies were found evaluating the speed reductions associated with these techniques.
Automated Speed Enforcement (also called Speed Cameras or Speed Photo Enforcement)		
Single-Point Automated Speed Enforcement	Moderate to High (3 to 8 mph)	Extensively used for work zone enforcement in Illinois and Maryland, some use in Oregon. Prohibited by statute in some states. European experience indicates that automated enforcement is one of the most effective ways to reduce work zone speeds and improve safety. Abrupt speed changes near cameras may reduce work zone capacity.
Point-to-Point Automated Enforcement	High (Most traffic within ±3 mph of speed limit in European studies)	Widely used in United Kingdom and continental Europe; no U.S. deployments to date. Requires drivers to observe limit throughout the entire work zone (not just near speed cameras). High compliance with speed limits reported. Also reduces speed variation and abrupt speed changes near cameras, resulting in safety and capacity benefits.
Public Outreach & Education		
Programmatic Work Zone Safety Campaigns	Unknown	In most jurisdictions the scope of outreach is quite limited due to budget constraints and conflicting priorities.
Project-Specific Campaigns	Unknown	Some agencies include reminders about proper work zone behavior in press releases concerning project-level closures and work progress.
Driver Education Materials & Programs	Unknown	Some states discuss work zone speeding in driver manuals, others do not.

enforcement substantially reduces work zone speeding, but automated enforcement is statutorily prohibited in several states. In Europe, automated enforcement using the point-to-point method has been shown to achieve very high compliance with work zone speed limits and substantial safety benefits; however, to date no point-to-point deployments have been reported in the United States. Chicanes (work zone layouts that incorporate a lane shift designed to slow traffic) such as the Iowa Weave have also been shown to be effective at reducing speeding in lower-volume work zones, but currently they are only used in a small number of states (generally in low-volume situations). Pace vehicles are routinely used in Ontario (Canada) to control traffic speeds during freeway paving operations where workers are in close proximity to high-speed traffic; however, in the United States the use of pace vehicles currently appears to be limited to rolling closures. The common thread linking these techniques is that they give the driver little choice but to comply with the work zone speed limit.

The need for speed reduction is partially a result of the dynamic nature of the work zone driving environment, which often requires high cognitive effort for the driver. To some extent, each speed management treatment deals with a different part of the work zone driving process:

- **Public outreach** (such as radio work zone safety campaigns or project-specific press releases) provides pre-trip information that explains why speed reduction is necessary and requests the public's cooperation. To be effective, the message must reach a sufficient number of drivers.

- **Upstream treatments** (such as gateway assemblies, transverse rumble strips, speed feedback displays, and police vehicles at the work zone approach) remind drivers that they are approaching an area where speed reduction is required.
- **Buffer area and activity area treatments** (such as automated enforcement using the average speed method, reduced lane width, or pace vehicles) help ensure that drivers continue their speed reduction throughout the work zone.
- **Downstream enforcement** intercepts speed violators observed in the work zone at a location where there is sufficient space for police operations to be carried out safely.
- **Post-work zone treatments** (which have received limited research attention) could potentially provide positive feedback to thank drivers who complied with the work zone speed limit. For example, the Augmented Enforcement System tested in California could potentially be adapted to this purpose. Such an approach would be consistent with recommendations in the Toward Zero Deaths National Strategy, which notes the importance of building on knowledge gained though the social sciences to incentivize cooperative behavior in addition to penalizing irresponsible behavior.

All (or nearly all) U.S. state DOTs conduct public outreach campaigns that are intended to reduce work zone speeding and improve overall work zone safety; however, agencies surveyed for this synthesis project often indicated that they have limited budgets for paid advertising. Consequently, most agencies appear to be relying on low-cost or no-cost media such as press conferences, press releases, Facebook, and Twitter for work zone safety communications. State driver handbooks and related educational materials vary considerably in the extent to which they address work zone speeding (and work zone safety in general).

Most U.S. highway agencies produce new work zone safety public service announcements (PSAs) on a regular basis; however, only two of the 42 responding agencies indicated that they have attempted to assess the effectiveness of their campaigns. Currently, the majority of state DOTs are producing their own individual PSAs, but very little of the content is state-specific. This suggests opportunities for DOTs to pool their work zone safety PSA production efforts, which might allow some resources to be redirected toward wider distribution of the resulting videos and radio spots.

Many agencies post their PSAs on YouTube, but view rates are generally quite low. Videos that feature workers doing their jobs and asking the driver to "help keep us safe" appear to be the most appealing to YouTube viewers; this is consistent with social science research indicating that cooperation is more likely if individuals perceive that an authority is acting based on collective interests rather than its own self-interest. On the basis of the limited information available, work zone videos with positive themes (benefits of staying safe) appear to be more appealing to YouTube viewers than those with negative themes (consequences of unsafe behavior).

Further research is necessary to clarify whether the PSAs are having the intended outcome of reducing speeding and other inappropriate behavior in work zones. Current U.S. work zone PSAs often attempt to compress a large amount of work zone driving advice into a timeframe that is typically very short (e.g., 30 seconds). Additional research is necessary to determine whether this approach should continue or if it would be more effective to focus the message more narrowly and provide drivers with specific speed reduction targets. It is also unclear whether the existing practice of relying on unpaid work zone PSA placements generates sufficient repetition to achieve behavioral changes.

Many highway agencies in the United States are subject to internal and external policy constraints, budgetary limitations, and risk aversion. In some cases, these issues preclude the use of certain work zone speed management techniques, particularly those that are controversial. Therefore, many agencies have taken the approach of combining several project-level work zone speed management techniques. A small number of studies have reviewed the effectiveness of combining engineering, enforcement, and/or outreach. Some combinations that have proven more effective than individual techniques include:

- Florida's Motorist Awareness System—a series of signs and feedback displays at the approach to a work zone.
- Police enforcement combined with a speed feedback display.
- Police enforcement combined with a Variable Message Sign displaying an enforcement message.
- Portable changeable message signs mounted on work equipment displaying work zone safety messages, combined with speed feedback displays.
- Chicanes combined with electronic signage.

Work zone driving conditions can change rapidly depending on the traffic volume, the number of available lanes, and the nature of the work operation. As a result, it may be necessary to adjust work zone traffic management tactics in real time. For example, during stable flow conditions some agencies find it desirable to deploy law enforcement personnel within the work zone to ensure that drivers respect the speed limit as they pass by the workforce. Under unstable flow conditions when traffic is backed up, it may be more effective to move the law enforcement upstream to encourage drivers to slow down gradually as they approach the back of the queue. Similarly, it may be appropriate to blank out devices such as speed feedback displays and portable changeable message signs displaying anti-speeding messages when the running speed drops below the speed limit, so that drivers are not presented with unnecessary information.

Although there is no universal solution to the work zone speed management problem, both the Capability–Maturity Model developed for the SHRP 2 research program and the Toward Zero Deaths National Safety Strategy discuss the importance of an ongoing, integrated, strategic approach to highway operations and safety. Implementation is likely to require significant coordination across functional areas of highway agencies, such as strong links between engineering officials and public outreach officials. Individual highway construction projects can be viewed as the means to implement a long-term, agencywide, or regionwide work zone speed reduction strategy aimed at overcoming the entrenched driver behaviors that compromise safety for both workers and road users. Strengthening work zone public outreach efforts and more closely linking them to relevant construction projects is likely to be an important step in this process. Additional work is also necessary to document the benefits of proven techniques (such as automated enforcement) and resolve actual or perceived concerns that have inhibited their more widespread use. Some aspects of work zone speed management could potentially be addressed through future multi-state efforts, such as greater coordination of work zone public outreach campaigns on a national or regional basis.

GLOSSARY

A number of the terms commonly used in speed literature have formal legal or mathematical definitions. For brevity, the definitions provided in this document are limited to two sentences. These definitions are intended to serve as a quick conceptual reminder and may not capture all of the nuances and caveats associated with certain terms. Consequently, other references may use or define these terms somewhat differently than this publication.

85th Percentile Speed: The speed at or below which 85% of vehicles travel on a specific roadway segment.

Active law enforcement: Police officers are present in or near the work zone with the intent of identifying and pulling over (intercepting) violators.

Advisory speed limit: A *recommended* (but not mandatory) speed for a roadway segment. In the United States advisory speed limits are marked using black-on-orange signs in work zones and black-on-yellow signs elsewhere.

Automated speed enforcement (ASE): A system for detecting speeding vehicles and issuing citations to the registered owner of the vehicle by mail, without pulling over or intercepting the vehicle.

Casualty: Any injury or fatality.

Chicane: A roadway segment designed to limit vehicle speeds by requiring vehicles to navigate two or more relatively sharp horizontal curves; an S curve.

Contraflow: A lane arrangement where traffic operates on the opposite of its usual side of the roadway; for example, a work zone that uses a median crossover followed by two-way operation on one side of a divided highway.

Design speed: The speed established for a specific roadway segment as part of the geometric design process.

Excessive speed: Exceeding the posted or statutory legal speed limit.

Free-flow speed: The speed that vehicles on a roadway segment tend to travel when the traffic volume is low, law enforcement is not present, and there are no adverse weather conditions.

Inappropriate speed: Driving too fast for the prevailing road and traffic conditions, but within the posted or statutory limits.

Mean (average) speed: A measure of the typical speeds on a roadway segment, computed by summing the instantaneous speeds of individual vehicles and dividing by the number of vehicles observed.

Median (50th percentile) speed: A measure of the typical speeds on a roadway segment, computed by listing the instantaneous speeds of individual vehicles in rank order (lowest to highest) and finding the value that is halfway down the list.

Multi-modal distribution: A statistical distribution with two or more clusters of frequently observed values.

Normal distribution: A bell-shaped statistical distribution that is symmetrical around the mean value.

Objective safety: The expected number of crashes or casualties (by type and severity) or (in some studies) the actual number of crashes observed over a multi-year period.

Ordinary speed limit: The speed limit without road work; the pre-construction speed limit.

Overtaking (or passing): Changing lanes to move past a slower vehicle.

Passive law enforcement: Police officers are visibly present in or near the work zone to remind drivers to slow down, but are not favorably positioned for pulling over (intercepting) violators.

Pilot car (or pilot vehicle): A designated vehicle that leads a platoon of other traffic through the work zone.

Posted speed limit: The maximum lawful vehicle speed for a roadway segment as displayed on a regulatory sign. (In the United States regulatory speed limits are displayed on white-on-black signs.)

Skew distribution: A statistical distribution that is not a normal distribution, but instead tends to be clustered at values above or below the mean.

Speed variance: A measure of how much a set of vehicle speed observations is spread out; specifically the square of the standard deviation. A variance of zero indicates that all vehicles in the traffic stream are travelling at the same speed.

Speed variation: The extent to which all vehicles on a roadway segment travel at different speeds. A low value indicates that all drivers choose similar speeds; a high value indicates that individual drivers select a wide range of speeds.

Standard deviation: A statistical measure of the amount of variation from the average. A low standard deviation indicates that the data points tend to be very close to the mean; a high standard deviation indicates that the data points are spread out over a large range of values.

Statutory speed limit: The maximum lawful vehicle speed for a category of roadways (such as freeways, rural two-lane highways, or residential streets), as defined in state, provincial, or local laws.

Strategy: An overall plan to achieve an objective; including the decision making that leads to tactical execution.

Subjective safety: The feeling or perception of safety; for example, how people subjectively experience traffic crash risks.

Tactic: The means and methods used to accomplish an objective; an element of a strategy.

Traffic calming: Any set of physical or visual devices (except traffic signs alone) that is designed to reduce traffic speeds and encourage greater driver awareness of other road users.

Two-way one-lane operation: A lane arrangement where only one lane is available for traffic and the lane is time-shared between opposing directions. In the United States, this is also called a flagging operation; in the United Kingdom, it is known as "shuttle working."

Unstable traffic flow: Traffic conditions characterized by frequent speed changes, commonly referred to as stop-and-go driving.

Work zone speed limit: A temporary speed limit imposed during roadway construction or maintenance.

NOTE ON THE USE OF METRIC UNITS IN THIS SYNTHESIS REPORT

This document summarizes work zone speed management research and agency practices from various countries. When metric units were used in the original source material, U.S. equivalents have been included in parentheses in this report. When values quoted in source material appear to be approximations (such as speeds rounded to the nearest 10 km/h), the equivalencies are also approximated, in most cases by making an exact conversion and then rounding to the nearest 5 mph.

Example 1: Using radar observations, Researcher A determined that median work zone speed decreased by 9.9 km/h (6.2 mph) when treatment X was deployed.

Example 2: In an interview, Policymaker B stated that in her jurisdiction the use of enforcement technique Y typically slows traffic by 10 to 20 km/h (5 to 10 mph).

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APPENDIX A

Engineering and Enforcement Survey Instrument

Survey Questionnaire: Work Zone Speed Management

The National Cooperative Highway Research Program (NCHRP) has contracted with the University of Wisconsin Traffic Operations & Safety Laboratory (TOPS Lab) to prepare a *Synthesis of Practice on Active & Passive Methods of Speed Control in Work Zones.* Our work covers speed management for work zones on freeways, multi-lane divided highways, and high-speed two-lane rural highways; work zones on urban streets and low-speed rural roads are not included in this project.

This survey covers engineering and enforcement-oriented techniques for managing work zone speeds.

Please take a few minutes to complete this survey (or forward it to the relevant subject-matter expert in your agency). The information you provide will help the research team, NCHRP, and Synthesis readers get a better understanding of which work zone speed management methods are in common use, what is working, what is not working, and where there is a need for additional technical and policy guidance.

Thank you for your participation!

>>

Agency Name

Agency Type

- Headquarters of a state/provincial transportation department
- Headquarters of a tollway authority or toll highway operator
- Region or district of a state/provincial/regional transportation department
- Region or district of a tollway authority or toll highway operator
- Federal land management agency
- County, municipal or tribal public works agency
- Regional transportation authority
- Headquarters of a state/provincial/regional police agency
- Region or district of a state/provincial/regional police agency
- County/municipal police department
- Public utility or railroad
- Highway construction contractor
- Other. Specify type of agency

Location/area served

Country

- United States
- Canada
- Other: Specify Country

Name of the person completing this survey

Telephone number

Email address

May we contact you with follow-up questions?

- Yes
- No

<< >>

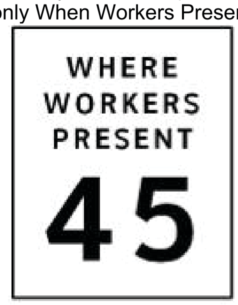
For work zones on **freeways and other multi-lane divided highways** please identify the engineering-oriented work zone speed management techniques that your agency has used in the past 3 years:

How often is it used in your jurisdiction?

Dynamic WZ Speed Limit Signs

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Dynamic WZ Speed Limit Signs					

Mandatory Reduced Speed Limit only When Workers Present



	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Mandatory Reduced Speed Limit only When Workers Present					

FINES DOUBLE IN WORK ZONES

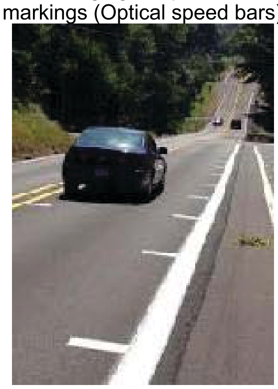
	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
FINES DOUBLE IN WORK ZONES					

Dynamic speed feedback signs

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Dynamic speed feedback signs					

How often is it used in your jurisdiction?

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Transverse rumble strips at approach to work zone 	○	○	○	○	○

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Converging bar pavement markings (Optical speed bars) 	○	○	○	○	○

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Reduction of lane width to encourage slower driving 	○	○	○	○	○

How often is it used in your jurisdiction?

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never

Modified cone/barrel spacing to encourage slower driving

All Work Zones | Most Work Zones | Some Work Zones | Occasional/Unique Situations | Never

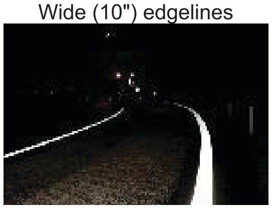
Pace cars/pilot vehicles

All Work Zones | Most Work Zones | Some Work Zones | Occasional/Unique Situations | Never

Speed reduction warning signs

All Work Zones | Most Work Zones | Some Work Zones | Occasional/Unique Situations | Never

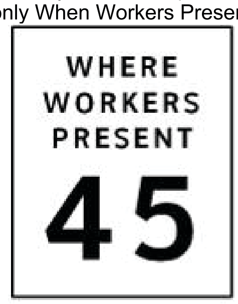
Wide (10") edgelines



Are there other engineering-related work zone speed management strategies you have deployed on **freeways or other multi-lane highways**? if so, please briefly describe.

For work zones on **high-speed two-lane rural highways** please identify the engineering-oriented work zone speed management techniques that your agency has used in the past 3 years:

How often is it used in your jurisdiction?

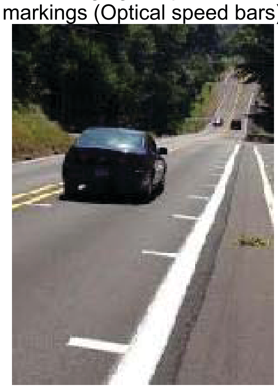
	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Dynamic WZ Speed Limit Signs 	○	○	○	○	○
Mandatory Reduced Speed Limit only When Workers Present 	○	○	○	○	○
FINES DOUBLE IN WORK ZONES 	○	○	○	○	○

How often is it used in your jurisdiction?

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Dynamic speed feedback signs	○	○	○	○	○

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Transverse rumble strips at approach to work zone	○	○	○	○	○

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Converging bar pavement markings (Optical speed bars)	○	○	○	○	○



	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Reduction of lane width to encourage slower driving	○	○	○	○	○

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
	○	○	○	○	○

How often is it used in your jurisdiction?

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Modified cone/barrel spacing to encourage slower driving	○	○	○	○	○

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Pace cars/pilot vehicles	○	○	○	○	○

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Speed reduction warning signs	○	○	○	○	○

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Wide (10") edgelines	○	○	○	○	○

Are there other engineering-related work zone speed management strategies you have deployed on **high-speed two-lane rural highways**? if so, please briefly describe.

<< >>

For work zones on **freeways and other multi-lane divided highways** please identify the enforcement-oriented work zone speed management techniques that your agency has used in the past 3 years:

How often is it used in your jurisdiction?

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Police vehicles in work zone - active enforcement					
Police vehicles (Flashing Lights **OFF**) present in work zone but not issuing tickets					
Police vehicles (Flashing Lights **ON**) present in work zone but not issuing tickets					
Decoy police vehicles					
Aerial enforcement					
Enhanced/stealth enforcement (spotters on overpass or shoulder)					
Automated Enforcement/ Speed Cameras					
Decoy Speed Cameras					
Automated Issuance of Written Warnings (non-citation)					
Drone radar					
	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never

Are there other enforcement-related work zone speed management strategies you have deployed on **freeways or other multi-lane highways**? If so, please briefly describe.

For work zones on **high-speed two-lane rural highways** please identify the enforcement-oriented work zone speed management techniques that your agency has used in the past 3 years:

How often is it used in your jurisdiction?

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Police vehicles in work zone - active enforcement					
Police vehicles (Flashing Lights **OFF**) present in work zone but not issuing tickets					
Police vehicles (Flashing Lights **ON**) present in work zone but not issuing tickets					

How often is it used in your jurisdiction?

	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never
Decoy police vehicles	◯	◯	◯	◯	◯
Aerial enforcement	◯	◯	◯	◯	◯
Enhanced/stealth enforcement (spotters on overpass or shoulder)	◯	◯	◯	◯	◯
Automated Enforcement/ Speed Cameras	◯	◯	◯	◯	◯
Decoy Speed Cameras	◯	◯	◯	◯	◯
Automated Issuance of Written Warnings (non-citation)	◯	◯	◯	◯	◯
Drone radar	◯	◯	◯	◯	◯
	All Work Zones	Most Work Zones	Some Work Zones	Occasional/Unique Situations	Never

Are there other enforcement-related work zone speed management strategies you have deployed on **high-speed two-lane rural highways**? If so, please briefly describe.

Have you established criteria for determining which enforcement techniques to apply to any particular work zone? If so, please describe. (Possible criteria: traffic volume, number of lanes, available lane width, truck volume, construction duration, speed limit (without roadwork), crash history, scope of work, type of work activity, cost, etc...)

How strictly are work zone speed limits enforced in your area? Specifically, by how many MPH could a driver exceed the posted work zone speed limit *without* being likely to be ticketed?

	0	2	4	6	8	10	12	14	16	18	20
Threshold (MPH)											

<< >>

Are there particular challenges or problems that you have experienced in general, or with any specific measures, in achieving speed reductions in work zones? Please describe.

Does your agency have a formal policy or guideline on how work zone speed limits should be set?

- Yes
- No

<< >>

Do you use any combined work zone strategies to manage work zone speeds, such as a series of enforcement and engineering measures at the approach to the work zone? If so, please describe.

Do your speed management policies/procedures differ at night? If so, how?

Are there speed control measures you have tried, that did not work well? If so, please describe.

Have any formal evaluations or case studies been performed to determine the effectiveness of the work zone speed management techniques employed in your area? If so, can you share with the research team and provide contact information for follow-up?

Is there any additional information the research team should know that is unique to the way work zone speed management is handled in your jurisdiction? Examples could include unique agency policies or procedures, legal mandates, or provisions of collective bargaining agreements that strongly influence the way work zone speed management is done in your area.

Are there specific knowledge gaps, uncertainties, or research needs related to work zone speed management that concern you? If so, what are they?

Is there anyone else we should contact for additional perspectives about the way work zone speed management is done in your area?

Thank you for your participation!

APPENDIX B

Responses to Open-Ended Engineering and Enforcement Survey Questions on Work Zone Speed Management

TABLE B1
AGENCY RESPONSES ON OTHER SPEED MANAGEMENT POLICIES

Are there other engineering-related work zone speed management techniques you have deployed on freeways or other multi-lane highways? If so, please briefly describe.

- Alberta Transportation: Our work zones are restricted to a maximum 3 kilometers length (a hair under 2 miles) for mobile work zones (patching, crack sealing, etc.). The intention is to limit the amount of time and distance that drivers have to slow down—typically from 110 km/hour (normal speed) to 80 km/hour (within the 3 km work zone area) to 60 km/hour (passing workers).

- California DOT (Caltrans): Those above listed as Occasional/Unique Situations are just that, and very rarely used, except when circumstances require. California only reduces speeds in work zones when the geometry requires it; for example, lanes narrow or move laterally, when they otherwise would not.

- Connecticut DOT: Adherence to the MUTCD for the signing of work zones.

- Idaho Transportation Department: We will occasionally pay for additional law enforcement patrols to keep speeds down.

- Illinois DOT: In selected work zones Smart Work Zone (ITS) technology has been deployed.

- Indiana DOT: While we don’t use the “Fines Doubled” sign, by state code for most work zones we must use Worksite Added Penalty signs—these signs warn motorists of higher fines for speeding and reckless driving. Similar work (on or about the traveled way not of a mobile nature) being done by or on behalf of other governmental agencies in Indiana must also be accompanied by this signing.

- Iowa DOT: Iowa uses extra enforcement on selected projects statewide. We use the Department’s Motor Vehicle Division weigh officers, Iowa State Patrol officers, and also county sheriff or city police officers. A copy of our Policy and Procedure can be provided upon contact.

- Michigan DOT: ITS stopped/slowed traffic advisories, work zone enforcement.

- Minnesota DOT: A 24/7 construction speed limit may be used when the environment of the WZ necessitates a slower speed primarily for driver safety. Examples include reduced lane width, nearby drop-offs, CPR projects, and 2L2W operations on multilane divided roadways.

- Montana DOT: Occasionally use Changeable Message Signs (CMS).

- North Carolina DOT: Work Zone Speed Reductions are used frequently. We typically use a “temporary” speed limit reduction through the use of CMSs or portable speed limit signs. The speed limits are returned to pre-work zone conditions once the condition such as a lane closure is removed. There are specific criteria to be met before this is utilized. Another form of a work zone speed limit reduction is the “long term” reduction. These are used when the conditions are ever present and the stationary speed limit signs are changed to reflect the conditions of the work zone. These also have specific conditions that must be met. Each of these requires a signed ordinance by the State Traffic Engineer.

- North Dakota DOT: Signs posted for state law when workers present: “Minimum fee $80.”

- Oklahoma DOT: For most interstate high ADT urban and rural areas we are use Smart Work Zone.

(*continued on next page*)

TABLE B1
(*continued*)

- Oregon DOT:
  - Currently in use:
    - Use of law enforcement (on overtime basis) to patrol work zones.
    - Use of Portable Changeable Message Signs (PCMS) to encourage drivers to reduce speeds or be alert for slowed or stopped traffic.
    - Limited use of temporary portable transverse rumble strips.
    - Limited use of lane and/or shoulder width reductions to reduce capacity and traffic speeds in some cases.
  - New/under development (for applicable projects and scopes of work):
    - Photo radar enforcement with citations issued through automated process.
    - Speed radar trailers to provide driver speed feedback and accompanying "SLOW DOWN" messages.
    - Work Zone ITS—providing real-time driver warnings about slowed or stopped traffic, entering construction vehicles, work zone travel time messages, detour/alternate route information, other work zone conditions, or operation information.

- Pennsylvania DOT:
  - Our wider edgelines are 6 in.
  - We use PA State Police assistance for queue protection.
  - Sequential lights on the approaching taper transitions.
  - We are deploying ITS devices this year for advance queue protection (prior to the taper transitions).
  - We are attempting to use Automated Speed Enforcement in work zones. Laws and regulations need revised before this can happen.

- Rhode Island DOT: If police/cruisers stationed in "presence" mode (to help control speeds) are considered an engineering-related work zone speed management strategy (RIDOT does), then take note that RIDOT uses this strategy on MOST work zones on freeways, and in SOME work zones on other multi-lane highways.

- Saskatchewan Ministry of Highways and Infrastructure: We have recently implemented gateway assemblies at the start and end of the work zones. It is to create awareness to the driver that the environment is changing and to create the feeling that the road is narrowing.

- South Carolina DOT: We have a squad of highway patrol troopers trained and designated to patrol work zones and high incident corridors. Approximately 80% of their activities take place in work zones.

- Texas DOT:
  - PCMS to display speeds.
  - Increased number and size of work zone speed limit signs.

- Virginia DOT: We have tried drone radar units with mixed results.

- Washington State DOT:
  - State patrol presence for work zone operations.
  - State patrol emphasis patrols.
  - Photo enforcement for work zones. We tried four different deployment operations. Information on the program can be found on our webpage, http://www.wsdot.wa.gov/Safety/ATSC.htm.

- West Virginia Division of Highways: Use of an off-duty uniformed police officer with a police vehicle.

- Wyoming DOT: We have used Portable Variable Message Signs and flaggers for silica fume pours, which require very low speeds during application and curing.

TABLE B2
OTHER ENFORCEMENT-RELATED TECHNIQUES ON FREEWAYS AND MULTI-LANE HIGHWAYS

Are there other enforcement-related work zone speed management strategies you have deployed on freeways or other multi-lane highways? If so, please briefly describe.

- Alberta Transportation: During extreme weather events (almost always winter storms) the police will issue a tow-ban, and now allow tow trucks to create work zones to recover vehicles in the ditch—until after conditions are better.
- Indiana DOT: Automated enforcement is not allowed by the Indiana State Code at this time.
- Iowa DOT: Iowa uses extra enforcement on selected projects statewide. We use the Department's Motor Vehicle Division weigh officers, Iowa State Patrol officers, and also County Sherriff or city police officers. A copy of our Policy and Procedure can be provided upon contact.
- Kansas DOT: No. Some items on the list were used in the far past, but not recently. Also, automated enforcement is not allowed in Kansas at this time.
- North Dakota DOT: We have had law enforcement program where officers patrol work zones above their normal work hours. Usually we ask Highway Patrol and they patrol more often in their normal working hours.
- Nova Scotia Transportation and Infrastructure Renewal: Police may provide enforcement if requested, based on previous problems with the work site.
- Pennsylvania DOT: We are working on Automated Speed Enforcement, but it will require state law and regulation changes.
- Saskatchewan Ministry of Highways and Infrastructure: Traffic compliance officers in work zones. Also, police in the work zone without identification and giving out tickets.
- South Carolina DOT: We have a squad of highway patrol troopers trained and designated to patrol work zones and high incident corridors. Approximately 80% of their activities take place in work zones.
- Texas DOT: Wolf pack patrol of work zone.

TABLE B3
OTHER ENFORCEMENT-RELATED TECHNIQUES ON HIGH-SPEED, TWO-LANE RURAL HIGHWAYS

Are there other enforcement-related work zone speed management strategies you have deployed on high-speed, two-lane rural highways? If so, please briefly describe.

- Indiana DOT: Note: Additional police patrols are used, although probably not with as much frequency as on freeways.
- Iowa DOT: Iowa uses extra enforcement on selected projects statewide. We use the Department's Motor Vehicle Division weigh officers, Iowa State Patrol officers, and also County Sherriff or city police officers. A copy of our Policy and Procedure can be provided upon contact.
- Minnesota DOT: Current research project is underway to study automated speed enforcement's impact on driver attention. However, Minnesota law does not allow ASE at this time.
- Nova Scotia Transportation and Infrastructure Renewal: Police may provide enforcement if requested, based on previous problems with the work site.
- Saskatchewan Ministry of Highways and Infrastructure: Traffic compliance officers in work zones. Also, police in the work zone without identification and giving out tickets.

TABLE B4
AGENCY CRITERIA FOR DETERMINING ENFORCEMENT TECHNIQUES

Have you established criteria for determining which enforcement techniques to apply to any particular work zone? If so, please describe.

- Alaska DOT: Very general criteria.
- California DOT (Caltrans): Geometry of the work zone, traffic volumes, scope of work, for construction work zones, and the final recommendation is from the Resident Engineer. For maintenance work zones, it is usually the area superintendent who makes the final decision.
- Delaware DOT: Delaware does not have this type of criteria. We are currently revisiting our law enforcement in work zone guidelines and this could potentially be added.
- Illinois DOT: Quantitative guidelines have not been established; however, many of the above factors are considered when determining which techniques to utilize.
- Iowa DOT: Iowa uses extra enforcement on selected projects statewide. We use the Department's Motor Vehicle Division weigh officers, Iowa State Patrol officers, and also County Sherriff or city police officers. A copy of our Policy and Procedure can be provided upon contact.
- Kansas DOT: No, each field office determines for itself which criteria warrants an enforcement request (using state funds to pay for highway patrol staff overtime) and the KHP sometimes runs work zones during regular hours.
- Michigan DOT: We have a Guidance Document on Work Zone Enforcement
- Minnesota DOT: No set criteria—decisions on the use of extraordinary enforcement are made by the District Project and Traffic personnel.
- Missouri DOT: No, type of enforcement is determined on a job-by-job basis by the contractor, engineer, and law enforcement dependent on the location, work activity, and weather.
- Montana DOT: Use of law enforcement only if drivers routinely not following traffic control devices.
- North Carolina DOT: Yes, our HAWKS program uses specific criteria to identify work zones for State Highway Patrol activities. Some of this includes: crash history, 85th percentile speeds, adjacent projects, etc.
- New York State DOT: No formal criteria but we do prioritize our requests to the police for enforcement. We also have the Work Zone Safety Act of 2005, which requires police presence to the extent practicable where workers are on foot without barrier on high-speed controlled-access freeways.
- North Dakota DOT: We have had law enforcement program where officers patrol work zones above their normal work hours. Usually we ask Highway Patrol and they patrol more often in their normal working hours.
- Ohio DOT: Our Traffic Engineering Manual (TEM) has sections relating to and plan notes for: Law Enforcement Officer (LEO) for Enforcement (640-19.2, 642-56); LEO for Assistance (640-19.1, 642-55); Work Zone Speed Zones (640-18/1203-2.9/642-24); and Increased Penalties Signs (605-4.3/640-18.3/642-27). We also have a pilot process developed for our variable speed limit signs (Digital Speed Limit signs, DSL signs) in work zones with proposal notes and plan detail drawings. They are not available on the web now as the pilot has concluded and we are waiting on pending research to be completed. They may change depending on research results. http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/TEM/Pages/default.aspx.
- Oregon DOT: Overtime enforcement usually focused on freeways and interstate work zones due to higher level of importance for the facility, type of work activity, higher traffic volumes and speeds, proximity of workers to live traffic, frequency of night work.
- Pennsylvania DOT: PA State Police assistance. Our focus is on Interstates and freeways projects. Other high-speed, high-volume roadways are approved on a case-by-case basis (and focus on roads with expected queues).
- Rhode Island DOT: RIDOT has published a Guidelines for the Use of Traffic Persons (Police) and flag persons in Work Zones Policy, which can be shared upon request. This guidance includes/covers some, but not all, of the criteria noted.
- South Carolina DOT: The highway patrol troopers patrol designated work zones.
- Virginia DOT: The use of law enforcement is nearly always determined in the planning stages of a project, and is based on traffic volumes, crash history, scope of work and duration, and availability of state police or other law enforcement personnel.
- West Virginia Division of Highways: Yes. Four-lane freeways with high ADT volumes, nighttime constructions, type of work activity, speed limit.
- Wisconsin DOT: Volumes, work zone configuration, and anticipated speeds.
- Wyoming DOT: Wyoming does not have the staff numbers available in the Wyoming Highway Patrol (a part of WYDOT) to make enforcement a standard part of work zones. When available, they have been used for enforcement in unique situations (such as silica fume pours) and have been an added presence for short-term (<1 hour) road closures (such as installing an overhead sign structure).

TABLE B5
CHALLENGES FACED IN GENERAL OR WITH PARTICULAR MEASURES

Are there particular challenges or problems that you have experienced in general, or with any specific measures, in achieving speed reductions in work zones? Please describe.

- Alabama DOT: We have found that drivers, in general, will not obey reduced speeds through a work zone when there's no apparent danger.
- Alberta Transportation: Our legislation for reduced speed when passing workers, or emergency vehicles with lights flashing, allows drivers to maintain regular speed if there is a full lane between the stopped vehicle and the passerby. Not many drivers understand this, and we're having a problem with different speed in the work zone as some drivers try to maintain normal speed in the "it's OK" lane, while other drivers slow no matter which lane they're in.
- Arizona DOT: Long work zones have particular difficulty in getting drivers to observe reduced speed limits. Many times the problem is just the opposite: artificially lowering speed limits where it's unnecessary/not justified.
- California DOT (Caltrans): Conditions vary widely throughout the state. Many decisions are made in the local district. With 12 districts, they are not always consistent. Some confusion in the various districts as to when they should or should not use law enforcement (California Highway Patrol) in work zones.
- Connecticut DOT: At this time we are considering the use of temporary rumble strips, especially after Texas' presentation at SCOTE. Rural roads are very difficult especially due to lack of enforcement areas.
- Delaware DOT: Even with double fines (mandated by state law) the fines alone do not appear to be a deterrent to speeding.
- District of Columbia DOT: One challenge we face in achieving speed reductions in work zones is payment to police. We have no written agreement with police on their roles and responsibilities in work zones.
- Idaho Transportation Department: It is difficult to get people to slow down for long-term speed reductions and for 24-hour speed reductions when there is no work occurring in the off hours. If speed reductions are only supposed to be effective when work is occurring, getting the signage to accurately reflect the work activity is difficult to manage.
- Illinois DOT: Road user compliance with work zone speed reduction varies across the state and depending upon the type of roadway and the type of work being performed.
- Indiana DOT: My experience is that driver adherence to speed limit reductions vary. So, in a given work zone on a given day, particularly if the speed reduction is substantial (say 20 or 25 mph), some drivers will not adjust their speed at all, most will reduce speed moderately, while some will obey the reduction. This becomes an enforcement and safety issue so we have learned that great temporary drops in speed limits can be problematic whether there is active enforcement or not.
- Iowa DOT: Having enough officers available for extra enforcement and also current procedures do not directly reimburse the cost center or local offices, but typically go back to the general fund of the agency.
- Michigan DOT: The speed study we have done shows that drivers do not slow down unless workers are working right next to the lane.
- Minnesota DOT: As is typical, drivers will not reduce their speeds based on regulatory sign alone; drivers will reduce speeds when the environment justifies a reduced speed or when enforcement is present.
- Montana DOT: Contractor not diligent with posting appropriate speed limits. Example, posting 35 mph in work zone on interstate projects with closed lane. Not posting an end of work zone speed limit once past work zone. 35 mph speed limit for extended miles after work zone without any work activity.
- North Carolina DOT: Yes, the number one problem is the installation of speed limit signs that reduce the speed limit before the condition is present. This reduces the credibility of the work zone speed limit reduction and little compliance is the result before and during the conditions that warrant the reduction.
- New Mexico DOT: Finding police officers devoted to the location.
- New York State DOT: Speed limit reductions are generally ineffective without police enforcement of them.
- Nova Scotia Transportation and Infrastructure Renewal: Simply posting signs has little effect. Making physical changes to the roadway to slow traffic is most effective.
- Ohio DOT: Obtaining compliance on interstates WITHOUT presence of law enforcement officers. Documentation issues with use of regulatory digital speed limit signs (knowing exactly where, when, and what speed was in effect at any given time with great accuracy).
- Oregon DOT: Lack of available law enforcement across the state due to budget cuts. Where speed reductions are warranted, without enforcement, compliance with regulatory posted speed is very low ($<5\%$). Where not warranted, application of speed reductions can be less effective in reducing speeds—and can even provide a false sense of security for workers. Politics, emotions, current driving behaviors, and a broad range of stakeholder interests present challenges in successfully creating, applying, and enforcing a uniform, consistent work zone speed reduction policy.
- Pennsylvania DOT: We are having issues with gaining the support from the PSP trooper's union on automated speed enforcement in work zones. We are looking to draft a policy on "how to establish" a consistent policy for setting the appropriate work zone speed limit.
- Rhode Island DOT:
    1. Administration/Costs of Enforcement
    2. Lack of Active/Targeted Speed Enforcement
    3. Road Users Failing to Adhere to Posted Limits.
- Saskatchewan Ministry of Highways and Infrastructure: Long work zones create drivers to increase their speeds through the work zone. General nature Saskatchewan environment of lower volumes and wide open space.
- South Carolina DOT: No specific problems with any specific speed reduction measure.

TABLE B5
(*continued*)

- Texas DOT:
  - Active enforcement areas to issue tickets
  - Enforcement while performing other active duties
  - Verification of workers present at time of ticket.
- Virginia DOT: Speed limit reductions are generally avoided if at all possible. The design of the work zone is based on pre-reduction speeds. A change in our legislature two years ago now requires flashing lights to be added to signs in the work zone and flashing when workers are present and the speed is reduced. Most contractors would rather not see the fines increased for speeding if they have to turn lights on and off throughout the day and perform the necessary documentation of flashing light activation. http://www.virginiadot.org/VDOT/Business/asset_upload_file411_44579.pdf /
- Washington State DOT: Drivers will not reduce speed unless they see or observe the need to do so. Arbitrarily reducing the speed does not do anything other than create a speed differential problem where you might get someone willing to reduce the speed to match the posted speed, but the problem is when you have other drivers that drive at the speed they are comfortable with regardless of if road work is ongoing.
- Wisconsin DOT: In general the traveling public does not obey work zone speed limits whether they are advisory or enforceable.
- Wyoming DOT: Wyoming is full of long stretches of roads. Our challenge is to make sure we are setting appropriate speed limits and that we are applying them only to active work zones. Good work zone maintenance is as important as enforcement. Credibility is our main goal.

APPENDIX C

Public Outreach Survey Instrument

Survey Questionnaire: Work Zone Speed Management

The National Cooperative Highway Research Program (NCHRP) has contracted with the University of Wisconsin Traffic Operations & Safety Laboratory (TOPS Lab) to prepare a *Synthesis of Practice on Active & Passive Methods of Speed Control in Work Zones.* Our work covers speed management for work zones on freeways, multi-lane divided highways, and high-speed two-lane rural highways; work zones on urban streets and low-speed rural roads are not included in this project.

This survey covers public outreach techniques for managing work zone speeds.

Please take a few minutes to complete this survey (or forward it to the relevant subject-matter expert in your agency). The information you provide will help the research team, NCHRP, and Synthesis readers get a better understanding of which work zone speed management methods are in common use, what is working, what is not working, and where there is a need for additional technical and policy guidance.

Thank you for your participation!

>>

Agency Name

Agency Type

- Headquarters of a state/provincial transportation department
- Headquarters of a tollway authority or toll highway operator
- Region or district of a state/provincial transportation department
- Region or district of a tollway authority or toll highway operator
- Federal land management agency
- County, municipal or tribal public works agency
- Regional transportation authority
- Headquarters of a stat/provincial police agency
- Region or district of a state/provincial police agency
- County/municipal police
- Public utility/railroad
- Highway construction contractor
- Other: Please Specify

Location/area served

Country

- United States
- Canada
- Other: Please Specify

Name of the person completing this survey

Telephone number

E-mail address

May we contact you with follow-up questions?

- Yes
- No

<< >>

Most DOTs conduct public outreach on a number of safety-related themes, such as impaired driving, motorcycle safety, pedestrian safety, and railroad crossing safety. Compared to other safety messages that your agency works on, how important is work zone speeding?

- Very High
- High
- Medium
- Low
- Very Low

Do you focus your work zone safety messages during certain times of the year? If so when?

What kinds of work zone safety campaigns do you conduct? (Please mark all that apply)

- General statewide campaigns
- Campaigns targeted toward specific major construction projects
- Campaigns targeted toward specific smaller construction projects
- Campaigns targeted toward geographic areas with a history of work zone crashes
- Other: Please Specify

Which media do you currently use to communicate with the public about work zone safety?

	Very Often	Often	Occasionally	Rarely	Never
Paid advertising on TV	○	○	○	○	○
Paid advertising on radio	○	○	○	○	○
Paid print advertising	○	○	○	○	○
Paid web advertising	○	○	○	○	○
TV public service announcements (PSAs)	○	○	○	○	○
Radio PSAs	○	○	○	○	○
Print PSAs	○	○	○	○	○
Press releases	○	○	○	○	○
Driver education materials and handbooks	○	○	○	○	○
Videos on agency website	○	○	○	○	○
Videos on YouTube	○	○	○	○	○
Facebook	○	○	○	○	○
Twitter	○	○	○	○	○

Are there any other media techniques being used? If so, please briefly describe.

For work zone safety messages, do you have different media strategies for large and small media markets? If yes, please describe.

Are you satisfied with the quality and quantity of airtime that RADIO stations devote to your work zone safety messages?

- ○ Very Satisfied
- ○ Satisfied
- ○ Neutral
- ○ Dissatisfied
- ○ Very Dissatisfied

Are you satisfied with the quality and quantity of airtime that TV stations devote to your work zone safety messages?

- Very Satisfied
- Satisfied
- Neutral
- Dissatisfied
- Very Dissatisfied

When creating a new work zone safety public outreach campaign, how much importance would you place on each of these themes:

	Very High	High	Medium	Low	Very Low
How often work zone crashes occur					
How often work zone fatalities occur					
Penalties for work zone traffic violations					
Protecting the safety of workers					
Protecting the safety of drivers					
Protecting the safety of passengers					
Reducing speed while in work zone					
Reducing distractions while in work zone					
Paying attention to work zone signs					
Paying attention to flaggers					
Expecting delays/being patient					

Overall, how good is public compliance with work zone speed limits in your area, in your opinion?

- Excellent
- Very Good
- Good
- Fair
- Poor

Have any formal evaluations of the effectiveness of work zone public outreach been done for your area?

- Yes
- No

What could be done to increase the effectiveness of work zone safety public outreach?

Are there specific knowledge gaps, uncertainties, or research needs related to work zone public outreach that concern you?

Is there anything else we should know that is unique to the way work zone safety outreach is done in your area?

Is there anyone else we should contact for additional perspectives about the way work zone safety outreach is done in your area? If yes, please include their contact information.

APPENDIX D

Responses to Open-Ended Engineering and Enforcement Survey Questions on Work Zone Safety Outreach

TABLE D1
TEMPORAL PATTERN OF WORK ZONE SAFETY OUTREACH CAMPAIGNS

Do you focus your work zone safety messages during certain times of the year? If so when?

- Alabama DOT: Yes, typically during April, which has traditionally been designated as a period for Work Zone Safety Awareness. We have, at times, conducted activity targeted toward certain large construction projects.
- Arizona DOT: We align our messages with the national work zone safety campaign that is usually in the April timeframe.
- California DOT: Focus is year-round, with a stronger emphasis from April–September.
- Delaware DOT: Month of April
- Florida DOT: National Work Zone Awareness Week.
- Georgia DOT: Yes. Usually the week of national “Work Zone Awareness.”
- Idaho Transportation Department: Work Zone Safety is a focus primarily during our construction season, and is usually heightened around the time of the national NHTSA campaign.
- Indiana DOT: Our work zone safety messages are focused in April during National Work Zone Awareness Week and reinforced throughout the construction season.
- Iowa DOT: We focus most of the efforts in April, especially during Work Zone Safety Week. However, we do outreach throughout the road construction season.
- Kansas DOT: National Work Zone Awareness Week; construction season in general.
- Kentucky Transportation Cabinet: A heavy emphasis during National Work Zone Safety Awareness Week with continued reminders throughout construction season. We also might mention it when promoting driver inattention issues.
- Louisiana DOT and Development: Mainly during National Work Zone Safety Week, which is always held in April.
- Michigan DOT: During Work Zone Awareness Week mainly.
- Minnesota DOT: Year-round, but two foci. In the spring and summer, we focus on construction project work zone safety. In the winter, we focus on snow plow operations safety—“give them room to work.” In the winter, we consider the entire road a work zone during snowstorms.
- Mississippi DOT: We focus messaging in April (for Work Zone Awareness Week); Memorial Day–Labor Day (for summer travel); December (for holiday travel).
- Missouri DOT: A Spring Kick-off event in April (Work Zone Awareness Week) followed by paid media campaign during summer months.
- Nebraska Department of Roads: We espouse work zone safety at every opportunity. From December thru March we focus on Winter Highway/Driving Safety. From April thru November we are all about Highway Work Zone Safety. We utilize multimedia messages.
- Nevada DOT: Start of construction season in the spring.
- New Hampshire DOT: Usually at the beginning of each construction season (spring time).
- New Jersey DOT: During the week of the annual Work Zone Safety Awareness Week.
- New Mexico DOT: During Work Zone Safety Month and major projects.
- New York State DOT: Start of construction season, usually a week or so after National Work Zone Awareness Week.
- North Carolina DOT: We run several activities throughout the year. We pay special attention during Work Zone Safety Week.
- North Dakota DOT: Yes. May–October.
- Ohio DOT: Yes. April during National Work Zone Safety Awareness week.
- Oklahoma DOT: Yes. We focus a Work Zone Safety Awareness campaign annually during National Work Zone Awareness Week in April. While we highlight work zone safety year-round, this is the week where we make an extra push to bring attention to the issue.
- Oregon DOT: Summer construction season is the primary time for work zone safety messages, but no matter what time of year, we incorporate work zone safety into project outreach.
- Pennsylvania DOT: We initiate big pushes during work-zone awareness week and through construction season. In 2013, we launched a video discussing work-zone safety, not just speeding: http://www.youtube.com/watch?v=6aOHMHipXXk.
- Rhode Island DOT: Other than general outreach in conjunction with National Work Zone Awareness Week each April, RIDOT hasn’t/doesn’t typically disseminate work zone safety messages to the public during established or predetermined times of year.
- South Dakota DOT: In the spring and summer months during construction.
- Tennessee DOT: We definitely emphasize work zone safety during National Work Zone Awareness Week, but also share messages throughout the year.

TABLE D1
(*continued*)

- Texas DOT: April, Work Zone Awareness Week in conjunction with national effort. March, April, and July: I-35 Work Zone Awareness Campaign (Waco area).
- Utah DOT: April and June are generally the times we focus on work zone safety messages. Last year we combined our efforts with a state senator and included work place safety.
- Vermont Agency of Transportation: May–September.
- Washington State DOT: We have messages about work zone safety from spring to fall—kicking off the year with the national kickoff event and weaving in all year.
- West Virginia Division of Highways: Generally May–September.
- Wisconsin DOT: Spring in coordination with National Work Zone Safety Awareness Week/peak holiday travel periods for Memorial Day, Fourth of July, Labor Day, Thanksgiving, year-end.
- Wyoming DOT: Late spring—WZ Awareness Week.

TABLE D2
ADDITIONAL TYPES OF WORK ZONE SAFETY OUTREACH CAMPAIGNS

What other kinds of work zone safety campaigns do you conduct?

- California DOT: High school tour outreach and Hispanic outreach.
- Delaware DOT: We have a small state with few major media, so a general campaign is sufficient.
- Nebraska Department of Roads: And targeted as needed ...
- Pennsylvania DOT: Regions reinforce safety message with regional events and in each construction press release/interview.
- Wyoming DOT: P.R. sent from FHWA.

TABLE D3
ADDITIONAL TYPES OF MEDIA USED FOR WORK ZONE SAFETY OUTREACH

Are there any other media techniques being used? If so, please briefly describe.

- Arkansas Highway & Transportation Department: Website: http://www.idrivearkansas.com.
- California DOT: Editorials (rarely though).
- Delaware DOT: Billboards and media events.
- Florida DOT: Digital message boards on roadways, video monitors at rest areas, website banners, etc.
- Indiana DOT: Press conferences with state or agency leaders and guided work zone visits.
- Kansas DOT: Have a week of safety blogs written by highway workers, law enforcement, and construction partners.
- Kentucky Transportation Cabinet: Press conferences throughout the state, audio news releases.
- Louisiana DOT and Development: Annual WZA press conference in April, in conjunction with state police, the Louisiana Highway Safety Commission, and the Federal Highway Safety Administration. The press conference includes a cone memorial installation on the front lawn of DOTD HQ, with each cone representing the number of lives lost nationwide in work zones for the most recent year this data is available. Vested Interest in Safety Campaign—we invite the public to submit photos of themselves in orange safety vests for use on our Facebook page.
- Michigan DOT: Messages on DMS and PCMB.
- Mississippi DOT: We also make social advertising buys on Facebook to reach new audiences that other advertising buys are not able to reach.
- Missouri DOT: Press conferences around the state to highlight regional construction. Scheduled radio/TV appearances to discuss topic with local reporters.
- Nebraska Department of Roads: We sponsor our messaging during sports-oriented programs, at special events, and during news conferences.
- North Dakota DOT: Billboards and displays in restaurants, gas stations.
- Oregon DOT: Websites, billboards, transit ads. We also include work zone safety messaging in project outreach materials such as fact sheets and flyers. Work zone safety is incorporated into public meetings about projects too.
- Pennsylvania DOT: Press events. We also emphasize work zone safety on our electronic message boards when posted near construction zones.
- Rhode Island DOT: This year RIDOT will provide an event to directly involve the media. Members of the media will be invited to experience a live work zone on one of the state highways. This will give media a live experience to report on and share with the public.
- Texas DOT: Gas pump toppers, billboards, moving billboards (two wrapped 18-wheelers), rest area posters in work zone areas, local interviews, TxDOT My35 website.
- Vermont Agency of Transportation: We have an agency staff member who reports on road conditions and construction delays on radio and television every week. We bake safety messaging into what he does.
- West Virginia Division of Highways: Billboards.
- Wisconsin DOT: Planned media events with various speakers.
- Wyoming DOT: Project specific work zone information for detours and delays. We use highway advisory radio systems for local information.

TABLE D4
OUTREACH STRATEGY DIFFERENCES FOR SMALL AND LARGE MEDIA MARKETS

For work zone safety messages, do you have different media strategies for large and small media markets? If yes, please describe.

- Alabama DOT: NA.
- Arizona DOT: Yes, we focus on newspapers and websites in the smaller markets and television and radio in the larger markets.
- Arkansas Highway & Transportation Department: No.
- California DOT: Strategies are similar, but advertising is less extensive.
- Delaware DOT: No.
- Florida DOT: Same.
- Idaho Transportation Department: Our method is essentially a one-size-fits-all approach.
- Indiana DOT: Press conferences are typically held in urban areas where there is a higher rate of work-zone crashes and a larger concentration of news media.
- Iowa DOT: For the most part all of our messages are state-wide. However, if we know we have a construction project in a specific area we may target social media messages to that specific project's social media page or the social media page of the geographic area the project is located in.
- Kentucky Transportation Cabinet: We might have a full-blown press conference close to a major construction site in a major media market. Possibly a smaller press conference or just a photo op in a smaller market.
- Maine DOT: No.
- Michigan DOT: Our communication rep works with local media stations to try and get the message into reports.
- Mississippi DOT: We have a regional media strategy in which we tailor messaging with traffic stats pulled from the Northern, Central, and Southern regions of the state.
- Missouri DOT: No, our markets are similar enough that strategies are the same.
- Montana DOT: No.
- Nebraska Department of Roads: We have multi-messaging with uncomplicated strategy. Our goal is to plant informational seeds that may grow and evolve into cognition upon some timely recognition. (AWARENESS + RELEVANCY = EPIPHANY.) This public health and safety issue seems a difficult performance item to measure. If one uses Crash and Fatality data…it does not prove effective. We, however, cannot give up. Onlookers implore "EDUCATION!" If highway safety public awareness and outreach provides an "educated public" than we have an educated public of willfully bad, irresponsible, and totally distracted drivers.
- North Dakota DOT: No.
- Oklahoma DOT: No. We have only two major media markets, but we do tailor our message somewhat for different types of media such as radio, print, or TV.
- Oregon DOT: In smaller markets, we're often able to do more face-to-face interaction with media representatives and community members.
- Rhode Island DOT: No (NA).
- South Dakota DOT: No.
- Texas DOT: No.
- Utah DOT: No.
- Vermont Agency of Transportation: We are a very small media market; 600,000 people in the whole state.
- Washington State DOT: No—we have a consistent statewide message.
- West Virginia Division of Highways: NA.
- Wyoming DOT: No.

TABLE D5
SUGGESTIONS FOR IMPROVING WORK ZONE SAFETY CAMPAIGN EFFECTIVENESS

- **What could be done to increase the effectiveness of work zone safety public outreach?**
- Alabama DOT: In our state, steps are being taken to designate a DOT staff member to specific assigned duties to coordinate traffic safety marketing/education and outreach. I anticipate this will result in improved coordination and effectiveness in all our efforts related to driver behavior.
- Arizona DOT: More messaging from the national level.
- California DOT: More funding and continuous outreach.
- Florida DOT: We currently provide data and tips to media and public.
- Georgia DOT: Fund overall and for specific projects.
- Idaho Transportation Department: Idaho, as a rural and low population-density state, doesn't have nearly the issue that some of the bigger states have in regard to this, so a message that would apply to us (or Montana, Wyoming, North and South Dakota, etc.) would be useful.
- Indiana DOT: We are continually frustrated with the media's lack of interest in this topic until after a fatality occurs. In prior years, we would have our employees wear orange in honor of our co-workers and contractors in harm's way. During Work Zone Awareness Week this year, Indiana launched a #SafetySelfie campaign that encouraged our employees, media, and the public to post self-portraits wearing hard hats and/or high-visibility vests. We find these types of activities to be more effective than earned media.
- Iowa DOT: More targeted campaigns. Money, time, and staff to devote to specific campaigns. With budget restrictions our staff and dollars are stretched pretty thin. We have to balance work zone campaigns with all other safety campaigns, as well as normal day-to-day communications.
- Kansas DOT: More law enforcement in work zones.
- Kentucky Transportation Cabinet: The availability of federal funds to purchase media. The Work Zone clearinghouse provides a television spot that we could use.
- Michigan DOT: We have not done much in Michigan. We are forming a committee for next year's Work Zone Awareness Week. It would help to have some funding to pay for PSAs.
- Minnesota DOT: Need to continue hammering the messages home, be consistent.
- Mississippi DOT: In 2014, we added the following components to our work zone safety messaging. We believe these additions have impacted positively the effectiveness of our work zone safety public outreach:
  - MDOT websites are "going orange" at http://www.GoMDOT.com and http://www.MDOTtraffic.com.
  - Social media sites are "going orange" (search MississippiDOT at Facebook.com, Twitter.com, and YouTube.com.).
  - Work Zone Safety Information Page: http://mdot.ms.gov/portal/workzone/index.html.
  - Three 30-second videos: http://www.youtube.com/playlist?list=PL35Emno659YOjKmFqoOK6sihGXkImYnwQ.
  - Five graphic concepts being used on the following platforms:
    - First floor display: Headquarters
    - Infocasters
    - MDOT@Work Spotlight
    - Rotating Banners on http://www.GoMDOT.com
    - Posters distributed to all MDOT facilities statewide through District Offices
    - Postings on MDOT's social media sites
    - Facebook ads promoting work zone safety to online audiences.
  - Two 30-second radio spots in statewide media markets.
  - Web banner ads on Clear Channel and The Radio People stations statewide.
  - Work Zone Safety Press Release to statewide media.
  - MDOT Administrative Building in downtown Jackson illuminated orange.
- Missouri DOT: The more a message is seen or heard, the better it is remembered. If a larger advertising budget existed, we could reach more markets with a more frequent message.
- Nebraska Department of Roads: We need there to be laws with accountable implications for faulty, reckless, not safety-buckled in, and distracted driving. If driving is truly a "privilege" then the privilege must be revoked accordingly. Lawmakers want to represent their constituents by limiting freedoms in many social and personal realms, yet this very public endemic way to die, be killed, and to kill continues on our country's roadways. Public awareness, information and "education" are woefully underqualified to win this war. Our efforts and sincere endeavors are soft. The hard stuff is law and order.

  You can have unique, you can have creative, and you can have the slogan of the month. Congratulations to marketing, sales, and promotional advocates one and all. As I've said, the words and graphics are the soft stuff. Accountability is the tough stuff. In a free society as is ours—if having the right answer and an agreeable solution to a time-worn problem were within reasonable reach, we would still have disagreement on recognizing it and implementing it. I am afraid *Toward Zero Deaths* is a dream not an attainable goal.

(*continued on next page*)

TABLE D5
(*continued*)

- Nevada DOT: More funding.
- New Hampshire DOT: Work zones come in many different sizes and complexity. Difficult to come up with a solution that can equally be applicable to all work zones. Interstate speed requirements and safety is vastly different than on a local two lane roadway, but by law both are considered work zones!
- New Jersey DOT: Put the information out.
- New York State DOT: Coordinate with public outreach for traffic management on large urban projects.
- North Dakota DOT: More of a nationwide campaign.
- Oklahoma DOT: Get more media buy-in. We struggle to get them to cover our work zone message or show up to media events.
- Oregon DOT: Good question. Paid advertising would help reinforce messages. However, like most safety messages it's a challenge. Everyone knows they should slow down and be alert in work zones; most people intend to do the right thing, but they still don't do it consistently. People just tend to be very self-involved when they are in their cars.
- Pennsylvania DOT: More of a budget for paid TV/radio campaigns, especially if it came from the federal level.
- Rhode Island DOT: Highlight actual/local examples of the devastating effects work zone crashes have had (or can/will have) on families/loved ones.
- South Dakota DOT: No, I think we do a good job with the consultant we use.
- Tennessee DOT: I'm not sure I have an answer for this, but one of the biggest challenges is that as a government agency, we do not spend money on advertising. Since there is no dedicated safety funding that would allow us to reach a broader audience through advertising, we must rely on social media, YouTube, and our own website, press releases, etc.
- Texas DOT: Increased funding to provide more frequent messaging.
- Utah DOT: Showcasing personal stories of workers or commuters who have been injured in work zone crashes. Media is more likely to cover personal stories of real people affected by this safety issue.
- Vermont Agency of Transportation: Diversify communications channels and methods. We rely too much on traditional media.
- Washington State DOT: Our limited research shows we need to focus on costs to the driver: ticket costs, insurance rate costs, costs of hitting someone, and going to jail.
- Wisconsin DOT: Dedicated funding for media buys.

TABLE D6
PERCEIVED KNOWLEDGE GAPS AND UNCERTAINTIES RELATED TO WORK ZONE SAFETY OUTREACH

Are there specific knowledge gaps, uncertainties, or research needs related to work zone public outreach that concern you?

- Arizona DOT: We need more stats that resonate with drivers.
- Indiana DOT: Primarily we are looking for effective strategies and tactics to reduce distractions in work zones and promote voluntary compliance with instructions of work zone traffic control devices.
- Minnesota DOT: Perhaps more info around the cost of work zone crashes.
- Mississippi DOT: We believe there are knowledge gaps related to legal penalties, work zone crash statistics, and work zone fatality statistics.
- Nebraska Department of Roads: If there were any more search and research we'd just have more data and similar stories to share.
- North Dakota DOT: Should do more about paying attention and not be distracted when driving in work zones.
- Oklahoma DOT: We can only do so much to reach citizens. We use Twitter, YouTube, and press releases to get the word out, but without an active media base through which to get the message to the citizens it is a struggle.
- Oregon DOT: It would be interesting to find out why thoughtful, kind, law-abiding citizens will speed right through a work zone not paying attention to signs, flaggers, or anything. What causes that behavior change? It's not ignorance about safety or knowledge; it's sort of an unconscious behavior change that happens when people get behind the wheel. Why?
- Pennsylvania DOT: Probably nuances related to speed limits in work zones when it's active vs not active—hard to get all of that across.
- Rhode Island DOT: Not really a pressing concern, but it seems there is a large knowledge gap—re: just how effective work zone public outreach actually is (hard to measure quantitatively, given multiple contributing factors that are often involved with highway crashes).
- Texas DOT: Best practices from the states on the various countermeasures and campaigns that work.
- Washington State DOT: Yes—costs.
- Wyoming DOT: Most highway drivers in rural areas are not locals. Uniformity of traffic control devices is most important.

TABLE D7
REPORTED REGIONAL/JURISDICTIONAL DIFFERENCES IN APPROACHES TO WORK ZONE SAFETY OUTREACH

Is there anything else we should know that is unique to the way work zone safety outreach is done in your area?

- Florida DOT: We use our state Capitol to display work zone safety messages to legislators during our session.
- Indiana DOT: Our focus has moved away from speeding to behaviors that crash statistics have shown lead to work zone crashes and fatalities. These include following too closely, failure to yield, and improper lane change.
- Kentucky Transportation Cabinet: We have public information officers in each of our 12 districts throughout the state. They work directly with the local media and decide the best way to publicize in their area.
- Mississippi DOT: In addition to the components listed in a previous question, below are some additional pieces of our work zone safety public outreach efforts:
  - Internal events held around the state in each District.
  - Internal communication pieces with staff and leadership.
  - Print materials at Welcome Centers around the state.
  - MDOT’s Local Technical Assistance Program (LTAP) promotes work zone safety at their training events in April.
- Missouri DOT: We have shifted our focus from long-term construction work zones to building awareness for short-term and moving work zones.
- Nebraska Department of Roads: We have many groups, agencies, and companies that are concerned with highway safety in Nebraska. We have extensive outreach in this state. We have no primary safety laws for motorists. Motivation relies totally on the driver. It is the single variable over which we have no control.
- Nevada DOT: Media events.
- Pennsylvania DOT: We have three workers’ memorials, one of which is a mobile display. Information is available on our safety website: http://www.justdrivepa.org/Traffic-Safety-Information-Center/Work-Zone/. PennDOT’s traveling Worker Memorial includes 84 posts topped by hard hats and draped in safety vests. Each post represents a PennDOT employee who died in the line of duty since 1970.
- Rhode Island DOT: Given we are a small state, it seems likely that we could (and do) learn a lot from our bigger sister states/DOTs, who have more resources to devote to work zone safety outreach.
- South Dakota DOT: The AGC of South Dakota partners with us in promoting work zone safety. They have a coloring contest in the elementary schools and the winners get prizes and their picture on a billboard during the construction season, the billboard is sponsored by a contractor and is located near a job they are doing.
- Texas DOT: Our ad agency wrapped two 18-wheeler trailers with a safety message and these trucks are frequently travelling the I-35 work zone.
- Utah DOT: Social media has become a key element to our department’s communication with media and the public. We tend to send out more tweets (with links to stories) and shy away from sending out traditional press releases.
- Vermont Agency of Transportation: Sadly, I think we are anything but unique.
- Washington State DOT: We also try to encourage our own employees to participate in campaigns to personalize the person in the work zone attire.

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
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
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
TDC	Transit Development Corporation
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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