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Evaluation of Post-Mounted Delineators and Curve Warning Message Markings Phase 1: Designing a Sampling Plan

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In 2022, the Virginia Transportation Research Council published *Guidance for and Effectiveness of Low-Cost Delineation Treatments*, a report that evaluated the effectiveness of several low-cost delineation countermeasures (Flintsch et al., 2022a). That report recommended that the Virginia Department of Transportation (VDOT) consider a pilot study of using post-mounted delineators (PMDs) and curve warning message markings (CWMMs). In response, this study's purpose was to design a sampling plan to evaluate the safety effectiveness of PMDs and CWMMs. The research team conducted a literature review, chose a countermeasure design for PMDs and CWMMs, and designed a statistically robust sampling plan. This study is the first phase of a three-phase effort to evaluate PMDs and CWMMs by deploying them on a sample of VDOT roads. A second phase, a future technical assistance study, will deploy the sampling plan and monitor PMDs and CWMMs in the field following the plan developed in the phase 1 study. A third phase of the study will conduct the before-and-after crash analysis, crash modification factor development, and benefit-cost analysis.

The research team limited the scope to two-lane, rural roads. For PMDs, the scope was limited to roads without guardrails present on the outside of curves because VDOT guardrails typically have delineators already attached to the posts or web at 40- or 80-foot increments. A proportionate stratified sampling approach was evaluated and deemed appropriate for the study. For both countermeasures, a sample size of approximately 100 sites was determined to be sufficient to detect a meaningful treatment effect with adequate statistical power. The reference group of sites identified in this study is appropriate for use with both countermeasures. In both cases, the test of comparability indicated that the odds ratio estimates of crashes in the treatment and reference groups were not statistically significantly different from 1.0. The research team recommended that VTRC plan the phase 2 effort to implement the sampling plan for PMDs and CWMMs.

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FINAL REPORT

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ABSTRACT

In 2022, the Virginia Transportation Research Council published *Guidance for and Effectiveness of Low-Cost Delineation Treatments*, a report that evaluated the effectiveness of several low-cost delineation countermeasures (Flintsch et al., 2022a). That report recommended that the Virginia Department of Transportation (VDOT) consider a pilot study of using post-mounted delineators (PMDs) and curve warning message markings (CWMMs). In response, this study's purpose was to design a sampling plan to evaluate PMDs and CWMMs. The research team conducted a literature review, chose a countermeasure design for PMDs and CWMMs, and designed a statistically robust sampling plan. This study is the first phase of a three-phase effort to evaluate the safety effectiveness of PMDs and CWMMs by deploying them on a sample of VDOT roads. A second phase, a future technical assistance study, will deploy the sampling plan and monitor PMDs and CWMMs in the field following the plan developed in the phase 1 study. A third phase of the study will conduct the before-after crash analysis, crash modification factor development, and benefit-cost analysis.

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FINAL REPORT

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INTRODUCTION

Road departure crashes (RDCs) are a major safety concern for the Virginia Department of Transportation (VDOT). From 2021 to 2023, RDCs constituted approximately 48% of all fatal crashes on Virginia's roads. VDOT has devoted significant resources and attention to strategies to prevent such crashes. In 2022, the Virginia Transportation Research Council (VTRC) published *Guidance for and Effectiveness of Low-Cost Delineation Treatments* (Flintsch et al., 2022a), a report that describes a human factors study performed to evaluate the effectiveness of several low-cost delineation countermeasures on the rural portion of the Virginia Smart Roads facility at the Virginia Tech Transportation Institute.

The treatments evaluated included curve warning signs, edge lines, centerlines, post-mounted delineators (PMDs) at 20- and 40-foot spacing, and plastic inlaid markers. The study participants overwhelmingly selected the PMDs as the most effective treatment. Participant ratings showed statistically significant differences between PMDs and other treatments for curve visibility, perceived treatment effectiveness, perceived curve sharpness, and curve awareness. No statistical difference among ratings for curve warning signs, edge lines, or plastic inlaid markers was found. Although the participant survey revealed a strong subjective preference for PMDs, the test track data—collected via a data-acquisition system mounted on the test vehicle—often showed little objective difference among the tested treatments. The two PMD spacings showed more improved performance indicators than the other treatments on many of the measured factors, but the difference was not typically statistically significant. The report recommended that VDOT's Traffic Operations Division (TOD) consider a pilot study using PMDs for spot treatments at roadway curves where the sight distance is limited, especially because of vertical curves and locations with smaller speed differential for which chevrons are a "may use" condition (Flintsch et al., 2022a). PMDs may also be used on the tangent section approaching the curve at a larger spacing.

The report also recommended that VDOT's TOD consider evaluating curve warning message markings (CWMMs) in a second phase (Flintsch et al., 2022a). District traffic engineers and the Technical Review Panel (TRP) gave evaluating these markings high priority, but they were not included in that effort. CWMMs include word, symbol, and arrow markings that warn of approaching curves. These markings can have several configurations, including the words CURVE or SLOW, arrows, advisory speeds, and white transverse bars. Apart from post-mounted signs that typically fall within peripheral vision, where they compete with other distractions and require drivers to move their eyes or head to bring the sign into foveal vision, on-pavement markings consistently appear within and remain in the driver's foveal vision while driving (Carlson et al., 2009).

A potential systemwide screening of suitable locations for PMDs and CWMMs should be conducted to facilitate implementation and maximize safety benefits. Figure 1 shows examples of the two treatment types.

Figure 1. Examples of Post-Mounted Delineator and Curve Warning Message Marking: (left) Post-Mounted Delineators (VDOT) and (right) Curve Warning Message Marking (FHWA (Donnell et al., 2019))

PURPOSE AND SCOPE

This study's purpose was to develop a sampling plan to evaluate PMDs and CWMMs. This study is the first phase of a three-phase effort to evaluate the safety effectiveness of PMDs and CWMMs by deploying them on a sample of VDOT roads. The first phase, this study, conducted literature review and outreach to determine the countermeasure design and then designed a statistically robust sampling plan. A second phase, a possible future technical assistance study, will deploy the sampling plan and monitor PMDs and CWMMs in the field following the plan developed in the phase 1 study. A phase 3 study will conduct the before and after crash analysis, crash modification factor (CMF) development, and benefit-cost analysis. The scope was limited to two-lane, rural roads. For PMDs, the scope was limited to roads without guardrails present on the outside of curves because VDOT guardrails typically have delineators already attached to the posts or the web at 40- or 80-foot increments.

METHODS

The research team performed the following tasks to meet the project objectives:

1. State-of-the-practice review.
2. Treatment selection and specification and site installation criteria.
3. Identification of potential sites.
4. Selection of treatment and reference sites.

State-of-the-Practice Review

A literature review produced a state-of-the-practice summary of the two treatment types, PMDs and CWMMs. The review provided a better understanding of the prevailing design options and installation guidelines, as well as a general appreciation of the factors known to influence the effectiveness of these treatments at mitigating roadway departure crashes. Academic databases and search engines, such as the Transportation Research International Documentation database (https://trid.trb.org/) and Google® Scholar (https://scholar.google.com/) were used to identify the relevant literature.

Treatment Selection and Specification and Site Installation Criteria

This task reviewed the treatment design options identified in task 1 and made recommendations for pilot deployment in Virginia. Options for each of the two treatment types were considered and a determination made as to which option made the most sense for each treatment given available resources (e.g., staffing and budgetary), competing needs, programming requirements, and conformance to current VDOT approved product lists and specifications.

Identification of Potential Sites

This task reviewed the state roadway network and created an inventory of sites that may benefit from the deployment of either treatment type. Sites of interest were curves on two-lane primary and secondary rural highways. The research team reviewed relevant VDOT data sources and generated an initial list of potential sites. A final database was created that summarized candidate sites for each treatment type along with relevant site characteristics and crash histories. This database constituted the sampling frame from which sites were selected for later potential deployment.

Three primary types of data were collected. These were curve geospatial data, roadway attribute data, and crash records.

Curve Data

A Geographic Information Systems, or GIS, shapefile of horizontal curves on the statewide network—including relevant locational and geometric attributes such as the beginning and end mile points, radius, curve length, deflection angle, and the presence or otherwise of an intersection along the curve—were obtained from VDOT's TOD. These curve data were identified and extracted from version 20.1 of the VDOT linear referencing system map by Yang and Ma (2020). The original dataset included approximately 664,500 horizontal curves. These curves were screened to include only curves on primary and secondary rural highways that were at least 0.1 mile long and had no intersection along the curve, reducing the number of curves to approximately 47,200.

Road Attribute Data

VDOT's Road Network System databases were queried to generate a list of two-lane primary and secondary rural roadway segments. Each segment was defined by route name, start milepost, and end milepost. No information was available about horizontal alignment (that is, curve or tangent segment). Roadway attribute data—including shoulder width, speed limit, and annual average daily traffic (AADT) data for the identified segments—were retrieved from the database for the years 2019–2023. Segments that had either no AADT data available or very low AADT (fewer than 100 vehicles per day) were excluded from this study. In addition, segments with posted speed limits of less than 25 mph were excluded. The roadway attribute dataset contained information on approximately 60,200 segments.

Crash Data

The VDOT Road Network System databases were also queried for crash records for the years 2019–2023. The records included unique identification (ID), time and date, route name, and mile post of the crash location.

The crash dataset was combined with the two other datasets (curve data and roadway attribute data) to create a composite dataset for later sampling. As Figure 2 shows, all three datasets included route name and milepost information, and these keys were used to combine the datasets. Python™ scripts were developed to create the composite datasets. Merging the datasets on these fields eliminated tangent segments and curves for which the speed limit and AADT were either low (as previously defined) or unavailable. The final dataset included approximately 10,800 curve segments and was used as the sampling frame for this study.

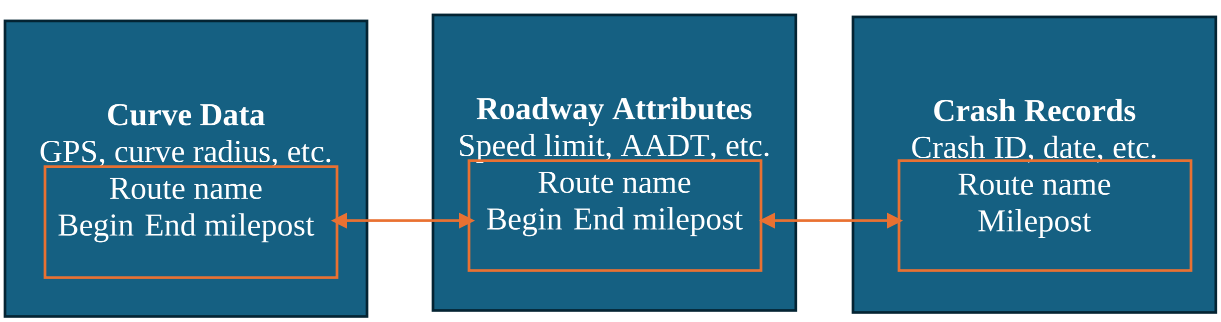


Figure 2. Datasets Used to Define the Sampling Frame of Sites from Which Samples Were Selected. The three datasets were merged on the highlighted attributes (route name and milepost). AADT = annual average daily traffic; GPS = Global Positioning System; ID = identification.

Selection of Treatment and Reference Sites

Once the sampling frame was defined, the next step identified subsets of sites where the two treatment types would be deployed. The initial sampling frame was grouped into smaller sampling frames or strata according to pertinent site data including AADT, speed limit, curve radius, and curve length prior to sampling. Sites were sampled from each stratum proportionate to the size of the stratum in the initial sampling frame. Adopting a proportionate stratified sampling approach helped ensure that the subset of sites selected for the study were adequately representative of the broader population of sites where the treatments would be deployed (Särndal et al., 2003).

Ultimately, the primary purpose of the three-phase study, of which this report is the first part, was to determine the safety effectiveness of the two treatment types through estimating appropriate CMFs. Because CMF is the ratio of two crash frequencies by definition and because current practice is to model crash frequencies with the negative binomial distribution, this task determined an overall sample size for the study based on formulas and results outlined in Zhu and Lakkis (2014) for comparing the ratio of two negative binomial event rates. An implementation of these formulas in the statistical software R's sample size package, PASSED, was used to calculate the sample size (Li et al., 2023). The inputs for the sample size function included the desired power, the level of significance, event rates for the two groups, average treatment duration, and the negative binomial dispersion parameter. A range of inputs were specified and used to propose a sample size for the study, with adequate power to detect a meaningful effect size or CMF.

In addition to the set of sites selected for treatment, this task identified another set of sites from the sampling frame to use as the reference group. Sites were selected for inclusion in the reference group based on similarity to the treated groups. Candidate reference groups were assessed for appropriateness using the "test of comparability" of reference and comparison groups proposed by Hauer (1997). The test involved calculating the odds ratio of crashes between sites in the reference and treatment groups (using Equation 1) for pairs of consecutive years in the period before treatment implementation. A candidate reference group was deemed similar to the treatment group if the mean of the sequence of odds ratio estimates did not significantly differ from 1.0 (Gross et al., 2010). Even though safety effectiveness evaluation was not done as part of this phase 1 study, identifying candidate reference sites at this stage provided assurance that the necessary data were available and that credible CMFs may be determined post deployment.

$$sample\ odds\ ratio = \frac{(T_i R_{i+1})/(T_{i+1} R_i)}{1+\frac{1}{T_{i+1}}+\frac{1}{R_i}} \qquad \text{(Equation 1)}$$

Where:
T_i = total crashes for the treatment group in year i.
T_{i+1} = total crashes for the treatment group in year $i + 1$.
R_i = total crashes for the comparison group in year i.
R_{i+1} = total crashes for the comparison group in year $i + 1$.

RESULTS

State-of-the-Practice Review

This section is divided into three parts: PMDs, CWMM, and Virginia Highway Safety Improvement Program (VHSIP) Two-Lane Rural Roads (TLRR) initiative (VDOT, 2024b).

Post-Mounted Delineators

PMDs are intended to guide or warn drivers of an approaching curve and provide a better understanding of the sharpness of a curve. Typically, these PMDs stand about 4 feet tall and are required to match the color of the adjacent edge line. The specific standards for PMDs are outlined in Chapter 3G of the *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA, 2023). According to these guidelines, delineators must be equipped with retroreflective devices that clearly reflect light under normal weather conditions from 1,000 feet when illuminated by a vehicle’s high beams.

In the Virginia supplement to the 2009 MUTCD (VDOT, 2011), two types of retroreflective elements are introduced for PMDs: D-1 delineators, which have one square or circular retroreflective element, and D-2 delineators, which either consist of two D-1 elements mounted together or a vertically extended D-1 element with double the height. D-1 delineators are required on the right side of freeways and expressways and on at least one side of interchange ramps, particularly on the outer curve, except under certain conditions. PMDs installed in Virginia must be placed 2 to 8 feet outside the shoulder’s outer edge. D-1 delineators are positioned on the right side of main roadways with a spacing of 528 feet and on interchange ramps with a spacing of 100 feet, except in horizontal curve sections, where spacing follows Table 1. D-2 delineators are positioned on acceleration and deceleration lanes at 100-foot intervals.

Table 1. Spacing for Post-Mounted Delineators on Horizontal Curves on Virginia Roadways (FHWA, 2023; VDOT, 2011)

Radius (R) of Curve in Feet	Approximate Spacing (S) on Curve in Feet
50	20
115	25
180	35
250	40
300	50
400	55
500	65
600	70
700	75
800	80
900	85
1,000	90

Carlson et al. (2015) conducted a survey to identify the policies and practices used to treat curves based on the 2009 national MUTCD and documents each state department of transportation created (FHWA, 2009). States have the option to use their own manuals, fully adopt the national manual, or supplement the national manual with additional guidance and policies. The survey found that 9 states developed their own MUTCD, 19 adopted the national manual, and 24 have supplements. Among those 24 states with supplements, 6 states were randomly selected and added to a set of 9 states that develop their own MUTCD. Table 2 summarizes those selected 15 states and Virginia's delineator guidelines in comparison to the 2009 MUTCDs. All states follow the 2009 MUTCD guidelines in terms of delineator placement and spacing.

Table 2. Summary of Delineator Guidelines of State *Manual on Uniform Traffic Control Devices*

MUTCD Section	State MUTCD															
	AL	AZ	CA	CO	DE	IL	IN	MD	MI	MN	MO	NE	OH	OR	TX	VA
Sec. 3F.03 Delineator Application	●	●	○	●	●	●	●	▲	●	●	●	●	●	●	○	▲
Sec. 3F.04 Delineator Placement and Spacing	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

●Accepts 2009 MUTCD in its entirety; ▲Minor revision; ○Major revision. MUTCD = *Manual on Uniform Traffic Control Devices*.

Gan et al. (2005) surveyed other state's departments of transportations' practices of CMF countermeasures. The study found that Arkansas, Kentucky, Missouri, and Montana stated that PMDs decreased all crashes by 20 to 30% on horizontal curves.

Chrysler et al. (2009) evaluated two types of PMDs through a closed-course nighttime driving test, a driver survey using video clips of curves, and a field test assessing vehicle performance at four rural Texas locations. The study examined the following treatments: (1) standard PMDs with retroreflective material along the entire post and a single reflector at the top, referred to as dot PMDs, and (2) standard chevrons along with chevrons featuring yellow retroreflective material applied to the entire post, referred to as full PMDs. The study's findings indicated that any form of vertical delineation enhances vehicle lane positioning at the entry and mid-point of horizontal curves, with fully reflective PMDs offering better lane positioning and reducing encroachment more effectively than standard posts. However, no statistically significant decrease in operating speed was observed after PMDs were installed along horizontal curves. Based on these results, the study recommended updating specifications for two-lane rural roads to require fully reflective posts.

More recently a study from the Kansas Department of Transportation found that installing PMDs on curved segments of two-lane rural roads showed a 15 to 31% reduction for all lane-departure crashes and a 10 to 32% reduction for fatal and injury crashes (Dissanayake and Galgamuwa, 2017). However, the CMF clearinghouse (www.cmfclearinghouse.org) gave these two CMFs a rating of only two stars. Table 3 summarizes CMFs of PMDs from these studies.

Table 3. CMFs for Installing Post-Mounted Delineators on Two-Lane Rural Roads and Freeways

Study	Type of Road/Area Type	Type of Crash	Severity	CMF	Stars
Dissanayake and Galgamuwa (2017)	Two-lane and rural roads	Run off road	All	0.69 to 0.85	2
		Run off road	KABC	0.68 to 0.9	2
Gan et al. (2005)	Not specified	All	NA	0.7 to 0.8	NA

CMF = crash modification factor; KABC = KABCO crash scale (K = fatal injury; A = serious injury; B = minor injury; C = possible injury); NA = not available.

Molino et al. (2010) conducted a simulator evaluation of low-cost safety improvements on rural, two-lane, undivided roads. For PMD configuration installation, the study tested multiple scenarios aligned with the 2009 MUTCD and PMDs on one side of curves in addition to the MUTCD option (FHWA, 2009). The study found that PMDs are effective in reducing average speeds by between 3.6 and 8.7 mph. Table 4 summarizes the results in more detail.

Table 4. Speed Reduction for Post-Mounted Delineators (Molino et al., 2010)

Treatment	Speed Change	Speed Reduction (mph)
Sequential flashing PMDs	Mean speed at point of curvature	– 8.7
	Mean speed at middle of curvature	– 4.8
PMDs on both sides of curve	Mean speed at point of curvature	– 8.0
	Mean speed at middle of curvature	– 4.3
Single-Side PMDs	Mean speed at point of curvature	– 6.9
	Mean speed at middle of curvature	– 3.6

PMDs = post-mounted delineators.

The VTRC project, *Guidance for and Effectiveness of Low-Cost Delineation Treatments*, also produced a Low-Cost Delineation Benefit Cost Analysis Tool (Flintsch et al., 2022b). The tool is a Microsoft® Excel™ spreadsheet that calculates benefit-cost ratios for selected countermeasures based on a range of input variables and available CMFs. The Low-Cost Delineation Benefit Cost Analysis Tool allows engineers to compute benefit-cost ratios for specific crashes depending on the availability of CMFs. The tool uses a unit cost of $85.87 for a PMD (based on 2020 data), a service life of 3 years, and two CMFs: KABC run off road (ROR) = 0.9 (CMF ID 9728) and KABCO ROR = 0.85 (CMF ID 9727).[1] The CMFs are from Dissanayake and Galgamuwa (2017).

Curve Warning Message Markings

Pavement messages, alongside other traffic control devices, offer an additional method to enhance road delineation. General design and application of "Pavement word, symbol, and arrow markings" are detailed in section 3B.20 of both MUTCD and the Virginia supplement to MUTCD (FHWA, 2009; VDOT, 2011). The following are some of the standards and guidance:

[1] KABCO crash scale (K = fatal injury; A = serious injury; B = minor injury; C = possible injury; O = property damage only).

- Word, symbol, and arrow markings shall be white, except as otherwise provided in Section 3B.20.
- Letters and numerals should be 6 feet or more in height.
- Word and symbol markings should not exceed three lines of information.
- If a pavement marking word message consists of more than one line of information, the message should read in the direction of travel. The first word of the message should be nearest to the user.

Additional design guidelines can be found in NCHRP Report 600, *Human Factors Guidelines for Road Systems* (Campbell et al., 2012), such as: Use “SLOW” with arrow surface markings in the tangent section approximately 230 feet before the curve to augment treatments in high-hazard areas or at sharp curves.

Chrysler and Schrock (2005) conducted a driver comprehension field test of route guidance pavement markings. The study found that warnings with advisory speeds (CURVE text with advisory speed) were more effective than those that simply warned of an upcoming curve (CURVE AHEAD text).

1Hallmark et al. (2012) conducted a study to evaluate the effectiveness of speed reduction for on-pavement curve warning pavement markings at horizontal curve locations on two-lane rural highways in Iowa. The study’s experiments gave mixed results. The study showed that horizontal curve pavement markings reduce operating speeds when approaching the curve for one site, but another location showed that the markings did not affect operating speed within the limits of the curve.

In *Safety Evaluation of Two Curve Warning Treatments*, Lyon et al. (2017) provided CMFs for installing in-lane curve warning pavement markings from a before-after study using the empirical Bayes method on data collected from sites in Iowa and Pennsylvania. Donnell et al. (2019) also conducted an observational before-after safety study for evaluating the effectiveness of horizontal curve warning pavement marking. From 263 treated curves and 21,902 reference curves, the study found reductions of 34.8% for total crashes, 30.7% for fatal and injury crashes, 23.1% for ROR crashes, 29.2% for nighttime crashes, 25.5% for nighttime ROR crashes, and 22.9% for nighttime fatal and injury crashes. Table 5 details these CMFs of CWMMs.

For CWMMs, the Low-Cost Delineation Benefit Cost Analysis Tool uses a unit cost of $1,569.86 (based on 2020 data), a service life of 3 years, and two CMFs: KABC = 0.693 (CMF ID 10313) from Lyon et al. (2017) and KABCO = 0.616 (CMF ID 9167) from Donnell at al. (2019).

Table 5. CMFs for Installing In-Lane Curve Warning Pavement Markers in Iowa and Pennsylvania

Study	Type of Road/ Area Type	Type of Crash	Severity	CMF	Stars
Lyon et al. (2017)	Not Specified	All	All	0.616	4
		All	KABC	1.01	3
		Run off road	All	1.67	3
		Nighttime	All	0.649	3
Donnell et al. (2019)	Rural	All	All	0.652	5
		All	KABC	0.693	5
		Run off road	All	0.769	4
		Nighttime	All	0.708	4
		Run off road and nighttime	All	0.745	4

CMF = crash modification factor; KABC = KABCO crash scale (K = fatal injury; A = serious injury; B = minor injury; C = possible injury).

Virginia Highway Safety Improvement Program Two-Lane Rural Roads Initiative

VDOT has been administering the Virginia Highway Safety Improvement Program Proactive Systemic Initiatives program for VDOT-maintained roads since 2019. This program deploys highly effective, low-cost safety improvements to reduce serious injury and fatal crashes across the Commonwealth using a data-driven strategy that focuses on proactively targeting locations with higher crash risk. Its most recent addition is the TLRR effort (VDOT, 2024b).

The most common type of crash on two-lane rural roads is the roadway departure crash, accounting for about 58% of all crashes. Because these crashes are widely distributed across the state, installing low-cost, effective countermeasures to reduce the number of crashes on these roads is an important strategy. Low-cost, effective measures to reduce roadway departure crashes that are eligible treatments for this program include signs, markings, marking messages, delineators, rumble strips, pavement markers, and limited tree removal. The countermeasures are grouped in three tiers (Table 6). Tier 1 is the base point to ensure that segments meet MUTCD and the Virginia supplement to MUTCD standards (FHWA, 2009; VDOT, 2011). Tiers 2 and 3 are ordered from the least to the most expensive for implementation and maintenance costs. PMDs are in tier 2 and CWMMs are in tier 3. Recently, VDOT staff have been reviewing opportunities to reduce costs associated with paving schedules and examining marking maintenance costs. Long-term maintenance costs for traffic-control devices in general are of interest to VDOT traffic operations staff and are continually being investigated. Quantifying the return on investment for PMDs and CWMMs will be part of the phase 3 research effort. Note that some flexibility exists to add other countermeasures if needed and appropriate, such as intersection markings and warning signs.

Table 6. Countermeasures and Tiers for the Highway Safety Improvement Program Two-Lane Rural Roads Initiative

Tier	Countermeasures
1	Center line pavement markings
	Regular width edge line pavement markings
	Static chevron alignment signs
	Curve warning signs
2	Wider edge line pavement markings
	Retroreflective sign post strips
	Retroreflective delineators (markers) on guardrails
	Ground-mounted flexible post delineators
	Selective tree removal
	Enhancements to curve warning signs (e.g., larger signs and so on)
3	Transverse rumble strips
	SLOW message and curve symbol pavement markings
	Centerline rumble strips
	Shoulder rumble strips
	Plastic inlaid markers
	Dynamic speed feedback signs

Previously identified higher risk, two-lane, rural road sections are eligible for these countermeasures in Table 6. The program includes $150 million to add countermeasures on up to 2,000 miles of road, with expected results of up to a 50% crash reduction. The first phase of this HSIP effort is under way.

Treatment Selection and Specification and Site Installation Criteria

For the VDOT HSIP Two Lane Rural Road Program, a countermeasure reference sheet was prepared for each of the 10 countermeasures, including the following information (VDOT, 2023a, 2023b):

1. What: Countermeasure description.
2. Where: Conditions under which this countermeasure should be applied.
3. How: How the countermeasure is designed and implemented (materials, installation details, and general notes).
4. Typical applications and examples.
5. Pay items and quantities.
6. Sign and seal requirements, if any.
7. Useful references.

The reference sheet cited sources such as MUTCD, the Virginia supplement to MUTCD, VDOT *Road and Bridge Specifications*, and VDOT Materials Division’s “Materials Approved Lists” (FHWA, 2009; VDOT, 2011, 2020, 2024a). Although the dimensions of the retroreflective sheeting are not clearly stated, a 3- x 12-inch piece of reflective sheeting or similar material on a 4-foot post is expected based on the approved product list.

For PMDs or ground-mounted flexible post delineators, the installation criteria are the following:

- Delineators may be used on long, continuous sections of roadway or through short stretches where changes in horizontal alignment exist. Delineators should be considered where a need to enhance indication of the roadside or roadway alignment is present.
- Delineators are often placed near the edge of through travel lanes, so District preferences should be considered for the type of delineator because longer term maintenance needs will develop. The District will likely want to stockpile delineators for maintenance and addressing replacements over time (e.g., flex post, mounting and anchoring style, or specific device type).

Table 1 is used to determine the spacing of PMDs. The general notes mention that other forms of delineation should be used for sharper curves, such as chevron alignment signs. Figure 3 illustrates a typical example of PMD placement.

The reference sheet states where to consider CWMMs or “SLOW” message and curve symbol pavement markings as follows:

- Apply the treatment to rural two-lane roadway locations experiencing a high number of horizontal curve-related crashes. When compound curves are present, the most hazardous curve should be addressed with the treatment.
- Avoid installing the countermeasure in locations where the potential for driver confusion is present because of intersecting roadways or driveways.
- May install the treatment at locations where existing horizontal alignment signage is present (i.e., MUTCD W1-1 through W1-8) or in conjunction with new installations of horizontal alignment signage and an advisory speed plaque (i.e., MUTCD W13-1P).
- Install the treatment only at locations with a minimum 10-foot width travel lane with marked yellow centerlines and white edge lines.

Figure 4 shows the typical layout for the CWMM made of Type B, Class II thermoplastic material.

The reference sheets provide sufficient specification, design, and guidance detail for the two countermeasures. Therefore, the reference sheets will be used for this project effort. Using these designs will also facilitate the use of HSIP TLRR sites in this study (VDOT, 2024b).

The expected service life is 3 years for both countermeasures. Also, the need for maintenance may possibly occur during the phase 3 after-study period. Typical maintenance protocols for such traffic-control devices should be provided.

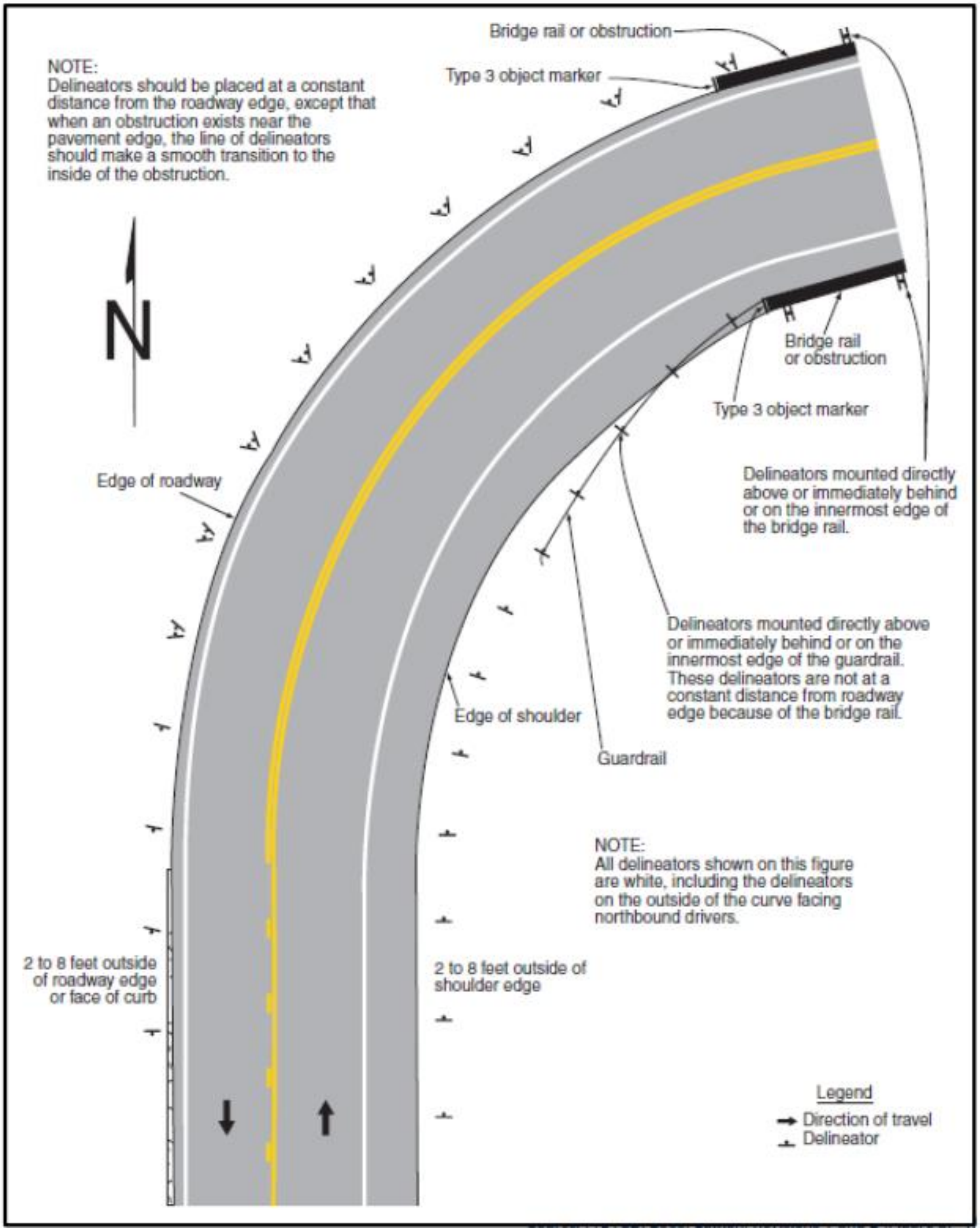
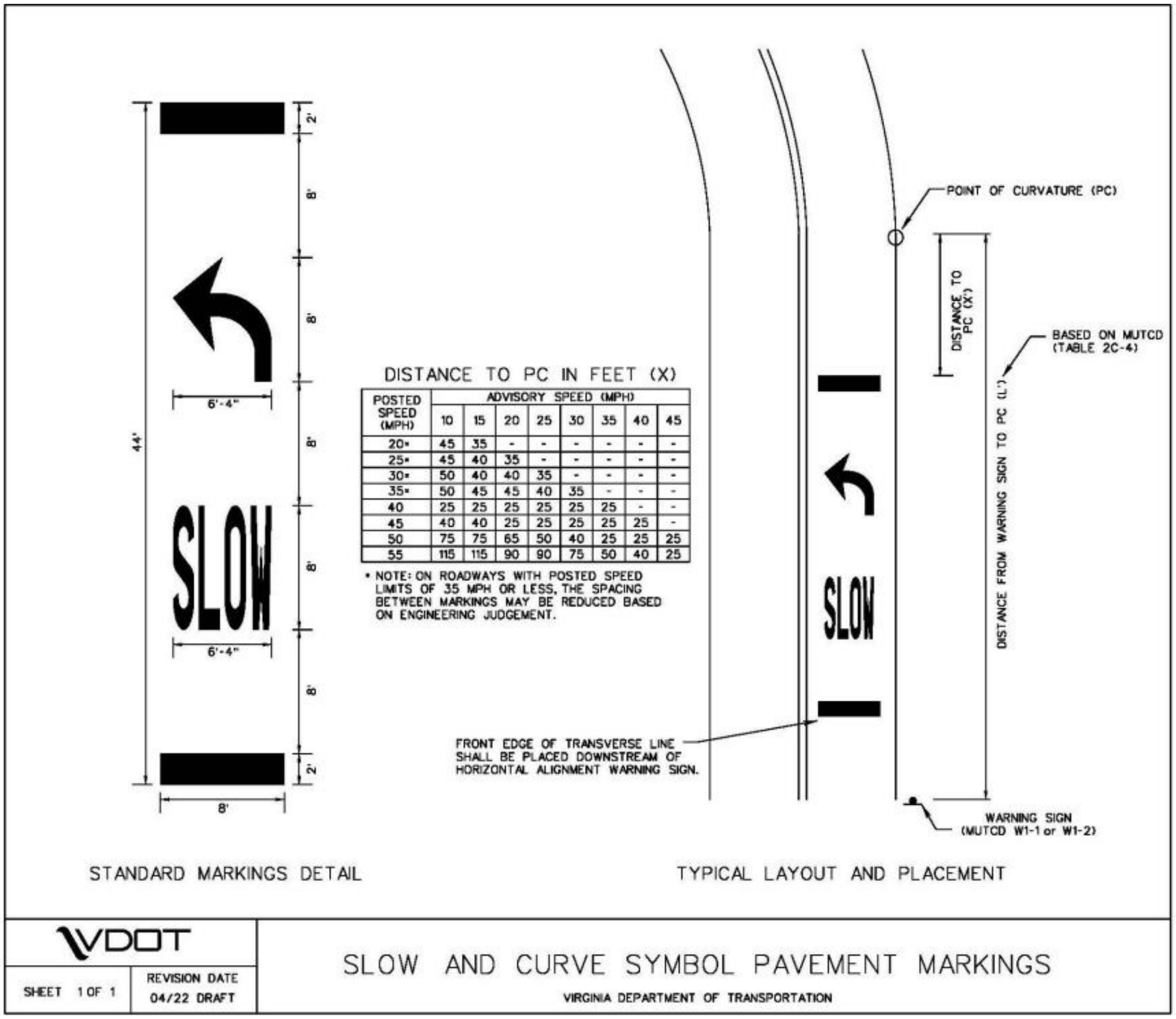


Figure 3. Example of Post-Mounted Delineators' Placement (VDOT, 2023a)



POSTED SPEED (MPH)	ADVISORY SPEED (MPH)							
	10	15	20	25	30	35	40	45
20*	45	35	-	-	-	-	-	-
25*	45	40	35	-	-	-	-	-
30*	50	40	40	35	-	-	-	-
35*	50	45	45	40	35	-	-	-
40	25	25	25	25	25	25	-	-
45	40	40	25	25	25	25	25	-
50	75	75	65	50	40	25	25	25
55	115	115	90	90	75	50	40	25

* NOTE: ON ROADWAYS WITH POSTED SPEED LIMITS OF 35 MPH OR LESS, THE SPACING BETWEEN MARKINGS MAY BE REDUCED BASED ON ENGINEERING JUDGEMENT.

Figure 4. Typical Layout for Curve Warning Message Markings (VDOT, 2023b). MUTCD = *Manual on Uniform Traffic Control Devices*.

Identification of Potential Sites

This section presents the sampling frame of potential sites from which treatment and reference sites were selected for the study, including summary and descriptive statistics of key study variables. The sampling frame was created by merging curve, roadway attribute, and crash data from VDOT sources.

The initial sampling frame included 10,778 two-lane curve segments on rural primary and secondary highways across the state. The total length was 1,504 miles, and 5,526 crashes occurred during the 5-year analysis period, for an average of 0.73 crashes per mile-year. Table 7 provides summary characteristics of salient variables in the secondary dataset. Figure 5 shows histograms of these variables.

Table 7. Summary Statistics for Key Roadway Attributes in the Sampling Frame Dataset

Variable	Mean	Minimum	Median	Maximum
Speed limit (mph)	43.7	25	45	55
Radius (feet)	639.0	63.5	498	3,274
Segment length (miles)	0.14	0.1	0.13	0.55
Annual average daily traffic (vehicles per day)	1,312	100	636	24,800
Crash count per 5 years (2019–2023)	0.51	0	0	20

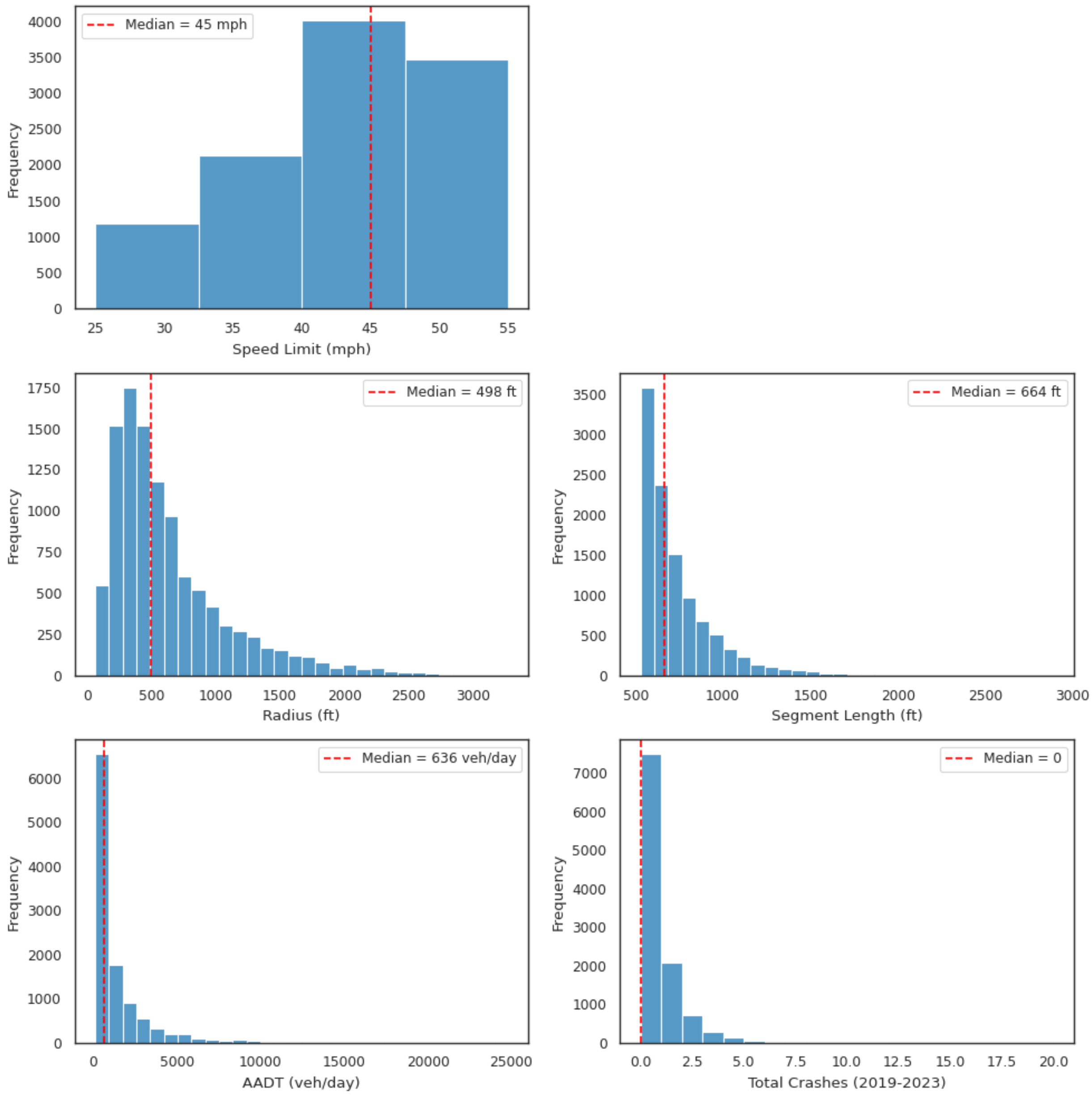


Figure 5. Histograms of the Distribution of Speed Limit, Curve Radius, Segment Lengths, AADT, and Crash Frequency in the Sampling Frame Dataset. AADT = annual average daily traffic; veh/day = vehicles per day.

The initial sampling frame was stratified into 16 strata by combining different levels of four variables known to influence crash risk on horizontal curves (Ma et al., 2020) as follows:

- Speed limit: Less than 45 mph versus 45 mph or faster.
- Curve radius: Less than 500 feet versus 500 feet or longer.
- Segment length: Less than 700 feet versus 700 feet or longer.
- AADT: Fewer than 650 vehicles per day versus 650 vehicles per day or more.

Table 8 provides the summary characteristics of the different strata and shows that the crash experience was different for the various strata. Therefore, stratification was deemed beneficial in reducing sampling variance and ensuring that the set of sites selected for this study reflected the diversity of the population of potential deployment sites.

Table 8: Characteristics of Different Subgroups or Strata of the Sampling Frame

Stratum ID	Speed Limit (mph)	Curve Radius (feet)	Segment Length (feet)	AADT (veh/day)	Number of Segments	Length (miles)	Total Crashes	Crashes per Mile-Year
A	< 45	< 500	< 700	< 650	1,659	187.9	220	0.23
B	< 45	< 500	< 700	≥ 650	429	48.4	257	1.06
C	< 45	< 500	≥ 700	< 650	830	136.1	156	0.23
D	< 45	< 500	≥ 700	≥ 650	195	31.9	175	1.10
E	< 45	≥ 500	< 700	< 650	504	56.9	48	0.17
F	< 45	≥ 500	< 700	≥ 650	293	33.1	122	0.74
G	< 45	≥ 500	≥ 700	< 650	243	41.6	40	0.19
H	< 45	≥ 500	≥ 700	≥ 650	154	25.9	105	0.81
I	≥ 45	< 500	< 700	< 650	808	92.2	199	0.43
J	≥ 45	< 500	< 700	≥ 650	579	66.0	548	1.66
K	≥ 45	< 500	≥ 700	< 650	483	82.0	145	0.35
L	≥ 45	< 500	≥ 700	≥ 650	439	75.2	499	1.33
M	≥ 45	≥ 500	< 700	< 650	535	60.7	76	0.25
N	≥ 45	≥ 500	< 700	≥ 650	1,456	167.5	944	1.13
O	≥ 45	≥ 500	≥ 700	< 650	381	66.7	70	0.21
P	≥ 45	≥ 500	≥ 700	≥ 650	1,790	332.1	1,922	1.16

AADT = annual average daily traffic; ID = identification; veh/day = vehicles per day.

Selection of Treatment and Reference Sites

This section presents the results of the sampling design used to select sites for the study. The study design involved sample size analysis, treatment assignment, site selection, and evaluation of treatment and reference site groups for comparability.

Sample Size Analysis

The sample size analysis assessed the sample size needed to detect an overall CMF or expected change in safety with adequate statistical power. Sample sizes were calculated assuming a parallel two-group design in which one group receives the treatment, and the other group serves as the reference or control group (Zhu and Lakkis, 2014). The sample size estimates were deemed conservative because an empirical Bayesian or fully Bayesian method would be used for the phase 3 evaluation study and would likely require fewer sites (Srinivasan et al., 2009).

Sample sizes were calculated using the R sample size estimation package, PASSED. Sample sizes were calculated for a range of likely rate ratios (CMFs), study durations, statistical power, and statistical significance. The event rate in the reference group was assumed to be equal to 0.75 crashes per mile-year. This rate was selected based on the 0.73 crashes per mile-year observed in the sampling frame. The negative binomial dispersion parameter was set equal to 0.4 based on the Virginia-specific safety performance function for rural two-lane roadway segments estimated by Garber et al. (2010). The number of reference sites was also assumed to be equal to the number of treatment sites. Table 9 provides the sample size estimates obtained for several combinations of the inputs.

Table 9. Sample Size Estimates for Different Combinations of the Rate Ratio (or Crash Modification Factor), Study Duration, Statistical Power, and Significance Level

Rate Ratio	Duration (years)	Power	Significance Level	Sample Size
0.9	3	0.7	0.05	966
0.9	3	0.7	0.1	737
0.9	3	0.8	0.05	1,228
0.9	3	0.8	0.1	968
0.9	4	0.7	0.05	836
0.9	4	0.7	0.1	637
0.9	4	0.8	0.05	1,063
0.9	4	0.8	0.1	837
0.9	5	0.7	0.05	758
0.9	5	0.7	0.1	578
0.9	5	0.8	0.05	963
0.9	5	0.8	0.1	758
0.8	3	0.7	0.05	222
0.8	3	0.7	0.1	170
0.8	3	0.8	0.05	283
0.8	3	0.8	0.1	223
0.8	4	0.7	0.05	192
0.8	4	0.7	0.1	146
0.8	4	0.8	0.05	244
0.8	4	0.8	0.1	192
0.8	5	0.7	0.05	173
0.8	5	0.7	0.1	132
0.8	5	0.8	0.05	220
0.8	5	0.8	0.1	174
0.7	3	0.7	0.05	90

Rate Ratio	Duration (years)	Power	Significance Level	Sample Size
0.7	3	0.7	0.1	69
0.7	3	0.8	0.05	115
0.7	3	0.8	0.1	91
0.7	4	0.7	0.05	78
0.7	4	0.7	0.1	59
0.7	4	0.8	0.05	99
0.7	4	0.8	0.1	78
0.7	5	0.7	0.05	70
0.7	5	0.7	0.1	53
0.7	5	0.8	0.05	88
0.7	5	0.8	0.1	70
0.6	3	0.7	0.05	46
0.6	3	0.7	0.1	35
0.6	3	0.8	0.05	58
0.6	3	0.8	0.1	46
0.6	4	0.7	0.05	39
0.6	4	0.7	0.1	30
0.6	4	0.8	0.05	50
0.6	4	0.8	0.1	40
0.6	5	0.7	0.05	35
0.6	5	0.7	0.1	27
0.6	5	0.8	0.05	45
0.6	5	0.8	0.1	36

The sample size decreased as the effect size (rate ratio) increased and as the study duration increased. The effect of size seems to have a particularly large effect on the required sample size. For example, a minimum of 968 sites would be required to detect a 10% reduction in the number of crashes per mile-year, with 80% power at a significance level of 0.1 for a 3-year study. However, the number of sites needed reduces to 223, 91, and 46 if the expected reductions were 20, 30, and 40%, respectively, and everything else stayed constant. Consistent with the findings in Srinivasan et al. (2009), the sample size needed to detect a reduction smaller than 10% would likely be prohibitively large.

Based on the results in Table 9, the expected lifespan of the treatments and the range of CMFs observed in the literature (see Tables 3 and 5), a sample size of 100 was recommended for this study. This sample size was sufficient to determine a 30% reduction in crashes with 80% power and 90% confidence. For the purposes of this study, a 30% reduction was considered meaningful because it would suggest approximately 0.5 crashes per mile-year post treatment. On the other hand, the larger sample sizes needed to detect smaller reductions and the expected number of crashes per mile-year post treatment implied by such reductions would perhaps make a study based on an expected small percentage reduction not worthwhile. CMF estimates may be determined with greater power, and a smaller reduction in crashes may be detectable if a longer study duration is used. Likewise, the same would be true if the event rate in the reference group turns out to be higher than assumed—such as for subgroups and strata with higher event rates or for sites with nonzero crash experience.

Treatment Assignment

With the sample size determined, each site in the sampling frame was assigned to one of the two treatment types or to the reference group. The assignment to any of the three groups was random, such that each site in the sampling frame had the same probability of being placed into one of the groups. Random assignment was used to even the playing field and increase confidence that any observed differences post treatment could be reasonably attributed to the treatment.

Site Selection

Before selection, each of the 16 strata defined previously was further divided into six smaller subgroups based on the following levels of the crashes per mile-year variable: 0, 0–1.5, 1.5–3.0, 3.0–4.5, 4.5–6.0, and > 6.0. This division resulted in 96 potential strata. Some of these strata had zero or only a few (less than 25) and were merged into adjacent strata. The final sampling frame consisted of 46 strata (Table 10).

A random sample of size 120 was selected from each set of candidate treatment or reference sites. The 120 sites (an additional 20%) were selected instead of the recommended sample size of 100 to allow for the possibility that some of the selected sites might not be viable for reasons such as the presence of other treatment types. In each case, the 120 sites were sampled from the different strata, with the number of sites selected from each stratum being proportional to the size of the stratum.

Table 10. Characteristics of the Final Stratification Scheme Used for Sampling

Stratum ID	Speed Limit (mph)	Curve Radius (feet)	Segment Length (feet)	AADT (veh/day)	Crashes per Mile-Year	Number of Segments	Length (miles)	Total Crashes	Crashes per Mile-Year
1	< 45	< 500	< 700	< 650	0	1,472	166.6	0	0.00
2	< 45	< 500	< 700	< 650	> 0, ≤ 3.0	161	18.4	161	1.75
3	< 45	< 500	< 700	< 650	> 3.0	26	2.9	59	4.04
4	< 45	< 500	< 700	≥ 650	0	287	32.4	0	0.00
5	< 45	< 500	< 700	≥ 650	> 0, ≤ 3.0	81	9.2	81	1.77
6	< 45	< 500	< 700	≥ 650	> 3.0	61	6.9	176	5.11
7	< 45	< 500	≥ 700	< 650	0	706	115.8	0	0.00
8	< 45	< 500	≥ 700	< 650	> 0, ≤ 1.5	96	15.9	97	1.22
9	< 45	< 500	≥ 700	< 650	> 1.5	28	4.4	59	2.68
10	< 45	< 500	≥ 700	≥ 650	0	91	14.9	0	0.00
11	< 45	< 500	≥ 700	≥ 650	> 0, ≤ 1.5	58	9.6	58	1.20
12	< 45	< 500	≥ 700	≥ 650	> 1.5	46	7.3	117	3.20
13	< 45	≥ 500	< 700	< 650	0	458	51.7	0	0.00
14	< 45	≥ 500	< 700	< 650	> 0	46	5.2	48	1.84
15	< 45	≥ 500	< 700	≥ 650	0	203	22.9	0	0.00
16	< 45	≥ 500	< 700	≥ 650	> 0, ≤ 3.0	65	7.4	65	1.76
17	< 45	≥ 500	< 700	≥ 650	> 3.0	25	2.8	57	4.10
18	< 45	≥ 500	≥ 700	< 650	0	205	35.0	0	0.00
19	< 45	≥ 500	≥ 700	< 650	> 0	38	6.6	40	1.21
20	< 45	≥ 500	≥ 700	≥ 650	0	91	15.1	0	0.00
21	< 45	≥ 500	≥ 700	≥ 650	> 0	63	10.9	105	1.94
22	≥ 45	< 500	< 700	< 650	0	659	75.2	0	0.00
23	≥ 45	< 500	< 700	< 650	> 0, ≤ 3.0	118	13.5	118	1.75
24	≥ 45	< 500	< 700	< 650	> 3.0	31	3.6	81	4.53
25	≥ 45	< 500	< 700	≥ 650	0	296	33.7	0	0.00
26	≥ 45	< 500	< 700	≥ 650	> 0, ≤ 3.0	149	16.9	149	1.77
27	≥ 45	< 500	< 700	≥ 650	> 3.0	134	15.4	399	5.18
28	≥ 45	< 500	≥ 700	< 650	0	377	63.8	0	0.00

Stratum ID	Speed Limit (mph)	Curve Radius (feet)	Segment Length (feet)	AADT (veh/day)	Crashes per Mile-Year	Number of Segments	Length (miles)	Total Crashes	Crashes per Mile-Year
29	≥ 45	< 500	≥ 700	< 650	> 0, ≤ 1.5	78	13.8	79	1.15
30	≥ 45	< 500	≥ 700	< 650	> 1.5	28	4.4	66	2.98
31	≥ 45	< 500	≥ 700	≥ 650	0	199	33.6	0	0.00
32	≥ 45	< 500	≥ 700	≥ 650	> 0, ≤ 1.5	118	20.5	120	1.17
33	≥ 45	< 500	≥ 700	≥ 650	> 1.5, ≤ 3.0	77	13.6	164	2.40
34	≥ 45	< 500	≥ 700	≥ 650	> 3.0	45	7.4	215	5.78
35	≥ 45	≥ 500	< 700	< 650	0	472	53.5	0	0.00
36	≥ 45	≥ 500	< 700	< 650	> 0	63	7.3	76	2.10
37	≥ 45	≥ 500	< 700	≥ 650	0	869	99.5	0	0.00
38	≥ 45	≥ 500	< 700	≥ 650	> 0, ≤ 3.0	378	43.6	378	1.73
39	≥ 45	≥ 500	< 700	≥ 650	> 3.0	209	24.4	566	4.63
40	≥ 45	≥ 500	≥ 700	< 650	0	321	55.8	0	0.00
41	≥ 45	≥ 500	≥ 700	< 650	> 0	60	11.0	70	1.28
42	≥ 45	≥ 500	≥ 700	≥ 650	0	785	139.2	0	0.00
43	≥ 45	≥ 500	≥ 700	≥ 650	> 0, ≤ 1.5	556	107.1	584	1.09
44	≥ 45	≥ 500	≥ 700	≥ 650	> 1.5, ≤ 3.0	286	55.8	630	2.26
45	≥ 45	≥ 500	≥ 700	≥ 650	> 3.0, ≤ 6.0	133	24.8	485	3.92
46	≥ 45	≥ 500	≥ 700	≥ 650	> 6.0	30	5.2	223	8.56

AADT = annual average daily traffic; ID = identification.

Comparability of Treatment and Comparison Groups

Candidate reference groups were assessed for appropriateness by evaluating the sequence of odds ratio estimates determined for pairs of consecutive years in the period before treatment. The odds ratios were estimated for the sampled sites using Equation 1. Table 11 summarizes the results. Appendix A (Tables A1, A2, and A3) presents detailed lists of the proposed candidate reference group, PMD, and CWMM treatment sites.

Table 11. Odds Ratio Estimates for Crash Counts in the Sampled Sites

Year	Reference Group	PMD Treatment		CWMM Treatment	
	Observed Crashes	Observed Crashes	Odds Ratio	Observed Crashes	Odds Ratio
2019	12	9	NA	10	NA
2020	18	15	0.95	15	0.87
2021	12	10	0.87	10	0.87
2022	15	15	1.03	13	0.89
2023	9	12	1.13	10	1.08

CWMM = curve warning message markings; PMD = post-mounted delineator; NA = not applicable.

The mean of the sequence of odds ratios was estimated as 1.00 (95% confidence interval 0.78 to 1.21) and 0.93 (95% confidence interval 0.73 to 1.13) for the PMD treatment sites and CWM treatment sites, respectively. Because in both cases the confidence interval included the value 1.0, the reference group was deemed appropriate.

DISCUSSION

Several approaches for phase 2 and outcomes should be considered. Some concern may arise that the recommended sample size of 100 may not be sufficient for PMDs because the sample size is based on a 30% reduction in crashes, whereas a 10 to 15% reduction may be expected from CMFs in Table 3. One possible scenario that may revise the sampling plan is prioritizing one or both countermeasures for roads that exceed a determined AADT threshold or number of crashes. Other approaches are possible as well, such as revising other variables that determine the sample size. PMDs and CWMMs are 2 of the 16 countermeasures in Table 6 for the HSIP TLRR initiative (VDOT, 2024b). Because more commonly used countermeasures may be preferred, more consideration or priority may need to be given to PMDs and CWMMs. These approaches and others may be considered in phase 2, with greater input from TRP and other VDOT staff that are stakeholders in this effort.

CONCLUSIONS

- *The VDOT HSIP TLRR countermeasure reference sheets provide sufficient specification, design and guidance detail for the two countermeasures to merit adoption for this project effort* (VDOT, 2023a, 2023b, 2024b).

- *For both countermeasures, a sample size of approximately 100 sites was determined to be sufficient to detect a meaningful treatment effect with adequate statistical power.*

- *The reference group of sites identified in this study seems appropriate for use with both countermeasures.* In both cases the test of comparability indicated that the odds ratio estimates were not statistically significantly different from 1.0.

RECOMMENDATION

1. *It is recommended that VTRC undertake a phase 2 research effort to implement the sampling plan developed in this phase 1 study. The phase 2 effort should be conducted in close coordination with the HSIP TLRR* initiative (VDOT, 2024b).

IMPLEMENTATION AND BENEFITS

Researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and to determine the benefits of doing so. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

To implement the sampling plan for potential sites for PMDs and CWMMs, a funding source is needed to review and screen potential sites, then plan and install the devices. The HSIP TLRR initiative is completing the planning for many sites (VDOT, 2024b). Sites have been selected and planning is under way to develop and advertise contracts to install the selected countermeasures. In some districts, VDOT staff may install some countermeasures. A small number of PMDs and CWMMs may possibly be included in this effort. These sites will be considered for the sampling plan and undergo screening. The TLRR initiative most likely will continue. If so, an opportunity to include PMDs and CWMMs as key countermeasures and to coordinate the research and HSIP efforts will be available, which will likely involve revising the sampling plan developed and presented in this report. The HSIP Project Delivery Program Manager has agreed to work closely with the research team, HSIP support contractors, and Districts to coordinate these efforts. A backup plan would fund implementation through the VTRC implementation program at a much smaller scale, which would require revising the sampling plan in the phase 2 research effort. Implementation (that is, beginning the process of implementing the sampling plan) is expected to begin within 12 months of the report’s publication.

Benefits

VDOT has been devoting significant resources and attention to strategies that prevent RDCs, given that from 2015 to 2020, RDCs constituted about 52% (2,400 of 4,650) of fatal crashes in Virginia. This study fits well into current VDOT safety programs, policies, and initiatives for reducing RDCs. Positive research results, demonstrating beneficial return on investment, would provide additional countermeasures statewide for RDCs, which will facilitate comparisons to commonly used countermeasures, such as the chevron sign, and benefit the ongoing systemic safety program. VDOT will benefit from developing CMFs specific to Virginia by determining the expected return on investment in phase 3. The phase 2 study is critical in providing the foundation for development of credible CMFs.

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APPENDIX A

Table A-1. Potential Sites for Post-Mounted Delineator Deployment

Route	District	Speed Limit (mph)	Start Milepost	End Milepost	Radius (feet)	AADT (2019–2023)	Crashes (2019–2023)
R-VA013SC00639EB	Bristol	25	4.6	4.7	181.7	132	0
R-VA013SC00638EB	Bristol	40	19.2	19.3	390.3	376	0
R-VA098SC00619EB	Bristol	40	26.5	26.6	264.4	420	0
R-VA010SC00604EB	Bristol	35	1.5	1.6	324.2	270	0
R-VA097SC00699EB	Bristol	25	0.8	1.0	217.5	746	0
R-VA097SC00671EB	Bristol	40	6.1	6.2	118.7	1,178	0
R-VA095SC00714NB	Bristol	35	4.9	5.1	323.8	825	2
R-VA038SC00785NB	Bristol	40	1.4	1.6	477.5	208	0
R-VA098SC00617EB	Bristol	35	3.1	3.2	581.9	302	0
R-VA US00058EB	Bristol	40	71.5	71.6	1,384.0	2,871	0
R-VA092SC00738EB	Bristol	30	0.3	0.4	613.6	118	0
R-VA SR00016NB	Bristol	55	53.4	53.5	176.4	236	0
R-VA SR00070NB	Bristol	55	8.4	8.5	396.8	696	1
R-VA SR00016NB	Bristol	55	15.7	15.8	310.6	941	2
R-VA US00058EB	Bristol	55	158.0	158.3	493.3	439	0
R-VA SR00160EB	Bristol	55	1.7	1.9	172.7	224	1
R-VA SR00072NB	Bristol	55	46.7	46.8	642.2	1,336	0
R-VA SR00042NB	Bristol	55	21.2	21.4	582.2	136	0
R-VA002SC01555NB	Culpeper	25	0.1	0.3	234.6	360	0
R-VA032SC00645NB	Culpeper	40	1.0	1.1	236.7	851	0
R-VA023SC00610EB	Culpeper	35	10.5	10.6	799.5	547	0
R-VA032SC00656EB	Culpeper	25	0.6	0.7	881.3	167	0
R-VA US00029NBBUS009	Culpeper	35	1.4	1.5	1,432.0	2,738	0
R-VA068SC00692NB	Culpeper	45	11.0	11.2	166.4	108	0
R-VA032SC00639EB	Culpeper	50	2.9	3.1	346.5	462	0
R-VA002SC00664EB	Culpeper	45	2.7	2.9	418.6	693	0
R-VA068SC00644NB	Culpeper	45	3.4	3.6	395.0	1,210	2
R-VA056SC00629EB	Culpeper	45	1.9	2.0	716.1	418	0
R-VA US00522NB	Culpeper	55	34.7	34.8	773.7	5,758	1
R-VA US00015NBBUS003	Culpeper	55	0.3	0.4	1,481.8	1,869	1
R-VA023SC00729NB	Culpeper	50	3.4	3.6	528.9	2,048	1
R-VA SR00230EB	Culpeper	55	2.8	2.9	1,108.6	4,078	2
R-VA028SC01070NB	Fredericksburg	25	0.4	0.5	306.6	316	0
R-VA016SC00609NB	Fredericksburg	35	1.4	1.5	428.9	136	0
R-VA051SC00673NB	Fredericksburg	35	0.1	0.3	350.8	195	0
R-VA049SC00609EB	Fredericksburg	40	11.1	11.3	498.2	133	0
R-VA066SC00800NB	Fredericksburg	25	0.6	0.8	306.9	147	0
R-VA079SC00624NB	Fredericksburg	45	15.3	15.5	464.3	720	0

Route	District	Speed Limit (mph)	Start Milepost	End Milepost	Radius (feet)	AADT (2019–2023)	Crashes (2019–2023)
R-VA050SC00628EB	Fredericksburg	45	0.9	1.0	716.1	248	0
R-VA SR00203EB	Fredericksburg	55	1.0	1.1	1,494.5	2,310	0
R-VA051SC00622EB	Fredericksburg	45	4.5	4.6	528.5	708	0
R-VA SR00218EB	Fredericksburg	45	15.0	15.2	929.1	3,534	2
R-VA047SC00606EB	Hampton Roads	35	5.3	5.4	202.1	406	1
R-VA087SC00646NB	Hampton Roads	25	3.7	3.9	413.6	541	1
R-VA046SC00603EB	Hampton Roads	35	11.4	11.5	731.4	1,403	3
R-VA SR00035NB	Hampton Roads	55	9.1	9.2	1,184.9	1,677	0
R-VA SR00010EB	Hampton Roads	55	42.5	42.7	1,598.9	1,777	0
R-VA006SC00647NB	Lynchburg	35	6.3	6.4	291.4	427	1
R-VA019SC00727NB	Lynchburg	35	2.9	3.0	904.6	1,323	0
R-VA041SC00621EB	Lynchburg	45	14.9	15.0	354.1	224	0
R-VA014SC00665NB	Lynchburg	45	2.4	2.5	318.2	433	1
R-VA015SC00622EB	Lynchburg	45	10.3	10.5	347.0	695	0
R-VA071SC00649EB	Lynchburg	45	19.2	19.3	572.3	319	0
R-VA005SC00608EB	Lynchburg	45	5.5	5.7	716.1	196	0
R-VA015SC00684EB	Lynchburg	45	2.7	2.8	648.5	271	0
R-VA041SC00613EB	Lynchburg	45	3.3	3.4	554.4	416	3
R-VA US00060EB	Lynchburg	55	108.5	108.6	1,074.3	889	0
R-VA041SC00716EB	Lynchburg	45	7.6	7.7	572.6	276	0
R-VA071SC00655EB	Lynchburg	45	2.5	2.6	818.4	631	0
R-VA062SC00657NB	Lynchburg	55	1.8	2.0	687.2	784	0
R-VA SR00024EB	Lynchburg	55	55.5	55.7	1,296.9	4,333	0
R-VA SR00130EB	Lynchburg	55	28.2	28.4	1,718.7	6,411	1
R-VA SR00360EB	Lynchburg	55	13.8	14.0	799.1	979	1
R-VA073SC00643NB	Lynchburg	45	2.0	2.2	624.4	1,685	3
R-VA063SC00619EB	Richmond	40	0.2	0.3	261.6	527	0
R-VA063SC00627NB	Richmond	40	7.3	7.5	349.9	912	1
R-VA072SC00645NB	Richmond	35	1.5	1.6	563.0	112	0
R-VA058SC00779NB	Richmond	45	0.9	1.0	399.2	167	0
R-VA018SC00650EB	Richmond	45	2.3	2.4	154.5	401	0
R-VA037SC00603NB	Richmond	45	8.8	9.0	365.6	172	0
R-VA020SC00630EB	Richmond	45	2.2	2.4	498.1	720	0
R-VA020SC00602EB	Richmond	45	9.8	9.9	483.9	2,235	1
R-VA058SC00621NB	Richmond	45	5.0	5.1	715.9	360	0
R-VA SR00137EB	Richmond	55	11.0	11.1	1,402.9	654	0
R-VA063SC00613EB	Richmond	45	3.3	3.4	1,108.6	2,096	0
R-VA SR00273NB	Richmond	45	1.3	1.5	818.4	4,317	0
R-VA SR00153NB	Richmond	55	14.8	14.9	1,346.6	5,048	1
R-VA SR00005EB	Richmond	55	20.2	20.3	550.7	5,148	1
R-VA SR00049NB	Richmond	55	60.4	60.6	1,165.1	1,420	0

Route	District	Speed Limit (mph)	Start Milepost	End Milepost	Radius (feet)	AADT (2019–2023)	Crashes (2019–2023)
R-VA SR00153NB	Richmond	55	3.5	3.6	982.1	2,610	0
R-VA SR00040EB	Richmond	55	161.2	161.6	1,297.0	1,299	2
R-VA US00033EB	Richmond	55	107.2	107.4	953.8	5,053	2
R-VA009SC00832EB	Salem	25	0.2	0.3	179.7	159	0
R-VA009SC00644EB	Salem	40	16.4	16.5	140.7	319	0
R-VA009SC00608NB	Salem	35	21.1	21.2	147.9	360	0
R-VA031SC00739EB	Salem	35	6.4	6.5	361.0	101	0
R-VA009SC00734NB	Salem	30	6.5	6.6	194.8	291	0
R-VA009SC00616NB	Salem	40	8.2	8.3	424.4	210	0
R-VA033SC00657NB	Salem	35	1.3	1.4	452.0	102	0
R-VA077SC00624NB	Salem	25	2.8	3.0	177.1	1,051	0
R-VA060SC00806NB	Salem	25	0.7	0.9	244.0	188	0
R-VA033SC00707EB	Salem	35	3.1	3.2	350.5	262	0
R-VA011SC00648NB	Salem	30	1.4	1.6	483.9	275	0
R-VA033SC00707EB	Salem	35	4.0	4.1	904.6	262	0
R-VA033SC00890EB	Salem	40	9.0	9.1	904.7	701	1
R-VA009SC00644EB	Salem	45	3.8	3.9	221.6	136	0
R-VA070SC00660NB	Salem	45	2.8	2.9	283.8	228	0
R-VA US00221NB	Salem	55	36.2	36.4	485.9	2,494	0
R-VA SR00116NB	Salem	55	9.7	9.9	338.3	6,832	7
R-VA SR00043NB	Salem	55	43.6	43.8	279.6	396	0
R-VA033SC00674EB	Salem	45	7.7	7.9	343.4	764	0
R-VA SR00043NB	Salem	55	25.2	25.3	763.7	1,813	0
R-VA SR00122NB	Salem	45	15.1	15.2	929.0	12,624	3
R-VA SR00100NB	Salem	55	5.8	5.9	763.7	3,503	0
R-VA SR00122NB	Salem	55	1.0	1.2	1,858.1	5,004	0
R-VA SR00043NB	Salem	55	47.7	47.8	693.9	1,585	2
R-VA034SC00692NB	Staunton	35	3.3	3.4	137.7	216	0
R-VA021SC00604NB	Staunton	35	3.6	3.8	200.9	107	0
R-VA082SC00617NB	Staunton	30	5.8	5.9	377.6	1,451	3
R-VA034SC00619NB	Staunton	45	2.1	2.2	272.6	461	0
R-VA SR00263EB	Staunton	45	3.2	3.3	437.2	1,966	0
R-VA US00250EB	Staunton	55	19.9	20.0	442.5	1,077	1
R-VA US00033EB	Staunton	45	15.8	15.9	1,562.4	9,285	0
R-VA SR00039EB	Staunton	55	19.6	19.7	838.4	1,496	0
R-VA069SC00638NB	Staunton	45	8.2	8.3	673.4	799	0
R-VA SR00055EB	Staunton	55	0.6	0.7	582.7	3,026	2
R-VA SR00269EB	Staunton	55	1.6	1.7	680.4	486	2
R-VA SR00042NB	Staunton	55	161.4	161.6	880.6	701	1
R-VA SR00039EB	Staunton	55	28.0	28.1	1,718.3	1,640	1

AADT = annual average daily traffic.

Table A-2. Potential Sites for Curve Warning Message Markings Deployment

Route	District	Speed Limit (mph)	Start Milepost	End Milepost	Radius (feet)	AADT (2019–2023)	Crashes (2019–2023)
R-VA025SC00621NB	Bristol	25	0.5	0.6	222.8	131	0
R-VA052SC00606NB	Bristol	25	16.5	16.6	100.2	587	0
R-VA052SC00611NB	Bristol	35	4.9	5.0	365.2	161	0
R-VA025SC00631NB	Bristol	30	10.7	10.8	227.4	141	0
R-VA092SC00637NB	Bristol	35	17.3	17.4	300.7	160	0
R-VA098SC00690EB	Bristol	35	1.7	1.9	288.6	509	0
R-VA092SC00637NB	Bristol	35	8.0	8.1	263.9	180	1
R-VA092SC00644EB	Bristol	40	13.4	13.5	435.0	772	0
R-VA SR00083EB	Bristol	40	50.6	50.7	432.3	2,650	1
R-VA084SC00665NB	Bristol	35	9.2	9.3	199.8	125	0
R-VA083SC00653NB	Bristol	25	0.8	0.9	118.8	238	0
R-VA092SC00624NB	Bristol	30	4.7	4.9	491.0	298	0
R-VA038SC00634EB	Bristol	35	3.9	4.0	603.0	144	0
R-VA SR00042NB	Bristol	35	22.5	22.7	881.4	136	1
R-VA086SC00610EB	Bristol	45	16.7	16.8	330.5	163	0
R-VA038SC00603EB	Bristol	45	4.8	4.9	233.8	297	0
R-VA US00052NB	Bristol	55	57.5	57.6	345.4	791	0
R-VA SR00063NB	Bristol	55	29.6	29.8	345.6	822	1
R-VA SR00160EB	Bristol	55	5.9	6.1	545.8	224	0
R-VA SR00598NB	Bristol	55	1.1	1.2	723.1	152	0
R-VA SR00016NB	Bristol	45	30.7	30.8	968.3	2,007	0
R-VA US00011NB	Bristol	55	32.0	32.2	1,408.9	2,632	0
R-VA SR00042NB	Bristol	55	42.0	42.1	981.0	2,584	1
R-VA095SC00762EB	Bristol	45	4.3	4.4	513.0	510	1
R-VA SR00083EB	Bristol	55	25.2	25.3	903.9	2,658	0
R-VA002SC00637EB	Culpeper	35	12.2	12.4	435.0	1,475	0
R-VA039SC00624NB	Culpeper	35	0.2	0.3	213.5	249	1
R-VA054SC00628NB	Culpeper	45	2.8	2.9	137.5	419	0
R-VA054SC00648NB	Culpeper	45	0.8	0.9	399.7	936	0
R-VA030SC00647EB	Culpeper	45	0.2	0.3	483.9	726	1
R-VA039SC00667NB	Culpeper	45	2.6	2.8	470.6	544	0
R-VA030SC00600EB	Culpeper	45	3.2	3.3	1,010.7	2,512	0
R-VA US00033EB	Culpeper	55	90.9	91.0	976.3	3,182	0
R-VA SR00020NB	Culpeper	55	73.5	73.7	1,599.0	9,436	3
R-VA089SC01496NB	Fredericksburg	25	0.2	0.4	274.4	297	0
R-VA050SC01238NB	Fredericksburg	25	0.1	0.2	212.1	140	0
R-VA028SC01060EB	Fredericksburg	35	0.9	1.0	232.0	204	0
R-VA089SC00724EB	Fredericksburg	30	0.2	0.3	490.8	305	0
R-VA050SC00615NB	Fredericksburg	40	4.8	4.9	298.6	315	0
R-VA089SC00614NB	Fredericksburg	40	0.9	1.0	291.2	814	2

Route	District	Speed Limit (mph)	Start Milepost	End Milepost	Radius (feet)	AADT (2019–2023)	Crashes (2019–2023)
R-VA088SC00606EB	Fredericksburg	35	19.3	19.4	1,145.6	14,247	4
R-VA048SC00629EB	Fredericksburg	45	4.0	4.2	358.1	397	1
R-VA079SC00624NB	Fredericksburg	45	9.6	9.7	554.1	1,052	0
R-VA SR00003EB	Fredericksburg	55	65.6	65.7	1,041.8	7,150	1
R-VA096SC00645EB	Fredericksburg	45	5.2	5.3	715.9	815	1
R-VA089SC00651EB	Fredericksburg	45	2.5	2.6	1,108.8	3,395	2
R-VA SR00002NB	Fredericksburg	55	45.4	45.5	1,676.7	5,257	0
R-VA SR00198EB	Fredericksburg	55	14.8	14.9	2,455.0	3,980	0
R-VA096SC00631NB	Fredericksburg	45	1.2	1.4	982.2	3,501	2
R-VA065SC00606NB	Hampton Roads	35	1.1	1.2	715.7	662	0
R-VA US00258EB	Hampton Roads	35	23.9	24.0	1562.4	3,159	0
R-VA US00258EB	Hampton Roads	55	25.8	26.1	2,095.9	5,431	1
R-VA073SC00688NB	Lynchburg	35	0.5	0.7	174.6	155	0
R-VA005SC00609NB	Lynchburg	35	0.7	0.8	223.1	181	0
R-VA062SC00634NB	Lynchburg	25	4.3	4.4	470.5	425	0
R-VA014SC00670NB	Lynchburg	35	3.4	3.6	196.4	686	0
R-VA071SC00845EB	Lynchburg	35	2.4	2.5	881.1	124	0
R-VA015SC00615EB	Lynchburg	35	15.7	15.8	1,108.6	445	0
R-VA024SC00600NB	Lynchburg	25	14.9	15.0	648.6	408	0
R-VA014SC00609NB	Lynchburg	55	3.8	4.0	385.9	126	0
R-VA005SC00608EB	Lynchburg	45	3.7	3.8	192.7	196	0
R-VA SR00043NB	Lynchburg	55	8.9	9.2	373.0	255	0
R-VA SR00056EB	Lynchburg	55	51.8	51.9	346.3	391	0
R-VA041SC00603EB	Lynchburg	45	7.8	7.9	545.7	549	0
R-VA014SC00652NB	Lynchburg	55	11.3	11.4	1,145.9	548	0
R-VA US00060EB	Lynchburg	55	104.5	104.6	1,161.4	1,581	0
R-VA US00060EB	Lynchburg	55	84.9	85.0	859.2	1,625	2
R-VA073SC00695EB	Lynchburg	45	3.0	3.1	505.2	309	0
R-VA SR00056EB	Lynchburg	55	42.2	42.4	881.0	883	0
R-VA071SC00844NB	Lynchburg	45	4.4	4.7	686.8	1,880	1
R-VA SR00006EB	Lynchburg	55	13.2	13.4	996.3	4,345	3
R-VA US00060EB	Lynchburg	55	89.2	89.3	987.3	2,421	4
R-VA053SC01156EB	Northern Virginia	25	0.1	0.2	343.8	263	0
R-VA076SC00619EB	Northern Virginia	45	17.5	17.6	333.7	2,797	2
R-VA037SC00634NB	Richmond	40	5.9	6.0	323.8	195	0
R-VA063SC00644NB	Richmond	35	0.5	0.7	838.1	209	0
R-VA067SC00618EB	Richmond	25	3.0	3.1	582.6	376	0
R-VA US00360EBBUS003	Richmond	35	0.9	1.0	1,998.8	1,961	0
R-VA055SC00701NB	Richmond	45	1.4	1.6	429.4	288	0
R-VA042SC00605EB	Richmond	45	7.6	7.7	210.7	340	1
R-VA058SC00655NB	Richmond	45	3.4	3.5	204.2	593	2

Route	District	Speed Limit (mph)	Start Milepost	End Milepost	Radius (feet)	AADT (2019–2023)	Crashes (2019–2023)
R-VA037SC00606NB	Richmond	45	1.7	1.9	306.7	837	0
R-VA SR00046NB	Richmond	55	0.5	0.6	1,527.3	1,377	0
R-VA SR00006EB	Richmond	55	85.0	85.1	1,562.3	5,515	0
R-VA SR00005EB	Richmond	45	21.2	21.3	1,273.3	5,148	0
R-VA026SC00624NB	Richmond	45	11.8	11.9	982.0	288	0
R-VA SR00006EB	Richmond	55	79.9	80.2	1,808.9	4,352	0
R-VA072SC00614NB	Richmond	45	2.3	2.5	537.2	696	0
R-VA SR00040EB	Richmond	55	159.3	159.5	586.9	1,299	1
R-VA SR00049NB	Richmond	55	20.4	20.6	1,808.9	1,781	1
R-VA US00033EB	Richmond	55	108.9	109.0	760.5	5,053	1
R-VA033SC00643NB	Salem	35	1.3	1.5	321.2	585	0
R-VA033SC00602NB	Salem	25	1.7	1.8	262.5	173	0
R-VA011SC00640EB	Salem	40	0.5	0.6	413.6	941	0
R-VA060SC01255EB	Salem	25	1.1	1.3	191.3	297	0
R-VA009SC00695NB	Salem	35	8.6	8.7	193.0	148	0
R-VA033SC00821NB	Salem	40	1.5	1.6	260.3	243	0
R-VA033SC01105NB	Salem	25	0.4	0.6	227.6	153	0
R-VA044SC00606NB	Salem	40	9.7	10.0	390.2	955	1
R-VA070SC00728NB	Salem	35	0.3	0.4	537.0	277	0
R-VA033SC00945NB	Salem	45	1.2	1.4	286.1	1,443	0
R-VA031SC00681EB	Salem	45	2.4	2.5	470.9	880	1
R-VA044SC00610NB	Salem	45	6.9	7.1	419.2	875	0
R-VA031SC00681EB	Salem	45	6.4	6.6	673.5	537	0
R-VA SR00043NB	Salem	55	54.7	54.8	1,011.2	656	0
R-VA SR00024EB	Salem	55	21.9	22.1	892.6	2,364	1
R-VA081SC00679NB	Staunton	25	1.0	1.1	233.8	502	1
R-VA081SC00631EB	Staunton	30	11.9	12.0	763.8	1,466	1
R-VA007SC00657NB	Staunton	45	2.2	2.3	293.8	335	0
R-VA034SC00641NB	Staunton	45	1.3	1.4	244.7	1,347	2
R-VA007SC00608NB	Staunton	45	6.3	6.5	303.6	528	0
R-VA SR00018NB	Staunton	55	16.8	17.0	256.7	1,270	2
R-VA US00250EB	Staunton	55	1.2	1.3	943.5	331	0
R-VA SR00252NB	Staunton	55	12.4	12.5	608.1	288	1
R-VA US00340NB	Staunton	55	84.4	84.5	2,203.4	5,429	0
R-VA SR00042NB	Staunton	55	195.5	195.6	781.0	3,257	1
R-VA US00250EB	Staunton	55	5.8	6.1	933.4	331	0
R-VA US00220NB	Staunton	55	152.1	152.3	671.2	812	0
R-VA US00033EB	Staunton	55	43.7	43.9	1,321.4	6,853	0
R-VA SR00039EB	Staunton	55	24.9	25.1	848.5	1,640	2
R-VA US00340NB	Staunton	55	81.5	81.6	1,363.0	4,521	2

AADT = annual average daily traffic.

Table A-3. Potential Reference Sites

Route	District	Speed Limit (mph)	Start Milepost	End Milepost	Radius (feet)	AADT (2019–2023)	Crashes (2019–2023)
R-VA010SC00612EB	Bristol	35	10.5	10.6	163.0	139	0
R-VA013SC00660NB	Bristol	25	0.8	0.9	236.7	218	0
R-VA038SC00624NB	Bristol	35	4.7	4.8	286.5	570	0
R-VA013SC00648EB	Bristol	30	1.1	1.3	261.7	128	0
R-VA097SC00738NB	Bristol	25	0.3	0.5	207.6	454	0
R-VA010SC00620EB	Bristol	25	1.2	1.3	270.0	144	0
R-VA092SC00644EB	Bristol	40	12.9	13.1	204.0	772	0
R-VA092SC00699NB	Bristol	35	0.3	0.4	377.7	953	0
R-VA025SC00631NB	Bristol	40	8.2	8.3	377.3	173	0
R-VA038SC00711EB	Bristol	35	8.3	8.4	395.1	241	0
R-VA086SC00637NB	Bristol	35	0.4	0.6	190.5	758	1
R-VA084SC00619NB	Bristol	35	6.3	6.5	624.9	545	0
R-VA098SC00644EB	Bristol	35	3.1	3.3	687.3	174	0
R-VA083SC00615EB	Bristol	45	20.2	20.3	202.1	154	0
R-VA025SC00652NB	Bristol	45	20.4	20.5	124.9	118	0
R-VA US00058EB	Bristol	55	140.9	141.0	346.7	442	0
R-VA US00052NB	Bristol	55	60.2	60.3	270.7	184	0
R-VA US00058EB	Bristol	55	126.2	126.5	463.8	532	0
R-VA038SC00882NB	Bristol	45	0.8	1.0	498.2	808	0
R-VA US00052NB	Bristol	55	76.8	76.9	1,145.2	570	0
R-VA SR00063NB	Bristol	55	1.2	1.3	1,561.5	3,913	0
R-VA SR00016NB	Bristol	55	13.2	13.3	701.3	1,291	0
R-VA SR00061EB	Bristol	55	15.5	15.7	996.2	411	0
R-VA030SC00688NB	Culpeper	40	25.3	25.5	205.7	206	0
R-VA032SC00626NB	Culpeper	40	0.3	0.4	491.0	298	0
R-VA002SC00676NB	Culpeper	35	2.8	2.9	429.3	340	0
R-VA054SC00850NB	Culpeper	35	0.7	0.8	747.0	224	0
R-VA032SC00631NB	Culpeper	45	6.8	6.9	299.0	353	0
R-VA054SC00639EB	Culpeper	50	5.2	5.4	229.1	374	0
R-VA023SC00711EB	Culpeper	45	1.8	1.9	429.7	209	0
R-VA032SC00640NB	Culpeper	45	9.0	9.1	572.8	1,170	1
R-VA032SC00629EB	Culpeper	45	2.2	2.3	513.0	148	1
R-VA SR00231NB	Culpeper	55	18.5	18.7	673.1	1,291	0
R-VA016SC00613NB	Fredericksburg	30	0.0	0.1	404.3	111	0
R-VA079SC00612EB	Fredericksburg	35	3.7	3.8	314.8	194	1
R-VA088SC00667NB	Fredericksburg	25	0.9	1.1	347.2	114	0
R-VA016SC00601EB	Fredericksburg	40	13.3	13.4	1,494.5	523	0
R-VA050SC00608EB	Fredericksburg	40	11.1	11.2	929.1	598	0
R-VA016SC00630EB	Fredericksburg	35	4.9	5.0	1,374.9	398	1
R-VA088SC00656NB	Fredericksburg	35	3.4	3.5	563.4	1,034	0

Route	District	Speed Limit (mph)	Start Milepost	End Milepost	Radius (feet)	AADT (2019–2023)	Crashes (2019–2023)
R-VA057SC00611EB	Fredericksburg	25	3.5	3.6	687.5	704	0
R-VA088SC00605EB	Fredericksburg	40	9.4	9.5	505.4	1,509	1
R-VA048SC00609NB	Fredericksburg	25	1.6	1.8	929.0	1,726	1
R-VA SR00218EB	Fredericksburg	45	16.2	16.3	424.6	3,534	2
R-VA SR00003EB	Fredericksburg	55	96.7	96.9	2,021.5	4,784	0
R-VA036SC00629NB	Fredericksburg	45	7.1	7.3	928.7	2,923	1
R-VA US00301NB	Hampton Roads	55	25.7	25.8	826.3	958	0
R-VA US00258EB	Hampton Roads	55	34.0	34.3	1,210.4	4,728	1
R-VA SR00180EB	Hampton Roads	55	9.6	9.8	2,546.2	1,188	2
R-VA SR00180EB	Hampton Roads	55	6.9	7.4	2,291.5	1,188	4
R-VA024SC00600NB	Lynchburg	25	8.4	8.5	603.0	279	0
R-VA SR00059EB	Lynchburg	40	0.2	0.4	1,322.1	1,452	0
R-VA041SC00621EB	Lynchburg	45	15.6	15.7	491.1	224	0
R-VA SR00056EB	Lynchburg	55	50.8	50.9	142.4	391	1
R-VA006SC00608EB	Lynchburg	45	3.1	3.2	414.1	935	0
R-VA071SC00750NB	Lynchburg	45	8.7	8.8	464.4	2,080	2
R-VA SR00344EB	Lynchburg	55	9.4	9.6	332.0	770	0
R-VA SR00013EB	Lynchburg	55	0.3	0.4	1,057.6	1,016	0
R-VA071SC00729NB	Lynchburg	45	9.4	9.5	636.5	2,181	0
R-VA SR00360EB	Lynchburg	55	15.7	15.9	592.3	979	2
R-VA SR00020NB	Lynchburg	55	18.5	18.7	1,432.2	5,593	4
R-VA053SC00692EB	Northern Virginia	25	1.5	1.6	235.1	165	1
R-VA053SC00663EB	Northern Virginia	25	8.9	9.0	272.1	708	1
R-VA063SC00618NB	Richmond	40	6.2	6.3	398.9	499	0
R-VA020SC00780NB	Richmond	25	1.4	1.6	428.7	361	0
R-VA012SC00675EB	Richmond	40	2.9	3.0	1,010.9	192	0
R-VA055SC00653EB	Richmond	35	1.5	1.7	582.7	373	0
R-VA037SC00669NB	Richmond	45	3.1	3.2	235.4	133	0
R-VA055SC00635NB	Richmond	45	13.2	13.3	458.0	838	0
R-VA042SC00605EB	Richmond	45	4.6	4.7	218.6	889	1
R-VA042SC00733EB	Richmond	45	1.5	1.6	513.2	603	0
R-VA012SC00646NB	Richmond	45	0.4	0.5	1,227.6	283	0
R-VA SR00046NB	Richmond	55	30.4	30.5	1,762.4	1,933	0
R-VA SR00045NB	Richmond	45	35.0	35.1	1,057.7	1,081	0
R-VA072SC00613NB	Richmond	45	1.6	1.7	701.0	4,278	1
R-VA SR00004NB	Richmond	55	8.5	8.7	1,126.9	1,166	0
R-VA SR00046NB	Richmond	55	6.2	6.4	1,403.1	1,377	0
R-VA SR00273NB	Richmond	45	0.7	0.9	1,041.4	4,317	1
R-VA009SC00734NB	Salem	30	4.0	4.2	464.2	291	0
R-VA070SC00694EB	Salem	25	7.4	7.6	281.2	352	0
R-VA009SC00660NB	Salem	35	2.9	3.0	177.9	135	0

Route	District	Speed Limit (mph)	Start Milepost	End Milepost	Radius (feet)	AADT (2019–2023)	Crashes (2019–2023)
R-VA009SC01061NB	Salem	25	0.3	0.5	154.1	130	0
R-VA022SC00615EB	Salem	35	9.3	9.4	440.6	121	0
R-VA009SC00695NB	Salem	35	7.2	7.3	414.2	148	0
R-VA044SC00681EB	Salem	35	3.7	3.9	361.6	776	0
R-VA009SC00635NB	Salem	35	5.8	5.9	95.0	203	0
R-VA044SC00632NB	Salem	35	3.9	4.0	174.8	175	0
R-VA009SC00645EB	Salem	40	5.5	5.7	471.0	478	1
R-VA033SC00688NB	Salem	40	3.5	3.6	361.6	707	0
R-VA044SC00698NB	Salem	40	8.8	9.0	458.1	2,848	2
R-VA SR00043NB	Salem	55	55.4	55.5	372.1	656	1
R-VA SR00100NB	Salem	55	38.4	38.6	358.2	4,636	7
R-VA SR00061EB	Salem	55	40.6	40.8	2,217.6	562	0
R-VA035SC00635EB	Salem	45	4.0	4.1	716.1	822	0
R-VA SR00311NB	Salem	55	24.6	24.7	771.8	1,596	1
R-VA SR00097EB	Salem	55	1.8	1.9	1,126.6	2,165	2
R-VA SR00057EB	Salem	55	41.1	41.3	1,909.8	2,109	0
R-VA US00221NB	Salem	55	34.4	34.5	1,868.2	2,494	1
R-VA SR00057EB	Salem	55	34.4	34.5	982.1	3,445	1
R-VA SR00040EB	Salem	55	40.3	40.5	848.6	6,155	3
R-VA003SC00629NB	Staunton	35	3.6	3.7	305.8	982	0
R-VA021SC00601NB	Staunton	40	2.0	2.1	166.6	1,145	9
R-VA069SC00662NB	Staunton	25	4.1	4.3	317.6	473	0
R-VA007SC00635NB	Staunton	45	6.5	6.6	390.4	959	0
R-VA SR00252NB	Staunton	55	0.0	0.2	359.3	519	0
R-VA034SC00703NB	Staunton	45	1.8	2.1	161.5	482	1
R-VA034SC00641NB	Staunton	45	0.7	0.9	390.2	1,347	1
R-VA SR00311NB	Staunton	55	48.8	48.9	1,091.1	493	0
R-VA US00220NB	Staunton	55	136.8	136.9	759.6	1,789	0
R-VA US00033EB	Staunton	55	8.7	8.8	1,302.0	1,763	0
R-VA SR00042NB	Staunton	55	214.1	214.2	686.7	2,623	1
R-VA SR00253EB	Staunton	55	8.4	8.5	2,291.6	5,781	1
R-VA082SC00613NB	Staunton	45	13.7	13.8	563.3	1,339	2
R-VA SR00084EB	Staunton	55	4.4	4.6	1,857.9	208	0
R-VA US00220NB	Staunton	55	173.9	174.2	3,182.7	593	0
R-VA SR00252NB	Staunton	55	19.1	19.3	859.0	1,283	0
R-VA007SC00613NB	Staunton	45	13.1	13.3	648.4	1,549	0
R-VA SR00055EB	Staunton	55	22.0	22.3	1,249.8	4,454	1

AADT = annual average daily traffic.