Improving the Effectiveness of Speed Feedback Trailers in Freeway Work Zones

Final Report
March 2024

SWZDI
Smart Work Zone Deployment Initiative

Sponsored by
Smart Work Zone Deployment Initiative
(Part of TPF-5(438))
Federal Highway Administration
(InTrans Project 20-733)

The preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its "Second Revised Agreement for the Management of Research Conducted by Iowa State University for the Iowa Department of Transportation" and its amendments.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
Part of TPF-5(438)		

4. Title and Subtitle	5. Report Date
Improving the Effectiveness of Speed Feedback Trailers in Freeway Work Zones	March 2024
	6. Performing Organization Code
7. Author(s)	**8. Performing Organization Report No.**
Timothy Gates, Peter Savolainen, Praveen Edara, Henry Brown, Sakar Pahari, Sagar Keshari, Myles Overall, Magdalena Cavka, Sarah Premo, and John Racine	Part of InTrans Project 20-733
9. Performing Organization Name and Address	**10. Work Unit No. (TRAIS)**
Department of Civil and Environmental Engineering Michigan State University 428 S. Shaw Ln East Lansing, MI 48824	**11. Contract or Grant No.**
12. Sponsoring Organization Name and Address	**13. Type of Report and Period Covered**
Smart Work Zone Deployment Initiative Iowa Department of Transportation 800 Lincoln Way Ames, Iowa 50010 Federal Highway Administration U.S. Department of Transportation 1200 New Jersey Avenue SE Washington, DC 20590	Final Report **14. Sponsoring Agency Code** Part of TPF-5(438)

15. Supplementary Notes

Visit https://swzdi.intrans.iastate.edu/ for color pdfs of this and other research reports.

16. Abstract

This study investigated methods for improving the effectiveness of speed feedback trailers (SFTs) when used as a speed management strategy in highway work zones. The research included a literature review, a state department of transportation (DOT) survey, and field evaluations conducted at several freeway work zones. The findings were synthesized to provide recommendations on methods for optimizing the deployment of SFT in freeway work zones. The state DOT survey revealed that SFTs are widely implemented in work zones across the United States, most commonly for lane closures and traffic shifts. Their use varies across states, ranging from optional to mandatory under specific conditions. SFTs are most commonly positioned near the work area or in advance of the lane closure taper and are often relocated as the work progresses. From there, a series of field studies were conducted within freeway work zones in Michigan and Missouri to evaluate the effectiveness of various SFT deployment strategies towards reducing work zone speeds and improving speed compliance. These evaluations, conducted in multiple phases and at five freeway work zone locations, sought to yield insights and recommendations for optimizing SFT deployment and introducing measures to improve their overall effectiveness. The evaluations specifically assessed the impact of strategically placing SFTs at various locations within the work zones, including near the start of a lane closure, approaching a work area, approaching a lane shift, and within a freeway crossover. Additionally, the effectiveness of SFTs were also assessed when combined with other strategies, like digital speed limits (DSLs) signs and police vehicle presence within the work zone. Although SFTs were generally effective at reducing work zone speeds regardless of the deployment characteristics, they tended to be more effective when positioned closer to the work area, including ingress/egress locations, where speeds were up to 3.6 mph lower when the SFT was present and active. SFTs were also effective at lowering work zone speeds when positioned within 1,000 beyond the end of the lane closure taper, within 1,000 ft in advance of the start of the taper, and within freeway crossovers. The speed reduction effects were generally sustained for at least one-half mile beyond the SFT. SFTs were also found to improve speed reductions measured near a police vehicle positioned within the lane closure by an additional 1.4 mph. Additionally, when paired with DSL signs on the same trailer assembly, the speed feedback display reduced speeds near the work area by an additional 1.8 mph. It is recommended that if only a single SFT is to be used, it should be positioned near the work area, approximately 200 ft in advance of the active work. If additional SFTs are available, then it is recommended that one be positioned within 1,000 ft upstream of the lane closure, shift, or crossover. Additionally, an SFT should be placed shortly beyond the end (e.g., within 1,000 ft) of any lane closure taper, preferably adjacent to the initial speed limit sign.

17. Key Words	18. Distribution Statement
enforcement—lane closure—speed feedback trailer—speed management—work zone	No restrictions.

19. Security Classification	20. Security Classification	21. No. of Pages	22. Price
Unclassified.	Unclassified.	166	NA

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

IMPROVING THE EFFECTIVENESS OF SPEED FEEDBACK TRAILERS IN FREEWAY WORK ZONES

Final Report
March 2024

Principal Investigator
Timothy J. Gates, Professor, Michigan State University

Co-Principal Investigators
Peter T. Savolainen, MSU Foundation Professor, Michigan State University

Praveen Edara, Professor, University of Missouri

Henry Brown, Research Engineer, University of Missouri

Research Assistants
Sakar Pahari, Sagar Keshari, Myles Overall, Magdalena Cavka, Sarah Premo, and John Racine

Authors
Timothy J. Gates, Peter T. Savolainen, Praveen Edara, Henry Brown, Sakar Pahari, Sagar Keshari, Myles Overall, Magdalena Cavka, Sarah Premo, and John Racine

Sponsored by
Smart Work Zone Deployment Initiative and
Federal Highway Administration Pooled Fund Study TPF-5(438):
Iowa (lead state), Illinois, Kansas, Michigan, Missouri, Nebraska, Texas, and Wisconsin

Preparation of this report was financed in part
through funds provided by the Iowa Department of Transportation
through its Research Management Agreement with the
Institute for Transportation
(InTrans Project 20-733)

A report from
Smart Work Zone Deployment Initiative
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
https://swzdi.intrans.iastate.edu/

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AFAD	automated flagger assistance device
BDE	Bureau of Design and Environment
CMS	changeable message sign
DOT	department of transportation
MUTCD	*Manual on Uniform Traffic Control Devices*
PCMS	portable changeable message sign
RSFS	radar speed feedback sign
SFT	speed feedback tailer
SWZDI	Smart Work Zone Deployment Initiative
TAC	technical advisory committee
TMP	Transportation Management Plan
U	unit item
WZDSLS	work zone digital speed limit sign

ACKNOWLEDGMENTS

This research was conducted under the Smart Work Zone Deployment Initiative (SWZDI) and Federal Highway Administration (FHWA) Pooled Fund Study TPF-5(438), involving the following state departments of transportation:

- Iowa (lead state)
- Illinois
- Kansas
- Michigan
- Missouri
- Nebraska
- Texas
- Wisconsin

The authors would like to thank the FHWA, the Iowa Department of Transportation (DOT), and the other pooled fund state partners for their financial support and technical assistance. The Iowa DOT also used Federal SPR Part II, CFDA 20.205 funding for this work

The authors would also like to thank the technical advisory committee (TAC) for this project, including Chris Brookes, (Project Manager, Michigan DOT [MDOT]), Keith Brown (MDOT), Chuck Bergmann (MDOT), Sarah Hoffman (MDOT), Davis Woo (MDOT), Andrew Daukşts (Give 'Em a Break Safety), Dan Smith (Missouri DOT [MoDOT]), and Randy Morris (MoDOT).

EXECUTIVE SUMMARY

While reducing speed limits in work zones is a common practice, ensuring compliance with these limits remains a significant concern, necessitating the exploration of alternative strategies for improvement. Speed feedback trailers (SFTs) are frequently deployed by state departments of transportation (DOTs) to mitigate issues associated with work zone speed compliance. However, research is needed to determine methods for optimizing the effectiveness of SFTs as a speed management strategy in work zones. This project aimed to assess the effectiveness of various SFT deployment strategies for work zones in order to inform the guidelines and practices for SFT implementation utilized by state DOTs.

Example speed feedback trailer in a freeway work zone lane closure in Michigan

To achieve this goal, researchers conducted a synthesis of best practices on the use of SFTs as a work zone speed management treatment through an extensive review of research reports, journal articles, and state DOT policies, guidelines, and practices. A nationwide state agency survey of work zone SFT utilization was also conducted, which yielded responses from 40 state DOTs. From there, a series of field studies were conducted within freeway work zones in Michigan and Missouri to evaluate the effectiveness of various SFT deployment strategies towards reducing work zone speeds and improving speed compliance. The findings were then synthesized to provide guidance and recommendations on the use of SFT in freeway work zones.

State DOT Practices for SFT Use in Work Zones

Results from the literature review and DOT survey indicate a wide range of DOT practices for speed feedback trailers in work zones. The use of speed feedback trailers in work zones is relatively prevalent among state DOTs, with 31 of 40 responding DOTs indicating their use in the survey. Based on the survey results, 19 responding DOTs have developed policies, guidance, or standards for speed feedback trailers in work zones. Depending on the state, the use of speed feedback trailers in work zones can be optional, recommended, or required under certain conditions. Example criteria for which DOTs consider or require the use of speed feedback trailers include: worker presence, absence of positive protection, work type (e.g., paving), roadway facility type (e.g., freeway), project cost, lane closures, night work, and high crash frequency. For work zones on both freeways and non-freeways, speed feedback trailers are most frequently used for lane closures, followed by traffic shifts.

For placement of speed feedback trailers, DOTs most frequently place speed feedback trailers near the work area or prior to the taper (e.g., in the advance warning area). In some cases, DOTs require the use of more than one speed feedback trailer in the work zone. Regarding practices for repositioning speed feedback trailers in work zones, the most common practice among state DOTs is repositioning the speed feedback trailer as the work area moves, followed by leaving it in one location and periodically repositioning it within the same work zone.

DOTs sometimes use built-in features for speed feedback trailers. The most commonly used built-in feature for speed feedback trailers in work zones is a flashing speed display when a vehicle exceeds a threshold speed. The threshold speed varies between DOTs but is typically 1 to 10 mph over the work zone speed limit. Some DOTs do not allow the numbers on the display to flash. At higher speeds, some DOTs require the display to be blank to discourage drivers from trying to get a high speed displayed on the panel. State DOTs also have various other requirements for speed feedback trailers in work zones, such as detection distances, color, duration of use at one location, approved products lists, data logging, training, monitoring, and basis of payment.

Among the DOTs that use performance measures to assess SFTs, speed limit compliance or non-compliance is most often utilized. Previously completed research studies documented in the literature show that use of speed feedback trailers in work zones is effective in reducing vehicle speeds, with average speed reductions ranging from 0.8 to 10 mph. DOTs perceive trailer location within the work zone and police presence to be the factors that most influence the performance of speed feedback trailers in work zones.

DOTs perceive the lack of data on performance as the greatest challenge to implementing speed feedback trailers in work zones. Another concern noted by some DOTs was a perceived tendency for their reduced effectiveness over time at the same location.

Field Evaluations of SFT Effectiveness in Freeway Work Zones

A series of field evaluations were performed within five freeway work zone lane closures in 2022 and 2023 to evaluate strategies aimed at enhancing the effectiveness of SFTs towards reducing work zone speeds and improving compliance. These evaluations, conducted in multiple phases and at five freeway work zone locations, sought to yield insights and recommendations for optimizing SFT deployment and introducing measures to improve their overall effectiveness. The majority of the evaluations were performed in Michigan, with one evaluation performed in Missouri. The test conditions evaluated during the field studies are displayed along with the selected freeway work zone locations are displayed in the table below.

Field evaluations test conditions and selected freeway work zone sites

No.	Test Condition Evaluated	Work Zone Location
1	SFT positioning at a lane closure taper	EB I-69, Lapeer, MI
2	SFT positioning in the advance warning area approaching a lane shift	EB I-70, Rocheport, MO
3	SFT positioning approaching the work area within a lane closure	WB I-69, Lapeer, MI
4	SFT paired with a police vehicle in a lane closure	EB I-69, Lapeer, MI
5	SFT in a median crossover	SB I-69, Olivet, MI
6	SFT paired with digital speed limit (DSL) signs in a lane closure	NB US 127, Leslie, MI

For the field evaluations performed in Michigan, speed data were collected using a series of handheld LiDAR guns operated by a team of technicians positioned within unmarked vehicles on the roadside within the work zone. A sequence of either two or three LiDAR data collection vehicles were spaced at strategic locations to continuously track individual vehicle speeds throughout the entire target area of the work zone. For each field evaluation, the LiDAR data collection vehicles were positioned on the roadside, away from critical speed measurement points, to minimize the potential influence of the data collection vehicle on driver speed selection behavior. Trailer-mounted microwave speed sensors were positioned on the shoulder upstream and downstream of the SFT for collection of work zone speeds at the Missouri field evaluation location. The key findings from the field evaluations in freeway work zones are summarized as follows:

- **SFT Positioning at a Lane Closure Taper**: Positioning the SFT slightly beyond the end (e.g., 800 ft) of a lane closure taper and adjacent to the nearest R2-1a work zone speed limit sign resulted in speed reductions that were both greater in magnitude and sustained further into the work zone compared to when the SFT was located at the taper start or taper end. With the SFT placed 800 ft beyond the taper end, speeds measured 2,900 ft beyond the SFT (4,800 ft beyond the start of the taper) were 1.4 mph lower compared to the other SFT positions.
- **SFT Positioning in the Advance Warning Area Approaching a Lane Shift:** The SFT was increasingly more effective at reducing daytime and nighttime speeds at the lane shift as it was positioned closer to the start of the lane shift. With the SFT in the closest position to the lane shift (approximately 1,000 ft in advance of the shift), speeds were 2.0 mph and 2.7 mph lower during the day and night, respectively, compared to when the SFT was not present.
- **SFT Positioning Approaching the Work Area Within a Lane Closure:** The SFT was increasingly more effective at reducing speeds of vehicles approaching and entering the work area as it was positioned closer to the work area. With the SFT positioned 200 ft from the start of the work area, speeds were 3.6 mph lower entering the work area compared to when the SFT was positioned further upstream.
- **Police Vehicle Placement Within a Lane Closure:** Greater speed reductions were observed when the police vehicle was positioned at the initial R2-1a sign within the lane closure (approximately 800 ft after the end of the taper), compared to when the police vehicle was positioned the taper end. The presence of the police vehicle at this location accounted for average speed reductions of approximately 4 mph, which was largely sustained for at least 1,000 ft downstream as drivers proceeded towards the work area.

- **Combined Use of SFT With a Police Vehicle:** Adding an SFT to a lane closure with a police vehicle present provided an incremental speed reduction effect. With the police vehicle positioned near the R2-1a sign, speeds were 1.4 mph lower with the SFT present at the taper compared to when no SFT was present, and 5.4 mph lower compared to when neither treatment was present at the work zone.
- **SFT Within a Median Crossover**: The use of an SFT within a freeway crossover reduced speeds of passenger vehicles by 1.1 mph but did not affect speeds of large trucks.
- **SFT Paired With a Digital Speed Limit (DSL) Sign in a Lane Closure:** Lowering the speed limit on the DSL from 60 to 45 mph reduced vehicle speeds by 3.6 mph when an MDOT work truck was positioned on the shoulder. Activating the SFT in combination with the DSL reduced speeds by an additional 1.8 mph near the work truck. These findings support the continued use of the combined SFT + DSL assembly as a speed reduction strategy in freeway work zone lane closures, especially near work areas due to the simplicity of switching between the 60 and 45 mph work zone speed limits and the reduced ambiguity for motorists.

Recommendations for Improving SFT Effectiveness in Freeway Work Zones

When deployed in work zones, the primary purpose of an SFT is to alert motorists of the need for compliance with the work zone speed limit, particularly near potential conflict points, such as a merging taper, work area, or lane shift. Thus, there is value to providing SFTs at multiple strategic locations approaching and within the work zone. The state agency survey found that DOTs were most likely to deploy SFTs in advance of the taper (65%), followed by near the work area (58%), and at the taper (32%). The field evaluations tested the effects of SFTs in each of these general areas within freeway work zones, which allowed for recommendations to be made.

Optimal SFT Deployment Locations

Although SFTs were generally effective at reducing work zone speeds regardless of the deployment characteristics, they tended to be more effective when positioned closer to the work area, including ingress/egress locations. Thus, if only a single SFT is to be used, which is commonly the case for work zones of a shorter distance, it should be positioned near the work area, approximately 200 ft upstream of the start of the active work. Positioning the SFT in this manner helps ensure that motorists receive the speed feedback message in a timely manner within sight of the work area, but also with adequate time to comfortably decelerate. The authors caution against placing the SFT at too great a distance upstream of the work area, as drivers may be more likely to disregard such an early warning message. For work zones with multiple active work areas, an SFT should be deployed in advance of each area while workers are present.

The use of additional SFTs at other locations within the work zone, particularly for work zones that cover a substantial distance, is also encouraged. If additional SFTs are available, then it is recommended that one be positioned within 1,000 ft upstream of the lane closure, shift, or median crossover. Additionally, an SFT should be placed shortly beyond the end (e.g., within 1,000 ft) of any lane closure taper, preferably adjacent to the initial speed limit sign in order to draw drivers' attention to the work zone speed limit upon entering the lane closure. Deployment of an SFT within a median crossover is also encouraged, although less critical if barrier separation of opposing traffic flows is provided.

The spacing of successive SFTs within a lane closure should be based on the distance that the SFT-related speed reduction effects are sustained beyond the SFT, which was generally at least one-half mile beyond the SFT. However, half-mile SFT spacing is likely impractical for most lengthy work zones, and greater SFT spacings (e.g., 2 miles) are generally acceptable.

Combining SFTs with Other Speed Management Strategies

SFTs are also encouraged for use in combination with work zone police enforcement vehicles, regardless of whether any active enforcement is being performed. While a police vehicle positioned near the end of the taper will, by itself, reduce speeds by approximately 4 mph, adding a nearby SFT provides an additional speed reduction effect. Finally, the combined use of an SFT and digital speed limits is also encouraged, especially near work areas. This is due to the incremental speed reductions provided by the SFT along with the simplicity of switching between speed limits (e.g., work zone vs. non work zone, workers present vs. not-present) and, subsequently, the reduced ambiguity for motorists as to which speed limit is in effect at any given time and location within the work zone.

1. INTRODUCTION

1.1. Background and Problem

Greater than 100,000 work zone crashes were reported in the United States in 2021, resulting in 874 fatalities and claiming the lives of 956 people (ARTBA 2023). Speeding was identified as a contributing factor in approximately one-third of fatal crashes that occurred in work zones (FHWA 2023). Despite the common practice of reducing speed limits in work zones, ensuring compliance with these limits remains a significant concern. This challenge is exacerbated by the nationwide increase in maximum highway speed limits, as work zone speed limits are typically determined based on the original posted speed limits, following the guidance of the *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA 2009). Both workers and drivers in work zones face a precarious situation, as construction activities are conducted while traffic flow is maintained. Establishing appropriate work zone speed limits and ensuring compliance with these limits continue to be crucial for providing safer conditions for both drivers and workers.

The MUTCD recommends the use of reduced speed limits in work zones only when specific conditions or restrictive features are present. Furthermore, the MUTCD advises against frequent changes in speed limits. The temporary traffic control (TTC) plan should be designed "so that vehicles can travel through the TTC zone with a speed reduction of no more than 10 mph." If a speed limit reduction of more than 10 mph is justified, the MUTCD suggests the incorporation of additional driver notification measures (FHWA 2009). Notably, the process for establishing work zone speed limits on freeways varies from state to state. In Michigan, work zone speed limits on freeways are set at 45 mph where workers are present and 60 mph in all other areas (Michigan DOT 2005).

One significant concern in establishing work zone speed limits is the extent to which drivers adhere to these limits. Prior research has found that drivers tend to reduce speeds in work zones only when they perceive the need to do so (Finley et al. 2015). Moreover, drivers traversing lengthy stretches of inactive work zones with reduced speed limits often question the validity of these limits (Outcalt 2009, Richards et al. 1985, Migletz et al. 1999) and maintain normal highway speeds, regardless of the presence of reduced speed limit signs (Brewer et al. 2006). Work zones with more substantial speed limit reductions tend to experience higher levels of non-compliance, irrespective of ongoing work activities (Bham and Mohammadi 2011). These findings collectively underscore the necessity for strategies that complement regulatory work zone speed limit signs with effective speed management countermeasures. This need is particularly evident in states like Michigan, where the work zone speed limit of 45 mph when workers are present represents a 25 to 30 mph reduction from the typical speed limit on rural freeways.

The National Cooperative Highway Research Program (NCHRP) Synthesis 482 (Shaw et al. 2015) delved into speed management strategies for work zones on high-speed roads. This comprehensive review focused on a range of speed management techniques, encompassing speed management devices, alterations in the physical driving environment, and enforcement measures. Numerous studies support the effectiveness of enforcement in reducing speeds (Finley 2015, Medina et al. 2009, Benekohal et al. 1992, Wasson et al. 2011), with the most substantial reductions observed during peak enforcement activity (Wasson et al. 2011). It is noteworthy, however, that these effects diminish almost immediately after enforcement activities cease (Benekohal et al. 1992, Wasson et al. 2011). The efficacy of enforcement is also influenced by the normal operating speeds of the roadway and the specifics of the temporary traffic control plan (Wasson et al. 2011). NCHRP Report 746 provides in-depth information on work zone speed enforcement administration, addressing related issues such as determining the required level of enforcement and optimal police vehicle positioning (Ullman et al. 2013).

Considering the safety challenges and practical complexities associated with speed enforcement in work zones, there is a pressing need to explore alternative strategies for enhancing compliance with work zone speed limits. One such strategy involves the deployment of dynamic speed feedback signs (DSFS), also referred to as speed display signs, which utilize speed data from an integrated radar to display real-time speed-related messages to drivers on a digital display panel in various formats, most commonly the measured speed of the approaching vehicle (e.g., “YOUR SPEED XX”) or a speed warning message (e.g., “SLOW DOWN” or “TOO FAST”). Furthermore, DSFS can be configured to display different messages or alerts to target certain motorists, such as alternating the measured speed with a speed warning message, flashing the measured speed, or activating warning lights when a speed threshold is exceeded. DSFS installations can be post-mounted, integrated into portable changeable message signs (PCMS), or mounted on a trailer to improve portability. When utilized in work zones, the trailer mounted version is typically used, which is commonly referred to as a speed feedback trailer (SFT) or speed display trailer (Figure 1).

Figure 1. Typical speed feedback trailer used in freeway work zones in Michigan

The effectiveness of SFT deployments have previously been evaluated in various work zone contexts, details of which are provided in the literature review found in the following chapter. This includes a recent study conducted by members of this research team as part of the Smart Work Zone Deployment Initiative (SWZDI), which investigated work zone speed limit policies and practices along with methods for improving work zone speed compliance, including the use of SFTs (Savolainen et al. 2022). The present study sought to build upon this and other previous work zone SFT evaluations and provide an assessment of various use-conditions of SFTs deployed in freeway work zones that had previously not been extensively researched.

1.2. Study Objectives

This project aimed to assess the effectiveness of various SFT deployment strategies for work zones in order to inform the guidelines and practices for SFT implementation utilized by state departments of transportation (DOTs). To that end, the objectives of this project were as follows:

- Conduct a synthesis of best practices in the use of SFTs as a work zone speed management treatment through an extensive literature review and nationwide state agency survey.

- Perform field studies in freeway work zones to evaluate the effectiveness of various SFT deployment strategies towards reducing work zone speeds and improving compliance.
- Provide guidance and recommendations on the use of SFT in freeway work zones.

The remainder of the report provides details related to the work performed to accomplish the study objectives. To that end, the remainder of this report is organized as follows:

- Chapter 2: Literature Review
- Chapter 3: State DOT Survey
- Chapter 4: Field Evaluation Methodology
- Chapters 5 through 10: Field Evaluation Procedures and Results
- Chapter 11: Conclusions and Recommendations

2. LITERATURE REVIEW

This chapter presents the results of the literature review for speed feedback trailers in highway work zones. Reference source materials that were compiled for the literature review included research reports, journal articles, along with state DOT guidelines, policies, and standards. The chapter is organized into the following sections: research studies for speed feedback trailers in work zones (Section 2.1) followed by a summary of state DOT guidelines, policies, and standards for speed feedback trailers in work zones (Section 2.2). Tabular summaries of state DOT guidelines, policies, and standards are provided in Appendix A, while example layouts and standards are provided in Appendix B.

2.1. Research Studies for Speed Feedback Trailers in Work Zones

Several research studies have shown speed feedback trailers to be effective in reducing vehicle speeds in work zones, which are noted below.

- In the most recent study, analysis of data from the Second Strategic Highway Research Program Naturalistic Driving Study showed that dynamic speed feedback signs led to an average speed reduction of 4.0 mph (Hallmark et al. 2023).
- The results from a field investigation of the effects of dynamic speed feedback signs on vehicle speeds at two work zones in Kansas indicated speed reductions at both locations, although one location had speeds closer to the work zone speed limit than the other location (Cunningham et al. 2021). In addition, passenger cars and tractor-trailer trucks were found to be the vehicles most prone to speeding in work zones.
- Results from a field evaluation of radar speed feedback signs mounted on Oregon DOT maintenance trucks moving at slow speed in multilane maintenance work zones showed that the use of the signs led to reduced vehicle speeds and less speed variation between vehicles (Jafarnejad et al. 2017). The speed reduction varied from 0.8 to 5.6 mph.
- Results from a field study in Utah showed that the average vehicle speed was reduced an additional 4 mph as compared to the no-treatment case (Saito and Bowie 2003). In addition, 95% of respondents in a driver questionnaire indicated that they would reduce their speed if a SFT indicated that they were exceeding the speed limit.
- The use of SFTs was evaluated on a section of I-80 in Nebraska over a five-week period (Pesti and McCoy 2001). Results showed that the average speed decreased by 3 to 4 mph. In addition, improvements were observed in speed uniformity and speed compliance. Statistically significant speed reductions were also noted one week after the removal of the trailers.
- A field evaluation of SFTs was conducted at two maintenance work zones on two-lane highways in Texas (Fontaine and Carlson 2001). The results indicated that speed reductions of up to 10 mph were obtained with the SFTs. Higher speed reductions were noted for trucks than for passenger cars.
- A field investigation of speed feedback trailers on I-35 in Iowa showed moderate decreases in vehicle speed and increased speed compliance (Kamyab et al. 2000).
- On an Interstate highway in South Dakota, the use of a speed feedback trailer was associated with average speed reductions of 4 to 5 mph in the work zone (McCoy et al. 1995).

- In a national survey conducted for a study sponsored by Illinois DOT on flaggers and spotters, respondents rated the effectiveness of speed feedback trailers as 0.731 on a scale of 0 (least effective) to 1 (most effective) (El-Rayes et al. 2014).

Prior research has also found the use of PCMSs to display vehicle speeds to be effective in reducing vehicle speeds. For example, a field evaluation of radar speed feedback signs in Arizona also included the use of an alternating monetary fine message (Figure 2) (Roberts and Smaglik 2014). Results from the study showed that that the use of the alternating messages led to a 50% reduction in the number of vehicles driven at least 15 mph over the speed limit. A Virginia study investigated the effect of duration when using a PCMS with radar (Garber and Srinivasan 1998). The sign displayed the message “YOU ARE SPEEDING SLOW DOWN” when a speeding vehicle was found. Results showed that the use of the sign led to speed reductions of 8 to 10 mph. In addition, the duration of exposure of the sign did not significantly impact the results, and there were no discernible differences in speed reductions among different vehicle types. A field evaluation of a PCMS with radar was conducted in Georgia (Wang et al. 2003). The sign showed the message “You Are Speeding, Slow Down Now” to vehicles exceeding the work zone speed limit by at least 5 mph (work zone speed limit was 45 mph) and the message “Active Workzone, Reduce Speed” when there were no vehicles present or vehicles traveling at speeds less than 50 mph. The results showed a decrease in average speed of 7 to 8 mph, and the effect continued for three weeks. However, the speed reduction was 0.9 to 1.6 mph at the active work area, possibly due to the high length (12 miles) of the work zone.

Roberts and Smaglik 2014

Figure 2. Speed feedback PCMS in Arizona study

Other research studies have investigated the effects of flashing beacons and message size. Field testing of a speed-activated sign in South Carolina was performed by Mattox et al. (2007). The static sign included the message "YOU ARE SPEEDING IF FLASHING" with a flashing beacon activated when the speed threshold is exceeded. Results showed an average reduction in mean speed of 3.3 mph on two-lane highways, with comparable results on a multilane divided highway and Interstate freeway (Mattox et al. 2007). In a study by Teng et al. (2009), the effectiveness of SFTs was assessed at two work zones in Nevada. The study found that the use of larger messages, flashing signs, and multiple SFTs led to higher speed reductions. The extent of the effect varied with vehicle classification, lane usage, and time of day. The researchers suggested the use of a larger message size, flashing signs, and multiple SFTs to help reduce vehicle speeds.

Other research studies have shown speed reductions when speed display signs are used in conjunction with other countermeasures. For example, an assessment of the effectiveness of presence lighting and digital speed limit trailers at a work zone on I-65 in Indiana was conducted using commercially available speed data for connected vehicles (Sakhare et al. 2021). Results showed that median speeds were reduced by 4 to 13 mph during nighttime. Results from a field evaluation of six work zone speed countermeasures in New Brunswick showed that the following three combinations provided the best speed reductions: Traffic Control Person and Floating Speed Zone (zone of speed reduction that moves with active work area), Fake Police Vehicle and Floating Speed Zone, and Radar Speed Display Board and Floating Speed Zone (Mason 2013). The mean speed reduction for the Radar Speed Display Board and Floating Speed Zone was 12 mph. Results from a California field study indicated that the use of a speed feedback trailer with PCMS resulted in an additional 3 to 7 mph speed reduction than just the lane closure alone in the work zone (Ravani et al. 2012). The use of a law enforcement officer in conjunction with the trailer resulted in a 5 to 9 mph further speed reduction than with the closure alone.

Previous research has also investigated the use of red and blue lights on speed feedback trailers in work zones. A field study and driving simulator study of various work zone speed countermeasures, including speed feedback trailers, were conducted in Missouri (Brown et al. 2022). Variations of the SFT included flashing vehicle speed and the use of flashing red and blue lights. The SFT with red and blue lights is shown in Figure 3. For the field study, the use of a SFT with red and blue lights resulted in an additional speed reduction of 2.8 mph during daytime and 2.1 mph during nighttime as compared to the base scenario with no work zone speed countermeasures. In the simulator study, the use of the SFT without red and blue lights led to additional speed reductions of 1.4 mph during daytime, while the SFTs with and without red and blue lights were not associated with additional speed reductions during nighttime. In a post-simulator survey, participants indicated a belief that the SFT with red and blue lights was more effective than the SFT without red and blue lights. Results from a general driver survey indicated that respondents thought that the SFT with red and blue lights was the highest rated work zone speed control strategy for both daytime and nighttime.

Brown et al. 2022

Figure 3. Speed feedback trailer with flashing red and blue lights in Missouri field study

2.2. State DOT Guidelines, Policies, and Standards for Speed Feedback Trailers in Work Zones

This section summarizes state DOT guidelines, policies, and standards for speed feedback trailers in work zones. Additional information may be found in tabular summaries in Appendix A, and example layouts and standards are provided in Appendix B.

2.2.1. Conditions for Use of Speed Feedback Trailers in Work Zones

DOTs consider or require the use of speed feedback trailers for work zones for different conditions. Examples of these conditions are provided below.

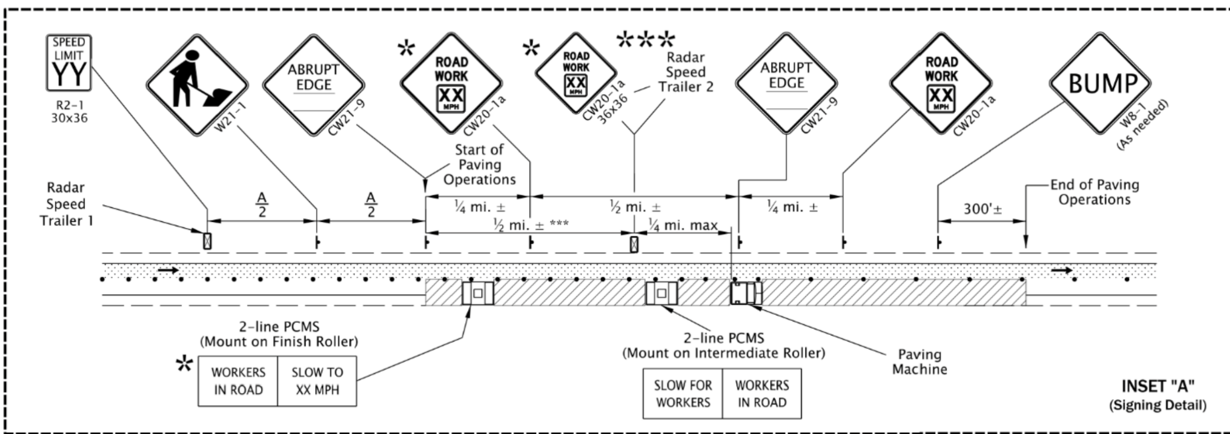
- Indiana DOT indicates that speed feedback trailers should be considered if positive protection is not provided (Indiana DOT 2013).
- For Maryland DOT, the SFT should be deployed in work zones with existing or anticipated concerns with speeding (Maryland State Highway Administration 2005).
- Minnesota DOT allows the use of speed feedback trailers with a regular posted speed limit sign, 24/7 construction speed limit assembly, workers present speed limit assembly, or a plaque for advisory speed (Minnesota DOT 2014).
- Nevada DOT provides a work zone speed reduction countermeasure matrix to facilitate the selection of work zone speed reduction countermeasures, including speed feedback trailers, based on work zone conditions (Nevada DOT 2019).
- Oregon DOT requires the use of SFTs for paving operations on freeways and allows for their use elsewhere as engineers deem appropriate (Oregon DOT 2023).
- In Pennsylvania, the use of SFTs is required for Interstate work zones with project cost greater than $300,000 (Pennsylvania General Assembly 2002).
- South Dakota DOT indicates that speed feedback trailers for work zones should be considered under various conditions, such as Interstate projects with lane closures and workers present, locations with work zone crashes, and night work (South Dakota DOT 2020).
- For the Vermont Agency of Transportation, example conditions under which the use of speed feedback trailers should be considered include significant construction projects, lane closures on expressways or multi-lane highways, narrow shoulders, pavement edge drop-offs, night work, excessive speeding, or high crash frequency (VTrans 2016).
- For Washington State DOT, the use of a radar SFT is required for construction (recommended for maintenance) when freeway traffic is shifted onto the shoulder and optional for freeway lane closures when traffic is not shifted onto the shoulder (Washington State DOT 2021).

2.2.2. Placement of Speed Feedback Trailers in Work Zones

Some DOTs also include requirements for the placement of SFTs in work zones. These requirements often specify that the SFTs should be located near the work area or as otherwise directed. Example DOT requirements for the placement of SFTs are provided below.

- A standard layout from Illinois DOT shows a portable speed feedback trailer located upstream of the taper (Illinois DOT 2022).
- Standard drawings from Iowa DOT show a speed feedback trailer at the end of the merge taper when the non-work zone speed limit is 60 mph or higher (Iowa DOT 2023). In addition, the optimum location to place the speed feedback trailer, as noted by Iowa DOT, is on a tangent section of the roadway between 500 and 2,500 ft of the workers or the hazardous conditions (Iowa DOT 2018).
- According to Maryland DOT, placement should be upstream of the location of the work zone (Maryland State Highway Administration 2005).
- Missouri DOT prescribes that the SFT should be placed downstream from the initial sign package based on the plans or Engineer’s direction (Missouri DOT 2021).

- The Oregon DOT standard layout for a one lane closure with speed reduction for paving operations shows two SFTs: one prior to paving area and one within paving area (Figure 4). A note on the layout drawing indicates that trailers should be placed as shown or directed (Oregon DOT 2021).
- South Dakota DOT indicates that speed feedback trailers should be placed at a location upstream of the activity area on the right shoulder or right closed lane (South Dakota DOT 2020).
- According to the Vermont Agency of Transportation, the SFTs should be placed in advance of the activity area of the work zone on the right side (VTrans 2016). More than one trailer should be used for work zones longer than one mile.
- According to Washington State DOT, the preferred location of the radar speed feedback sign is plus or minus 500 ft from the work area (Washington State DOT 2022a.). Placement should be at least 4 ft from the edge of a travel lane (Washington State DOT 2022b).



Oregon DOT 2021

Figure 4. Layout for one lane closure with speed reduction (paving operations) and speed feedback trailers for Oregon DOT (Standard Drawing TM880)

2.2.3. Operational Requirements for Speed Feedback Trailers in Work Zones

DOTs also specify operational requirements for SFTs in work zones. These requirements can include provisions for flashing the speed or displaying the message "SLOW DOWN" when the work zone speed limit is exceeded. In some cases, speeds above a threshold value are not displayed to discourage drivers from trying to get high numbers. Example DOT operational requirements are provided below.

- The system should display the speed limit and vehicle speed and have a limit for the maximum speed that is displayed (Arkansas DOT 2018).
- Illinois DOT requires the displayed speed to flash when the speed is higher than the work zone posted speed limit. In addition, speeds over a maximum cutoff speed (15 mph or 25 mph over the work zone speed limit) should not be displayed (Illinois DOT 2021).
- Iowa DOT does not allow the use of text, strobe lights, or flashing (Iowa DOT 2018).

- Michigan DOT prescribes that the unit should include display options to flash the vehicle speed when the vehicle speed is 1 to 10 mph over the work zone speed limit and to display the message “SLOW DOWN” if the vehicle speed is greater than 10 mph above the work zone speed limit (Michigan DOT 2021).
- Minnesota DOT indicates that the system should flash when the vehicle speed is above the advisory speed. The display should go blank when a threshold speed is exceeded (Minnesota DOT 2020).
- As required by Missouri DOT, the system should display the speed (not flashing) when the speed is at or below the work zone speed limit, flash the speed when the speed is 1 to 10 mph over the work zone speed limit, and show the message “SLOW DOWN” when the speed is more than 10 mph over the work zone speed limit (Missouri DOT 2021).
- Oregon DOT prescribes that the system should be able to display the vehicle speed (static or flashing) and an alternating “SLOW DOWN” message (Oregon DOT 2022). Various operating modes for the SFT are shown in Figure 5. In addition, the display should turn blank when the speed is more than 30 mph above the speed limit to discourage drivers from trying to get a high speed displayed on the panel (Oregon DOT 2023).
- South Dakota DOT does not allow the numbers on the display to flash (South Dakota DOT 2020).
- As prescribed by the Vermont Agency of Transportation, the system should not include any rapid flashing or animation and should be able to show a blank display when the speed is more than 15 mph over the work zone speed limit (VTrans 2016).
- Washington State DOT indicates that the system should flash speed when work zone speed limit is exceeded and should have a maximum cutoff for displaying speeds (Washington State DOT 2022b).

Operating Mode	Panel Display	Sign	Advisory Speed (YY) Operation			
			<[YY-10] MPH	[(YY-10) to YY] MPH	>[YY] MPH	
Radar Speed	Numeral (Static & Flashing)		No Display	Display Vehicle Speed “XX”	Alternate Vehicle Speed “XX” (0.5 seconds) followed by “SLOW DOWN” (1.5 seconds)	
			Regulatory Speed (ZZ) Operation			
			<[ZZ-20] MPH	[(ZZ-20) to ZZ] MPH	[ZZ to (ZZ-20)] MPH	>[YY+20] MPH
Warning Message	Alpha/Legend (Static & Flashing)		No Display	Display Vehicle Speed “XX”	Alternate Vehicle Speed “XX” (0.5 seconds) followed by “SLOW DOWN” (1.5 seconds)	No Display

Oregon DOT 2022

Figure 5. Operating modes for speed feedback trailer for Oregon DOT

2.2.4. Other Requirements for Speed Feedback Trailers in Work Zones

State DOTs also have various other requirements for SFTs in work zones, such as detection distances, color, duration of use at one location, approved products list, data logging, training, monitoring, and basis of payment. Examples of these requirements are shown below.

- Michigan requires the unit to detect vehicles at a distance of at least 400 yd, while the minimum detection distance for Missouri DOT is 1,000 ft (Michigan DOT 2021, Missouri DOT 2021).
- Several DOTs, such as Illinois DOT and Vermont Agency of Transportation, indicate that the color should be yellow on a black background (Illinois DOT 2021, VTrans 2016). The Vermont Agency of Transportation also allows black on a yellow background (VTrans 2016). A draft special provision from Virginia DOT indicates that the display should be white on a black background (Virginia DOT n.d.).
- Maryland DOT indicates that the preferred time limit for deployment is two weeks. For longer deployments of several weeks, periodic law enforcement should be provided (Maryland State Highway Administration 2005).
- Alabama DOT lists five products approved for radar speed signs, while Minnesota DOT provides a list of four standard size and two oversized products for vehicle speed feedback signs (Alabama DOT 2023, Minnesota DOT 2023a).
- Several DOTs, such as Michigan DOT, Missouri DOT, Oregon DOT, and Washington State DOT, include data logging requirements (Michigan DOT 2021, Missouri DOT 2021, Oregon DOT 2021, Washington State DOT 2022b). Michigan DOT prescribes that the system must log traffic volume data in 10-minute increments, and cellular service is required for remote access and data management (Michigan DOT 2021).
- In Arkansas, the Contractor must provide the system to the Department. The Contractor provides training but does not operate the system. After training, the system is owned by the Department (Arkansas DOT 2018).
- Minnesota DOT provides an evaluation guide to assess the condition (acceptable, marginal, or unacceptable) of trailer-mounted electronic devices (Minnesota DOT 2018). The SFTs should be monitored to ensure proper operation (Minnesota DOT 2022).
- The basis of payment is typically per each SFT. For Washington State DOT, measurement and payment based on each hour that each sign is operating (Washington State DOT 2022b).
- In Pennsylvania, the use of PCMSs to display vehicle speeds is allowed as an alternative (Penn Code).

3. STATE DOT SURVEY

This chapter presents the methodology and results for the survey that was administered to DOTs within all 50 states and the District of Columbia.

3.1. Methodology

An online survey on speed feedback trailers was developed and administered by the researchers. The survey consisted of 19 questions and was reviewed by the project technical advisory committee (TAC) before being sent to the DOTs from all 50 states and the District of Columbia via Qualtrics survey software (Qualtrics 2023). The survey was sent to one respondent from each DOT using a contact list that was developed based on information obtained from FHWA and from previous surveys conducted by the researchers on work zone related topics. Each DOT respondent received a unique survey link that could be shared within the DOT for collaboration purposes, with responses limited to one per DOT. As shown in Figure 6, responses were received from 40 DOTs for a response rate of 78%. The survey response rate for the SWZDI states was 89%.

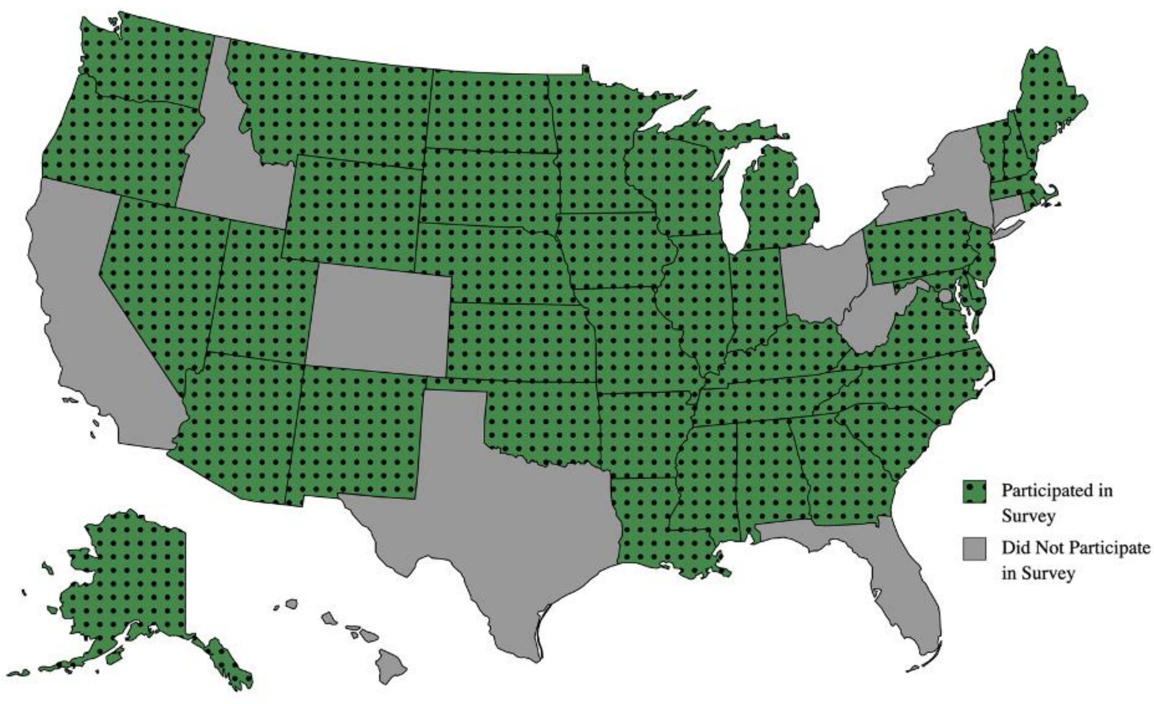


Figure 6. Map showing DOTs that responded to the survey on speed feedback trailers

The survey covered various topics regarding speed feedback trailers, such as extent of use, practices and policies, performance, and implementation challenges. The survey utilized skip logic based on whether the responding DOT uses speed feedback trailers in work zones. Survey respondents who indicated in response to the first question that they do not use speed feedback trailers in work zones were only asked two additional questions regarding factors that hinder use of speed feedback trailers in work zones. DOTs that use speed feedback trailers in work zones were asked all 19 survey questions. A copy of the full survey is provided in Appendix C, and the survey responses for each DOT, including comments and resources submitted, are given in Appendix D.

3.2. Results

This section presents the survey results and is divided into the following subsections: Use of Speed Feedback Trailers in Work Zones (Questions 1, 3–6), Practices for Speed Feedback Trailers in Work Zones (Questions 2, 7–13), Performance of Speed Feedback Trailers in Work Zones (Questions 14–17), Challenges to Using Speed Feedback Trailers in Work Zones (Question 18), and Other Survey Feedback (Question 19).

3.2.1. Use of Speed Feedback Trailers in Work Zones

The first section of the survey sought information from DOTs regarding their use of speed feedback trailers in work zones. The first question asked DOTs if they currently use speed feedback trailers in work zones. As shown in Table 1, approximately 78% of responding DOTs indicated that they use speed feedback trailers in work zones.

Table 1. Survey results for use of speed feedback trailers in work zones (Q1)

Answer Choice	Response	Count
Yes	77.5%	31
No	22.5%	9
No Response	0%	0

Note: Total number of respondents = 40.

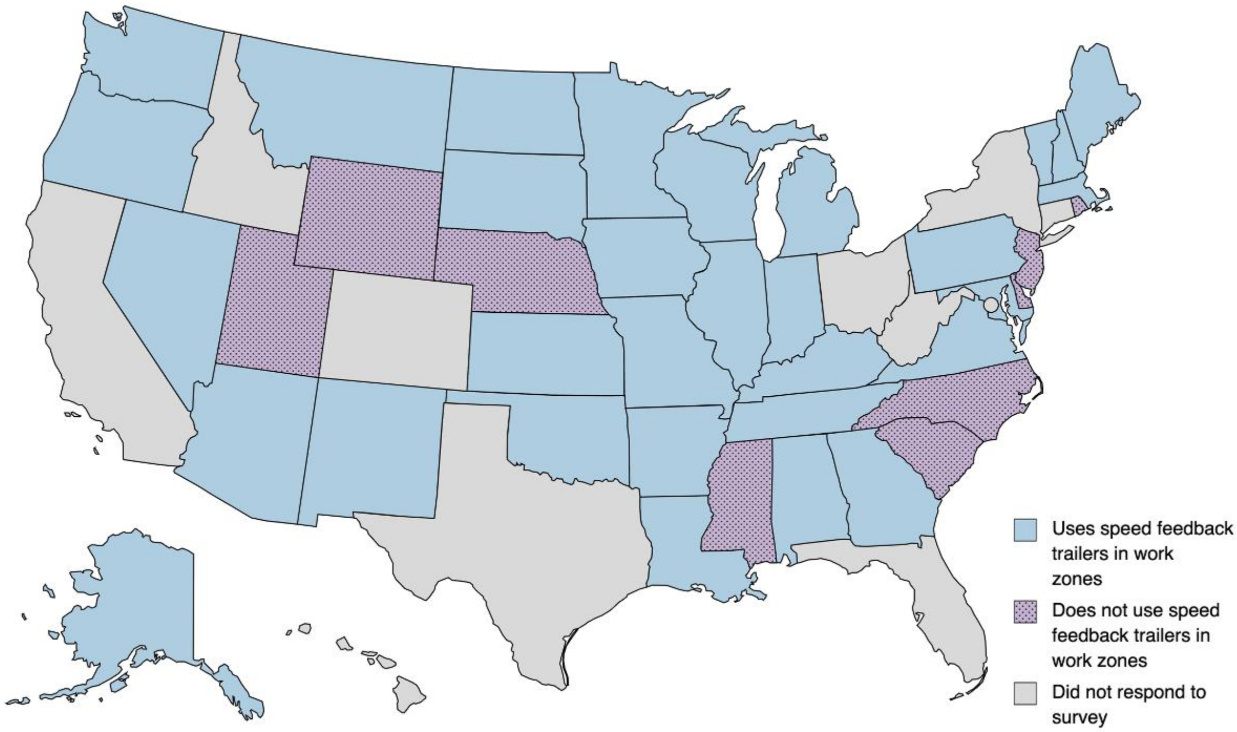


Figure 7. Map showing use of speed feedback trailers in work zones by DOT

Question 3 sought information from the DOTs who answered yes to Question 1 regarding the types of work zone configurations for which DOTs use speed feedback trailers in work zones on freeways. As shown in Table 2, speed feedback trailers are most frequently used for lane closures, followed by traffic shifts and crossovers. Only seven DOTs indicated that they use speed feedback trailers for shoulder closures. Other responses include Interstate resurfacing and problematic areas (e.g., excessive speeding or high crash area).

Table 2. Survey results for types of work zone configurations for which speed feedback trailers are used in work zones on freeways (Q3)

Work Zone Configuration	Response	Count
Lane closures	84%	26
Traffic shifts	52%	16
Crossovers	52%	16
Lane-narrowing	32%	10
Shoulder closures	23%	7
Other	29%	9
None of the above	3%	1
No Response	0%	0

Note: Percentages based on number of respondents who answered the question (n=31); multiple answers were allowed.

Question 4 asked DOTs about types of work zone configurations for which speed feedback trailers are used in work zones on non-freeways. The results, shown in Table 3, indicate that speed feedback trailers are most frequently used for lane closures and traffic shifts. Other responses include off-shoulder work on freeways and based on conditions.

Table 3. Survey results for types of work zone configurations for which speed feedback trailers are used in work zones on non-freeways (Q4)

Work Zone Configuration	Response	Count
Lane closures	61%	19
Traffic shifts	52%	16
Crossovers	35%	11
Lane-narrowing	39%	12
Shoulder closures	29%	9
Other	26%	8
None of the above	26%	8
No response	0%	0

Note: Percentages based on number of respondents who answered the question (n=31); multiple answers were allowed.

Question 5 sought information regarding the frequency of use for speed feedback trailers in work zones on freeways and non-freeways. As shown in Table 4, speed feedback trailers are generally used more frequently on freeways than non-freeways. Six DOTs indicated that they do not use speed feedback trailers in work zones on non-freeways, while all 31 DOTs use them on freeways.

Table 4. Survey results for frequency of use of speed feedback trailers in work zones (Q5)

Facility type	Frequently	Sometimes	Rarely	Never	No response
Freeways	39%	39%	23%	0%	0%
Non-Freeways	6%	39%	35%	19%	0%

Note: Percentages based on number of respondents who answered the question (n=31).

Question 6 asked DOTs if they use speed feedback trailers in non-work zone situations. The results, shown in Table 5, indicate that 15 DOTs use speed feedback trailers in non-work zone situations. Example applications as noted by survey respondents include school zones, speed transitions with low speed compliance, and high-risk locations.

Table 5. Survey results for use of speed feedback trailers in non-work zone situations (Q6)

Answer Choice	Response	Count
Yes	48%	15
No	52%	16
No Response	0%	0

Note: Percentages based on number of respondents who answered the question (n=31).

3.2.2. Practices for Speed Feedback Trailers

Questions 2 and 7-13 asked DOTs about various aspects of their practices for using speed feedback trailers in work zones. Question 2 asked the DOTs that answered yes to Question 1 if they have developed any policies, guidance, or standards regarding the use of speed feedback trailers in work zones. As shown in Table 6, 61% of responding DOTs indicated that they have developed policies, guidance, or standards for speed feedback trailers in work zones. DOTs were also asked to describe their policies and to provide relevant documents. Results from the policy descriptions, which are provided in Appendix D, indicate that the use of speed feedback trailers in work zones can be optional, recommended, or required under certain conditions. Seventeen DOTs submitted documents in response to this question, and a list of these documents (with hyperlinks if available) is provided in Appendix D.

Table 6. Survey results for development of policies, guidance, or standards for speed feedback trailers in work zones (Q2)

Answer Choice	Response	Count
Yes	61.3%	19
No	35.5%	11
No Response	3.2%	1

Note: Percentages based on number of respondents who answered the question (n=31).

Question 7 asked DOTs where the position speed feedback trailers within the work zone. As shown in **Table 7**, DOTs most frequently place speed feedback trailers near the work area or prior to the taper. Other locations noted by respondents include after a speed reduction or speed limit signage or with variable speed limit signs.

Table 7. Survey results for positioning of speed feedback trailers within the work zone (Q7)

Location	Response	Count
Prior to taper (e.g., advanced warning area)	58%	18
Start of taper	16%	5
End of taper	16%	5
Near work area	65%	20
Beyond work area	3%	1
Other	16%	5
None of the above	0%	0
No response	0%	0

Note: Percentages based on number of respondents who answered the question (n=31).

Question 8 sought information regarding the use of speed feedback trailers with built-in features. As shown in **Table 8**, DOTs most frequently use a flashing speed display when a vehicle exceeds a threshold speed. None of the responding DOTs indicated the use of license plate recognition with speed feedback trailers in work zones. Other features mentioned by respondents include speed data collection capabilities and automatic dimming for nighttime operation.

Table 8. Survey results for use of speed feedback trailers with built-in features (Q8)

Feature	Response	Count
Flashing lights, strobes, or beacon when vehicle exceeds threshold speed	13%	4
Flashing speed display when vehicle exceeds threshold speed	61%	19
Speed warning message (e.g., "SLOW DOWN" or "TOO FAST") when vehicle exceeds threshold speed	39%	12
License plate recognition	0%	0
Other (please describe in box below)	10%	3
None of the above	23%	7
No Response	3%	1

Note: Percentages based on number of respondents who answered the question (n=31); multiple answers were allowed.

Question 9 asked DOTs about the threshold speed used to activate built-in features on speed feedback trailers. As shown in Table 9, DOTs use a wide range of speeds, with 0 to 4 mph over the work speed limit most frequently used. Examples of other practices described by survey respondents include flashing speed for 0 to 9 mph above the speed limit with a SLOW DOWN message for 10 mph or more over the speed limit and blanking out the sign above a certain speed.

Table 9. Survey results for threshold speed for built-in features (Q9)

Threshold Speed	Response	Count
0 to 4 mph over work zone speed limit	19%	6
5 mph over work zone speed limit	13%	4
10 mph over work zone speed limit	13%	4
15 mph over work zone speed limit	0%	0
Other (please describe in box below)	16%	5
My agency does not use threshold speeds in conjunction with these built-in features	39%	12
No response	0%	0

Note: Percentages based on number of respondents who answered the question (n=31).

Question 10 of the survey sought information regarding use of speed feedback trailers in conjunction with other speed countermeasures in work zones. The results, shown in **Table 10**, indicate that enforcement, end of queue warning system, and temporary rumble strips are the speed countermeasures mostly frequently used along with speed feedback trailers. Five DOTs indicated that they do not use any of these features in conjunction with speed feedback trailers.

Table 10. Survey results for use of speed feedback trailers in conjunction with other speed countermeasures in work zones (Q10)

Countermeasure	Response	Count
Automated flagger assistance device (AFAD)	10%	3
Automated work zone speed enforcement	10%	3
End of queue warning system	39%	12
Notification of construction equipment entering/exiting	6%	2
Temporary rumble strips	32%	10
Digital speed limit signs	13%	4
Variable speed limits based on worker presence	19%	6
Enforcement	42%	13
Other (please describe in the box below)	0%	0
None of the above	16%	5
No response	3%	1

Note: Percentages based on number of respondents who answered the question (n=31); multiple answers were allowed.

Question 11 asked DOTs about their practices for repositioning speed feedback trailers in work zones. As shown in Table 11, the most common practice is repositioning the speed feedback trailer as the work area moves, followed by leaving it in one location and periodically repositioning it within the same work zone. One DOT indicated that speed feedback trailers are moved based on recommendations from law enforcement.

Table 11. Survey results for practices for repositioning of speed feedback trailers in work zones (Q11)

Practice	Response	Count
Speed feedback trailers remain in one location for the duration of the work zone	42%	13
Speed feedback trailers are repositioned as the work area moves	61%	19
Speed feedback trailers are periodically repositioned within the same work zone to maintain effectiveness	39%	12
Speed feedback trailers are periodically rotated between different work zones to maintain effectiveness	3%	1
Other	16%	5
No response	0%	0

Note: Percentages based on number of respondents who answered the question (n=31); multiple answers were allowed.

In Question 12, DOTs were asked about their primary source for obtaining speed feedback trailers. The results, provided in Table 12, show that 29 DOTs primarily obtain the speed feedback trailers from contractors, while only two DOTs usually provide them.

Table 12. Survey results regarding primary source for obtaining speed feedback trailers for work zones (Q12)

Source	Response	Count
Contractor	94%	29
Law Enforcement	0%	0
My agency provides the speed feedback trailers	6%	2
Other	0%	0
No response	0%	0

Note: Percentages based on number of respondents who answered the question (n=31).

The results for Question 13, shown in Table 13, indicate that DOTs most frequently use a measured pay item as the basis for payment of speed feedback trailers, followed by lump sum pay item. One DOTs noted use of a monthly rental rate.

Table 13. Survey results for most frequent method for basis of payment for speed feedback trailers in work zones (Q13)

Method	Response	Count
Measured pay item	68%	21
Lump sum pay item	16%	5
No direct payment	3%	1
Other	13%	4
No response	0%	0

Note: Percentages based on number of respondents who answered the question (n=31).

3.2.3. Performance of Speed Feedback Trailers in Work Zones

Survey questions 14 through 17 concerned various aspects of the performance of speed feedback trailers in work zones. Question 14 sought information regarding the use of performance measures. As shown in Table 14, approximately half of the DOTs that use speed feedback trailers do not track performance measures for them. Among the DOTs that use performance measures, speed limit compliance or non-compliance is most often utilized. One DOT noted the use of third-party real-time speed measurement programs.

Table 14. Survey results for use of performance measures for speed feedback trailers in work zones (Q14)

Performance Measure	Response	Count
Average (or median) speed	13%	4
85th percentile speed	10%	3
Speed limit compliance/non-compliance	19%	6
Pace	6%	2
Standard deviation (or variance) of speed	3%	1
Worker feedback	26%	8
Other	10%	3
My agency does not use performance measures to assess the performance of speed feedback trailers in work zones	48%	15
No response	6%	2

Note: Percentages based on number of respondents who answered the question (n=31); multiple answers were allowed.

In Question 15, DOTs were asked to rate the overall performance of speed feedback trailers in work zones on a scale of 1 (highly ineffective) to 5 (highly effective). As shown in Table 15, the average rating, based on 30 ratings, was 3.20 with a standard deviation of 0.76. Two DOTs noted in the comments that the effectiveness of the speed feedback trailers decreases over time.

Table 15. Survey results for performance ratings for speed feedback trailers in work zones (Q15)

Statistic	Value
Average	3.20
Standard Deviation	0.76
Maximum	5
Minimum	2
Number of ratings	30

Note: Percentages based on number of respondents who answered the question (n=31).

The results for Question 16, which asked DOTs about the extent to which they believe that various factors influence the performance of speed feedback trailers in work zones, are provided in Table 16. The results indicate that, based on the strongly agree plus somewhat agree responses, DOTs perceive trailer location within the work zone and police presence to be the factors that most influence the performance of speed feedback trailers in work zones. Less than half of the DOTs that use speed feedback trailers in work zones agree that presence of positive protection and work zone duration affect their performance.

Table 16. Survey results for factors perceived to influence the performance of speed feedback trailers in work zones (Q16)

Factor	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree	No Response
Trailer location within work zone	48%	42%	10%	0%	0%	0%
Presence of positive protection	35%	13%	45%	3%	0%	3%
Work zone speed limit	32%	45%	16%	6%	0%	0%
Use of built-in features (e.g., flashing beacons or message)	10%	52%	35%	0%	3%	0%
Use of additional countermeasures (e.g., enforcement)	52%	26%	19%	0%	0%	3%
Police presence	71%	19%	10%	0%	0%	0%
Type of message displayed	10%	45%	32%	6%	0%	6%
Type of work activity	19%	35%	42%	0%	0%	3%
Amount of time the trailer stays at a specific location	19%	35%	39%	3%	0%	3%
Worker proximity	29%	52%	19%	0%	0%	0%
Traffic volumes	16%	39%	39%	3%	0%	3%
Work zone duration	13%	35%	39%	10%	0%	3%
Work zone length	23%	35%	39%	10%	0%	3%
Other	0%	0%	3%	0%	0%	97%

Note: Percentages based on number of respondents who answered the question (n=31).

Question 17 asked DOTs if they have completed any formal evaluation studies to evaluate the effectiveness of speed feedback trailers in work zones. As shown in Table 17, only four DOTs indicated that they have completed such studies.

Table 17. Survey results for completion of formal studies to evaluate the effectiveness of speed feedback trailers in work zones (Q17)

Answer Choice	Response	Count
Yes	13%	4
No	84%	26
No response	3%	1

Note: Percentages based on number of respondents who answered the question (n=31).

3.2.4. Challenges to Using Speed Feedback Trailers in Work Zones

Question 18 asked all DOT respondents about the extent to which they believe that various concerns hinder efforts to implement speed feedback trailers in work zones, and the results are shown in Table 18. Based on the strongly agree plus somewhat agree responses, DOTs perceive the lack of data on performance as the greatest challenge to implementing speed feedback trailers in work zones. Only five DOTs believe that lack of legislative authority hinders efforts to use speed feedback trailers in work zones.

Table 18. Survey results for concerns that hinder efforts to implement speed feedback trailers in work zones (Q18)

Concern	Strongly Agree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Disagree	Strongly Disagree	No Response
Cost	3%	15%	43%	15%	25%	0%
Lack of Agency Buy-In	0%	20%	43%	15%	23%	0%
Lack of Availability of Equipment	0%	23%	23%	28%	28%	0%
Lack of Contractor Buy-In	5%	20%	23%	28%	25%	0%
Lack of Data on Performance	15%	40%	33%	3%	10%	0%
Lack of Identified Funding	8%	5%	40%	18%	30%	0%
Lack of Legislative Authority	5%	8%	43%	13%	33%	0%
Lack of Perceived Need	5%	30%	28%	25%	13%	0%
Other Speed Countermeasures are Higher Priority	5%	20%	45%	18%	10%	3%
Public Perception	5%	18%	40%	23%	15%	0%
Other	3%	0%	0%	0%	0%	98%

Note: Percentages based on number of respondents who answered the question (n=40).

3.2.5. Other Survey Feedback

The final question of the survey asked DOTs to provide any other comments regarding the use of speed feedback trailers in work zones. A full list of these comments is provided in Appendix D. Some example comments are highlighted below.

- One DOT is starting to use speed feedback trailer in work zones with crossovers.
- Some motorists like to see how high they can get the speed numbers on the signs.
- Speed feedback trailers may be most effective when placed in advance of work activity when positive protection is not provided.

3.3. Summary of Key Survey Findings

The key findings from the survey of state DOTs are summarized as follows.

3.3.1. Key Survey Findings for Use of Speed Feedback Trailers in Work Zones

- Approximately 78% (n = 31) of the 40 responding DOTs use SFTs in work zones.
- For work zones on both freeways and non-freeways, speed feedback trailers are most frequently used for lane closures, followed by traffic shifts.
- Speed feedback trailers are generally used in work zones more frequently on freeways than non-freeways. Six DOTs indicated that they do not use speed feedback trailers in work zones on non-freeways, while all 31 DOTs use them on freeways.
- Fifteen of the responding DOTs that use speed feedback trailers in work zones also use them in non-work zone situations for various applications, such as school zones, speed transitions with low speed compliance, and high-risk locations.

3.3.2. Key Survey Findings for Practices for Speed Feedback Trailers in Work Zones

- Nineteen responding DOTs have developed policies, guidance, or standards for speed feedback trailers in work zones. The use of speed feedback trailers in work zones can be optional, recommended, or required under certain conditions.
- DOTs most frequently place speed feedback trailers near the work area or prior to the taper.
- The most commonly used built-in feature for speed feedback trailers in work zones is a flashing speed display when a vehicle exceeds a threshold speed. None of the responding DOTs indicated the use of license plate recognition with speed feedback trailers in work zones. DOTs use a wide range of speed thresholds to activate built-in features on speed feedback trailers in work zones, with 0 to 4 mph over the work speed limit most often applied.
- Enforcement, end of queue warning system, and temporary rumble strips are the speed countermeasures mostly frequently deployed along with speed feedback trailers in work zones.
- Regarding practices for repositioning speed feedback trailers in work zones, the most common practice among state DOTs is repositioning the speed feedback trailer as the work area moves, followed by leaving it in one location and periodically repositioning it within the work zone.
- The majority of DOT obtain speed feedback trailers from contractors.
- DOTs most frequently use a measured pay item as the basis for payment of speed feedback trailers, followed by lump sum pay item.

3.3.3. Key Survey Findings for Performance of Speed Feedback Trailers in Work Zones

- Approximately half of the responding DOTs that use speed feedback trailers (15 DOTs) do not track performance measures for SFTs. Among the DOTs that use performance measures, speed limit compliance or non-compliance is most often utilized.
- DOTs perceive trailer location within the work zone and police presence to be the factors that most influence the performance of speed feedback trailers in work zones.
- Only four DOTs indicated that they have completed formal evaluation studies to assess the effectiveness of speed feedback trailers in work zones.

3.3.4. Key Survey Findings for Challenges to Using Speed Feedback Trailers in Work Zones

- DOTs perceive the lack of data on performance as the greatest challenge to implementing speed feedback trailers in work zones.
- Some motorists accelerate to see how high they can get the speed numbers on the signs.

4. FIELD EVALUATION METHODOLOGY

A series of field evaluations were performed at several freeway work zone lane closures in 2022 and 2023 to evaluate strategies aimed at enhancing the effectiveness of SFTs towards reducing work zone speeds and improving compliance. These evaluations, conducted in multiple phases and at multiple freeway work zone locations, sought to yield insights and recommendations for optimizing SFT deployment and introducing measures to improve their overall effectiveness. The majority of the evaluations were performed in Michigan, with one evaluation performed in Missouri. As such, the majority of the methods discussed within this chapter specifically relate to the Michigan evaluations, while the Missouri field study will be described in a separate standalone chapter. The subsequent subsections offer a broad perspective on the conducted field evaluations, encompassing aspects such as the treatments implemented, site selection, field data collection techniques, and analytical methods. Detailed information related to each individual field evaluation are provided within the respective chapter.

4.1. Speed Feedback Trailer Characteristics

The SFT deployed in the field evaluations performed in Michigan freeway work zones consisted of a solar and battery-powered trailer-mounted radar speed feedback sign featuring a high-definition full-matrix display that is used to provide real-time speed information to approaching vehicles. The sign uses Doppler radar and can detect vehicles up to 2,000 ft in advance of its location and across two lanes per direction. The display is designed to automatically adjust the brightness of feedback messages based on ambient lighting conditions. An example SFT utilized in the Michigan evaluations is displayed in Figure 8.

Figure 8. Speed feedback trailer in a freeway work zone lane closure in Michigan

The sign assembly included a 60-mph speed limit sign, indicative of the work zone speed limit at freeway lane closures in Michigan when no workers are present. The display panel, measuring 35 by 36 in., featured 20 in. speed display digits visible up to 1,000 ft away. Additionally, a smaller black-on-white “YOUR SPEED” panel is positioned on top of the display, accompanied by a solar panel for continuous power. The standard battery/solar configuration enables the sign to operate autonomously for up to one year in most regions without requiring manual charging. The sign assembly is mounted on a trailer with four adjustable stabilizer legs, a tongue wheel jack, and a 3 in. pintle eye coupler, ensuring stability, safe and efficient setup, and easy towing. This design allows for quick relocation to different areas within the work zone.

Throughout the field evaluations, the SFT was configured to the standard specification utilized by MDOT, which is described as follows. The SFT displayed the approaching vehicle’s speed when the speed was below the work zone speed limit of 60 mph. The speed digits would flash for cases where the approach speed was between 60 and 70 mph. For vehicles exceeding 70 mph, the SFT displayed the speed digits alternating at 1 hertz cycle with “SLOW DOWN”.

During the course of this study, Digital Speed Limits (DSLs) were approved for pilot implementation in freeway work zones in Michigan. DSL typically include a digital panel that displays the speed limit in effect at that time. For work zone implementations, these DSL signs are typically trailer-mounted and are modified to display the appropriate speed limit (e.g., 60 mph or 45 mph) based on worker presence within the work zone. The DSL may be modified manually (either on-site or remotely) or based on presence of a worker transponder. The obvious benefit of the DSL is that it removes the ambiguity for drivers as to what speed limit is in place at a given time while traversing the work zone.

In an effort to optimize the effectiveness of the DSLs, a strategy was deployed during one of the field evaluations that involved pairing the DSL with an SFT to assess driver response to the DSL with and without the SFT in a freeway lane closure in Michigan. This particular evaluation is detailed in Chapter 10, with specific specifications for the SFT + DSL assembly (Figure 9) noted as follows. The SFT + DSL Assembly (product name: Speed Wizard), manufactured by VER-MAC, is a sign assembly that includes a 48-in by 60-in R2-1 speed limit panel, within which sits a 24.5-in by 42.375-in solar/battery-powered speed display panel with 18 in. white LED digits affixed where the speed limit digits would typically be found on a traditional R2-1 sign. Beneath the DSL display is a radar-activated 24.5-in by 42.375-in solar/battery-powered full-matrix speed feedback display panel with 18 in. amber LED digits. At the top of the assembly is a 48-in by 12-in black on orange "WORK ZONE" plaque and a solar panel.

In the study involving the use of the SFT + DSL assembly, the work zone speed limit was displayed on the white LED display, while the amber feedback display was configured to provide speed feedback information based on approaching vehicle speeds. When vehicles were below the speed limit, the amber display showed their current speeds. If approaching speeds exceeded the limit by up to 10 mph, the speed digits would flash. For vehicles exceeding 10 mph above the limit, the amber display showed the speed digits followed by "SLOW" and "DOWN" messages on separate frames, which is a slight departure from the standard SFT, which would show "SLOW DOWN" on a single frame.

Figure 9. SFT + DSL assembly deployed in a freeway lane closure in Michigan

4.2. Test Conditions and Site Selection

The field evaluations were designed to evaluate the effectiveness of various SFT deployment strategies in freeway work zones in an attempt to identify those strategies that provide optimal speed reduction performance. The research team met with the project manager and technical panel to identify the specific characteristics related to the SFTs that were of greatest interest for the field evaluations. After determination of the specific SFT-related objectives to evaluate in the field, the team worked with DOT staff to identify appropriate freeway work zone locations at which to perform the evaluations. It should be noted that MDOT's current special provision mandates the use of SFTs on all freeway work zones with speed reductions lasting longer than 3 days.

The research team identified multiple potential freeway work zones, considering the purpose of the evaluation and site characteristics relevant to each assessment, including the presence and type of temporary traffic control devices and suitability for data collection. In the end, five rural work zone sites were chosen, which are presented in Table 19 along with the respective test conditions evaluated at each site. Four of the study sites were in Michigan, with the fifth located in Missouri. Details of each field evaluation are described in subsequent chapters.

Table 19. Test conditions evaluated and selected freeway work zone sites

No.	Test Condition Evaluated	Work Zone Location
1	SFT positioning at a lane closure taper	EB I-69, Lapeer, MI
2	SFT positioning in the advance warning area approaching a lane shift	EB I-70, Rocheport, MO
3	SFT positioning approaching the work area within a lane closure	WB I-69, Lapeer, MI
4	SFT paired with a police vehicle in a lane closure	EB I-69, Lapeer, MI
5	SFT in a median crossover	SB I-69, Olivet, MI
6	SFT paired with digital speed limit (DSL) signs in a lane closure	NB US 127, Leslie, MI

4.3. Data Collection Methods

Speed data were collected using a series of handheld LiDAR guns operated by a team of technicians positioned within unmarked vehicles on the roadside within the work zone. A sequence of either two or three LiDAR data collection vehicles were spaced at strategic locations to continuously track individual vehicle speeds throughout the entire target area of the work zone. The LiDAR guns utilized in this study were ProLaser III manufactured by Kustom Signals Inc. These devices are able to measure vehicular speed and distance three times per second with an accuracy of ±1 mph at a range of 6,000 ft. Depending on sight limitations caused by geometry, each LiDAR gun was utilized within the range of 1,000 to 2,500 ft.

For each field evaluation, the LiDAR data collection vehicles were positioned on the roadside, away from critical speed measurement points, to minimize the potential influence of the data collection vehicle on driver speed selection behavior. Consistent data collection positions and procedures were maintained across all data collection periods within each evaluation. Figure 10 provides a visual representation of a sample LiDAR data collection at a freeway work zone lane closure using a three-person LiDAR setup. This general data collection technique was utilized for all work zone evaluations during this study.

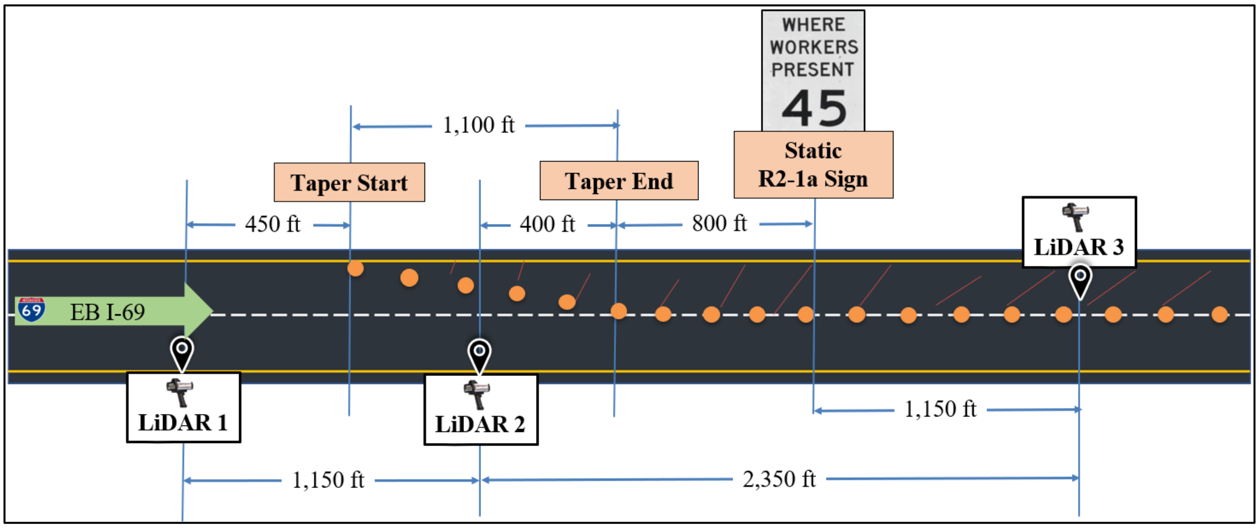
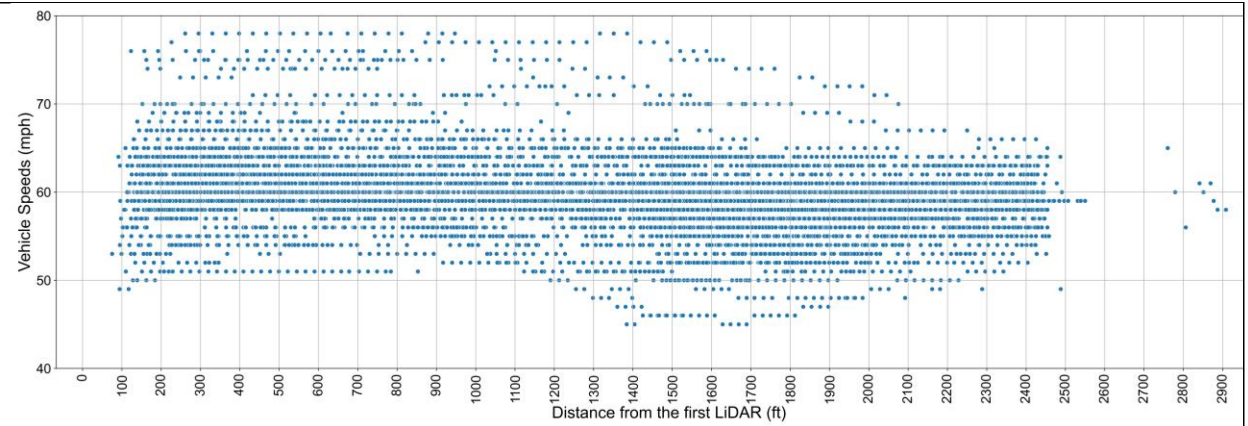


Figure 10. A typical three-person LiDAR data collection setup

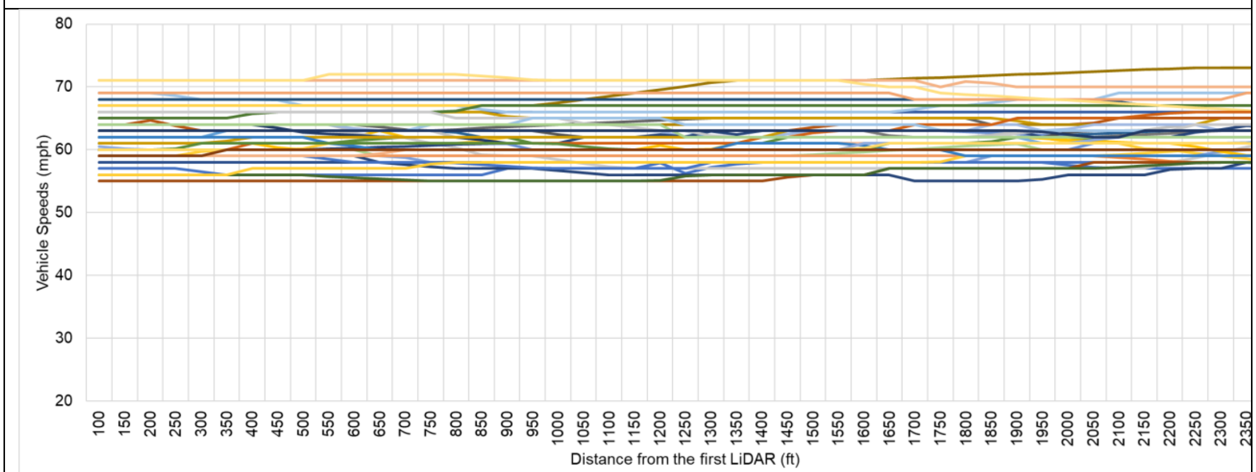
Throughout the data collection process, effective communication among data collectors was maintained through cellular communications to ensure a seamless 'hand-off' of speed tracking as each subject vehicle traversed the site. This involved the upstream technician communicating the type and color of each subject vehicle to the downstream LiDAR collector. The upstream data collector initiated the tracking of each subject vehicle and continued tracking for at least 100 ft beyond the downstream LiDAR technician. Subsequently, tracking responsibilities were transferred to the next LiDAR technician, who tracked the vehicle for at least 100 ft beyond the subsequent LiDAR technician or for the remaining distance. To focus solely on driver responses to traffic control devices or enforcement presence, only free flowing vehicles (e.g., with a minimum 3-second headway) were tracked. This approach with LiDAR facilitated the tracking of vehicle speed trajectories over the entire segment of interest.

Each LiDAR gun was connected to a laptop using a serial cable, enabling real-time recording of the timestamp, distance, and speed for each LiDAR measurement. The computer-based LiDAR recordings included timestamps, distances, and speeds for each measurement. After completing the LiDAR tracking for each subject vehicle, all data collectors entered remarks on the type and color of the vehicle, along with any other relevant comments. This information was later used to combine the data sets into a continuous speed profile for each subject while traversing through the site. The data was stored in a .txt format, which was then converted into an Excel file for further data processing. Vehicles that could not be tracked for the entire distance or exhibited unusual behavior were duly noted in the comments and subsequently excluded from the analysis.

After completion of the LiDAR field data collection, the individual vehicle speed trajectories were joined using the vehicle information recorded in the comments. As the relative distances between the LiDAR collectors and the fixed reference points at the sites were known, all distances were converted to be relative to a single reference point. Because LiDAR speeds cannot be measured at the same locations on the roadway for every vehicle, it was necessary to convert this data to a series of spot speeds using an interpolation technique, thereby allowing speeds to be assessed at select reference points. The combined raw data were linearly interpolated at 1 ft increments using the adjacent speeds. Interpolated speeds were then calculated at 50 ft intervals using a reference point on the road. Compiling the data in this manner provided a robust array of spot speeds throughout the study site that could be used to assess the effects of the various test conditions.



Spot speeds obtained from the raw LiDAR speed data



Individual vehicle speed trajectories obtained after interpolation for 50 ft interval

Figure 11. LiDAR speed data before and after interpolation

4.4. Analytical Methods

The data obtained from each field evaluation were analyzed using multiple linear regression. Separate models were developed for each site to analyze the speed effects of the various SFT test conditions. The speeds were often assessed at multiple points of interest within the work zone. The categorical factors of interest (e.g., speed measurement location, SFT test condition, and vehicle type) were included in the models as a series of binary indicator variables, although separate models were often developed for passenger vehicles and heavy vehicles. The results were then compared to the baseline site condition (e.g., the absence of an SFT or other speed management treatment) in order to determine the effectiveness of each particular SFT condition. The regression analysis was performed using the RStudio software. The general form of the multiple linear regression model is given by Equation 1:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_k X_{ik} + \varepsilon_i \quad (1)$$

where Yi is the speed for vehicle i, X_{i1} to X_{ik} are independent variables, β0 is an intercept, β1 to βk are estimated regression coefficients for each independent variable, and ε_i is a normally distributed error term with variance σ^2. Only fixed-effects were included in these models, such as speed measurement location, vehicle type, and SFT test condition.

It should be noted that the speed measured at the furthest upstream point at each site was included as an independent variable (covariate) in the regression models. Including upstream speed as a covariate controlled for the variation in the speed selection tendencies of drivers between the data collection periods, which did often occur due to various factors. This analytical strategy allowed for the magnitude of speed reduction during each sign test condition to be directly interpreted from the corresponding parameter estimates, while controlling for variations between drivers and site conditions.

4.5. Overview of Subsequent Chapters Detailing Field Evaluation Results

The specific details pertaining to the test conditions, procedures, data, analysis, and results specific to each field evaluation were too extensive to present within a single chapter of this report. Thus, these items have been partitioned into separate chapters specific to the test conditions assessed within each evaluation, as follows. Note that all evaluations were performed within rural freeway work zones located in Michigan, except for one rural freeway work zone site in Missouri, which is noted below.

- Chapter 5: Evaluation of SFT position at a lane closure taper
- Chapter 6: Evaluation of SFT position in the advance warning area near a lane shift (Missouri)
- Chapter 7: Evaluation of SFT position approaching the work area within a lane closure
- Chapter 8: Evaluation of SFT paired with a police vehicle in a lane closure
- Chapter 9: Evaluation of SFT in a median crossover
- Chapter 10: Evaluation of SFT paired with digital speed limit signs in a lane closure

5. EVALUATION OF SFT POSITION AT A LANE CLOSURE TAPER

5.1. Study Design and Site Characteristics

An evaluation was conducted to evaluate the effects of SFT positioning near the start of a freeway work zone lane closure in order to determine the location that yielded the greatest speed reduction effects on vehicles approaching, entering, and traversing through the lane closure. To achieve this, a field study was designed with a single SFT placed at three different locations near the start of a freeway work zone lane closure, including (1) near the taper start, (2) near the taper end, and (3) beyond the taper end.

The study was conducted at a work zone single-lane closure along eastbound I-69 near Lapeer, Michigan. This section of I-69 is a limited-access freeway with two lanes in each direction and a speed limit of 75 mph for passenger cars and 65 mph for heavy vehicles. The right lane remained open for travel, while the left lane was closed to facilitate essential traffic flow adjustments associated with a crossover, situated several thousand feet beyond the data collection point. During the course of this study, the SFT was consistently positioned on the closed left lane, aligning with the typical placement for freeway lane closures specified by MDOT. The lane closure was marked using orange drums and included an entry taper spanning 1,100 ft in length. The speed limit signs that were present within this work zone included 60 mph (R2-1) speed limit signs upstream of the taper and 45 mph WHERE WORKERS PRESENT (R2-1a) speed limit signs 800 ft beyond the end of the taper. For the purpose of this study, the location of the "WHERE WORKERS PRESENT 45" speed limit signs also served as the designated placement for the SFT beyond the taper end. The study site layout that depicting the locations of the taper start, taper end, and the R2-1a sign are illustrated in Figure 12.

Figure 12. Eastbound I-69 work zone study site layout to evaluate optimal SFT position near the start of the freeway work zone lane closure

5.2. Test Conditions and Data Collection

The SFT was positioned at three different locations near the start of the freeway lane closure during data collection, including (1) near the taper start, (2) near the taper end, and (3) near the R2-1a "WHERE WORKERS PRESENT 45" sign, which was 800 ft beyond the taper end. Additionally, the SFT was temporarily removed from the study site to collect the data for a period when no SFT was present, which represented the baseline condition. Ultimately, the study assessed the following four test conditions related to the SFT:

- No SFT present
- SFT placed near the taper start
- SFT placed near the taper end
- SFT placed near the "WHERE WORKERS PRESENT 45" sign

Data collection occurred during daylight off-peak periods for two weekdays, on the same day of the week, within the same times of the day, and under similar weather conditions. Both days involved data collection for all four conditions in the same sequence, ensuring consistent data sets for all test conditions. The three-person LiDAR handoff method was employed, with the first (upstream) LiDAR collector positioned 450 ft upstream of the taper start to track speeds approaching and entering the taper. The second (middle) LiDAR collector was located within the taper, 400 ft upstream of the taper end. The third (downstream) LiDAR collector was positioned 1,150 ft beyond the R2-1a sign, situated 800 ft beyond the taper end. The data collection setup is illustrated in Figure 13.

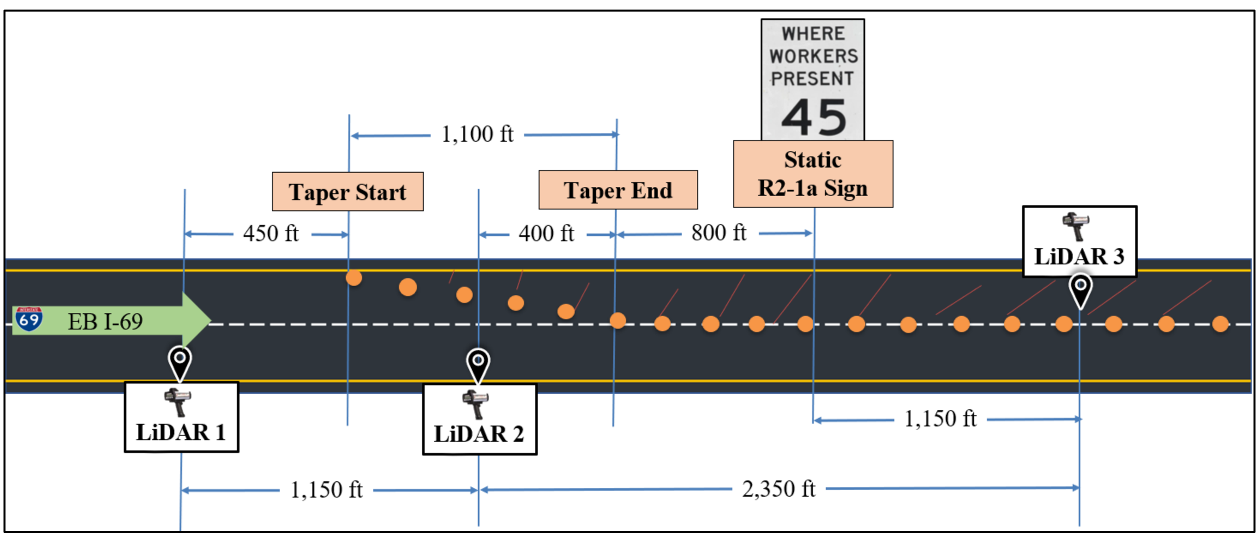


Figure 13. Data collection setup using three-person LiDAR handoff method

5.3. Data Summary

After data collection, speed data from each condition were joined, organized, and coded into a single file for detailed analysis, resulting in a final dataset comprising complete speed trajectories of 490 vehicle observations. Descriptive statistics of these datasets at key locations of interest can be found in Table 20.

Table 20. Descriptive statistics for speed of vehicles approaching, entering, and traversing the lane closure based on SFT position near the start of the lane closure

Test Condition	Min	Max	Average	Std. Dev
Speed at the Furthest Upstream Data Collection Point (300 ft before taper start)				
No SFT	54.0	79.0	65.9	5.50
SFT Positioned Near Taper Start	53.0	79.0	64.7	5.88
SFT Positioned Near Taper End (1,100 ft downstream of taper start)	56.0	79.0	66.0	4.87
SFT Positioned Near R2-1a Sign (1,900 ft downstream of taper start)	56.0	79.0	65.6	5.05
Speed at Taper Start				
No SFT	54.1	79.0	65.6	5.32
SFT Positioned Near Taper Start	53.0	79.0	64.0	5.87
SFT Positioned Near Taper End (1,100 ft downstream of taper start)	56.0	78.1	65.6	4.79
SFT Positioned Near R2-1a Sign (1,900 ft downstream of taper start)	56.0	77.0	65.3	4.99
Speed at Taper End (1,100 ft downstream of taper start)				
No SFT	49.5	74.0	63.4	4.83
SFT Positioned Near Taper Start	52.0	75.0	61.4	4.57
SFT Positioned Near Taper End (1,100 ft downstream of taper start)	53.0	75.8	62.3	4.39
SFT Positioned Near R2-1a Sign (1,900 ft downstream of taper start)	51.0	77.0	62.1	4.72
Speed at the "WHERE WORKERS PRESENT 45" (R2-1a) Sign (1,900 ft downstream of taper start)				
No SFT	49.0	76.0	63.5	4.65
SFT Positioned Near Taper Start	53.0	75.0	62.4	4.39
SFT Positioned Near Taper End (1,100 ft downstream of taper start)	52.0	74.0	62.0	4.11
SFT Positioned Near R2-1a Sign (1,900 ft downstream of taper start)	52.0	77.0	61.5	4.40
Speed at the Furthest Downstream Data Collection Point (4,800 ft downstream of taper start)				
No SFT	48.0	72.2	60.6	4.84
SFT Positioned Near Taper Start	40.5	75.0	60.3	5.46
SFT Positioned Near Taper End (1,100 ft downstream of taper start)	51.0	74.0	60.5	4.20
SFT Positioned Near R2-1a Sign (1,900 ft downstream of taper start)	47.0	76.0	59.1	4.99

Note: All data are presented in miles per hour (mph)

Figure 14 illustrates the graphical representation of average speed trajectories across all test conditions, revealing notable trends in the speed effects of SFT placement in different locations within a freeway work zone lane closure. From Figure 14, it is observed that average speeds were reduced near the taper end compared to speeds from the furthest upstream data collection point. The presence of the SFT at either taper end or near the R2-1a sign had a similar impact on speed. Beyond the taper end, average speed continuously decreased when the SFT was placed near the R2-1a sign compared to other test conditions, extending beyond the end of the LiDAR tracking range (i.e., greater than 4,800 ft beyond the end of the taper). The observations regarding the effects of SFT placement in a freeway work zone lane closure were verified based on parameter estimates from the regression models discussed in the next section.

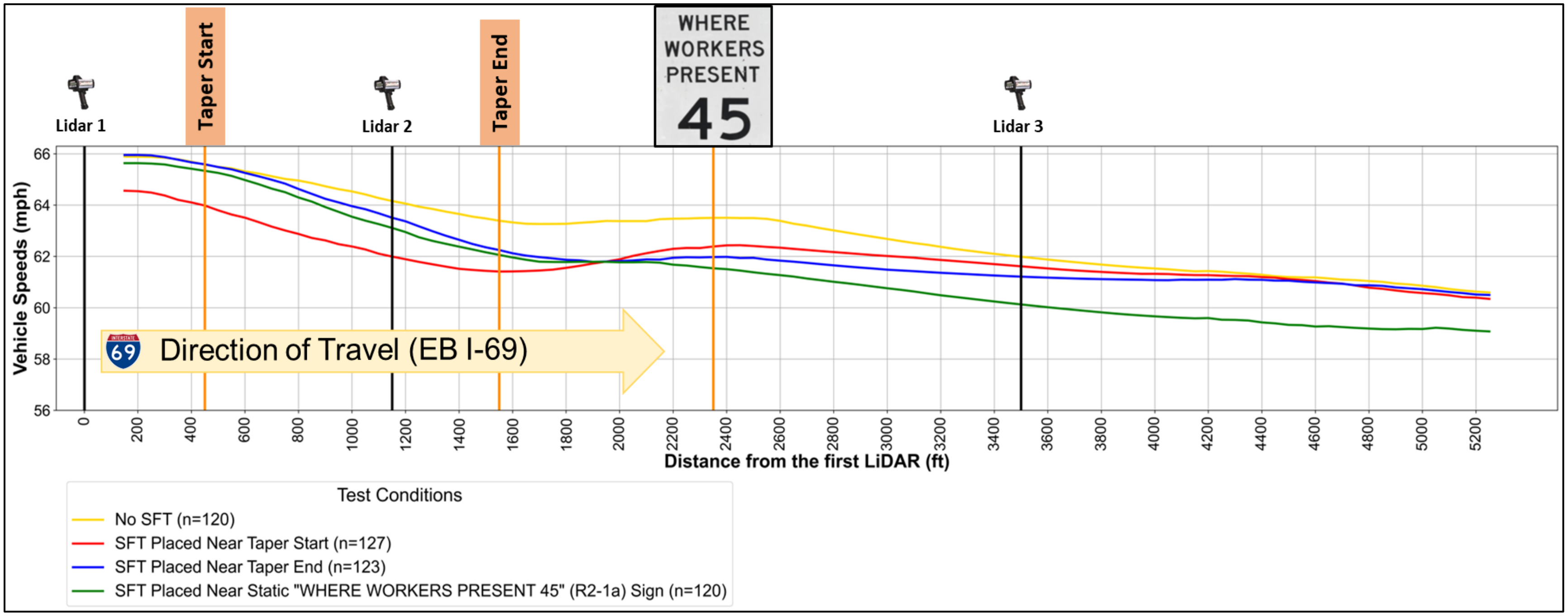


Figure 14. Average speed trajectories for vehicles approaching, entering, and traversing the lane closure based on SFT position near the start of the lane closure

5.4. Results and Discussion

The speed trends observed in the prior section were verified by comparison of the regression parameter estimates for speed as a function of SFT test condition and vehicle type. Separate regression modes were developed for each of the four locations of interest across, which are presented in Table 21. It is important to note that the speed measured at the furthest upstream data collection point (300 ft upstream of the taper start) was included as an independent variable (covariate) in the regression model. This inclusion aimed to control for variations in the speed selection tendencies of drivers between data collection periods, as evident in the comparison of the upstream portion of speed trajectories in Figure 14. Such an analytical approach allows for the direct interpretation of the magnitude of speed reduction during each sign test condition from the corresponding parameter estimates when compared to the baseline condition, while accounting for variations between drivers, site conditions, time of day, and other factors.

The parameter estimates from Table 21 for each SFT test condition can be directly interpreted as the change in mean speeds due to the placement of the SFT compared to the base condition (i.e., without the SFT present at the site). For example, for speed measured at the taper end, a mean speed reduction of approximately 1.1 mph is observed when the SFT is placed near the taper start, compared to when the SFT was not present within the work zone.

The regression results suggest that the SFT, regardless of the specific position near the taper, has a significant speed reduction effect for motorists traversing the lane closure taper compared to when no SFT is present at the site. For speeds measured near the end of the taper, speed reductions were approximately 1.1 mph greater for each SFT test condition compared to when no SFT was present. However, the speed reductions were sustained further into the work zone as the SFT was positioned further into the work zone. The most sustained speed reductions were observed when the SFT was positioned at the R2-1a sign, which was 800 ft downstream of the taper end. With the SFT in this position, speeds measured at the furthest downstream data collection point (4,800 ft downstream of taper start) were 1.4 mph lower than all other SFT test conditions. Additionally, the speed reduction effects for all other SFT locations (i.e., at the start of the taper and at the end of the taper) had dissipated when reaching the furthest downstream data collection point.

Therefore, to maximize the speed reduction effectiveness of the SFT, both in terms of the magnitude of the effect and the duration of the speed reduction while traversing the initial portion of the work zone, it is recommended that the SFT be positioned slightly beyond the end of the taper and near a regulatory speed limit sign. This positioning will help ensure that drivers are able to simultaneously observe both the speed feedback message and the work zone speed limit sign.

Table 21. Linear regression results for speed of vehicles approaching, entering, and traversing the lane closure based on SFT position near the start of the lane closure

Parameter	Estimate (mph)	Std. Error	p- value
Speed at the Taper Start			
Intercept	1.782	0.523	<0.001
Upstream Speed	0.968	0.008	<0.001
Passenger Cars		*Base Condition*	
Heavy Vehicles	-0.033	0.100	0.740
No SFT		*Base Condition*	
SFT Present Near Taper Start	-0.304	0.108	0.005
SFT Present Near Taper End (1,100 ft downstream of taper start)	-0.044	0.108	0.684
SFT Present Near R2-1a Sign (1,900 ft downstream of taper start)	0.012	0.109	0.914
Speed at Taper End (1,100 ft downstream of taper start)			
Intercept	20.240	1.822	<0.001
Upstream Speed	0.656	0.027	<0.001
Passenger Cars		*Base Condition*	
Heavy Vehicles	-0.376	0.348	0.280
No SFT		*Base Condition*	
SFT Present Near Taper Start	-1.086	0.375	0.004
SFT Present Near Taper End (1,100 ft downstream of taper start)	-1.159	0.377	0.002
SFT Present Near R2-1a Sign (1,900 ft downstream of taper start)	-1.122	0.381	0.002
Speed at the "WHERE WORKERS PRESENT 45" (R2-1a) Sign (1,900 ft downstream of taper start)			
Intercept	30.756	2.096	<0.001
Upstream Speed	0.499	0.031	<0.001
Passenger Cars		*Base Condition*	
Heavy Vehicles	-0.739	0.400	0.065
No SFT		*Base Condition*	
SFT Present Near Taper Start	-0.411	0.432	0.341
SFT Present Near Taper End (1,100 ft downstream of taper start)	-1.511	0.434	0.001
SFT Present Near R2-1a Sign (1,900 ft downstream of taper start)	-1.756	0.438	<0.001
Speed at the furthest downstream data collection point (4,800 ft downstream of taper start)			
Intercept	43.530	2.885	<0.001
Upstream Speed	0.261	0.043	<0.001
Passenger Cars		*Base Condition*	
Heavy Vehicles	-0.805	0.551	0.145
No SFT		*Base Condition*	
SFT Present Near Taper Start	0.140	0.594	0.814
SFT Present Near Taper End (1,100 ft downstream of taper start)	-0.065	0.594	0.914
SFT Present Near R2-1a Sign (1,900 ft downstream of taper start)	-1.365	0.603	0.024

6. EVALUATION OF SFT POSITION IN THE ADVANCE WARNING AREA APPROACHING A LANE SHIFT

6.1. Site Characteristics

In order to evaluate the impact of SFT position approaching a work zone lane shift on vehicle speeds, the Interstate 70 Rocheport Bridge replacement project was chosen as the work zone evaluation site for the Missouri portion of the study. As a long-term work zone, it provided the research team with the opportunity to change the position of the SFT on a weekly basis and assess its influence on speed. The evaluation site was located on the eastbound lanes of I-70, prior to the Rocheport Bridge, covering the stretch between mile markers 111 and 114 (Figure 15). The work area was located on the shoulder and roadside with moderate encroachment into the right travel lane, which prompted the use of a dual-lane shift for the traffic control configuration.

Figure 15. Location of the selected work zone in Missouri

As shown in Figure 16, the work zone includes a two-lane shift. The speed limit on I-70 is 70 mph, while the work zone speed limit was reduced to 60 mph. To specifically isolate the impact of the SFT at each of the specified deployment positions, law enforcement was not present during the evaluation period.

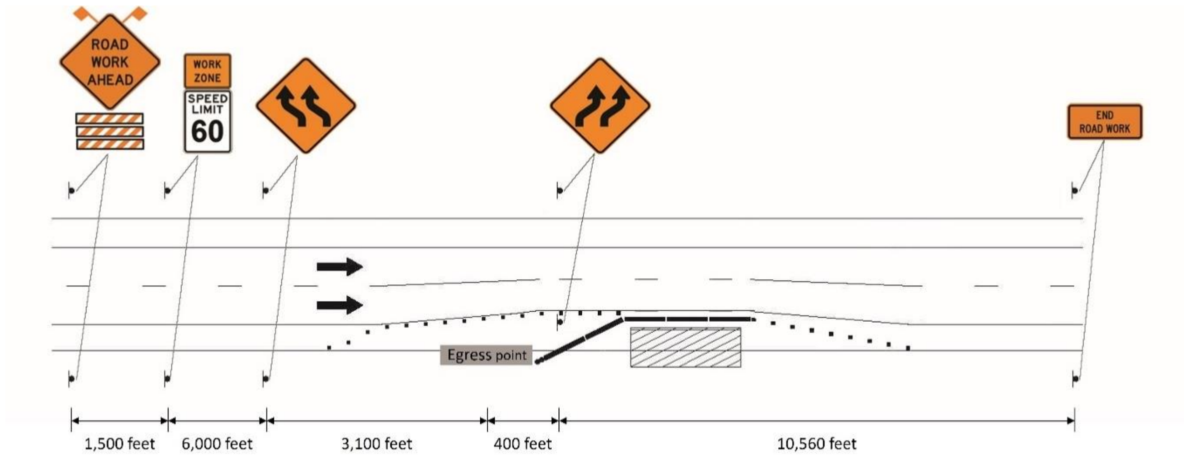


Figure 16. Two-lane shift work zone on EB I-70 near the Rocheport Bridge

6.2. Speed Data Collection Sensor Locations

In order to monitor the change of vehicle speed before and after deployment of the SFT, two speed sensors were deployed. The speed sensors used were the Houston Radar SpeedLane Pro® (Houston Radar 2023). The sensors function in all weather and lighting conditions and are capable of accurately detecting the lane, speed, and class of each vehicle. The sensor data can be used to calculate lane-specific volume, occupancy, and other relevant metrics. Both sensors were mounted on masts attached to portable trailers at the roadside for non-intrusive traffic data collection.

On September 9, 2022, the research team collaborated with Missouri DOT staff to carry out a field survey aimed at determining the positions of the upstream and downstream speed sensors. In order to capture the driver's response to the SFT, the speed sensors needed to be positioned at a distance from the SFT. In addition, the chosen positions required a flat open space for trailer parking and speed sensor setup. Following the field survey, the positions for the speed sensors were determined as shown in Figure 17.

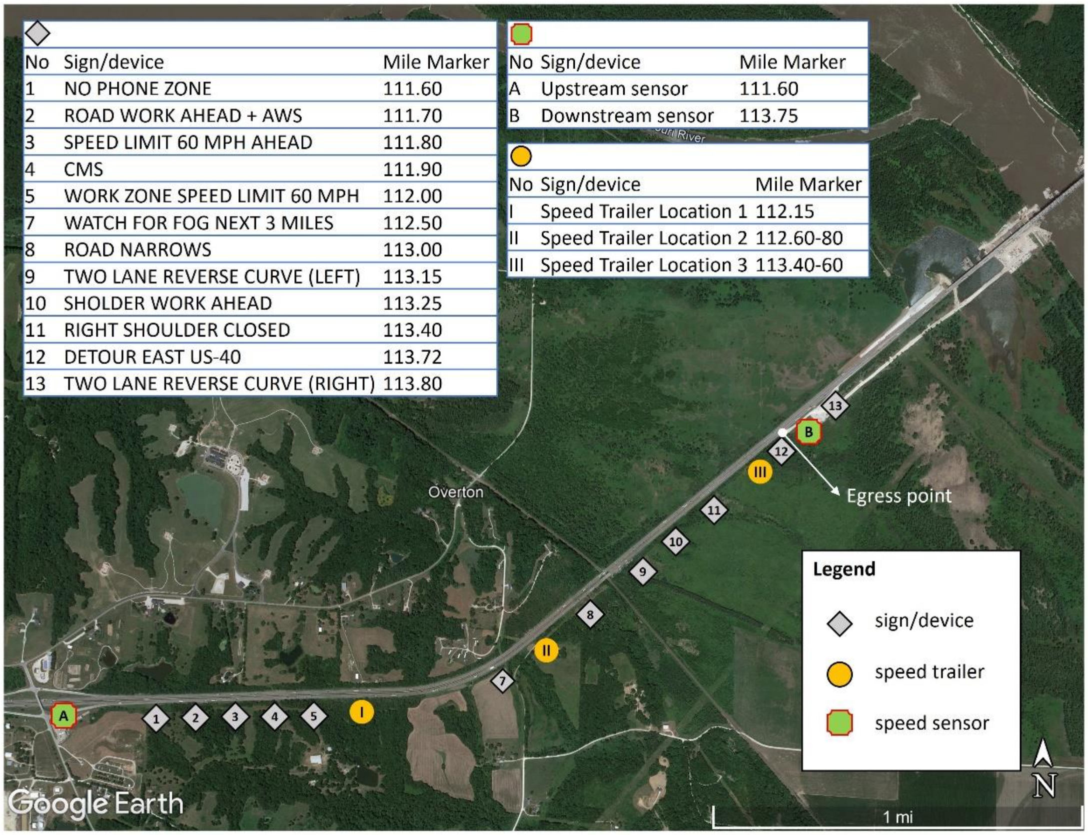


Figure 17. Positions of traffic signs, devices, and speed feedback trailer

The upstream sensor was placed near the entrance ramp of the I-70 interchange at MO-179 (mile marker 111). This placement ensured that the speed sensor exclusively tracked vehicles on I-70, excluding those on the entrance ramp. The downstream sensor after the SFT was deployed on the shoulder within the work zone near mile marker 113.80. The sensor was intentionally positioned approximately 260 ft after an egress point to exclude data on low-speed work vehicles. The sensors as placed in the field are shown in Figure 18 through Figure 20.

Figure 18. Speed sensor mounted on portable trailer at upstream location (eastbound entrance ramp of the I-70 interchange at MO-179)

Figure 19. Speed sensor mounted on portable trailer at downstream location (eastbound I-70 near mile marker 113.80)

Figure 20. Speed sensor and egress point at downstream location (eastbound I-70 near mile marker 113.80)

6.3. Speed Feedback Trailer Positions

To evaluate the effectiveness of the SFT and evaluate the effects of its position on speed, the research team conducted tests under four conditions: without a SFT and with a SFT positioned at three different locations within the advance warning area approaching the lane shift for the work area. As shown in Figure 17, the locations of the three sites for the SFT are well-separated within the work zone. Each site provides ample shoulder space for the SFT and ensures adequate spacing, with at least 500 ft between the SFT and nearby traffic signs. For each scenario, the SFT was progressively moved closer to the lane shift and egress point for work vehicles. The absence of the SFT served as a baseline for comparison in the field evaluation, alongside the three SFT scenarios.

6.4. Data Analysis

6.4.1. Overview of Data Analysis

Weekdays (Tuesday, Wednesday, and Thursday) of each week were selected for analysis to compare typical traffic patterns. The speed, timestamp (yyyy-mm-dd hh:mm:ss), and direction of each vehicle were collected from the upstream and downstream speed sensors. The time of day was divided into daytime (8 am to 6 pm) and nighttime (6 pm to 8 am).

For each week, the total duration, total count of vehicles, average speed, 85th percentile speed, standard deviation, percentage of vehicles complying with the work zone speed limit, and percentages of vehicles exceeding the work zone speed limit by 10 mph, 20 mph, and 30 mph were analyzed for daytime and nighttime. The differences between the upstream and downstream speeds were calculated. In addition, the differences in the count of vehicles were recorded. These differences may be due to work vehicles entering at the upstream speed sensor location and exiting before passing the downstream speed sensor.

6.4.2. Weekly Results for Missouri Field Study

Table 22 shows the results of the first week, without the speed feedback trailer. The difference in the count of vehicles was recorded for daytime and nighttime. This is assumed because work vehicles enter the upstream speed sensor and exit before passing the downstream speed sensor. The average speed shows a decrease at the downstream location, but it still exceeds the work zone speed limit of 60 mph by 6.79 mph during daytime. Only 15.65% of vehicles complied with the work zone speed limit at the downstream sensor location during daytime, while 32.16% of vehicles exceeded the limit by 10 mph or more. The data collected during nighttime yielded slightly higher speeds. The downstream sensor recorded an average speed of 67.78 mph, surpassing the work zone speed limit of 60 mph. Only 13.07% of vehicles complied with the speed limit, while 36.03% of vehicles exceeded it by 10 mph or more.

Table 22. Field study results for week 1 (no SFT)

	UD1	DD1	Diff.	UN1	DN1	Diff.
Total Duration (hours)	20	20	0	42	42	0
Count (vehicles)	31033	34882	3849	20883	25265	4382
Average Speed (mph)	73.19	66.79	-6.41	71.73	67.78	-3.95
85th Percentile Speed (mph)	78	76	-2	75	76	1
Standard Deviation (mph)	7.21	9.18	-	7.53	8.99	-
Speed Limit (mph)	70	60	-	70	60	-
Average Speed-WZ Speed Limit (mph)	3.19	6.79	3.59	1.73	7.78	6.05
Minimum Speed Difference	-57	-54	3	-56	-49	7
Maximum Speed Difference	42	53	11	34	52	18
% Complying with WZ limit	38.08%	15.65%	-22.43%	47.97%	13.07%	-34.90%
% Exceeding WZ Speed Limit by 10+ mph	8.38%	32.16%	23.78%	6.24%	36.03%	29.78%
% Exceeding WZ Speed Limit by 20+ mph	1.16%	3.12%	1.96%	0.89%	4.23%	3.35%
% Exceeding WZ Speed Limit by 30+ mph	0.01%	0.65%	0.65%	0.00%	1.07%	1.07%

Note: UD = upstream daytime, DD = downstream daytime, UN = upstream nighttime, DN = downstream nighttime.

The difference in the percentage of vehicles that complied with or exceeded the speed limit shows the reaction of traffic when the traffic encountered the work zone. The speed limit at the upstream sensor was 70 mph, while the work zone speed limit at the downstream sensor was 60 mph. The percentage of vehicles exceeding the speed limit increased at the downstream location in the work zone. The percentage of vehicles exceeding the speed limit by 10 mph or more increased from 8.38% (upstream) to 32.16% (downstream) during daytime and from 6.24% (upstream) to 36.03% (downstream) at nighttime.

The results of each week were visualized using scatter plots and line graphs for vehicle speeds and counts. To improve clarity of data presentation, the speed data was aggregated into 5-minute windows, and the number of vehicles was aggregated into 15-minute windows. Scattered dots represent the relationship between upstream and downstream speeds for both daytime and nighttime. The line graph below the scattered points represents the traffic count, showing the trendline for the number of vehicles and illustrating the relationship between the number of vehicles and the speed difference between the upstream and downstream sensor locations.

The results for the first week are shown in Figure 21. When traffic density is high, typically during daytime, the speed difference between the upstream and downstream locations tends to increase. Conversely, when traffic density is low, typically during nighttime, the scattered points tend to cluster in similar areas, indicating a smaller speed difference between the upstream and downstream locations. Upstream speeds are generally lower at nighttime than daytime, and downstream speeds are generally higher at nighttime.

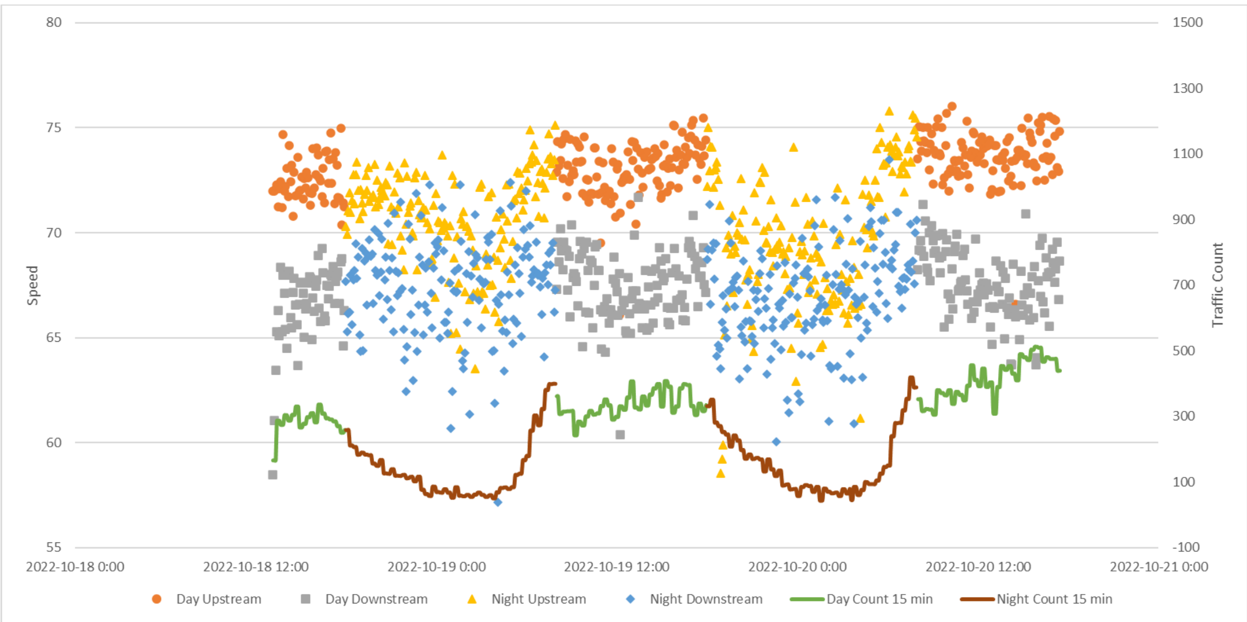


Figure 21. Graph of speed and traffic counts for week 1 of Missouri field study (no SFT)

In the second week, the speed feedback trailer was placed near the upstream speed sensor, where the work zone was not visible. The speed feedback trailer was located approximately 8,450 ft from the downstream sensor and 8,190 ft from the egress point for work vehicles. Table 23 shows the results of the second week. In the second week, during daytime, the average speed recorded on the downstream speed sensor was 64.09 mph, which was 2.7 mph lower than the first week. The percentage of vehicles complying with the work zone speed limit decreased from 46.20% (upstream) to 24.33% (downstream). Additionally, the percentage of vehicles exceeding the work zone speed limit by 10 mph or more increased from 5.03% (upstream) to 20.05% (downstream). In contrast, during nighttime, the downstream traffic speed was slightly higher than during the daytime. An average speed of 66.39 mph was recorded at the downstream speed sensor. The percentage of vehicles complying with the speed limit was 16.47% at the downstream sensor.

Table 23. Field study results for week 2 (SFT at Location I, mile marker 112.15)

	UD2	DD2	Diff.	UN2	DN2	Diff.
Total Duration (hours)	27	27	0	42	42	0
Count (vehicles)	28230	35309	7079	19071	23806	4735
Average Speed (mph)	71.68	64.09	-7.59	71.59	66.39	-5.20
85th Percentile Speed (mph)	77	74	-3	77	76	-1
Standard Deviation (mph)	7.77	9.67	-	7.52	10.11	-
Speed Limit (mph)	70	60	-	70	60	-
Average Speed-WZ Speed Limit (mph)	1.68	4.09	2.41	1.59	6.39	4.80
Minimum Speed Difference	-58	-49	9	-57	-52	5
Maximum Speed Difference	28	54	26	29	44	15
% Complying with WZ limit	46.20%	24.33%	-21.87%	48.79%	16.47%	-32.32%
% Exceeding WZ Speed Limit by 10+ mph	5.03%	20.05%	15.02%	5.36%	30.59%	25.23%
% Exceeding WZ Speed Limit by 20+ mph	0.57%	2.33%	1.76%	0.62%	4.25%	3.62%
% Exceeding WZ Speed Limit by 30+ mph	0.00%	0.58%	0.58%	0.00%	1.06%	1.06%

Note: UD = upstream daytime, DD = downstream daytime, UN = upstream nighttime, DN = downstream nighttime.

The graph of speed and counts for the second week is shown in Figure 22. During the daytime, the gap between upstream and downstream speeds tends to be larger when the traffic count is higher. In contrast, the upstream speed during nighttime is generally lower than during daytime.

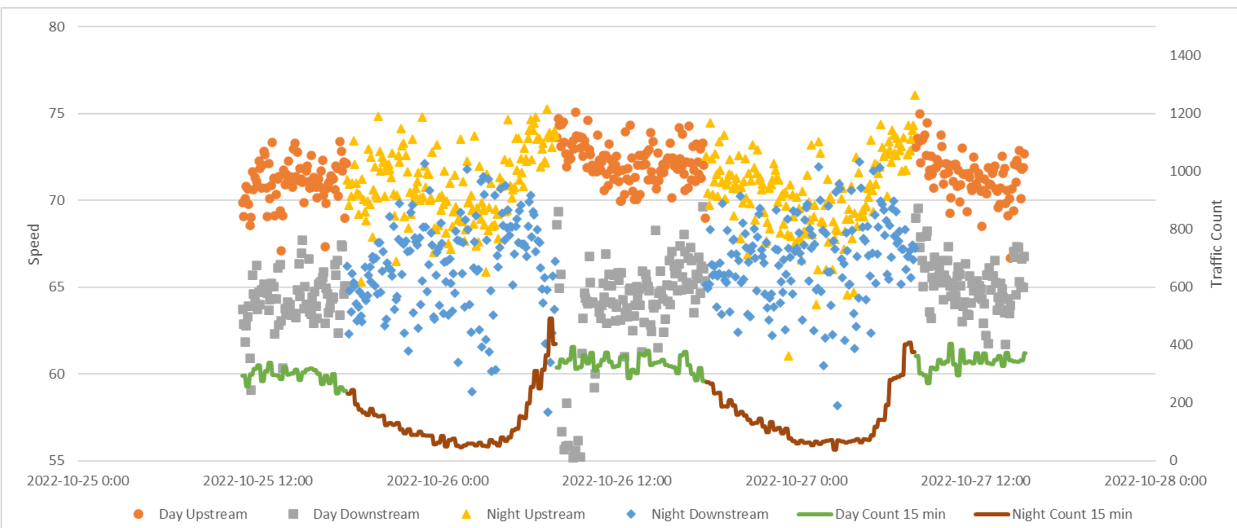


Figure 22. Graph of speed and traffic counts for week 2 of Missouri field study (SFT at Location I, mile marker 112.15)

In the third week, the speed feedback trailer was located right after the curve prior to the lane shift. The speed feedback trailer was located approximately 5,500 ft from the downstream sensor and approximately 5,240 ft from the egress point for work vehicles. Table 24 shows the results for the third week. During the daytime of the third week, a lower average speed was observed compared to the first two weeks. An average speed of 63.89 mph was recorded at the downstream speed sensor. At the downstream sensor, 24.51% of vehicles complied with the work zone speed limit during daytime, while only 17.41% of vehicles exceeded the limit by 10 mph or more.

Table 24. Field study results for week 3 (SFT at Location II, mile marker 112.60-80)

	UD3	DD3	Diff.	UN3	DN3	Diff.
Total Duration (hours)	27	27	0	42	42	0
Count (vehicles)	30529	36676	6147	19537	24268	4731
Average Speed (mph)	71.99	63.89	-8.10	71.89	66.55	-5.34
85% Percentile Speed (mph)	77	70	-7	77	76	-1
Standard Deviation (mph)	7.95	8.77	-	7.35	9.04	-
Speed Limit (mph)	70	60	-	70	60	-
Average Speed-WZ Speed Limit (mph)	11.91	3.89	-8.02	1.89	6.55	4.66
Minimum Speed Difference	-47	-54	-7	-58	-52	6
Maximum Speed Difference	42	46	4	29	43	14
% Complying with WZ limit	34.60%	24.51%	-10.09%	46.70%	16.15%	-30.54%
% Exceeding WZ Speed Limit by 10+ mph	4.27%	17.41%	13.13%	5.51%	29.00%	23.49%
% Exceeding WZ Speed Limit by 20+ mph	0.53%	1.64%	1.11%	0.68%	3.80%	3.12%
% Exceeding WZ Speed Limit by 30+ mph	0.01%	0.33%	0.32%	0.00%	0.90%	0.90%

Note: UD = upstream daytime, DD = downstream daytime, UN = upstream nighttime, DN = downstream nighttime.

Similarly, during the nighttime of the third week, the average speed at the downstream speed sensor remained consistent at 66.55 mph. The percentage of vehicles complying with the work zone speed limit at the downstream sensor was 16.15%, while 29.00% of vehicles exceeded the speed limit by 10 mph or more.

The graph of speed and counts for the third week is shown in Figure 23. The graphs show a similar relationship between the traffic speed and the traffic count to the two previous weeks. However, the speed gap between upstream and downstream was higher than the first two weeks, especially during daytime.

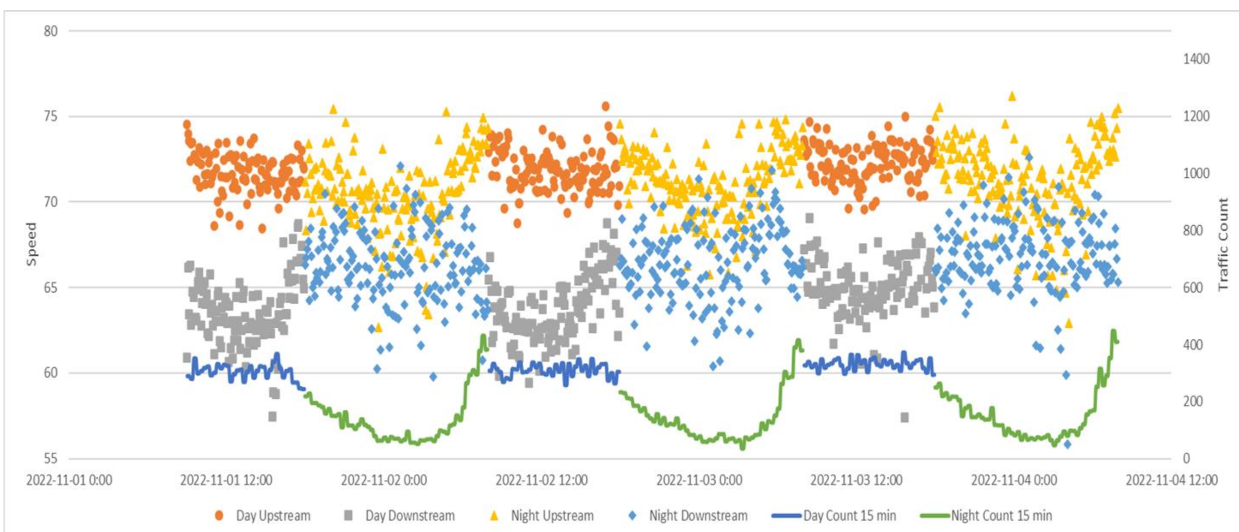


Figure 23. Graph of speed and traffic counts for week 3 of Missouri field study (SFT at Location II, mile marker 112.60-80)

In the fourth and final week, the speed feedback trailer was located nearest to the lane shift and egress point for work vehicles. The speed feedback trailer was located approximately 1,320 ft from the downstream sensor and approximately 1,060 ft from the egress point for work vehicles. Table 25 shows the results for the last week. During daytime, the results for the fourth week were similar to the third week. The average speed at the downstream sensor was 63.98 mph during daytime and 65.67 mph during nighttime. The average nighttime speed at the downstream sensor during the fourth week was 0.88 mph lower than during the third week. Approximately 24.20% of vehicles at the downstream sensor complied with the work zone speed limit during daytime, while only 15.95% of vehicles exceeded the limit by 10 mph or more.

Table 25. Field study results for week 4 (SFT at Location III, mile marker 113.40-60)

	UD4	DD4	Diff.	UN4	DN4	Diff.
Total Duration (hours)	24	24	0	35	35	0
Count (vehicles)	25591	30344	4753	15754	19368	3614
Average Speed (mph)	72.44	63.98	-8.46	72.31	65.67	-6.64
85th Percentile Speed (mph)	77	70	-7	77	75	-2
Standard Deviation (mph)	7.51	8.04	-	6.91	9.07	-
Speed Limit (mph)	70	60	-	70	60	-
Average Speed-WZ Speed Limit (mph)	2.44	3.98	1.54	2.31	5.67	3.36
Minimum Speed Difference	-56	-48	8	-58	-49	9
Maximum Speed Difference	29	42	13	28	42	14
% Complying with WZ limit	42.02%	24.20%	-17.83%	45.13%	18.55%	-26.59%
% Exceeding WZ Speed Limit by 10+ mph	6.23%	15.95%	9.72%	6.26%	24.92%	18.66%
% Exceeding WZ Speed Limit by 20+ mph	0.80%	1.64%	0.83%	0.86%	3.07%	2.21%
% Exceeding WZ Speed Limit by 30+ mph	0.00%	0.26%	0.26%	0.00%	0.69%	0.69%

Note: UD = upstream daytime, DD = downstream daytime, UN = upstream nighttime, DN = downstream nighttime.

The graph of speed and counts for the fourth week is shown in Figure 24. Week 4 exhibited the largest gap between the recorded speeds at the upstream and downstream sensors. The downstream speed observations, especially during nighttime, ranged from 60 to 70 mph. There was a noticeable speed drop around midnight on November 9th. A lane closure was reported on that day from 6 pm to 1 am.

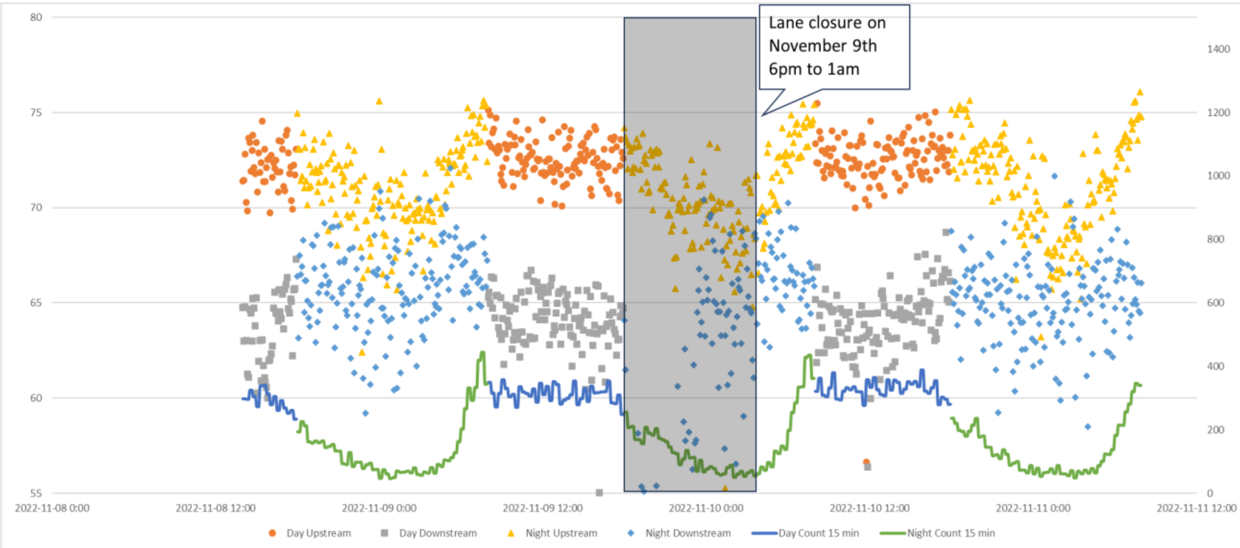


Figure 24. Graph of speed and traffic counts for week 4 of Missouri field study (SFT at Location III, mile marker 113.40-60)

6.4.3. Boxplot Analysis

To compare the speed data for each week, boxplots were utilized. A boxplot visualizes the distribution and central tendency of the data. The box represents the range from the first quartile to the third quartile, with the line in the middle representing the median. The X sign in the middle of the boxes indicates the mean value. The whiskers extending from the boxes represent the smallest and largest values within the data range. Dots plotted outside of the whiskers represent outliers, which differ significantly from the range. Since the boxplots for each week are presented side by side, the data can be compared on a weekly basis. The upstream boxes are ordered by odd numbers, while the downstream boxes are ordered by even numbers.

Figure 25 shows the boxplot for daytime over a period of four weeks. The size of the boxes for upstream is smaller than the boxes for downstream. This indicates greater variation in downstream speeds. The upstream speed remains consistently within the range of 70 to 75 mph. However, the downstream speed gradually decreases as the speed feedback trailer gets closer to the lane shift and egress point for work vehicles. In the first week, the downstream speed remains in the middle range of 65 to 70 mph. In the second week, the speed hovers around 65 mph. The third week shows a speed just below 65 mph, and the fourth week exhibits the lowest speeds. This result indicates that the speed feedback trailer effectively reduces vehicle speed when located near the lane shift and egress point for work vehicles during daytime.

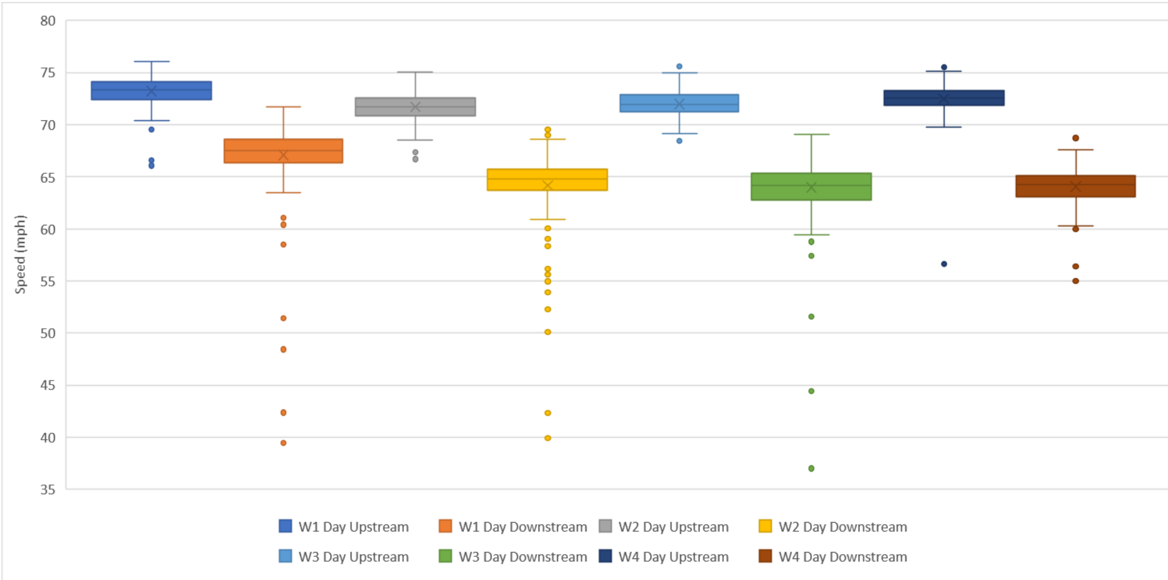


Figure 25. Speed boxplot for daytime for Missouri field study

The boxplot in Figure 26 represents the nighttime data for each of the four weeks. The size of the boxes for nighttime is larger than the boxes for daytime. This indicates that there is greater variation in vehicle speeds during nighttime. Furthermore, the recorded speeds from each week are generally higher compared to the speeds during daytime. This suggests that vehicles tend to drive faster at nighttime, although some vehicles still maintain lower speeds. However, the speed difference between upstream and downstream locations is smaller during nighttime than during daytime. Nonetheless, the effectiveness of the speed feedback trailer, based on its location, yields similar results to daytime observations. The downstream speeds decrease as the SFT is moved closer to the lane shift and egress point for work vehicles.

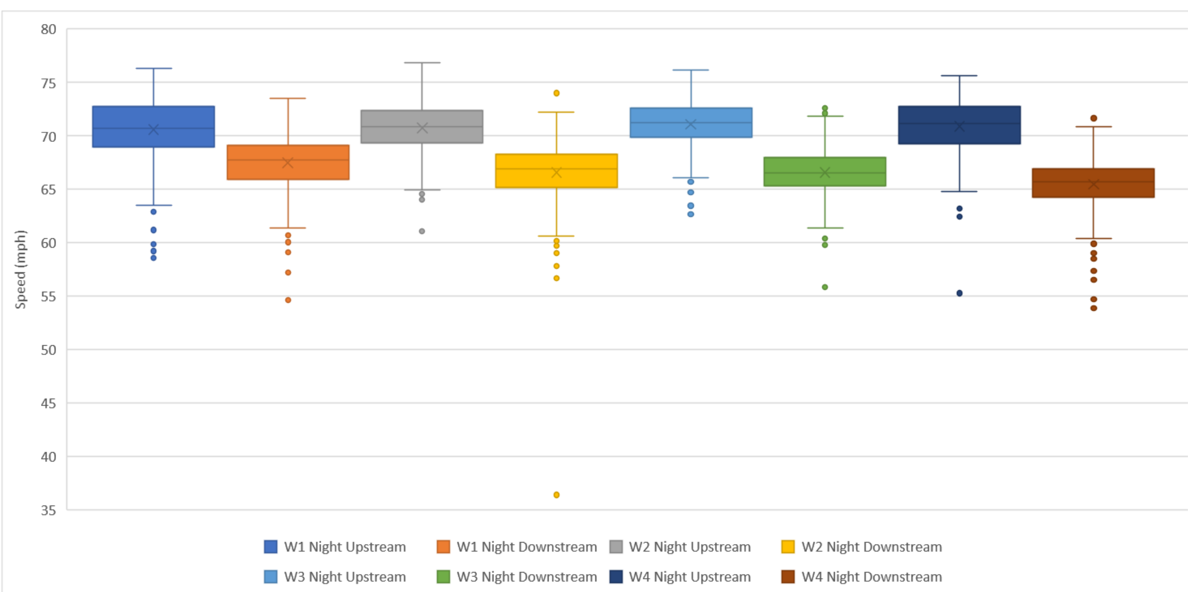


Figure 26. Speed boxplot for nighttime for Missouri field study

6.5. Results and Discussion

To evaluate the impact of the position of an SFT in the advance warning area on vehicle speeds approaching a freeway lane shift, two speed sensors (one upstream of the work zone and one near the work vehicle egress point) were deployed to collect data for four weeks. No SFT was on the site for the first week, which served as the baseline condition. Thereafter, the SFT was then moved increasingly closer to the lane shift area/work vehicle egress point for each subsequent week. Data was partitioned by week and by daytime and nighttime to perform a comparison of the differences in traffic counts and vehicle speed metrics.

Table 26 shows the overall results for daytime data. The difference between the average daytime speeds upstream and downstream increases as the location of the SFT is moved closer to the lane shift/egress point, increasing from 6.40 mph without the SFT to 8.46 mph with the SFT. This suggests that the SFT in the closest position to the lane shift/egress point provided an additional daytime speed reduction of approximately 2.0 mph compared to when no SFT was present. In addition, the percentage of vehicles exceeding the work zone speed limit by 10 mph or more decreased as the SFT was positioned closer to the lane shift/egress point. These results indicate that the SFT becomes more effective at reducing daytime speeds as the SFT is moved closer to the lane shift/egress point.

Table 27 shows the overall results for nighttime data. Similar to the daytime results, the difference between the average nighttime speeds upstream and downstream increases as the location of the SFT is moved closer to the lane shift/egress point for work vehicles, increasing from 3.95 mph without the SFT to 6.64 with the SFT. This suggests that the SFT in the closest position to the lane shift/egress point provided an additional nighttime speed reduction of approximately 2.7 mph compared to when no SFT was present, which was even larger than the daytime difference. Again, the percentage of vehicles complying with the speed limit increases and the percentage of vehicles exceeding the work zone speed limit by 10 mph or more decreases as the location of the SFT gets closer to the lane shift/egress point. These results indicate that the SFT also becomes more effective at reducing nighttime speeds as the SFT is moved closer to the lane shift/egress point.

Table 26. Summary of daytime speed results for Missouri field study of SFT position

Parameter	Week 1	Week 2	Week 3	Week 4
Distance from SFT to Egress Point for Work Vehicles (ft)	No SFT	8190	5240	1060
Total Number of Vehicles (Downstream)	34,882	35,309	36,676	30,344
Average Upstream Speed (mph)	73.19	71.68	71.99	72.44
Standard Deviation Upstream Speed (mph)	7.21	7.77	7.95	7.51
Average Downstream Speed (mph)	66.79	64.09	63.89	63.98
Standard Deviation Downstream Speed (mph)	9.18	9.67	8.77	8.04
Difference between Average Upstream Speed and Average Downstream Speed (mph)	6.40	7.59	8.10	8.46
Percent of Vehicles Complying with Work Zone Speed Limit (Downstream)	15.65%	24.33%	24.51%	24.20%
Percent of Vehicles Exceeding Work Zone Speed Limit by 10 mph or More (Downstream)	32.16%	20.05%	17.41%	15.95%

Table 27. Summary of nighttime speed results for Missouri field study of SFT position

Parameter	Week 1	Week 2	Week 3	Week 4
Distance from SFT to Egress Point for Work Vehicles (ft)	No SFT	8190	5240	1060
Total Number of Vehicles (Downstream)	25,265	23,806	24,268	19,368
Average Upstream Speed (mph)	71.73	71.59	71.89	72.31
Standard Deviation Upstream Speed (mph)	7.53	7.52	7.35	6.91
Average Downstream Speed (mph)	67.78	66.39	66.55	65.67
Standard Deviation Downstream Speed (mph)	8.99	10.11	9.04	9.07
Difference between Average Upstream Speed and Average Downstream Speed (mph)	3.95	5.20	5.34	6.64
Percent of Vehicles Complying with Work Zone Speed Limit (Downstream)	13.07%	16.47%	16.15%	18.55%
Percent of Vehicles Exceeding Work Zone Speed Limit by 10 mph or More (Downstream)	36.03%	30.59%	29.00%	24.92%

7. EVALUATION OF SFT POSITION APPROACHING THE WORK AREA WITHIN A LANE CLOSURE

7.1. Study Design and Site Characteristics

Following the evaluations of the effects of the SFT positioning on vehicle speeds near the start of the freeway work zone lane closure (Chapter 5) and the start of a lane shift (Chapter 6), a subsequent evaluation was conducted to determine the optimal placement of an SFT in relation to the work area. This study took place within a lane closure in the westbound lanes of I-69 near Lapeer, Michigan, where construction activities were active at the South Branch Flint River bridge. Westbound I-69 is a rural limited-access freeway consisting of two lanes traveling in each direction, with normal speed limits of 75 mph for passenger vehicles and 65 mph for heavy vehicles. The lane closure, which was marked by orange drums, began approximately six miles upstream of the work area. No positive protection was present at this location, and thus, the speed limit was 45 mph at the work area as workers were present during the entire study period.

Importantly, no active work occurred between the beginning of the lane closure and the work area of interest throughout the data collection period. This allowed the SFT that would typically be placed at the taper end to be repositioned near the work area for purposes of this study, thus ensuring that no other SFT was encountered by drivers while traveling through this lane closure prior to approaching the study site. The right lane remained closed throughout the study to facilitate the work area located at the right shoulder, while the left lane remained open for travel. The work area remained stationary, and workers were present throughout the study, creating a controlled environment for the evaluation and allowing for adjustments to the positioning of the SFT as needed for the study. Figure 27 shows the site layout, depicting the work area, as well as the SFT deployment locations at 200, 700, and 1,450 ft in advance of work area.

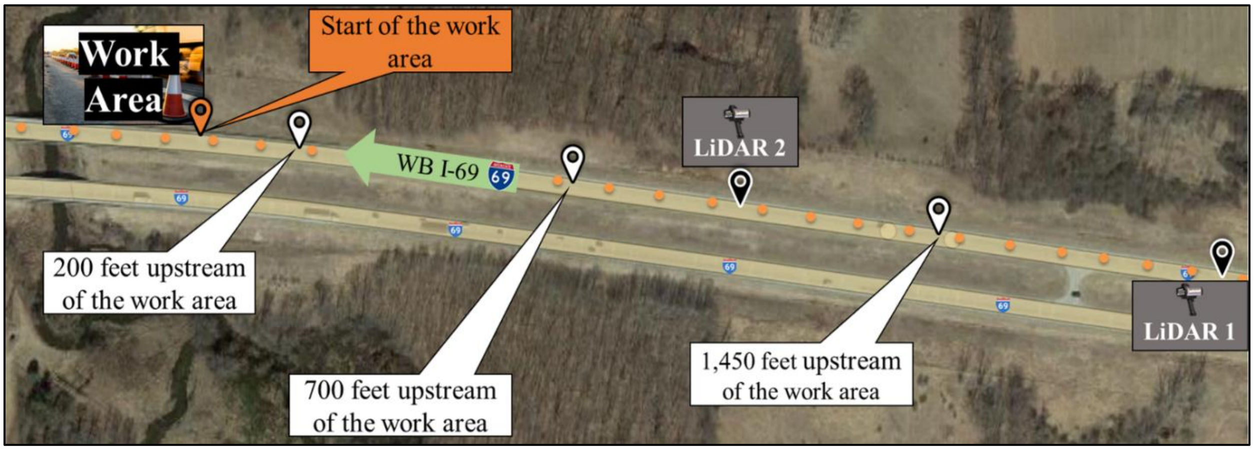


Figure 27. Westbound I-69 work zone study site

7.2. Test Conditions and Data Collection

The position of the SFT was varied between three predetermined locations to assess the speed reduction effects of the SFT as a function of the distance from the work area. Data collection was thus conducted for the following three different SFT test conditions:

- SFT placed 1,450 ft upstream of the work area,
- SFT placed 700 ft upstream of the work area, and
- SFT placed 200 ft upstream of the work area.

Speed data were collected using the two-person LiDAR handoff method. As illustrated in Figure 28, the upstream and downstream LiDAR data collection vehicles were positioned 2,100 ft and 1,050 ft before the work area, respectively. Both LiDAR vehicles were parked in the closed right lane, enclosed by orange drums. The locations of the LiDAR data collection vehicles were strategically determined to collect vehicle speeds traveling through the lane closure and approaching the SFTs all three locations where the SFT is positioned, as well as speeds when approaching the work area. These four locations are the key locations of interest for this study.

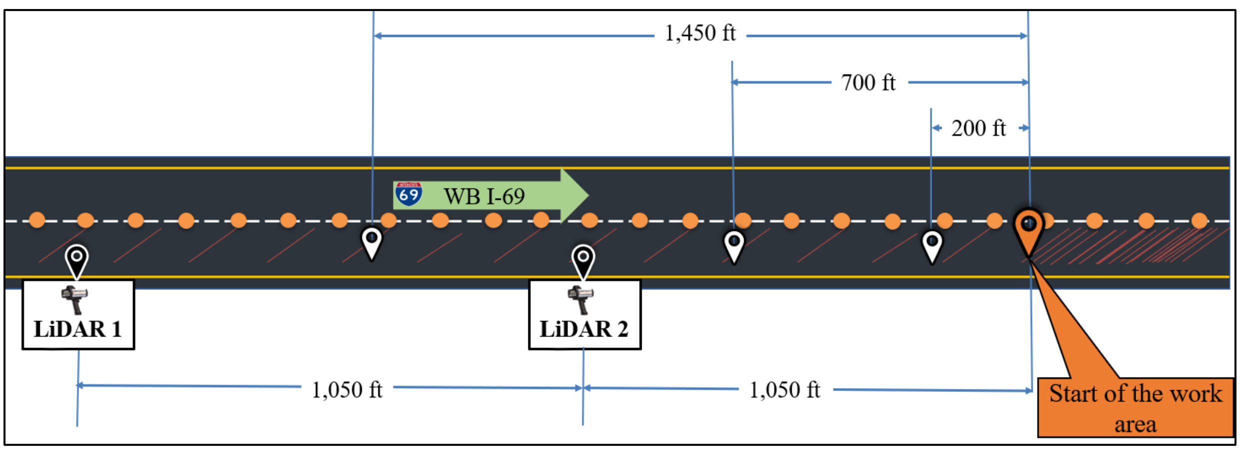


Figure 28. Data collection setup using two-person LiDAR handoff method

7.3. Data Summary

Following the data collection, the speed data acquired for each test condition were joined, organized, and coded into a single file for analysis, resulting in a final dataset that consisted of complete speed trajectories for 242 vehicle observations. The descriptive statistics for speed across all test conditions at key locations of interest can be found in Table 28.

Table 28. Descriptive statistics for speed of vehicles approaching and entering the work area based on SFT position in advance of the work area

Test Condition	Min	Max	Average	Std. Dev
Speed 1,450 ft Upstream of the Work Area				
SFT Placed 1,450 ft Upstream of the Work Area	52.0	70.0	59.9	3.54
SFT Placed 700 ft Upstream of the Work Area	49.0	73.0	60.8	4.64
SFT Placed 200 ft Upstream of the Work Area	50.0	71.0	60.7	3.63
Speed 700 ft Upstream of the Work Area				
SFT Placed 1,450 ft Upstream of the Work Area	46.0	68.0	59.1	4.28
SFT Placed 700 ft Upstream of the Work Area	45.0	71.0	59.3	5.38
SFT Placed 200 ft Upstream of the Work Area	41.0	74.0	58.2	4.93
Speed 200 ft Upstream of the Work Area				
SFT Placed 1,450 ft Upstream of the Work Area	44.9	68.5	57.6	5.18
SFT Placed 700 ft Upstream of the Work Area	44.6	71.0	58.4	6.03
SFT Placed 200 ft Upstream of the Work Area	41.0	72.0	55.3	5.56
Speed at the Work Area				
SFT Placed 1,450 ft Upstream of the Work Area	45.0	69.0	57.0	5.55
SFT Placed 700 ft Upstream of the Work Area	44.0	71.0	58.1	6.20
SFT Placed 200 ft Upstream of the Work Area	40.0	71.0	53.8	6.62

Note: All data are presented in miles per hour (mph)

The graphical representation of average speed trajectories for all test conditions is depicted in Figure 29, revealing noteworthy speed trends associated with the effects of the SFT in various proximity scenarios from the work area. Generally, speeds were lowest at the work area location across all test conditions, with a significant impact observed when the SFT was placed 200 ft upstream of the work area. Figure 29 demonstrates similar speed trends in the green and blue lines, representing conditions when the SFT is placed 1,450 and 700 ft before the work area, respectively. In both conditions, vehicle speeds are slightly lower at the SFT locations as compared to the other conditions, otherwise showing similar speed trends. The impact on vehicle speeds due to different placement scenarios of the SFT in relation to its proximity from the work area will be further examined based on the parameter estimates of the regression models in the next section.

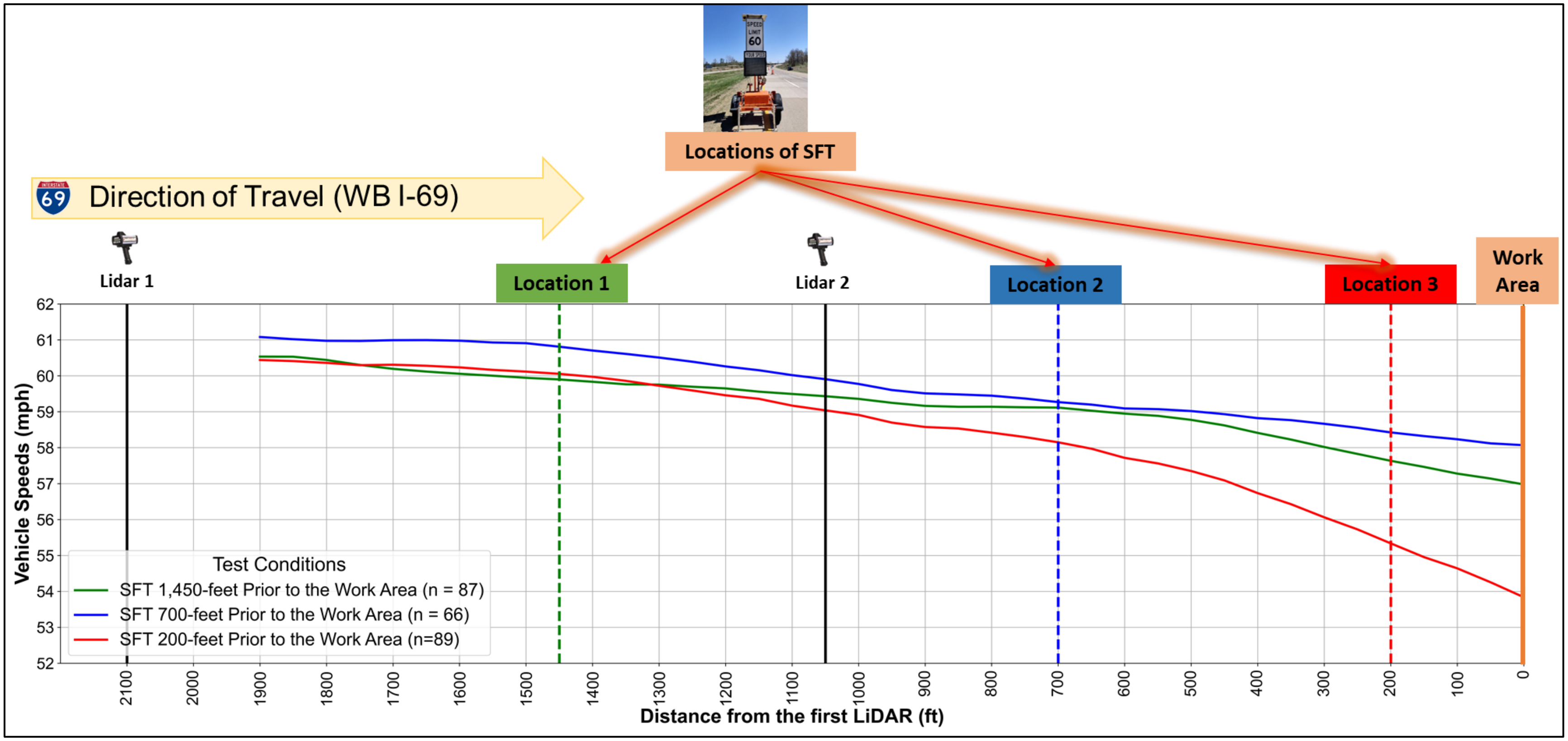


Figure 29. Average speed trajectories for vehicles approaching and entering the work area based on SFT position in advance of the work area

7.4. Results and Discussion

The speed data were analyzed considering both test conditions and vehicle types to validate the speed trends outlined in the previous section. For each point of interest, the speeds in each test condition were compared to those when the SFT was placed 1,450 ft upstream of the work area, considered as the baseline condition. It is important to note that the speed measured at the furthest upstream point (2,100 ft upstream of the work area) was included as an independent variable (covariate) in the regression model. This inclusion controlled for variations in the speed selection tendencies of drivers between data collection periods, as evident in the comparison of the upstream portion of speed trajectories in Figure 29. This analytical approach allows for the direct interpretation of the magnitude of speed reduction during each sign test condition from the corresponding parameter estimates while accounting for variations between drivers and site conditions.

The results from the multiple linear regression models for the three locations of interest across all conditions are displayed in Table 29. The parameter estimates from Table 29 for each test condition can be interpreted as the difference in mean speed as compared to the base condition, which was when the SFT was placed at the furthest upstream point (1,450 ft upstream of the work area). The results presented in Table 29 indicate that the most substantial speed reduction effects were observed when the SFT was placed closest to the work area. Specifically, when the SFT was positioned 200 ft upstream of the work area, average speeds at the start of the work area were 3.6 mph lower compared to when the SFT was placed further upstream at 700 or 1,450 ft prior the work area. No significant differences were observed between the speeds of passenger vehicles and heavy trucks.

Table 29. Linear regression results for speed of vehicles approaching and entering the work area based on SFT position in advance of the work area

Parameter	Estimate (mph)	Std. Error	p-value
Speed 1,450 ft Upstream of the Work Area			
Intercept	-3.061	1.594	0.056
Upstream Speeds	1.038	0.026	<0.001
Passenger Vehicles		*Base Condition*	
Heavy Vehicles	0.391	0.190	0.041
SFT Placed 1,450 ft Upstream of the Work Area		*Base Condition*	
SFT Placed 700 ft Upstream of the Work Area	0.320	0.229	0.164
SFT Placed 200 ft Upstream of the Work Area	0.232	0.212	0.274
Speed 700 ft Upstream of the Work Area			
Intercept	-1.999	3.909	0.610
Upstream Speeds	1.007	0.063	<0.001
Passenger Vehicles		*Base Condition*	
Heavy Vehicles	0.452	0.466	0.333
SFT Placed 1,450 ft Upstream of the Work Area		*Base Condition*	
SFT Placed 700 ft Upstream of the Work Area	-0.426	0.562	0.449
SFT Placed 200 ft Upstream of the Work Area	-0.896	0.519	0.086
Speed 200 ft Upstream of the Work Area			
Intercept	-1.111	5.324	0.835
Upstream Speeds	0.966	0.085	<0.001
Passenger Vehicles		*Base Condition*	
Heavy Vehicles	1.199	0.627	0.057
SFT Placed 1,450 ft Upstream of the Work Area		*Base Condition*	
SFT Placed 700 ft Upstream of the Work Area	0.185	0.756	0.807
SFT Placed 200 ft Upstream of the Work Area	-2.459	0.733	0.001
Speed at the Work Area			
Intercept	-1.518	5.920	0.798
Upstream Speeds	0.967	0.095	<0.001
Passenger Vehicles		*Base Condition*	
Heavy Vehicles	1.274	0.697	0.069
SFT Placed 1,450 ft Upstream of the Work Area		*Base Condition*	
SFT Placed 700 ft Upstream of the Work Area	0.482	0.840	0.566
SFT Placed 200 ft Upstream of the Work Area	-3.602	0.815	<0.001

These results emphasize the critical role of SFT placement proximity in achieving effective speed reduction, particularly with the closest placement (200 ft prior to the work area) showing the most significant impact on reducing vehicle speeds approaching and at the work area. Therefore, in addition to deploying an SFT near the start of the lane closure, it is also recommended to position a SFT in close proximity (e.g., within 200 ft) of the work area. This approach ensures that motorists receive the speed feedback message in a timely manner within sight of the work area, but with enough time to make any necessary speed reduction.

8. EVALUATION OF SFT PAIRED WITH A POLICE VEHICLE WITHIN A LANE CLOSURE

8.1. Study Design and Site Characteristics

A field evaluation was performed at a freeway work zone lane closure to evaluate the speed reduction effects of a police vehicle positioned at two different locations within the lane closure, and any additional effects provided by the deployment of an SFT. The evaluation was carried out at a freeway single-lane closure along eastbound I-69, near Lapeer, Michigan. Eastbound I-69 is a rural limited-access freeway with two-lanes in either direction and a speed limit of 75 mph for passenger cars and 65 mph for heavy vehicles. The left lane of the freeway was closed to facilitate the ongoing construction work beyond the left shoulder, which was occurring several thousand feet beyond the data collection location near the end of the taper. The speed limit signs that were present within this work zone included 60 mph R2-1 speed limit signs upstream of the taper and 45 mph WHERE WORKERS PRESENT R2-1a speed limit signs 800 ft beyond the end of the taper. Orange drums were utilized to delineate the lane closure, which included an entry taper that was 1,100 ft in length. The locations of taper start, taper end, and R2-1a sign (i.e., "WHERE WORKERS PRESENT 45" sign) are the key locations of interest for this study in terms of placement of SFT and the police vehicle. It should be noted that no workers were present in the proximity of the study location, and thus, the speed limit within the lane closure was 60 mph. The study site, along with the locations of interest and the locations of the LiDAR vehicles are illustrated in Figure 30.

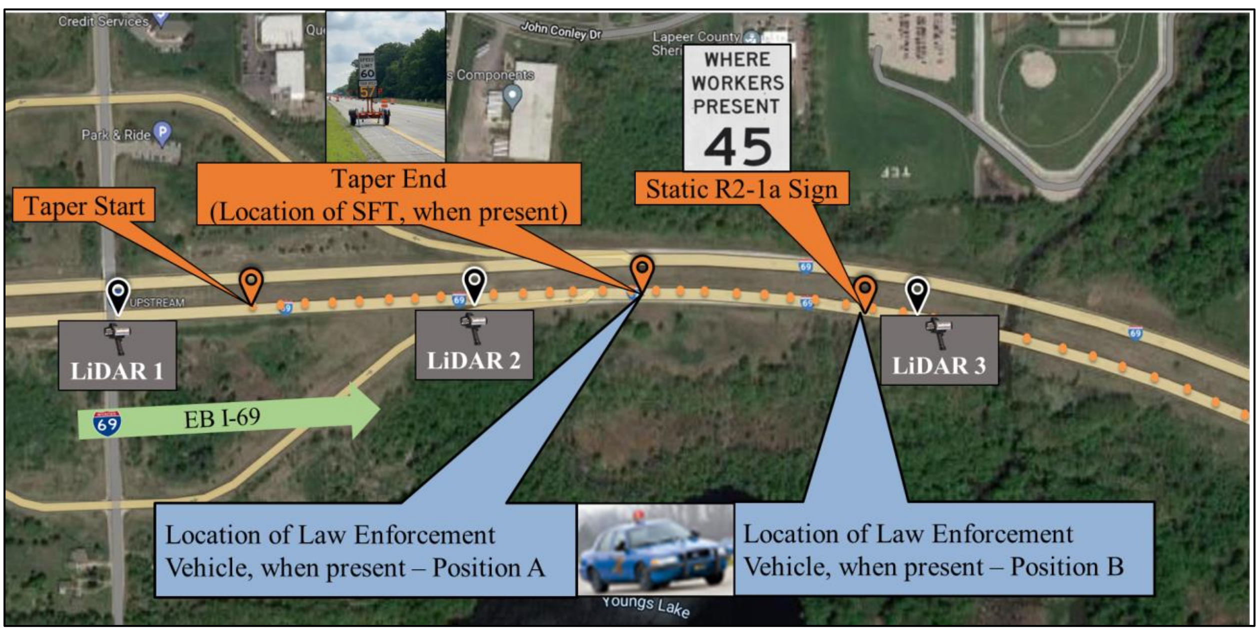


Figure 30. Eastbound I-69 lane closure for evaluation of SFT paired with police vehicle

The vehicle, a Michigan State Police sedan, was positioned on the roadside within the median adjacent to the closed left lane facing oncoming traffic with its flashers turned off, as depicted in Figure 31. Throughout the course of this study, the police vehicle, when present, was positioned at either of two locations: (1) at the taper end and (2) near the "WHERE WORKERS PRESENT 45" sign, which was approximately 800 ft beyond the taper end. A police officer was seated inside the vehicle at all times during data collection and did not pursue speeding motorists at any time. Thus, the police vehicle was for speed management purposes only, and not for active enforcement involving ticketing.

Figure 31. Police vehicle near the R2-1a sign at the study site, EB I-69 Lapeer, Michigan

8.2. Test Conditions and Data Collection

The police vehicle was positioned in two different locations during data collection: (1) near the taper end and (2) near the R2-1a "WHERE WORKERS PRESENT 45" sign which was 800 ft beyond the taper end. Speed data were collected with the police vehicle in each position with and without the SFT present at the end of the taper. Additionally, data were also collected during periods without the police vehicle or SFT present at the study site, which represented the baseline condition. Thus, five different test conditions were evaluated:

- No police vehicle present
- Police vehicle present near taper end (position A)
- Police vehicle present near "WHERE WORKERS PRESENT 45" sign (position B)
- SFT near taper end + police vehicle present near taper end (position A)
- SFT near taper end + police vehicle present near "WHERE WORKERS PRESENT 45" sign (position B)

Speed data were collected entirely during a single weekday daylight off-peak period. This allowed for controlling external factors that may otherwise influence speeds. The first (upstream) LIDAR collector was positioned 650 ft upstream of the start of taper and was used to track speeds approaching and entering the taper, prior to encountering the police vehicle and SFT. The second (middle) LIDAR collector was positioned within the taper, 400 ft upstream of the end of the taper. The third (downstream) LIDAR collector was located 150 beyond the R2-1a sign, which was 800 ft beyond the end of the taper. The data collection setup is illustrated in Figure 32.

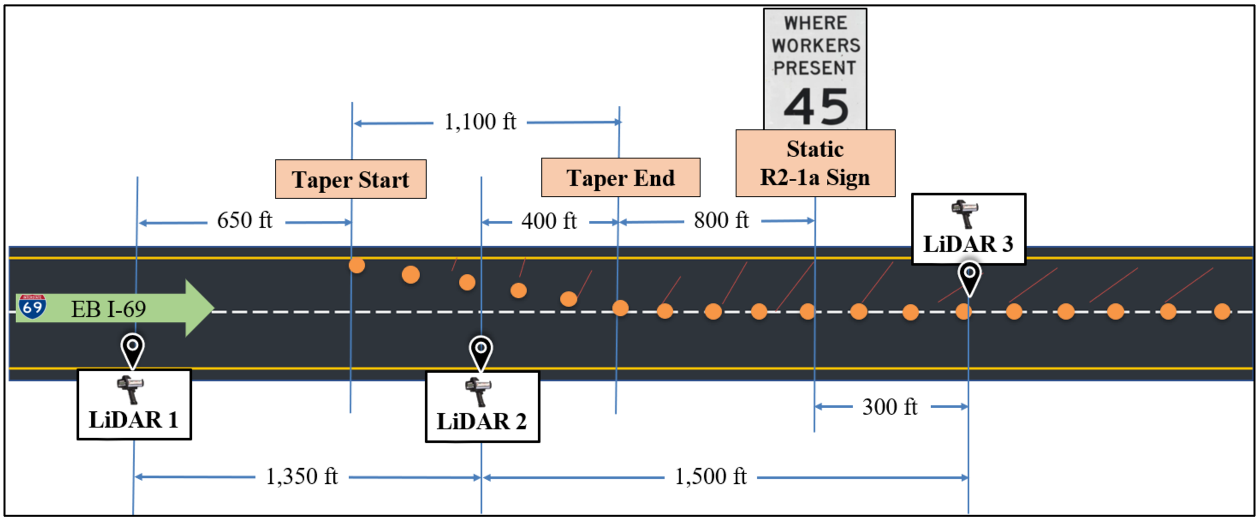


Figure 32. Data collection setup using three-person LiDAR handoff method for evaluating effects of pairing an SFT with a police vehicle at Eastbound I-69

8.3. Data Summary

After completion of the LIDAR field data collection, all files from the LIDAR technicians were joined using the vehicle information recorded in the comments. Complete speed trajectories were collected for a total of 481 vehicles, which included 201 without the SFT and 180 vehicles with the SFT. The descriptive statistics of vehicle speeds at key locations of interest across all test conditions are presented in Table 30.

Graphical representation of the average speed trajectories across all test conditions are presented in Figure 33. This figure reveals interesting trends regarding the speed effects associated with the presence and positioning of the police vehicle and when the SFT is added at the end of the taper. Generally speaking, speeds were consistently lowest at the R2-1a sign across all test conditions, with the presence and positioning of the police vehicle having a considerable effect on speed. Additional speed effects were observed when the SFT was included along with the police vehicle. The effects of the police vehicle and SFT + police vehicle were confirmed based on the parameter estimates from the regression models, which are described in the next section.

Table 30. Descriptive statistics for speed of vehicles approaching, entering, and traversing the lane closure based on presence and position of police vehicle and SFT

Test Condition	Min	Max	Average	Std. Dev
Speed at the Furthest Upstream Data Collection Point (1,650 ft Upstream of the Taper End)				
No Police Car	55.0	75.0	62.5	4.26
Police Car Near Taper End	54.0	73.0	63.5	4.55
Police Car Near R2-1a Work Zone Speed Limit Sign	54.0	79.0	63.3	5.17
SFT Near Taper End, Police Car Near Taper End	53.0	79.0	63.7	5.38
SFT Near Taper End, Police Car Near R2-1a Work Zone Speed Limit Sign	50.0	80.0	63.6	5.61
Speed at Taper End				
No Police Car	49.0	74.0	60.4	4.71
Police Car Near Taper End	46.0	72.1	58.7	5.21
Police Car Near R2-1a Work Zone Speed Limit Sign	51.0	76.0	60.2	4.35
SFT Near Taper End, Police Car Near Taper End	48.0	68.0	58.2	4.11
SFT Near Taper End, Police Car Near R2-1a Work Zone Speed Limit Sign	50.0	80.0	59.9	5.26
Speed at R2-1a WHERE WORKERS PRESENT 45 Sign (800 ft Downstream of Taper End)				
No Police Car	44.9	73.5	59.6	4.93
Police Car Near Taper End	44.3	68.1	57.6	4.55
Police Car Near R2-1a Work Zone Speed Limit Sign	43.0	71.8	56.0	5.37
SFT Near Taper End, Police Car Near Taper End	48.0	67.6	57.5	4.26
SFT Near Taper End, Police Car Near R2-1a Work Zone Speed Limit Sign	41.5	63.5	54.7	4.87
Speed at the Furthest Downstream Data Collection Point (1,850 ft Downstream of Taper End)				
No Police Car	46.0	70.0	60.5	4.46
Police Car Near Taper End	49.0	68.0	58.8	4.68
Police Car Near R2-1a Work Zone Speed Limit Sign	45.0	71.0	57.3	5.07
SFT Near Taper End, Police Car Near Taper End	48.0	73.0	58.9	4.61
SFT Near Taper End, Police Car Near R2-1a Work Zone Speed Limit Sign	45.0	64.0	56.7	4.41

Note: All data are presented in miles per hour (mph)

8.4. Results and Discussion

The speed data were analyzed as a function of test condition and vehicle type to verify the speed trends noted in the prior section. The results are displayed in Table 31.

Table 31. Linear regression results for speed of vehicles approaching, entering, and traversing the lane closure based on presence and position of police vehicle and SFT

Parameter	Estimate (mph)	Std. Error	p-value
Intercept	31.831	1.762	<0.001
Upstream Speed	0.458	0.027	<0.001
Vehicle Type:			
Passenger Cars	*Base Condition*		
Heavy Vehicles	-0.143	0.303	0.638
Test Conditions:			
At Taper End			
No Police Car	*Base Condition*		
Police Car Near Taper End	-2.158	0.736	0.003
Police Car Near R2-1a Work Zone Speed Limit Sign	-0.540	0.747	0.470
SFT Near Taper End, Police Car Near Taper End	-2.728	0.777	<0.001
SFT Near Taper End, Police Car Near R2-1a Work Zone Speed Limit Sign	-1.042	0.757	0.169
At R2-1a WHERE WORKERS PRESENT 45 Sign (800 ft Downstream of Taper End)			
No Police Car	-0.816	0.787	0.300
Police Car Near Taper End	-3.199	0.736	<0.001
Police Car Near R2-1a Work Zone Speed Limit Sign	-4.821	0.747	<0.001
SFT Near Taper End, Police Car Near Taper End	-3.412	0.777	<0.001
SFT Near Taper End, Police Car Near R2-1a Work Zone Speed Limit Sign	-6.213	0.757	<0.001
At the Furthest Downstream Data Collection Point (1850 ft Downstream of Taper End)			
No Police Car	0.092	0.787	0.907
Police Car Near Taper End	-2.031	0.736	0.006
Police Car Near R2-1a Work Zone Speed Limit Sign	-3.475	0.747	<0.001
SFT Near Taper End, Police Car Near Taper End	-2.057	0.777	0.008
SFT Near Taper End, Police Car Near R2-1a Work Zone Speed Limit Sign	-4.250	0.757	<0.001

The results of each test condition were compared to the speeds measured at the end of the taper without the police vehicle or SFT present, which was considered the baseline condition. It should be noted that the speed measured at the furthest upstream point (1,650 ft upstream of taper end) was included as an independent variable (covariate) in the regression model. Including upstream speed as a covariate controlled for the variation in the speed selection tendencies of drivers between the data collection periods, which did occur during the evaluation as evidenced by comparison of the upstream portion of the speed trajectories displayed in Figure 33. This analytical strategy allowed for the magnitude of speed reduction during each sign test condition to be directly interpreted from the corresponding parameter estimates, while controlling for variations between drivers and site conditions. The magnitude of speed reduction can be obtained by subtracting the parameter estimates between the various test conditions.

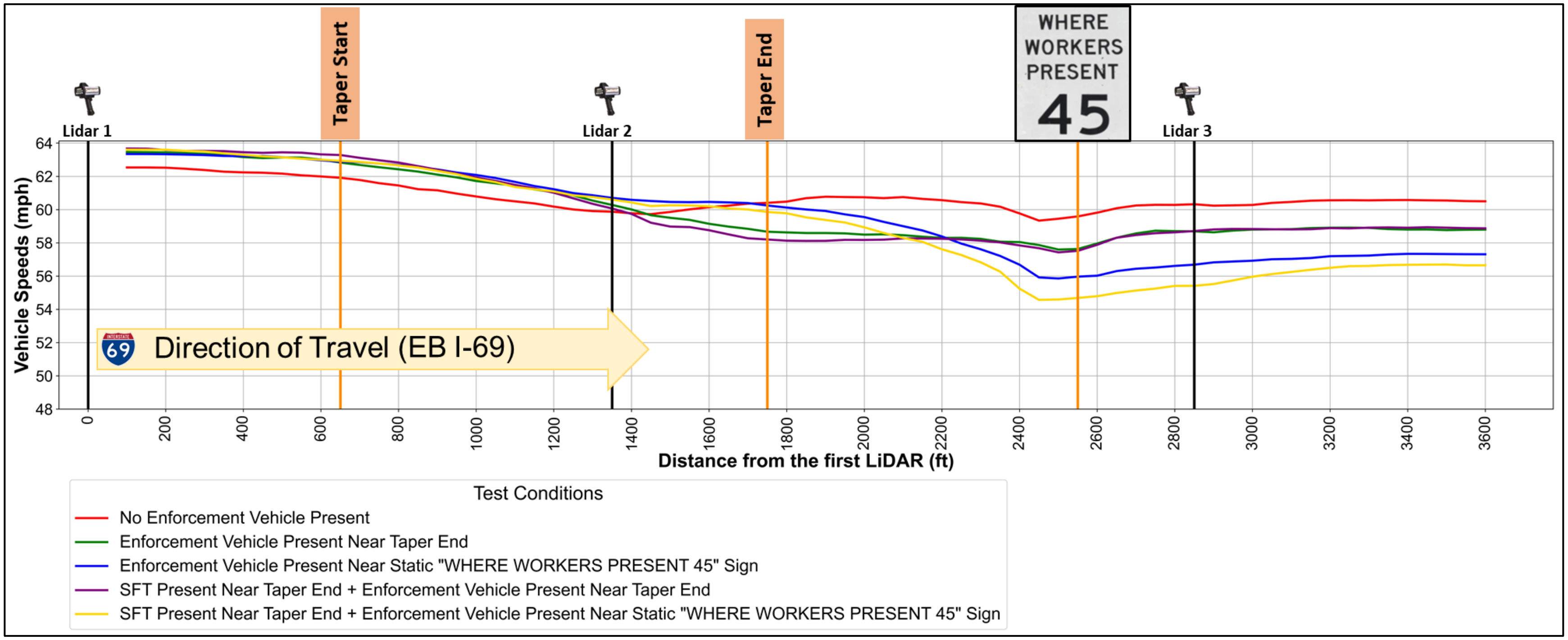


Figure 33. Average speed trajectories for vehicles approaching, entering, and traversing the lane closure based on presence and position of police vehicle and SFT

8.4.1. Effect of Police Vehicle Presence and Location

The results presented in Table 31 suggest that the police car presence and position had a statistically significant effect on the speed of vehicles traversing the work zone. Not surprisingly, the mere presence of the police car significantly reduced vehicular speeds near the vehicle regardless of the vehicle's location within the work zone. However, significantly greater speed reductions were observed when the police vehicle was positioned at the R2-1a sign compared to the taper end. With the police vehicle at the R2-1a sign, average speeds were 4 mph lower at the R2-1a sign compared to when no police vehicle was present and 1.6 mph lower than when the police vehicle was positioned at the end of the taper. More importantly, these effects were largely sustained 1,050 ft downstream of the R2-1a sign as drivers proceeded towards the work area.

8.4.2. Effect of Pairing SFT with the Police Vehicle

Comparison between the data collection periods with and without the SFT suggest that the SFT positioned at the taper provided an incremental speed reduction effect of 1.4 mph at the R2-1a sign when paired with the police vehicle positioned near the R2-1a sign. Furthermore, with this combination, average speeds were 5.4 mph lower at the R2-1a sign compared to when no police vehicle or SFT was present. This combination also provided the most sustained speed reductions, as speeds measured 1,050 ft downstream of the R2-1a sign remained 4.3 mph lower compared to when neither treatment was present.

9. EVALUATION OF SFT WITHIN A MEDIAN CROSSOVER

9.1. Study Design and Site Characteristics

After evaluating the SFT within a freeway work zone lane closure, a subsequent field assessment was conducted within a median crossover to assess the impact of the SFT on vehicle speeds when used in this context. The study site for this evaluation was the crossover section on the northbound I-69 roadway for southbound I-69 traffic toward Garfield Road near Olivet, Michigan. This section of I-69 is a limited-access freeway with two lanes in either direction and a speed limit of 75 mph for passenger cars and 65 mph for heavy vehicles. The crossover consisted of one travel lane for each direction, with a concrete barrier separating the two directions of traffic. The evaluation site was located approximately 6 miles beyond the start of the crossover where vehicles from southbound traffic were redirected towards the northbound I-69 roadway. During the study, the SFT was positioned on the emergency pull-off area on the right, maintaining a sufficient lateral distance from the travel lane and facing toward the incoming traffic from the southbound direction. It should be noted that the SFT was not initially installed within the crossover, but it was placed inside the stretch of the crossover for this study, as displayed in Figure 34.

Figure 34. SFT in a freeway work zone crossover

9.2. Test Conditions and Data Collection

To obtain the baseline condition, the radar speed feedback sign was carefully and completely covered with opaque cardboard to block the feedback generated by the SFT to the drivers. The cardboard was then carefully removed during the active conditions to display the feedback to the drivers. Covering and uncovering the feedback sign in this manner allowed for efficient manipulation of the test conditions during data collection, thereby allowing data collection for a specific test condition to be conducted multiple times in a day. Data was collected for two test conditions:

- SFT Covered
- SFT Active

Speed data of the vehicles traversing through the crossover was collected using two-person LiDAR handoff method. The data were collected entirely during a single weekday daylight off-peak period, allowing for control over external factors that may otherwise contribute to speed variation. The first (upstream) LiDAR was located approximately 1,000 ft before the SFT near the median crossover. The second (downstream) LiDAR, positioned approximately 350 ft beyond the SFT on the emergency pull-off area, tracked vehicle speeds downstream of the SFT. The locations of the LiDAR data collection vehicles and the SFT are illustrated in Figure 35.

Figure 35. Data collection setup at the work zone study site, SB I-69, Olivet, Michigan

9.3. Data Summary

After the data collection, the speed data for each test condition were combined, arranged, and coded into a unified file to facilitate a thorough analysis. The final dataset consisted of comprehensive speed profiles for 354 vehicle observations, including 234 passenger vehicles and

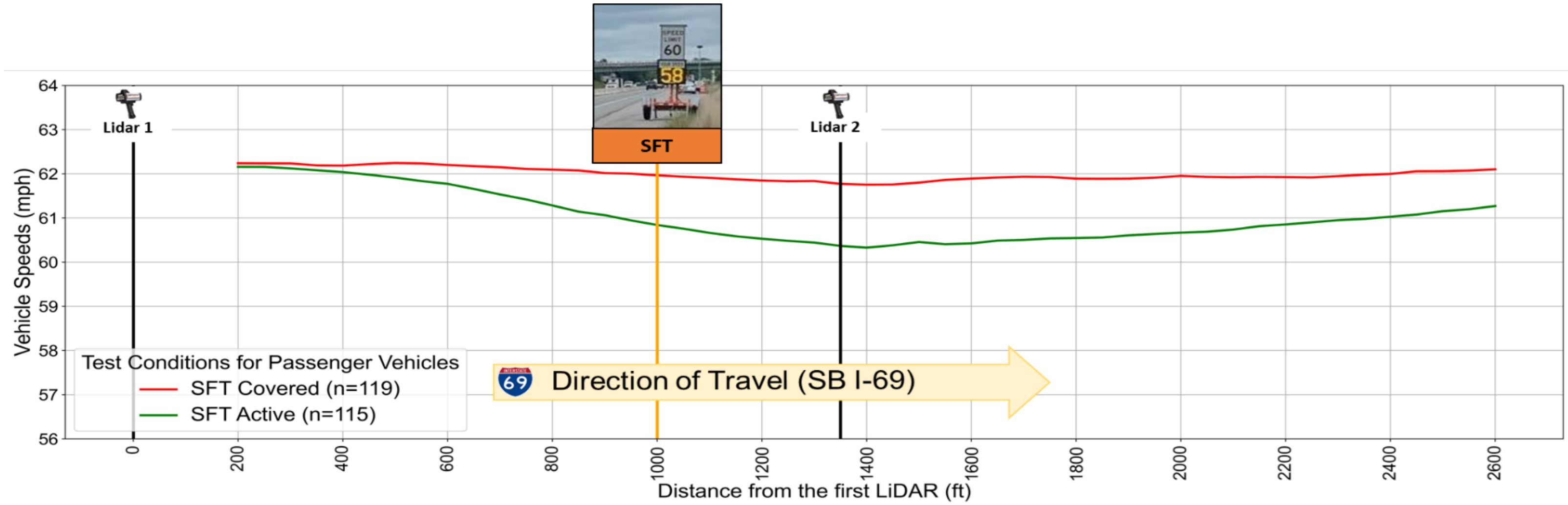
120 heavy vehicles. Descriptive statistics of vehicles at different locations are separately presented in Table 32 based on vehicle type.

Table 32. Descriptive statistics for speed of vehicles in the crossover based on SFT use

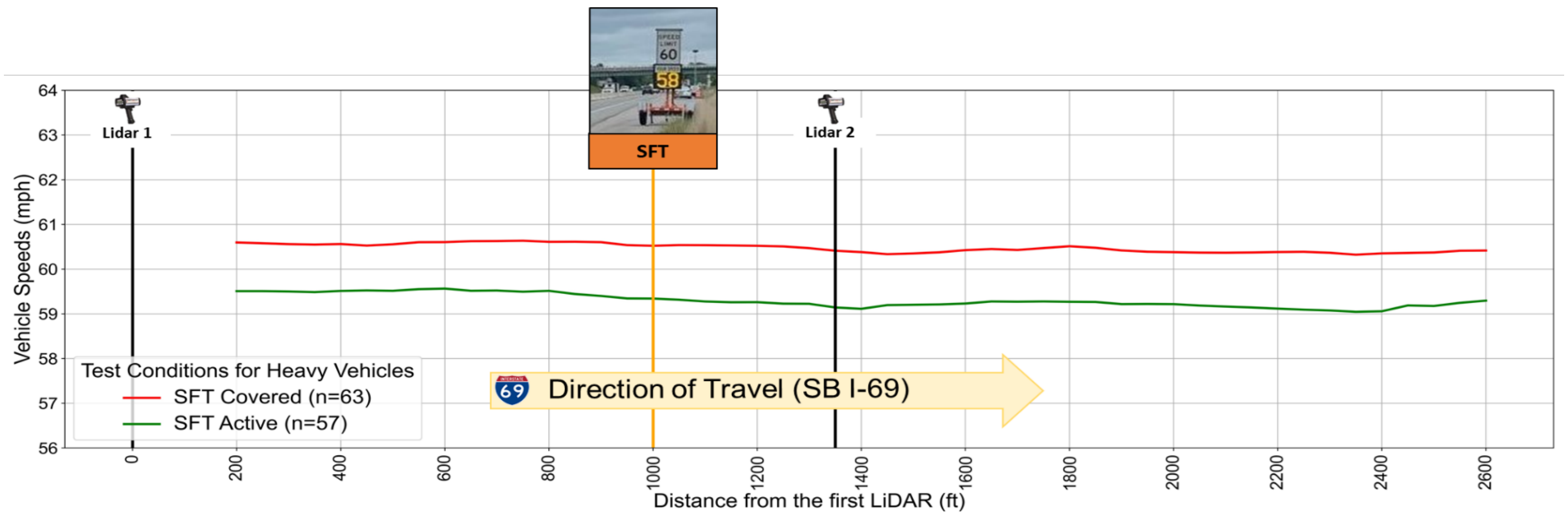
Vehicle Type	Passenger Vehicles				Heavy Vehicles			
Test Condition	**Min**	**Max**	**Average**	**Std. Dev**	**Min**	**Max**	**Average**	**Std. Dev**
Speed at the Furthest Upstream Data Collection Point (800 ft upstream of the SFT)								
SFT Covered	54	71	62.2	3.63	52	66	60.6	2.62
SFT Active	50	73	62.2	4.47	50	70	59.5	3.16
Speed at the Location of SFT								
SFT Covered	55	74	62.0	3.48	51	66	60.5	2.81
SFT Active	50	73	60.8	3.71	52	69	59.3	2.87
Speed 800 ft downstream of SFT								
SFT Covered	53	72	61.9	3.48	53	68	60.5	2.87
SFT Active	50	69	60.5	3.36	53	68	59.3	2.85
Speed 1,600 ft downstream of the SFT								
SFT Covered	50	73	62.1	3.67	52	69	60.4	2.99
SFT Active	53	71	61.3	3.29	41	67	59.3	3.34

Note: All data are presented in miles per hour (mph)

The vehicle speed trajectories for passenger and heavy vehicles are individually depicted in Figure 36a and Figure 36b, revealing distinct speed trends for each vehicle type in response to the SFT in a freeway median crossover and its impact on vehicle speeds. Notably, the presence of SFT has a considerable effect on vehicle speeds for passenger vehicles. In contrast, for heavy vehicles, average speed trajectories during SFT Active and SFT Covered show similar trends. These effects of SFT on different vehicle types were further confirmed through the parameter estimates derived from the regression models, as elaborated in the next section.



(a)



(b)

Figure 36. Average speed trajectories for (a) passenger vehicles, and (b) heavy vehicles traversing through a freeway work zone crossover with and without an active SFT

9.4. Results and Discussion

The speed data were separately analyzed for passenger and heavy vehicles to confirm the speed trends noted in the prior section, as displayed in Table 33. For both vehicle types, speeds measured when the SFT was active were compared to those measured when the SFT was covered, which served as a baseline condition at the location of the SFT. Speeds were assessed at the SFT, 800 ft downstream of the SFT, and 1,600 ft downstream of the SFT. The speed measured at the furthest upstream data collection point (800 ft upstream of the SFT) was included as an independent variable in the regression models, allowing for the control of variations in drivers' speed selection tendencies between data collection periods. This approach enables the direct interpretation of the magnitude of speed reduction during each sign test condition from the corresponding parameter estimates while considering variations between drivers and site conditions.

Table 33. Linear regression results for speed of vehicles in the crossover based on SFT use

Vehicle Type	Passenger Vehicles			Heavy Vehicles		
Parameter	**Estimate (mph)**	**Std. Error**	**p-value**	**Estimate (mph)**	**Std. Error**	**p-value**
Speed at the Location of SFT						
Intercept	14.775	1.876	<0.001	5.239	1.895	0.007
Upstream Speed	0.758	0.030	<0.001	0.912	0.031	<0.001
SFT Covered	*Base Condition*			*Base Condition*		
SFT Active	-1.063	0.243	<0.001	-0.188	0.184	0.310
Speed 800 ft downstream of SFT						
Intercept	22.791	2.309	<0.001	11.751	3.145	<0.001
Upstream Speed	0.628	0.037	<0.001	0.805	0.052	<0.001
SFT Covered	*Base Condition*			*Base Condition*		
SFT Active	-1.294	0.299	<0.001	-0.367	0.305	0.232
Speed 1,600 ft downstream of the SFT						
Intercept	27.326	2.684	<0.001	21.628	4.949	<0.001
Upstream Speed	0.559	0.043	<0.001	0.640	0.081	<0.001
SFT Covered	*Base Condition*			*Base Condition*		
SFT Active	-0.786	0.347	0.025	-0.424	0.481	0.380

The results from the linear regression models, as presented in Table 33 provide insights into the effects of active SFT compared to the covered SFT conditions at three speed measurement locations within the crossover. The parameter estimates in Table 33 for the active SFT condition signify the difference in mean speed compared to the base condition (SFT covered). The outcomes reveal distinct effects of the SFT based on the type of vehicle within the median crossover.

For passenger vehicles, the active SFT had a statistically significant effect on reducing speeds, with speeds decreasing by 1.1 mph at the SFT location when the SFT was active compared to when covered. This reduction persisted downstream, with speeds 0.8 mph lower 1,600 ft beyond the SFT. In contrast, the SFT had no effect on reducing speeds of heavy vehicles within the median crossover, as no significant changes in vehicle speeds were observed for heavy vehicles traversing the location regardless of whether the SFT was active. However, it should be noted that heavy vehicles were already traveling at least 1.0 mile slower, on average, upstream of the study area during the periods that the SFT active.

These nuanced results underscore the significance of considering vehicle type when evaluating the effectiveness of SFT deployments within freeway median crossovers. While heavy vehicles did not exhibit speed reduction when the SFT was active and uncovered, a consistent speed reduction of approximately 1 mph was observed over a stretch of 1,600 ft for passenger vehicles under the same conditions. These findings also imply that recommending the use of SFT as a speed reduction countermeasure within a freeway work zone crossover is appropriate, particularly for locations with a high volume of passenger cars, given the observed results.

10. EVALUATION OF SFT PAIRED WITH DIGITAL SPEED LIMIT SIGNS IN A LANE CLOSURE

10.1. Study Design and Site Characteristics

This field evaluation aimed to assess the impact on work zone speeds of the combined use of an SFT and Digital Speed Limit (DSL) sign, which was implemented using the Speed Wizard described in Chapter 4. Specifically, the study compared the effects of the SFT + DSL combination with standalone DSL configurations, considering both scenarios with and without the presence of a work vehicle. The evaluation site was a single freeway lane closure on the northbound section of US 127 near Leslie, Michigan. This segment of US 127 is a limited-access freeway with a speed limit of 70 mph. The freeway work zone stretch covered 11 miles, and the study was conducted 3 miles downstream of the start of the work zone taper. At the evaluation site, the right lane remained open for travel, while the left lane was closed due to ongoing construction work in the median, encroaching into the left shoulder of the roadway. The lane closure was marked using drums.

During the course of the evaluation, the SFT + DSL assembly was positioned at the closed left lane. Additionally, a second standalone DSL without an SFT was placed approximately 1,550 ft upstream of the SFT + DSL assembly at the right shoulder, displaying a speed limit of 60 mph, which is referred to as the 'Upstream DSL' from this point forward. Notably, before the start of the work zone taper located approximately 3 miles upstream of the evaluation site, another DSL was present, also displaying a speed limit of 60 mph. Transverse rumble strips were not present before entering the single-lane operating segments.

Throughout the evaluation, no actual work was in progress at this particular location, and thus, an MDOT work truck was used to simulate worker presence at the site. As illustrated in Figure 37, the MDOT vehicle was periodically positioned on the left shoulder 400 ft downstream of the SFT + DSL assembly and facing away from the oncoming traffic with its top beacon and flashers active. The evaluation site, along with the locations of key interest, which include SFT + DSL assembly, DSL, the MDOT vehicle, and the positions of LiDAR vehicles, are illustrated in Figure 38.

Figure 37. MDOT vehicle (with top beacon and flashers on) positioned at the closed left lane of the Northbound US 127 evaluation site

Figure 38. Northbound US 127 site for SFT + DSL evaluation

10.2. Test Conditions and Data Collection

When the MDOT vehicle was present, the SFT + DSL assembly was programmed to display a speed limit of 45 mph. Speed data were collected with and without activating the speed feedback display. Furthermore, data were also collected with the SFT + DSL assembly displaying a speed limit of 45 mph, active feedback display, and no MDOT vehicle present. Additionally, speed data were collected with the SFT + DSL assembly displaying a speed limit of 60 mph with an active feedback display, representing the baseline condition. Ultimately, four different test conditions were evaluated:

- Upstream DSL 60 mph, downstream DSL 60 mph (active SFT)
- Upstream DSL 60 mph, downstream DSL 45 mph (inactive SFT, MDOT truck present)
- Upstream DSL 60 mph, downstream DSL 45 mph (active SFT)
- Upstream DSL 60 mph, downstream DSL 45 mph (active SFT, MDOT truck present)

Data collection was conducted using the three-person LiDAR handoff method entirely during a single weekday daylight off-peak period to control external factors that may otherwise contribute to speed variation. The first LiDAR was positioned approximately 350 ft prior to the upstream DSL, tracking vehicle speeds before reaching the SFT + DSL assembly. The second LiDAR, located about 650 ft before the SFT + DSL assembly, recorded vehicle speeds approaching and passing through the SFT + DSL assembly. The third LiDAR, situated approximately 250 ft beyond the SFT + DSL assembly, tracked vehicle speeds after passing through the SFT + DSL assembly. The layout for the data collection setup is displayed in Figure 39.

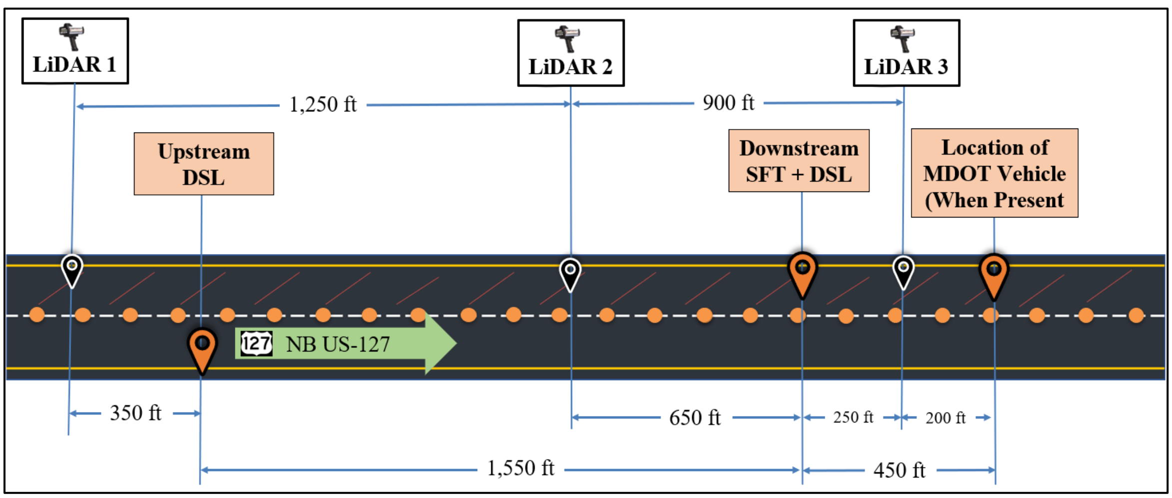


Figure 39. Data collection setup for SFT + DSL evaluation using three-person LiDAR handoff

10.3. Data Summary

Speed data collected for the speed effects of the combination of DSL signs and DSFS in freeway work zones were merged, organized, and coded to a single dataset that contained speed profiles of 314 vehicles across all four sign conditions, which included 265 passenger vehicles and 49 heavy vehicles. The descriptive statistics of the vehicle speeds across key locations of interest is displayed in Table 34.

Table 34. Descriptive statistics for speed of vehicles traversing the lane closure based on the SFT + DSL status and work vehicle presence

Test Condition	Min	Max	Avg.	Std. Dev
Speed at the First DSL Sign (1,600 ft before SFT+DSL)				
Upstream DSL 60 mph, Downstream DSL 60 mph (active SFT)	47.6	69.2	58.9	4.41
Upstream DSL 60 mph, Downstream DSL 45 mph (inactive SFT + MDOT truck)	48.8	72.0	59.1	4.65
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT)	50.0	71.0	58.9	4.40
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT + MDOT truck)	48.0	68.8	58.5	4.10
Speed at the SFT+DSL				
Upstream DSL 60 mph, Downstream DSL 60 mph (active SFT)	51.0	68.0	59.1	3.36
Upstream DSL 60 mph, Downstream DSL 45 mph (inactive SFT + MDOT truck)	42.3	69.0	55.8	6.34
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT)	39.8	68.0	55.4	6.29
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT + MDOT truck)	37.0	66.6	53.9	6.14
Speed at the Location of MDOT Vehicle (450 ft beyond SFT+DSL)				
Upstream DSL 60 mph, Downstream DSL 60 mph (active SFT)	50.0	65.0	58.7	3.01
Upstream DSL 60 mph, Downstream DSL 45 mph (inactive SFT + MDOT truck)	42.5	69.0	55.3	6.15
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT)	40.0	68.7	55.0	6.27
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT + MDOT truck)	39.0	66.0	53.0	6.18
Speed at the Furthest Downstream Data Collection Point (1,300 ft beyond SFT+DSL)				
Upstream DSL 60 mph, Downstream DSL 60 mph (active SFT)	46.0	69.0	58.9	3.54
Upstream DSL 60 mph, Downstream DSL 45 mph (inactive SFT + MDOT truck)	44.0	69.0	56.2	5.40
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT)	40.3	69.0	55.8	6.05
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT + MDOT truck)	44.0	68.0	54.6	5.48

Note: All data are presented in miles per hour (mph).

The graphical representation of the average speed trajectories for vehicles passing through the work zone lane closure study site is depicted in Figure 40, providing insights into the impact of DSL + SFT on vehicle speeds. As expected, vehicle speeds were reduced when the 45 mph speed limit was displayed. The magnitude of the speed reductions were similar when either the MDOT work vehicle was present or when no vehicle was present, but the SFT was active. However, the strongest speed reduction effects were observed when the SFT was active along with the MDOT work vehicle being present. The magnitude of the speed reduction effects of the SFT + DSL assembly during the various test conditions were further validated through parameter estimates obtained from the regression models, detailed in the subsequent section.

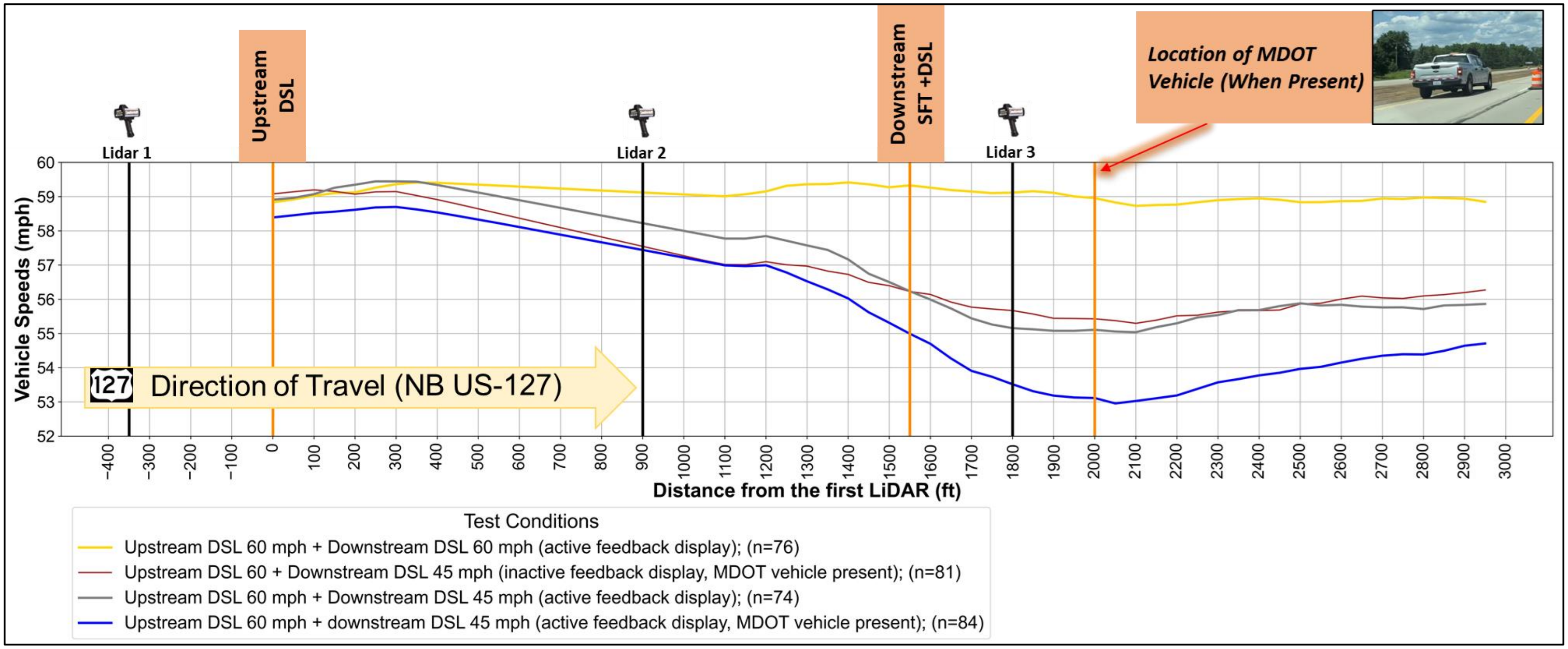


Figure 40. Average speed trajectories for vehicles traversing the lane closure based on the SFT + DSL status and work vehicle presence

10.4. Results and Discussion

The speed data were analyzed as a function of test condition to validate the speed trends identified in the preceding section. The results are presented in Table 35. The results for each test condition were compared to the speeds recorded at the SFT + DSL assembly location when displaying a speed limit of 60 mph with an active speed feedback display, which was considered the baseline condition. Notably, the speed measured at the furthest upstream data collection point, specifically at the location of the upstream DSL (1,600 ft before the SFT + DSL assembly), was included as an independent variable (covariate) in the regression model. Doing so aimed to control for variations in speed selection tendencies among drivers during different data collection periods. This analytical approach enabled the direct interpretation of the magnitude of speed reduction for each test condition from the corresponding parameter estimates while mitigating variations between drivers and site conditions.

Table 35. Linear regression results for speed of vehicles traversing the lane closure based on the SFT + DSL status and work vehicle presence

Parameter	Estimate (mph)	Std. Error	p-value
Intercept	18.934	2.104	<0.001
Speed at Upstream DSL (Upstream Speed)	0.683	0.035	<0.001
Speed at the Location of SFT+DSL Assembly			
Upstream DSL 60 mph, Downstream DSL 60 mph (active SFT)	*Base Condition*		
Upstream DSL 60 mph, Downstream DSL 45 mph (inactive SFT + MDOT truck)	-3.532	0.741	<0.001
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT)	-3.738	0.758	<0.001
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT + MDOT truck)	-4.925	0.735	<0.001
Speed at the Location of MDOT Vehicle (450 ft beyond SFT+DSL Assembly)			
Upstream DSL 60 mph, Downstream DSL 60 mph (active SFT)	-0.419	0.755	0.579
Upstream DSL 60 mph, Downstream DSL 45 mph (inactive SFT + MDOT truck)	-4.005	0.741	<0.001
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT)	-4.143	0.758	<0.001
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT + MDOT truck)	-5.805	0.735	<0.001
Speed at the Furthest Downstream Data Collection Point (1,300 ft beyond SFT+DSL Assembly)			
Upstream DSL 60 mph, Downstream DSL 60 mph (active SFT)	-0.209	0.755	0.782
Upstream DSL 60 mph, Downstream DSL 45 mph (inactive SFT + MDOT truck)	-3.105	0.741	<0.001
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT)	-3.345	0.758	<0.001
Upstream DSL 60 mph, Downstream DSL 45 mph (active SFT + MDOT truck)	-4.190	0.735	<0.001

The speed effects displayed in Table 35 may be assessed by comparing the parameter estimates between test conditions. Comparison between the test conditions suggests that reducing the magnitude of displayed speed limits on the SFT + DSL assembly from 60 to 45 mph reduced vehicle speeds by 3.6 mph. More importantly, with an MDOT work vehicle present, the use of the SFT along with the DSL reduced speeds by an additional 1.8 mph at the location of a work vehicle compared to when the SFT was not active. These speed reductions were largely sustained up to 1,300 ft beyond the SFT + DSL assembly. These findings support the continued use of the SFT + DSL assembly as a speed reduction strategy in freeway work zone lane closures, especially near work areas due to the ease of switching between the 60 and 45 mph work zone speed limits and the reduced ambiguity for motorists.

11. CONCLUSIONS AND RECOMMENDATIONS

This research project sought to assess the effectiveness of various deployment strategies for speed feedback trailers used in freeway work zones in order to inform state DOT policies and practices. To achieve this goal, researchers conducted a synthesis of best practices regarding the use of SFTs as a work zone speed management treatment. A nationwide state agency survey of work zone SFT utilization was also conducted, which yielded responses from 40 state DOTs. From there, a series of field studies were conducted within freeway work zones in Michigan and Missouri to evaluate the effectiveness of various SFT deployment strategies towards reducing work zone speeds and improving speed compliance. The findings were then synthesized to provide guidance and recommendations on the use of SFT in freeway work zones. The following subsections present a summary of the research performed along with conclusions and recommendations.

11.1. Summary of State DOT Practices for SFT Use in Work Zones

Results from the literature review and DOT survey indicate a wide range of DOT practices for speed feedback trailers in work zones. The use of speed feedback trailers in work zones is relatively prevalent among state DOTs, with 31 of 40 responding DOTs indicating their use in the survey. Based on the survey results, 19 responding DOTs have developed policies, guidance, or standards for speed feedback trailers in work zones. Depending on the state, the use of SFTs in work zones can be optional, recommended, or required under certain conditions. Example criteria for which DOTs consider or require the use of speed feedback trailers include: worker presence, absence of positive protection, work type, roadway facility type, project cost, lane closures, night work, and high crash frequency. For work zones on both freeways and non-freeways, speed feedback trailers are most frequently used for lane closures, followed by traffic shifts.

For placement of speed feedback trailers, DOTs most frequently place speed feedback trailers near the work area or prior to the taper (e.g., in the advance warning area). In some cases, DOTs require the use of more than one speed feedback trailer in the work zone. Regarding practices for repositioning speed feedback trailers in work zones, the most common practice among state DOTs is repositioning the speed feedback trailer as the work area moves, followed by leaving it in one location and periodically repositioning it within the same work zone.

DOTs sometimes use built-in features for speed feedback trailers. The most commonly used built-in feature for speed feedback trailers in work zones is a flashing speed display when a vehicle exceeds a threshold speed. The threshold speed varies between DOTs but is typically 1 to 10 mph over the work zone speed limit. Some DOTs do not allow the numbers on the display to flash. At higher speeds, some DOTs require the display to be blank to discourage drivers from trying to get a high speed displayed on the panel. State DOTs also have various other requirements for speed feedback trailers in work zones, such as detection distances, color, duration of use at one location, approved products lists, data logging, training, monitoring, and basis of payment.

Among the DOTs that use performance measures to assess SFTs, speed limit compliance or non-compliance is most often utilized. Previously completed research studies documented in the literature show that use of speed feedback trailers in work zones is effective in reducing vehicle speeds, with average speed reductions ranging from 0.8 to 10 mph. DOTs perceive trailer location within the work zone and police presence to be the factors that most influence the performance of speed feedback trailers in work zones. DOTs perceive the lack of data on performance as the greatest challenge to implementing speed feedback trailers in work zones.

11.2. Conclusions and Key Findings from Field Evaluations of SFTs in Freeway Work Zones

A series of field evaluations were performed within five freeway work zone lane closures in 2022 and 2023 to evaluate strategies aimed at enhancing the effectiveness of SFTs towards reducing work zone speeds and improving compliance. These evaluations, conducted in multiple phases and at five freeway work zone locations, sought to yield insights and recommendations for optimizing SFT deployment and introducing measures to improve their overall effectiveness. The majority of the evaluations were performed in Michigan, with one evaluation performed in Missouri. The conclusions and key findings from the field evaluations are summarized as follows:

- **SFT Positioning at a Lane Closure Taper**: Positioning the SFT slightly beyond the end (e.g., 800 ft) of a lane closure taper and adjacent to the nearest R2-1a work zone speed limit sign resulted in speed reductions that were both greater in magnitude and sustained further into the work zone compared to when the SFT was located at the taper start or taper end. With the SFT placed 800 ft beyond the taper end, speeds measured 2,900 ft beyond the SFT (4,800 ft beyond the start of the taper) were 1.4 mph lower compared to the other SFT positions.
- **SFT Positioning in the Advance Warning Area Approaching a Lane Shift:** The SFT was increasingly more effective at reducing daytime and nighttime speeds at the lane shift as it was positioned closer to the start of the lane shift. With the SFT in the closest position to the lane shift (approximately 1,000 ft in advance of the shift), speeds were 2.0 mph and 2.7 mph lower during the day and night, respectively, compared to when the SFT was not present.
- **SFT Positioning Approaching the Work Area Within a Lane Closure:** The SFT was increasingly more effective at reducing speeds of vehicles approaching and entering the work area as it was positioned closer to the work area. With the SFT positioned 200 ft from the start of the work area, speeds were 3.6 mph lower entering the work area compared to when the SFT was positioned further upstream.
- **Police Vehicle Placement Within a Lane Closure:** Greater speed reductions were observed when the police vehicle was positioned at the initial R2-1a sign within the lane closure (approximately 800 ft after the end of the taper), compared to when the police vehicle was positioned the taper end. The presence of the police vehicle at this location accounted for average speed reductions of approximately 4 mph, which was largely sustained for at least 1,000 ft downstream as drivers proceeded towards the work area.
- **Combined Use of SFT With a Police Vehicle:** Adding an SFT to a lane closure with a police vehicle present provided an incremental speed reduction effect. With the police

vehicle positioned near the R2-1a sign, speeds were 1.4 mph lower with the SFT present at the taper compared to when no SFT was present, and 5.4 mph lower compared to when neither treatment was present at the work zone.

- **SFT Within a Median Crossover**: The use of an SFT within a median crossover reduced speeds of passenger vehicles by 1.1 mph, which was largely sustained 1,600 ft beyond the SFT. The SFT had no effect on reducing speeds of large trucks within the crossover.
- **SFT Paired With a Digital Speed Limit (DSL) Sign in a Lane Closure:** Lowering the speed limit on the DSL from 60 to 45 mph reduced vehicle speeds by 3.6 mph when an MDOT work truck was positioned on the shoulder. Activating the SFT in combination with the DSL reduced speeds by an additional 1.8 mph near the work truck. These findings support the continued use of the combined SFT + DSL assembly as a speed reduction strategy in freeway work zone lane closures, especially near work areas due to the simplicity of switching between the 60 and 45 mph work zone speed limits and the reduced ambiguity for motorists.

11.3. Recommendations for Improving the Effectiveness of Speed Feedback Trailers in Freeway Work Zones

When deployed in work zones, the primary purpose of an SFT is to alert motorists of the need for compliance with the work zone speed limit, particularly near potential conflict points, such as a merging taper, work area, or lane shift. Thus, there is value to providing SFTs at multiple strategic locations approaching and within the work zone. The state agency survey found that DOTs were most likely to deploy SFTs in advance of the taper (65%), followed by near the work area (58%), and at the taper (32%). The field evaluations tested the effects of SFTs in each of these general areas within freeway work zones, which allowed for recommendations to be made, which are provided as follows.

11.3.1. Optimal SFT Deployment Locations

Although SFTs were generally effective at reducing work zone speeds regardless of the deployment characteristics, they tended to be more effective when positioned closer to the work area, including ingress/egress locations. Thus, if only a single SFT is to be used, which is commonly the case for work zones of a shorter distance, it should be positioned near the work area, approximately 200 ft upstream of the start of the active work. Positioning the SFT in this manner helps ensure that motorists receive the speed feedback message in a timely manner within sight of the work area, but also with adequate time to comfortably decelerate. The authors caution against placing the SFT at too great a distance upstream of the work area, as drivers may be more likely to disregard such an early warning message. For work zones with multiple active work areas, an SFT should be deployed in advance of each area while workers are present.

The use of additional SFTs at other locations within the work zone, particularly for work zones that cover a substantial distance, is also encouraged. If additional SFTs are available, then it is recommended that one be positioned within 1,000 ft upstream of the lane closure, shift, or median crossover. Additionally, an SFT should be placed shortly beyond the end (e.g., within 1,000 ft) of any lane closure taper, preferably adjacent to the initial speed limit sign in order to draw drivers' attention to the work zone speed limit upon entering the lane closure. Deployment of an SFT within a median crossover is also encouraged, although less critical if barrier separation of opposing traffic flows is provided.

The spacing of successive SFTs within a lane closure should be based on the distance that the SFT-related speed reduction effects are sustained beyond the SFT, which was generally at least one-half mile beyond the SFT. However, half-mile SFT spacing is likely impractical for most lengthy work zones, and greater SFT spacings (e.g., 2 miles) are generally acceptable.

11.3.2. Combining SFTs with Other Speed Management Strategies

SFTs are also encouraged for use in combination with work zone police enforcement vehicles, regardless of whether any active enforcement is being performed. While a police vehicle positioned near the end of the taper will, by itself, reduce speeds by approximately 4 mph, adding a nearby SFT provides an additional speed reduction effect. Finally, the combined use of an SFT and digital speed limits is also encouraged, especially near work areas. This is due to the incremental speed reductions provided by the SFT along with the simplicity of switching between speed limits (e.g., work zone vs. non work zone, workers present vs. not-present) and, subsequently, the reduced ambiguity for motorists as to which speed limit is in effect at any given time and location within the work zone.

REFERENCES

Alabama DOT. 2019. *Radar Speed Display Sign (Special Provision No. 18-0737)*. Alabama Department of Transportation, Montgomery, AL.

Alabama DOT. 2023. *List IV-3: Work Zone Traffic Control Devices*. Alabama Department of Transportation. https://www.dot.state.al.us/publications/Materials/pdf/MSDSAR/QMSD/Liv03.pdf.

ARTBA. 2023. National & State Traffic Data. National Work Zone Safety Information Clearinghouse. American Road & Transportation Builders Association. https://workzonesafety.org/work-zone-data/work-zone-fatal-crashes-and-fatalities/.

Arkansas DOT. 2018. *Special Provision (Mobile Speed Notification System)*. Arkansas Department of Transportation, Little Rock, AR.

Benekohal, R. F., P. T. V. Resende, and R. L. Orloski. 1992. Effects of Police Presence on Speed in a Highway Work Zone: Circulating Marked Police Car Experiment. FHWA-IL/UI-240. University of Illinois, Urbana, Illinois.

Bham, G. H., and M. A. Mohammadi. 2011. Evaluation of Work Zone Speed Limits: An Objective and Subjective Analysis of Work Zones in Missouri. Missouri Department of Transportation, Jefferson City, MO.

Brewer, M. A., G. Pesti, and W. Schneider. 2006. Improving Compliance with Work Zone Speed Limits Effectiveness of Selected Devices. *Transportation Research Record*, No. 1948.

Brown, H., P. Edara, C. Sun, Q. Zeng, Z. Qing, S. Long, S. Engstrom, and S. Patil. 2022. *Effectiveness of Speed Management Methods in Work Zones*. Missouri Department of Transportation, Jefferson City, MO.

Caltrans. 2014. *California MUTCD 2014 Edition*. California Department of Transportation, Sacramento, CA.

Colorado DOT. 2009. *Work Zone Speed Control*. Colorado Department of Transportation. Denver, Colorado.

Cunningham, I., R. Jack, S. M. Anderson, E. J. Fitzsimmons, and B. G. Nye. 2021. *Analysis of Speed Profiles and Evaluation of Dynamic Signs in Kansas Work Zones*. Report No. K-TRAN: KSU-18-6. Kansas Department of Transportation, Topeka, KS.

El-Rayes, K., L. Liu, N. El-Gohary, and A.Z. Abdelmohsen. 2014. *Effect of Flaggers and Spotters in Directing Work Zone Traffic for Illinois Expressways and Freeway*s. FHWA-ICT-14-001. Illinois Department of Transportation, Springfield, IL.

FHWA. 2009. *Manual on Uniform Traffic Control Devices (MUTCD).* Federal Highway Administration, Washington, DC.

FHWA. 2023. FHWA Work Zone Facts and Statistics - FHWA Office of Operations. Federal Highway Administration. https://ops.fhwa.dot.gov/wz/resources/facts_stats.htm.

Finley, M. D., J. Jenkins, and D. S. McAvoy. 2015. Motorists' Speed Response to Nonvariable and Variable Work Zone Speed Limits and Other Work Zone Conditions. *Transportation Research Record*, Vol. 2485, pp. 70–77. https://doi.org/10.3141/2485-09.

Fontaine, M. D., and P. J. Carlson. 2001. Evaluation of Speed Displays and Rumble Strips at Rural-Maintenance Work Zones. *Transportation Research Record*, Vol. 1745, pp. 27–38.

Garber, N. J., and S. Srinivasan. 1998. Influence of Exposure Duration on the Effectiveness of Changeable-Message Signs in Controlling Vehicle Speeds at Work Zones. *Transportation Research Record*, Vol. 1650, pp. 62–70.

Hallmark, S., G. Basulto-Elias, N. Oneyear, A. Goswamy, R. Thapa, S. T. Chrysler, and O. Smadi. 2023. Evaluation of the Impact of Work Zone Traffic Control Devices on Change of Speed Using the SHRP 2 Naturalistic Driving Study. *Transportation Research Record*, Vol. 2677, No. 10.

Houston Radar. 2023. *Houston Radar SpeedLane® Pro Multi-lane Radar*. https://houston-radar.com/products/radar-data-collectors/speedlane-pro-multi-lane-radar/.

Illinois DOT. 2021. *Special Provision for Speed Display Trailer*. Illinois Department of Transportation. https://public.powerdms.com/IDOT/documents/2279554/Speed%20Display%20Trailer.

Illinois DOT. 2022. 2022 *Illinois Highway Standards for Traffic Control*. Illinois Department of Transportation, Springfield, IL.

Indiana DOT. 2013. *Indiana Design Manual*. Indiana Department of Transportation, Indianapolis, IN.

Iowa DOT. 2023. *Standard Road Plans*. Iowa Department of Transportation, Ames, IA.

Jafarnejad, A., J. Gambatese, and S. Hernandez. 2017. Influence of Truck-Mounted Radar Speed Signs in Controlling Vehicle Speed for Mobile Maintenance Operations: Oregon Case Study. *Transportation Research Record*, Vol. 2617, pp. 19–26.

Kamyab, A., T. Maze, S. Gent, and C. Poole. 2000. Evaluation of Speed Reduction Techniques at Work Zones. Proceedings of the Mid-Continent Transportation Research Symposium, Ames, IA, May 15–16, 2000.

Lee, B., D. Azaria, and S. Neely. 2014. *Work Zones and Travel Speeds: The Effects of Uniform Traffic Officers & Other Speed Management Measures*. TRC Report 14-004. University of Vermont Transportation Research Center, Burlington, VT.

Maryland State Highway Administration. 2005. *Use of Speed Display Trailers in Work Zones*. Maryland State Highway Administration, Annapolis, MD.

Mason, D. 2013. *Evaluation of Traffic Control Countermeasures to Improve Speed Limit Compliance in Work Zones on High-Speed Roadways*. Master's Thesis. University of New Brunswick, Fredericton, New Brunswick, Canada.

Mattox III, J. H., W. A. Sarasua, J. H. Ogle, R. T. Eckenrode, and A. Dunning. 2007. Development and Evaluation of Speed-Activated Sign to Reduce Speeds in Work Zones. *Transportation Research Record*, Vol. 2015, No. 1, pp. 3–11.

McCoy, P. T., J. A. Bonneson, and J. A. Kollbaum. 1995. Speed Reduction Effects of Speed Monitoring Displays with Radar in Work Zones on Interstate Highways. *Transportation Research Record*, Vol. 1509, pp. 65–72.

Medina, J. C., R. F. Benekohal, A. Hajbabaie, M.-H. Wang, and M. V. Chitturi. 2009. Downstream Effects of Speed Photo-Radar Enforcement and Other Speed Reduction Treatments on Work Zones. *Transportation Research Record*, Vol. 2107, pp. 24–33.

Michigan DOT. 2005. *Guidelines to Establish Speed Limits in Work Zones*. Bureau of Highway Instructional Memorandum 2005-16. Michigan Department of Transportation, Lansing, MI.

Michigan DOT. 2021. *Special Provision 20SP-812J-01: Temporary Speed Radar Trailer*. Michigan Department of Transportation, Lansing, MI.

Migletz, J., J.L. Graham, I.B. Anderson, D.W. Harwood, and K.M. Bauer. 1999. Work Zone Speed Limit Procedure. *Transportation Research Record*, Vol. 1657, pp. 24-30

Minnesota DOT. 2014. *Speed Limits in Work Zones Guidelines*. Minnesota Department of Transportation, St. Paul, MN.

Minnesota DOT. 2018. *Minnesota Temporary Traffic Control Field Manual*. Minnesota Department of Transportation, St. Paul, MN.

Minnesota DOT. 2020. *IWZ Toolbox*. Minnesota Department of Transportation, St. Paul, MN.

Minnesota DOT. 2022. *Special Provision S-254: Vehicle Speed Feedback Signs*. Minnesota Department of Transportation. https://dot.state.mn.us/pre-letting/prov/index.html.

Minnesota DOT. 2023a. *Minnesota Manual on Uniform Traffic Control Dev*ices. Minnesota Department of Transportation, St. Paul, MN.

Minnesota DOT. 2023b. *Approved/Qualified Products: Vehicle Speed Feedback Signs*. Minnesota Department of Transportation. https://www.dot.state.mn.us/products/signing/vehiclespeedfeedbacksigns.html.

Missouri DOT. 2021. *NJSP 21-06: Radar Speed Advisory System*. Missouri Department of Transportation. https://epg.modot.org/index.php/Job_Special_Provisions.

Nevada DOT. 2019. *Work Zone Safety and Mobility Implementation Guide*. Nevada Department of Transportation, Reno, NV.

Oregon DOT. 2021a. *Oregon Standard Specifications for Construction*. Oregon Department of Transportation, Salem, OR.

Oregon DOT. 2021b. *Oregon Standard Drawings*. Oregon Department of Transportation, Salem, OR.

Oregon DOT. 2022. *Standard Guidelines for Product Review*. Oregon Department of Transportation. https://www.oregon.gov/odot/Construction/Doc_ProductReview/radar_speed_trailer.pdf.

Oregon DOT. 2023. *Traffic Control Plans Design Manual*. Oregon Department of Transportation, Salem, OR.

Pennsylvania Code. Chapter 212, Title 67.

Pennsylvania General Assembly. 2002. 2002 Act 229.

Pesti, G., and P. T. McCoy. 2001. Long-Term Effectiveness of Speed Monitoring Displays in Work Zones on Rural Interstate Highways. *Transportation Research Record*, Vol. 1754, pp. 21–30.

Ravani, B., C. Wang, D. Ma, W. A. White, and P. Fyhrie. 2012. *Evaluation of Methods to Reduce Speed in Work Zones*. Report No. CA 13 2247. California Department of Transportation, Sacramento, CA.

Roberts, C. A., and E. J. Smaglik. 2014. *Reduction of Speed in Work Zones Using ITS DMS Instant Feedback to Drivers: Vehicle Speed Versus Traffic Fine*. Report No. FHWA-AZ-14-681. Arizona Department of Transportation, Phoenix, AZ.

Saito, M., and J. Bowie. 2003. *Efficacy of Speed Monitoring Displays in Increasing Speed Limit Compliance in Highway Work Zones*. Report No. UT – 03.12. Utah Department of Transportation, Salt Lake City, UT.

Sakhare, R. S., J. C. Desai, J. K. Mathew, J. D. McGregor, and D. M. Bullock. 2021. Evaluation of the Impact of Presence Lighting and Digital Speed Limit Trailers on Interstate Speeds in Indiana Work Zones. *Journal of Transportation Technologies*, Vol. 11, No. 2., pp. 157–167.

Savolainen, P. T., T. J. Gates, P. Edara, H. Brown, M. S. Mahmud, and M. U. Megat-Johari. 2022. *Work Zone Speed Limits and Motorist Compliance*. Smart Work Zone Deployment Initiative, Ames, IA.

Shaw, J. W., M. V. Chitturi, W. Bremer, and D. A. Noyce. 2015. *NCHRP Synthesis 482: Work Zone Speed Management*. National Cooperative Highway Research Program, Washington, DC.
South Dakota DOT. 2020. *SDDOT Construction Manual*. South Dakota Department of Transportation, Pierre, SD.
Teng, H., X. Xu, X. Li, V. Kwigizile, and A. R. Gibby. 2009. Evaluation of Speed Monitoring Displays for Work Zones in Las Vegas, Nevada. *Transportation Research Record*, Vol. 2107, No. 1, pp. 46–56.
Ullman, G. L., M. A. Brewer, J. E. Bryden, M. O. Corkran, C. W. Hubbs, A. K. Chandra, and K. L. Jeannotte. 2013. *NCHRP Report 746: Traffic Law Enforcement for Work Zones*. National Cooperative Highway Research Program, Washington, DC.
VTrans. 2016. *Use of Radar Speed Feedback Signs within Work Zones*. Vermont Agency of Transportation, Montpelier, VT.
Virginia DOT. n.d. *Special Provision: Work Zone Digital Speed Limit Sign Trailer*. Virginia Department of Transportation, Richmond, VA.
Washington State DOT. 2021. *Traffic Manual*. Washington State Department of Transportation, Olympia, WA.
Washington State DOT. 2022a. *Work Zone Typical Traffic Control Plans.* Washington State DOT. https://wsdot.wa.gov/engineering-standards/all-manuals-and-standards/plan-sheet-library/work-zone-typical-traffic-control-plans-tcp.
Washington State DOT. 2022b. *General Special Provisions*. Washington State Department of Transportation, Olympia, WA.
Wasson, J. S., G.W. Boruff, A. M. Hainen, S. M. Remias, E. A. Hulme, G. D. Farnsworth, and D. M. Bullock. 2011. Evaluation of Spatial and Temporal Speed Limit Compliance in Highway Work Zones. *Transportation Research Record*, Vol. 2258, pp. 1–15

APPENDIX A. SUMMARY OF EXISTING GUIDANCE, POLICIES, AND STANDARDS FOR WORK ZONE SPEED LIMITS

Table A-1. Summary of DOT guidance, policies, and standards for speed feedback trailers in work zones

State	Title	Reference	Hyperlink	Summary
Alabama	Radar Speed Display Sign (Special Provision No. 18-0737)	Alabama DOT 2019	-	Radar speed display signs should be in accordance with the MUTCD and shall be chosen from approved product list. They shall be installed based on the plans or Engineer's direction within transition areas of lane or shoulder closures during construction activities. Measurement and payment is per each.
Alabama	List IV-3: Work Zone Traffic Control Devices	Alabama DOT 2023	https://www.dot.state.al.us/publications/Materials/pdf/MSDSAR/QMSD/Liv03.pdf	Includes list of five products approved for radar speed signs.
Arkansas	Special Provision (Mobile Speed Notification System)	Arkansas DOT 2018	-	Contractor must provide the system to the Department. The Contractor provides training but does not operate the system. After training, the system is owned by the Department. The system should display the speed limit and vehicle speed and have a limit for the maximum speed that is displayed. Requirements for power supply, electronics, and warranty are specified. Measurement and payment are per each.
California	California MUTCD 2014 Edition (Chapter 2B: Regulatory Signs, Barricades, and Gates)	Caltrans 2014	https://dot.ca.gov/programs/safety-programs/camutcd	Vehicle Speed Feedback Signs may be used with temporary speed signs in temporary traffic control zones.
Illinois	Special Provision for Speed Display Trailer	Illinois DOT 2021	https://public.powerdms.com/IDOT/documents/2279554/Speed%20Display%20Trailer	Provides system requirements for speed feedback trailers. The color should be a yellow legend on black background. The displayed speed should flash when the speed is higher than the work zone posted speed limit. Speeds over a maximum cutoff speed (15 mph or 25 mph over the work zone speed limit) should not be displayed.
Illinois	Standard 701400-11 (Approach to Lane Closure)	Illinois DOT 2022	https://idot.illinois.gov/content/dam/soi/en/web/idot/documents/doing-business/manuals-guides-and-handbooks/highways/safety-engineering/2022-illinois-highway-standards-for-traffic-control.pdf	Layout for approach to lane closure on a freeway or expressway which shows a portable speed feedback trailer located upstream of the taper.

State	Title	Reference	Hyperlink	Summary
Indiana	Indiana Design Manual (Section 503-3.05(02): Use of Positive Protection)	Indiana DOT 2013	https://www.in.gov/dot/div/contracts/design/Part%205/Current%20Version%20of%20Chapter%20503%20-%20Traffic%20Maintenance.pdf	Radar speed display signs should be considered if positive protection is not provided.
Iowa	Design Manual (9B-11: Speed Feedback Trailer Signs)	Iowa DOT 2018	https://iowadot.gov/design/design-manual	The display should be posted with a regulatory speed limit sign with "YOUR SPEED" sign next to the dynamic "XX" sign. No text, strobe lights, or flashing should be utilized. Speed feedback trailers should be located next to the workers and work activity or prior to the roadway conditions that need speed reduction. The optimum location to place the speed feedback trailer is on a tangent section of the roadway between 500 and 2,500 ft of the workers or the hazardous conditions. The speed feedback trailer should not be placed near a horizontal curve.
Iowa	Standard Road Plans (Section TC: Traffic Control)	Iowa DOT 2023	https://iowadot.gov/design/SRP/CurrentBook/Sections/tc_section.pdf	Show layouts for lane closures. Drawings show speed feedback sign at the end of the merge taper when the non-work zone speed limit is 60 mph or higher.
Maryland	Use of Speed Display Trailers in Work Zones	Maryland State Highway Administration 2005	https://www.roads.maryland.gov/OOTS/03Speed%20DisplayTrailer.pdf	Provides deployment guidelines for SFTs in work zones. The SFT should be deployed in work zones with existing or anticipated concerns with speeding. Placement should be upstream of the location of the work zone. The preferred time limit for deployment is two weeks. For longer deployments of several weeks, periodic law enforcement should be provided. Typical display configurations are provided. Discusses advantages (e.g., increased speed compliance) and disadvantages (e.g., effectiveness decreases over time) of SFTs.

State	Title	Reference	Hyperlink	Summary
Michigan	Special Provision 20SP-812J-01: Temporary Speed Radar Trailer	Michigan DOT 2021	https://miloginworker.michigan.gov/sssp/getDocument.htm?projNum=704577&fileName=20SP-812J-01(Rev).pdf	Requirements for materials and construction are specified. The system should display the speed limit and vehicle speed. The unit should include display options to flash the vehicle speed when the vehicle speed is 1 to 10 mph over the work zone speed limit and to display the message “SLOW DOWN” if the vehicle speed is greater than 10 mph above the work zone speed limit. The unit must be able to detect vehicles at a distance of at least 400 yd. The system must log traffic volume data in 10-minute increments, and cellular service is required for remote access and data management. Measurement and payment are per each.
Minnesota	Speed Limits in Work Zones Guidelines	Minnesota DOT 2014	https://edocs-public.dot.state.mn.us/edocs_public/DMResultSet/download?docId=25956316	Dynamic speed display signs can be used with a regular posted speed limit sign, 24/7 construction speed limit assembly, workers present speed limit assembly, or a plaque for advisory speed. Provides guidance for operation based on type of speed limit.
Minnesota	Minnesota Temporary Traffic Control Field Manual	Minnesota DOT 2018	https://dot.state.mn.us/trafficeng/publ/fieldmanual/fieldmanual.pdf	Includes evaluation guide to assess the condition (acceptable, marginal, or unacceptable) of trailer-mounted electronic devices.
Minnesota	IWZ Toolbox	Minnesota DOT 2020	http://www.dot.state.mn.us/trafficeng/workzone/iwz/iwz-toolbox.pdf	Provides specifications for display size, operational guidelines, and an example layout for dynamic speed display signs. The system should flash when the vehicle speed is above the advisory speed. The display should go blank when a threshold speed is exceeded.
Minnesota	Special Provision S-254: Vehicle Speed Feedback Signs	Minnesota DOT 2022	https://dot.state.mn.us/pre-letting/prov/index.html	Provides construction requirements for vehicle speed feedback signs. The signs should be monitored to ensure proper operation. Measurement and payment are per each.
Minnesota	Approved/Qualified Products: Vehicle Speed Feedback Signs	Minnesota DOT 2023a	https://www.dot.state.mn.us/products/signing/vehiclespeedfeedbacksigns.html	Provides list of four standard size and two oversized products for vehicle speed feedback signs.

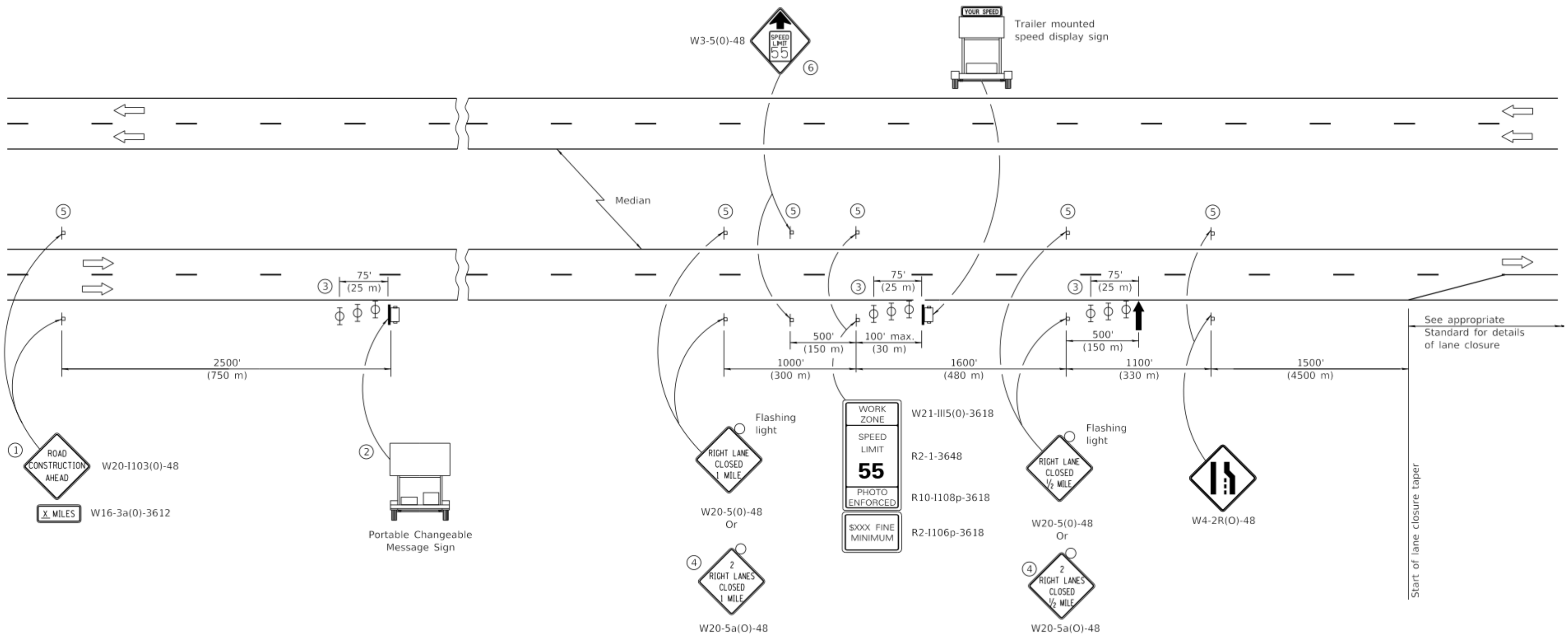
State	Title	Reference	Hyperlink	Summary
Minnesota	Minnesota Manual on Uniform Traffic Control Devices (Chapter 6H: Speed Limits in Temporary Traffic Control Zones)	Minnesota DOT 2023b	http://www.dot.state.mn.us//trafficeng/publ/mutcd/index.html	Includes layout showing example implementation of vehicle speed feedback sign with an advisory speed limit.
Missouri	NJSP 21-06: Radar Speed Advisory System	Missouri DOT 2021	https://epg.modot.org/index.php/Job_Special_Provisions	Provides system requirements for radar speed advisory system. The system should be able to detect vehicles at a distance of at least 1,000 ft and include a data logger. The system should be placed downstream from the initial sign package based on the plans or Engineer's direction. The system should display the speed (not flashing) when the speed is at or below the work zone speed limit, flash the speed when the speed is 1 to 10 mph over the work zone speed limit, and show the message "SLOW DOWN" when the speed is more than 10 mph over the work zone speed limit. Measurement and payment are per each.
Nevada	Work Zone Safety & Mobility Implementation Guide (Section 2.5: Policies Applicable to Work Zones and Appendix C: Work Zone Speed Reduction Countermeasure Matrix)	Nevada DOT 2019	https://www.dot.nv.gov/home/showpublisheddocument/16985/637042222790330000	Indicates that electronic driver feedback signs can help to reduce driver speeds. A work zone speed reduction countermeasure matrix is provided to help in the selection of work zone speed reduction countermeasures based on work zone conditions.
Oregon	Oregon Standard Drawings (TM880: Freeway or Divided Highway Speed Reduction (Paving Operations))	Oregon DOT 2021a	https://www.oregon.gov/odot/Engineering/Pages/Drawings-Traffic.aspx	Shows layout for speed reduction for paving operations on freeway or divided highway. Shows two SFTs: one prior to paving area and one within paving area. Note indicates that trailers should be placed as shown or directed. SFTs should not be delineated.
Oregon	Oregon Standard Specifications for Construction (Section 00222: Temporary Traffic Control Signs)	Oregon DOT 2021b	https://www.oregon.gov/odot/Business/Specs/2021_STANDARD_SPECIFICATIONS.pdf	Message "SLOW DOWN" should be displayed when threshold speed is exceeded. Defines over speed threshold as posted speed on the SFT. Speeds above 85 mph should not be displayed. Log data for speeds should be provided to the Engineer. Payment is per each.

State	Title	Reference	Hyperlink	Summary
Oregon	Standard Guidelines for Product Review (Section 00222.15C: Radar Speed Trailer)	Oregon DOT 2022	https://www.oregon.gov/odot/Construction/Doc_ProductReview/radar_speed_trailer.pdf	Provides system requirements for Type 1 (40 mph or below or for maintenance operations) or Type 2 (45 mph or higher) SFTs. The system should be able to display the vehicle speed (static or flashing) and an alternating "SLOW DOWN" message. Operational parameters are provided for advisory speed operation and regulatory speed operation. A table is provided which shows what should be displayed based on the operating mode and speed.
Oregon	Traffic Control Plans Design Manual (Section 2.7.1: Temporary Electrical Signs)	Oregon DOT 2023	https://www.oregon.gov/ODOT/Engineering/Pages/TCP-Manual.aspx	SFTs must be used for paving operations on freeways and may be used elsewhere as engineers deem appropriate. The display should display the vehicle speed with an alternating "SLOW DOWN" message when the speed exceeds a threshold speed. In addition, the display should turn blank when the speed is more than 30 mph above the speed limit to discourage drivers from trying to get a high speed displayed on the panel.
Pennsylvania	Chapter 212, Title 67, Pennsylvania Code	Commonwealth of Pennsylvania Code—Official Traffic Control Devices	https://www.pacodeandbulletin.gov/Display/pacode?file=/secure/pacode/data/067/chapter212/chap212toc.html	Use of PCMS to display vehicle speeds is allowed as an alternative. The PCMSs can display messages such as "YOU ARE SPEEDING" or "SLOW DOWN" which should be located 0.5 mile to 1 mile in advance of the work zone.
Pennsylvania	2002 Act 229	Pennsylvania General Assembly 2002	https://www.legis.state.pa.us/cfdocs/legis/li/uconsCheck.cfm?yr=2002&sessInd=0&act=229	Use of SFTs is required for Interstate work zones with project cost greater than $300,000. The trailer should be located at least 500 ft before entering the work zone.
South Dakota	SDDOT Construction Manual (Section 1 – Project Management, Chapter 15: Work Zone Traffic Control)	South Dakota DOT 2020	https://dot.sd.gov/media/documents/Chapter%2015%20-%20Work%20Zone%20Traffic%20Control.pdf	Provides list of conditions for which Radar Speed Feedback Signs (RSFS) should be considered, such as Interstate projects with lane closures and workers present, locations with work zone crashes, and night work. Indicates that RSFS should be placed at a location upstream of the activity area on the right shoulder or right closed lane. The numbers on the sign are not allowed to flash.

State	Title	Reference	Hyperlink	Summary
Vermont	Use of Radar Speed Feedback signs within Work Zones	VTrans 2016	https://vtrans.vermont.gov/sites/aot/files/highway/documents/highway/tei%2016-600%20work%20zone%20radar%20speed%20feedback%20signs.pdf	Radar speed feedback signs should be considered for various conditions, such as significant construction projects, lane closures on expressways or multi-lane highways, narrow shoulders, pavement edge drop-offs, night work, excessive speeding, or high crash frequency. The signs should be located in advance of the activity area of the work zone on the right side. More than one sign should be used for work zones longer than one mile. Product specifications and maintenance considerations are also presented. The system should not include any rapid flashing or animation and should be able to show a blank display when the speed is more than 15 mph over the work zone speed limit. The color should be yellow on black background (or reverse).
Virginia	Special Provision: Work Zone Digital Speed Limit Sign Trailer	Virginia DOT n.d.	-	Draft special provision for Work Zone Digital Speed Limit Sign (WZDSLS) Trailer for displaying the work zone speed limit. Includes requirements for materials, installation, operation, and removal. The trailer should provide information on status (e.g., location, sign message). The display should be white on a black background. Data logs are required.
Washington	Traffic Manual (Section 5-18: Speed Limit Reductions in Work Zones)	Washington State DOT 2021	https://wsdot.wa.gov/engineering-standards/all-manuals-and-standards/manuals/traffic-manual	The use of a radar speed display sign is required for construction (recommended for maintenance) when freeway traffic is shifted onto the shoulder and optional for freeway lane closures when traffic is not shifted onto the shoulder. The sign should be placed within 500 ft of work crews if possible.
Washington	Work Zone Typical Traffic Control Plans	Washington State DOT 2022a	https://wsdot.wa.gov/engineering-standards/all-manuals-and-standards/plan-sheet-library/work-zone-typical-traffic-control-plans-tcp	Various drawings (e.g., TC236) show layouts of traffic control devices (including radar speed feedback signs) for different scenarios. The location of the radar speed feedback sign is plus or minus 500 ft from the work area.

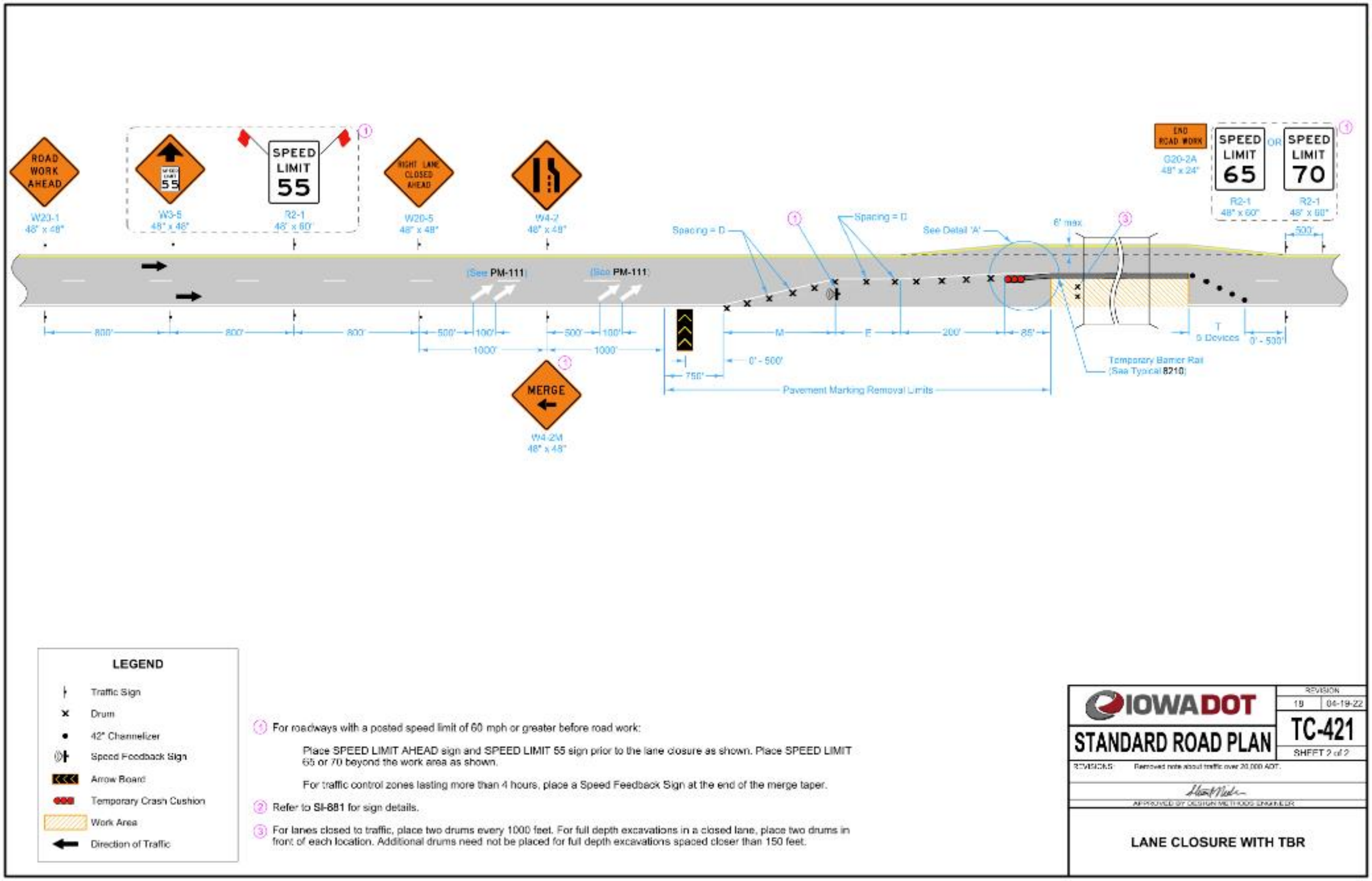
State	Title	Reference	Hyperlink	Summary
Washington	General Special Provisions (Section 1-10.3(3)OPT2.GR1: Radar Speed Display Signs)	Washington State DOT 2022b	https://wsdot.wa.gov/engineering-standards/all-manuals-and-standards/general-special-provisions-gsps	Radar speed display signs should be considered when lane closures result in a single lane of traffic and workers are present and near channelization devices. Placement should be at least 4 ft from the edge of a travel lane. Per additional special provisions, system should flash speed when work zone speed limit is exceeded. The system should have a maximum cutoff for displaying speeds. The system should also be able to collect traffic data. Measurement and payment are by hour that each sign is operating.

APPENDIX B. EXAMPLE LAYOUTS AND STANDARDS FOR SPEED FEEDBACK TRAILERS IN WORK ZONES



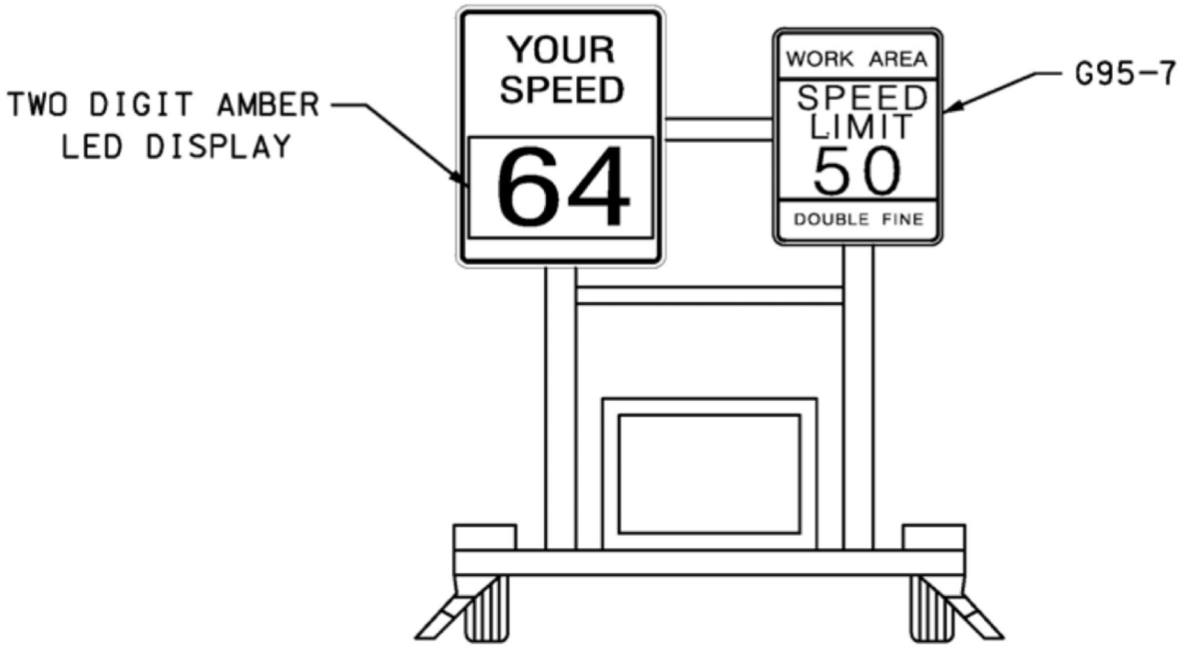
Illinois DOT 2022

Figure B-1. Layout for lane closure approach on freeway or expressway with speed feedback trailer for Illinois DOT (Standard 701400-11)



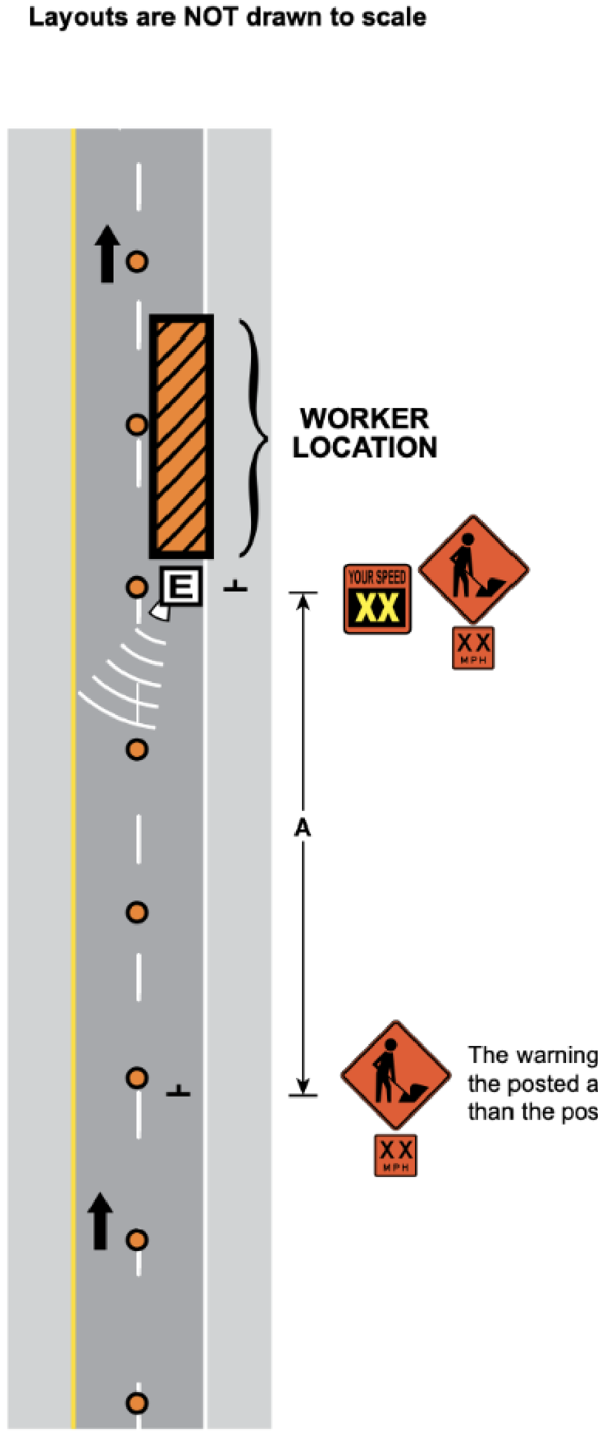
Iowa DOT 2023

Figure B-2. Layout for lane closure with speed feedback trailer for Iowa DOT (Standard Road Plan TC-421)



Maryland State Highway Administration 2005

Figure B-3. Preferred speed feedback trailer configuration for Maryland DOT

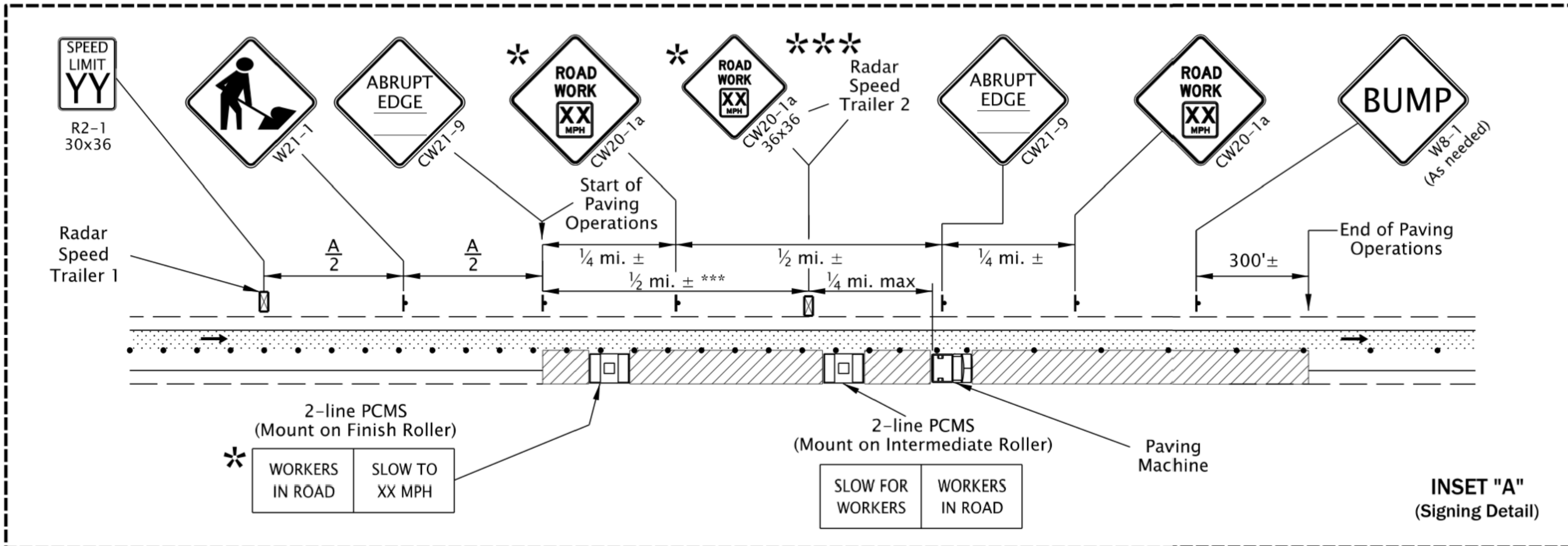


NOTES

- Advance warning signs and other standard temporary traffic control devices have not been shown on this layout. Refer to the MN MUTCD for typical layout examples.
  - MN MUTCD Chapter 6: ***http://www.dot.state.mn.us/trafficeng/publ/mutcd/index.html***
  - IWZ Long Term Typical Applications ***http://www.dot.state.mn.us/trafficeng/workzone/iwz.html***
- This layout shows a Dynamic Speed Display used with a Workers Present Warning Sign and an Advisory Speed plaque. A Dynamic Speed Display may be used with either an Advisory Speed plaque or a regulatory speed limit.
- When the DSD sign is used with an Advisory Speed plaque, a warning sign shall be displayed adjacent to the DSD sign location. The Advisory Speed Plaque may be attached to the warning sign, or mounted on the DSD sign device. The “YOUR SPEED” sign on the DSD device shall be black on orange.
- When utilizing the DSD sign with a regulatory speed limit such as a Workers Present speed limit, the “YOUR SPEED” sign on the DSD device shall be black on orange. The DSD sign shall be either placed adjacent to the posted speed limit sign, or the appropriate speed limit sign shall be mounted to the DSD device.

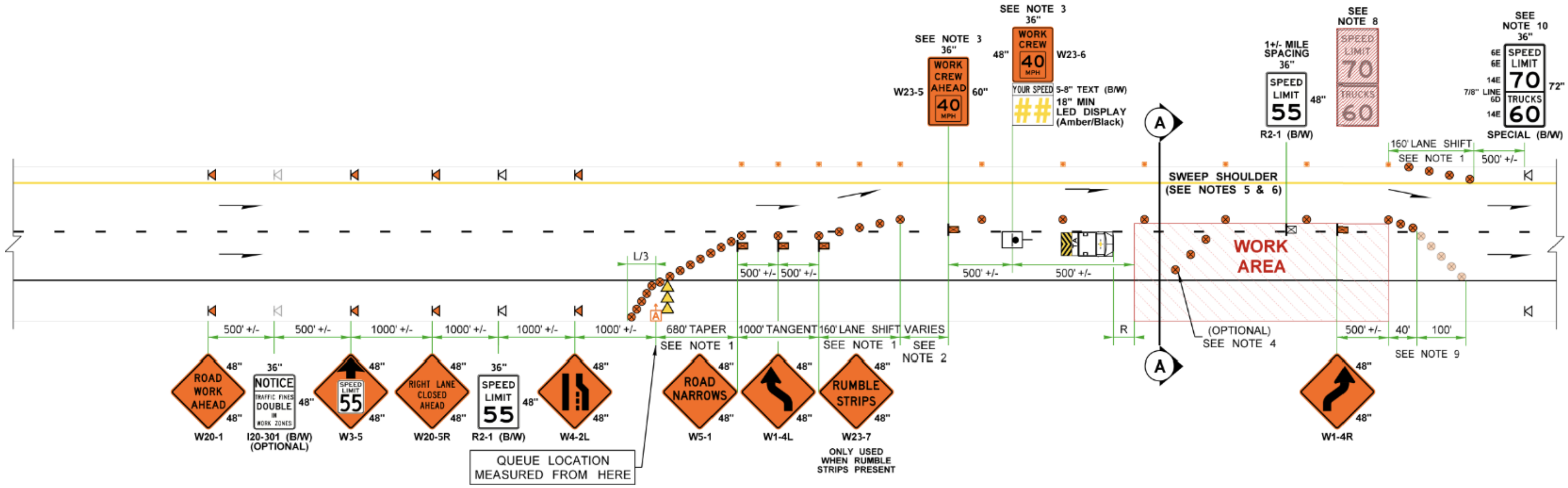
Minnesota DOT 2020

Figure B-4. Example work zone layout for speed feedback trailer for Minnesota DOT



Oregon DOT 2021

Figure B-5. Layout for one lane closure with speed reduction (paving operations) and speed feedback trailers for Oregon DOT (Standard Drawing TM880)



Washington State DOT 2022a

Figure B-6. Layout for right lane closure (maximum 4 ft left shoulder shift, 55 mph work zone speed limit) with speed feedback trailer for Washington State DOT (Typical Traffic Control Plans TC236)

APPENDIX C. STATE DOT SURVEY QUESTIONNAIRE

Smart Work Zone Deployment Initiative

Analysis of Improvements in the Effectiveness of Speed Feedback Trailers in Work Zones

Survey

LETTER TO THE RESPONDENT

Dear Participant,

The Smart Work Zone Deployment Initiative (SWZDI) is sponsoring a research study titled "Analysis of Improvements in the Effectiveness of Speed Feedback Trailers." A speed feedback trailer (SFT) (Figure 1) includes a dynamic digital message panel that utilizes speed measured from an integrated radar unit to display the real-time speed value to the driver. The research is being performed by Michigan State University and the University of Missouri. A principal objective is to conduct a review of best practices for the use of speed feedback trailers in work zones by agencies across the United States. A field study will also be performed to assess the operational and safety effectiveness of speed feedback trailers in work zones. The information obtained will be used to develop guidance towards maximizing the operational and safety effectiveness of speed feedback trailers in work zones.

Courtesy Michigan DOT

Figure 1. Speed feedback trailer deployed in work zone

Your cooperation in completing this survey will help to ensure the success of this research project. You have been identified as the appropriate person at your DOT to complete this survey. The survey link that you received is unique for your DOT. If it would be more appropriate for someone else at your DOT to take this survey, please forward the email with the survey link to them or send their name and email address to Henry Brown (brownhen@missouri.edu). Additional instructions are provided at the beginning of the survey. If you would like to download a PDF version of the survey for informational purposes, please click here.

Please complete this survey by December 7, 2022. Depending on your agency's experience and level of involvement with speed feedback trailers in work zones, the survey includes 3 to 19 questions, and we estimate that the survey will take approximately 5 to 20 minutes to complete. If you have any questions, please contact Henry Brown at (573) 882-0832 or brownhen@missouri.edu. Any supporting materials may be sent by email to Henry or uploaded in lieu of providing URLs. Thank you for participating in this survey!

SURVEY INSTRUCTIONS

1. To begin the survey, click the forward arrow at the bottom of this page.
2. To view and print the entire survey for informational purposes, click on this survey link and download and print the document.
3. To save your partial answers and complete the survey later, close the survey. Answers are automatically saved upon closing the browser window. To return to the survey later, open the original email from Henry Brown and click on the survey link.
4. To pass a partially completed survey to a colleague, close the survey and forward the original email from Henry Brown to a colleague. Note that only one person may work on the survey at a time; the survey response should only be active on one computer at a time.
5. To view and print your answers after completing the survey, submit the survey by clicking "Submit" on the final page. Download and print the PDF on the following page which contains a summary of your responses.
6. To submit the survey, click on "Submit" on the last page.

SURVEY TIPS

Survey navigation is conducted by selecting the forward and back arrows at the bottom of each page.

If you are unable to complete the survey, you can return to the survey at any time by reentering through the survey link.

QUESTIONS

Contact Information

Name ____________________
State ____________________
Job Title ____________________
Division ____________________

Phone Number ______________________
Email Address _______________________

1. Does your agency currently use speed feedback trailers in work zones?

Yes (continue to Question No. 2)
No (skip to Question No. 18)

2. Has your agency developed any policies, guidance, or standards regarding the use of speed feedback trailers in work zones?

Yes
No

If you answered yes, please briefly describe your agency's policy, guidance, or standards in the box below. If possible, please at least describe the criteria for determining when SFTs would be used in a work zone.

____

If you answered yes, please provide URL(s) for the relevant documents in the box below, upload files, or email files to brownhen@missouri.edu:

____

Additional comments:

____

3. In what types of work zone configurations do you use speed feedback trailers **on freeways**? Please select all that apply.

Lane closures
Traffic shifts
Crossovers
Lane-narrowing
Shoulder closures
Other (please describe) _____________
None of the above

Comments:

____

4. In what types of work zone configurations do you use speed feedback trailers **on non-freeways**? Please select all that apply.

Lane closures
Traffic shifts
Crossovers
Lane-narrowing
Shoulder closures
Other (please describe) ____________
None of the above

Comments:

---

5. For each of the roadway facility types is listed below, indicate the frequency of speed feedback trailer utilization in work zones by your agency.

Facility Type	Frequently	Sometimes	Rarely	Never
Freeways	☐	☐	☐	☐
Non-Freeways	☐	☐	☐	☐

Comments:

---

6. Does your agency also use speed feedback trailers in non-work zone situations?

Yes
No

If yes, please briefly provide a few examples of non-work zone situations where speed feedback trailers are used and/or provide a link to agency standards/specifications/guidance for the use of speed feedback trailers in non-work zone settings. You may also upload files or email files to brownhen@missouri.edu.

Additional comments:

---

7. Where are speed feedback trailers typically positioned within the work zone? Please select all that apply.

Prior to taper (e.g., advanced warning area)
Start of taper
End of taper
Near work area
Beyond work area
Other (please describe) ____________
None of the above

Comments:

____

8. Does your agency use speed feedback trailers in work zones along with any of the following built-in features? Please select all that apply.

Flashing lights, strobes, or beacon when vehicle exceeds threshold speed
Flashing speed display when vehicle exceeds threshold speed
Speed warning message (e.g., "SLOW DOWN" or "TOO FAST") when vehicle exceeds threshold speed
License plate recognition
Other (please describe) ____________
None of the above

Comments:

____

9. What is the threshold speed used by your agency to activate the built-in features (e.g., flashing lights, strobes, or beacons; flashing speed display; speed warning message) mentioned in the previous question?

0 to 4 mph over work zone speed limit
5 mph over work zone speed limit
10 mph over work zone speed limit
15 mph over work zone speed limit
Other (please describe) ____________
My agency does not use threshold speeds in conjunction with these built-in features

Comments:

____

10. Does your agency use speed feedback trailers in conjunction with any of the following work zone speed countermeasures in the same work zone? Please select all that apply.

Automated Flagger Assistance Device (AFAD)
Automated Work Zone Speed Enforcement
End of Queue Warning System
Notification of Construction Equipment Entering/Existing System
Temporary Rumble Strips
Digital Speed Limit Signs
Variable Speed Limits Based on Worker Presence
Enforcement
Other (please describe) _____________
None of the above

Comments:

____

11. Speed feedback trailers are often moved within or between work zones. Please select all that apply to your agency's practice regarding the deployment of speed feedback trailers.

Speed feedback trailers remain in one location for the duration of the work zone
Speed feedback trailers are repositioned as the work area moves
Speed feedback trailers are periodically repositioned within the same work zone to maintain effectiveness
Speed feedback trailers are periodically rotated between different work zones to maintain effectiveness
Other (please describe) ____________________

If the trailers are periodically repositioned or rotated to maintain effectiveness, please briefly describe how long the trailers stay in one position before being moved.

____

Additional comments:

____

12. Where does your agency most often obtain the speed feedback trailers that are used in work zones?

Contractor
Law enforcement
My agency provides the speed feedback trailers
Other (please describe) _____________

Comments:

---

13. What method does your agency most frequently use for basis of payment for contracts with speed feedback trailers in work zones?

Measured pay item
Lump sum pay item
No direct payment
Other (please describe) _____________

Comments:

---

14. What performance measures does your agency use to assess the performance of speed feedback trailers in work zones? Please select all that apply.

Average (or median) speed
85th percentile speed
Speed limit compliance/non-compliance
Pace
Standard deviation (or variance) of speed
Worker feedback
Other (please describe) _____________
My agency does not use performance measures to assess the performance of speed feedback trailers in work zones

Comments:

---

15. On a scale of 1 to 5 (1 = Highly Ineffective, 5 = Highly Effective), how would you rate the overall effectiveness of the speed feedback trailers implemented in work zones under your agency's jurisdiction?

1 (Highly Ineffective)
2
3
4
5 (Highly Effective)

Comments:

---

16. How strongly do you agree or disagree that the following factors influence the effectiveness of speed feedback trailers in work zones?

Factor	Strongly Agree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Disagree	Strongly Disagree
Trailer Location within the Work Zone	☐	☐	☐	☐	☐
Presence of Positive Protection	☐	☐	☐	☐	☐
Work Zone Speed Limit	☐	☐	☐	☐	☐
Use of Built-in Features (e.g., Flashing Beacons or Message)	☐	☐	☐	☐	☐
Use of Additional Countermeasures (e.g., Enforcement)	☐	☐	☐	☐	☐
Police Presence	☐	☐	☐	☐	☐
Type of Message Displayed	☐	☐	☐	☐	☐
Type of Work Activity	☐	☐	☐	☐	☐
Amount of Time the Trailer Stays at a Specific Location	☐	☐	☐	☐	☐
Worker Proximity	☐	☐	☐	☐	☐
Traffic Volumes	☐	☐	☐	☐	☐
Work Zone Duration	☐	☐	☐	☐	☐
Work Zone Length	☐	☐	☐	☐	☐
Other (Please describe) _____	☐	☐	☐	☐	☐

Please comment on any particular features or conditions that improve the effectiveness of speed feedback trailers in work zones:

____

Other Comments:

____

17. Has your agency completed any formal studies to evaluate the effectiveness of speed feedback trailers in work zones?

Yes
No

If you answered yes, please provide URL(s) for evaluation documents in the box below, upload files, or email files to brownhen@missouri.edu:

____

Comments:

____

18. How strongly do you agree or disagree that the following concerns have hindered your agency's efforts to implement speed feedback trailers in work zones?

Concern	Strongly Agree	Somewhat Agree	Neither Agree Nor Disagree	Somewhat Disagree	Strongly Disagree
Cost	☐	☐	☐	☐	☐
Lack of Agency Buy-In	☐	☐	☐	☐	☐
Lack of Availability of Equipment	☐	☐	☐	☐	☐
Lack of Contractor Buy-In	☐	☐	☐	☐	☐
Lack of Data on Performance	☐	☐	☐	☐	☐
Lack of Identified Funding	☐	☐	☐	☐	☐
Lack of Legislative Authority	☐	☐	☐	☐	☐
Lack of Perceived Need	☐	☐	☐	☐	☐
Other Speed Countermeasures are Higher Priority	☐	☐	☐	☐	☐
Public Perception	☐	☐	☐	☐	☐
Other (Please describe) _____	☐	☐	☐	☐	☐

Comments:

____

19. Please provide any additional comments that you may have regarding the use of speed feedback trailers in work zones.

____
____
____

SUBMITTAL INSTRUCTIONS

To complete the survey and record your answers, please click the "Submit" button.

Please note that once you click the "Submit" button, you will not be able to modify your answers. To save your partial answers and complete the survey later, close the survey. Answers are automatically saved upon closing the browser window. To return to the survey later, open the original email from Henry Brown and click on the survey link. To pass a partially completed survey to a colleague, close the survey and forward the original email from Henry Brown to a colleague. Note that only one person may work on the survey at a time; the survey response should only be active on one computer at a time. To review your answers before submitting, please select the forward and back arrows at the bottom of each page.

END OF SURVEY

Thank you for completing this survey. Your efforts are greatly appreciated. Your responses are very important, and your feedback is welcome. For your information, a copy of your responses is provided below. You may download your responses in pdf format using the "Download pdf" link shown below. If you have any questions or comments, please contact the principal investigator, Henry Brown:

Henry Brown, P.E.
E2509 Lafferre Hall
University of Missouri
Columbia, MO 65211
(573) 882-0832
brownhen@missouri.edu

Your responses have been recorded, and you may now close your browser.

APPENDIX D. INDIVIDUAL SURVEY RESPONSES FROM STATE DOTS

Table D-1. Individual survey responses for Question 1 (use of speed feedback trailers in work zones)

Respondent	Response Text
Alabama	Yes
Alaska	Yes
Arizona	Yes
Arkansas	Yes
California	-
Colorado	-
Connecticut	-
Delaware	No
District of Columbia	-
Florida	-
Georgia	Yes
Hawaii	-
Idaho	-
Illinois	Yes
Indiana	Yes
Iowa	Yes
Kansas	Yes
Kentucky	Yes
Louisiana	Yes
Maine	Yes
Maryland	Yes
Massachusetts	Yes
Michigan	Yes
Minnesota	Yes
Mississippi	No
Missouri	Yes
Montana	Yes
Nebraska	No
Nevada	Yes
New Hampshire	Yes
New Jersey	No
New Mexico	Yes
New York	-
North Carolina	No
North Dakota	Yes
Ohio	-
Oklahoma	Yes
Oregon	Yes
Pennsylvania	Yes
Rhode Island	No
South Carolina	No
South Dakota	Yes
Tennessee	Yes
Texas	-
Utah	No
Vermont	Yes
Virginia	Yes

Respondent	Response Text
Washington	Yes
West Virginia	-
Wisconsin	Yes
Wyoming	No
Number of Yes	31
Number of No	9
Number of Responses	40

NOTE: Summary of responses – Yes (31), No (9), No response (0)

Table D-2. Individual survey responses for Question 2 (development of policies, guidance, or standards for speed feedback trailers in work zones)

Respondent	Response Text
Alabama	Yes
Alaska	No
Arizona	Yes
Arkansas	Yes
Georgia	Yes
Illinois	Yes
Indiana	-
Iowa	Yes
Kansas	No
Kentucky	No
Louisiana	No
Maine	Yes
Maryland	Yes
Massachusetts	No
Michigan	Yes
Minnesota	Yes
Missouri	Yes
Montana	Yes
Nevada	Yes
New Hampshire	No
New Mexico	No
North Dakota	No
Oklahoma	No
Oregon	Yes
Pennsylvania	Yes
South Dakota	Yes
Tennessee	No
Vermont	Yes
Virginia	Yes
Washington	Yes
Wisconsin	No

NOTE: Summary of responses – Yes (19), No (11), No response (1)

Table D-3. Policy descriptions for Question 2 (development of policies, guidance, or standards for speed feedback trailers in work zones)

Respondent	Policy Description
Alabama	We have a special provision to our Standard Specifications.
Arizona	Not criteria for use, but standards for the device itself
Arkansas	Arkansas DOT's Mobile Speed Notification Systems are described in the attached Special Provision.
Georgia	We have piloted the use of speed trailer and anticipate using them on interstate lane closures.
Illinois	Illinois DOT Bureau of Design and Environment (BDE) Special Provisions: Speed Display Trailer. Standard 701400: Approach to Lane Closure, Freeway/Expressway
Indiana	Currently they are an optional strategy for speed management and are at the discretion of the Transportation Management Plan (TMP) Team.
Iowa	For now, we routinely deploy speed feedback trailers at the end of a lane merge taper. We are interested in this pooled fund study to help develop better criteria.
Maine	Recommended for all Interstate work zones, as well as higher volume roadways.
Maryland	The speed display trailer should be used in work zones where speeding is expected to be or has been shown to be a problem. Speed display trailers may be used in both urban and rural areas; however, its use in urban environments is discouraged due to the smaller display. Speed display trailers should not be used on highways with three or more lanes in one direction. In these cases, PCMS with Speed Display feature are recommended. Preferably, speed display trailers should not be used over an extended period of time (i.e., for more than two weeks), particularly in locations with high commuter traffic volume. However, if the display is going to be active for several weeks, periodic police enforcement should be arranged to maintain its effectiveness. For more information, please see: https://www.roads.maryland.gov/OOTS/03Speed%20DisplayTrailer.pdf
Michigan	20SP 812J 01 TEMPORARY SPEED RADAR TRAILER – Use in all freeway projects where the existing speed limit is 55 mph or higher and a speed reduction is required during construction for longer than three days. Optional use for local agency and all other trunkline projects.
Minnesota	We do not have a specific policy governing their use, it is generally up to the districts if they feel they would be beneficial in slowing traffic. We do have an approved products list for the sign portion, along with product requirements, a special provision, and guidance for work zone use in our document on work zone speed limits.
Montana	We are currently in the development stage. Our current guidance is to only use speed feedback where workers are present.
Nevada	Driver feedback signs are identified in Nevada DOT's Work Zone Safety and Mobility Implementation Guide (Red Book, section 2.5 and matrix) as a mitigation strategy for temporary speed reduction. Also, Standard Plans - see sheet TC 1 (note 1). For reduced posted speed, driver feedback sign would be placed at the reduced speed limit sign (see examples after sheet TC 1.
Oregon	Used as determined by Engineer. Standard use on Freeway Paving project.
Pennsylvania	Act 229 of 2003 (state Law) requires the use of speed display signs (Speed Feedback Trailers) on any project with an estimated cost of $300K or more.
South Dakota	Go to page 8 of the Work Zone Traffic Control Chapter of our Construction Manual (linked in the next box). Use is optional; we give situations where they could be considered. We require them to be posted with a work zone speed limit sign or advisory speed plaque and warning sign.
Washington	Speed feedback trailers are a device that should be considered in freeway work zones at Washington State DOT. Per a project delivery memo, they are required when freeway traffic is reduced to a single lane and traffic is shifted onto a shoulder. See links for more info.

Table D-4. Resources submitted for Question 2 (development of policies, guidance, or standards regarding the use of speed feedback trailers in work zones)

Respondent	Description of Resource	URL (if available)
Alabama	Special Provision 18-0737 (Radar Speed Display Sign)	-
Arkansas	Special Provision (Mobile Speed Notification System) 12-06-18	-
Georgia	Special Provision (Mobile Speed Notification System)	-
Illinois	Standard 701400-11 (Approach to Lane Closure, Freeway/Expressway), Special Provision for Speed Display Trailer	https://idot.illinois.gov/Assets/uploads/files/Doing-Business/Standards/Highway-Standards/PDF/226-701400-11_ApprchToLnClosure-FrwayExpway.pdf https://public.powerdms.com/IDOT/documents/2279554/Speed%20Display%20Trailer
Indiana	Indiana Design Manual (Section 503-3.05(02): Use of Positive Protection)	https://www.in.gov/dot/div/contracts/design/Part%205/Current%20Version%20of%20Chapter%20503%20-%20Traffic%20Maintenance.pdf
Iowa	Standard Road Plans (TC-418: Lane Closure on Divided Highway, TC-421: Lane Closure with TBR)	https://iowadot.gov/erl/current/RS/content_eng/tc418.pdf https://iowadot.gov/erl/current/RS/content_eng/tc421.pdf
Maryland	Use of Speed Trailers in Work Zones	https://www.roads.maryland.gov/OOTS/03Speed%20DisplayTrailer.pdf
Michigan	Special Provision 20SP-812J-01: Temporary Speed Radar Trailer	https://miloginworker.michigan.gov/sssp/getDocument.htm?projNum=704577&fileName=20SP-812J-01(Rev).pdf
Minnesota	Approved/Qualified Products: Vehicle Speed Feedback Signs, Work Zone Speed Limits, Minnesota Intelligent Work Zone Toolbox, Special Provision S-254: Vehicle Speed Feedback Signs	https://www.dot.state.mn.us/products/signing/vehiclespeedfeedbacksigns.html http://www.dot.state.mn.us/trafficeng/workzone/wzmanual.html https://dot.state.mn.us/pre-letting/prov/index.html
Missouri	Job Special Provision NJSP 21-06: Radar Speed Advisory System	https://epg.modot.org/index.php/Job_Special_Provisions
Nevada	Work Zone Safety and Mobility Implementation Guide, Nevada DOT Standard Plans for Road and Bridge Construction 2020	https://www.dot.nv.gov/home/showpublisheddocument/16985/637042222790330000 https://www.dot.nv.gov/home/showpublisheddocument/17276/637322602696100000

Respondent	Description of Resource	URL (if available)
North Dakota	North Dakota DOT Requirements for the Use of Vehicle Speed Feedback Signs on the State Highway System	https://www.dot.nd.gov/divisions/programming/Requirements%20for%20Installation%20of%20Vehicle%20Speed%20Feedback%20Signs.pdf
Oregon	Standard Guidelines for Product Review (Section 00222.15C: Radar Speed Trailer)	https://www.oregon.gov/odot/Construction/Doc_ProductReview/radar_speed_trailer.pdf
Oregon	Oregon Standard Specifications for Construction (Section 00222: Temporary Traffic Control Signs)	https://www.oregon.gov/odot/Business/Specs/2021_STANDARD_SPECIFICATIONS.pdf
Oregon	Traffic Control Plans Design Manual (Section 2.7.1: Temporary Electrical Signs)	https://www.oregon.gov/ODOT/Engineering/Pages/TCP-Manual.aspx
South Dakota	South Dakota DOT Construction Manual Section (Chapter 15: Work Zone Traffic Control)	https://dot.sd.gov/media/documents/Chapter%2015%20-%20Work%20Zone%20Traffic%20Control.pdf
Vermont	Temporary Use of Radar Speed Feedback Signs within Work Zones, Guidelines for the Use of Radar Speed Feedback Signs on the State Highway System	https://vtrans.vermont.gov/sites/aot/files/workzone/rsfs/Use%20of%20Radar%20Speed%20Feedback%20Signs%20Guidelines%203014.pdf
Virginia	Special Provisions (Work Zone Digital Speed Limit Sign Trailer) - Draft	-
Washington	Special Provision (1-10.3(3).OP2.GR1: Radar Speed Display Signs, Traffic Manual (Chapter 5: Work Zone Traffic Control), Typical Traffic Control Plans (TC236)	https://wsdot.wa.gov/publications/fulltext/projectdev/gspspdf/egsp1.pdf https://wsdot.wa.gov/publications/manuals/fulltext/M51-02/Chapter5.pdf (see 5-18B) https://wsdot.wa.gov/publications/fulltext/Standards/psl/TC-200/236Fwy1RtLane4MaxLtShift70to55WZSL40Adv.pdf

Table D-5. Additional comments for Question 2 (development of policies, guidance, or standards regarding the use of speed feedback trailers in work zones)

Comment
In fiscal year 2022, speed feedback trailers were used on approximately nine construction contracts in our state.
We are just starting to use them on shorter designed crossovers on divided highways.
Many times these are not in the original scope or contract item but are added items.
Section 1063.10 Radar Speed Advisory: Link to the section. https://www.modot.org/sites/default/files/documents/2022_Missouri_Standard_Specific MHTC_Jan_2023_combined2.pdf

Table D-6. Individual survey responses for Question 3 (types of work zone configurations for which speed feedback trailers are used on freeways)

Respondent	Lane Closures	Traffic Shifts	Crossovers	Lane-Narrowing	Shoulder Closures	Other	None of the Above
Alabama	X	X	-	-	-	-	-
Alaska	-	-	-	-	-	X	-
Arizona	X	X	X	X	X	X	-
Arkansas	X	X	X	X	X	-	-
Georgia	X	-	-	-	-	-	-
Illinois	X	-	X	-	-	-	-
Indiana	X	X	X	X	-	-	-
Iowa	X	-	-	-	-	-	-
Kansas	-	-	-	-	-	-	X
Kentucky	X	X	X	-	-	-	-
Louisiana	X	X	-	X	-	-	-
Maine	X	-	-	-	-	-	-
Maryland	X	X	X	X	X	X	-
Massachusetts	X	-	X	-	-	-	-
Michigan	X	X	X	X	X	X	-
Minnesota	X	X	X	-	-	-	-
Missouri	X	X	-	-	-	X	-
Montana	X	-	X	-	-	-	-
Nevada	X	X	X	X	X	X	-
New Hampshire	-	-	-	-	-	X	-
New Mexico	X	X	X	X	X	-	-
North Dakota	-	-	X	-	-	-	-
Oklahoma	X	X	-	-	-	-	-
Oregon	X	-	-	-	-	X	-
Pennsylvania	X	X	X	X	X	-	-
South Dakota	X	-	-	-	-	-	-
Tennessee	-	-	-	-	-	X	-
Vermont	X	-	X	-	-	-	-
Virginia	X	-	-	-	-	-	-
Washington	X	X	-	-	-	-	-
Wisconsin	X	X	X	X	-	-	-
Count	**26**	**16**	**16**	**10**	**7**	**9**	**1**

Table D-7. Other text responses for Question 3 (types of work zone configurations for which speed feedback trailers are used on freeways)

Other–Text
Typically included on Freeway type projects but not really tied to any specific configuration.
Automated Speed Enforcement in work zone
Interstate resurfacing
any speed reduction
Mostly upon request of the construction team or specific location concerns, not based on type of work zone.
Lanes closures for paving on freeway is only standard use of Radar Speed Trailers.
Problematic areas: excessive speeding, high crash area, police recommendation area.
There is no specific traffic control configuration that triggers a driver feedback sign. The driver feedback is a mitigation strategy when a temporary speed reduction is requested.
They are only used in our state at the Contractor's request with justification, but they can be deployed for any of the above reasons.

Table D-8. Survey comments for Question 3 (types of work zone configurations for which speed feedback trailers are used on freeways)

Comment
There is no specific traffic control configuration that triggers a driver feedback sign. The driver feedback is a mitigation strategy when a temporary speed reduction is requested.
Mostly for lane closures and lane closures with shifts but can be included on any of the above conditions.
We don't limit their use to lane closures, but to date, this is the only place they have been used on our state DOT projects.

Table D-9. Individual survey responses for Question 4 (types of work zone configurations for which speed feedback trailers are used on non-freeways)

Respondent	Lane Closures	Traffic Shifts	Crossovers	Lane-Narrowing	Shoulder Closures	Other	None of the Above
Alabama	X	X	-	-	-	-	-
Alaska	-	-	-	-	-	X	-
Arizona	X	X	X	X	X	X	-
Arkansas	X	X	X	X	X	-	-
Georgia	-	-	-	-	-	-	X
Illinois	-	-	-	-	-	-	X
Indiana	X	X	X	-	-	-	-
Iowa	-	-	-	-	-	-	X
Kansas	X	X	-	X	X	X	-
Kentucky	X	X	-	X	-	-	-
Louisiana	X	X	-	X	-	-	-
Maine	X	-	-	-	-	-	-
Maryland	X	X	X	X	X	X	-
Massachusetts	-	-	-	-	-	-	X
Michigan	X	X	X	X	X	X	-
Minnesota	X	X	-	X	X	-	-
Missouri	-	-	-	-	-	X	X
Montana	X	X	X	X	X	-	-
Nevada	X	X	X	X	X	-	-
New Hampshire	-	-	-	-	-	X	-
New Mexico	X	X	X	X	-	-	-
North Dakota	-	-	X	-	-	-	-
Oklahoma	X	-	-	-	-	-	-
Oregon	-	-	-	-	-	X	-
Pennsylvania	X	X	X	X	X	-	-
South Dakota	-	-	-	-	-	-	X
Tennessee	-	-	-	-	-	-	X
Vermont	-	-	-	-	-	-	X
Virginia	X	-	-	-	-	-	-
Washington	X	X	-	-	-	-	-
Wisconsin	X	X	X	-	-	-	-
Count	**19**	**16**	**11**	**12**	**9**	**8**	**8**

Table D-10. Other text responses for Question 4 (types of work zone configurations for which speed feedback trailers are used on non-freeways)

Other-Text
As needed, determined by the Engineer of Record.
At this time, we are not familiar with non-freeway use of speed trailers.
Same as above, based on conditions, not work zone type
Sometimes included on non-freeway type projects but not really tied to any specific configuration.
If the speed limit is 55 MPH or higher we use them, optional for lower speed roadways.
We do not specify where it should be used but more open to any work zone.
Off shoulder work within the right-of-way.
Same as the answer above, many of our state's roads are not freeways.

Table D-11. Survey comments for Question 4 (types of work zone configurations for which speed feedback trailers are used on non-freeways)

Comment
There is no specific traffic control configuration that triggers a driver feedback sign. The driver feedback is a mitigation strategy when a temporary speed reduction is requested.
Again, could be used by region project offices in any of the above conditions.
We are not prohibited from using them on non-freeway facilities, I just don't know of a case where we have used them on non-freeways yet.

Table D-12. Individual survey responses for Question 5 (frequency of use of speed feedback trailers in work zones)

Respondent	Freeways	Non-Freeways
Alabama	3	3
Alaska	3	3
Arizona	2	2
Arkansas	3	2
Georgia	2	1
Illinois	4	2
Indiana	3	2
Iowa	4	1
Kansas	2	1
Kentucky	3	2
Louisiana	3	2
Maine	4	3
Maryland	3	2
Massachusetts	2	1
Michigan	4	3
Minnesota	3	3
Missouri	2	1
Montana	3	2
Nevada	4	4
New Hampshire	4	3
New Mexico	4	3
North Dakota	4	4
Oklahoma	3	3
Oregon	4	3
Pennsylvania	4	3
South Dakota	2	1
Tennessee	3	3
Vermont	4	2
Virginia	2	2
Washington	4	3
Wisconsin	3	2
Average	**3.2**	**2.3**
Standard deviation	**0.8**	**0.9**
Total responses	**31**	**31**

NOTE: 4 = Frequently, 3 = Sometimes, 2 = Rarely, 1 = Never

Table D-13. Survey comments for Question 5 (frequency of use of speed feedback trailers in work zones)

Comment
We will use them on shorter design crossover applications.
Long-term reduction in speed has been found to be extremely small.
Use in non-freeways is not required but allowed. Also local police departments have been using these devices in non-work zone locations.
They are a tool that can be used, and have been specified in a couple interstate projects, but have not been widely used to date.
Looking to implement for all freeway lane closures

Table D-14. Individual survey responses for Question 6 (use of speed feedback trailers in non-work zone situations)

Respondent	Response Text
Alabama	Yes
Alaska	No
Arizona	Yes
Arkansas	No
Georgia	No
Illinois	No
Indiana	No
Iowa	Yes
Kansas	No
Kentucky	Yes
Louisiana	No
Maine	No
Maryland	No
Massachusetts	Yes
Michigan	No
Minnesota	Yes
Missouri	Yes
Montana	Yes
Nevada	Yes
New Hampshire	No
New Mexico	Yes
North Dakota	Yes
Oklahoma	No
Oregon	No
Pennsylvania	Yes
South Dakota	Yes
Tennessee	No
Vermont	Yes
Virginia	No
Washington	No
Wisconsin	Yes

NOTE: Summary of responses – Yes (15), No (16), No response (0)

Table D-15. Examples of use for Question 6 (use of speed feedback trailers in non-work zone situations)

Example of Use
Only time I've seen them used outside of a work zone is in a new traffic pattern situation or to help make users aware of speed zone.
There are some permanent speed feedback signs installed on the primary system when the route passes through smaller towns. These are not work zones.
We have placed them in areas of concern on major freeways. We allow local governments to install them on our roadways.
I uploaded the NDDOT Requirements for the Use of Vehicle Speed Feedback Signs on the state Highway System.
The Department, along with municipalities, will often use speed feedback trailers to remind motorists of a reduced speed limit upon entering a borough, town, or other municipality.
See page 10 of our Permanent Signing Manual: https://dot.sd.gov/media/documents/PermanentSigningManual.pdf
See special studies for driver feedback requirements: https://www.dot.nv.gov/home/showpublisheddocument/14229/637360368588500000
Our agency does not but other cities and townships have them at some locations. Police offices also have them as well.
Our DOT developed a grant program for rural communities to provide them with speed feedback trailers for their use at high-risk locations.
Cities and Counties will ask for a speed trailer to be used in an area as traffic control or moderation. Not necessarily work zone related.
I believe we use them on some state highways that are located near schools.
Safety blitz with local law enforcement for Highway Safety.
They are temporarily used in situations where we may have a speed limit change or a speed transition where we seem to be getting low compliance.
Not that I am aware of. Some DOT regions have the equipment, but I think they use it in maintenance work zones or in region project work zones.
School zones
This is not a standard practice but there have instances where speed feedback trailers were used in areas where speeding was a concern of the public.
School zones

Table D-16. Survey comments for Question 6 (use of speed feedback trailers in non-work zone situations)

Comment
Our state has a few permanent speed feedback signs, some are at ramps with a history of truck rollovers, and others were installed by local public agencies under an agreement with our DOT.
Our DOT does not deploy these outside of work zones. However, local police departments have deployed these for speed compliance.
There are some instances where our Highway Safety Engineer will recommend permanent installation of radar speed feedback signs. Where their use has not been recommended by our Highway Safety Engineer, but we have a request from a local agency to install, we do allow by permit to occupy ROW. The signs are then owned and maintained by the local agency.

Table D-17. Individual survey responses for Question 7 (positioning of speed feedback trailers within the work zone)

Respondent	Prior to taper	Start of taper	End of taper	Near work area	Beyond work area	Other	None of the Above
Alabama	-	-	-	-	-	X	-
Alaska	-	X	-	-	-	-	-
Arizona	-	-	-	X	-	X	-
Arkansas	X	-	-	-	-	-	-
Georgia	X	-	-	-	-	X	-
Illinois	X	-	-	X	-	-	-
Indiana	X	-	-	-	-	-	-
Iowa	-	-	X	-	-	-	-
Kansas	X	-	-	X	-	-	-
Kentucky	-	-	-	X	-	-	-
Louisiana	X	-	-	X	-	-	-
Maine	-	-	X	X	-	-	-
Maryland	X	X	-	-	-	-	-
Massachusetts	X	-	X	X	-	-	-
Michigan	X	-	-	X	X	X	-
Minnesota	-	X	-	X	-	-	-
Missouri	-	X	-	X	-	-	-
Montana	-	-	-	X	-	-	-
Nevada	X	-	-	X	-	-	-
New Hampshire	X	-	-	-	-	-	-
New Mexico	X	-	-	-	-	-	-
North Dakota	-	-	X	X	-	-	-
Oklahoma	X	X	-	X	-	-	-
Oregon	X	-	-	X	-	-	-
Pennsylvania	X	-	-	-	-	-	-
South Dakota	-	-	X	X	-	X	-
Tennessee	-	-	-	X	-	-	-
Vermont	X	-	-	X	-	-	-
Virginia	X	-	-	-	-	-	-
Washington	-	-	-	X	-	-	-
Wisconsin	X	-	-	X	-	-	-
Count	**18**	**5**	**5**	**20**	**1**	**5**	**0**

Table D-18. Other text responses for Question 7 (positioning of speed feedback trailers within the work zone)

Other–Text
With variable speed limit signs.
We try and move the location during the project, after two weeks normally.
After speed reduction or speed limit signage but before the actual work area, if possible, so mostly prior to taper but sometimes in the buffer area.
Recommended to be prior to the work area. We reduce the speed for interstate lane closures prior to the taper so placement would be after or with the speed reduction, but prior to the work area.

Table D-19. Survey comments for Question 7 (positioning of speed feedback trailers within the work zone)

Comment
See Nevada DOT Standard Plans, typical traffic configurations after page TC 1.
The device required by the standard is in the advanced warning area. We have seen additional speed display trailers deployed near the work area.
Oregon DOT Standard Drawing TM 880 shows standard use on freeway paving projects. https://www.oregon.gov/ODOT/Engineering/BaselineReport/TM880.pdf
Typically try to set these in advance of the work area. This is often simply trying to find a place where there is room to safely place them and where they are afforded the most sight distance for the traveling public.
Exact location typically varies based upon field condition.
Mobile Speed Notification System shall be located on the shoulder, 2,000 ft in advance of the lane closure for mainline traffic.

Table D-20. Individual survey responses for Question 8 (use of speed feedback trailers with built-in features)

Respondent	Flashing lights, strobes, or beacon when vehicle exceeds threshold speed	Flashing speed display when vehicle exceeds threshold speed	Speed warning message (e.g., "SLOW DOWN" or "TOO FAST") when vehicle exceeds threshold speed	License plate recognition	Other	None of the Above
Alabama	-	X	X	-	-	-
Alaska	-	X	-	-	-	-
Arizona	-	-	-	-	X	-
Arkansas	-	-	-	-	-	X
Georgia	-	X	X	-	-	-
Illinois	-	X	X	-	X	-
Indiana	-	X	X	-	-	-
Iowa	-	-	-	-	-	X
Kansas	-	X	-	-	-	-
Kentucky	X	X	-	-	-	-
Louisiana	-	X	-	-	-	-
Maine	X	X	X	-	-	-
Maryland	-	-	-	-	-	X
Massachusetts	-	X	-	-	-	-
Michigan	-	X	X	-	-	-
Minnesota	-	X	-	-	-	-
Missouri	-	-	X	-	-	-
Montana	-	X	X	-	-	-
Nevada	-	-	-	-	-	X
New Hampshire	-	X	-	-	-	-
New Mexico	-	-	-	-	-	X
North Dakota	-	X	-	-	-	-
Oklahoma	X	X	X	-	-	-
Oregon	-	X	X	-	-	-
Pennsylvania	-	-	-	-	-	-
South Dakota	-	-	-	-	-	X
Tennessee	-	-	-	-	-	X
Vermont	-	-	X	-	-	-
Virginia	X	-	-	-	-	-
Washington	-	X	-	-	X	-
Wisconsin	-	X	X	-	-	-
Count	**4**	**19**	**12**	**0**	**3**	**7**

Table D-21. Other text responses for Question 8 (use of speed feedback trailers with built-in features)

Other - Text
Words, flashing lights, and other items are not allowed per FHWA.
Trailers shall have speed data collection capabilities.
Automatic dimming for nighttime operation.

Table D-22. Survey comments for Question 8 (use of speed feedback trailers with built-in features)

Comment
Maximum of 25 MPH over the posted speed will be displayed.
While contractors will sometimes utilize these devices in one of the manners indicated above, MUTCD guidance is contrary to those applications. We try to enforce use as per the MUTCD and our specifications, but it can be challenging.
Sometimes contractors set the speed feedback trailers to flash when speed is exceeded; however, that is not by policy. We discourage flashing signs.
We prohibit the display from flashing in accordance with FHWA memorandum guidance.
Screen does not show vehicle speeds over a certain amount over the speed limit.

Table D-23. Individual survey responses for Question 9 (threshold speed for built-in features)

Respondent	Answer
Alabama	Other
Alaska	5 mph over work zone speed limit
Arizona	My agency does not use threshold speeds in conjunction with these built-in features
Arkansas	My agency does not use threshold speeds in conjunction with these built-in features
Georgia	Other
Illinois	Other
Indiana	10 mph over work zone speed limit
Iowa	My agency does not use threshold speeds in conjunction with these built-in features
Kansas	10 mph over work zone speed limit
Kentucky	5 mph over work zone speed limit
Louisiana	5 mph over work zone speed limit
Maine	0 to 4 mph over work zone speed limit
Maryland	0 to 4 mph over work zone speed limit
Massachusetts	0 to 4 mph over work zone speed limit
Michigan	Other
Minnesota	0 to 4 mph over work zone speed limit
Missouri	10 mph over work zone speed limit
Montana	5 mph over work zone speed limit
Nevada	My agency does not use threshold speeds in conjunction with these built-in features
New Hampshire	My agency does not use threshold speeds in conjunction with these built-in features
New Mexico	My agency does not use threshold speeds in conjunction with these built-in features
North Dakota	Other
Oklahoma	0 to 4 mph over work zone speed limit
Oregon	0 to 4 mph over work zone speed limit
Pennsylvania	My agency does not use threshold speeds in conjunction with these built-in features
South Dakota	My agency does not use threshold speeds in conjunction with these built-in features
Tennessee	My agency does not use threshold speeds in conjunction with these built-in features
Vermont	My agency does not use threshold speeds in conjunction with these built-in features
Virginia	My agency does not use threshold speeds in conjunction with these built-in features
Washington	My agency does not use threshold speeds in conjunction with these built-in features
Wisconsin	10 mph over work zone speed limit

NOTE: Summary of responses – 0 to 4 mph over work zone speed limit (6), 5 mph over work zone speed limit (4), 10 mph over work zone speed limit (4), 15 mph over work zone speed limit (0), Other (5), My agency does not use threshold speeds in conjunction with these built-in features (12), No response (0)

Table D-24. Other text responses for Question 9 (threshold speed for built-in features)

Other–Text
The violation alert flashes the detected speed that exceeds the work zone posted speed limit. There is a maximum speed cutoff. For facilities with a normal posted speed limit greater than or equal to 45 mph, the detected speed of the vehicles traveling more than 25 mph over the work zone speed limit will not be displayed. For facilities with a normal posted speed limit less than 45 mph, the detected speed of vehicles traveling more than 15 mph over the work zone speed limit will not be displayed. Speeds that are less than 25 mph will not be displayed.
The speed will flash to anything over the posted speed limit in the work zones.
0 to 9 mph flashing, above 10 mph slow down.
(1) The speed of the approaching vehicle (flash mode) when that speed is 1 to 10 mph greater than the work zone speed limit. (2) A "SLOW DOWN" message to be flashed when the approaching vehicle is greater than 10 mph over the work zone speed limit.
Ours typically are set to the actual posted speed so anything over either flashes or provides feedback speed. Some of them display speed with flashing if over 10 mph above and some just say slow down.

Table D-25. Survey comments for Question 9 (threshold speed for built-in features)

Comment
This can be set per project and changed also.
Other than 25 MPH over max to be displayed.
Again, additional features were told to be removed by FHWA.
Not really sure, but I believe that we simply use factory default settings. Our Special Provision is silent on this.
Some of our busier school zones have these signs as well, but that is outside of our agency.

Table D-26. Individual survey responses for Question 10 (use of speed feedback trailers in conjunction with other speed countermeasures in work zones)

Respondent	Automated Flagger Assistance Device (AFAD)	Automated Work Zone Speed Enforcement	End of Queue Warning System	Notification of Construction Equipment Entering/Existing System	Temporary Rumble Strips	Digital Speed Limit Signs	Variable Speed Limits Based on Worker Presence	Enforcement	Other	None of the above
Alabama	X	-	-	-	X	-	X	X	-	-
Alaska	-	-	-	-	-	-	-	-	-	X
Arizona	-	-	X	X	-	X	-	-	-	-
Arkansas	-	-	X	-	-	-	-	-	-	-
Georgia	-	-	-	-	-	-	-	X	-	-
Illinois	-	X	X	-	X	-	-	X	-	-
Indiana	-	-	X	-	X	X	X	-	-	-
Iowa	-	-	X	-	-	-	-	-	-	-
Kansas	-	-	-	-	-	-	-	X	-	-
Kentucky	-	-	-	-	-	-	-	X	-	-
Louisiana	X	-	-	X	-	-	-	-	-	-
Maine	-	-	-	-	X	-	-	-	-	-
Maryland	-	X	-	-	-	-	-	-	-	-
Massachusetts	-	-	-	-	X	-	-	X	-	-
Michigan	-	-	X	-	X	X	X	X	-	-
Minnesota	-	-	-	-	-	-	X	-	-	-
Missouri	-	-	X	-	-	-	-	X	-	-
Montana	-	-	X	-	X	-	X	X	-	-
Nevada	-	-	-	-	X	-	-	X	-	-
New Hampshire	-	-	-	-	-	-	-	-	-	X
New Mexico	X	-	-	-	X	-	-	X	-	-
North Dakota	-	-	-	-	-	-	-	-	-	X
Oklahoma	-	-	X	-	-	-	-	-	-	-
Oregon	-	-	X	-	-	-	-	X	-	-
Pennsylvania	-	X	X	-	X	-	-	-	-	-
South Dakota	-	-	-	-	-	-	-	-	-	X
Tennessee	-	-	-	-	-	X	-	-	-	-
Vermont	-	-	-	-	-	-	-	X	-	-
Virginia	-	-	-	-	-	-	-	-	-	X
Washington	-	-	X	-	-	-	X	-	-	-
Wisconsin	-	-	-	-	-	-	-	-	-	-
Count	**3**	**3**	**12**	**2**	**10**	**4**	**6**	**13**	**0**	**5**

Table D-27. Survey comments for Question 10 (use of speed feedback trailers in conjunction with other speed countermeasures in work zones)

Comment
There may be enforcement, and in rare cases temporary portable rumble strips in the same location, but this is not required.
The systems are used at same time but are not linked together.
We have not set policy. This doesn't mean we would not use any of these depending on the project. For example, we occasionally will have uniformed officers in a vehicle providing enforcement.
Mostly enforcement and sometimes the others
Items not checked, only because we don’t use them.
We don't have a requirement to use more than one of these but often are used together.

Table D-28. Individual survey responses for Question 11 (repositioning of speed feedback trailers in work zones)

Respondent	Speed feedback trailers remain in one location for the duration of the work zone	Speed feedback trailers are repositioned as the work area moves	Speed feedback trailers are periodically repositioned within the same work zone to maintain effectiveness	Speed feedback trailers are periodically rotated between different work zones to maintain effectiveness	Other
Alabama	X	X	-	-	X
Alaska	-	-	X	-	-
Arizona	-	X	-	-	-
Arkansas	-	-	-	-	X
Georgia	-	X	-	-	-
Illinois	X	X	-	-	-
Indiana	X	-	-	-	-
Iowa	X	-	-	-	-
Kansas	-	X	X	-	-
Kentucky	-	X	-	-	-
Louisiana	-	X	X	-	-
Maine	X	-	-	-	-
Maryland	X	-	-	-	-
Massachusetts	-	X	X	-	-
Michigan	-	X	X	-	-
Minnesota	-	X	X	X	-
Missouri	-	-	-	-	X
Montana	-	X	X	-	-
Nevada	X	X	X	-	-
New Hampshire	-	X	-	-	-
New Mexico	-	X	-	-	-
North Dakota	X	-	-	-	X
Oklahoma	X	-	-	-	-
Oregon	-	-	X	-	-
Pennsylvania	X	X	-	-	-
South Dakota	X	X	-	-	X
Tennessee	-	X	X	-	-
Vermont	X	-	-	-	-
Virginia	-	X	X	-	-
Washington	-	X	-	-	-
Wisconsin	X	-	X	-	-
Count	**13**	**19**	**12**	**1**	**5**

Table D-29. Other text responses for Question 11 (repositioning of speed feedback trailers in work zones)

Other–Text
The systems are paid for as part of the construction contract and remain the property of the contractor.
There may be projects where the speed feedback trailer remains on the upstream end of the work zone, where the work zone speed reduction is posted. Others may move the speed feedback trailer with the work area to provide notice just prior to where workers are located.
We just started using these for crossover applications.
Speed trailer moved on recommendation from law enforcement.
For detours and stationary type work we typically leave them in one place, but in more dynamic work zones we move them around with the work.

Table D-30. Supplemental descriptions for Question 11 (repositioning of speed feedback trailers in work zones)

Supplemental Description
See our traffic control plans: 220 258 https://wsdot.wa.gov/engineering standards/all manuals and standards/plan sheet library/work zone typical traffic control plans tcp
We try for two weeks but this is not always the case and is based on the project office.
The speed display trailer should remain in the same position with regards to the location of the taper so if the taper moves, the speed display trailer moves.
TM 880... https://www.oregon.gov/odot/engineering/202207/TM880.pdf Maintain radar speed trailers within 1/4 mile of paving machine.
Supposed to be a maximum of three weeks in one location but is often not followed.
There is no policy that details this, it based on collaboration between the DOT and Contractor field personnel.
It varies, but usually not more than a week.
No set threshold. If moved, would depend on how often and how far the active work area moves.
Usually four to six weeks

Table D-31. Survey comments for Question 11 (repositioning of speed feedback trailers in work zones)

Comment
Most often trailers move with the work like lane closures for paving operations. They could be used in one location if associated with static work zones or temporary traffic control features like a temporary alignment change or crossover strategy.

Table D-32. Individual survey responses for Question 12 (primary source for obtaining speed feedback trailers for work zones)

Respondent	Answer
Alabama	Contractor
Alaska	My agency provides the speed feedback trailers
Arizona	Contractor
Arkansas	Contractor
Georgia	Contractor
Illinois	Contractor
Indiana	Contractor
Iowa	Contractor
Kansas	Contractor
Kentucky	My agency provides the speed feedback trailers
Louisiana	Contractor
Maine	Contractor
Maryland	Contractor
Massachusetts	Contractor
Michigan	Contractor
Minnesota	Contractor
Missouri	Contractor
Montana	Contractor
Nevada	Contractor
New Hampshire	Contractor
New Mexico	Contractor
North Dakota	Contractor
Oklahoma	Contractor
Oregon	Contractor
Pennsylvania	Contractor
South Dakota	Contractor
Tennessee	Contractor
Vermont	Contractor
Virginia	Contractor
Washington	Contractor
Wisconsin	Contractor

NOTE: Summary of responses – Contractor (29), Law Enforcement (0), My agency provides the speed feedback trailers (2), Other (0), No response (0)

Table D-33. Survey comments for Question 12 (primary source for obtaining speed feedback trailers for work zones)

Comment
Bid item
We have provisions to include them as a pay item in our projects. https://wsdot.wa.gov/publications/fulltext/projectdev/gspspdf/1 10.3(3).OPT2.GR1.PDF https://wsdot.wa.gov/publications/fulltext/projectdev/gspspdf/1 10.3(3)(9 35.8).OPT1.GR1.PDF https://wsdot.wa.gov/publications/fulltext/projectdev/gspspdf/1 10.4(2).OPT3.GR1.PDF https://wsdot.wa.gov/publications/fulltext/projectdev/gspspdf/1 10.5(2).OPT2.GR1.PDF
For maintenance operations, our DOT has purchased speed display trailers.
Contractors typically provide them and move/maintain on projects, but our Traffic Maintenance section has also helped out to provide them in some of the detour and spot-specific less duration moments.

Table D-34. Individual survey responses for Question 13 (most frequent method for basis of payment for speed feedback trailers in work zones)

Respondent	Answer
Alabama	Other
Alaska	Other
Arizona	Measured pay item
Arkansas	Measured pay item
Georgia	Measured pay item
Illinois	Other
Indiana	Measured pay item
Iowa	Lump sum pay item
Kansas	Measured pay item
Kentucky	No direct payment
Louisiana	Measured pay item
Maine	Measured pay item
Maryland	Lump sum pay item
Massachusetts	Measured pay item
Michigan	Measured pay item
Minnesota	Measured pay item
Missouri	Measured pay item
Montana	Measured pay item
Nevada	Lump sum pay item
New Hampshire	Lump sum pay item
New Mexico	Lump sum pay item
North Dakota	Measured pay item
Oklahoma	Measured pay item
Oregon	Measured pay item
Pennsylvania	Measured pay item
South Dakota	Other
Tennessee	Measured pay item
Vermont	Measured pay item
Virginia	Measured pay item
Washington	Measured pay item
Wisconsin	Measured pay item

NOTE: Summary of responses – Measured pay item (21), Lump sum pay item (5), No direct payment (1), Other (4), No response (0)

Table D-35. Other text responses for Question 13 (most frequent method for basis of payment for speed feedback trailers in work zones)

Other – Text
We have a bid item for plans: Contractor Furnished Speed Monitoring Radar Trailer, Each.
They are provided by DOT at the Contractor's request. DOT installs the trailer, and the Contractor is not compensated for them.
Part of the standard, not paid for separately.
Monthly Rental Rate or Each Item

Table D-36. Survey comments for Question 13 (most frequent method for basis of payment for speed feedback trailers in work zones)

Comment
Per day rental
Speed feedback trailers are paid as part of the lump sum bid item which also includes signs, arrow boards, channelizing devices, etc.
These would be a Unit Item (U) and we would prorate the payment over the length of the project with the maximum being one U for each device used on the project.
See Question 12 comments.
Law Enforcement does provide speed trailers at times.

Table D-37. Individual survey responses for Question 14 (use of performance measures for speed feedback trailers in work zones)

Respondent	Average (or median) speed	85th percentile speed	Speed limit compliance/non-compliance	Pace	Standard deviation (or variance) of speed	Worker feedback	Other	My agency does not use performance measures to assess the performance of speed feedback trailers in work zones
Alabama	-	-	-	-	-	X	-	X
Alaska	-	-	-	-	-	-	-	X
Arizona	-	X	X	-	X	-	-	-
Arkansas	-	-	-	-	-	X	-	-
Georgia	-	-	-	-	-	-	-	X
Illinois	-	-	-	-	-	-	X	-
Indiana	-	-	-	-	-	X	-	-
Iowa	-	-	-	-	-	-	-	X
Kansas	-	-	-	-	-	-	-	X
Kentucky	-	-	-	-	-	-	-	-
Louisiana	X	-	X	-	-	-	-	-
Maine	-	-	-	-	-	-	-	-
Maryland	X	X	X	X	-	-	-	-
Massachusetts	-	-	-	-	-	-	-	X
Michigan	-	-	-	-	-	X	X	-
Minnesota	-	-	X	-	-	X	-	-
Missouri	-	-	-	-	-	-	-	X
Montana	-	-	-	-	-	X	-	-
Nevada	-	-	-	-	-	-	-	X
New Hampshire	-	-	-	-	-	-	-	X
New Mexico	-	-	-	-	-	-	-	X
North Dakota	-	-	-	-	-	-	-	X
Oklahoma	-	-	-	-	-	-	-	X
Oregon	-	-	-	-	-	X	-	-
Pennsylvania	X	-	-	-	-	-	X	-
South Dakota	-	-	-	-	-	-	-	X
Tennessee	-	-	-	-	-	-	-	X
Vermont	-	-	X	-	-	X	-	-
Virginia	-	-	X	-	-	-	-	-
Washington	X	X	-	X	-	-	-	-
Wisconsin	-	-	-	-	-	-	-	X
Count	**4**	**3**	**6**	**2**	**1**	**8**	**3**	**15**

Table D-38. Other text responses for Question 14 (use of performance measures for speed feedback trailers in work zones)

Other – Text
SWZDI projects
We refer back to a research study completed prior to institutionalization.
Measured through RITIS or other third-party real-time speed measuring program.

Table D-39. Survey comments for Question 14 (use of performance measures for speed feedback trailers in work zones)

Comment
Comparing the speed reduction within first two weeks, with the sustained reduction.
Law enforcement is helpful with feedback.
We are new to this so there may be an opportunity to measure this in the future.
We have yet to assess the effectiveness of these with quantitative measures. Currently only qualitative feedback from contractors that they believe they are beneficial.

Table D-40. Individual survey responses for Question 15 (performance ratings for speed feedback trailers in work zones)

Respondent	Rating
Alabama	4
Alaska	3
Arizona	2
Arkansas	3
Georgia	3
Illinois	4
Indiana	3
Iowa	3
Kansas	3
Kentucky	2
Louisiana	2
Maine	4
Maryland	4
Massachusetts	3
Michigan	4
Minnesota	4
Missouri	4
Montana	4
Nevada	3
New Hampshire	3
New Mexico	2
North Dakota	-
Oklahoma	3
Oregon	4
Pennsylvania	2
South Dakota	3
Tennessee	3
Vermont	3
Virginia	5
Washington	3
Wisconsin	3
Average	**3.2**
Standard Deviation	**0.8**
Number of Responses	**30**

Table D-41. Survey comments for Question 15 (performance ratings for speed feedback trailers in work zones)

Comment
Could be better if the offices moved them around more without being reminded to.
Since this is new to us, I can't give a number. I am hoping it will be highly effective, but time will tell.
The longer the speed feedback trailers are deployed in the same location, the less effective they become. This is a gut feel, not based in any performance measures.
The speed feedback trailers with Red/Blue lights were more effective than the speed feedback trailers without lights.
I think they are more effective than just signage and help to make users aware of the recommended/posted speed and aware of their own speed and when paired with enforcement and other countermeasures, they can be pretty effective. Stand-alone units are only helpful to make people aware because it seems only a fraction of drivers alter their speeds upon realization of over the limit driving without a change of condition they experience or enforcement, but the industry will always vote for a reduction of speed even if it is only a small percentage.
Valuable/effective for a limited time period.
Automated enforcement is against the law, and enforcement in work zones is rare. Trailers are not moved, or used with specific use / concern. No performance-based design or implementation, therefore public becomes “numb” to them fairly quickly.
No quantitative measure of effectiveness, but there are those that report braking and slower traffic in the vicinity of the speed feedback sign in the work zone. Does this last over time with commuter traffic that is familiar with their presence? We couldn't say.

Table D-42. Individual survey responses for Question 16 (factors perceived to influence the performance of speed feedback trailers in work zones)

Respondent	Trailer Location within the Work Zone	Presence of Positive Protection	Work Zone Speed Limit	Use of Built-in Features (e.g., Flashing Beacons or Message)	Use of Additional Countermeasures (e.g., Enforcement)	Police Presence	Type of Message Displayed	Type of Work Activity	Amount of Time the Trailer Stays at a Specific Location	Worker Proximity	Traffic Volumes	Work Zone Duration	Work Zone Length	Other
Alabama	5	5	5	4	5	4	3	4	3	4	4	4	4	-
Alaska	4	4	5	4	4	5	4	5	5	5	5	5	5	-
Arizona	5	3	4	3	5	5	3	4	5	4	4	3	3	-
Arkansas	4	3	3	3	4	5	3	3	3	3	3	3	3	3
Georgia	5	5	4	4	3	4	3	3	3	4	4	4	3	-
Illinois	5	3	5	4	5	5	4	3	2	4	3	2	2	-
Indiana	4	-	2	4	4	5	4	4	4	4	2	2	4	-
Iowa	5	3	4	4	3	5	4	5	5	5	4	4	4	-
Kansas	5	3	5	5	5	5	4	4	5	5	4	4	5	-
Kentucky	3	3	4	4	-	5	-	-	-	4	-	-	-	-
Louisiana	4	5	4	5	5	5	4	5	3	5	4	3	3	-
Maine	5	5	5	5	5	4	5	3	4	4	3	3	3	-
Maryland	4	5	4	4	5	5	4	3	3	4	3	3	3	-
Massachusetts	4	3	4	3	5	3	2	3	4	3	4	4	4	-
Michigan	5	5	5	4	4	5	4	4	5	4	3	4	5	-
Minnesota	4	3	4	4	5	5	3	4	4	4	4	4	4	-
Missouri	3	3	2	4	5	5	3	4	3	4	5	2	3	-
Montana	5	3	5	4	5	5	4	3	3	5	5	3	2	-
Nevada	4	3	4	3	5	5	4	4	3	3	3	5	5	-
New Hampshire	4	4	3	3	4	4	3	3	4	3	4	4	4	-
New Mexico	4	5	5	4	5	5	5	5	4	4	5	4	4	-
North Dakota	4	5	4	4	4	5	4	4	3	4	3	3	3	-
Oklahoma	3	3	3	3	3	3	3	3	3	3	3	3	3	-
Oregon	5	4	4	4	5	5	5	4	4	5	3	4	5	-
Pennsylvania	5	5	3	3	3	4	4	5	4	4	4	3	4	-
South Dakota	5	2	4	1	4	5	2	3	4	5	3	3	4	-
Tennessee	4	4	3	3	5	5	-	4	3	3	3	3	3	-
Vermont	4	3	4	3	4	5	3	3	3	4	4	4	4	-
Virginia	5	5	4	4	3	4	4	3	4	4	5	5	5	-
Washington	5	3	5	3	5	5	4	3	4	5	4	3	4	-
Wisconsin	5	5	5	3	3	3	3	5	5	5	3	5	5	-
Average	**4.4**	**3.8**	**4.0**	**3.6**	**4.3**	**4.6**	**3.6**	**3.8**	**3.7**	**4.1**	**3.7**	**3.5**	**3.8**	**3.0**
Standard Deviation	**0.7**	**1.0**	**0.9**	**0.8**	**0.8**	**0.7**	**0.8**	**0.8**	**0.8**	**0.7**	**0.8**	**0.9**	**0.9**	**-**
Total Responses	**31**	**30**	**31**	**31**	**30**	**31**	**29**	**30**	**30**	**31**	**30**	**30**	**30**	**1**

NOTE: 5 = Strongly agree, 4 = Somewhat agree, 3 = Neither agree nor disagree, 2 = Somewhat disagree, 1 = Strongly disagree

Table D-43. Text responses for features or conditions for Question 16 (factors perceived to influence the performance of speed feedback trailers in work zones)

Features or Conditions That Improve the Effectiveness of Speed Feedback Trailers Within Work Zones
Enforcement presence in work zones seems to be the most effective condition in vehicles driving at the required speed.
Location in a zone, enforcement or police presence, and user understanding of why whether it is actual path changes or activity are the most effective.
The location and line of sight. Having some enforcement on site also helps the public slow down as they think they are being used to track them.
The speed feedback trailers seem to be less effective in areas with a high population density.
Flashers and Beacons are not allowed, nor are any messages, or even flashing of the speed itself. Work zone duration itself, would depend on if the signs are moved and/or removed and replaced later.

Table D-44. Survey comments for Question 16 (factors perceived to influence the performance of speed feedback trailers in work zones)

Comment
Auto enforcement is a great tool that allows for more impact, but not all states have this ability.

Table D-45. Individual survey responses for Question 17 (completion of formal studies to evaluate the effectiveness of speed feedback trailers in work zones)

Respondent	Response Text
Alabama	No
Alaska	No
Arizona	No
Arkansas	No
Georgia	No
Illinois	Yes
Indiana	-
Iowa	No
Kansas	No
Kentucky	No
Louisiana	No
Maine	No
Maryland	No
Massachusetts	No
Michigan	Yes
Minnesota	No
Missouri	Yes
Montana	No
Nevada	No
New Hampshire	No
New Mexico	No
North Dakota	No
Oklahoma	No
Oregon	No
Pennsylvania	No
South Dakota	No
Tennessee	No
Vermont	Yes
Virginia	No
Washington	No
Wisconsin	No

NOTE: Summary of responses – Yes (4), No (26), No response (1)

Table D-46. Resources submitted for Question 17 (completion of formal studies to evaluate the effectiveness of speed feedback trailers in work zones)

Respondent	Description	URL
Illinois	Effect of Flaggers and Spotters in Directing Work Zone Traffic for Illinois Expressways and Freeways (research report)	https://apps.ict.illinois.edu/projects/getfile.asp?id=3109
Iowa	Webpage for Smart Work Zone Deployment Initiative	https://swzdi.intrans.iastate.edu/
Vermont	Work Zones and Travel Speeds: The Effects of Uniform Traffic Control Officers and Other Speed Management Measures	https://scholarworks.uvm.edu/cgi/viewcontent.cgi?article=1189&context=trc

Table D-47. Survey comments for Question 17 (completion of formal studies to evaluate the effectiveness of speed feedback trailers in work zones)

Comment
Not that I am aware of
Nothing formal, but I could probably get you some analysis not sure if you could publish.

Table D-48. Individual survey responses for Question 18 (concerns that hinder efforts to implement speed feedback trailers in work zones)

Respondent	Cost	Lack of Agency Buy In	Lack of Availability of Equipment	Lack of Contractor Buy In	Lack of Data on Performance	Lack of Identified Funding	Lack of Legislative Authority	Lack of Perceived Need	Other Speed Countermeasures are Higher Priority	Public Perception	Other
Alabama	3	3	1	2	3	3	3	5	4	4	-
Alaska	2	3	3	4	4	1	1	3	4	3	-
Arizona	1	3	1	4	4	2	5	4	4	5	-
Arkansas	3	3	3	3	4	3	3	3	3	3	-
California	-	-	-	-	-	-	-	-	-	-	-
Colorado	-	-	-	-	-	-	-	-	-	-	-
Connecticut	-	-	-	-	-	-	-	-	-	-	-
Delaware	1	1	1	1	5	1	1	2	5	5	5
District of Columbia	-	-	-	-	-	-	-	-	-	-	-
Florida	-	-	-	-	-	-	-	-	-	-	-
Georgia	2	3	1	4	4	1	1	2	1	1	-
Hawaii	-	-	-	-	-	-	-	-	-	-	-
Idaho	-	-	-	-	-	-	-	-	-	-	-
Illinois	1	1	1	1	1	1	1	1	1	1	-
Indiana	2	2	2	2	2	2	1	4	2	2	-
Iowa	4	3	2	1	4	1	1	1	2	3	-
Kansas	3	4	4	2	1	3	3	2	2	2	-
Kentucky	3	3	3	3	3	3	3	3	3	4	-
Louisiana	3	3	4	4	3	4	4	4	5	2	-
Maine	1	1	4	1	3	1	5	1	1	4	-
Maryland	4	4	3	4	5	5	4	4	4	4	-
Massachusetts	2	1	2	2	3	2	1	2	3	2	-
Michigan	3	4	4	5	4	2	3	3	3	3	-
Minnesota	4	1	1	2	3	3	3	2	2	3	-
Mississippi	3	4	2	2	4	3	3	4	4	3	-
Missouri	4	4	4	3	4	4	3	2	3	3	-
Montana	3	2	4	4	4	2	2	2	2	2	-
Nebraska	3	3	3	3	4	3	2	4	2	2	-
Nevada	3	4	4	2	5	3	1	5	2	2	-
New-Hampshire	1	3	1	3	4	1	2	4	3	3	-
New-Jersey	3	4	2	2	3	3	3	4	4	4	-
New-Mexico	1	1	1	1	4	1	1	1	3	1	-
New-York	-	-	-	-	-	-	-	-	-	-	-
North-Carolina	3	3	2	4	4	3	1	4	4	1	-

Respondent	Cost	Lack of Agency Buy In	Lack of Availability of Equipment	Lack of Contractor Buy In	Lack of Data on Performance	Lack of Identified Funding	Lack of Legislative Authority	Lack of Perceived Need	Other Speed Countermeasures are Higher Priority	Public Perception	Other
North-Dakota	3	3	3	3	3	3	3	3	3	3	-
Ohio	-	-	-	-	-	-	-	-	-	-	-
Oklahoma	3	3	3	3	3	3	3	3	3	3	-
Oregon	1	1	1	1	1	1	1	3	3	3	-
Pennsylvania	1	1	1	1	1	1	1	1	1	1	-
Rhode-Island	2	2	2	2	4	3	3	4	-	3	-
South-Carolina	3	3	3	3	3	3	3	3	3	3	-
South-Dakota	4	3	2	2	5	2	2	2	3	2	-
Tennessee	2	2	2	2	3	2	2	2	3	3	-
Texas	-	-	-	-	-	-	-	-	-	-	-
Utah	5	4	4	5	5	5	3	4	4	4	-
Vermont	4	3	4	4	5	5	4	3	3	4	-
Virginia	3	2	2	1	3	3	3	3	3	3	-
Washington	1	2	2	1	4	1	3	2	3	2	-
West-Virginia	-	-	-	-	-	-	-	-	-	-	-
Wisconsin	1	1	1	1	4	1	1	4	3	1	-
Wyoming	3	3	3	3	3	3	3	3	3	3	-
Average	**2.6**	**2.6**	**2.4**	**2.5**	**3.5**	**2.4**	**2.4**	**2.9**	**2.9**	**2.8**	**5.0**
Standard Deviation	**1.1**	**1.1**	**1.1**	**1.2**	**1.1**	**1.2**	**1.2**	**1.1**	**1.0**	**1.1**	**-**
Total Responses	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**39**	**40**	**1**

NOTE: 5 = Strongly agree, 4 = Somewhat agree, 3 = Neither agree nor disagree, 2 = Somewhat disagree, 1 = Strongly disagree

Table D-49. Other text responses for Question 18 (concerns that hinder efforts to implement speed feedback trailers in work zones)

Other – Text
Motorist disregard and often use these as a “high score” attempt
Not at this time

Table D-50. Survey comments for Question 18 (concerns that hinder efforts to implement speed feedback trailers in work zones)

Comment
The data we have collected shows little improvement.
Everyone's perception of when it is most effective is different, so a decision matrix would be helpful to help folks understand when to include it as a contract item and some best practices for different scenarios.
Our state cannot use these or other devices for enforcement, so the data we gather is simply vehicle type and speed entering the work zone. We have had no issues with implementation, it is problematic for the Contractors to find enough at times to cover the amount of projects and work zones.
We've been looking into using speed feedback trailers but haven't yet. Highway Patrol currently sets some out throughout the state (I think they have four statewide) using standard portable changeable message signs, but anecdotal evidence is that they are not effective in reducing speeds or increasing safety.
I believe implementation in our state has been relatively successful.

Table D-51. Survey comments for Question 19 (other survey feedback)

Comment
We would like to see research or information from other states on the effectiveness of speed feedback trailers in work zones, if they have any. We would encourage more use if we knew it to be an effective measure.
Our DOT plans to investigate the use of speed feedback trailers in lane closures.
I have seen them used in some work zones in our state, but it is rare and there is no policy in place at this time for their use. However, we do implement speed feedback signs on some roadways where we have had speeding concerns. We often partner with municipality Police Departments to temporarily place them on roadways where we have received speeding complaints.
Let me know if you have any additional questions.
Our DOT uses these in conjunction with other traffic control devices, in temporary or longer term lane closures. We feel they are part of an effective work zone package and provide immediate driver feedback, which helps reduce speeds to where we want them.
Our DOT would like to deploy speed feedback trailers as effectively as possible. My initial impression is that to be effective the unit should be deployed in advance of work activity where workers are not protected by positive barriers. This may mean several units throughout the lane closure.
Some motorists like to see how high they can get the numbers to!
We are just starting to use these in work zones where crossovers are being used. Hopefully next summer we can get a better feel on how well they work.
With newer technology these will be useful as they can collect, store, and transmit data. These devices coupled with other speed counter measures are very effective. Our DOT is currently putting together a speed countermeasure pilot program using a combination of intrusive and non-intrusive devices.
Our DOT mainly uses speed feedback trailers as passive devices. There have been no studies to determine their effectiveness.
While we do not use them now, we have had discussions on using speed feedback trailers in the future.
Since we have not done any studies on the effectiveness of these, it's difficult to answer the questions. It would be interesting to see what other states have done. We include them in many projects, but it’s then left up to the Contract Administrators and inspectors to use as they see fit.