TECH**BRIEF**

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Developing Crash Modification Factors For Variable Speed Limits

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This document is a technical summary of the Federal Highway Administration Report *Developing Crash Modification Factors for Variable Speed Limits* (FHWA-HRT-21-053) (Avelar et al. 2021).

INTRODUCTION

The Federal Highway Administration established the Development of Crash Modification Factors (DCMF) program in 2012 to address highway safety research needs for evaluating new and innovative safety strategies (i.e., improvements) by developing reliable quantitative estimates of their effectiveness in reducing crashes. The Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS) functions under the DCMF program. The Technical Advisory Committee (TAC) formed by the ELCSI-PFS' 41 State department of transportation (DOT) members provides the DCMF program with technical feedback on safety improvements. The participating State DOTs then implement new safety improvements to facilitate evaluations.

The research summarized in this TechBrief addresses and evaluates variable speed limits (VSLs) as a safety improvement strategy. The ELCSI-PFS TAC selected VSL treatment as one of their priority treatments of interest.

This TechBrief provides an overview and summary of the literature review, data collection, statistical evaluations, crash modification factors (CMFs), and benefit–cost (B/C) ratios for VSLs.

Study Objective

This study assessed VSLs as a safety improvement strategy in addition to their potential to reduce crashes in the format of CMFs. The evaluations conducted in the study included total, fatal and injury, and property-damage-only (PDO) crashes. Additionally, this research developed B/C ratios for implementing VSLs as a safety improvement strategy. Jointly, practitioners can use the resulting CMFs and B/C ratios for decisionmaking in project development and safety-planning processes.

VSLs

VSL deployments vary speed limits based on real-time traffic, roadway, or weather conditions (FHWA 2014). VSLs are also known as dynamic speed limits, variable advisory speeds, and speed harmonization. They are used for three primary functions: (1) reducing congestion, (2) reducing speeds during inclement weather, and (3) managing speeds during traffic events, such as work zones or incidents. The speed limits

Figure 1. Photograph. VSLs on I–5 in Seattle, WA.

can be either regulatory (i.e., enforceable) or advisory (i.e., nonenforceable), and they can apply to an entire roadway segment or individual lanes (FHWA 2017). Figure 1 shows an example of VSLs deployed in Seattle, WA.

In the application shown in figure 1, the Washington State DOT installed an active traffic-management system on I–5, SR 520, and I–90 that included dynamic lane-use control, dynamic message signs, and enforceable VSL signage to alert drivers of delays and direct drivers out of incident-blocked lanes (FHWA 2012).

VSL applications vary depending on the algorithms that govern the VSL technology. Many States have implemented VSL technology that manages speeds during adverse weather conditions (e.g., Virginia and Wyoming), whereas other technologies aim to harmonize operating speeds and volume conditions (e.g., the I–5 case in Washington shown in figure 1). Past research has indicated operational benefits after VSL implementation, with varying magnitudes of the safety effects (MDOT 2010; Randolph 2015; Sohrab and Al-Kaisy 2017; Gonzales and Fontaine 2018).

DATA

Initially, the research team reached out to multiple DOTs requesting recommendations for potential data sources and locations for evaluation. After reviewing preliminary data obtained from these DOTs, the research team decided to develop safety databases for three States: Georgia, Virginia, and Wyoming.

Table 1. Descriptive statistics of VSL corridor in Georgia (63 directional segments without ramps).				
Variable Name	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Number of lanes in one direction	4	7	4.5	0.75
Lane width (ft)	10.8	12.6	11.8	0.23
Right shoulder width (ft)	7.6	13.9	11.0	1.19
Left shoulder width (ft)	5	8.8	6.4	0.77
Length (mi)	0.24	1.63	0.77	0.37
Annual average daily traffic	120,000	242,000	172,107	33,104
Total crashes (per segment)	1	302	56.78	54.69
Fatal and injury (KABC) crashes (per segment)	1	71	14.88	14.05

Georgia

The Georgia DOT (GDOT) installed VSLs along the I–285 loop in Atlanta in October 2014, between I–20 on the west side and I–20 on the east side. These VSLs are regulatory and always active, with the intent being to harmonize and level out the flow of traffic, allowing for greater throughput. The speed limit before VSL installation was 55 mph. After the project, the maximum speed limit increased to 65 mph. Possible displays on the VSL signs are 65, 55, 45, and 35 mph. The southern side of the I–285 loop (i.e., south of I–20) did not undergo VSL treatment. However, GDOT raised speed limits from 55 to 65 mph during the VSL treatment period for the northern part of the loop. The research team then treated the segments in the northern section as the treatment group and the segments in the southern section as the comparison group. The team directionally defined a total of 63 segments. Of these 63 segments, the research team used 20 as comparison segments and 43 as treatment segments. The details the team collected using Google® Earth™ satellite imagery included lane width, shoulder width, median type, and presence and number of curves and ramps. Rumble strips were present throughout the section for before, during, and after periods, so the research team eliminated the strips as a variable from the analysis. GDOT representatives provided crash data for 2012–2014 and 2015–2017.

GDOT maintains annual average daily traffic (AADT) collection stations every 1/3 mi, or about 210 stations total in this project area, each collecting data in 20-s increments. The research team used GDOT's interactive online tool (GDOT 2020) to collect AADT values along the I–285 loop. Data were available from 52 locations. AADT volumes on I–285 ranged from approximately 140,000 vehicles on the east and west sides of I–285 to 230,000 on the north side (both directions combined). Table 1 presents a summary of the data collected from Georgia for this study.

Virginia

The research team used Google Earth (2018) satellite imagery to collect data on roadway geometry elements from a 12-mi section of I–77. The team segmented the entire corridor into 22 parts (11 in each direction), with the minimum length of a segment being 0.4 mi and the maximum length being 1.75 mi. The Virginia DOT (VDOT) deployed the VSL technology in October 2016, with the upper speed limit bound set to 65 mph. The displayed speed limits were 35, 45, 55, and 65 mph, depending on the logic programmed into the system. The signs displayed speed limits lower than 65 mph primarily in response to reduced visibility conditions, estimated at 5 percent of the time or less.

The research team obtained 8 yr of crash data (2010–2017) from VDOT (VDOT 2019). The team assigned crashes to segments based on the geolocation coded in the crash. Out of 697 total crashes, 538 occurred during the before period (January 2010–May 2016), 65 occurred during the intervention period (June 2016–January 2017), and 94 occurred during the after period (February 2017–December 2017). VDOT reported the crash counts for each study segment based on injury severity (using the KABCO scale where K is fatal injury, A is major injury, B is minor injury, C is possible injury, and O is no injury or PDO) crash type. There were a total of 14 K, 40 A, 92 B, 33 C, and 518 O crashes within the 22 segments considered by the research team. The research team also obtained 6 yr of AADT data (2010–2016) from VDOT for the segments (VDOT 2019). Table 2 details the descriptive statistics for the resulting database for Virginia.

Table 2. Descriptive statistics of VSL corridor in Virginia (22 segments).				
Variable Name	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Number of lanes in one direction	2	3	2	0.4
Lane width (ft)	11.4	13.4	12.1	0.4
Right shoulder width (ft)	9.6	14.3	11.8	1.3
Left shoulder width (ft)	3.8	9.9	5.7	1.7
Length (mi)	0.38	1.7	1.1	0.39
AADT	16,048	20,463	17,914	1,118
Number of ramps	0	2	0.4	0.80
Total crashes (per segment)	10	59	31.7	12.8
Fatal (K) crashes (per segment)	0	2	0.64	0.68
Major-injury (A) crashes (per segment)	0	4	1.8	1.6
Minor-injury (B) crashes (per segment)	1	9	4.2	2.2
Possible-injury (C) crashes (per segment)	0	4	1.5	1.4
PDO (O) crashes (per segment)	7	52	23.5	10.8

Table 3. Descriptive statistics of VSL corridor in Wyoming (64 segments).				
Variable Name	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Number of lanes in one direction	2	3	2	0.20
Lane width (ft)	11.4	12.7	12	0.30
Right shoulder width (ft)	7.1	11.4	9.5	0.80
Left shoulder width (ft)	3.4	6.3	4.6	0.60
Length (mi)	0.60	1.9	1.5	0.40
AADT	10,194	11,090	10,605	284.7
Number of curves	0	2	0.84	0.62
Number of connectors	0	2	0.81	0.59
Total crashes (per segment)	33	1,056	273.4	181.9
Fatal (K) crashes (per segment)	0	3	0.48	0.75
Major-injury (A) crashes (per segment)	0	18	4.5	3.8
Minor-injury (B) crashes (per segment)	0	78	19.4	14.6
Possible-injury (C) crashes (per segment)	0	84	16.5	16.3
PDO (O) crashes (per segment)	25	840	221.6	153.9
Total rear-end crashes (per segment)	0	37	7.6	6.7
Total fixed-object crashes (per segment)	1	152	31.2	26.4

Wyoming

This study included the Elk Mountain corridor in Wyoming, which is located in southeastern Wyoming on I–80 between Laramie, WY, and Rawlins, WY. Before VSL implementation, this corridor had an existing posted speed limit of 75 mph. The research team divided the 52-mi I–80 Elk Mountain corridor into 64 segments (32 segments in each direction). No major highways intersect this rural four-lane freeway within the boundaries of the study corridor. The Wyoming DOT (WYDOT) deployed the VSLs in February 2009, displaying speed limit values ranging from 35 to 75 mph. WYDOT expanded the VSL system in the 2009–2010 winter season to include eight additional VSL signs in four new locations (two each in the eastbound and westbound directions).

The research team collected the following geometric details for the corridor using Google Earth satellite imagery: lane width, shoulder width, median type, curve presence, ramp connectors, and rumble strips. WYDOT provided crash data from 2004–2014. The research team first spatially assigned crashes to each segment based on their location. They also excluded crashes occurring at three minor interchanges from the analysis. Out of the 3,699 crash records the research team obtained after excluding anomalous records, 1,433 occurred during the before period (February 2004–October 2008), 313 occurred during the intervention period (November 2008–May 2009), and 1,943 occurred during the after period (June 2009–February 2014). The research team collected 10 yr of AADT data (2004–2014) from the WYDOT website (WYDOT 2012). Because this section of road is a straight corridor without major interchanges, the research team assumed the AADT values remained similar throughout the entire road segment. Table 3 details the descriptive statistics of the resulting database for Wyoming.

ANALYSIS

Safety Effectiveness

The research team analyzed the three databases (Georgia, Virginia, and Wyoming) to estimate various CMFs representing the safety effectiveness of VSL technologies. The team implemented separate analyses for each dataset, attending to differences in the data structure and available variables. For Virginia and Wyoming, the study design was an interrupted time series, and the estimation method was logistic segmented regression with generalized estimating equations. The research team implemented an interrupted time series with comparison group design for Georgia, and the estimation method was negative binomial generalized linear segmented regression analysis with generalized estimating equations. Table 4 summarizes the results from these evaluations.

The Virginia database included safety data obtained from 22 freeway segments (corresponding to 24.4 mi) for 96 mo (January 2010–December 2017). The analysis found no statistically significant safety shifts from VSL installations. These inconclusive results are not evidence of lack of effectiveness of the State's VSL system. Because this system is triggered by fog, some measure of exposure to foggy conditions is an additional covariate that future work should explicitly consider. An evaluation focused on crashes during foggy conditions would better capture the safety impact of the system when the signs are actively regulating the operating speed. Recent work by VDOT suggests preliminary reductions in crash rates during reduced visibility conditions, although there was not a large change in overall crash occurrence (Gonzales and Fontaine 2018). Another factor that might have contributed to the inconclusive results is the limited length of the after period.

Table 4. Summary of CMFs by State.

State	Total Crashes	F+I Crashes	PDO Crashes	Rear-End Crashes	Rear-End F+I Crashes	Fixed-Object Crashes	Daytime Crashes	Nondry Crashes
Georgia	*0.71**	0.89	—	*0.65**	0.82	—	0.73**	1.01
Virginia	1.23	0.87	1.20	1.22	1.78	1.43	—	1.10
Wyoming	*0.66**	*0.49**	*0.71**	*0.35**	0.34	*0.59**	—	—

—Variable was not included in the model.
F+I = fatal and injury.
Note: Double asterisks indicate statistically significant results at the 95-percent confidence level. Italicized font with a single asterisk indicates statistically significant results at the 90-percent confidence level.

The research team obtained Wyoming safety data from 63 segments (corresponding to 92.9 mi) for 121 mo (February 2004–February 2014). This analysis yielded statistically significant and large crash reductions ranging from a 28.8-percent reduction in PDO crashes up to a 65.2-percent reduction in rear-end crashes.

The Georgia crash data consisted of monthly crash data the research team obtained from 63 segments (corresponding to 48.9 mi) for 72 mo (January 2012–December 2017). Out of 63 segments, 43 segments (corresponding to 30.6 mi) were treatment sites with VSLs installed in October 2014, and the remaining 20 segments (corresponding to 18.3 mi) were comparison sites. Results from this analysis were consistent with the findings from the analysis of the Wyoming dataset. The analysis found statistically significant crash reductions (at the 95-percent confidence level) of 29.2 percent for total crashes and 35.2 percent for rear-end crashes. Additionally, the analysis found a statistically significant crash reduction (27.2 percent) at the 90-percent confidence level for daytime crashes.

Economic Effectiveness

The research team also performed an analysis to estimate the economic effectiveness of VSL technologies. The team estimated B/C ratios for only Georgia and Wyoming because these were the two States whose analyses yielded statistically significant results in the safety evaluation. For the economic analysis, the research team estimated B/C ratios of 40.4 for Georgia and 9.05 for Wyoming, indicating the VSL implementation types at each of these sites yield larger benefits than costs.

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