Texas A&M Transportation Institute

Traffic Control Device Analysis, Testing, and Evaluation Program: FY2023 Activities

Technical Report 0-7096-R3

Cooperative Research Program

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16. Abstract
Traffic control devices are a primary means of communicating highway information to road users. The design, application, and maintenance of traffic control devices are under constant transformation as new technologies, methodologies, and policies are introduced. This project provides the Texas Department of Transportation with a mechanism to conduct high-priority, limited-scope evaluations of traffic control devices. Research activities conducted and concluded during the 2023 fiscal year included:

- Evaluation of increasing the shoulder rumble strip offset.
- Evaluation of driveway assistance devices in lane closures on two-lane, two-way roads.

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TRAFFIC CONTROL DEVICE ANALYSIS, TESTING, AND EVALUATION PROGRAM: FY 2023 ACTIVITIES

by

Melisa D. Finley, P.E
Senior Research Engineer
Texas A&M Transportation Institute

Michael P. Pratt, P.E., PTOE
Associate Research Engineer
Texas A&M Transportation Institute

and

LuAnn Theiss, P.E., PTOE, PMP
Research Engineer
Texas A&M Transportation Institute

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TEXAS A&M TRANSPORTATION INSTITUTE
College Station, Texas 77843-3135

DISCLAIMER

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CHAPTER 1: INTRODUCTION

Traffic control devices are a primary means of communicating highway information to road users. The design, application, and maintenance of traffic control devices are under constant transformation as new technologies, methodologies, and policies are introduced. This project provides the Texas Department of Transportation (TxDOT) with a mechanism to conduct high-priority, limited-scope evaluations of traffic control devices. Research activities conducted during the 2023 fiscal year (September 2022–August 2023) included:

- Evaluation of increasing the shoulder rumble strip offset.
- Evaluation of driveway assistance devices (DADs) in lane closures on two-lane, two-way roads.
- Investigation of the use and effectiveness of maintenance work zone speed limits.
- Investigation and evaluation of the use of milled rumble strips on seal coats.
- Evaluation of driver understanding of and preference for alternative wait time display configurations used with portable traffic signals (PTSs).

The findings from the first two activities are documented in this report. The examination of maintenance work zone speed limits and milled rumble strips on seal coats were considered internal in nature, so they are not included herein. The remaining activity is ongoing and will be documented in future reports, as deemed appropriate.

CHAPTER 2: OPERATIONAL EFFECTS OF SHOULDER RUMBLE STRIP OFFSETS

Shoulder rumble strips are used as a safety treatment to reduce run-off-road crashes on highways. They are typically installed by grinding a series of grooves into the shoulder pavement. Rumble strips are designed to give errant drivers audible and vibratory warnings when they depart the lane and their tires encounter the strips.

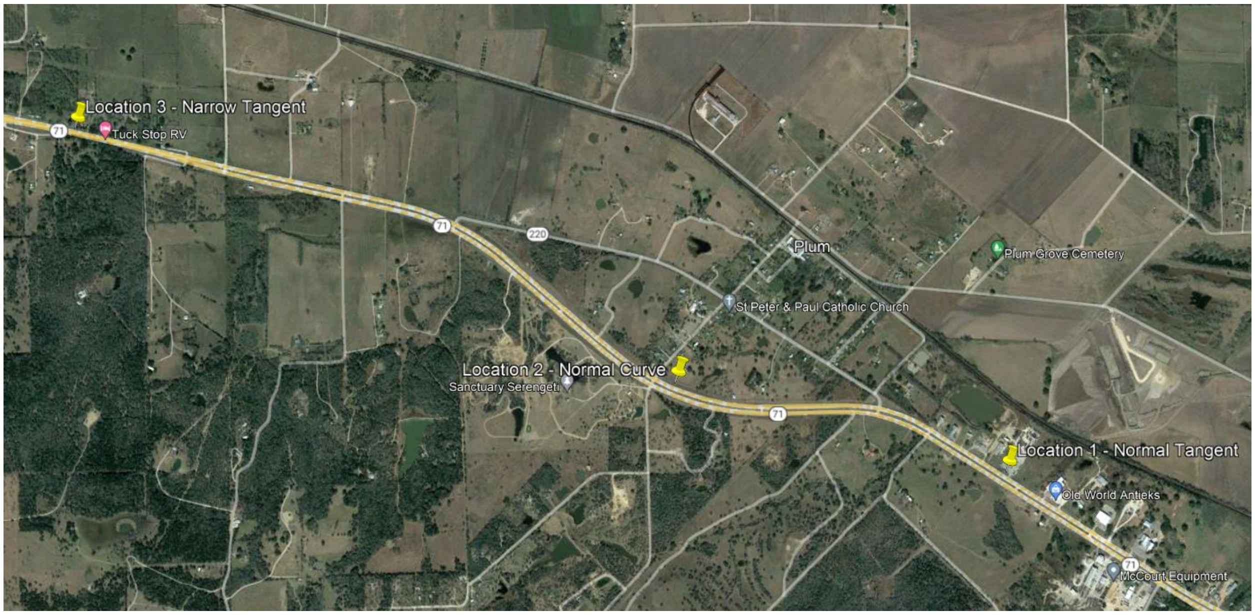
Though rumble strips are commonly recognized as effective safety treatments, they do have the disadvantage of increasing highway noise impacts. In Texas, for applications on the right (outside) shoulder of divided highways, rumble strips are typically installed on or near the edgeline pavement marking. It is possible to mitigate noise impacts by increasing the offset distance between the edgeline and the rumble strips such that errant drivers have more time to correct their path before hitting the strips. However, a longer offset also decreases the amount of time between lane departure and warning.

In this activity, researchers analyzed operational measures of effectiveness at three rural divided highway sites where shoulder rumble strips were moved from an edgeline application to a mid-shoulder application.

DATA COLLECTION AND REDUCTION

Researchers collected video footage at three sites on State Highway (SH) 71 between the towns of La Grange and West Point, Texas (see Figure 1). SH 71 is a four-lane rural divided highway throughout this corridor, with 12-ft lanes, 11-ft right shoulders, and 3-ft left shoulders. Researchers defined a zone of approximately 500 to 1000-ft length at each site and deployed cameras at the midpoint of the zone to obtain views upstream and downstream of the midpoint. The zones included only the lanes and shoulders of the westbound roadbed. The three sites were characterized as follows:

1. Normal tangent—At this site, SH 71 had four lanes and a depressed grass median. The upstream view included a median opening to accommodate U-turns and a business driveway. A residential driveway and several business driveways were visible past the downstream end of the zone.
2. Normal curve—At this site, SH 71 had four lanes and a depressed grass median. The highway alignment curved to the right with a radius of approximately 3500 ft and a deflection angle of 40 degrees. There was an unsignalized intersection shortly past the downstream end of the zone.
3. Narrow tangent—At this site, SH 71 had four lanes and a narrow median with a concrete barrier.



(Source: © 2022 Google Earth Pro)

Figure 1. Three Study Sites on SH 71 between LaGrange and West Point.

Researchers collected video footage for the before condition (i.e., rumble strips near the right edgeline) on January 29–31, 2020 (see Figure 2) and the after condition (i.e., rumble strips in the center of the right shoulder) on July 13–15, 2020 (see Figure 3). Each time period included approximately 24 hours of footage at each site in daytime, clear-weather conditions. The rumble strips were moved in June 2020.

Figure 2. Location of Rumble Strips in Before Condition.

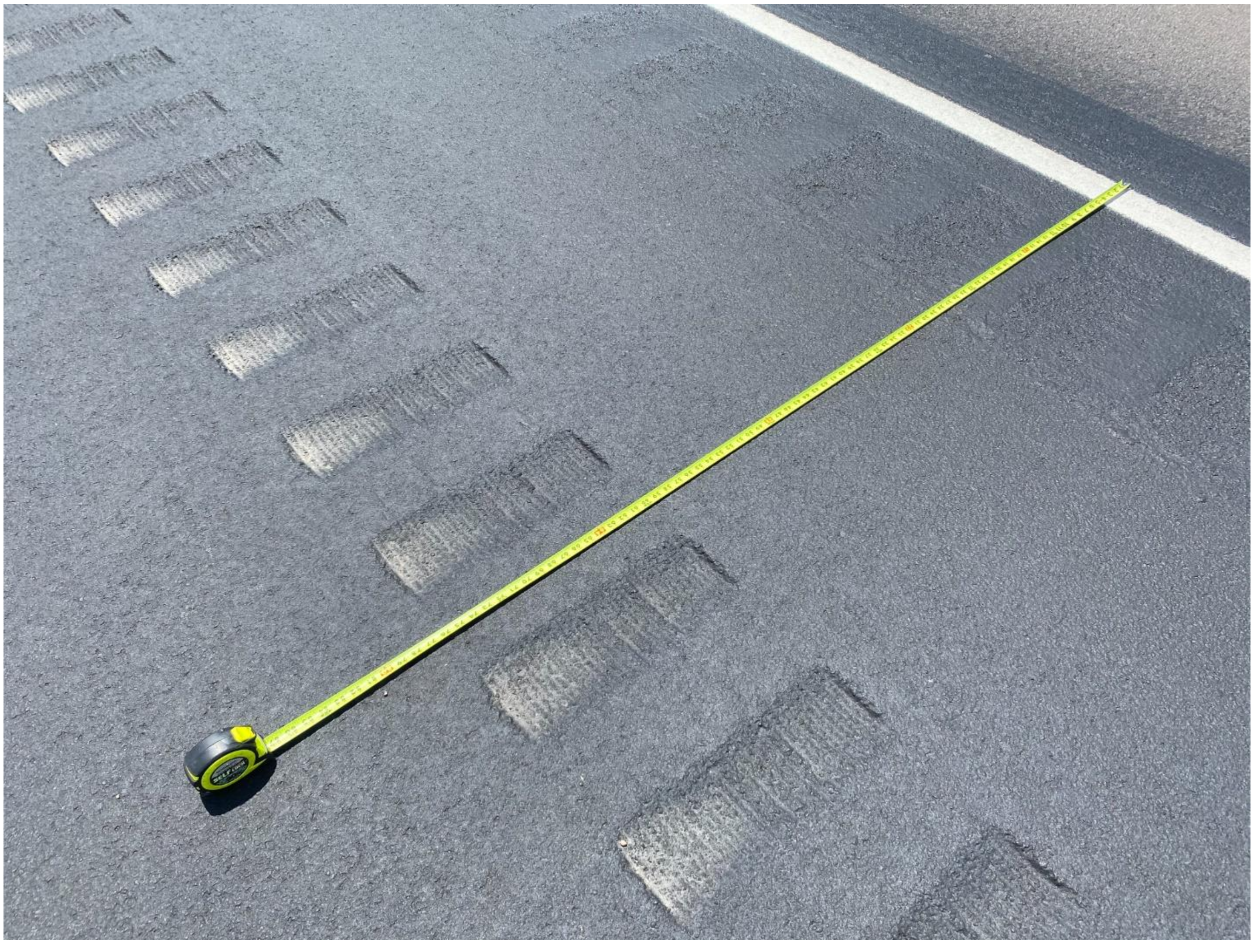


Figure 3. Location of Rumble Strips in After Condition.

Researchers reviewed the video footage at each site to extract the following variables to describe each vehicle:

- Classification (i.e., passenger car, passenger car with trailer, box truck/van, commercial motor vehicle, motorcycle, and bicycle).
- Zone entry timestamp.
- Travel lane (i.e., left, right, or shoulder).
- Right tire position for vehicles in the right lane, categorized as follows:
  - 0: Stayed in lane.
  - 1: Hit the edgeline.
  - 2: Crossed over the edgeline but did not hit the rumble strips.
  - 3: Hit the rumble strips.
  - 4: Crossed over the rumble strips.
  - 5: Crossed the center of the shoulder.
- Timestamps when vehicles in the right lane departed and re-entered the lane (i.e., encroached onto the right shoulder).

- Travel path (i.e., proceeded through or turned right) for vehicles in the right lane.
- Binary flag to indicate if a driver who departed the lane did so because another object influenced the maneuver (e.g., performing an evasive maneuver or swerving to avoid debris on the pavement).

These variables allowed the analysis of several research questions after the rumble strips were moved from near the edgeline to the center of the shoulder. The research questions included:

1. Did more through vehicles hit the edgeline?
2. Did more through vehicles hit the rumble strips?
3. Did through vehicles that departed the lane spend more time out of the lane before correcting?
4. Did right-turning vehicles change their lateral position during their turn maneuvers?

DATA ANALYSIS

Researchers conducted an exploratory analysis of all variables and then addressed the research questions. They conducted the exploratory analysis for all non-influenced vehicles in the right lane and then focused separately on non-influenced through and right-turning vehicles in the right lane to answer the research questions.

Exploratory Analysis

The video footage included about 20,000 vehicles in each time period (i.e., before and after). Researchers defined "trucks" as any vehicle with the following classifications: passenger car with trailer, box truck/van, or commercial vehicle. Researchers defined "other" vehicles as bicycles or motorcycles. Table 1 provides the distribution of vehicles by type, site, and time period. Across all sites and time periods, trucks represented about 19 percent of the observed vehicles.

Table 2 provides the distribution of vehicles by path (i.e., through or turn) and right tire position. As expected, all but a few of the turning vehicles hit both the edgeline and the rumble strips with their right tires, while few of the through vehicles did so. Fewer than one percent of the through vehicles hit the rumble strips, but the number of through vehicles hitting the rumble strips was approximately equal to the number of turning vehicles hitting the rumble strips. These vehicles are of interest because they generate increased noise impacts. Across all vehicles and paths in the right lane, about 6 percent of vehicles hit the edgeline and about 1.5 percent hit the rumble strips.

Table 1. Vehicle Count by Site and Time Period.

Time Period	Site Number	Number of Passenger Cars	Number of Trucks	Number of Other Vehicles	Total Number of Vehicles
Before	1	6674	1211	9	7894
	2	5785	1201	4	6990
	3	5862	1168	29	7059
	All	18,321	3580	42	21,943
After	1	5963	1663	14	7640
	2	4994	1403	8	6405
	3	4973	1320	12	6305
	All	15,930	4386	34	20,350

Table 2. Vehicle Right Tire Position by Vehicle Path.

Right Tire Position	Right Tire Position Category	Through Vehicle Count	Through Vehicle Percent	Turning Vehicle Count	Turning Vehicle Percent
Stayed in lane	Stayed in lane	39,133	93.35	16	4.55
Hit edgeline	Hit edgeline	1927	4.60	6	1.70
Crossed edgeline, did not hit rumble strips	Hit edgeline	532	1.27	10	2.84
Hit rumble strips	Hit edgeline and rumble strips	285	0.68	5	1.42
Crossed rumble strips	Hit edgeline and rumble strips	28	0.07	315	89.49
Crossed center of shoulder	Hit edgeline and rumble strips	15	0.04		
All positions	All categories	41,920	100.00	352[a]	100.00

[a] Excludes 21 turning vehicles for which the right tire position could not be determined due to view occlusion in the video footage.

Answers to Research Questions

To answer research questions 1 and 2, researchers computed the percentages of through vehicles falling within the right tire position categories in the second column of Table 2, broken out by vehicle type (i.e., car versus truck), site, and time period. These percentages are shown in tabular format in Table 3 and in graphical format in Figure 4 and Figure 5. Below are noteworthy trends:

- A notable percentage of trucks hit the edgeline at all sites both before and after the treatment. This trend is likely related to the increased width of trucks compared to cars as well as the tendency of trailers to sway. The largest reduction in the percentage of trucks hitting the edgeline occurred at site 3 (the narrow tangent site).
- At sites 1 and 2, there was little change in the percentage of cars hitting the edgeline following treatment. However, at site 3, there was a notable reduction in the percentage of cars hitting the edgeline.
- At site 1, there was no practical change in the percentage of vehicles of either type hitting the rumble strips.

- At sites 2 and 3 (the normal curve and narrow tangent sites, respectively), there was a notable reduction in both types of vehicles hitting the rumble strips.

Table 3. Through Vehicle Right Tire Position Percentages (Tabular Format).

Vehicle Type	Time Period	Site Number	Vehicle Count	Percent of Vehicles Hitting Edgeline	Percent of Vehicles Hitting Rumble Strips
Car	Before	1	6594	3.38	0.26
		2	5699	3.81	0.51
		3	5856	8.83	1.93
	After	1	5904	2.98	0.24
		2	4919	4.25	0.08
		3	4971	2.45	0.16
Truck	Before	1	1185	18.99	0.51
		2	1190	14.96	1.60
		3	1166	32.85	8.92
	After	1	1645	11.67	0.36
		2	1398	13.23	0.00
		3	1320	11.67	0.38

Researchers conducted odds ratio tests to determine if the observed changes were statistically significant. Table 4 provides the results of these tests. In all but one case, the computed odds ratios were less than 1.0, indicating a measured decrease in the percentage of vehicles hitting the edgeline or the rumble strips. The one exception was a 12.1 percent increase in the percentage of cars hitting the edgeline at site 2 (the normal curve site). More vehicles were observed "cutting" the curve after the rumble strips were moved to the center of the shoulder. However, there was also an 82.4 percent decrease in the percentage of cars hitting the rumble strips at site 2 following the treatment.

Table 4 includes the 95-percent confidence intervals for the computed odds ratios. A change is defined as statistically significant if the confidence interval excludes 1.00. The analysis shows that the observed increase in cars hitting the edgeline at site 2 is not statistically significant. The following events experienced a statistically significant decrease:

- Edgeline hits by cars at site 3.
- Edgeline hits by trucks at sites 1 and 3.
- Rumble strip hits by both vehicle types at sites 2 and 3.

The results of the analysis show statistically significant reductions in the percentage of through vehicles hitting the rumble strips at the normal curve and narrow tangent sites. These changes represent reductions in noise impacts of the rumble strips at these sites.

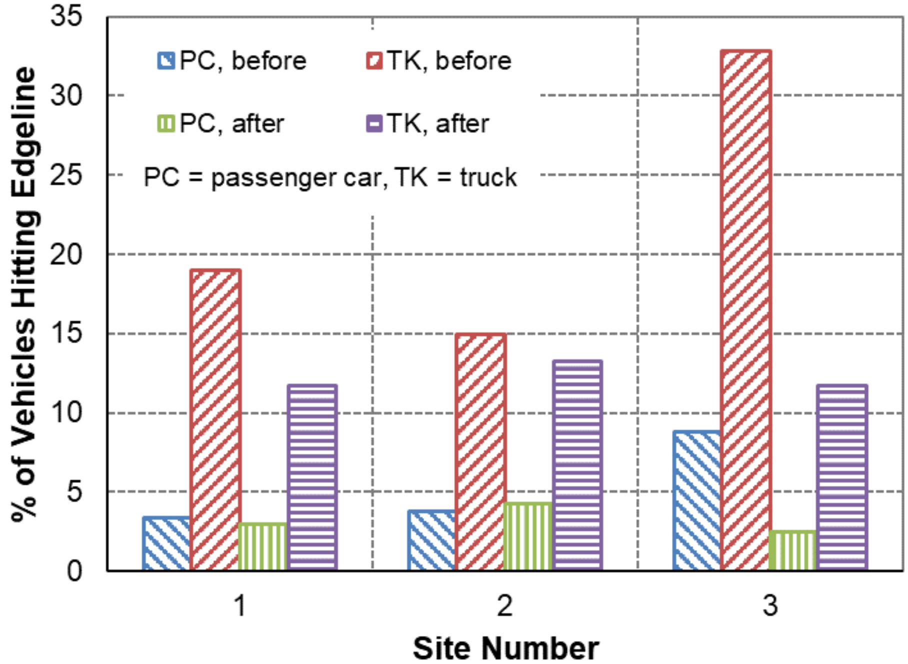


Figure 4. Through Vehicle Right Tire Edgeline Hits (Graphical Format).

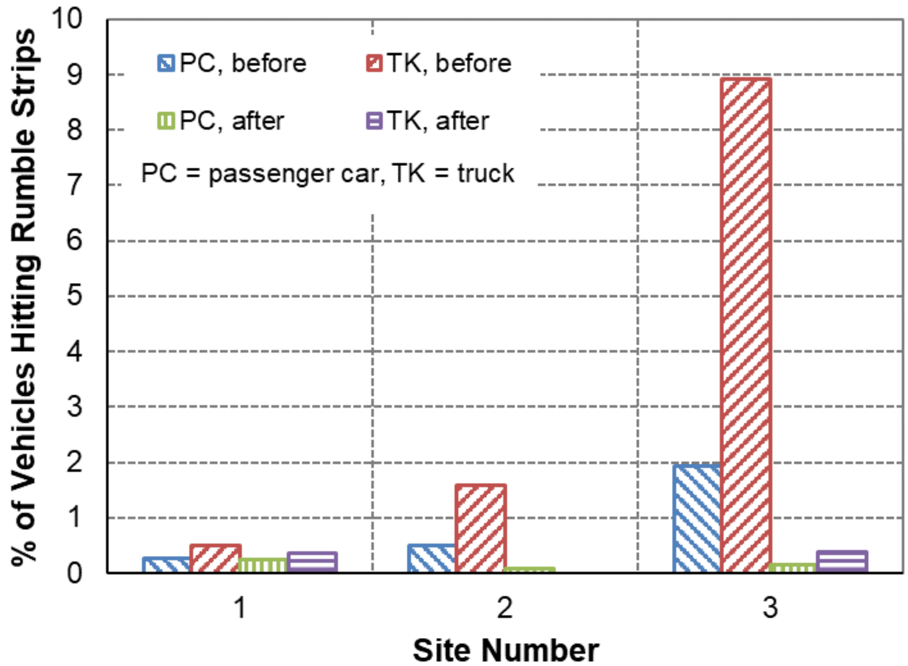


Figure 5. Through Vehicle Right Tire Rumble Strip Hits (Graphical Format).

Table 4. Odds Ratio Test Results.

Vehicle Type	Site Number	Edgeline Hits			Rumble Strip Hits		
		Odds Ratio	95% Confidence Interval	Statistical Change	Odds Ratio	95% Confidence Interval	Statistical Change
Car	1	0.878	0.72-1.07	None	0.925	0.46-1.86	None
	2	1.121	0.92-1.36	None	0.176	0.07-0.47	Decrease
	3	0.261	0.21-0.32	Decrease	0.087	0.04-0.17	Decrease
Truck	1	0.564	0.46-0.70	Decrease	0.719	0.29-1.77	None
	2	0.867	0.69-1.08	None	0.021	0.00-0.35	Decrease
	3	0.271	0.22-0.33	Decrease	0.043	0.02-0.10	Decrease

For question 3, researchers used the timestamps for through vehicles departing and re-entering the right lane to compute the average lane departure duration. This quantity was computed as the total time through vehicles spent out of the lane divided by the number of through vehicles departing the lane. Figure 6 shows the results of this calculation. Note the following observations:

- At site 1 (the normal tangent site), trucks spent more time outside the lane after the rumble strips were moved. This may be due to less precise driving or increased time allowed between lane departure and encountering the rumble strips.
- At site 2 (the normal curve site), both cars and trucks spent more time outside the lane. This increase is likely due to drivers "cutting" the curve.
- At site 3 (the narrow tangent site), both cars and trucks spent more time outside the lane after the rumble strips were moved. This may be due to less precise driving or increased time allowed between lane departure and encountering the rumble strips.
- In some cases, the magnitudes of observed changes (increase or decrease) exceeded 0.5 seconds. A threshold value of 0.5 seconds can be considered notable because it represents the amount of time needed for a vehicle to shift a lateral distance of 10 ft (which is most or all the width of a typical right shoulder) at a speed of 75 mph and a lane departure angle of 10 degrees.

For question 4, researchers examined the turning vehicles' right tire positions before and after the rumble strips were moved. Table 5 shows the results of this analysis. The only notable change was the decrease in the percent of turning vehicles that stayed in the lane before turning. A closer examination showed that this change was entirely attributed to site 2, which is the normal curve site. This finding indicates that moving the rumble strips to the center of the shoulder may encourage turning vehicles to pull onto the shoulder before turning, which avoids impeding through vehicles behind them and reduces the risk of rear-end crashes. Moving the rumble strips to the center of the shoulder also did not reduce the percent of turning vehicles whose right tire crossed the center of the shoulder (i.e., vehicle completely on the shoulder).

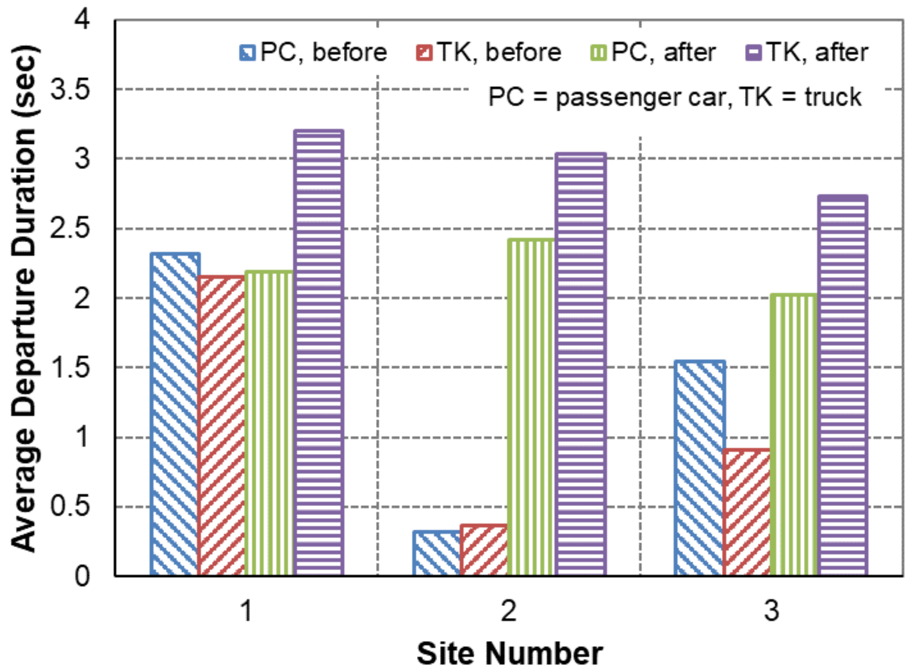


Figure 6. Average Lane Departure Duration.

Table 5. Turning Vehicle Right Tire Position by Time Period.

Right Tire Position	Right Tire Position Category	Before Vehicle Count	Before Vehicle Percent	After Vehicle Count	After Vehicle Percent
Stayed in lane	Stayed in lane	15	7.81	1	0.63
Hit edgeline	Hit edgeline	5	2.60	1	0.63
Crossed edgeline, did not hit rumble strips	Hit edgeline	4	2.08	6	3.75
Hit rumble strips	Hit edgeline and rumble strips	4	2.08	1	0.63
Crossed rumble strips	Hit edgeline and rumble strips	3	1.56	151	94.38
Crossed center of shoulder	Hit edgeline and rumble strips	161	83.85		
All positions	All categories	192	100.00	160	100.00

Note: This table excludes 21 turning vehicles for which the right tire position could not be determined due to view occlusion in the video footage.

FINDINGS AND CONCLUSIONS

Researchers examined the changes in edgeline hits, rumble strip hits, and average lane departure duration when shoulder rumble strips were moved at the three sites on SH 71. Table 6 summarizes the notable findings. In general, researchers found that moving the rumble strips to the center of the shoulder did not significantly increase the edgeline hits at any sites. This trend suggests that moving the rumble strips did not result in more vehicles departing the lane (and hence possibly needing a warning to shift back into the lane). In addition, researchers observed a notable decrease in rumble strip hits at two sites when the rumble strips were moved, resulting in a reduction in noise impacts. Researchers also noted that moving the rumble strips to the center of the shoulder did not negatively impact right turning vehicle behavior. However, vehicles that departed the lane at all three sites spent more time out of the lane. The magnitude of this trend was greatest at the curve site.

Table 6. Summary of Analysis Findings.

Site Number	Site Type	Maneuver Type	Vehicle Type	Changes Observed
1	Normal tangent	Through	Car	None
		Through	Truck	Edgeline hits decreased; spent more time out of lane
2	Normal curve	Through	Car	Rumble strip hits decreased; spent more time out of lane
		Through	Truck	Rumble strip hits decreased; spent more time out of lane
		Turn	All	Pulled onto the shoulder before turning
3	Narrow tangent	Through	Car	Edgeline and rumble strip hits decreased
		Through	Truck	Edgeline and rumble strip hits decreased; spent more time out of lane

Based on the limited findings of this research activity it appears that shoulder rumble strips can be moved from edgeline applications to center-of-shoulder applications at tangents and on the insides of curves. This change should not result in increased frequency of shoulder encroachment, and it should decrease noise impacts. However, it will allow drivers who deliberately “cut” curves to do so for a longer period before encountering a warning.

Researchers recommend a long-term crash study be conducted to determine the safety effect of shoulder rumble strips in edgeline versus center-of-shoulder applications. This study should consider the horizontal alignment of the segment (i.e., tangent, curve deflecting to the right, or curve deflecting to the left) and the locations of run-off-road crashes (i.e., inside or outside of the curve), in addition to exposure, other geometric, and traffic control variables.

CHAPTER 3:
EVALUATION OF DRIVEWAY ASSISTANCE DEVICES

INTRODUCTION

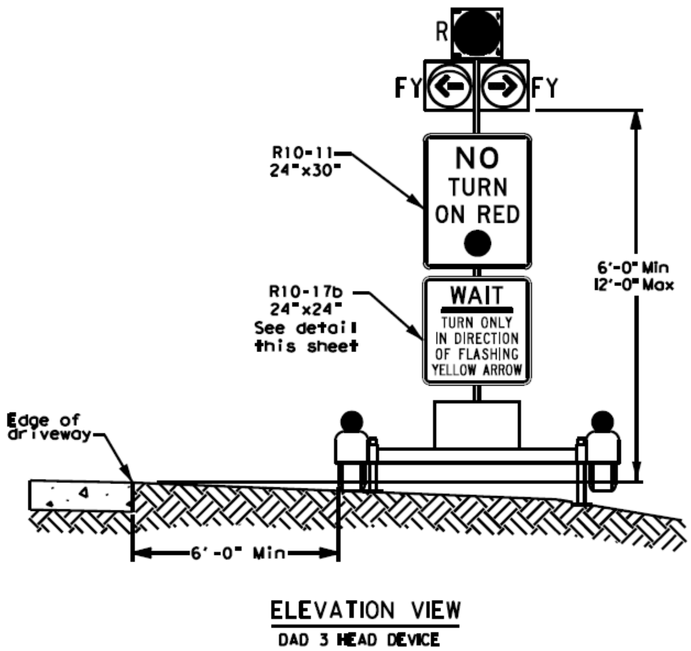
When a lane is closed on a two-lane, two-way road for construction or maintenance activities, provisions must be made to alternate one-way movement of the two original travel lanes through the work area. Quite often there are minor approaches, such as residential driveways, within the one-lane road section. While these minor approaches should be monitored, existing methods (e.g., flaggers and PTSs) are not always feasible based on conditions such as work duration, traffic volume, time of day, and cost of the method.

In 2012, TxDOT and the Texas A&M Transportation Institute (TTI) developed DADs to control traffic entering the one-lane road section from low-volume driveways (*1*). DADs are neither a PTS nor an automated flagger assistance device. Instead, DADs are a new device designed to work in synchronization with PTSs placed at each end of the lane closure on the main road. Since DADs were not included in *The Manual on Uniform Traffic Control Devices* (*2*), TxDOT submitted a request to experiment with DADs to the Federal Highway Administration (FHWA). The request was approved by FHWA on June 27, 2013. Since that time, TxDOT has continued to use and evaluate DADs.

Background on the development and application of DADs by TxDOT and results from prior field studies conducted from March 2019 to May 2022 can be found in the fiscal year 2022 report for this project (*3*). This chapter includes background material pertinent to the studies contained herein and documents the findings from recent field studies and a motorist survey conducted to evaluate motorist comprehension of various DAD designs.

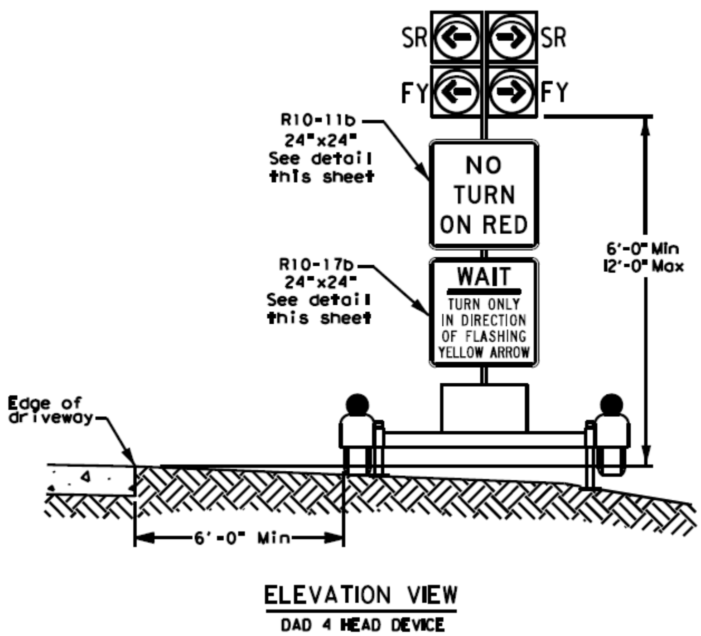
BACKGROUND

Currently, TxDOT allows the three-section doghouse (see Figure 7) and four-section stacked (see Figure 8) DAD designs to be used and evaluated in Texas with prior approval from the TxDOT Traffic Safety Division. The three-section doghouse DAD uses a 12-inch steady circular red indication and 12-inch flashing yellow arrows to control traffic. The steady circular red indication is shown when the minor approach traffic must stop and remain stopped. Since drivers facing a steady circular red indication may turn right after stopping when no other traffic control device is in place prohibiting a turn on red, a NO TURN ON RED sign (R10-11) is displayed. The flashing yellow arrows indicate that the minor approach traffic is permitted to cautiously enter the roadway only in the direction of the arrow. The second supplemental sign (WAIT TURN ONLY IN DIRECTION OF ARROW) was included based on recommendations from a recent study conducted by Gates et al. (*4*). Previously, TxDOT used a TURN ONLY IN DIRECTION OF ARROW sign with the three-section doghouse DAD.



R=Red; FY=Flashing Yellow

Figure 7. TxDOT Three-Section Doghouse DAD Design.



SR=Steady Red; FY=Flashing Yellow

Figure 8. TxDOT Four-Section Stacked DAD Design.

The four-section stacked DAD includes two 12-inch steady red arrow indications and two 12-inch flashing yellow indications. The steady red arrows indicate which direction a driver cannot turn, while the flashing yellow arrows indicate which direction a driver may turn. During the all-red phase, both steady red arrows are illuminated. Since the four-section stacked DAD displays steady red arrow indications instead of a steady circular red indication, the R10-11b sign is used. Since two colors of arrows are used, the second supplemental sign was modified to indicate the type (i.e., flashing) and color (i.e., yellow) of the arrow.

The recent study by Gates et al. (*4*) investigated several DAD designs and supplemental sign messages via a survey and field studies. Below is a summary of the key findings:

- The three-section doghouse DAD more effectively conveyed the proper driving action compared to the four-section stacked DAD.
- Yellow flashing arrows contributed to an improved response rate over red flashing arrows in terms of the proper driving action.
- Supplemental signs should provide information on what action drivers should take during both phases.
- The R10-11 sign improved message effectiveness in all cases and increased the rate of proper response to the circular red indication.
- TURN (opposed to YIELD) on the second supplemental sign more effectively conveyed the proper driving action.
- WAIT should be included on the second supplemental sign to further enhance the appropriate driving action during the stop phase.

While this recent study contributes to the state-of-the practice, the survey respondents rated the effectiveness of the treatments after being told the proper driving action. In addition, survey respondents indicated their preference for supplemental signs after they were provided with a description of the proper driving action. So, the survey only measured opinions about the treatments. The survey did not assess if the survey participant understood the device on its own merit.

FIELD STUDIES

In August 2022, TTI researchers documented and evaluated the use of DADs on a construction project in La Salle County. The project (CSJ 1545-02-023) consisted of the rehabilitation of FM 468 from the Dimmit County line to 0.28 mi west of FM 469 (see Figure 9). TxDOT used the three-section doghouse DAD design for this project (see Figure 10). The second supplemental sign was slightly different than the current design shown in Figure 7 (i.e., does not include FLASHING YELLOW) because the standard design at the time the project began used a TURN ONLY IN DIRECTION OF ARROW sign with the three-section doghouse DAD.

(Source: © 2022 Google Earth Pro)

Figure 9. FM 468 between Cotulla and Dimmit County Line.

Figure 10. DAD Design.

Data Collection

Figure 11 shows the section of roadway under construction in August 2022. The one lane section was approximately 1.4 mi long. DADs were used at 12 locations (see pink pins with circles and aqua pins with diamonds in Figure 11). On August 9–11, 2022, TTI researchers observed traffic approaching FM 468 from driveway 18, which served a petroleum industry business (see Figure 12 and Figure 13). Driveway 18 was in the middle of the one-lane section (i.e., approximately 3600 ft from both PTSs). Data collection began around 11:50 p.m. on Tuesday and ended around 12:30 p.m. on Thursday.

(*Source: © 2022 Google Earth Pro*)

Figure 11. FM 468 August 2022 Entire One-Lane Study Section.

On August 16–18, 2022, TTI researchers observed traffic approaching FM 468 from driveway 20, which served an equipment rental business (see Figure 12 and Figure 14). Driveway 20 was closer to the west end of the one-lane section (i.e., approximately 2800 ft from the PTS controlling the eastbound traffic). Data collection began around noon on Tuesday and ended around 12:30 p.m. on Thursday.

At both locations, the DAD was located on the nearside of the intersection and construction was occurring in the eastbound lanes. For both time periods, the average eastbound and westbound cycle times were approximately 4 minutes each. However, the red time was almost three-quarters of the cycle length in each direction (i.e., about 2 minutes and 45 seconds long).

(*Source: © 2022 Google Earth Pro*)

Figure 12. FM 468 August 2022 One-Lane Section near Driveways 18 and 20.

Figure 13. Driveway 18.

Figure 14. Project 8 Driveway 20.

Results

Over the 48 hours and 35 minutes of data collection at driveway 18, 97 vehicles arrived at the DAD. Thirty-one drivers (32 percent) did not comply with the DAD. Most of the violations (58 percent) were drivers turning on red in the same direction of the subsequent flashing yellow arrow (i.e., anticipating the next phase and/or getting ahead of the next mainlane traffic queue). The long red time (almost 3 minutes) may have contributed to this behavior, especially as drivers learned how the DADs and PTSs operated. Violations also included drivers turning on red in the same direction of the preceding flashing yellow arrow to join the mainlane traffic queue (32 percent). While both these types of maneuvers were considered violations, they are not necessarily unsafe driving actions.

Three drivers (10 percent) did turn on red in the opposite direction of the subsequent flashing yellow arrow (i.e., turning in the direction of oncoming traffic). All these violations were drivers turning right on red when the next display was a left flashing yellow arrow. The violation rate for driveway 18 was 4.3 violations per 100 stop cycles (31 violations divided by 728 stop cycles multiplied by 100).

Over the 48 hours and 30 minutes of data collection at driveway 20, 125 vehicles arrived at the DAD. Seventy-eight drivers (62 percent) did not comply with the DAD. However, 89 percent of violations were not necessarily unsafe driving actions. Most of the violations (65 percent) were drivers turning on red in the same direction of the subsequent flashing yellow arrow. Again, the long red time and familiar drivers may have contributed to this behavior. Twenty-four percent of violations were drivers turning on red to join the mainlane traffic queue.

Researchers did observe some unsafe driving actions at driveway 20. Seven percent of the violations were drivers that turned on red in the opposite direction of the subsequent flashing yellow arrow (i.e., turning in the direction of oncoming traffic). Of these violations, 60 percent were drivers turning right on red when the next display was a left flashing yellow arrow, and 40 percent were drivers turning left on red when the next display was a right flashing yellow arrow. In addition, 4 percent of the violations were drivers turning in the opposite direction of the flashing yellow arrow. Of these violations, approximately two-thirds were drivers turning left when a right flashing yellow arrow was displayed, and one-third were drivers turning right when a left flashing yellow arrow was displayed. The violation rate for driveway 20 was 10.7 violations per 100 stop cycles (78 violations divided by 727 stop cycles multiplied by 100).

Table 7 and Table 8 summarize the violation rate statistics and violation types, respectively, for the two driveways studied on FM 468. Overall, the violation rate was 7.5 violations per 100 stop periods. However, nearly two-thirds of the violations were drivers turning on red in the same direction of the subsequent flashing yellow arrow. These drivers were most likely anticipating the next phase where they would be allowed to proceed. In addition, more than a quarter of the violations were drivers turning on red in the same direction of the preceding flashing yellow arrow to join the mainlane traffic queue. While both of these maneuvers were considered violations, they were not considered to be unsafe driving actions. The phase timing, specifically the long red time (almost 3 minutes) may have contributed to these behaviors. Overall, 10 percent of the violations were determined to be unsafe driving actions since the drivers were turning in the direction of oncoming traffic.

Table 7. Violation Rate Statistics.

Intersection	Location of DAD	Hours of Study	Number of Stop Periods	Number of Violations	Violations per 100 Stop Periods[a]
Driveway 18	Nearside	48.6	728	31	4.3
Driveway 20	Nearside	48.5	727	78	10.7
Total	All	97.1	1455	109	7.5

[a] Rate computed as violations/stop periods × 100.

Table 8. Summary of Violation Types.

Intersection	Turned on Red Prior to FYA Same Direction	Turned on Red to Join Main Road Traffic Same Direction	Turned on Red Opposite Direction	Turned in Opposite Direction of FYA
Driveway 18	58%	32%	10%	0%
Driveway 20	65%	24%	7%	4%
Total	63%	27%	7%	3%

FYA = Flashing Yellow Arrow.

MOTORIST SURVEY

To build upon the findings from the recent study by Gates et al. (*4*), TTI researchers developed and conducted a Qualtrics online survey to assess motorist comprehension of the three-section doghouse and four-section stacked DADs with the appropriate R10-11 sign and various second supplemental signs. The survey was considered human subjects research by the Texas A&M University Human Research Protection Program. For this reason, all participant recruiting materials and survey questions, as well as the study protocol, were reviewed and approved by the Texas A&M Institutional Review Board.

Treatments

Figure 15 through Figure 20 contain the second supplemental signs studied. Treatment 1 is the sign currently used by TxDOT. Treatment 2 is the same message as Treatment 1 but without WAIT. TxDOT previously used Treatment 2 with the three-section doghouse DAD. Treatment 3 is the same message as Treatment 1 but without FLASHING YELLOW. Treatment 4 is the same message as Treatment 1 but without WAIT and FLASHING YELLOW. Treatment 5 is another sign that was recommended by Gates et al. (*4*). Treatment 6 is the same message as Treatment 5 but with FLASHING YELLOW added. Researchers tested treatments 1 through 6 with the three-section doghouse DAD to compare motorist understanding of these signs with and without WAIT and with and without FLASHING YELLOW. Researchers tested treatments 1, 2, and 6 with the four-section stacked DAD to compare motorist understanding with the three-section doghouse DAD.

Figure 15. Treatment 1 Sign.

Figure 16. Treatment 2 Sign.

Figure 17. Treatment 3 Sign.

Figure 18. Treatment 4 Sign.

Figure 19. Treatment 5 Sign.

Figure 20. Treatment 6 Sign.

Researchers used graphics editing software to create scene view images for each desired top and bottom sign combination. Then researchers developed graphics interchange format (GIF) files to create various flashing lens indications for both DAD designs. Researchers overlaid the GIF files on the scene view images to create the displays used in the online survey. The Treatment 1 displays are shown in Figure 21 through Figure 26.

Figure 21. Proceed Left Three-Section Doghouse DAD.

Figure 22. Proceed Right Three-Section Doghouse DAD.

Figure 23. Stop Three-Section Doghouse DAD.

Figure 24. Proceed Left Four-Section Stacked DAD.

Figure 25. Proceed Right Four-Section Stacked DAD.

Figure 26. Stop Four-Section Stacked DAD.

Overall, the combinations of signs and lens indications resulted in 27 different displays. There were 18 displays for the three-section doghouse DAD (consisting of proceed left, proceed right, and stop phases for each of the second supplemental signs) and nine displays for the four-section stacked DAD (consisting of proceed left, proceed right, and stop phases for three second supplemental signs).

Participant Recruitment, Consent, Demographics, and Qualifications

Researchers advertised the opportunity to participate in the survey using an email distributed to Texas A&M employees via the bulk mail system. In addition, a social media advertisement targeting Texans aged 18 and older was used to promote the survey.

Upon accessing the online survey, participants received information about the study and were asked to provide their consent to participate in the study. The consent language conformed to the protocol that was reviewed and approved by the Texas A&M Institutional Review Board. Next, the survey asked participants to provide demographic information, including selection of their age group from the following choices:

- 18–24.
- 25–34.
- 35–44.
- 45–54.
- 55–64.
- 65–74.
- 75–84.
- 85+.

Participants were also asked to select if they were male, female, or preferred not to provide that information. The survey then asked participants two qualification questions:

- Do you hold a valid Texas driver’s license?
- Are you completing this survey on a laptop computer, desktop computer, or a full-size electronic tablet?

Researchers determined that surveys requiring the interpretation of roadway images cannot be accurately completed on devices with small screens, such as smartphones. A negative response to either of these questions disqualified the participant from the rest of the study.

Finally, because driver interpretation of color could impact traffic control device comprehension, participants were asked if they were colorblind and what type of colorblindness they had. A series of colorblind test images were used to confirm if participants were colorblind. If the participant indicated they were colorblind or they incorrectly answered any of the colorblindness test images, they were still permitted to complete the survey, but researchers did not include their responses in the analysis.

Survey Protocol

Next, all participants saw an explanatory page, which gave background information necessary to answer the survey questions about the traffic control device (see Figure 27). Researchers intentionally did not use the terms driveway assistance device or DAD in the survey.

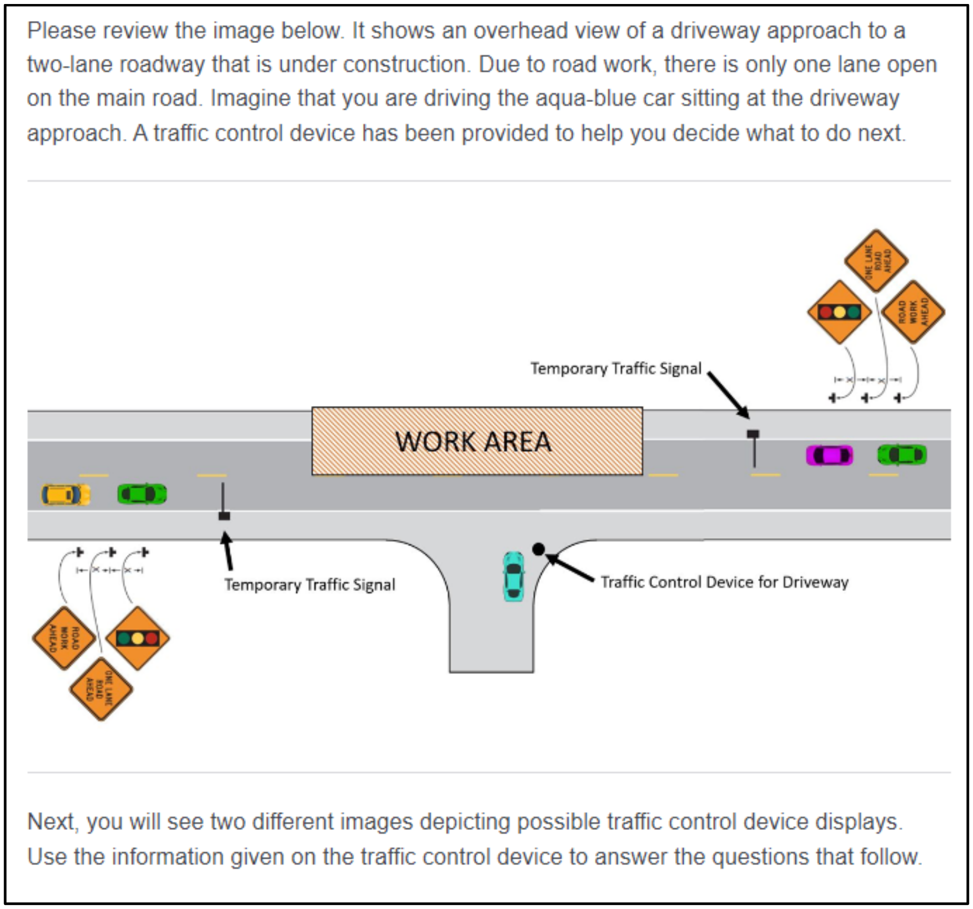


Figure 27. Explanation Page Displayed to Participants.

Next, each participant saw one proceed phase display and one stop phase display with the same second supplemental sign. Researchers randomized the phases so half of the participants saw a proceed phase first and the other half saw a stop phase first. The initial question for either phase was “Can you turn onto the main road?” For the proceed phase initial question, the correct answer was “Yes.” Based on the participant’s answer to this initial question, follow-up questions were used to better understand their interpretation of the device. Follow-up questions for the correct answer in the proceed phase included:

- Which direction can you turn (i.e., left and right, left only, or right only)?
- Which direction do you think vehicles on the main road are going (i.e., to the left and right, to the right, to the left, or unsure)?
- Do you need to yield to vehicles on the main road (i.e., yes, no, or unsure)?

Follow-up questions for the incorrect answer in the proceed phase included:

- Which direction can you NOT turn (i.e., left only, right only, neither left nor right, or unsure)?
- Why do you think you should not turn onto the main road?
- Which direction do you think vehicles on the main road are going (i.e., to the left and right, to the right, to the left, or unsure)?

For the stop phase initial question, the correct response was “No.” Follow-up questions for the correct answer in the stop phase included:

- Which direction can you not turn (i.e., left only, right only, or both directions)?
- Would you stop and then turn onto the main road (like you would for a STOP sign) or would you remain stopped until otherwise indicated by the device (i.e., remain stopped until otherwise indicated by the device, stop and then go [like you would for a STOP sign], or unsure)?

Follow-up questions for the incorrect answer in the stop phase included:

- Which direction can you turn (i.e., left only, right only, and left and right)?
- Why do you think you should be able to turn onto the main road?
- Would you stop and then turn onto the main road (like you would for a STOP sign) or would you remain stopped until otherwise indicated by the device (i.e., remain stopped until otherwise indicated by the device, stop and then go [like you would for a STOP sign], or unsure)?

The survey program randomized the answer choices for each question. Upon completion of the questions for each phase, each participant saw a close-out page thanking them for their time spent taking the survey and assuring them that their response was recorded.

Participant Demographics

Researchers opened the survey on March 3, 2023, and closed the survey on April 11, 2023. Excluding participants who were disqualified for lack of driver licensing or for not using an appropriate device (i.e., computer or tablet), researchers collected 338 completed surveys. Researchers did not use data for 35 participants because they either stated they were colorblind (six participants) or failed to pass the colorblindness test (29 participants). This left a total of 303 participants. Table 9 contains the demographic data for the survey participants, along with 2021 demographic data for licensed Texas drivers (*5*). Overall, the various demographic groups are well represented in the study, with no group having more than a 5 percent variation from the licensed driver population in Texas.

Table 9. Participant Demographic Data.

Age Group	Study Participants[a]			Licensed Texas Drivers		
	Male (n = 132)	Female (n = 167)	Totals (n = 299)	Male (n = 8,476,274)	Female (n = 8,665,829)	Totals (n = 17,142,103)
18–24	4%	7%	11%	6%	5%	11%
25–34	7%	6%	13%	9%	9%	18%
35–44	5%	10%	15%	9%	9%	18%
45–54	9%	11%	19%	9%	9%	18%
55–64	9%	13%	22%	8%	9%	17%
65–74	9%	8%	17%	6%	6%	12%
75–84	1%	2%	3%	2%	3%	5%
85+	< 1%	0%	0%	0%	1%	1%
Totals	44%	56%	100%	49%	51%	100%

[a] Four participants did not provide their gender information.

Analysis Methodology

Researchers entered all data collected into spreadsheets, categorized participant answers to all questions, and computed percentages of correct answers for each treatment to assess motorist comprehension of the devices evaluated. Researchers analyzed all data by phase (i.e., proceed and stop).

In motorist comprehension studies, a traffic control device is considered acceptable for use when 85 percent of the survey participants correctly interpret the meaning of the device (*6*). When the comprehension level was less than 85 percent, researchers used a confidence interval test with a 5 percent significance level (alpha = 0.05) to determine if the comprehension percentage was statistically different from the 85 percent criterion. If 0.85 fell within the boundaries of the confidence interval, then the level of comprehension for the tested device was not statistically different from 85 percent.

Researchers then used the Bernoulli model to determine whether the device impacted the proportion of motorists that chose the correct answer. The null hypothesis was that the two proportions were equal; while the alternative hypothesis was that the two proportions were not equal. The null hypothesis was rejected if the test statistic, Z, was greater than 1.96. This value was selected using a level of significance of alpha equal to 0.05 (i.e., a 95 percent level of confidence). Rejection of the null hypothesis indicated that there was a statistically significant difference in comprehension levels between the treatments. Since this model can only be used to assess two proportions at a time, researchers had to conduct multiple comparisons when more than two treatments were compared. In these instances, the individual level of significance of alpha was adjusted to keep the overall level of significance of alpha equal to 0.05 (i.e., a 95 percent level of confidence).

Results

This section contains the survey results for the three-section doghouse DAD and the four-section stacked DAD.

Three-Section Doghouse DAD

Table 10 and Table 11 contain the survey results for the three-section doghouse DAD for the proceed phase questions and for the stop phase questions, respectively. Overall, participants understood that they could turn onto the main road when there was a flashing yellow arrow and that they could not turn onto the main road when a steady circular red indication was displayed. This is evidenced by the comprehension levels exceeding 85 percent (or not statistically different than 85 percent) in both tables for all treatments. Participants also correctly understood which direction they could and could not turn, with comprehension levels greater than 85 percent in both tables for all treatments. In addition, participants correctly understood that they needed to yield to vehicles on the main road during the proceed phase (see Table 10) and remain stopped until otherwise indicated by the DAD during the stop phase (see Table 11) for all treatments.

Table 10. Survey Results for Three-Section Doghouse Proceed Phase.

Questions	Responses	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6
Can you turn onto the main road?	Sample size	37	32	33	35	34	34
	Yes	100.0%	87.5%	97.0%	94.3%	100.0%	100.0%
	No	0.0%	12.5%	3.0%	5.7%	0.0%	0.0%
Which direction can you turn?	Sample size	37	28	32	33	34	34
	Correct direction	97.3%	100.0%	96.9%	93.9%	97.1%	88.2%
	Incorrect direction(s)	2.7%	0.0%	3.1%	6.1%	2.9%	11.8%
Which direction can you NOT turn?	Sample size	0	4	1	2	0	0
	Correct direction	0.0%	25.0%	100.0%	0.0%	0.0%	0.0%
	Incorrect direction(s)	0.0%	50.0%	0.0%	100.0%	0.0%	0.0%
	Unsure	0.0%	25.0%	0.0%	0.0%	0.0%	0.0%
Which direction do you think vehicles on the main road are going?	Sample size	37	32	33	35	34	34
	Correct	62.2%	65.6%	81.8%	74.3%	67.6%	64.7%
	Incorrect	32.4%	25.0%	12.1%	20.0%	20.6%	29.4%
	Unsure	5.4%	9.4%	6.1%	5.7%	11.8%	5.9%
Do you need to yield to vehicles on the main road?	Sample size	37	32	33	35	34	34
	Yes	97.3%	84.4%	94.0%	88.6%	91.2%	88.2%
	No	2.7%	6.2%	3.0%	5.7%	5.9%	5.9%
	Unsure	0.0%	9.4%	3.0%	5.7%	2.9%	5.9%

Trt = Treatment.
Shading indicates correct percentage was greater than or not significantly different from the 85 percent criterion.

However, comprehension levels were low for correctly understanding which direction vehicles on the main road were going (ranging from 62.2 percent to 81.8 percent in Table 10). Researchers found that only the correct answers for Treatment 3 (WAIT TURN ONLY IN DIRECTION OF ARROW) and Treatment 4 (TURN ONLY IN DIRECTION OF ARROW) were not statistically different from the 85 percent criterion. Thus, these were the only two signs that met minimum comprehension levels for all questions when used with the three-section doghouse DAD.

Researchers found no significant differences in correct answers when FLASHING YELLOW or WAIT was added to the second supplemental sign.

Table 11. Survey Results for Three-Section Doghouse Stop Phase.

Questions	Responses	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6
Can you turn onto the main road?	Sample size	37	32	33	35	34	34
	Yes	10.8%	6.2%	12.1%	11.4%	17.6%	8.8%
	No	89.2%	93.8%	87.9%	88.6%	82.4%	91.2%
Which direction can you NOT turn?	Sample size	33	30	29	31	28	31
	Both directions	97.0%	96.7%	93.0%	93.6%	96.4%	96.8%
	Left only	3.0%	3.3%	3.5%	3.2%	3.6%	0.0%
	Right only	0.0%	0.0%	3.5%	3.2%	0.0%	3.2%
Which direction can you turn?	Sample size	4	2	4	4	6	3
	Left only	0.0%	0.0%	0.0%	25.0%	0.0%	0.0%
	Right only	0.0%	0.0%	25.0%	0.0%	16.7%	0.0%
	Left and right	100.0%	100.0%	75.0%	75.0%	83.3%	100.0%
Would you stop and then turn onto the main road (like you would for a STOP sign) or would you remain stopped until otherwise indicated by the device?	Sample size	37	32	33	35	34	34
	Remain stopped	97.3%	90.6%	93.9%	94.3%	100.0%	100.0%
	Stop and go	2.7%	3.1%	0.0%	5.7%	0.0%	0.0%
	Unsure	0.0%	6.3%	6.1%	0.0%	0.0%	0.0%

Trt = Treatment.
Shading indicates correct percentage was greater than or not significantly different from the 85 percent criterion.

Four-Section Stacked DAD

Table 12 and Table 13 contain the survey results for the four-section stacked DAD for the proceed phase questions and for the stop phase questions, respectively. Overall, participants understood that they could turn onto the main road when there was a flashing yellow arrow and that they could not turn onto the main road when dual steady red arrows were displayed. This is evidenced by the comprehension levels of 85 percent (or not statistically different than 85 percent) in both tables for all treatments. Participants also correctly understood which direction they could and could not turn, with comprehension levels greater than 85 percent in both tables for all treatments. In addition, participants correctly understood that they needed to yield to vehicles on the main road during the proceed phase (see Table 12) and remain stopped until otherwise indicated by the DAD during the stop phase (see Table 13) for all treatments.

Again, comprehension levels were low (ranging from 51.5 percent to 67.6 percent in Table 12) for correctly understanding which direction vehicles on the main road were going. For the four-section stacked DAD, the comprehension levels for all treatments were significantly less than the 85 percent criterion. Thus, none of the treatments met minimum comprehension levels for all questions when used with the four-section stacked DAD.

Table 12. Survey Results for Four-Section Stacked Proceed Phase.

Questions	Responses	Trt 1	Trt 2	Trt 6
Can you turn onto the main road?	Sample size	34	31	33
	Yes	94.1%	87.1%	97.0%
	No	5.9%	12.9%	3.0%
Which direction can you turn?	Sample size	37	28	34
	Correct direction	96.9%	92.6%	90.6%
	Incorrect direction(s)	3.1%	7.4%	9.4%
Which direction can you NOT turn?	Sample size	2	4	1
	Correct direction	100.0%	50.0%	100.0%
	Incorrect direction(s)	0.0%	50.0%	0.0%
	Unsure	0.0%	0.0%	0.0%
Which direction do you think vehicles on the main road are going?	Sample size	37	32	34
	Correct	67.6%	61.3%	51.5%
	Incorrect	20.6%	32.3%	33.3%
	Unsure	11.8%	6.4%	15.2%
Do you need to yield to vehicles on the main road?	Sample size	37	32	34
	Yes	91.2%	87.1%	87.9%
	No	2.9%	9.7%	3.0%
	Unsure	5.9%	3.2%	9.1%

Trt = Treatment.
Shading indicates correct percentage was greater than or not significantly different from the 85 percent criterion.

In order to assess the impact of adding WAIT to the bottom sign on the four-section stacked DAD, Treatment 1 (WAIT TURN ONLY IN DIRECTION OF FLASHING YELLOW ARROW) was compared to Treatment 2 (TURN ONLY IN DIRECTION OF FLASHING YELLOW ARROW). The only difference in this sign pair was the WAIT text. Researchers found no significant differences in correct answers when WAIT was added to the second supplemental sign.

Table 13. Survey Results for Four-Section Stacked Stop Phase.

Questions	Responses	Trt 1	Trt 2	Trt 6
Can you turn onto the main road?	Sample size	n = 34	n = 31	n = 33
	Yes	2.9%	19.4%	9.1%
	No	97.1%	80.6%	90.9%
Which direction can you NOT turn?	Sample size	n = 33	n = 25	n = 30
	Both directions	100.0%	100.0%	100.0%
	Left only	0.0%	0.0%	0.0%
	Right only	0.0%	0.0%	0.0%
Which direction can you turn?	Sample size	n = 1	n = 6	n = 3
	Left only	0.0%	0.0%	0.0%
	Right only	0.0%	0.0%	0.0%
	Left and right	100.0%	100.0%	100.0%
Would you stop and then turn onto the main road (like you would for a STOP sign) or would you remain stopped until otherwise indicated by the device?	Sample size	n = 34	n = 31	n = 33
	Remain stopped	97.1%	93.6%	97.0%
	Stop and go	0.0%	3.2%	0.0%
	Unsure	2.9%	3.2%	3.0%

SUMMARY AND CONCLUSIONS

For the field study on FM 486, the overall violation rate for the three-section doghouse DAD with a NO TURN ON RED sign (R10-11) and WAIT TURN ONLY IN DIRECTION OF ARROW sign was 7.5 violations per 100 stop periods. However, 90 percent of the violations were not considered to be unsafe driving actions since drivers where either turning onto the main road to get ahead of the mainlane traffic or joining the mainlane traffic queue after it passed by. The former was likely anticipating the next phase where they would be allowed to proceed. The phase timing, specifically the long red time (almost 3 minutes) may have contributed to these behaviors. These findings are similar to those observed in prior DAD field studies (*3*).

The survey findings support the use of the three-section doghouse DAD since only that DAD design with either a WAIT TURN ONLY IN DIRECTION OF ARROW sign (Treatment 3) or a TURN ONLY IN DIRECTION OF ARROW sign (Treatment 4) met the minimum comprehension levels for all questions. Since adding FLASHING YELLOW or WAIT to the second supplemental sign did not impact motorist comprehension of the proper driving actions, researchers recommend using the TURN ONLY IN DIRECTION OF ARROW sign.

Based on the field study findings analyzed to date (i.e., those documented herein and those in prior reports [*3*]), researchers recommend the use of the three-section doghouse DAD with a NO TURN ON RED sign (R10-11) and TURN ONLY IN DIRECTION OF ARROW sign. An example of the recommended DAD design is shown in Figure 28.

Figure 28. Example of Recommended DAD Design.

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