Report No. UT-26.04

EFFECTIVENESS OF TEMPORARY PORTABLE RUMBLE STRIPS ON WORK ZONES

Prepared For:

Utah Department of Transportation
Research & Innovation Division

Final Report
April 2026

RESEARCH

Keeping Utah Moving
Utah Department of Transportation - Research Division
4501 South 2700 West - P.O. Box 148410 - SLC,UT 84114-8410

DISCLAIMER

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16. Abstract

This study evaluates the effectiveness and operational implications of Temporary Portable Rumble Strips (TPRS) used by the Utah Department of Transportation (UDOT) to alert drivers to upcoming work zones. While TPRS are intended to capture driver attention and reduce crash risk, concerns remain regarding their influence on driver behavior, avoidance maneuvers, and maintenance requirements. A field experiment was conducted at four work zones in Utah during the Summer 2025 construction season. Four deployment conditions—no TPRS and three spacing configurations—were tested. Data collection included speed measurements using mobile radar detectors and video-based observations of vehicle classification, braking behavior, avoidance maneuvers, and TPRS displacement. Results indicate that the effect of TPRS on speed reduction is inconclusive. Drivers who braked in response to TPRS typically did so before reaching the devices, suggesting that visual cues may be as influential as tactile feedback. Avoidance behavior was common among motorcycles and occurred occasionally among other vehicles. Driver responses were more strongly influenced by site-specific factors—such as roadway geometry and sight distance—than by TPRS spacing. TPRS displacement occurred gradually under traffic but was not clearly related to traffic volume or speed, suggesting that device age and condition play a larger role. Maintenance requires traffic gaps of approximately 34 seconds, which may not be feasible at higher-volume sites. These findings highlight the need for further evaluation of TPRS effectiveness, standards for device condition, consideration of alternative measures for long-term work zones, and increased contractor discretion based on site conditions.

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Work zone safety, temporary portable rumble strips, rumble strips.

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UNIT CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
DOT	Department of Transportation
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
IIHS	Insurance Institute of Highway Safety
PSS	Plastic Safety Systems
TPRS	Temporary Portable Rumble Strips
UDOT	Utah Department of Transportation

EXECUTIVE SUMMARY

The Utah Department of Transportation (UDOT) uses Temporary Portable Rumble Strips (TPRS) – plastic and rubber devices placed transverse across the roadway – to alert drivers to upcoming work zones and other temporary traffic controls. Prior studies have suggested that TPRS effectively gain drivers' attention and may reduce crash rates. At the same time, there are potential downsides with TPRS. The degree to which drivers change their behavior regarding the upcoming work zone is unknown. Anecdotal evidence suggests that some motorists may attempt to avoid TPRS, creating safety issues. Similarly, TPRS can shift with repeated vehicle traffic, requiring workers to enter the roadway and correct their alignment.

This report describes a field experiment where four different arrangements of TPRS arrays – no installation as well as three spacing configurations – were all deployed to four different work zones in Utah during the Summer 2025 construction season. Researchers measured period speeds at and downstream of TPRS using mobile radar speed detectors. Researchers also observed vehicle classification, braking and avoidance behavior, and TPRS displacement and correction using video recordings.

An analysis of the data illustrates several findings. First, the effect of TPRS deployment on speed reduction ahead of work zones is inconclusive. When drivers activate their brakes in response to TPRS, they tend to brake before encountering the array rather than after. This could imply either that the effect of TPRS on braking is primarily visual, or that a small number of drivers did require tactile feedback to alert them to an upcoming work zone. A large proportion of motorcycles avoid TPRS, but a few other vehicles avoid as well. The effect of TPRS on braking and avoidance is a function of site more than TPRS spacing, implying that roadway geometry, sightlines, and other environmental factors play a larger role than TPRS specifically.

TPRS displace gradually under traffic loads, but not at a uniform rate controlling for the cumulative weight and speed of traffic. TPRS displacement is likely a function of device age and condition. Workers who correct TPRS require headways of conservatively 34 seconds, a gap that may not be available on all work sites in all periods.

Recommendations to UDOT resulting from this research include the following:

1. Further study of the effectiveness of TPRS in real and controlled conditions.

2. Establish standards for allowable vintage and condition of TPRS devices used on projects.
3. Consider more permanent control measures for long-term work sites.
4. Give contractors discretion and direction on TPRS use when volumes are high and gaps in traffic are short.

1.0 INTRODUCTION

1.1 Problem Statement

The Utah Department of Transportation (UDOT) uses Temporary Portable Rumble Strips (TPRS) – plastic and rubber devices placed transverse across the roadway – to alert drivers to upcoming work zones and other temporary traffic controls. Prior studies have suggested that TPRS effectively gain drivers' attention and may reduce crash rates. At the same time, there are potential downsides with TPRS. The degree to which drivers change their behavior regarding the upcoming work zone is unknown. Anecdotal evidence suggests that some motorists may attempt to avoid TPRS, creating safety issues. Similarly, the TPRS can shift with repeated impacts from vehicle traffic, requiring workers to enter the roadway and correct their alignment.

1.2 Objectives

The objectives of this research are to measure the degree to which TPRS alter driver behavior in the approach to work zones, quantify and describe TPRS displacement with respect to traffic conditions, and evaluate worker exposure related to correcting TPRS displacement.

1.3 Scope

To accomplish the objectives stated above, a team of faculty and students at Brigham Young University designed and executed an experiment to observe TPRS installations at work zones in Utah during the Summer 2025 construction season. The experiment involved deploying TPRS in four varied configurations at four different work sites. Trailer-mounted radar and video equipment allowed the researchers to measure change in vehicle speed, braking location relative to TPRS, and attempts to avoid TPRS as a function of vehicle type. The researchers also observed TPRS displacement as a function of traffic load, speed, and mass, along with the efforts of work staff to correct displaced TPRS.

1.4 Outline of Report

The report proceeds in several chapters with the following organization:

1. Introduction – this chapter, outlining the research need and objectives.
2. Literature Review – a chapter outlining use of TPRS and previous research.
3. Research Methods – a chapter describing the experiment and associated data collection methods.
4. Data Processing and Analysis – a chapter describing the data processing and relevant statistical analysis.
5. Findings and Limitations – a chapter restating the central findings of the research along with limitations and associated needs for future research.
6. Recommendations and Implementation – a chapter with outlined recommendations to UDOT and a plan to implement the findings of this research.

2.0 LITERATURE REVIEW

2.1 Overview

This chapter reviews existing academic and field research on the development and observed effectiveness of TPRS. This review includes an outline of the history of TPRS and related devices, followed by a description of current installation and use practices at UDOT and other departments of transportation (DOTs), particularly regarding the spacing between the individual strips in the installed arrays. The review then discusses findings from the literature regarding driver behavior and awareness, followed by a discussion of previous findings related to TPRS displacement. The chapter concludes with a summary of unresolved questions and concerns to examine in this research.

2.2 Product History

At the end of the 1990s, the Kansas DOT sought an alternative to the cold-mix asphalt rumble strips it used to alert drivers to upcoming work zones; Kansas DOT desired strips that were faster to install and remove, while still alerting drivers effectively (Meyer, 2000). This interest prompted over a decade of product development and study on TPRS. The first products available were peel-and-stick adhesive tapes around 1/8 in. thick placed in multi-strip arrays. Users of this product discovered that adhesive TPRS were too thin to make a noticeable impact (i.e., a noise heard by drivers) on vehicles passing over the strips (Maze, 2000; Meyer, 2000). These early studies attributed difference in driver behavior to the bright orange color of the adhesive TPRS and speculated that thicker strips with wider spacing would create stronger audible and tactile feedback to drivers (Meyer, 2000). Increased strip thickness, initially achieved by stacking the strips on top of one another, did create more noise within vehicles as well as reduce driver speed (Fontaine and Carlson, 2001). At the same time, adhesive strips require fair weather, a clean road surface, and periodic reapplication of adhesive, limiting the application and lifespan of adhesive tapes (Brown et al., 2022; Myers Industries, 2021).

Meyer et al. (2006) developed specifications for a non-adhesive rumble strip addressing limitations identified for adhesive strips. In December 2008, Plastic Safety Systems (PSS) released the RoadQuake, a non-adhesive strip 3/4 in. thick, made of rubber and steel (PSS, 2018). Studies using both track and field tests demonstrated that RoadQuake and similar non-adhesive TPRS generated more noise feedback than adhesive TPRS and remained in place when properly installed (Schrock et al., 2010; Schrock et al., 2016; Sun et al., 2011). Research on adhesive TPRS since the development of non-adhesive TPRS is lacking, indicating a strong industry shift. Unless stated otherwise, all mentions of TPRS in the remainder of this report refer to the non-adhesive variety.

2.3 Installation and Use

State DOTs and product manufacturers have a variety of policies and informal practices related to TPRS. Of particular interest to this research are policies related to the installation and spacing of TPRS arrays. The data presented here is not meant to be a comprehensive list of all specifications and policies across all states, but rather a sampling to illustrate the diversity of the specifications for TPRS spacing and to emphasize the significance that spacing of individual strips holds for this research.

Common brands of TPRS include the RoadQuake system manufactured by PSS (PSS, 2024), as well as the Alert strips produced by TrafFix Devices (TrafFix Devices, 2024). Both consist of heavy strips made of a thermoset cast urethane or other engineered polymer, as outlined in the guidelines for the New York State DOT (2020). These typically do not require adhesives for installation and are designed for short-term use and easy installation (PSS 2018). PSS' RoadQuake system and TrafFix's Alert system provide a unique opportunity to compare the specifications for TPRS, and the benefits and drawbacks from who provides them.

In addition to their design differences, PSS outlines substantially more direction for the use and specifications of their RoadQuake system than TrafFix Devices provides for their Alert strips. This is especially true when it comes to the spacing of their respective non-adhesive TPRS products. By Table 2.1 shows the specifications for spacing provided by PSS for the RoadQuake strips. Distances are measured in feet from the center of individual strips. In addition to this, PSS specifies that their strips are designed for posted speed limits up to 80 mph and are expected to last for a "three-to-five-year life under typical conditions" (PSS, 2018). By

Table 2.1 PSS RoadQuake Spacing Specifications

Speed (mph)	Spacing (ft)
≤40	10
41-55	15
56-65	20
>65	35+

contrast, the TrafFix Alert system does not provide such specifications on their website (TrafFix Devices, 2024).

In cases where manufacturers of TPRS have not provided spacing instructions, state DOTs have often done so. Figure 2.1 displays the trends in a sample of specifications for TPRS spacing from DOTs from Wisconsin (Wisconsin DOT, 2022), Florida (Florida DOT, 2021), Colorado (Colorado DOT, 2019), Maryland (Maryland DOT, 2021), Virginia (Virginia DOT, 2019, Table 6H-7), Minnesota (Minnesota DOT, 2024a), New York (New York State DOT, 2020), Texas (Texas DOT, 2022), and Missouri (ATSSA, 2020). For comparison, it also includes recommended specifications from PSS for their RoadQuake TPRS system (PSS, 2018). Many of these state DOTs include rumble strips made by both PSS and TrafFix Devices Inc. on their approved product list or approved materials list (Florida DOT, 2024; Maryland DOT, 2025; Minnesota DOT, 2024b; Wisconsin DOT, 2026). All specifications from each of these states use a standard of three strips per array of TPRS but display differences for standards regarding the spacing between the strips. The posted speed limit is the typical variable that dictates spacing for these standards. Colorado DOT (2019), Florida DOT (2021), and Wisconsin DOT (2022) all use a single standard spacing value between each strip in an array regardless of speed or road classification. Most of these specifications provide minimum speeds for a given spacing between strips in arrays but do not indicate anything about an absolute maximum speed. Figure 2.1 compares the spacing specifications outlined by different state DOTs. The figure also includes the manufacturer-recommended spacing (PSS, 2024). The manufacturer also suggested an unofficial guidance of 1:2 spacing where the distance between the strips in feet is half the posted speed limit in miles per hour. This guidance has been used on roads where observed speeds exceed 80 mph (Shawn T, personal communications, May 8, 2025).

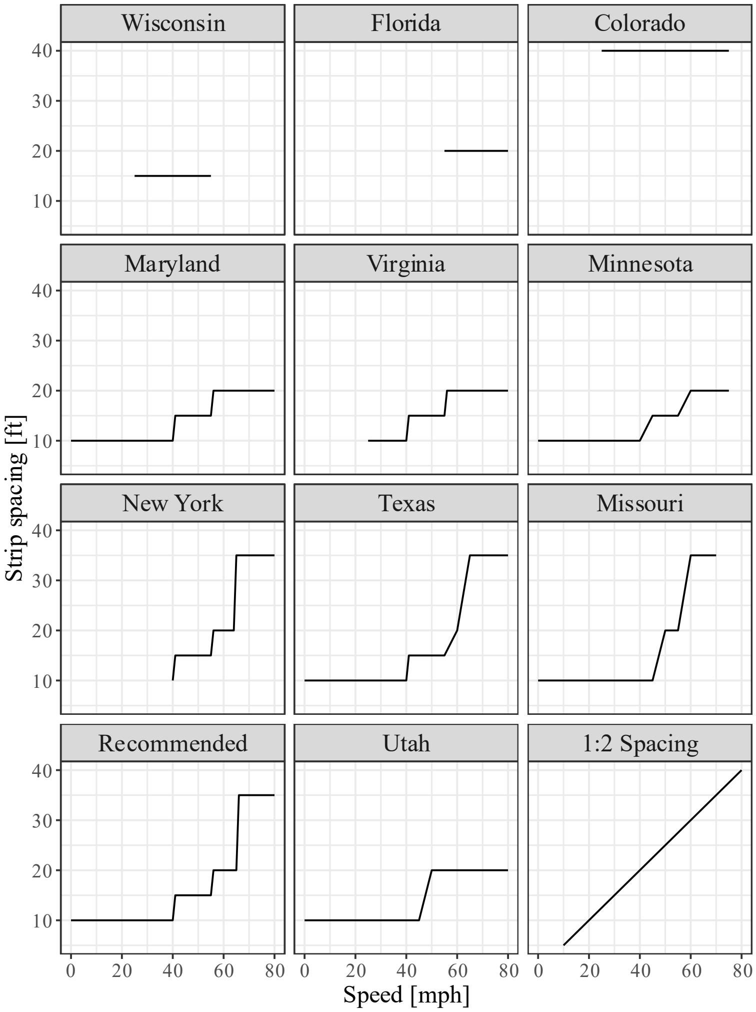


Figure 2.1 Spacing specifications by speed in multiple states.

UDOT incorporates TPRS into its standard worksite drawings. Region 4, which represents UDOT in the southern half of the state, specifies spacing which is half the distance of the statewide standards (UDOT, 2025, STD. DWG. NO. TC 4B4). Versions of the Region 4 drawings are repeated here as Figure 2.2 and Figure 2.3 (A. Ogden, personal communications, February 2, 2025). These drawings outline the standard layout and specific policies that Region 4 has in place for contractors using TPRS on their road work sites. The research team opted to use the Region 4 spacing specifications as they participated most actively in guiding this research.

LANE CLOSURE

TAPER, BUFFER ZONE & SIGN SPACING CHART

ROAD TYPE	POSTED SPEED MPH (S)	MINIMUM TAPER LENGTH(L)	LENGTH OF BUFFER(BZ)	MINIMUM SIGN SPACING (SS)					ONE LANE TWO-WAY FLAGGING
		12 FT LANE CLOSURE	DESIRABLE	A	B	C	D	E	TAPER LENGTH
		FT	FT	FT	FT	FT	FT	FT	FT
CONVENTIONAL	30 AND LOWER	180	200	100	100	100	100	50	50
	35	245	250	350	350	350	175	175	
	40	320	305						
	45	540	360	500	500	500	250	250	100
	50	600	425						
	55	660	495						
	60	720	570						
	65	780	645						

1- TAPER LENGTH FORMULAS

SPEED	FORMULA
FOR SPEEDS OF 40 MPH AND LESS	$L=\frac{WS^2}{60}$
FOR SPEEDS OF 45 MPH AND GREATER	$L= WS$

L = TAPER LENGTH IN FEET
W = WIDTH OF OFFSET IN FEET
S = SPEED IN MPH

⅓ L = FOR SHOULDER CLOSURE TAPER
½ L = FOR LANE SHIFT TAPER

2- CHANNELIZING DEVICES

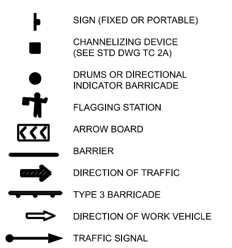
A) MERGING AND SHIFTING TAPERS: USE A MINIMUM OF 1 DEVICE PER FT OF LANE CLOSURE WIDTH, PLUS 1 ADDITIONAL DEVICE TO START.

B) SHOULDER, ONE-LANE TWO-WAY, AND DOWNSTREAM TAPERS: USE A MINIMUM OF 1 DEVICE PER 3 FT OF WIDTH (OR PORTION THEREOF), PLUS 1 ADDITIONAL DEVICE TO START.

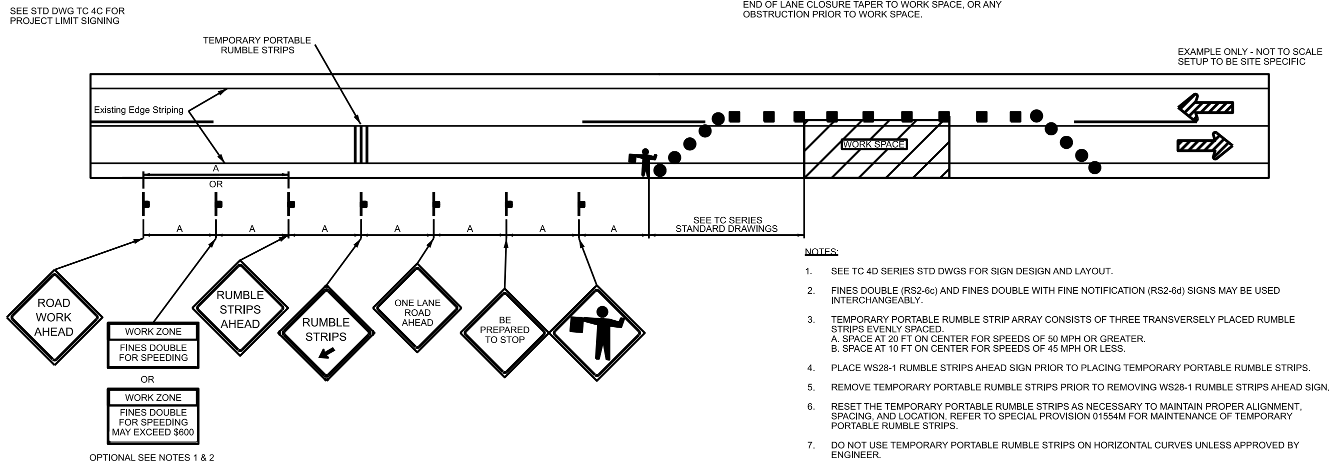
C) ON TANGENT: S x 2 = SPACING UP TO 120 FT MAXIMUM.

D) LENGTH OF BUFFER ZONE (BZ) IS THE DISTANCE FROM END OF LANE CLOSURE TAPER TO WORK SPACE, OR ANY OBSTRUCTION PRIOR TO WORK SPACE.

TRAFFIC CONTROL DEVICE LEGEND



STANDARD WORK ZONE SIGNING WITH TEMPORARY PORTABLE RUMBLE STRIPS ON CONVENTIONAL AND RURAL ROADS



NOTES:

1. SEE TC 4D SERIES STD DWGS FOR SIGN DESIGN AND LAYOUT.
2. FINES DOUBLE (RS2-6c) AND FINES DOUBLE WITH FINE NOTIFICATION (RS2-6d) SIGNS MAY BE USED INTERCHANGEABLY.
3. TEMPORARY PORTABLE RUMBLE STRIP ARRAY CONSISTS OF THREE TRANSVERSELY PLACED RUMBLE STRIPS EVENLY SPACED.
   A. SPACE AT 20 FT ON CENTER FOR SPEEDS OF 50 MPH OR GREATER.
   B. SPACE AT 10 FT ON CENTER FOR SPEEDS OF 45 MPH OR LESS.
4. PLACE WS28-1 RUMBLE STRIPS AHEAD SIGN PRIOR TO PLACING TEMPORARY PORTABLE RUMBLE STRIPS.
5. REMOVE TEMPORARY PORTABLE RUMBLE STRIPS PRIOR TO REMOVING WS28-1 RUMBLE STRIPS AHEAD SIGN.
6. RESET THE TEMPORARY PORTABLE RUMBLE STRIPS AS NECESSARY TO MAINTAIN PROPER ALIGNMENT, SPACING, AND LOCATION. REFER TO SPECIAL PROVISION 01554M FOR MAINTENANCE OF TEMPORARY PORTABLE RUMBLE STRIPS.
7. DO NOT USE TEMPORARY PORTABLE RUMBLE STRIPS ON HORIZONTAL CURVES UNLESS APPROVED BY ENGINEER.
8. DO NOT PLACE TEMPORARY PORTABLE RUMBLE STRIPS DURING SNOW EVENTS.
9. SIGN LAYOUT IS TO BE APPLIED TO EACH DIRECTION OF TRAFFIC.
10. RELOCATE THE TEMPORARY PORTABLE RUMBLE STRIPS AND ASSOCIATED SIGNING WHEN VEHICLE QUEUES ARE EXPECTED OR OCCUR IN ADVANCE OF TEMPORARY PORTABLE RUMBLE STRIPS.

Figure 2.2 TPRS layout at a lane closure.

PASSING LANE CLOSURE

TAPER, BUFFER ZONE & SIGN SPACING CHART

ROAD TYPE	POSTED SPEED MPH (S)	MINIMUM TAPER LENGTH(L)	LENGTH OF BUFFER(BZ)	MINIMUM SIGN SPACING (SS)					ONE LANE TWO-WAY FLAGGING
		12 FT LANE CLOSURE	DESIRABLE	A	B	C	D	E	TAPER LENGTH
		FT	FT	FT	FT	FT	FT	FT	FT
CONVENTIONAL	30 AND LOWER	180	200	100	100	100	100	50	50
	35	245	250	350	350	350	175	175	
	40	320	305						
	45	540	360	500	500	500	250	250	100
	50	600	425						
	55	660	495						
	60	720	570						
	65	780	645						

1- TAPER LENGTH FORMULAS

SPEED	FORMULA
FOR SPEEDS OF 40 MPH AND LESS	$L=\frac{WS^2}{60}$
FOR SPEEDS OF 45 MPH AND GREATER	L= WS

L = TAPER LENGTH IN FEET
W = WIDTH OF OFFSET IN FEET
S = SPEED IN MPH

⅓ L = FOR SHOULDER CLOSURE TAPER
½ L = FOR LANE SHIFT TAPER

2- CHANNELIZING DEVICES

A) MERGING AND SHIFTING TAPERS: USE A MINIMUM OF 1 DEVICE PER FT OF LANE CLOSURE WIDTH, PLUS 1 ADDITIONAL DEVICE TO START.

B) SHOULDER, ONE-LANE TWO-WAY, AND DOWNSTREAM TAPERS: USE A MINIMUM OF 1 DEVICE PER 3 FT OF WIDTH (OR PORTION THEREOF), PLUS 1 ADDITONAL DEVICE TO START.

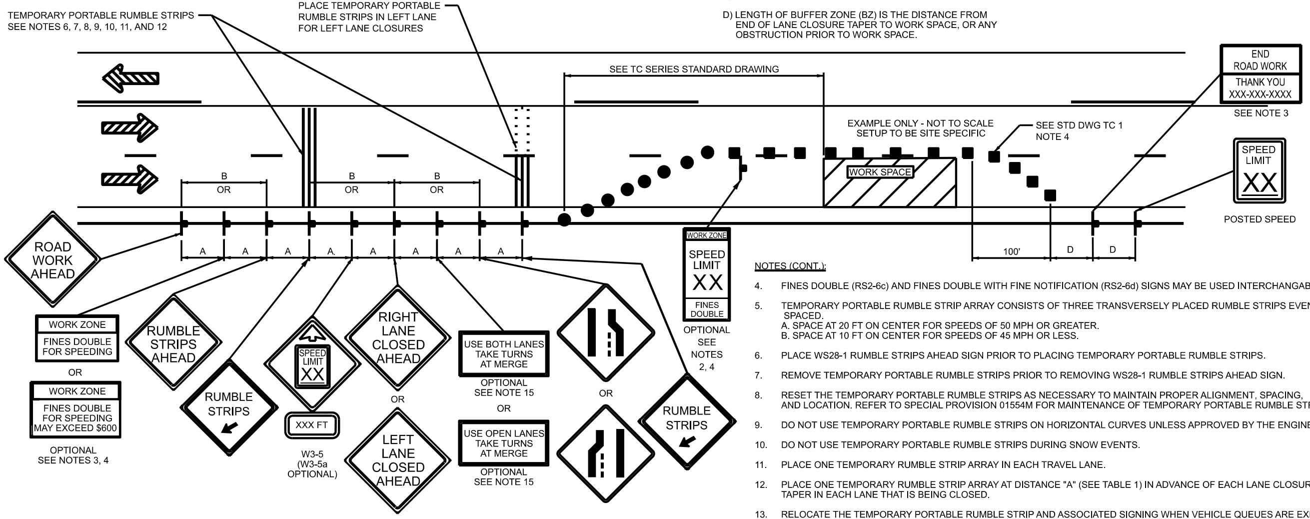
C) ON TANGENT: S x 2 = SPACING UP TO 120 FT MAXIMUM.

D) LENGTH OF BUFFER ZONE (BZ) IS THE DISTANCE FROM END OF LANE CLOSURE TAPER TO WORK SPACE, OR ANY OBSTRUCTION PRIOR TO WORK SPACE.

TRAFFIC CONTROL DEVICE LEGEND

┣	SIGN (FIXED OR PORTABLE)
■	CHANNELIZING DEVICE (SEE STD DWG TC 2A)
●	DRUMS OR DIRECTIONAL INDICATOR BARRICADE
🚩	FLAGGING STATION
⟨⟨⟨	ARROW BOARD
―	BARRIER
➡	DIRECTION OF TRAFFIC
┳┳┳	TYPE III BARRICADE
⇨	DIRECTION OF WORK VEHICLE

LANE CLOSURE SIGNING WITH TEMPORARY PORTABLE RUMBLE STRIPS ON CONVENTIONAL AND RURAL ROADS



NOTES

1. USE THE PRECONSTRUCTION POSTED SPEED LIMIT PRIOR TO WORK ZONE TO COMPUTE THE SIGN SPACING, TAPER LENGTH, BUFFER ZONE, AND WORK CLEAR ZONE DISTANCE. USE THE POSTED SPEED LIMIT DURING WORK TO DETERMINE THE TANGENT SPACING FOR CHANNELIZING DEVICES.

2. SIGN MAY BE USED IN WORK ZONES WHERE SPEED LIMIT IS NOT REDUCED.
   A. REPLACE EXISTING SPEED LIMIT SIGNS WITH RS2-6c ASSEMBLIES.
   B. PLACE ADDITIONAL WORK ZONE SPEED LIMIT ASSEMBLIES (RS2-1a), FINES DOUBLE (RS2-6c), AND FINES DOUBLE WITH FINES NOTIFICATION (RS2-6d) SIGNS AT ALL MAJOR INTERSECTIONS AND INTERCHANGES WITHIN THE PROJECT WHEN REDUCED SPEEDS AND THE FINES DOUBLE OR THE FINES DOUBLE WITH FINE NOTIFICATION SIGNING OPTION IS USED.

3. SEE TC 4D SERIES STD DWGS FOR SIGN DESIGN AND LAYOUT.

NOTES (CONT.):

4. FINES DOUBLE (RS2-6c) AND FINES DOUBLE WITH FINE NOTIFICATION (RS2-6d) SIGNS MAY BE USED INTERCHANGABLY.

5. TEMPORARY PORTABLE RUMBLE STRIP ARRAY CONSISTS OF THREE TRANSVERSELY PLACED RUMBLE STRIPS EVENLY SPACED.
   A. SPACE AT 20 FT ON CENTER FOR SPEEDS OF 50 MPH OR GREATER.
   B. SPACE AT 10 FT ON CENTER FOR SPEEDS OF 45 MPH OR LESS.

6. PLACE WS28-1 RUMBLE STRIPS AHEAD SIGN PRIOR TO PLACING TEMPORARY PORTABLE RUMBLE STRIPS.

7. REMOVE TEMPORARY PORTABLE RUMBLE STRIPS PRIOR TO REMOVING WS28-1 RUMBLE STRIPS AHEAD SIGN.

8. RESET THE TEMPORARY PORTABLE RUMBLE STRIPS AS NECESSARY TO MAINTAIN PROPER ALIGNMENT, SPACING, AND LOCATION. REFER TO SPECIAL PROVISION 01554M FOR MAINTENANCE OF TEMPORARY PORTABLE RUMBLE STRIPS.

9. DO NOT USE TEMPORARY PORTABLE RUMBLE STRIPS ON HORIZONTAL CURVES UNLESS APPROVED BY THE ENGINEER.

10. DO NOT USE TEMPORARY PORTABLE RUMBLE STRIPS DURING SNOW EVENTS.

11. PLACE ONE TEMPORARY RUMBLE STRIP ARRAY IN EACH TRAVEL LANE.

12. PLACE ONE TEMPORARY RUMBLE STRIP ARRAY AT DISTANCE "A" (SEE TABLE 1) IN ADVANCE OF EACH LANE CLOSURE TAPER IN EACH LANE THAT IS BEING CLOSED.

13. RELOCATE THE TEMPORARY PORTABLE RUMBLE STRIP AND ASSOCIATED SIGNING WHEN VEHICLE QUEUES ARE EXPECTED OR OCCUR IN ADVANCE OF TEMPORARY PORTABLE RUMBLE STRIPS.

14. REDUCED SPEEDS WILL NOT BE ALLOWED WITHOUT THE APPROVAL OF THE ENGINEER. USE THE REDUCED SPEED LIMIT AHEAD SIGN, THE FINES DOUBLE SPEED LIMIT SIGN, AND THE SPEED LIMIT SIGN.

15. SEE PROJECT SPECIFIC REQUIREMENTS FOR USE OF OPTIONAL ZIPPER MERGE SIGNING.
   A. USE ALTERNATE "USE OPEN LANES TAKE TURNS AT MERGE" SIGN WHEN FACILITY HAS 3 OR MORE LANES IN THE SAME DIRECTION.
   B. USE ZIPPER MERGE SIGNING WITHIN FINAL LANE CLOSURE SIGNING IF MULTIPLE LANE CLOSURES ARE BEING IMPLEMENTED.
   C. ON FREEWAYS (65 MPH OR GREATER), USE CHANGEABLE MESSAGE SIGN (CMS) IN PLACE OF STATIC SIGN "USE BOTH LANES TAKE TURNS AT MERGE" OR "USE OPEN LANES TAKE TURNS AT MERGE" MESSAGES IN TWO PHASES.

Figure 2.3 TPRS at a passing lane closure.

2.4 Driver Behavior

Prior research generally shows that TPRS minimize lane departures (Brown et al., 2022; Sun et al., 2011; Wang et al., 2013), reduce traffic speed (Brown et al., 2022; Sun et al., 2011; Wang et al., 2013; Yang et al., 2015), increase compliance with posted speed limits (Brown et al., 2022; Yang et al., 2015), and increase driver attentiveness (Brown et al., 2022; Sun et al., 2011; Wang et al., 2013; Yang et al., 2015), all with sufficient effectiveness to justify their cost (Brown et al., 2022). The following subsections discuss the effectiveness of TPRS in influencing driving speeds, driver braking response, driver avoidance of TPRS, and crash frequency.

2.4.1 Speed Reduction

Research investigating systems with TPRS installations shows a decrease in average driving speed and an increase in compliance with posted speed limits. Studies with TPRS installed show speed reductions ranging from 3.5 to 13.8 mph and an approximate 20 percent increase in compliance with posted speed limits (Brown et al., 2022; Fontaine and Carlson, 2001; Sun et al., 2011; Wang et al., 2013; Yang et al., 2015). The impact of TPRS is highly localized (Shahin et al., 2023), with a more limited speed reduction upstream from the worksite (McAvoy et al., 2009). As soon as drivers pass the first set of TPRS or other traffic-calming devices, they have been observed to accelerate unless they can see an additional obstacle, such as a flagger or another set of TPRS (Wang et al., 2013). Cars moving faster than other traffic, such as speeding vehicles or those driving in the left lane, slow down more than slower-moving vehicles (Wang et al., 2013; Yang et al., 2015). These findings all come from real-world tests on two-way, two-lane roads, except for Shahin et al. (2023), which was based on a driving simulator of a divided highway.

Brown et al. (2022) studied roads in Missouri, testing both divided highways and two-way, two-lane roads with adhesive and non-adhesive TPRS. Their results suggest that adhesive strips are more effective than non-adhesive strips at slowing traffic, but that non-adhesive strips are more effective than adhesive strips at improving compliance with posted speed limits. Missouri DOT used adhesive TPRS more frequently than non-adhesive TPRS at the time of the study, and the comparison between adhesive and non-adhesive TPRS was not statistically conclusive, which may explain the seeming contradiction. The current literature agrees that non-adhesive TPRS does work to slow traffic, but how different layouts impact its effectiveness is only beginning to be investigated.

2.4.2 Driver Braking Response

TPRS has been shown to improve driver awareness, as observed by tracking the number of vehicles that activate their brake lights when approaching TPRS. Researchers agree that drivers brake more often and earlier when TPRS are present, but they disagree on the extent to which this affects drivers, with estimates ranging from 11 percent to 55 percent (Brown et al., 2022; Sun et al., 2011; Wang et al., 2013; Yang et al., 2015). By looking at each study's tested work site, a few factors may be inferred. First, the type of vehicle may correlate with the driver's level of attentiveness. Commercial trucks are generally more cautious and will brake sooner than most personal vehicles (Wang et al., 2013). Additionally, drivers also tend to slow down most at the first set of TPRS. Either the driver sees the TPRS coming and slows down in advance or is alerted to the altered traffic pattern as they travel over the first array of TPRS and slow down to the appropriate speed before traveling over subsequent arrays (Wang et al., 2013).

Where TPRS are placed relative to the work zone and how far ahead a driver can see both affect how much they slow down for TPRS. Strips placed too far from the work site have little to no lasting impact on driving speed (McAvoy et al., 2009), except on curved roads without line of sight to the work zone, where TPRS did slow drivers (Wang et al., 2013). It may be more accurate to claim that when drivers can clearly see that the work site is further away, they will not slow down for TPRS. That is, it is possible drivers are slowing for the work zone rather than for the TPRS.

Brown et al. (2022) attempted to compare non-adhesive TPRS to adhesive TPRS on both divided highways and two-way, two-lane roads. Non-adhesive TPRS were found to be far more effective at getting drivers' attention than adhesive strips; 52.4 percent of drivers trigger their brake lights around non-adhesive TPRS but only 0.7 to 6.1 percent of drivers triggered their brake lights around adhesive TPRS. But there are several confounding variables. The non-adhesive strips were observed at night in combination with a flagger while the adhesive strips were observed during the day, without a flagger, and on different roads. While the experiments from Brown et al. (2022) were not a fair comparison between adhesive and non-adhesive TPRS, their observations do show that both kinds of TPRS get a response from drivers.

2.4.3 TPRS Avoidance

Early research into the impacts of TPRS focused on the threat of motorists evading TPRS arrays, thereby creating dangerous traffic situations by departing from their designated lanes and entering those adjacent. Sun et al. (2011) and Wang et al. (2013) report minimal evasion, and recent work from Brown et al. (2022) suggests that this behavior has further decreased over time.

Sun et al. (2011) observed higher lane departures on two-way, two-lane roads with narrower lanes, on a bridge, and during flagging operations. Although drivers may be motivated to avoid TPRS and thereby make a complete lane departure, partial lane departures could be motivated by either the lane geometry or the presence of TPRS. To minimize lane departures, Sun et al. (2011) recommended placing TPRS across the full width of the road in situations where two-way traffic is funneled into a single lane. This eliminates the ability to avoid TPRS by swerving with minimal impacts for traffic in the opposite direction.

Wang et al. (2013) examined two-way, two-lane roads and observed fewer lane departures as oncoming traffic volume increased. This study shows that lane departures increase when TPRS appear on a downhill slope. Furthermore, nearly all lane departures occur at the final set of TPRS, after the drivers have already encountered one or two sets and were closer to the flagger at the start of the work zone. Wang et al. (2013) did not give additional context to their findings, so a specific cause for avoiding the final set of TPRS cannot be determined from the study.

Brown et al. (2022) observed one vehicle out of 8,000 – a motorcycle – evade TPRS. This low evasion rate implies that lane departures are rare but also suggests that motorcyclists may perceive greater risk when traversing TPRS. The authors did not specify whether the motorcycle was evading the 1/8 in. adhesive TPRS or the 3/4 in. non-adhesive TPRS, nor under what traffic conditions or time of day the evasion was observed. Although Heaslip et al. (2010) discuss the increased risk motorcyclists may encounter with TPRS, most studies either do not mention motorcycles or explicitly exclude them (Wang et al., 2013). For passenger vehicles and trucks, lane departures appear to be a minimal concern. Lane departures may be further mitigated by improved signage warning of TPRS and better layout designs, but further research may be necessary.

2.4.4 Crash Reduction

Given that vehicle crashes are infrequent events, most studies have not evaluated a crash reduction factor related to TPRS directly and have instead evaluated indirect safety measures such as speed reduction (e.g., Yang et al., 2015). An exception is Ullman et al. (2018), who used historical crash data and compared the expected number of crashes with the actual number of crashes. The authors focused specifically on the I-35 expansions in Texas from 2012 to 2016, when Texas DOT widened I-35 to 6 lanes. They found that TPRS alone, placed before a traffic queue, reduced the number of crashes by 60 percent and of those crashes, the chance of serious injury was reduced from 50 percent to 16 percent (Ullman et al., 2018). The presence of queued traffic is significant. In non-queued traffic, TPRS only reduced crashes by 11 percent and did not have a significant impact on the severity of the crashes that did occur (Ullman et al., 2018). The 11 percent crash reduction was not shown to be statistically significant. The analysis was 98 percent confident when traffic was queued and crashes were reduced by 60 percent, but only 23 percent confident with unqueued traffic where the crash-reducing effect of TPRS was minimal (Ullman et al., 2018). It is important to note that these results are from a divided, multi-lane freeway, and not a two-way, two-lane road. These crash reduction estimates may not apply to two-way, two-lane roads.

Brown et al. (2022) built on this work and calculated a high cost-benefit ratio related to the use of TPRS, with benefits on the order of 8.6 to 26.3 times the cost invested. Most of the benefits estimated by Brown et al. (2022) were associated with the 11 percent lowered risk of crashes calculated by Ullman (2018), a finding that was not statistically significant in the original research. Brown et al. considered the costs of purchasing and installing the strips but did not consider the sometimes-considerable labor costs to adjust the strips, nor did they consider the rare but potential costs to subsequent vehicles from dislodged strips. These factors could reduce the estimated cost-to-benefit ratio.

2.5 Strip Displacement

A factor limiting the effectiveness of TPRS, which has not been as thoroughly or frequently explored in prior research, is the tendency for individual strips to shift over time and become displaced from their original position (Heaslip et al., 2010; Schrock, 2016; Sun et al., 2011). There is a limited understanding of the extent to which this shifting and displacement impact the effectiveness of TPRS and offer no evaluation of the increased safety risk posed to workers who adjust the strips. Non-adhesive rumble strips, such as the PSS RoadQuake product, depend on their weight and friction with the road surface to stay in place, rather than adhesives or fasteners (PSS, 2018). Such a design should be expected to shift under traffic, but only a few studies attempt to quantify the slip of these products under a given traffic load. Further, the rate of displacement may be related to the condition of the strip, with worn and damaged strips displacing more than new strips. No known research to this point evaluates how quickly these products degrade under a given traffic load and at what point the strips cease to be effective at staying in place.

Heaslip et al. (2010) showed that the weight of the vehicle, the speed of travel, and the number of passes over the strip have a positive linear trend with how much a particular strip will slide over time. The authors do not specify which brand of non-adhesive TPRS they tested, nor do they provide specifications for the exact weight or dimensions of the product, so the magnitude of displacement they observed cannot be compared with that of other products. Their testing used a closed course with a commercial truck, a sedan, and a motorcycle at different speeds, with measurements taken after every pass for a total of 30 passes per vehicle per speed. Schrock et al. (2016) showed a similar positive relationship between weight, speed, and displacement, also on a closed course using the RoadQuake and TrafFix rumble strips. Sun et al. (2011) is the only study that observed real-world use of the RoadQuake and tracked its rate of displacement, on a site with a posted work zone speed limit of 40 mph and low traffic volumes. Over the nearly 12-hour observation period across 2 days, only 850 cars passed through the work zone. This study does not provide insights into how well RoadQuake works at higher speeds and higher volumes, and the authors did not collect enough data to correlate vehicle weight to rate of displacement but did show that the strips slide less when they stay perpendicular to the direction of travel. This aligns with reports from UDOT engineers indicating that once strips rotate away from the perpendicular position, they will rotate and slide more with each impact (D. Monroe, personal communication, November 26, 2024).

Schrock et al. (2016) is the only study found that investigated how identified products (i.e., RoadQuake and TrafFix) move when hit at higher traffic speeds. The authors concluded that the RoadQuake stayed in place long enough to be used on roads with speeds up to 67.5 mph and an Annual Average Daily Traffic (AADT) of 3,000 vehicles/day, where the TrafFix product was only suitable for the lowest speeds and volumes on their scale. This study used a closed course and attempted to extrapolate 40 passes with a dump truck and sedan to a target AADT. This extrapolation asserted a linear relationship between vehicle impacts and rate of movement in TPRS, which might not be the cause as Sun et al. (2011) observed that TPRS placed at an angle to the traffic flow moved more per vehicle impact than TPRS placed perpendicular to the direction of travel. This suggests a non-linear relationship between vehicle impacts and TPRS movement and could compromise the Schrock et al. (2016) conclusion that the RoadQuake is adequate for freeway use. Schrock et al. (2016) also assumed that the strips could be adjusted every 4 hours over the workday. This places workers at a higher risk; changing that assumption to 9 hours would lead to a different conclusion that RoadQuake may not be suitable for higher speeds and volumes.

The research team did not identify any studies that considered the age or condition of the TPRS before and after use, which could be a possible factor in their rate of displacement. The manufacturer of these non-adhesive strips says the product has a shelf-life of 3-5 years and offers a 3-year limited warranty (PSS, 2024). A study of effectiveness as a function of wear would be useful but would require tracking where and when individual strips have been installed and how many vehicles passed over them and at what speeds.

2.6 Summary

State DOTs increasingly use TPRS to alert drivers to upcoming work zones. Specifications for installing and deploying TPRS vary widely between states. Existing research overwhelmingly suggests that TPRS effectively gain drivers attention, improving speed limit compliance and reducing crash rates. The magnitude of these effects, however, vary widely among the studies considered in this review. This variance in effect may be a result of the variance in deployment practice, particularly in the spacing of strips in a TPRS array. The spacing of TPRS may also affect the rate of strip displacement, and the associated need for workers to enter the roadway.

More research is needed to observe the actual rate of displacement of TPRS under high-volume, high-speed traffic in a real-world setting. No research identified in this review has addressed the spacing between strips within an array and how such spacing affects driver behavior in terms of speed reduction, braking behavior, or driver avoidance. Additionally, the research considered in this review did not generally observe driver behavior on mountainous, rural roads with high traffic speeds of the kind prevalent in Utah. These observations shaped the design of an experiment that will be the focus of the remainder of this report.

3.0 RESEARCH METHODS

3.1 Overview

This chapter describes a methodology to evaluate the effectiveness of PSS' TPRS product, called the RoadQuake, on rural highways in Utah. The research team identified research sites at four different work zones in the Summer 2025 construction season and observed each site with four different TPRS spacing designs, including one with no TPRS installed. The research team also developed an instrumentation plan to observe TPRS using video cameras and trailer-mounted portable radar detectors. This instrumentation plan facilitated observations of driver reactions to TPRS in the context of vehicle speed and speed reduction, braking behavior, and TPRS avoidance. The plan also facilitated measurements of TPRS displacement and related worker correction activities.

3.2 Site Selection and Strip Spacing

The research team identified four UDOT work zones in the Summer 2025 construction season compatible with the goals of this research. The work zones – with locations shown in Figure 3.1 and described in Table 3.1 – were chosen based on proximity to the research team in Provo, planned construction schedules, and expected traffic volume. All four work zones were available for observation in July or August 2025. Nearby traffic counting stations allowed the research team to confirm that the roads had a high enough AADT to statistically measure the potential effects of rumble strips on vehicle speed. Table 3.1 provides the location of the four work zones used for this project, the range of dates during which the research team observed the site, the posted speed limit, the work zone speed limit, and the closure type.

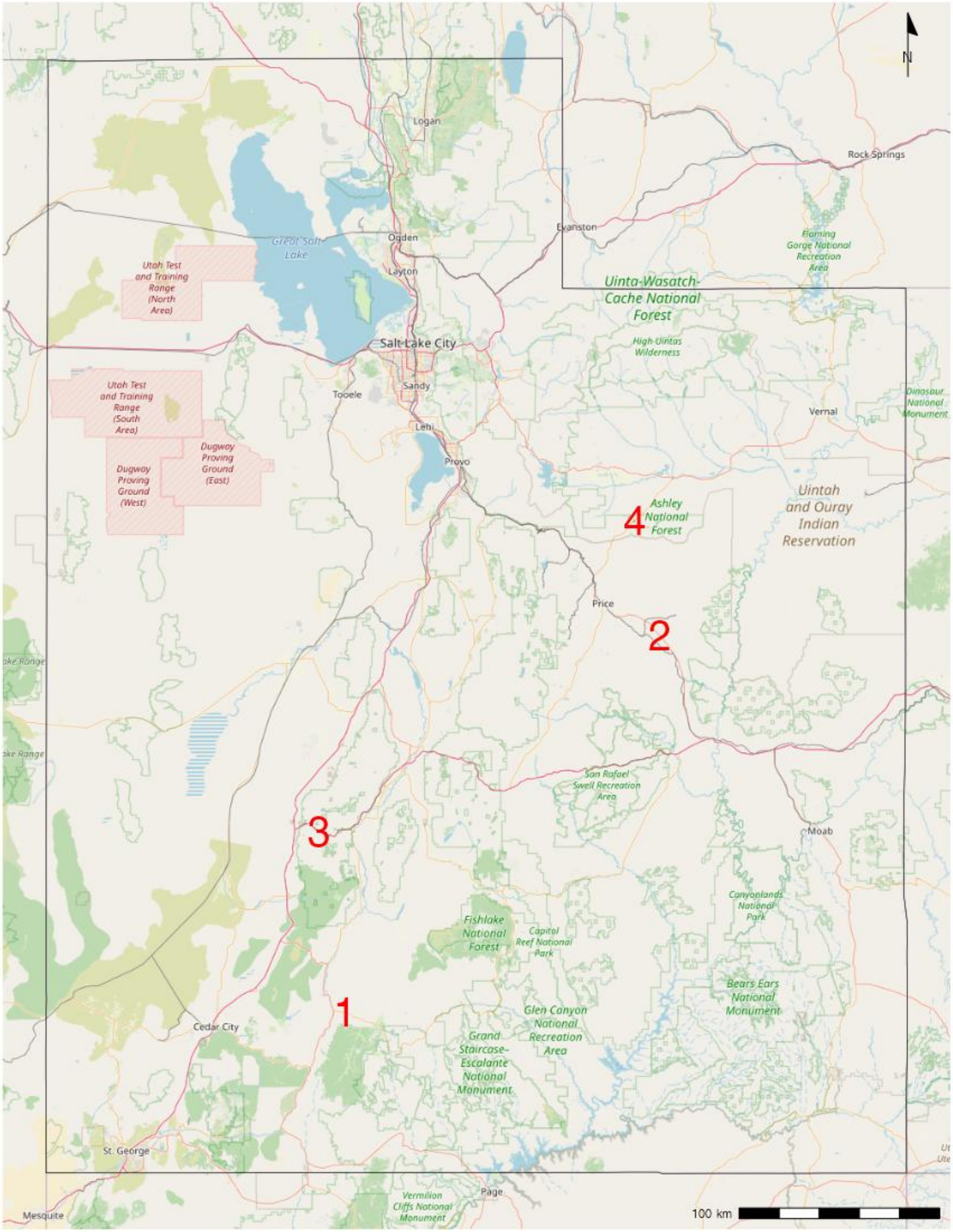


Figure 3.1 Map of Utah with study locations.

Table 3.1 Data Collection Sites

Site	Location	Data Collection		Posted Speed Limit	Work Zone Speed Limit	Closure Type
		Start	End			
SR-12 (1)	Mile marker 6.5	7/7/25	7/11/25	55	35	Full Lane
US-6 (2)	20 miles east of Wellington	7/15/25	7/18/25	65	Not Recorded	Full Lane
I-70 (3)	Clear Creek Summit	7/29/25	8/1/25	80	60	Passing Lane
US-191 (4)	North of summit	8/5/25	8/8/25	60	40	Full Lane

A key consideration in site selection was the need to obtain sufficient vehicle speed observations to measure any changes in speed with sufficient statistical power. The research team estimated the number of required speed observations N using a formula derived from the confidence interval of the mean of a normal distribution, outlined in Equation 1

$$N = \sigma^2 * z^2 * \frac{(2 + \mu)^2}{2 * E^2} \tag{1}$$

Where:

σ is the standard deviation of speeds, assumed to be 3 mph,
z is a parameter associated with the desired confidence in the estimate, with 1.96 implying a 95% confidence level,
μ adjusts for the non-centrality of an 85th percentile speed measurement, and
E is the desired confidence interval, set to ±1 mph.

With these parameters, a precise measure of the potential effects of TPRS requires a minimum of 54 observations. Reducing the margin of error to ±0.5 mph and the standard deviation in speeds to be 5 mph requires almost 600 observations.

Traffic count data near each potential work zone was analyzed to confirm traffic volumes during the work shift would exceed the number of minimum observations. Data from May 2023 to August 2023 was the most recent and complete data set corresponding with the road construction season. Figure 3.2 shows examples of several counting stations near candidate work sites and their respective average hourly volumes throughout the day. The minimum

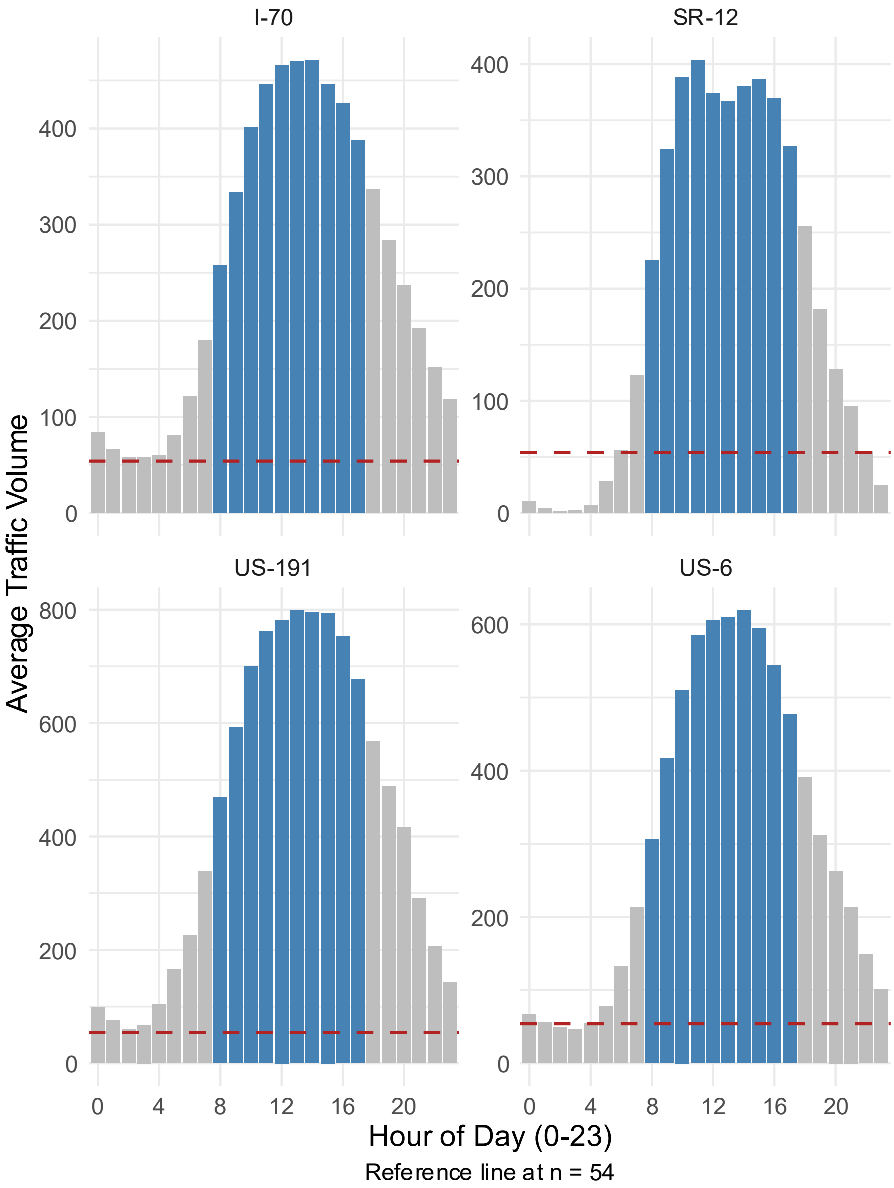


Figure 3.2 Average hourly volume from various counting stations near project sites.

required number of observations previously calculated is marked with a horizontal red line for each station. These plots showed that less than 1 hour of observation time would provide sufficient observations at each of the sites, alleviating the concern that too few speed measurements would be available.

The research team decided on four layouts for the arrays of TPRS to observe the impact of TPRS on driver behavior and strip displacement. The layouts are as follows:

- **No TPRS** – TPRS are not installed.

- **UDOT –** The current recommended specifications in Region 4, which are 10 ft. for roads with a posted speed limit up to 45 mph, and 20 ft. for roads with a posted speed limit of 50 mph or higher.
- **1:2** – TPRS spaced in feet at half the value of the posted speed limit in miles per hour (e.g., a 60-mph road will have spacing of 30 ft.).
- **Long –** TPRS spaced between five to twenty feet longer than the 1:2 spacing specification

Figure 3.3 illustrates the specifications for each layout based on the posted speed limit for the road where the TPRS were used. These specifications were developed through conversations with PSS, who shared that excessive TPRS displacement is generally solved by increasing TPRS spacing, but excessive spacing may reduce the effectiveness of TPRS (S. Tachovsky, personal communication, March 26, 2025). UDOT's specification is already shorter than the manufacturer's recommendations but was included for comparison. The 1:2 spacing specification is not the official standard from PSS, but a guidance that resembles the manufacturer's recommendations and accommodates speeds over 80 mph. Long spacing was determined by adding the difference between UDOT's spacing and 1:2 spacing to the 1:2 spacing specification. Testing the effect of all three specifications and the absence of TPRS creates variance in TPRS applications to aid in future analysis.

Each site was observed for 4 days in the same week, in the hours generally between 9:00 AM and 3:00 PM. Because local traffic and safety standards did not allow the research team to leave observation equipment up overnight, the research team set up and removed equipment each day. On each site, the contractors deployed TPRS according to the same series of spacing types, as follows:

- Tuesday – Region 4 current specifications for the roadway.
- Wednesday – no TPRS.
- Thursday – 1:2 spacing.
- Friday – "Long" specification.

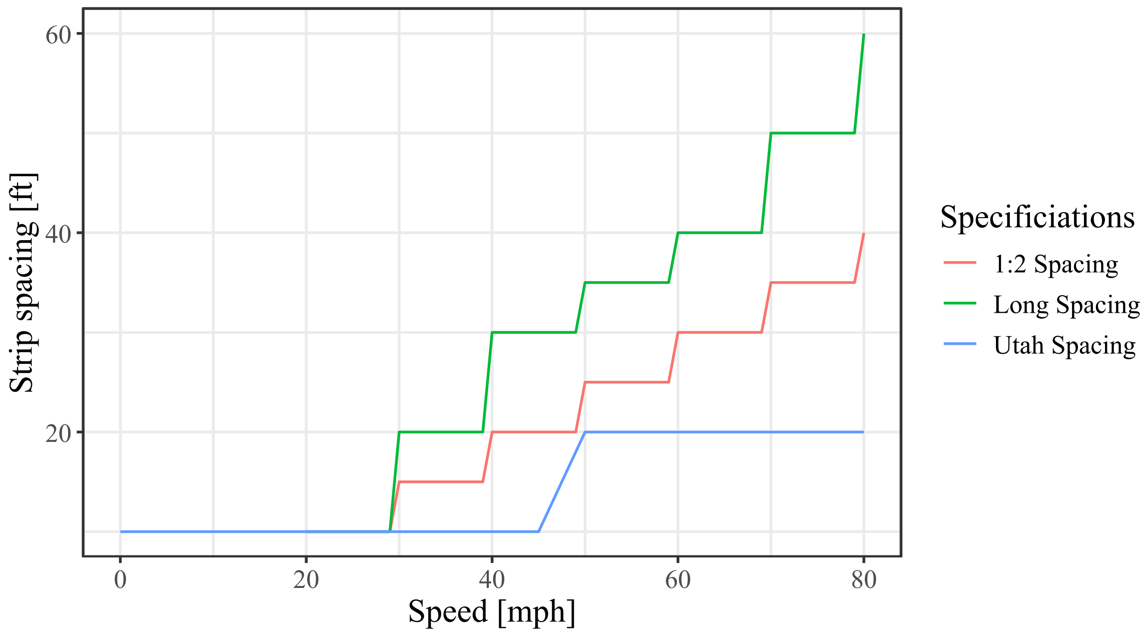


Figure 3.3 Spacing specifications for TPRS based on posted speed limit.

SR-12 was an exception to this basic plan, as travel to the work site necessitated a Monday to Thursday plan. Although a consistent daily assignment potentially conflates day-of-week effects with spacing types, a consistent plan facilitated discussions with contractors at each site.

3.3 Instrumentation Plan

Figure 3.4 illustrates the overall instrumentation plan applied at each site. The instrumentation plan consists of two video cameras, Camera 1 and Camera 2, located upstream of the first TPRS array and at the TPRS array, respectively. There are also two trailer-mounted radar speed detection devices manufactured by Wavetronix. These are called Wavetronix 1 and Wavetronix 2 and are located at the first TPRS array and downstream of the first TPRS array, respectively. Camera 1 and Wavetronix 2 were both installed where space on the shoulder of the roadway was available. Table 3.2 provides the actual distance separating Wavetronix 1 and Wavetronix 2 at each site on each day. Observations at SR-12 were divided into two days, resulting in two different measures.

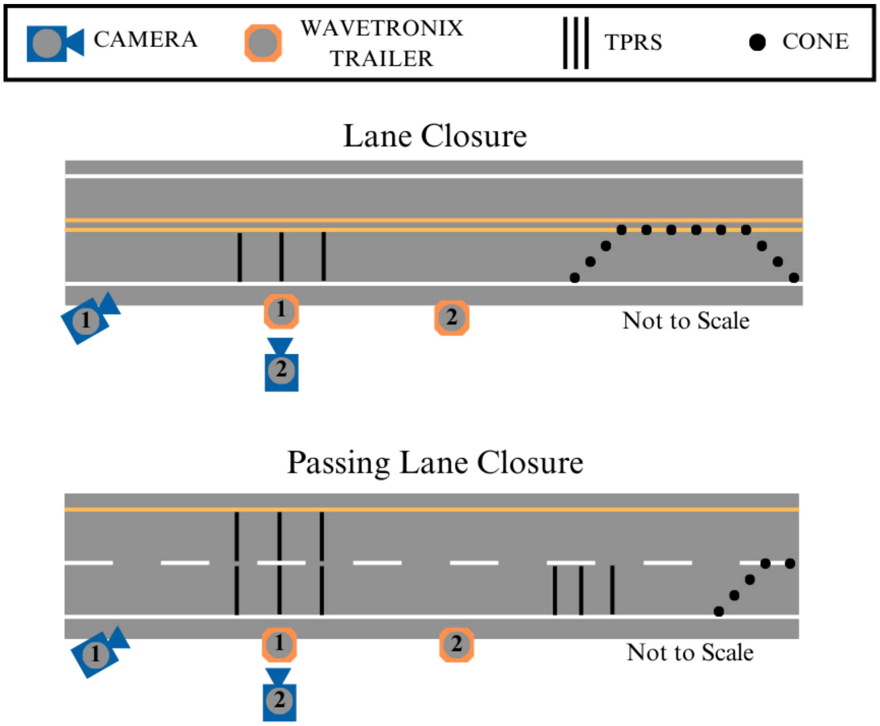


Figure 3.4 Instrumentation plan at a lane closure and at a passing lane closure.

Table 3.2 Separation [ft] Between Wavetronix Units

SITE	UDOT	NO TPRS	PSS	LONG
SR-12	762/875	851	878	898
US-6	516	516	516	516
I-70	800	804	782	765
US-191	782	748	781	759

The research team placed the quantifiable metrics of this study into two basic categories. The first is driver behavior as observed through change in speed, braking response, and avoidance behavior. The second consists of measured quantities related to TPRS movement, including individual strip displacement and worker exposure during adjustment. The subsections below describe the setup used in this observational study to measure these variables.

3.3.1 Driver Behavior – Change in Speed, Braking, and TPRS Avoidance

TPRS are designed principally to gain and increase driver attentiveness and not primarily to measure speeds (S. Tachovsky, personal communication, March 17, 2025); however, measuring driver awareness in the general population at an active worksite presents technical and safety challenges. Change in speed, braking response, and TPRS avoidance have been used in previous studies as appropriate proxy measures (Brown et al., 2022; Fontaine and Carlson, 2001; Sun et al., 2011; Wang et al., 2013; Yang et al., 2015).

Wavetronix units use radar to measure the speed of vehicles within their area of effect based on programmed lane location information adjusted for each site on each day. Accompanying software provides vehicle counts, average speeds, and 85th percentile speed measurements for the vehicles passing the units in bins specified by the user; this study used 15-minute bins. By taking the difference in the 85th percentile speed captured in the same 15-minute bin between Wavetronix 1 and Wavetronix 2, it is possible to measure the change in 85th percentile speed.

Camera 1 was placed roughly 100 ft. upstream from the first TPRS array and provided a view of the rear of vehicles as they encountered the strips. The research team watched the Camera 1 video and marked vehicle classification and relevant behavior using software developed by the research team for this purpose. The researchers recorded when each vehicle crossed the TPRS; classified each vehicle as either a motorcycle, passenger vehicle, or truck; identified whether a vehicle illuminated its brake lights before or after encountering TPRS; and identified whether the vehicle avoided the strips.

The researchers classified each vehicle traversing TPRS. Vehicles with fewer than four wheels were classified as motorcycles. Vehicles with two axles and four wheels were classified as passenger vehicles. Vehicles with more than four wheels or more than two axles (exclusive of trailers) were classified as trucks. This aligns with the FHWA’s 13-vehicle category classification with Class 1 as motorcycles, Classes 2 and 3 as passenger vehicles, and Classes 4 through 13 as trucks (FHWA, 2014). It is also consistent with the definition of truck used in calculating annual average daily truck traffic (FHWA, 2018).

The research team classified vehicles as braking before or after TPRS or not braking at all. Those driving on the shoulder or crossing the center dividing line – either partially or completely – were all counted as avoiding the TPRS. Vehicles engaged in passing the vehicle in front of them were not considered to be avoiding the strips.

3.3.2 TPRS Displacement and Worker Exposure

Camera 2 was mounted to the same mast as Wavetronix 1 and had a top-down view of the TPRS array, centered on the middle strip of the array. This perspective allowed the team to see how much the center strip of the TPRS array was displaced over time and how much time workers spent adjusting the TPRS.

The research team used a transparent overlay to track TPRS displacement over time. The overlay was based on PSS standards as outlined in their product guide, namely that the strips can move up to 5 ft. forward or back, 2 ft. to either side, and can rotate up to a 3 ft. differential between ends or roughly 15° (PSS, 2018). To provide more nuanced description of displacement, the researchers developed five categories of displacement based on these overall specifications: reset (no movement), some, moderate, significant, and out of specification. Figure 3.5 shows the overlay with dimensions for each area marked. The overlay was warped to approximate the perspective of the camera, allowing for errors derived from lens distortion. While errors from lens distortions were minimized, they could not be fully accounted for, making the five displacement categories subjective. The research team did not observe workers measuring the displacement or readjustment of the TPRS with notable precision, so a more precise scale was unnecessary. The innermost section and outer border of the image were scaled in size to match the dimensions of the strips and the allowed movement specified by PSS. The borders between the green and orange zones, and between the orange and red zones are approximations.

Camera 2 footage allowed researchers to evaluate worker exposure to traffic when correcting the strip alignment. The research team recorded when workers arrived on site to move TPRS, when vehicles passed while workers were on site, when workers started looking for a gap in traffic, when workers entered and exited the road, and when the workers left the site.

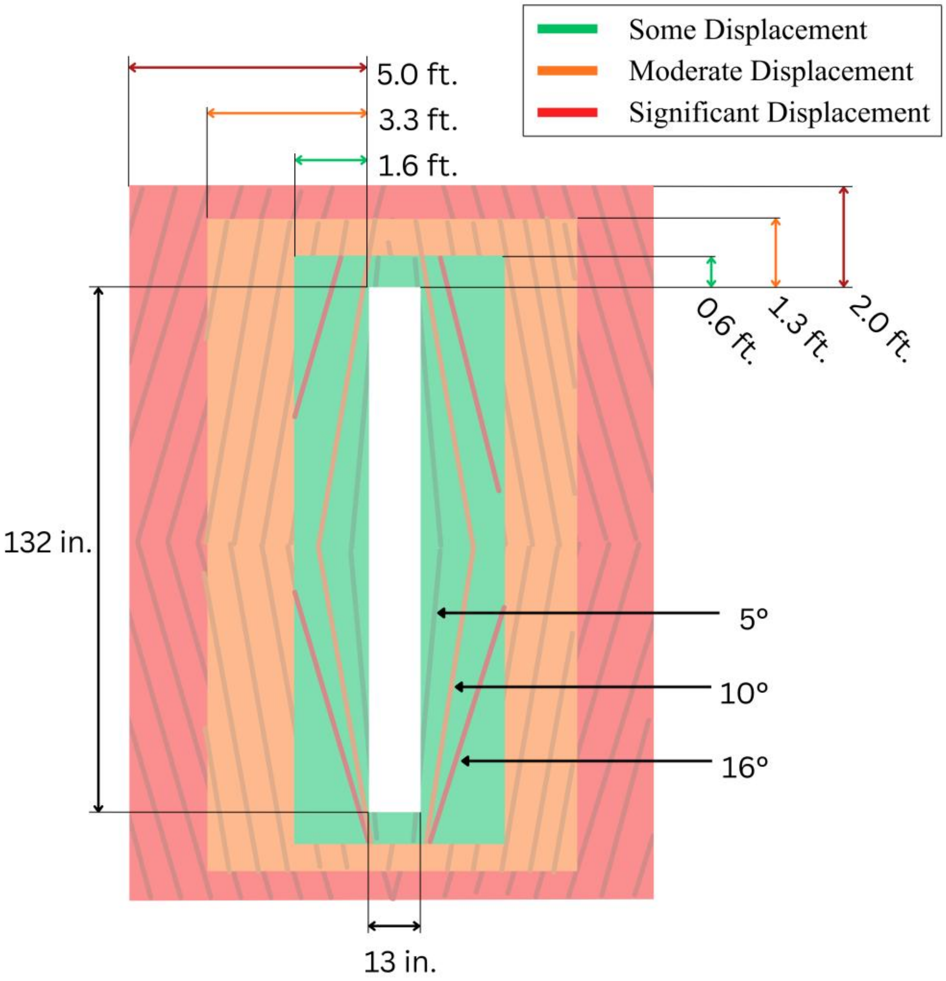


Figure 3.5 Strip displacement overlay.

3.4 Summary

In this observational study, two trailer-mounted radar units and two video cameras recorded vehicles and their drivers as they encountered the TPRS installed at the chosen work zones for this study. Some observed variables mirrored those utilized in previous studies such as vehicle classification, initial and final vehicle speeds, and driver behavior around TPRS arrays such as braking and avoidance of the TPRS. The study also collected data not previously considered, including the rate at which strips were displaced in real-world high-traffic conditions. This data will provide input to UDOT's questions concerning the effectiveness of TPRS on rural Utah highways.

4.0 DATA PROCESSING AND ANALYSIS

4.1 Overview

This chapter describes the results of the experiment method outlined in Chapter 3.0 . The analysis of the collected data considers first the impact of TPRS on driver behavior including changes in speed, braking response, and TPRS avoidance. This is followed by an analysis of TPRS displacement and related worker exposure to live traffic.

4.2 Driver Behavior

Driving behavior was quantified in this study by three major variables: change in speed, braking behavior, and avoidance of the TPRS. These variables were observed with the radar-based Wavetronix units and Camera 1 as shown in Figure 3.4. Wavetronix units provided vehicle mean speeds and 85th percentile speeds in 15-minute intervals at the TPRS array and again several hundred feet downstream. The footage from Camera 1 allowed researchers to categorize the braking response of each driver and provide a count of how many drivers avoided the TPRS. Observed vehicles also received the classification of motorcycle, passenger vehicle, or truck to compare behavior across vehicle types.

4.2.1 Change in Speed

The research team used change in speed as a proxy measure of TPRS effectiveness. The 85th percentile speed provided by the Wavetronix 2 was subtracted from the 85th percentile speed provided by the Wavetronix 1 for each 15-minute bin. The researchers calculated the 95 percent confidence interval for the difference in speed associated with each site and layout combination. Figure 4.1 illustrates these 95 percent confidence intervals, grouping the data by site and coloring by the TPRS layout. The red dashed line in the middle marks the point at which no change in speed occurs. Confidence intervals to the left of the red line show a decrease in speed after the TPRS, and confidence intervals to the right of the red line show an increase in speed after the TPRS. Any confidence intervals overlapping the red line show no statistically significant change in speed. Any confidence bounds that overlap each other are not statistically distinct and cannot be said to have different impacts.

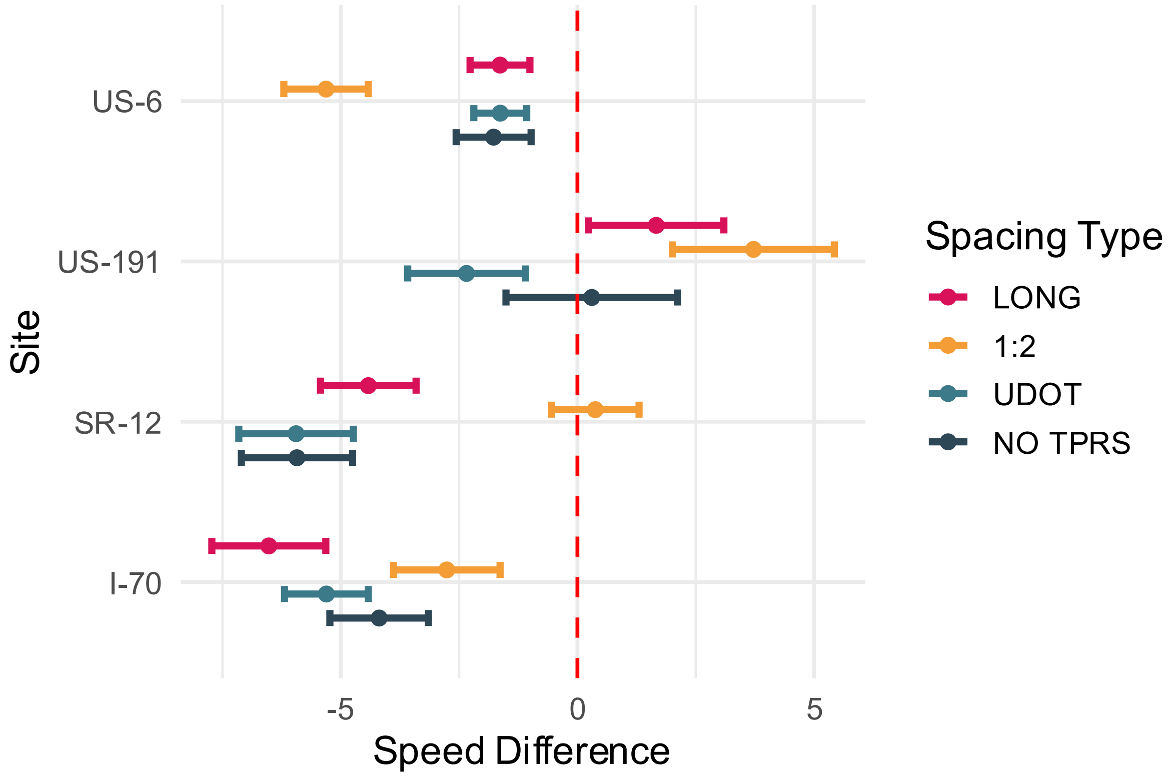


Figure 4.1 Change in speed by site and spacing.

The results of this analysis do not show any clear correlation between change in speed and TPRS spacing. If the TPRS spacing had a consistent impact on speed, the relative position between the spacing types would be consistent between sites. The data do not show this pattern; rather, the impact of TPRS presence or spacing varies inconsistently between sites. Notably, there are cases on US-191 where vehicle speeds increased after drivers traversed the array of TPRS. While this might seem to contradict the current consensus found in the literature, three studies did acknowledge that TPRS influence on speed is highly localized (Shahin et al., 2023; McAvoy et al., 2009; Wang et al., 2013). There are likely other factors that influence drivers' speed changes more than TPRS treatment at these sites. There are limitations to this analysis. First, the distance between the Wavetronix trailers varied to accommodate onsite limitations. Removing observations associated with some stormy hours during the US-6 data collection did not notably change the findings.

4.2.2 Driver Awareness and Braking Response

Using Camera 1, the research team tracked drivers' braking response to TPRS as another proxy measure of driver awareness. Vehicles were categorized as either a motorcycle, passenger vehicle, or truck. Each vehicle was marked as braking after the TPRS, before the TPRS, or not braking at all. Figure 4.2 shows the count of each driver's braking response across each TPRS spacing and vehicle type. Table 4.1 shows a multinomial logit model of braking behavior independently estimated for each site. In this model, significant positive numbers are correlated with an *increase* in the associated behavior relative to the not-braking reference. Vehicle type is not consistently and significantly correlated with braking behavior. Motorcycles and trucks are both more likely than passenger cars to brake before the strips at I-70, trucks more likely at US-191, and motorcycles at US-6. There is no correlation between vehicle type and after-strip braking at any site.

TPRS spacing is also not consistently and significantly correlated with braking behavior. Relative to the no-TPRS condition, before-strip braking is more likely at SR-12, US-6, and I-70 at all spacing types. Before-strip braking at US-191 is oddly somewhat less likely with strips installed than without strips in place. After-strip braking is more likely with strips installed on I-70, and with UDOT spacing on US-6. But after-strip braking is *less* common with strips installed on SR-12 than without strips installed.

The fact that many vehicles brake before TPRS may suggest that the influence of TPRS is primarily visual rather than tactile for most road users. If drivers are reacting to TPRS on sight rather than striking the strips, this could explain why motorcycle drivers seemed to brake more when TPRS are not present. Motorcycle drivers may be braking before they enter the camera's field of view when they see the TPRS installed, and are thus not being counted. But when TPRS are not installed, motorcycle drivers may be braking later in response to seeing the lane closure rather than the TPRS. This interpretation is speculative and more research is needed.

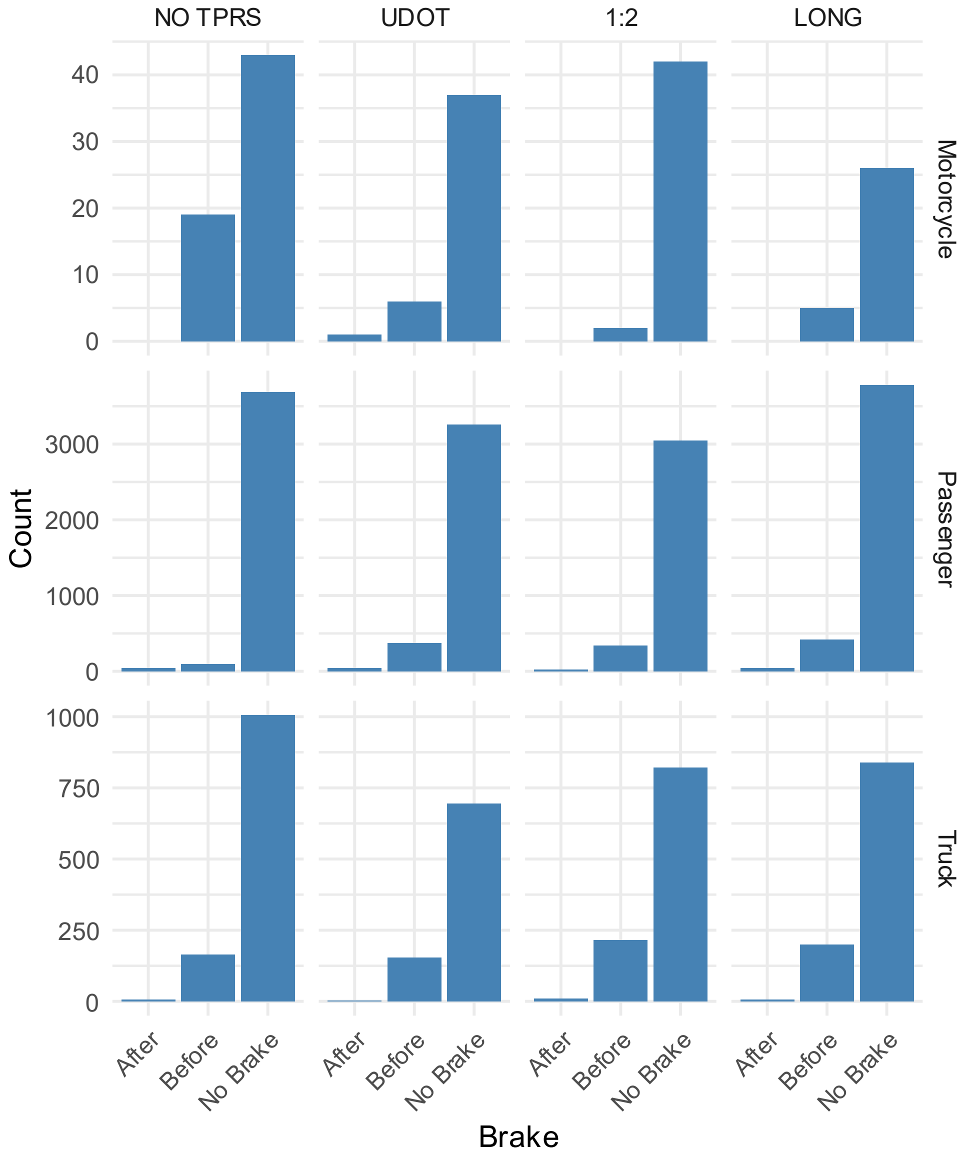


Figure 4.2 Braking behavior by spacing of TPRS layout and vehicle type.

Table 4.1 Multinomial Logit Model of Braking Behavior

	SR-12		US-6		I-70		US-191	
	Before	After	Before	After	Before	After	Before	After
(Intercept)	-2.929**	-3.378**	-4.064**	-5.292**	-3.730**	-7.336**	-2.019**	-5.367**
	(0.125)	(0.161)	(0.201)	(0.387)	(0.142)	(1.008)	(0.152)	(1.026)
Vehicle Classification (ref. Passenger cars)								
Truck	0.033	-0.580	0.021	-0.350	1.490**	0.333	1.631**	-1.088
	(0.157)	(0.597)	(0.139)	(0.384)	(0.094)	(0.367)	(0.136)	(1.114)
Motorcycle	0.435	-7.051	1.338**	1.322	1.860**	-7.554	0.669+	-6.144
	(0.302)	(28.714)	(0.473)	(1.034)	(0.699)	(179.37)	(0.387)	(45.540)
Spacing type (ref. no TPRS)								
UDOT	1.403**	-0.771*	1.830**	1.164**	0.554**	2.296*	-0.339*	-4.771
	(0.151)	(0.343)	(0.213)	(0.426)	(0.174)	(1.062)	(0.167)	(10.387)
1 × 2	1.155**	-1.683**	1.106**	1.066*	1.290**	2.321*	-0.517**	0.443
	(0.145)	(0.410)	(0.254)	(0.486)	(0.151)	(1.050)	(0.166)	(1.225)
LONG	1.161**	-1.495**	1.408**	0.485	1.315**	3.157**	0.054	0.680
	(0.147)	(0.389)	(0.218)	(0.465)	(0.154)	(1.024)	(0.164)	(1.225)
Num.Obs.	4963		6324		5933		1796	
R2	0.036		0.036		0.089		0.096	
R2 Adj.	0.035		0.036		0.089		0.095	
AIC	4296.1		3497.3		3827.9		1837.1	
RMSE	0.28		0.21		0.24		0.33	

$p < 0.1$, * $p < 0.05$, ** $p < 0.01$. Standard errors in parentheses.

4.2.3 TPRS Avoidance and Lane Departure

The research team observed lane departures where vehicles appeared to avoid TPRS. It is the opinion of the researchers who watched the camera footage that most vehicles that departed their lane to avoid TPRS did so in an orderly manner similar to passing another vehicle, as opposed to a chaotic adjustment. There was no differentiation in the observations between partial lane departures, where only one side of tires crossed the center line or right-side line, and full lane departures, where all tires crossed either edge of the lane. On I-70, where TPRS were laid across both lanes, there were approximately 10 vehicles that drove fully in the shoulder to avoid the TPRS, but these were not classified separately.

Figure 4.3 shows the counts of lane departure by vehicle class and spacing type and Table 4.2 presents a series of binomial logit models estimating the probability of lane departure at each site. In this model, significant positive coefficients indicate that vehicles are more likely to avoid TPRS. Motorcycles have a consistent and dramatically higher rate of lane departure than either passenger vehicles or trucks, but trucks and passenger vehicles avoid at the same rate. This finding confirms prior literature that motorcycles, as vulnerable road users and more agile vehicles, are both motivated and capable of avoiding the TPRS. While some passenger vehicles and trucks do leave their lane to avoid the TPRS, the vast majority do not.

The significance of the model coefficients showing TPRS avoidance at most TPRS layouts is a feature of TPRS avoidance being impossible when they are not deployed, which is the reference alternative in the model, and not a finding of importance. What is more important is that the estimated coefficients associated with TPRS spacing are not significantly different from each other at each site, indicating that the spacing does not incite or discourage TPRS avoidance more than any other.

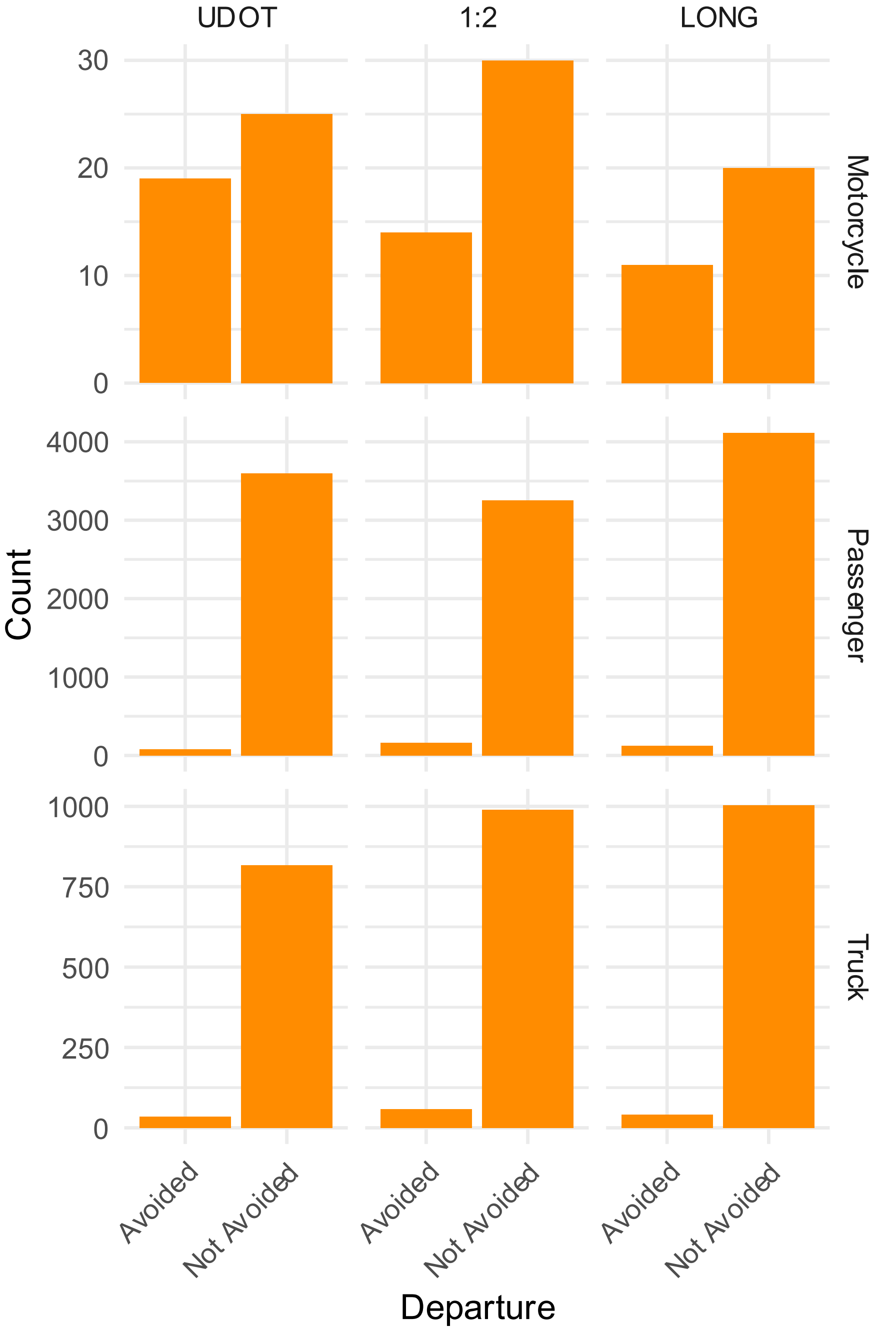


Figure 4.3 Counts of avoidance behavior by vehicle type and TPRS spacing.

Table 4.2 Binomial Model of TPRS Avoidance

	SR-12	US-6	I-70	US-191
(Intercept)	-5.622***	-7.577***	-21.499	-6.343***
	(0.413)	(1.012)	(754.412)	(1.009)
Vehicle Classification (ref. Passenger cars)				
Truck	0.306	0.536	-0.669+	0.121
	(0.204)	(0.364)	(0.388)	(0.172)
Motorcycle	2.192***	2.874***	3.836***	2.060***
	(0.282)	(0.777)	(0.948)	(0.354)
Spacing type (ref. Passenger cars)				
UDOT	2.868***	1.875+	16.662	4.313***
	(0.433)	(1.063)	(754.413)	(1.013)
1 × 2	3.092***	3.145**	17.971	4.312***
	(0.423)	(1.043)	(754.412)	(1.012)
LONG	3.165***	2.723**	15.184	4.071***
	(0.424)	(1.030)	(754.413)	(1.016)
Num.Obs.	4963	6324	5933	1796
AIC	2018.0	454.8	530.1	1022.9
BIC	2057.1	495.3	570.2	1055.9
Log.Lik.	-1003.004	-221.398	-259.041	-505.462
RMSE	0.23	0.08	0.09	0.28

$p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors in parentheses.

4.3 Strip Displacement

To analyze TPRS displacement, the research team used the displacement overlay template described previously in Section 3.3.2 . Figure 4.5 shows examples of the displacement overlay in

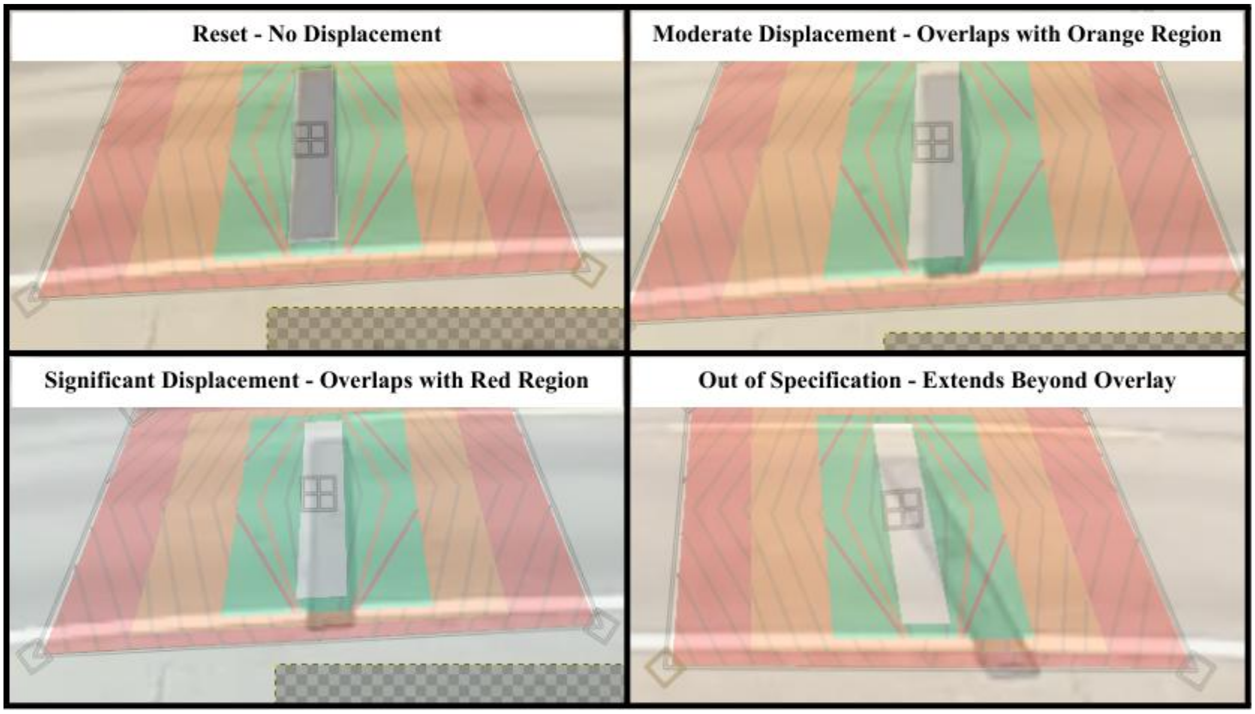


Figure 4.4 Examples of TPRS Displacement

use with an increasingly displaced TPRS device. The overlay defines five levels of displacement derived from the PSS user specifications:

1. Reset, or no displacement
2. Some displacement – overlaps with green region
3. Moderate displacement – overlaps with orange region
4. Significant displacement – overlaps with red region
5. Out of specification – extends beyond overlay

To normalize and visualize how many vehicle impacts it takes to displace a strip, the research team estimated the cumulative momentum applied to a strip. Momentum, classically defined as the product of mass and speed, serves as a proxy for how much force each strip received when struck by a vehicle. To calculate the momentum of each vehicle, the research team had to estimate the mass and speed of each vehicle.

As previously shown in Figure 3.4, Camera 1 provided a perspective allowing the researchers to classify each vehicle. According to data from the Environmental Protection Agency (EPA), the average 2024 model year vehicle weighs 4,419 lbs.; this includes sedans, SUVs, and pick-up trucks (US EPA, 2024). While most vehicles the research team observed were not from the model year 2024, it was the most conservative weight estimate, as the EPA data shows that model year 2024 had the heaviest average passenger vehicles. Truck weight was estimated by taking a weighted average of 2021 national truck registration counts by weight class, and was found to be 27,256 lbs. (Volpe Center, 2021, Table 1-22a). Only trucks in weight Class 3 through Class 8 were used in the weighted average, as these vehicle classifications most accurately reflect vehicle Classes 4 through 13 of the FHWA's 13-vehicle category classification system (FHWA, 2014). Each weight class was a range, so the middle value was used to calculate the average. Trucks in classes over 33,000 lbs. were assigned as 50,000 lbs. as the maximum weight for road trucks is 80,000 lbs. (Utah Office of Administrative Rules, 2025).

Motorcycles were assigned 800 lbs. While the Insurance Institute of Highway Safety (IIHS) provided a classification system for motorcycles and roughly how many of each type were registered in 2023 (Teoh, 2023), these figures did not provide an average weight associated with their classification system. One commercial site suggested that motorcycles can range between 200 and 1,000 lbs., depending on the manufacturer and style, with cruiser and touring motorcycles in the upper end of that range (Steyn, 2022). Since the IIHS data claimed that cruiser and touring motorcycles were the most registered (Teoh, 2023) – and the observations of the research team confirmed that such motorcycles were the most common types at these sites – 800 lbs. was used as the average motorcycle weight. Since there were so few motorcycles compared to passenger vehicles and trucks, a more precise estimate of motorcycle weight was unnecessary.

Wavetronix 1 supplied mean and 85th percentile speeds of vehicles in 15-minute periods. Each vehicle was therefore assigned to its associated mean 15-minute bin speed. Unfortunately, it is not possible with the data collected from this study to estimate individual speeds for each vehicle. Due to the limited accuracy of both the vehicle weights and vehicle speeds, this study cannot account for the effects of particularly heavy or fast-moving vehicles which may have an outlying impact on TPRS displacement. This study also cannot evaluate the rate of TPRS displacement in terms of number of axle or wheel impacts.

With each vehicle’s momentum estimated, the research team plotted the value of cumulative momentum which displaced the TPRS from one level of displacement to the next. A deeper explanation of these displacement states is found in Section 3.3.2 . Not all the transitions from one state to another could be used. On some observation days, the strips had already shifted significantly under traffic by the time the research team had arrived; these days were excluded. Only chains of transitions that started from the initial baseline condition, labeled “reset,” were considered to avoid any confounding variables related to the acceleration of displacement over time (Sun et al., 2011). The baseline condition is defined as whenever the strips were recently adjusted by workers or appeared unmoved and near perpendicular to the direction of travel. Figure 4.5 and Figure 4.6 show these chains of transitions as a continuous line. Each line represents a period of observation lasting until the strip is reset to the baseline condition when the observations began or after correction. Each line ends at the end of that day’s observation window, at the point when workers arrived to adjust the strips, or once the strips exceeded the manufacturer’s placement specifications. Lines with higher cumulative momentum represent TPRS that stayed in place longer than lines with lower cumulative momentum.

Based on this analysis, TPRS displacement correlates more with the site than with how far apart the TPRS were spaced or with speed and quantity of vehicles. If speed and traffic volume were the primary variables determining how quickly TPRS were displaced, the lines in Figure 4.5 and Figure 4.6 would be more closely grouped. If TPRS spacing was the primary factor, Figure 4.6 would show a clearer pattern. Neither is the case, which suggests there is an unknown variable tied to the work zones which exercises greater influence over how quickly the TPRS are displaced. One hypothesis is that older or more worn strips will displace more quickly,

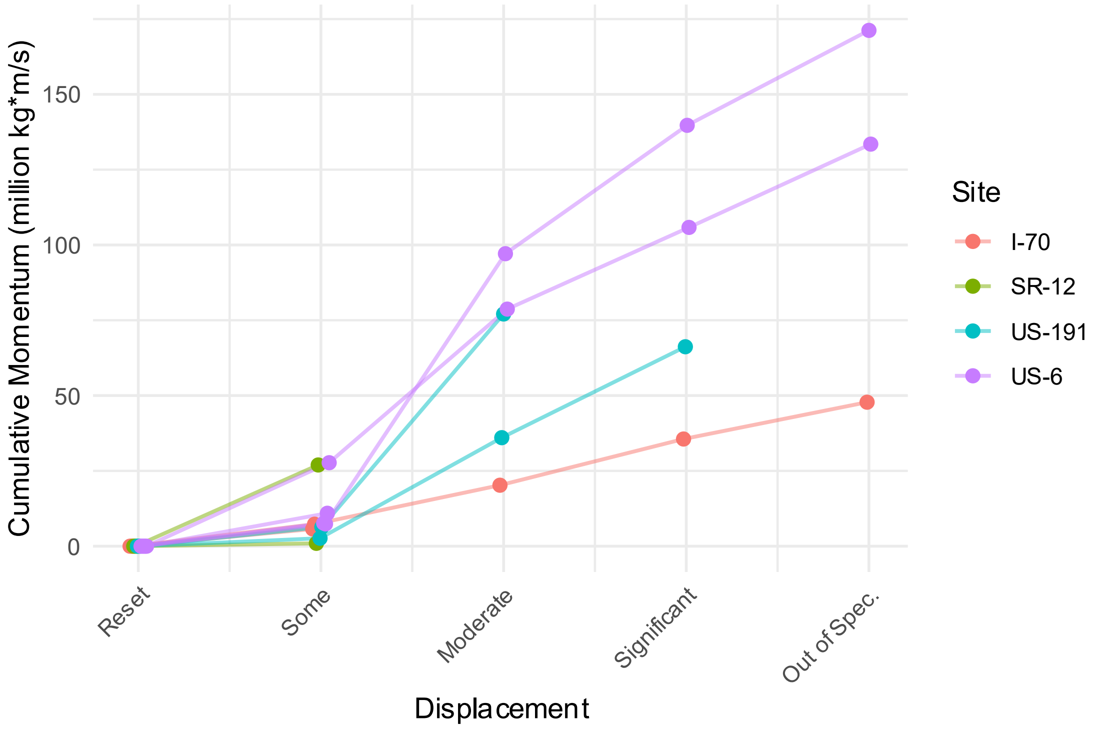


Figure 4.5 Rate of displacement by cumulative momentum by site.

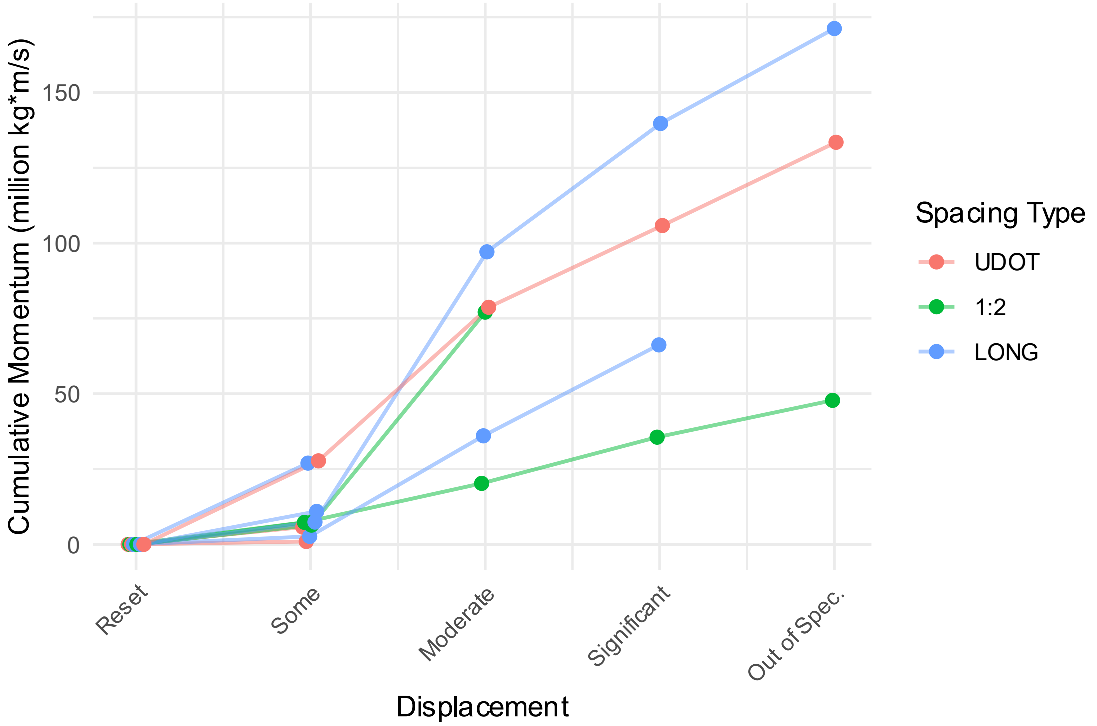


Figure 4.6 Rate of displacement by cumulative momentum and TPRS spacing.

a variable that this research did not control or evaluate. It is possible that old or worn-down strips could slide on the road more than new strips. On I-70, which showed the most strip displacement with the least amount of cumulative momentum, the middle strip appeared to have a torn handle based on footage from Camera 2. I-70 is also the road with the highest volumes and speeds; it is possible that strips may displace in a non-linear relationship with momentum.

This study only observed TPRS placed on asphalt roads. The researchers did not evaluate the condition of the asphalt. Along with strip condition, road conditions may also impact the rate at which TPRS are displaced.

The research team did observe that it was the second strip (of three) in the TPRS array that tended to move the most. This aligns with observations by PSS suggesting that something about the physical behavior of vehicles bouncing after hitting the first strip creates more displacement in the second strip (S. Tachovsky, personal communication, March 17, 2025). This research did not examine the rate of displacement of all three strips in the lane, only the middle strip. More research on strip wear and displacement is needed.

4.4 Worker Exposure

To evaluate the exposure of workers to live traffic, the research team compared the critical headway workers need to adjust the strips with how often that headway was available at each site. Headway data came from Camera 1 footage. The time the workers need to adjust the strips was calculated from observing six sessions of workers adjusting strips. During these sessions, researchers observed which headways traffic workers accepted or rejected and observed the headway length that more workers accepted than rejected, which was found to be 33.5 seconds. Figure 4.7 shows the cumulative distribution of headways at each work zone with a vertical dashed line marking the critical time. The boxed values along the y-axis list the value of the distribution at the critical time for each work zone. These values represent the percentage of headways which are shorter than the critical time. On US-6, for example, 87.5 percent of headways are shorter than the critical time which means workers only have enough time to adjust the strips in 12.5 percent of the gaps. Conversely, on US-191, only 54 percent of headways are shorter than the critical time, so workers have enough time in 46 percent of the headways.

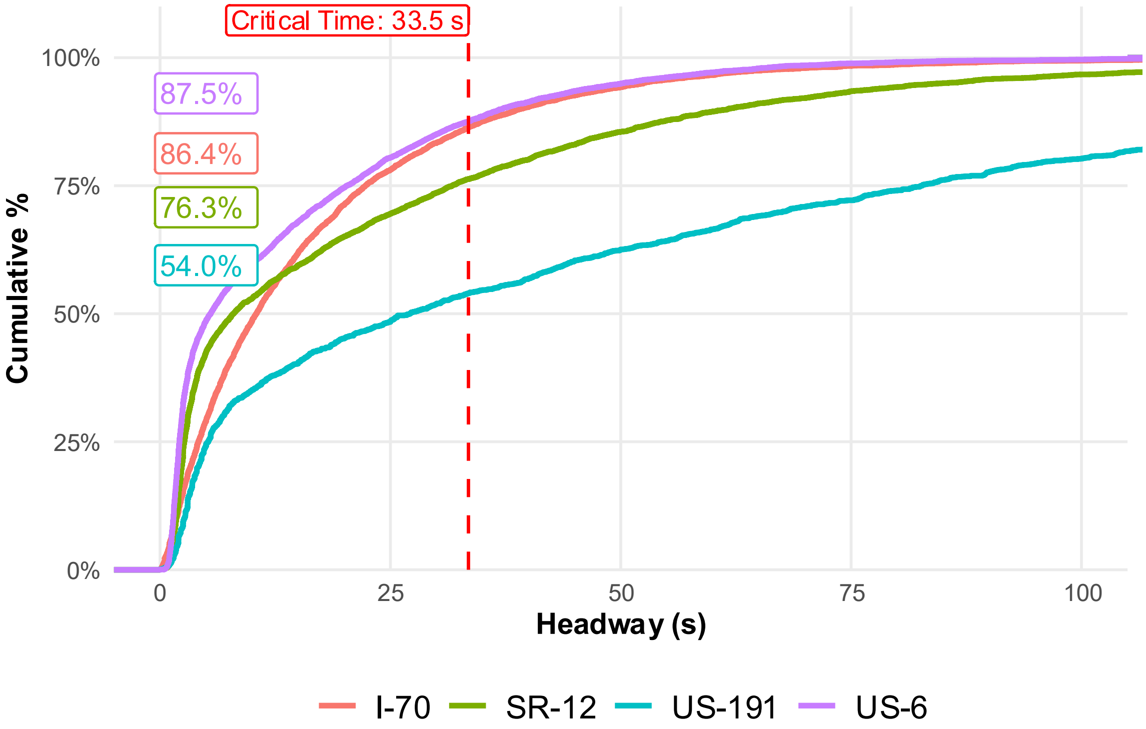


Figure 4.7 Cumulative distribution of headways at each site.

Roads that are busy and have a lower percentage of available headways pose greater risk to workers. Although workers may be roadside for the same amount of time from site to site, more vehicles are passing them in that time, and each passing vehicle is a possible collision. UDOT may find it helpful to set a threshold for available headways as a safety standard in the use of TPRS. Additional research is needed to both determine a more deeply researched critical time for the workers and thereby identify an acceptable threshold.

4.5 Summary

The results of this observational study found no clear correlation between changes in vehicle speed and the different spacing configurations used in the TPRS layouts. The various spacing arrangements of the layouts were also not consistently or significantly associated with braking behavior, nor did they particularly encourage or discourage drivers from maneuvering to avoid the TPRS. The analysis showed that TPRS displacement was driven more by other factors not measured in this experiment design than by spacing, speed, or traffic volume. This was evidenced by some strips shifting quickly even under low cumulative momentum and others remaining stable under much higher loads. Examples of potentially influential factors could include the age or level of wear for the individual TPRS or traits unique to each work zone. A headway of at least 33.5 seconds was sufficient for roadside workers to enter the roadway and adjust the TPRS, but the availability of this headway changes with the traffic characteristics of the road.

5.0 FINDINGS AND LIMITATIONS

5.1 Overview

This chapter restates the findings of the research as well as associated limitations with opportunities for future research, which are presented in terms of the five different variables tested. The findings and limitations relevant to changes in vehicle speed are discussed first. Driver braking behavior and TPRS avoidance are discussed together since they are analyzed in a similar fashion. Strip displacement and worker exposure are also discussed together because displacement rates influence how often workers must enter the road to adjust the TPRS. The results illustrate that the effectiveness and behavior of TPRS vary substantially by site, and the limitations inherent in measuring speed, braking and avoidance behavior, and TPRS displacement in live work zones underscore the need for more refined methods and broader data to fully understand these patterns.

5.2 Effect of TPRS on Speed

There was no consistent relationship between driver speed and the presence or absence of TPRS, and there was no consistent relationship between driver speeds and the spacing of strips in the TPRS array. This is contrary to the consensus of the studies discussed in Chapter 2, which found TPRS generally slows driving speeds by 3-13 mph. There are several hypothetical explanations for this observed discrepancy. One explanation is that Utah drivers behave differently with respect to TPRS than drivers in the states previously studied. Another is that TPRS technology is more mature now than when first studied; it may be that drivers have become accustomed to TPRS and previous studies observed drivers reacting to a novel technology.

Other explanations for the discrepancy between this study's findings and previous studies in the literature could be based in the methodology used for this research. The observed change in speed between sites was larger than the variance within a site, implying that other variables related to the site may have had a greater impact on drivers' speed than the TPRS treatment. Curves in the road, traffic conditions on any given day, and sight lines from the TPRS array to the work zone could all be factors affecting driver speed. It was not possible for this study to control for these variables as they were endogenous to the site; more sites would need to be observed to control for these elements. The study used commercial radar speed detection units available from UDOT; these units provide only average and 85th percentile speeds within fifteen-minute time intervals. It may be that TPRS slow only the fastest 15 percent of drivers, a beneficial effect that this study could not have observed. The location of the second radar device was inconsistent between sites and observation days, potentially impacting the speed reduction measured here. An ideal location to measure final speed would be at the lane closure, but space was not available at the work sites to place this collection device at that point. A third speed measurement device could also have allowed the researchers to measure the speed of vehicles ahead of TPRS, providing more information on their effectiveness.

Finally, the primary design of TPRS as a traffic control device is to gain the attention of potentially inattentive drivers, with a reduction in speed as a potential consequence. Although change in speed is a common proxy measure for TPRS effectiveness, it would be better to observe driver attention directly. Prior studies have observed this effect by instrumenting the interior of cars with drivers in a closed and controlled setting; this would be difficult to do in field research.

5.3 Driver Braking and Avoidance Response

Most drivers were not observed to activate their brake lights at any point as they traversed the TPRS. Of the drivers this study observed activating their brake lights, more did so before striking the TPRS than after. Braking behavior varied more across sites than within sites, indicating strong site-specific effects.

There are multiple interpretations of these findings. If the purpose of TPRS is to gain the attention of distracted drivers, then the fact that more drivers brake before TPRS – with visual warning rather than tactile warning – may suggest that visual cues are more influential than tactile cues. On the other hand, the fact that some drivers are observed braking after TPRS suggests that for that small number of drivers, TPRS may have played a tactile role in alerting the driver of an upcoming work zone.

A primary limitation to observing brake lights was the difficulty in detecting activated brake lights and the limited observation window before the vehicle encountered TPRS. Some vehicles kept rear-facing tail lights illuminated similar to daytime running lights, relying on an increase in brightness to signal braking. Some brake light housings reflected the sunlight, making it difficult to see whether brake lights were illuminated. Both factors made it difficult to discern activated brake lights from false positives. To mitigate this, Camera 1 was placed closer to the TPRS array to see the vehicles in more detail. However, placing the camera closer shortened the amount of time vehicles were observed before striking the TPRS. Before the TPRS, vehicles were in frame for around 1-2 seconds or less, depending on the speed of traffic. After the TPRS, vehicles were in frame for 3 or more seconds. It is possible that some drivers braked before entering the field of view of Camera 1. The count of vehicles that activated their brake lights after the TPRS is likely more accurate than the counts of vehicles that braked before or not at all. Additional research is needed where a camera is placed farther upstream of the TPRS where drivers first see TPRS. Such footage would provide better insight into how drivers react to TPRS before striking them.

Most drivers in passenger vehicles and trucks do not leave their lane to avoid the TPRS, but a large portion of motorcycle drivers do. Drivers of all vehicle types appeared to avoid the TPRS in a manner similar to passing a slow-moving vehicle; that is, this study did not observe abrupt or sudden evasive maneuvers. The low rates of lane departure amongst drivers of passenger vehicles and trucks suggest that the increased risk of related collisions due to TPRS is low, but additional research would be needed to measure this effect.

5.4 Strip Displacement and Worker Exposure

TPRS move and displace during operation. The middle strip in a three-strip array appears to displace the most relative to the first and third strips. The amount of displacement was not affected by the spacing between the strips, and there is not a strong relationship between displacement and cumulative traffic momentum. Displacement was more correlated with the site. This could be a function of roadway geometry, pavement condition, or the condition of the strips themselves. All observed sites had asphalt surfaces, but this study did not measure pavement roughness or other specific characteristics that could have explained variation in displacement.

This study also did not measure the level of wear of the individual TPRS or their age. Based on the strip designs used at these work zones, it is possible that some strips are more than 10 years old. Additionally, the assumptions made to calculate the cumulative momentum for TPRS displacement are very limited in their precision. While this is the first study to measure TPRS displacement in the field under live traffic loads, additional research is needed to correlate strip age and wear with displacement as well as refine methods to normalize traffic load on TPRS between sites.

Workers enter live traffic streams to correct the installation of displaced strips. This study measured that workers seek headway times in traffic of approximately 34 seconds in order to make these corrections. At all of the sites observed in this research, such a headway was observed at least 10 percent of the time. It may be that at roads with more traffic and therefore smaller headways, workers will accept shorter headways and take more risks. The necessary headway of 34 seconds is calculated from only six observed correction events; more observations may yield a more precise measure.

5.5 Summary

The findings of this research suggest that driver responses to TPRS and the performance of the TPRS themselves are highly variable and strongly dependent on site-specific conditions rather than layout spacing, traffic speeds, or traffic volumes. Changes in vehicle speed showed no consistent relationship with the varied spacing of the TPRS layouts. Likely influences on speed data include uncontrolled differences across work zones and limitations in the setup and equipment used in the field research. Braking and avoidance behaviors were similarly inconsistent and difficult to interpret due to challenges in detecting brake activation and limited visibility. The data suggests that only a minority of drivers respond to TPRS, and of those that do most brake on the approach or maneuver around them as if passing a vehicle. Strip displacement also varies widely by site and does not correlate with spacing or estimated traffic momentum, suggesting influence from factors not observed in this study such as pavement condition, age and condition of the individual TPRS, and limitations in the method used to estimate momentum. While sufficient headways were present at the observed work zones, the results for worker exposure were based on only six instances when workers were observed to enter the roadway to adjust the TPRS. These limitations underscore the potential of future research implementing more precise measurements, expanded site sampling, and improved methods for assessing driver attention, braking, and TPRS condition.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Recommendations

This chapter contains recommendations for UDOT as it considers policies and practices related to the use of TPRS on work sites in Utah. There are four primary recommendations. The first is to pursue further research and address the limitations outlined in the previous section. The second is to set standards for strip condition. The third is to reexamine TPRS applications in short-term and long-term work zones. The final recommendation is to outline conditions when contractors or safety engineers can use discretion in the use of TPRS.

6.1.1 Pursue Further Research

The discussion in Chapter 5 identified opportunities for future research. These future research needs include measuring individual vehicle speeds before, at, and after the TPRS, observing braking behavior farther upstream of the TPRS and observing a greater number and variety of work sites. Another potential methodology could use connected vehicle data obtained from a manufacturer of connected vehicles; such data would allow for objective analysis of vehicle speed and braking controls rather than manual and sometimes subjective interpretation of video feeds. This methodology would also allow for more sites to be measured – thereby enabling controls for site geometry – but a sufficient sample of vehicles would need to be available at all sites.

6.1.2 Set Standards for Strip Condition

Observations in this study suggest that some strips in use on Utah roads are old and in deteriorating condition. Such strips are more likely to displace, creating dangerous conditions for motorists and the workers who must correct them. The manufacturer states that TPRS has a 3-5-year life expectancy of normal use and has guidelines for evaluating acceptable and unacceptable levels of wear (PSS, 2018). UDOT currently does not have standards regarding age or level of wear of TPRS (A. Ogden, personal communications, February 2, 2025). UDOT should either adopt the manufacturer’s recommendations or conduct further research to establish their own standards.

6.1.3 Investigate TPRS Applications in Short- and Long-Term Work Zones

TPRS are designed to be temporary traffic controls. UDOT should consider using TPRS for short-term work zones where work is completed in hours or days or where work zones are moving along the road. Short-term applications may be better suited to the capabilities of TPRS. For work sites where TPRS are to be installed for several days or weeks, it would be better to consider other technologies or plan on inspecting and possibly adjusting the strips every 4 to 8 hours. If longer periods without adjustment or inspection are desired, UDOT should work with PSS or other manufacturers to investigate techniques that affix TPRS to the pavement surface with adhesives or stakes. UDOT should also consider researching adhesive-tape-style TPRS. Previous studies have found that the adhesive tapes stay in place longer (Brown et al., 2022) and if TPRS alerts most drivers visually, adhesive tapes may be as effective as non-adhesive TPRS. Determining if adhesive tapes are just as effective as non-adhesive strips would require additional research.

6.1.4 Contractor Discretion for TPRS

The risk to workers who correct displaced strips on high-speed and high-volume roads is real. PSS manufactures equipment that can recover and deploy strips, but mandating this equipment may not be justified given the equivocal findings of this research. UDOT may wish to observe or estimate headway distributions at work sites as in Figure 4.7. For work zones where a sufficient headway is infrequent, UDOT should have a process to allow contractors or traffic control engineers to request an exemption to rules requiring the use of TPRS.

6.2 Implementation Plan

To implement the recommendations in the previous section, UDOT will consider doing the following:

- The Traffic and Safety Division may submit a problem statement in a future year research cycle to explore methods to attach TPRS to pavement. This research may involve cooperation with manufacturers, literature searches, laboratory studies, or field observation. If a field study, this can also address some research gaps left unclosed in the present study.

- The Traffic and Safety Division may develop standards for TPRS condition, and conditions when contractors may elect to not use TPRS with approval from UDOT.

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