Indoor Simulator Study and Field Study Evaluation of Sequential Flashing Chevron Signs on Two-lane Rural Highways - Technical Brief

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TECHBRIEF: INDOOR SIMULATOR AND FIELD STUDY EVALUATION OF SEQUENTIAL FLASHING CHEVRON SIGNS ON TWO-LANE RURAL HIGHWAYS

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FHWA Contact: Joseph Cheung, HAS-1, (202) 366-6994, joseph.cheung@dot.gov

This document is a technical summary of the Federal Highway Administration report *Indoor Simulator and Field Study Evaluation of Sequential Flashing Chevron Signs on Two-lane Rural Highways* (FHWA-SA-18-075).

OBJECTIVE

The Federal Highway Administration (FHWA) recently published *Low-cost Treatments for Horizontal Curve Safety 2016*, which offers guidance concerning the safety effects of various countermeasures intended to mitigate roadway departure crashes along horizontal curves.[1] One sign application with potential safety improvements along horizontal curves on two-lane rural highways was the Sequential Dynamic Curve Warning System (SDCWS). The SDCWS is a series of horizontal curve chevron signs with solar-powered flashing lights embedded in the signs. The flashing lights can be simultaneous or a sequence of lights moving toward or away from the driver. In the sequential mode, each sign begins flashing at a time that is offset relative to the adjacent sign, producing a sequential flashing effect. An example SDCWS application is shown in Figure 1.

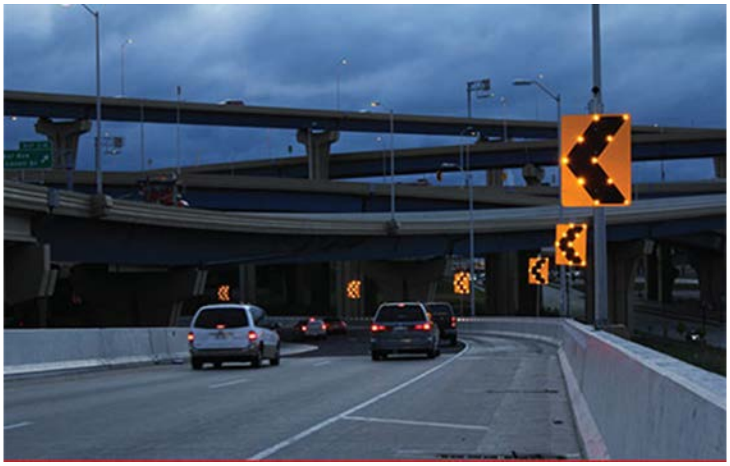

Figure 1. Photo. SDCWS.[2]

The purpose of this study was to identify effective flash rates, speed-activation thresholds, and flashing sequences when deploying SDCWS along horizontal curves on two-lane rural highways.

INTRODUCTION

In 2016, there were nearly 7.3 million police-reported crashes, resulting in 37,461 fatalities and more than 3.1 million injuries on highways and streets in the United States.[3]

More than 30 percent of all fatal crashes involved a single vehicle and occurred off of the roadway. One plausible safety management approach aims to prevent vehicles from leaving the roadway through encouragement of driver selection of lower speeds through horizontal curves via use of traffic control devices like SDCWS. Published research related to SDCWS is limited, but research efforts related to dynamic curve warning signs (DCWS), speed feedback signs, and speed-activated signs in work zones have been documented. Studies show DCWS, speed feedback signs, and work zone speed-activated signs are associated with decreases in driver operating speeds. (See references 4, 5, 6, 7, and 8.) Studies also show that continued use of DCWS produce a lasting operating speed reduction while speed feedback signs and work zone speed-activated signs do not have a lasting influence on operating speeds because these devices are not permanent. (See references 6, 7, 8, 9, 10, and 11.) A study of 22 horizontal curve locations on rural, two-lane highways in Arizona, Florida, Iowa, Ohio, Oregon, Texas, and Washington showed mean operating speeds were reduced by 1.8 mph one month after installation of DCWS, 2.6 mph 12 months after installation, and 2.0 mph 24 months after installation.[12] Studies have also shown DCWS decrease operating speeds on high- and low-traffic volume roads. One study evaluated the vehicle speed impact of DCWS on low-volume rural local roads in Minnesota.[10] The before-after study showed that the unadjusted average speed reduction was 1.0 to 8.8 mph at the point of curvature and 1.8 to 6.3 mph within the curve after installation of DCWS.

METHODOLOGY

This study examined effective flash rates, speed activation thresholds, and flashing sequences when deploying SDCWS along horizontal curves on two-lane rural highways through two evaluations. A driving simulator study at the University of Utah's Utah Traffic Lab identified several SDCWS settings that impacted operating speeds and lane keeping behavior along a simulated version of Pennsylvania (PA) State Route 851 with 17 horizontal curves. Sixty-eight participants (35 males, 33 females) between the ages of 18 and 25 were recruited to participate in the study. The study employed a 3 (flashing pattern) x 2 (flashing rate) experimental design with a hanging control group. The three flashing patterns were: (1) flashing in sequence toward the driver, (2) flashing in sequence away from the driver, and (3) flashing in unison (i.e., simultaneous). The two flashing rates were: (1) slow flashing, defined as one flash per second, and (2) fast flashing, defined as five flashes per second. To implement this experimental design, a six-mile stretch of PA State Route 851 was divided into three distinct groups of curves, each roughly two miles in length. One of the flashing treatments (with a treatment distinguished by the combination of a flashing pattern and rate) was applied to each of these curve sections. Overall, six distinct simulator scenarios were created, each scenario with three distinct flashing treatments, one on each of the three defined sections of PA State Route 851. A seventh scenario consisted of the same three groups of curves with no flashing treatment.

Based on the outcome of the simulator study, an outdoor field study was completed at three sites in Wisconsin to further assess the potentially effective flash rates and flashing patterns identified in the simulator study. Four different conditions were studied in the field, including a speed-activation threshold that was either 5 or 10 mph above the curve advisory speed, two different flash rates (simultaneous and away from the driver), and two different flashing patterns (three flashes per second and one flash per second). A sample of observed operating speeds was used to create speed distributions that showed the range of driver speed behavior at each study site. These distributions were used to calculate performance measures, such as the mean operating speed, standard deviation of speed, 85^{th}-percentile operating speed, and the proportion of vehicles exceeding the horizontal curve advisory speed.

RESULTS

This brief presents the research results in three parts. The first part contains aggregate results for the driving simulator study. The second and third parts are based on a disaggregate analysis that sought to identify the most effective flashing characteristics for SDCWS.

Aggregate Analysis of Driving Simulator Data

The aggregate results of the driving simulator study did not appear to show any statistically significant differences in mean speed across the various flashing treatments. The mean speeds were generally lowest for the control condition, which was the PA State Route 851 scenario with only static signs and no flashing, but confidence intervals for the mean speed estimates corresponding to treatment and control conditions overlapped. With regards to lateral vehicle position, there were no consistent and statistically significant differences in lateral position across all treatment conditions and the control. Drivers tended to position the centroid of the simulator vehicle approximately one to two feet to the right of the center of their lane.

Disaggregate Analysis of Driving Simulator Data

The disaggregate analysis of the driving simulator data first used a binary logit model to estimate the probability of one or more lane departures as a driver traverses a horizontal curve as a function of roadway characteristics (including curve treatments). Indicator variables for the six treatments indicated that none of the six applied treatments showed statistically significant impacts on lane departure probabilities at the 95 or 90 percent confidence levels when compared to the control condition. However, the treatment of low flashing rate away from the driver was associated with a lower probability of one or more lane departures and the odds ratio was statistically significant at slightly more than the 85 percent confidence level. This is particularly interesting because speed-related findings, to be discussed in the next paragraph, also showed the “low-away” treatment resulting in a horizontal curve speed nearly 4 mph less than the control condition for drivers that approach a horizontal curve at 50 mph or more.

The research team also conducted an ordinary least squares regression to model the potential linear-in-parameters relationship between the six different treatments, the control condition, and mean horizontal curve speed, while also controlling for the effect of other driver and roadway characteristics. The mean horizontal curve speed in this analysis was the mean of instantaneous speeds at the point of curvature, one-quarter point through the curve, halfway point through the curve, three-quarter point through the curve, and the point of tangency. The results showed that four different flashing treatments were associated with lower speeds than the control condition: low toward, low simultaneous, low away, and high simultaneous by 0.89, 1.0, 3.8, and 2.4 mph, respectively. While the flashing treatments were not associated with any change in speed across all drivers, they appeared to be effective at reducing operating speeds for drivers approaching a curve at a "high" operating speed (identified for this experiment as 50 mph or more, at least 5 to 10 mph above the posted speed limit). The low-away treatment was associated with the lowest mean curve speed of all treatment and control conditions (and from the previous section, with a reduction in lane departure probability compared to all other treatments and the control condition). The research team made the following recommendations based on the overall findings of this simulator effort for consideration during the field evaluation:

- Continue to explore "low-away" and "high-simultaneous" flashing treatments, as both resulted in the greatest and most statistically significant speed reduction effects on drivers approaching horizontal curves at higher speeds; "low-away" also resulted in the lowest probability of one or more lane departures along the horizontal curves.
- Expand the driver age ranges beyond 18-25 years old to include older drivers.
- Establish a procedure for determining a "threshold speed" over which the flashing treatments will be effective that can be applied across a range of roadway designs; using an empirical approach, the simulator study showed this threshold speed to be 50 mph for the study section of PA State Route 851.

Disaggregate Analysis of Field Study Data

Based on the results of the driving simulator study, two chevron flashing patterns appeared to offer promise in managing operating speeds along horizontal curves of two-lane rural highways. These included: (1) low flash rate away from the driver, and (2) high flash rate with simultaneous flashing. Because these patterns had the most pronounced effect on the sample of drivers approaching horizontal curves at high speeds, two speed-activation thresholds were also considered for the field study – one set 5 mph above the curve advisory speed and the other set 10 mph above the curve advisory speed. In total, five conditions were tested in the field study. The first was a baseline condition, when all chevrons were set in a static condition with no flashing, two conditions with the low-away flashing sequence with two speed-activation thresholds, and two conditions with the high-simultaneous flashing pattern and two speed-activation thresholds.

When considering the collective results of a speed difference analysis, defined as the change in operating speed between the approach tangent and the midpoint of the horizontal curve, there appeared to be more significant operating speed benefits for the sequential flashing signs during nighttime conditions than during the daytime conditions. During the nighttime conditions, condition #1 (simultaneous flashing pattern at a rate of 3Hz, with a speed activation threshold 5 mph above the advisory speed) produced the lowest mean and 85th-percentile operating speeds relative to the baseline and other sequential flashing patterns. Condition #2 (same simultaneous flashing as condition #1 with speed activation threshold that is 10 mph above the curve advisory speed) produced operating speeds at night that were also generally lower than the baseline condition. Conditions #3 and #4 (flashing pattern away from the driver at 1Hz) did not have consistent, significant effects on vehicle operating speeds at night.

SUMMARY AND CONCLUSIONS

The objective of this study was to identify effective flash rates, speed-activation thresholds, and flashing sequences when deploying SDCWS along horizontal curves on two-lane rural highways. The study used data from an indoor driving simulator study and a three-site field study in Wisconsin to examine effects on lane keeping and operating speeds along horizontal curves if a SDCWS was present.

Based on the indoor driving simulator study, a flashing sequence away from the driver at a low flash rate (1 Hz), or a simultaneous flashing pattern with a high flash rate produced the greatest speed reduction effects on drivers approaching horizontal curves at higher speeds on two-lane rural highways. The flashing sequence away from the driver also produced the lowest probability of a lane departure event. These two conditions were then evaluated in the field at three locations in Wisconsin. In addition to the flashing pattern and flash rate, the speed-activation threshold was also varied in the field to either 5mph or 10mph above the curve advisory speeds.

The field study found that, among the conditions tested, the simultaneous flashing pattern, set to activate at a rate of 3 Hz when a driver approached the curve more than 5 mph above the curve advisory speed, produced the most desirable outcome based on the speed metrics considered in the present study. However, a flashing pattern away from the driver with a flashing rate of 1 Hz set to activate when approach speeds exceed the curve advisory speed by any amount appears to be another effective setting when the present field study results are assessed in conjunction with findings from the driving simulator study and a previous study by Smadi et al.[13]

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Researchers— Eric Donnell, R.J. Porter, Milan Zlatkovic, Joel Cooper, L. Li, David Strayer, and Mingde Lin.

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Key Words— two-lane rural highways, flashing chevron signs, 85th -percentile, lane departure, operating speed, posted speed limit, and vehicle lateral position.

FHWA, Office of Safety
Joseph Cheung

202-366-6994

joseph.cheung@dot.gov

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