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research report

Evaluation of Best Practices in Traffic Operations and Safety: Phase I: Flashing LED Stop Sign and Optical Speed Bars

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E. D. ARNOLD, Jr.
Associate Principal Research Scientist

K. E. LANTZ, Jr.
Senior Research Scientist

Virginia Transportation Research Council, 530 Edgemont Road,
Charlottesville, VA 22903-2454, www.vtrc.net, (434) 293-1900

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16. Abstract

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The flashing LED stop sign was installed at a T-intersection in western Albemarle County, Virginia, where the number of crashes was higher than expected. The measures of effectiveness for the sign were average speed of drivers approaching the sign and compliance with the sign. Average speeds decreased significantly (statistically) after the sign was installed, but only by 1 to 3 mph. Speeds decreased more during the night than during the day. The results of the compliance study were inconclusive

Optical speed bars were installed on the centerline and edge line on both approaches to a short section of two-lane roadway in Fairfax County, Virginia. The section of roadway is hazardous, as it has inadequate vertical and horizontal alignment, narrow lanes, and reduced shoulders. A number of crashes had occurred on the section over the years, including a recent fatality. Average speeds both decreased and increased after installation, and the decreases were statistically significant right before and in the middle of the section. The decreases ranged from 1 to 3 mph.

Optical speed bars were also installed across lanes on a major, four-lane undivided highway, at two approaches to a reduced speed limit zone in the town of Zuni, Virginia. Average speeds both decreased and increased after installation. The decreases were statistically significant at the beginning of the 45 mph speed zone on each end of town. The decreases ranged from 3 to 10 mph.

Given the general positive results of the installations, the report recommends that flashing LED stop signs and optical speed bars be considered as safety countermeasures at appropriate locations where the numbers of crashes or crash rates are higher than expected or where excessive speeding occurs.

A costs and benefits assessment indicated that, generally, the benefits in terms of reduced crashes exceeded the costs of the installed measures if only one crash was prevented.

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E. D. Arnold, Jr.
Associate Principal Research Scientist

K. E. Lantz, Jr.
Senior Research Scientist

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ABSTRACT

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INTRODUCTION

Improving the safety of the nation's highways continues to receive the attention of federal, state, and local officials and public and private organizations. Although great strides have been made in highway and vehicular safety (a recent U.S. Department of Transportation study estimates that 329,000 lives have been saved since 1960 because of vehicle safety technologies),[1] a significant number of highway deaths still occurs. Although Virginia has the 12th safest highway system in the nation and the state's fatality rate has decreased over time,[2] 961 persons were killed on Virginia' highways in 2006 (Transportation Safety Services, Department of Motor Vehicles, Richmond, Virginia, unpublished data, May 16, 2007). In response to the continued loss of life, the American Association of State Highway and Transportation Officials (AASHTO) announced a state highway safety plan with the national highway safety goal of reducing fatalities by 1,000 per year, thus saving a cumulative total of more than 50,000 lives within the next decade and moving toward halving the number of fatalities over the next two decades.[3,4] Individual states, including Virginia, have developed strategic highway safety plans as part of this national emphasis on improving highway safety. Virginia's *Strategic Highway Safety Plan 2006-2010* has a goal of reducing number of deaths and injuries that occurred in 2005 by 100 and 4,000, respectively, by 2010. The plan calls for a multi-perspective approach to identify problems in the human factors, environmental, and fundamental emphasis areas. Countermeasures to address these problems will be based on current research, discussions with safety partners, and experience.[2]

Although the United States is considered a leader in technology and best practices regarding traffic operations and safety, there are technologies and practices worldwide that are not commonplace in the United States. In an earlier research effort,[5] 42 technologies and practices used overseas but not currently employed in Virginia were identified and evaluated for their potential as pilots using 10 subjective criteria.

As a result of the evaluation, 2 measures were categorized as practices that can be implemented without piloting, 12 as good candidates for piloting, 22 that are questionable for piloting, and 6 that cannot be piloted. The 12 measures with the potential for piloting were as follows:

1. colored and textured pavements for speed warnings (e.g., entrance feature at change from rural to commercial area, entrance curve on ramp, two-lane roadway)

2. animated eyes on warning signs in advance of crosswalks to prompt motorists to watch for pedestrians

3. on divided highways with pedestrian crossings, offset the crossings and use barriers to cause a pedestrian to turn in the direction of the oncoming traffic

4. automated pedestrian detection and green phase extension technologies

5. zigzag pavement markings on the approaches to mid-block pedestrian crossings

6. messages painted on the pavement (“horizontal signing”), to include highway route numbers, stop and yield markings, traffic or parking prohibitions, bus lanes, school zones, lane markings carried through intersections, and dotted edge lines through exit and entrance ramps at interchanges

7. a “Look Left/Right” message marked on the street at pedestrian crossings to remind pedestrians to look for motor vehicles before stepping into the street

8. optical speed bars to warn of a hazardous area (transverse lines configured such that the spacing between the lines decreases as the hazard is approached, thus creating an optical illusion of acceleration to the driver and the impression of traveling faster than intended)

9. chevrons and dots to indicate proper vehicle spacing

10. stop signs equipped with red flashing light emitting diodes (LEDs) embedded at each corner

11. colored electronic international symbols for warning messages on changeable message signs

12. pulsing white lights to notify motorists of an active work zone.

In September 2005, the researchers attended a meeting of the Virginia Department of Transportation’s (VDOT) central office and district traffic engineers and presented the results of this investigation,[5] giving particular emphasis to the 12 measures identified as having potential for piloting. The traffic engineers were asked to identify the measures they were interested in as well as possible locations for piloting. Based on input from the meeting, two measures were selected for piloting: a stop sign equipped with flashing LEDs at each corner and optical speed bars.

PURPOSE AND SCOPE

The purpose of the study was to evaluate through before and after studies a flashing LED stop sign and optical speed bars. The measures of effectiveness used in evaluating the flashing LED stop sign were the average speed of vehicles approaching the stop sign and stop sign compliance. For the optical speed bars, the average speed of vehicles was used as the measure of effectiveness. The research effort did not include a crash analysis as time was not available to obtain the recommended minimum of 3 years of crash data after installation of a countermeasure.

The flashing LED stop sign was installed and evaluated at one site in Virginia, and the optical speed bars were installed and evaluated at two sites in Virginia.

METHODS

The research involved the following tasks.

1. *Select the pilot sites at which the flashing LED stop sign and optical speed bars were to be installed and evaluated, and collect background information at each.* Information was needed to document existing conditions at each site, including the problem and how the measure would address it.

2. *Develop an evaluation plan to guide the before and after data collection efforts.*

3. *Install the sign and speed bars, collect the data, and conduct the evaluation.*

Flashing LED Stop Sign

Selection of Pilot Site and Collection of Background Information

Traffic engineers in VDOT's Lynchburg District recommended that a flashing LED stop sign be installed and evaluated on Virginia Primary Route 151 at its T-intersection with U.S. Route 250 in Albemarle County. They noted that the intersection has a crash rate higher than the average rate for similar intersections in the district, particularly when compared to two nearby intersections south on Route 151. During the period 2003 through 2005, 14 accidents were recorded; these included no fatalities and 7 injuries. In addition, drivers failing to stop at the stop sign caused 4 of the crashes.

Route 151, posted at 55 mph, is a north-south two-lane highway generally running parallel to U.S. Route 29. It begins in the south on Route 29 just north of Amherst, runs for approximately 35 miles through several small towns (including Piney River, Wintergreen, and Nellysford), and ends at a stop sign at a T-intersection with Route 250 at the foot of Afton Mountain. A small island separates north and south movements on Route 151 at the intersection. Route 250, posted at 55 mph, is not controlled and is two-lane with a left-turn lane as it approaches Route 151 from the east and is three-lane (two up the mountain away from Route 151 and one down the mountain toward Route 151) with a right-turn lane as it approaches from the west. A large, year-round vacation and conference facility, Wintergreen Resort, is located approximately 20 miles south on Route 151. Motorists traveling to and from Wintergreen via I-64 and Route 250 use this intersection. The traffic volume was estimated at 7,100 vehicles per day in 2005.[8]

The district's traffic engineers suggested that the higher-than-expected crash rate is caused by several factors on the Route 151 northbound approach. These include a high approach speed, limited sight distance on a horizontal curve, a downgrade into the intersection, and sign clutter at the intersection. A number of countermeasures had been implemented, including the installation of two "stop ahead" signs with accompanying "stop ahead" horizontal pavement markings, rumble strips on both sides of the second horizontal "stop ahead" pavement marking, and a 48-inch oversized stop sign. In addition, VDOT had been considering the installation of flashing beacons on the stop sign and a right-turn lane on the Route 151 approach. These plans were postponed pending an evaluation of the flashing LED stop sign.

Evaluation Plan

The objective of installing a flashing LED stop sign is to heighten motorists' awareness of the stop sign and to increase motorists' compliance. Motorists should see the flashing LED stop sign sooner than a regular stop sign and hence slow down more quickly and more likely stop. Therefore, two measures of effectiveness were used in the evaluation: average speed of vehicles approaching the stop sign and stop sign compliance.

Traffic volumes and speeds were obtained with traffic counters before and after the installation. Counters were placed at three locations along Route 151 on the northbound approach to the flashing stop sign. These locations, identified in further discussion as Stations 1, 2, and 3, were located approximately 1,410, 710, and 375 feet, respectively, from the intersection. The stop sign is just visible to motorists at Station 1. The before and after data were collected at 15-minute intervals for 7 days. The after data were collected at two times, the first within 7 days to measure initial reaction to the sign and the second within 90 days to allow evaluation of the "novelty" effect of the sign. Before and after comparisons were made for all days, weekdays (Monday through Friday), weekends, daytime (6 A.M. to 6 P.M.), nighttime (6 P.M. to 6 A.M.), morning peak period (6 A.M. to 9 A.M.), midday peak period (11 A.M. to 1 P.M.), and evening peak period (3 P.M. to 6 P.M.).

For the stop sign compliance study, data were also collected before the installation, within 7 days after installation, and approximately 90 days after installation. Data were collected at 15-minute intervals during the morning peak period (6 A.M. to 9 A.M.), midday or lunch peak period (11 A.M. to 1 P.M.), afternoon peak period (3:30 P.M. to 6:00 P.M.), and evening period (6:30 P.M. to 9:00 P.M.). This last period was included in an attempt to obtain nighttime data. Field observers recorded the data on a Stop Sign Compliance Field Sheet (see Appendix A). The data comprised the number of motorists who came to a full stop voluntarily, came to a full stop because of conflicting traffic, rolled through the stop sign (0 to 3 mph), and blew through the stop sign (less than 3 mph).

Installation

VDOT crews installed a 48-inch flashing LED stop sign at the intersection on June 14, 2006. The sign was a solar Day-Viz™ BlinkerStop™ sign donated to VDOT by Traffic & Parking Control Company (TAPCO) for evaluation. The unit contains red 7/8-inch-diameter LEDs in each of the eight corners of the sign. A solar panel, 13.5 by 15 inches, supplies a 4.8-volt NiMH 6-inch battery pack. The sheeting is 3M VIP/DG3 diamond grade or similar prismatic sheeting. The LEDs are wired to turn on and off simultaneously and flash continuously at a rate of 1 flash per second. There is automatic dimming for reduced night brightness. Figures 1 and 2 show the installation. The 48-inch sign sells for $1,860. The standard 36-inch and 30-inch Day-Viz™ BlinkerStop™ signs sell for $1,640 and $1,600, respectively. TAPCO offers an approximate 25 percent discount to state departments of transportation (DOTs). Costs associated with installation included $175 for a post and anchor and $650 for labor, equipment, and traffic control.

Figure 1. View of Approach to Flashing LED Stop Sign on Route 151

Figure 2. Flashing LED Stop Sign Installed on Route 151

Optical Speed Bars

Two sites were chosen to evaluate the optical speed bars. Although Section 3B.15 of the MUTCD[8] discusses transverse markings, the particular pattern of the optical speed bars evaluated in this study and their purpose of reducing speeds are not included. As a consequence, the researchers were required to submit a "Request for Experimentation" to the Federal Highway Administration in order to install the markings.

Lee Chapel Road

Selection of Pilot Site and Collection of Background Information

Traffic engineers in VDOT's Northern Virginia District recommended that optical speed bars be installed and evaluated on Lee Chapel Road in Fairfax County. Although the road is posted at 40 mph, its geometrics at either end encourage higher speeds. The district's traffic engineers noted that an August 2005 speed study taken just north of the Route 123 intersection recorded an average speed of 48 mph and an 85th percentile speed of 55 mph for 5,215 vehicles approaching the section from the south. Further, there were 22 crashes during 2002, 2003, and 2004 and the annual crash rates (crashes per 100 million vehicle miles traveled) between Viewcrest Drive on the south and Pond Point Drive on the north were 356, 130, and 308, respectively. These were higher than typically found on other secondary roads in Fairfax County, and there were 16 injuries and 2 fatalities during that period. In addition, a fatal crash occurred in August 2005, and excessive speed was reported as a likely contributing factor.

The overall segment of concern is 1.05 miles long and is located between signalized intersections at Route 123, Ox Road, on the south and Route 7100, Fairfax County Parkway, on the north. The typical sections immediately north of Route 123 and south of the Fairfax County Parkway are four-lane plus various turn lanes; both have good horizontal and vertical alignment, and both are downgrades away from the respective intersection. However, a middle section of approximately 0.37 mile between the bridge at South Run and Pond Point Drive is two-lane and has inadequate vertical and horizontal alignment, narrow lanes, and reduced shoulders. This section is adjacent to South Run Park and runs through several residential areas. There are no plans for upgrading this section; in fact, such plans seem unlikely because of the park and residential environment. Rumble strips were not considered as a countermeasure to the speeding problem because of their noise impact on the adjacent residential and park areas. Accordingly, VDOT traffic engineers wanted to try optical speed bars to reduce the speeds of motorists entering the section.

Evaluation Plan

The specific objective of installing the optical speed bars on both approaches to and just in advance of the 0.37-mile hazardous section of Lee Chapel Road was to reduce motorists' average speeds to around 40 mph. Therefore, speed of vehicles was used as the measure of effectiveness.

Traffic volumes and speeds were obtained with traffic counters placed at 10 locations: 5 in the southbound lane and 5 in the northbound lane. In the southbound lane, a counter was placed well in advance of the bars, at the beginning of the bars, in the middle of the bars, and at the end of the bars. These locations are identified in further discussion as Stations 1, 2, 3, and 4, respectively. An additional counter was placed in the southbound lane approximately in the middle of the hazardous section and is identified as Station 5. Identical placements were made in the northbound direction, with Stations 6, 7, 8, and 9 located well in advance of the bars, at the beginning of the bars, in the middle of the bars, and at the end of the bars, respectively. Station 10 was located approximately in the middle of the hazardous section.

The counters collected speeds during three data collection periods: before installation of the optical speed bars, within 7 days after installation to measure the initial reaction to the bars, and within 90 days after installation to allow evaluation of the "novelty" effect of the bars. Before and after comparisons were made for all days, weekdays (Monday through Friday), weekends, daytime (6 A.M. to 6 P.M.), and nighttime (6 P.M to 6 A.M.). Before and after data were collected at 60-minute intervals over 7 days. Analysis of variance (ANOVA) was used to determine statistical differences at the 95 percent confidence level.

Installation

VDOT crews installed optical speed bars on May 3, 2006, on the approach lanes at the north and south ends of the hazardous section to reduce the speeds of vehicles entering the section. A pattern used at a site in New York (see Appendix B) was used for installing the bars. It consisted of 31 bars over a length of 530 feet. Because of the intersection of Lee Chapel Road with a local residential street, only 448 feet were available for the installation of the pattern on the north end of the section. The spacing between the bars varied from 24 to 12 feet. A field review prior to installation located where the patterns were to begin on both approaches to the hazardous section.

VDOT traffic engineers were concerned about the visual and aesthetic effects of installing bars completely across the travel lanes. There was also the potential for motorist confusion in the vicinity of the painted median on the north approach. As a consequence, the optical speed bars consisted of thermoplastic pavement markings, 18 inches by 12 inches, installed on the approach lane to the hazardous area and extending from both the edge line and the centerline. Figures 3 and 4 show the installed bars at each end of the section. Installation was completed in about half a day and cost approximately $1,800, which included labor, material, and equipment.

Route 460 Through Town of Zuni

Selection of Pilot Site and Collection of Background Information

Traffic engineers in VDOT's Hampton Roads District recommended that optical speed bars be installed and evaluated on Route 460 in the town of Zuni in Isle of Wight County. The Route 460 approaches to Zuni are on a straight alignment and are posted at 55 mph, both of which encourage motorists to "speed" through the town's 45 mph posted speed limit. The district's traffic engineers noted that speed samples taken through the study area in August 2005 recorded average speeds of 47 mph for both directions and 85th percentile speeds of 52 and 51 mph for eastbound and westbound directions, respectively. In addition, there was a total of 15 crashes during the period 2003 through 2005 that included 7 injuries and 1 fatality.

U.S. Route 460 is a major four-lane undivided highway running from Petersburg to Suffolk that carries a significant amount of intercity traffic, including a significant percentage of trucks. In 2005, the traffic volume in the vicinity of Zuni was 12,000 vehicles per day, which

Figure 3. Optical Speed Bars on South End of Lee Chapel Road Installation. *Top:* View Looking North. B*ottom:* View Looking South.

Figure 4. Optical Speed Bars on North End of Lee Chapel Road Installation. ***Top:*** **View Looking North. B*ottom:*** **View Looking South.**

included about 10 percent heavy trucks.[11] Route 460 is posted at 55 mph throughout except for reduced speeds through a number of small towns.

The segment of concern is a 1-mile section with a posted speed limit of 45 mph that runs through Zuni. Alignment through the town consists of a reverse curve that has intersecting roadways. This alignment restricts sight distance for motorists on U.S. 460 as well as on the side streets. VDOT installed W3-5 speed reduction signs approximately 600 feet in advance of the 45 mph speed limit signs on both sides of the town. There are also curve-warning signs on both approaches, with the eastbound approach carrying a 35 mph warning plate. In addition, there is a sign with a 35 mph warning plate that advises motorists to watch for turning traffic in the vicinity of the intersection with Route 644. In particular, motorists on Route 644 on the northbound approach have limited sight distance when looking west at the intersection with Route 460. Transverse rumble strips had been installed on Route 460 on approaches to other small towns along the corridor to mitigate the speeding problem; however, VDOT traffic engineers were concerned about the impact of noise on nearby residences and wanted to try optical speed bars as a speed reduction measure.

Evaluation Plan

The objective of installing the optical speed bars on both the east and west approaches to Zuni was to reduce motorists' average speeds to 45 mph or less prior to or at the beginning of the 45 mph zone through the town. Therefore, speed of vehicles was used as the measure of effectiveness.

Traffic volumes and speeds were obtained with traffic counters at four locations before installation and six locations after installation. This inconsistency was due to miscommunication regarding the counter locations. To be consistent in further discussions, the "after" locations are identified as Stations 1 through 6. Stations 1 through 3 were westbound placements well in advance of the bars in the 55 mph speed zone, at the end of the bars just at the beginning of the 45 mph speed zone, and approximately in the center of town, respectively. Stations 4 through 6 were identical placements, except in the eastbound direction. Speeds well in advance of the bars in the 55 mph speed zone (Stations 1 and 4) were not collected before installation due to the aforementioned miscommunication.

The speeds were collected during three data collection periods: before installation of the optical speed bars, within 7 days after installation to measure the initial reaction to the bars, and within 90 days after installation to allow evaluation of the "novelty" effect of the bars. Before and after comparisons were made for all days, weekdays (Monday through Friday), weekends, daytime (6 A.M. to 6 P.M.), and nighttime (6 P.M. to 6 A.M.). Before and after data were collected at 15-minute intervals over 7 days. Analysis of variance (ANOVA) was used to determine statistical differences at the 95 percent confidence level.

Installation

VDOT crews installed optical speed bars using thermoplastic pavement markings on the two approach lanes of Route 460 on the eastern and western sides of Zuni on July 10 and 11,

2006. A pattern used at a site in Texas (see Appendix C) was used for the installation. It consisted of 32 bars in the westbound direction and 40 bars in the eastbound direction. The eight additional bars in the eastbound direction were installed in order to reduce speeds to 40 mph at the intersection with Route 644 because of its aforementioned poor sight distance to the west. The spacing between the bars varied from 24 to 17 feet westbound and from 24 to 15 feet eastbound.

The bars were 12 inches wide and were placed 1 foot off the edge line, skip centerline, and solid yellow centerline separating the east and westbound lanes. Lanes are approximately 10.5 feet through the section; thus, the bars are approximately 8.5 feet long. Figures 5 and 6 show the installed bars on each approach to Zuni. The bars were installed in an estimated total time of 9 to 10 hours and with an estimated cost for labor and materials of $15,000.

RESULTS

Flashing LED Stop Sign

Vehicle Speeds on Route 151

The findings are presented in Table 1 and summarized here:

- Vehicle speeds decreased as motorists traveled north through the stations toward the stop sign during all time periods and all data collection periods. These speeds were approximately 54, 47, and 38 mph at Stations 1, 2, and 3, respectively.

- Vehicle speeds during the eight time periods analyzed varied little in any of the data collection periods; i.e., neither the day of the week nor the time of day seemed to influence driver speeds. The maximum variation was about 4 mph.

- Vehicle speeds generally decreased at each station during both after data collection periods. (The “after” data collection period is defined as occurring within 7 days after installation; the “after 90” data collection period is defined as occurring approximately 90 days after installation.) Although these decreases were small, many of the differences were statistically significant. Speeds increased slightly in both after periods in a few of the time periods, but none of the increases was statistically significant.

- With only one exception, vehicle speeds at Stations 1 and 2 increased between the after and after 90 periods. On the other hand, vehicle speeds at Station 3, which was located closest to the stop sign, decreased between the after and the after 90 periods.

- Vehicle speeds decreased significantly (statistically) during six of the eight time periods during the after period at Station 1, which was located just as the stop sign came into view. The decreases ranged from 1.1 to 2.3 mph, with the average of 1.8

Figure 5. Optical Speed Bars on Route 460, West Side of Zuni. *Top,* View Looking East. *Bottom,* View Looking West.

Figure 6. Optical Speed Bars on Route 460, East Side of Zuni. ***Top,*** **View Looking West.** ***Bottom,*** **View Looking East.**

Table 1. Average Speeds (mph) Northbound on Route 151

Station 1	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	54.40	52.72[a]	53.82
Weekday	54.26	52.59[a]	53.75
Weekend	54.90	53.00[a]	53.97
Day (6 A.M.-6 P.M.)	54.61	53.48[a]	54.13
Night (6 P.M.-6 A.M.)	54.19	51.93[a]	53.50
AM Peak (6 A.M.-9 A.M.)	54.74	53.58	53.96
PM Peak (3 P.M.-6 P.M.)	55.13	53.11[a]	53.50
Lunch Peak (11 A.M.-1 P.M.)	53.92	53.87	54.36
Station 2	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	46.84	45.47[a]	46.52
Weekday	46.66	45.37[a]	46.10
Weekend	47.28	45.71[a]	47.87
Day (6 A.M.-6 P.M.)	47.07	46.52	46.84
Night (6 P.M.-6 A.M.)	46.62	44.42[a]	46.07
AM Peak (6 A.M.-9 A.M.)	46.87	46.32	46.55
PM Peak (3 P.M.-6 P.M.)	46.72	46.26	45.26
Lunch Peak (11 A.M.-1 P.M.)	46.58	46.93	47.22
Station 3	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	39.14	37.65[a]	36.74[a]
Weekday	38.84	37.34[a]	36.63
Weekend	39.90	38.43[a]	36.90[a]
Day (6 A.M.-6 P.M.)	37.74	37.16	35.89[a]
Night (6 P.M.-6 A.M.)	40.55	38.14[a]	37.59[a]
AM Peak (6 A.M.-9 A.M.)	36.75	36.69	35.97
PM Peak (3 P.M.-6 P.M.)	36.75	36.11	33.40[a]
Lunch Peak (11 A.M.-1 P.M.)	37.95	37.62	37.20

After = within 7 days after installation; after 90 = approximately 90 days after installation.
[a]Speed is significantly (statistically) different from before speed (ANOVA at 95 percent confidence level).

mph being a 3.3 percent decrease. There were no significant decreases in speeds in the after 90 period.

- Vehicle speeds decreased significantly (statistically) during four of the eight time periods during the after period at Station 2, which was located about 710 feet from the intersection. The decreases ranged from 1.3 to 2.2 mph, with the average of 1.6 mph being a 3.4 percent decrease. There were no significant decreases in speeds during the after 90 period.

- Vehicle speeds decreased significantly (statistically) during four of the eight time periods in the after period at Station 3, which was located about 375 feet from the intersection. The decreases ranged from 1.5 to 2.4 mph, with the average of 1.7 mph being a 4.3 percent decrease. Vehicle speeds also decreased significantly (statistically) during five of the eight after 90 periods. The decreases ranged from 1.9 to 3.4 mph, with the average of 2.7 mph being a 7.0 percent decrease.

- Vehicle speeds at all three stations decreased more during the night (as represented by the period 6 P.M. to 6 A.M.) than during the day (6 A.M. to 6 P.M.) in both after periods. For those periods in which the decreases in speed were statistically significant, the night period most often had the largest decrease, presumably because of the flashing LEDs. For example, at Station 3, day speeds decreased by only 0.6 and 1.9 mph in the after and after 90 periods, respectively, whereas comparable night speeds decreased 2.4 and 3.0 mph.

Stop Sign Compliance on Route 151

The researchers attempted to collect stop sign compliance data during the before, after, and after 90 periods. The data plan included the number of vehicles that came to a complete, voluntary stop at the stop sign, came to a complete stop with other vehicles in front of them (forced stop), rolled through the stop sign (at a speed less than 3 mph), or "blew through" the stop sign at a speed greater than 3 mph. The intent was to collect these data with trained observers at the site. However, the same observers were not available for data collection for the three periods and the variance in observer interpretation of the data categories resulted in inconsistencies in the data that rendered them invalid for further analysis.

Optical Speed Bars

Lee Chapel Road

The findings are presented in Tables 2, 3, and 4 and summarized here.

Average Vehicle Speeds

At all stations, average vehicle speeds during the five time periods varied little in any of the data collection periods; i.e., neither the day of the week nor the time of day seemed to influence driver speeds. The maximum variation was about 2 mph.

For the remainder of the discussion, the 10 locations counted are logically separated into travel through the speed bars southbound from Fairfax County Parkway (Stations 1 to 4, Table 2); travel through the speed bars northbound from Ox Road (Stations 6 to 10, Table 3); and bi-directional speeds in the middle of the hazardous section (Stations 5 and 10, Table 4).

Southbound Through Optical Speed Bars (Table 2).

- Vehicle speeds did not change consistently as motorists traveled through the section from a point in advance of the bars to the end of the bars. Before the bars were installed, speeds were approximately 42, 44, 45, and 42 mph at the four stations located before the beginning of the bars, at the beginning of the bars, in the middle of the bars, and at the end of the bars, respectively. In the after period, these speeds were approximately 38, 40, 42, and 40 mph. In the after 90 period, the speeds were approximately 42, 39, 43, and 41 mph.

Table 2. Average Speeds (mph) Before and Through Optical Speed Bars on Lee Chapel Road Southbound from Fairfax County Parkway (Route 7100)

Station 1	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	42.00	37.90[a]	41.58
Weekday	41.85	37.84[a]	41.38
Weekend	42.38	38.06[a]	42.08
Day (6 A.M.-6 P.M.)	42.20	37.78[a]	41.30[a]
Night (6 P.M.-6 A.M.)	41.80	38.04[a]	41.87
Station 2	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	44.02	40.33[a]	38.65[a]
Weekday	43.93	40.19[a]	38.58[a]
Weekend	44.25	40.69[a]	38.85[a]
Day (6 A.M.-6 P.M.)	43.73	39.98[a]	37.80[a]
Night (6 P.M.-6 A.M.)	44.32	40.69[a]	39.51[a]
Station 3	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	45.34	41.68[a]	42.83[a]
Weekday	45.23	41.43[a]	42.43[a]
Weekend	45.60	42.29[a]	43.81[a]
Day (6 A.M.-6 P.M.)	45.18	41.32[a]	42.33[a]
Night (6 P.M.-6 A.M.)	45.50	42.03[a]	43.32[a]
Station 4	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	42.02	40.45[a]	40.66[a]
Weekday	41.89	40.23[a]	40.58[a]
Weekend	42.33	41.00[a]	40.88[a]
Day (6 A.M.-6 P.M.)	41.54	39.77[a]	39.71[a]
Night (6 P.M.-6 A.M.)	42.50	41.12[a]	41.61

After = within 7 days after installation; after 90 = approximately 90 days after installation.
[a]Speed is significantly (statistically) different from before speed (ANOVA at 95 percent confidence level).

- With only one exception (a 0.07-mph increase that was not statistically significant), vehicle speeds decreased in both after periods and during all time periods. Eighty-eight percent of the decreases were statistically significant.

- Vehicle speeds in the after 90 period had generally increased from comparable speeds recorded in the after period at Stations 1, 3, and 4. Speeds continued to decrease at Station 2, which was at the beginning of the bars.

- At Station 1, vehicle speeds decreased the most in the after period. The statistically significant decreases for all time periods ranged from 3.8 to 4.4 mph, with the average of 4.1 mph being a 9.8 percent decrease.

- At Station 2, vehicle speeds decreased the most in the after 90 period. The statistically significant decreases for all time periods ranged from 4.8 to 5.9 mph, with the average of 5.4 mph being a 12.3 percent decrease.

- At Station 3, vehicle speeds decreased the most in the after period. The statistically significant decreases for all time periods ranged from 3.3 to 3.9 mph, with the average of 3.6 mph being a 7.9 percent decrease.

- At Station 4, vehicle speeds decreased the most in the after period. The statistically significant decreases for all time periods ranged from 1.3 to 1.8 mph, with the average of 1.4 mph being a 3.3 percent decrease.

Northbound Through Optical Speed Bars (Table 3).

- Vehicle speeds did not change consistently as motorists traveled through the section from a point in advance of the bars to the end of the bars. Before the bars were installed, speeds were approximately 45, 51, 48, and 49 mph at the four stations located before the beginning of the bars, at the beginning of the bars, in the middle of the bars, and at the end of the bars, respectively. In the after period, these speeds were approximately 45, 50, 48, and 45 mph. In the after 90 period, the speeds were approximately 48, 49, 50, and 47 mph.

Table 3. Average Speeds (mph) Before and Through Optical Speed Bars on Lee Chapel Road Northbound from Ox Road (Route 123)

Station 6	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	44.65	44.76	47.67[a]
Weekday	44.75	44.80	47.83[a]
Weekend	44.42	44.67	47.27[a]
Day (6 A.M.-6 P.M.)	45.00	45.08	47.81[a]
Night (6 P.M.-6 A.M.)	44.31	44.44	47.54[a]
Station 7	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	50.51	50.33	48.68[a]
Weekday	50.68	50.43	48.77[a]
Weekend	50.10	50.08	48.48[a]
Day (6 A.M.-6 P.M.)	50.94	50.81	49.32[a]
Night (6 P.M.-6 A.M.)	50.08	49.85	48.05[a]
Station 8	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	48.08	47.74	49.82
Weekday	48.23	47.77	49.86[a]
Weekend	47.71	47.67	49.73[a]
Day (6 A.M.-6 P.M.)	48.69	48.10	50.11[a]
Night (6 P.M.-6 A.M.)	47.48	47.38	49.54[a]
Station 9	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	48.75	44.85[a]	47.14[a]
Weekday	48.84	44.79[a]	47.17[a]
Weekend	48.52	44.98[a]	47.06[a]
Day (6 A.M.-6 P.M.)	48.71	44.80[a]	47.07[a]
Night (6 P.M.-6 A.M.)	48.79	44.89[a]	47.20[a]

After = within 7 days after installation; after 90 = approximately 90 days after installation.
[a]Speed is significantly (statistically) different from before speed (ANOVA at 95 percent confidence level).

- Unlike the findings at the optical speed bar on the north end of Lee Chapel Road, vehicle speeds measured in the before, after, and after 90 periods exhibited no general patterns regarding increases and decreases. The observations at specific stations are discussed later.

- Vehicle speeds in the after 90 period had generally increased from comparable speeds in the after period at Stations 6, 8, and 9. Speeds decreased between the two periods at Station 7, which was at the beginning of the bars.

- At Station 6, vehicle speeds increased for all time periods after the bars were installed. These increases were not statistically significant in the after period, but they were statistically significant for all time periods in the after 90 period. The statistically significant increases ranged from 2.8 to 3.2 mph, with the average of 3.0 mph being an increase of 6.7 percent.

- At Station 7, vehicle speeds decreased for all time periods after the bars were installed. These decreases were not statistically significant in the after period, but they were for all of the time periods in the after 90 period. The statistically significant decreases ranged from 1.6 to 2.0 mph, with the average of 1.8 mph being a decrease of 3.6 percent.

- At Station 8, vehicle speeds decreased slightly for all time periods in the after period but then increased for all time periods in the after 90 period. These increases were statistically significant when compared to the before speeds in four of the five time periods. The increases ranged from 1.4 to 2.1 mph, with the average of 1.8 mph being an increase of 3.7 percent.

- At Station 9, vehicle speeds decreased for all time periods in both after periods. Even though speeds in the after 90 period increased considerably from the speeds in the after period, all decreases were statistically significant when compared to the before speeds. The decreases in the after period ranged from 3.5 to 4.1 mph, with the average of 3.9 mph being a decrease of 7.9 percent. The decreases in the after 90 period ranged from 1.5 to 1.7 mph, with the average of 1.6 mph being a 3.3 percent decrease.

Middle of the Hazardous Section (Table 4).

- Vehicle speeds at both stations decreased for all time periods in both after periods. Speeds increased slightly from the after to the after 90 period at Station 10. Speeds decreased between the two periods at Station 5.

- At Station 5, vehicle speeds decreased for all time periods during both after periods. These decreases were statistically significant and ranged from 1.0 to 1.7 mph, with the latter decrease being 4.0 percent.

Table 4. Average Speeds (mph) in Hazardous Section on Lee Chapel Road Both Directions

Station 5 Southbound	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	42.63	41.48[a]	40.94[a]
Weekday	42.60	41.41[a]	40.93[a]
Weekend	42.71	41.67[a]	40.98[a]
Day (6 A.M.-6 P.M.)	42.42	41.23[a]	40.52[a]
Night (6 P.M.-6 A.M.)	42.85	41.74[a]	41.36[a]
Station 10 Northbound	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	43.35	41.15[a]	41.45[a]
Weekday	43.42	41.17[a]	41.53[a]
Weekend	43.19	41.13[a]	41.25[a]
Day (6 A.M.-6 P.M.)	43.60	41.27[a]	41.45[a]
Night (6 P.M.-6 A.M.)	43.11	41.04[a]	41.45[a]

After = within 7 days after installation; after 90 = approximately 90 days after installation.
[a]Speed is significantly (statistically) different from before speed (ANOVA at 95 percent confidence level).

- At Station 10, vehicle speeds decreased for all time periods during both after periods. These decreases were statistically significant and ranged from 1.7 to 2.3 mph, with the highest average decrease being 5.0 percent.

Route 460 Through Town of Zuni

Average Vehicle Speeds

The findings are presented in Tables 5 and 6 and summarized here.

At all stations, average vehicle speeds during the five time periods analyzed varied little in any of the periods; i.e., neither the day of the week nor the time of day seemed to influence driver speeds. The maximum variation was about 2 mph.

For discussion purposes, the six locations counted are logically separated into westbound travel through Zuni (Stations 1 to 3, Table 5) and eastbound travel through Zuni (Stations 4 to 6, Table 6).

Westbound Travel Through Zuni (Table 5).

- Vehicle speeds generally decreased as motorists traveled from the outskirts of Zuni to the center of town for all periods. Before installation of the bars, speeds decreased from approximately 54 mph at the first 45 mph speed limit sign to approximately 46 mph in the center of town. (As mentioned previously, speed data were not collected before installation in the 55 mph zone approaching Zuni.) In the after period, speeds decreased from approximately 57 to 49 to 40 mph as motorists traveled from the 55 mph zone, past the 45 mph speed limit sign, and into the center of town, respectively. In the after 90 period, speeds at the same benchmarks decreased from approximately 59 to 51 to 47 mph.

Table 5. Average Speeds (mph) Westbound on Route 460 Through Town of Zuni

Station 1	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days		56.71	59.16
Weekday		56.71	58.78
Weekend		56.71	59.42
Day (6 A.M.-6 P.M.)		56.86	59.12
Night (6 P.M.-6 A.M.)		56.56	59.23
Station 2	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	54.42	49.31[a]	51.02[a]
Weekday	54.49	49.59[a]	50.85[a]
Weekend	54.25	48.74[a]	51.45[a]
Day (6 A.M.-6 P.M.)	54.74	49.86[a]	51.85[a]
Night (6 P.M.-6 A.M.)	54.09	48.85[a]	50.19[a]
Station 3	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	45.56	39.98[a]	46.91[a]
Weekday	44.95	39.96[a]	46.95[a]
Weekend	45.68	40.06[a]	46.63
Day (6 A.M.-6 P.M.)	46.05	40.19[a]	47.23[a]
Night (6 P.M.-6 A.M.)	45.05	39.72[a]	46.53[a]

After = within 7 days after installation; after 90 = approximately 90 days after installation.
[a]Speed is significantly (statistically) different from before speed (ANOVA at 95 percent confidence level).

- Vehicle speeds for all time periods decreased in the after period at the two stations (Stations 2 and 3) where before speeds were obtained. All decreases were statistically significant.

- At the two stations affected by the presence of the bars (Stations 2 and 3), vehicle speeds in the after 90 days period increased from comparable speeds in the after period.

- At Station 2, vehicle speeds decreased the most in the after period. The decreases were significantly different statistically for all time periods and ranged from 4.9 to 5.5 mph, with the average of 5.1 mph being a 9.4 percent decrease.

- At Station 3, vehicle speeds decreased the most in the after period. The decreases were significantly different statistically for all time periods and ranged from 5.0 to 5.9 mph, with the average of 5.5 mph being a 12.0 percent decrease. Vehicle speeds then increased in the after 90 period for all time periods, even to the point of being statistically higher than before the bars were installed. The increases that were statistically significant ranged from 1.2 to 2.0 mph, with the average of 1.5 mph being only a 3.3 percent increase. The average speed at Station 3 for all time periods in the after 90 period was 46.6 mph, only slightly above the 45 mph speed limit in the center of town.

Eastbound Travel Through Zuni (Table 6).

- Vehicle speeds generally decreased as motorists traveled from the outskirts of Zuni to the center of town for all data collection periods. Before installation of the bars, speeds decreased from approximately 57 mph at the first 45 mph speed limit sign to approximately 37 mph in the center of town. (As mentioned previously, speed data were not collected before installation in the 55 mph zone approaching Zuni.) In the after period, speeds decreased from approximately 60 to 56 to 42 mph as motorists traveled from the 55 mph zone, past the 45 mph speed limit sign, and into the center of town, respectively. In the after 90 period, speeds decreased from approximately 60 mph in the 55 mph zone to 47 mph at both the 45 mph speed limit sign and in the center of town.

- Vehicle speeds for all time periods decreased slightly in the after period at Station 5, and the decreases were statistically significant Statistically significant increases in speed occurred for all time periods at Station 6 in the after period.

- At the two stations affected by the presence of the bars (Stations 5 and 6), vehicle speeds in the after 90 period increased from comparable speeds recorded in the after period at Station 6 but decreased at Station 5.

- At Station 5, vehicle speeds decreased the most in the after 90 period. The decreases were significantly different statistically for all time periods and ranged from 9.3 to 9.8 mph, with the average of 9.5 mph being a 16.8 percent decrease.

Table 6. Average Speeds (mph) Eastbound on Route 460 Through Town of Zuni

Station 4	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days		59.54	59.69
Weekday		59.58	59.64
Weekend		59.45	59.79
Day (6 A.M.-6 P.M.)		59.73	59.87
Night (6 P.M.-6 A.M.)		59.35	59.50
Station 5	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	56.77	55.57[a]	47.22[a]
Weekday	56.75	55.68[a]	47.18[a]
Weekend	56.79	55.30[a]	47.34[a]
Day (6 A.M.-6 P.M.)	57.02	56.16[a]	47.71[a]
Night (6 P.M.-6 A.M.)	56.51	54.97[a]	46.74[a]
Station 6	**Data Collection Period**		
Time Period	**Before**	**After**	**After 90**
All Days	37.25	41.99[a]	47.04[a]
Weekday	37.43	42.02[a]	47.09[a]
Weekend	36.79	41.94[a]	46.70[a]
Day (6 A.M.-6 P.M.)	36.93	41.79[a]	46.75[a]
Night (6 P.M.-6 A.M.)	37.57	42.20[a]	47.37[a]

After = within 7 days after installation; after 90 = approximately 90 days after installation.
[a]Speed is significantly (statistically) different from before speed (ANOVA at 95 percent confidence level).

- At Station 6, vehicle speeds increased in both after periods; all increases were statistically significant. The increases were the largest in the after 90 period and ranged from 9.7 to 9.9 mph, with the average of 9.8 mph being a 26.4 percent increase. The average speed at Station 6 for all time periods in the after 90 period was 47.0 mph, only slightly above the 45 mph speed limit in the center of town.

DISCUSSION

In general, the results must be considered in view of the limited number of sites evaluated. Even though two installations of optical speed bars were evaluated, the pattern was substantially different at each site.

Flashing LED Stop Sign

Although statistically significant decreases in speed occurred after installation of the flashing LED stop sign, it is questionable whether the very small decreases in actual speeds are practically significant.

The reader is reminded that a number of countermeasures had been previously implemented along Route 151 to alert motorists to the upcoming stop-sign controlled intersection. These included the installation of two “stop ahead” signs with accompanying “stop ahead” horizontal pavement markings, rumble strips on both sides of the second horizontal “stop ahead” pavement marking, and a 48-inch oversized stop sign. It is possible that these prior installations had already led to a decrease in motorists’ speeds and thus possibly explain the relatively small additional decreases found after installation of the flashing LED stop sign.

As noted previously, the results of the compliance study undertaken as a part of this effort were inconclusive. Other studies cited in the literature did find significant increases in compliance after the installation of the LED stop sign. It is likely that the LED stop sign would provide the biggest improvements in compliance where sign conspicuity is the primary reason for noncompliance, and that may not have been the case at this intersection, given the number of alternative countermeasures in place.

Optical Speed Bars

Lee Chapel Road

Although a large number of statistically significant decreases in speed occurred after installation of the optical speed bars, with the higher decreases ranging from 8 to 12 percent at specific stations, most of the decreases were much smaller and it is questionable whether the decreases in actual speeds are practically significant.

Route 460 Through Town of Zuni

The thermoplastic tape used for the markings produced a slight bumping when motorists rode over the bars, similar to what occurs with cross-lane rumble strips. The effect was not as pronounced as only one layer was placed for the bars versus the typical two layers of tape for the rumble strips. The noise impact of traveling over the bars was also less because of the single layer versus the double layer.

Speed decreases were generally higher in Zuni, where the speed bars were 8.5 feet wide and placed in the center of the travel lanes, than on Lee Chapel Road, where the bars were 18 inches wide and placed on the edges of the travel lanes.

SUMMARY OF FINDINGS

Flashing LED Stop Sign

The results of vehicle speed studies conducted at the pilot site at three locations and during three data collection periods (before, immediately after, and approximately 90 days after installation of the flashing sign) may be summarized as follows:

- The flashing LED stop sign had an overall positive impact on vehicle speeds, which generally decreased at all three stations after installation; however, these decreases were small.

- Many of the decreases in speed were statistically significant and during the various time periods analyzed ranged right after installation from 1.1 to 2.3 mph at Station 1, which was farthest from the intersection; 1.3 to 2.2 mph at Station 2; and 1.5 to 2.4 mph at Station 3, which was closest to the intersection.

- Speeds decreased further 90 days after installation at Station 3. Compared to the before speeds, the statistically significant decreases ranged from 1.9 to 3.4 mph. The average decrease of 2.7 mph represented a 7.0 percent decrease.

- The flashing sign had a greater positive impact at night than during the day. Compared to speeds before installation, the decrease in speed at all stations was greater during the night than during the day. Statistically significant speed decreases averaged 2.0 percent during the day and ranged from 4.2 percent to 7.3 percent at night.

- There was a trend for speeds to increase slightly between the initial installation and approximately 90 days after installation at two of the stations. None of these increases was large; therefore, it cannot be concluded that motorists became accustomed to the flashing sign and reverted to the speeds before installation.

- Although the results of the compliance study were inconclusive, there is nothing to indicate that the effectiveness of the signs cited in other studies would not also hold true in Virginia, particularly given the reductions in speed on the approach to the stop sign that seem to indicate the LED stop sign has caught the drivers' attention.

Optical Speed Bars

Lee Chapel Road

The results of vehicle speed studies conducted at the pilot site at 10 locations and during three data collection periods (before, immediately after, and approximately 90 days after installation of the bars) may be summarized as follows:

- The optical speed bars had an overall positive impact, as vehicle speeds decreased at all key locations, i.e., the two stations located just before the hazardous section on each end and the two stations located in the middle of the hazardous section. However, the decreases were small.

- Statistically significant decreases ranged from 1.0 to 2.3 mph at these key stations, with decreases ranging from 3.3 to 5.0 percent 90 days after installation.

- Speeds ranged between 40 and 42 mph for the various time periods at the northern beginning and the middle of the hazardous section 90 days after installation. These speeds were in line with the 40 mph posted speed limit for the section. At the southern beginning of the hazardous section, speeds decreased after installation; however, they were still around 47 mph, which was well above the 40 mph posted speed limit.

- Although the speed decreases at these key stations were small, greater decreases occurred at other stations. For example, speeds at the beginning of the bars on the northern end decreased immediately after and 90 days after installation. The latter decreases, which were statistically significant, ranged from 4.8 to 5.9 mph, with the average of 5.4 mph being a 12.3 percent decrease. At the southern end, speeds also decreased at the beginning of the bars, although not as greatly. These decreases, which were statistically significant, ranged from 1.6 to 2.0 mph, with the average of 1.8 mph being a 3.6 percent decrease. The decreases that occurred before the end of the bars partly explain the smaller speed decreases at the end of the bars and right before the hazardous section.

- Given the theory behind the effectiveness of optical speed bars in decreasing motorists' speeds, it was anticipated that drivers would slow down as they tracked through the bars. This trend was not observed.

- There was a trend for speeds to increase between the initial installation and approximately 90 days after installation at 8 of the 10 stations. At several of the stations, these increases were several miles per hour. Therefore, it can be concluded that motorists became accustomed to the bars and increased their speeds; however, as noted earlier, speeds were generally still decreased from the speeds before the bars were installed.

Route 460 Through Town of Zuni

The results of vehicle speed studies conducted at the pilot site at six locations and during three data collection periods (before, immediately after, and approximately 90 days after installation of the bars) may be summarized as follows:

- The optical speed bars had an overall positive impact, as vehicle speeds recorded at the 45 mph speed limit sign at the downstream end of the bars decreased for all time periods 90 days after installation at both ends of town.

- Statistically significant decreases at the eastern side of town averaged 3.3 mph, which was a 6.1 percent decrease. At the western end of town, statistically significant decreases averaged 9.5 mph, which was a 16.8 percent decrease.

- Vehicle speeds increased for all time periods at the two stations in the center of town 90 days after installation. The average speeds of 46.6 mph westbound and 47.0 mph eastbound, however, were only slightly above the posted 45 mph speed.

- It cannot be concluded that motorists became accustomed to the bars and therefore increased their speeds after a period of time. Speeds increased between initial installation and approximately 90 days after installation at the end of the speed bars on the eastern side of town but decreased at the end of the bars on the western end. Speeds increased 90 days after installation at the two stations in the center of town; however, because of the distance between the bars and the location of the count stations, it is questioned whether the bars influenced the speeds at all.

- Decreases in speed were generally greater for the Zuni installation, where bars extended across the lanes, than for the Lee Chapel Road installation, where bars extended only 18 inches from the edge and centerlines.

CONCLUSIONS

Based on the results of this study (even though limited by the number of sites) and the reviewed literature, the following is concluded:

- *A flashing LED stop sign is effective in reducing the speeds of vehicles approaching an intersection, particularly when visibility of the sign is an issue; however, the speed reductions are likely to be small.* Speed reductions are greater during dusk and nighttime hours. Accordingly, these devices should be considered as a potential safety countermeasure when addressing accident problems at stop sign controlled intersections.

- *Optical speed bars are effective in reducing the speeds of vehicles approaching a hazardous roadway section, a reduced speed zone, or other roadway/travel change area.* The reductions in speeds may be small.

- *Optical speed bars that extend across the travel lane are more effective in reducing speeds than those that just extend a short distance from the centerline or edge line.*

- *If thermoplastic tape is used for installation of the optical speed bars, motorists traversing the bars experience a slight bumping effect, similar to that with rumble strips but less pronounced and not as noisy.* This experience likely enhances the effectiveness of the bars in reducing speeds.

RECOMMENDATIONS

Flashing LED Stop Signs

1. *VDOT's Traffic Engineering Division and regional traffic engineers should consider the use of a flashing LED stop sign as a safety countermeasure at intersections controlled by a stop sign where the number of crashes is higher than expected.* Field testing found statistically significant speed decreases of vehicles approaching such a sign, which suggest drivers are more aware of the stop sign and thus more prone to stop. The speed decreases may be small, however: in the range of 1 to 3 mph. Speed decreases tended to be greater during the night than during the day. These facts, along with the costs of installing the sign and other site-specific conditions of the problem location, should be considered when comparing the use of a flashing LED stop sign with the use of alternative countermeasures; i.e., a flashing LED stop sign is one of many tools in a traffic engineer's toolbox that may be applicable at a site given its specific conditions.

Optical Speed Bars

2. *VDOT's Traffic Engineering Division and regional traffic engineers should consider the use of optical speed bars as a safety countermeasure to be placed just in advance of a hazardous area, a reduced speed zone, or another roadway/travel change area where the number of crashes is higher than expected or where excessive speeding occurs.* Field testing found statistically significant speed decreases of vehicles at the downstream terminus of a set of such bars, which suggest drivers are more aware of the upcoming hazard or speed zone and thus more prone to be traveling at a recommended safe speed. The speed decreases may be small, however: in the range of 1 to 3 mph, especially with bars that are 18 inches long and extend from both edges of the travel lane. Speed decreases are higher when the bars extend across the travel lane, and this configuration should be considered first. If laid out with thermoplastic tape (and not just paint), the bars extending across the lane also produce a

bumping sensation, similar to but less than that of transverse rumble strips but without the noise. These facts, along with the costs of installing the sign and other site-specific conditions of the problem location, should be considered when deciding the layout of the bars and when evaluating optical speed bars with alternative countermeasures; i.e., optical speed bars are one of many tools in a traffic engineer's toolbox that may be applicable at a site given its specific conditions.

COSTS AND BENEFITS ASSESSMENT

The purpose of installing the flashing LED stop sign was to reduce motorists' speeds as they approached the intersection and to improve their compliance with the stop sign. The purpose of installing the optical speed bars was to reduce motorists' speeds on they approached a hazardous area (on Lee Chapel Road) or a reduced speed zone (in the town of Zuni). In both cases, however, the ultimate objective was to reduce crashes and the possible injuries that might result.

The research effort did not include a crash analysis as time was not available to obtain the recommended minimum of 3 years of crash data after installation of a countermeasure. However, a review of 3 years of crash data at the three sites prior to installation of the measures revealed the following:

- Route 151{ 14 crashes (2003-2005) that included 7 injuries and 4 crashes caused by drivers running the stop sign
- Lee Chapel Road: 22 crashes (2002-2004) that included 2 fatalities and 16 injuries; excessive speed was likely a contributing factor in an August 2005 fatal crash.
- Route 460 in Zuni: 15 crashes (2003-2005) that included 1 fatality and 7 injuries.

Excessive speed is often a contributing factor in a crash; therefore, it is logical to assume that measures that reduce motorists' speeds can lead to a reduction in crashes. Therefore, the following discussion is based on the supposition that since flashing LED stop signs and optical speed bars decrease speeds, there will be crashes prevented or avoided if these measures are installed. In an economic analysis, the costs of crashes that are prevented or avoided are assumed to be the economic benefit of the countermeasure.

Table 7 compares the cost of installing each pilot with the estimated costs of motor vehicle crashes of varying severity in 2006 dollars.

A benefit/cost (b/c) ratio greater than 1.0 is desirable as it shows that the savings resulting from the benefits of a countermeasure exceed its costs. Based on the b/c ratios shown in Table 7, it can be said (with one exception) that if even one crash is prevented by the piloted countermeasure, then the resulting savings exceed the cost of implementation. In those cases where severe injuries are prevented, the resulting savings can be sizeable. The exception

Table 7. Costs and Benefits Analysis

Flashing LED Stop Sign			
A. Cost of Pilot[1] (2006 Dollars)	**B. Crash Type[2]**	**C. Cost per Injury[2] (2006 Dollars)[3]**	**D. Benefit/Cost Ratio (C/A)**
2210	Fatality	3,341,620	1512.05
2210	Incapacitating Injury	231343	104.68
2210	Evident Injury	46269	20.94
2210	Possible Injury	24420	11.05
2210	Property Damage Only	2570	1.16
Optical Speed Bars On Lee Chapel Road			
A. Cost of Pilot (2006 Dollars)	**B. Crash Type[2]**	**C. Cost per Injury[2] (2006 Dollars)[3]**	**D. Benefit/Cost Ratio (C/A)**
1800	Fatality	3,341,620	1856.46
1800	Incapacitating Injury	231343	128.52
1800	Evident Injury	46269	25.71
1800	Possible Injury	24420	13.57
1800	Property Damage Only	2570	1.43
Optical Speed Bars On Route 460 In Zuni			
A. Cost of Pilot (2006 Dollars)	**B. Crash Type[2]**	**C. Cost per Injury[2] (2006 Dollars)[3]**	**D. Benefit/Cost Ratio (C/A)**
15,000	Fatality	3,341,620	222.77
15,000	Incapacitating Injury	231343	15.42
15,000	Evident Injury	46269	3.08
15,000	Possible Injury	24420	1.63
15,000	Property Damage Only	2570	0.17

[1]Sign cost at DOT discount.
[2]*Source:* Federal Highway Administration, *Motor Vehicle Accident Costs*, Technical Advisory T 7570.2., Washington, D.C., October 31, 1994.
[3]The 1994 dollar amount reported in the technical advisory was inflated to 2006 dollars using the Gross Domestic Product (GDP).

involves a crash that results in property damage only (no injuries) where optical speed bars with a layout similar to that in the Zuni pilot are installed. In this case, six such crashes would have to be prevented to result in a b/c ratio greater than 1.0 (6 crashes × $2,570 "savings" per property-damage-only crash ÷ $15,000 cost = 1.03).

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APPENDIX A

STOP SIGN COMPLIANCE FIELD SHEET

STOP SIGN COMPLIANCE FIELD SHEET

Location NB approach of Route 151 at its intersection with Route 250 Recorder ______________________________

Date ____________ Time __________ to __________ Weather ____

TIME	LEFT TURN AUTOS	LEFT TURN TRUCKS	COMPLIANCE	RIGHT TURN TRUCKS	RIGHT TURN AUTOS
0 to 15 minutes			FULL STOP VOLUNTARY		
			FULL STOP BY TRAFFIC		
			ROLLING STOP 0 – 3 mph		
			BLOW THRU >3 mph		
15 to 30 minutes			FULL STOP VOLUNTARY		
			FULL STOP BY TRAFFIC		
			ROLLING STOP 0 – 3 mph		
			BLOW THRU >3 mph		
30 to 45 minutes			FULL STOP VOLUNTARY		
			FULL STOP BY TRAFFIC		
			ROLLING STOP 0 – 3 mph		
			BLOW THRU >3 mph		
45 to 60 minutes			FULL STOP VOLUNTARY		
			FULL STOP BY TRAFFIC		
			ROLLING STOP 0 – 3 mph		
			BLOW THRU >3 mph		

APPENDIX B

OPTICAL SPEED BAR SPACING ON LEE CHAPEL ROAD, FAIRFAX COUNTY

New York Pattern Spacing			
Initial Speed	65 mph		
Ending Speed	30 mph		
Distance	530 ft		
Deceleration	-6.8 ft/s^2		
Bar Frequency	4 bars/s		
Bar No. (from–to)	**Distance (feet)**	**Cumulative Distance (feet)**	**Speed (mph)**
1–2	24	24	64
2–3	23	47	63
3–4	23	70	61
4–5	23	93	60
5–6	22	115	59
6–7	22	137	58
7–8	21	158	57
8–9	21	179	56
9–10	21	200	54
10–11	20	220	53
11–12	19	239	52
12–13	19	258	51
13–14	19	277	50
14–15	18	295	49
15–16	18	313	47
16–17	18	331	46
17–18	17	348	45
18–19	16	364	44
19–20	16	380	43
20–21	16	396	42
21–22	15	411	40
22–23	15	426	39
23–24	15	441	38
24–25	14	455	37
25–26	13	468	36
26–27	13	481	35
27–28	13	494	33
28–29	12	506	32
29–30	12	518	31
30–31	12	530	30

Source: Katz, B.J. *Pavement Markings for Speed Reduction*. Science Applications International Corporation, McLean, Va., December 2004.

APPENDIX C

OPTICAL SPEED BAR SPACING ON ROUTE 460, ZUNI

Texas Pattern Spacing Westbound (Toward Richmond)			
Initial Speed	65 mph		
Ending Speed	45 mph		
Distance	632 ft		
Deceleration	-3.87 ft/s^2		
Bar Frequency	4 bars/s		
Bar No. (from–to)	**Distance (feet)**	**Cumulative Distance (feet)**	**Speed (mph)**
1–2	24	24	65
2–3	24	48	64
3–4	24	72	63
4–5	23	95	63
5–6	23	118	62
6–7	23	141	61
7–8	23	164	61
8–9	22	186	60
9– 10	22	208	59
10–11	22	230	59
11–12	22	252	58
12–13	21	273	57
13–14	21	294	57
14–15	21	315	56
15–16	21	336	55
16–17	20	356	55
17–18	20	376	54
18–19	20	396	53
19–20	20	416	53
20–21	19	435	52
21–22	19	454	51
22–23	19	473	51
23–24	19	492	50
24–25	18	510	49
25–26	18	528	49
26–27	18	546	48
27–28	18	564	47
28–29	17	581	47
29–30	17	598	46
30–31	17	615	46
31–32	17	632	45

Texas Pattern Spacing Eastbound (Toward Suffolk) use westbound spacing plus the below			
Initial Speed	65 mph		
Ending Speed	40 mph		
Distance	756 ft		
Deceleration	-3.87 ft/s^2		
Bar Frequency	4 bars/s		
Bar No. (from–to)	**Distance (feet)**	**Cumulative Distance (feet)**	**Speed (mph)**
32–33	16	648	44
33–34	16	664	44
34–35	16	680	43
35–36	16	696	42
36–37	15	711	42
37–38	15	726	41
38–39	15	741	40
39–40	15	756	40

Source: Katz, B.J. *Pavement Markings for Speed Reduction*. Science Applications International Corporation, McLean, Va., December 2004.