Evaluation of the Sequential Dynamic Curve Warning System

Summary of Full Report
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November 2015

HIGHWAYS FOR LIFE
Accelerating Innovation for the American Driving Experience.

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16. Abstract

Implementing safety countermeasures on rural horizontal curves to address speeding can improve the safety performance for those locations. State safety and traffic engineers are faced with making decisions on what type of technology to use and which sites to use the technology on in a fiscally constrained environment. The research conducted for this project evaluated a Sequential Dynamic Curve Warning System (SDCWS) that could be an additional tool for these engineers to use either separately or in combination with other countermeasures to address horizontal curve locations with a history of safety concerns. TAPCO provided the SDCWS evaluated in this project and provided installation and maintenance support to the DOTs.

The full report is available as a separate document (report no. FHWA-15-CAI-012-B).

This project was undertaken in 2011 by the Federal Highway Administration's Highways for LIFE Technology Partnerships Program, a discretionary program of SAFETEA-LU (Public Law 109-59). The purpose of the program is to evaluate, document, and disseminate the performance results of promising innovative highway safety technologies that are commercially available through a partnership with general industry and state and local highway agencies.

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SI* (MODERN METRIC) CONVERSION

FACTORS APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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LIST OF ABBREVIATIONS AND ACRONYMS

AADT	Annual average daily traffic
Caltrans	California Department of Transportation
CC	Center of curve
DOT	Department of Transportation
DSFS	Dynamic speed feedback sign
FARS	Fatality Analysis Reporting System
GES	General Estimates System
HSIS	Highway Safety Information System
LIDAR	Light detection and ranging
MUTCD	Manual on Uniform Traffic Control Devices
PC	Point of curvature
SD	Standard deviation
SDCWS	Sequential Dynamic Curve Warning System
TE	True effect
vpd	Vehicles per day

Background

While horizontal curves make up a small percentage of total road miles, one-quarter of all highway fatalities occur on them. The average crash rate for horizontal curves is about three times that of other highways segments. The majority of curve-related crashes is attributed to speeding and driver error and involves lane departures.

More than 25 percent of fatal crashes are associated with a horizontal curve, and the vast majority of these crashes involve a roadway departure. About three-quarters of curve-related fatal crashes involve a single vehicle leaving the roadway and striking trees, utility poles, rocks, or other fixed objects, or overturning. The majority of these crashes are speed related.

Problem Description

Implementing safety countermeasures on rural horizontal curves to address speeding can improve the safety performance for those locations. State safety and traffic engineers are faced with making decisions on the types of technology to use and which sites to use the technology on in a fiscally constrained environment.

A number of low-cost countermeasures are traditionally used to help keep drivers on the road and in their lane; however, the impacts of applying these countermeasures can be limited. This led to the need for additional research and testing on more dynamic devices to assist safety and traffic engineers in managing speed and safety across their diverse roadway networks.

Research Overview and Objective

The research conducted for this project evaluated a Sequential Dynamic Curve Warning System (SDCWS) that could be an additional tool for engineers to use either separately or in combination with other countermeasures to address horizontal curve locations with a history of safety concerns. The objective of this project was to test and evaluate the effectiveness of the SDCWS in reducing vehicle speed, as well as its potential to reduce the frequency and severity of speed-related crashes on rural horizontal curves. The evaluation included rural curves in five States (Iowa, Missouri, Texas, Washington, and Wisconsin). Figure EX.1 shows a map of the test sites.

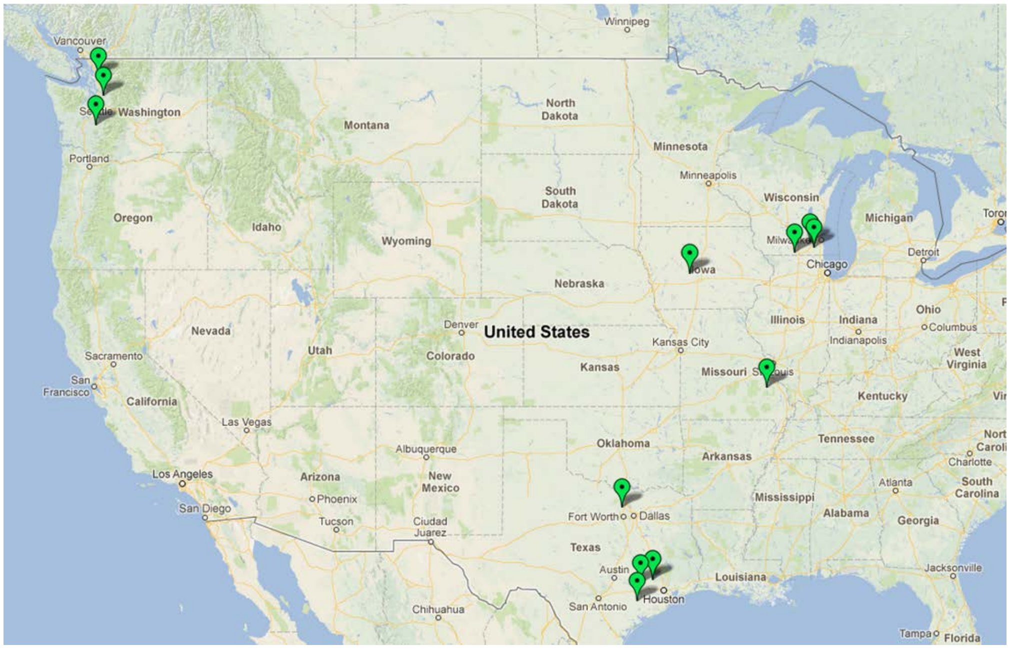

Figure EX.1. Map. Final test site locations. (Source: Google Maps)

While several dynamic curve sign systems have been tested in the past, this system is unique in terms of including guidance not just before or at the curve, but also throughout the curve with the blinking chevrons. The SDCWS is meant to replace existing static advance warning and chevron signage.

Research Description/Methodology

Site selection criteria were developed and the research team worked with each of the five participant States to develop a list of candidate locations. After reviewing the information from each State, the team developed a finalized list of potential sites and spatially located each site using Google Earth or the aerial images provided by the agency. The suitability of each curve location was evaluated. Locations that had major developments, railroads, or major points of access, including intersections other than low-volume intersections, were eliminated. Based on additional information received from each State about the remaining sites, the sites were ranked in terms of number of crashes. A threshold of at least 5 crashes over a 5-year period was used to define a high-crash location.

The research team conducted site visits to all candidate locations. Field observations identified roadway characteristics including curve layout, operational conditions, presence of speed and advisory signs, and relevant roadway conditions. In addition, a speed study was conducted using a radar gun and data were analyzed to verify whether a speeding problem exists. A field report was prepared which included all of the field information collected for each site visited.

Following the site visits, the research team selected the final test curve locations for installation of the SDCWS. Once the test sites were established, the research team provided the chevron quantity and sign curve warning sign details to the manufacturer (TAPCO). All installations were completed by the TAPCO with support from the respective State DOT. The manufacturer calibrated the sign and radar operational settings specific to each location.

The research team collected speed data using pneumatic road tubes for the 12 treatment sites. No sped data was collected for the 24 control sites. Speed data were collected before and one month after system installation, as well as 12 months, 18 months, and 24 months post installation. A simple crash analysis was conducted in addition to the speed analysis to determine the safety benefits.

Technology Description

TAPCO's SDCWS utilizes Day-Viz™ LED enhanced solar powered signs, and BlinkerBeam™ wireless controllers along with ultra-low power radar to detect and flash a series of chevron signs along with the advance warning sign in a horizontal curve. This system both warns and guides drivers through the upcoming horizontal curve. See Figure EX.2 for the system installation for the Iowa site.

Advance Warning sign

Chevron Installation

Chevron with LED and Solar Panel

Chevron in Operation

Figure EX.2. Photos. Installation of the TAPCO's SDCWS. (Source: ISU/TTI)

Using the length and speed of the curve, the user can set each of the W1-8 chevron signs to flash in a specific sequence or time interval in the direction of travel. Each curve design will have different sign placement and geometry for consideration when determining the appropriate flash sequence.

The radar can detect approaching vehicles up to 300 ft in advance of the curve sign. The threshold is commonly set to flash for vehicles approaching at or just below the advisory speed of the curve. When this speed threshold is exceeded, the radar will trigger the flash of the advance warning sign and sequential chevron signs using TAPCO's 900-Mhz BlinkerBeam™

wireless network. This wireless network is constantly communicating with each sign and providing a synchronization pulse throughout the network. This synchronization pulse is what each sign controller will use to keep the proper flash time and sequence. Figure EX.3 shows an example of the activation sequence.

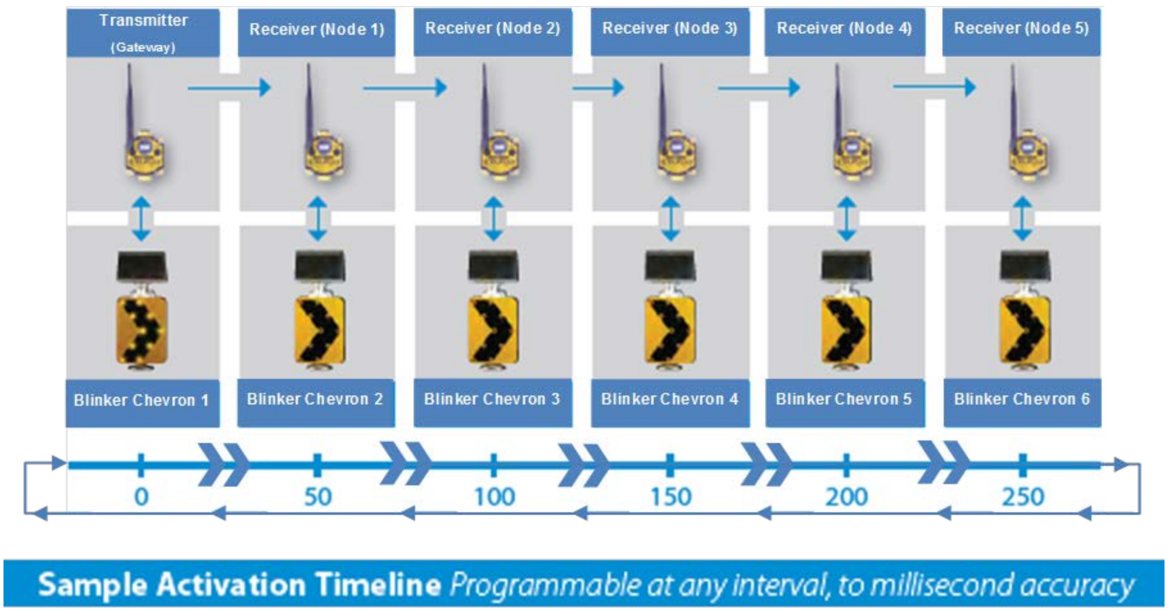

Figure EX.3. Diagram. Example SDCWS activation sequence. (Source: TAPCO)

Data Collection Protocol and Quality Assurance

Road tubes were placed to collect speed and volume data at three locations per curve test site. The data was only collected in one direction of travel for each curve. The goal was to measure driver speed selection in advance, at the beginning of the curve, and within the curve. These three locations were described as follows:

- Upstream – Road tubes were placed approximately 500 ft before the advance curve warning sign (just in advance of being detected by the radar within the advance curve warning sign area).
- Point of Curvature (PC) – These tubes were placed at the point of curvature or beginning point of the horizontal curve.
- Center of Curve (CC) – Tubes placed within the center of the horizontal curve.

Speed patterns can vary as a result of weather and time of year; therefore, the purpose of the upstream data collection was to measure any changes in speed that may have occurred independent of the sign installation. The upstream data collection locations were placed outside of the SDCWS radar detection area so that they would not be affected by the sign and would not adjust driver behavior. The upstream locations also allowed vehicles to be tracked through the point of curvature and center of curve to determine individual vehicle speed reductions.

Speed and volume data were collected for at least 24 consecutive hours during the week (Monday through Friday) for the before, one month, 12 months, and 18 months after installation.

For the final data collection period (24 months after installation) at least 48 consecutive hours of data were collected in order to analyze the day and night effects of the signs. During data collection, the equipment was spot checked to determine whether any problems had occurred. Data were also checked in the field during data collection to spot problems early, and the full data sets were checked when data collection was complete.

Data Reduction and Vehicle-Tracking

The data were reduced after each site collection period and a number of speed metrics were calculated for the direction of travel toward the SDCWS. They include average speed, standard deviation of speed, 50^{th} percentile speed, 85^{th} percentile speed, and percent of all vehicles traveling 5, 10, 15, or 20 mph over the posted speed limit and curve advisory speed. In addition to calculating these statistics for all vehicles collected, the dataset was further reduced by "tracking vehicles" through the curve.

Although data were collected and analyzed for all vehicles within the curve, vehicle tracking was used to remove vehicles with speeds impacted by turning movements or other vehicles. This allowed the analysis to hone in on the effect of SDCWS. Each vehicle that was recorded by the counter at all three data collection locations was designated a "tracked vehicle," removing vehicles that did not go through the entire curve from the "tracked vehicle" analysis. For example, a curve with a side street by the curve would have vehicles slowing down to make the turn or speeding up after turning off the side road. In both situations the lower speeds were influenced by the turning movement and not by the SDCWS. Tracking vehicles singles out only the vehicles that are influenced by the SDCWS through the curve.

Vehicles that were not in free flow, and thereby had their speed influenced by a vehicle in front or behind them were also removed from the analysis using the time between counters, the headway between vehicles, and the classification of the vehicles. The criteria for a free flowing vehicle used were having greater than a five second headway and/or three second tailway. If the upstream, point of curvature, or center of curve were not in free flow then the entire vehicles' data were removed.

The same speed metrics mentioned above for all vehicles were also calculated for tracked vehicles. In addition to these speed metrics for each tracked vehicle, a speed reduction metric can be calculated from the upstream to point of curvature, upstream to center of curve, and point of curvature to center of curve. The benefit to this metric is that it identifies where speed reductions are occurring. It also takes into account the speed reductions upstream where the other metrics used the upstream location as a control point. The average and 85^{th} percentile speed reduction between all of the data collection locations were then calculated for each site.

Key Findings

The SDCWS was shown to be effective at reducing speed during all data collection periods from 1 month to 24 months after installation.

Table EX.1 shows the average change in speed at the point of curvature across all sites by data collection period. The statistics in parenthesis show the results of only tracked vehicles through the curve, and are considered to be more representative of the driver response to the system without influence of other factors.

The change in mean speed was consistent between all data collection periods with reductions between 1.7 mph at 1 month after data collection, to 1.3 mph during the 12 and 18 month after data collection periods. The 85th percentile speed also showed reductions with a decrease of 1.7 mph during the 1 month after data collection period.

Also shown in Table EX.1, the fraction of vehicles exceeding the posted or advisory speed limit showed reductions during all data collection periods. The sites on average had a decrease of 11 percent in the fraction of vehicles exceeding the curve advisory speed by 5 mph or more. The fraction of vehicles exceeding the advisory speed by 10 mph or more decreased by an average of 22 percent and by 30 percent for the fraction of vehicles exceeding by 15 mph or more. An average decrease of 32 percent was shown in the fraction of vehicles exceeding the advisory speed by 20 mph or more.

Table EX.1. Average change across all sites at the point of curvature (PC).

<table>
<tr><th colspan="2"></th><th colspan="4">Time Period</th></tr>
<tr><th colspan="2"></th><th>1 Month</th><th>12 Month</th><th>18 Month</th><th>24 Month</th></tr>
<tr><td colspan="2">Change in mean speed (mph)</td><td>-1.7
(-1.8)</td><td>-1.3
(-1.3)</td><td>-1.3
(-1.6)</td><td>-1.5
(-1.4)</td></tr>
<tr><td colspan="2">Change in 85th percentile speed (mph)</td><td>-1.7
(-1.9)</td><td>-1.4
(-1.3)</td><td>-1.3
(-1.7)</td><td>-1.4
(-1.4)</td></tr>
<tr><td rowspan="4">Change in fraction of vehicles exceeding advisory speed by</td><td>5 mph</td><td>-13.5%
(-11.0%)</td><td>-9.1%
(-6.1%)</td><td>-11.2%
(-8.7%)</td><td>-10.7%
(-6.7%)</td></tr>
<tr><td>10 mph</td><td>-27.7%
(-24.5%)</td><td>-18.1%
(-12.9%)</td><td>-22.6%
(-18.5%)</td><td>-20.9%
(-15.7%)</td></tr>
<tr><td>15 mph</td><td>-29.1%
(-23.4%)</td><td>-32.6%
(-23.8%)</td><td>-31.9%
(-28.6%)</td><td>-27.7%
(-21.7%)</td></tr>
<tr><td>20 mph</td><td>-39.6%
(-48.0%)</td><td>-30.7%
(-43.9%)</td><td>-26.3%
(-26.4%)</td><td>-32.3%
(-38.7%)</td></tr>
<tr><td rowspan="4">Change in fraction of vehicles exceeding posted speed by</td><td>5 mph</td><td>-23.8%
(-15.2%)</td><td>-31.1%
(-18.8%)</td><td>-30.3%
(-23.8%)</td><td>-23.6%
(-16.8%)</td></tr>
<tr><td>10 mph</td><td>-10.5%
-1.6%</td><td>-3.2%
(-9.2%)</td><td>-15.0%
(-14.0%)</td><td>-15.2%
(-10.9%)</td></tr>
<tr><td>15 mph</td><td>0.0%
(-8.3%)</td><td>0.0%
(-6.7%)</td><td>-3.8%
(0.0%)</td><td>0.0%
(-7.4%)</td></tr>
<tr><td>20 mph</td><td>0.0%
(0.0%)</td><td>0.0%
(0.0%)</td><td>0.0%
(0.0%)</td><td>0.0%
(0.0%)</td></tr>
</table>

Note: Numbers in parentheses represent statistics for tracked vehicles only.

Table EX.2 further shows the downward trend of vehicles exceeding the advisory speed and speed limit by showing the percentage of vehicles exceeding both at each time period. The highest changes occurred in the percentage of vehicles exceeding the advisory speed by 10 mph with 54.3% of vehicles exceeding before installation and less than 46.7% of vehicles exceeding during all after periods.

Table EX.2. Percentage of vehicles exceeding speed metrics at point of curvature (PC) by time period.

	Time Period			
	1 Month	12 Month	18 Month	24 Month
Change in mean speed (mph)	-1.7 (-1.8)	-1.3 (-1.3)	-1.3 (-1.6)	-1.5 (-1.4)
Change in 85th percentile speed (mph)	-1.7 (-1.9)	-1.4 (-1.3)	-1.3 (-1.7)	-1.4 (-1.4)

		Time Period				
		Before	1 Month	12 Month	18 Month	24 Month
Percentage of vehicles exceeding advisory speed	5 mph	76.5% (80.7%)	69.8% (74.6%)	71.5% (80.8%)	68.3% (70.8%)	70.3% (75.9%)
	10 mph	54.3% (58.9%)	43.8% (47.8%)	46.7% (55.6%)	44.2% (48.3%)	45.7% (50.6%)
	15 mph	26.2% (29.8%)	18.6% (20.6%)	20.3% (25.3%)	20.4% (23.7%)	20.1% (23.3%)
	20 mph	10.0% (12.1%)	6.5% (7.3%)	6.8% (8.9%)	8.3% (9.5%)	6.5% (7.9%)
Percentage of vehicles exceeding posted speed	5 mph	4.9% (5.8%)	3.0% (3.7%)	3.6% (4.9%)	2.7% (3.1%)	2.6% (3.8%)
	10 mph	0.6% (0.8%)	0.3% (0.5%)	0.4% (0.5%)	0.3% (0.4%)	0.2% (0.3%)
	15 mph	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)
	20 mph	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)

Note: Numbers in parentheses represent statistics for tracked vehicles only.

Figure EX.4 and Figure EX.5 show the percentage of vehicles with a difference in speed (speed limit or advisory speed) during all time periods at the point of curvature. Looking at all of the sites, the leftward shift of the lines from the before speeds, specifically those exceeding the speed limit, shows there is a reduction in the percentage of vehicles that are exceeding the speed limit or advisory speed. In Figure EX.4., the lines for all after periods have shifted to the left and show that percentages of vehicles exceeding the speed limit were influenced – more vehicles traveled at or slightly below the speed limit after the system was installed. Furthermore in Figure EX.5, all of the after periods have shifted to the left from the before period showing the trend of slower speeds compared to the advisory speed at the point of curvature.

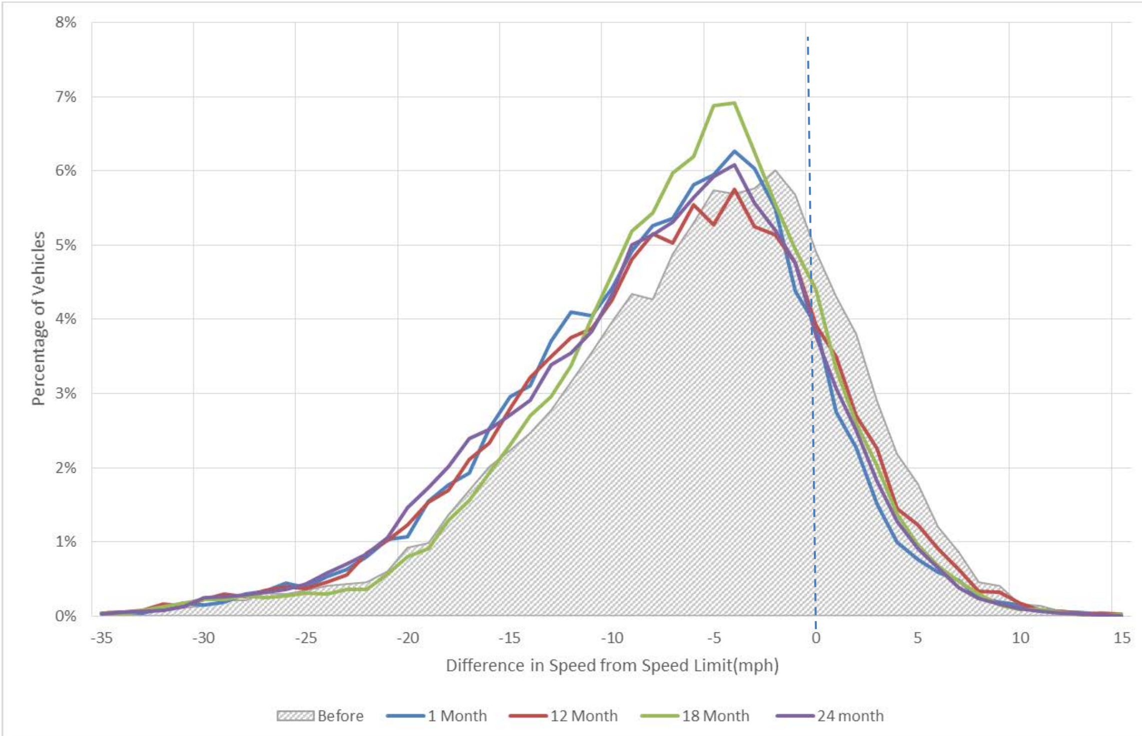

Figure EX.4. Graph. Percentage of vehicles with difference in speed from speed limit at point of curvature (PC).

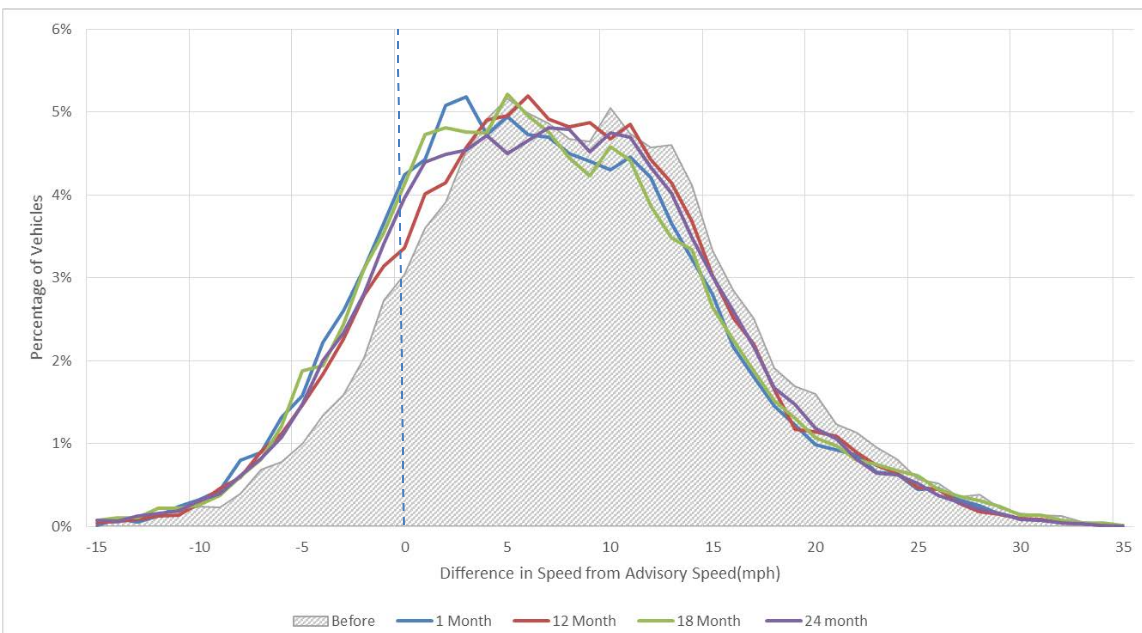

Figure EX.5. Graph. Percentage of vehicles with difference in speed from advisory speed at point of curvature (PC).

Table EX.3 shows the average change in speed at the center of curve across all sites by data collection period. The changes in mean speed were consistently lower across all time periods after installation.

The fraction of vehicles exceeding the posted or advisory speed also showed the effectiveness of the system in reducing speeds through decreases in vehicles exceeding speed/advisory limits. A 15 percent decrease in the fraction of vehicles exceeding the advisory speed by 5 mph or more was shown across all sites. For vehicles exceeding the advisory speed by 10 mph or more, the fraction of vehicles ranged from a decrease of 23.2 percent to 26.8 percent. The fraction of vehicles exceeding the advisory speed by 15 mph or more and 20 mph or more were 16 percent and 26 percent, respectively. The percentage of vehicles exceeding the advisory speed/speed limit at each time period at the center of curve is shown in Table EX.4. As shown, the percentage of vehicles exceeding were reduced and trended downward for all after periods.

Table EX.3. Average change across all sites at the center of curve (CC).

		Time Period			
		1 Month	12 Month	18 Month	24 Month
Change in mean speed (mph)		-1.2 (-1.3)	-1.1 (-1.1)	-1.4 (-1.2)	-1.2 (-1.3)
Change in 85th percentile speed(mph)		-1.3 (-1.8)	-1.1 (-1.3)	-1.4 (-1.6)	-1.1 (-1.2)
Change in fraction of vehicles exceeding advisory speed by	5 mph	-12.7% (-10.2%)	-14.9% (-11.0%)	-19.9% (-17.8%)	-14.6% (-11.0%)
	10 mph	-25.3% (-22.9%)	-25.7% (-21.1%)	-23.2% (-29.8%)	-26.8% -45.6%
	15 mph	-19.9% (-22.2%)	-11.0% (-21.4%)	-18.9% (-34.0%)	-14.7% (-29.2%)
	20 mph	-29.3% (-22.7%)	-20.3% (-3.7%)	-18.8% (-18.9%)	-37.0% (-35.4%)
Change in fraction of vehicles exceeding posted speed by	5 mph	-6.4% (-3.1%)	-9.4% (-5.0%)	-16.2% (-10.5%)	-9.2% (-7.6%)
	10 mph	-0.5% (-2.6%)	6.0% -3.1%	3.5% -2.6%	0.0% (-3.5%)
	15 mph	0.0% (-0.2%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (-4.1%)
	20 mph	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)

Table EX.4. Percentage of vehicles exceeding speed metrics at center of curve (CC) by time period.

	Time Period			
	1 Month	12 Month	18 Month	24 Month
Change in mean speed (mph)	-1.2 (-1.3)	-1.1 (-1.1)	-1.4 (-1.2)	-1.2 (-1.3)
Change in 85th percentile speed(mph)	-1.3 (-1.8)	-1.1 (-1.3)	-1.4 (-1.6)	-1.1 (-1.2)

		Time Period				
		Before	1 Month	12 Month	18 Month	24 Month
Percentage of vehicles exceeding advisory speed	5 mph	68.0% (71.8%)	59.9% (63.8%)	60.8% (68.7%)	57.8% (61.5%)	59.3% (64.2%)
	10 mph	34.0% (38.3%)	26.1% (29.0%)	27.8% (33.5%)	28.1% (31.3%)	25.9% (29.3%)
	15 mph	9.9% (12.3%)	6.7% (7.4%)	7.8% (9.8%)	8.4% (9.8%)	7.4% (8.6%)
	20 mph	2.0% (2.5%)	1.0% (1.3%)	1.3% (1.9%)	1.8% (2.3%)	1.2% (1.5%)
Percentage of vehicles exceeding posted speed	5 mph	2.8% (3.3%)	2.3% (3.1%)	2.7% (3.5%)	2.3% (2.9%)	1.8% (2.7%)
	10 mph	0.2% (0.3%)	0.3% (0.3%)	0.3% (0.5%)	0.3% (0.4%)	0.2% (0.2%)
	15 mph	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)
	20 mph	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)

Note: Numbers in parentheses represent statistics for tracked vehicles only.

Figure EX.6 and Figure EX.7 show the percentage of vehicles with a difference in speed from the speed limit or advisory speed during all time periods at the center of curve. Both graphs show a reduction in the percentage of vehicles exceeding the speed limit or advisory speed during all after periods. Although not as defined as data from the point of curvature, the lines for all after periods have shifted, showing a reduction in speeds at the center of curve.

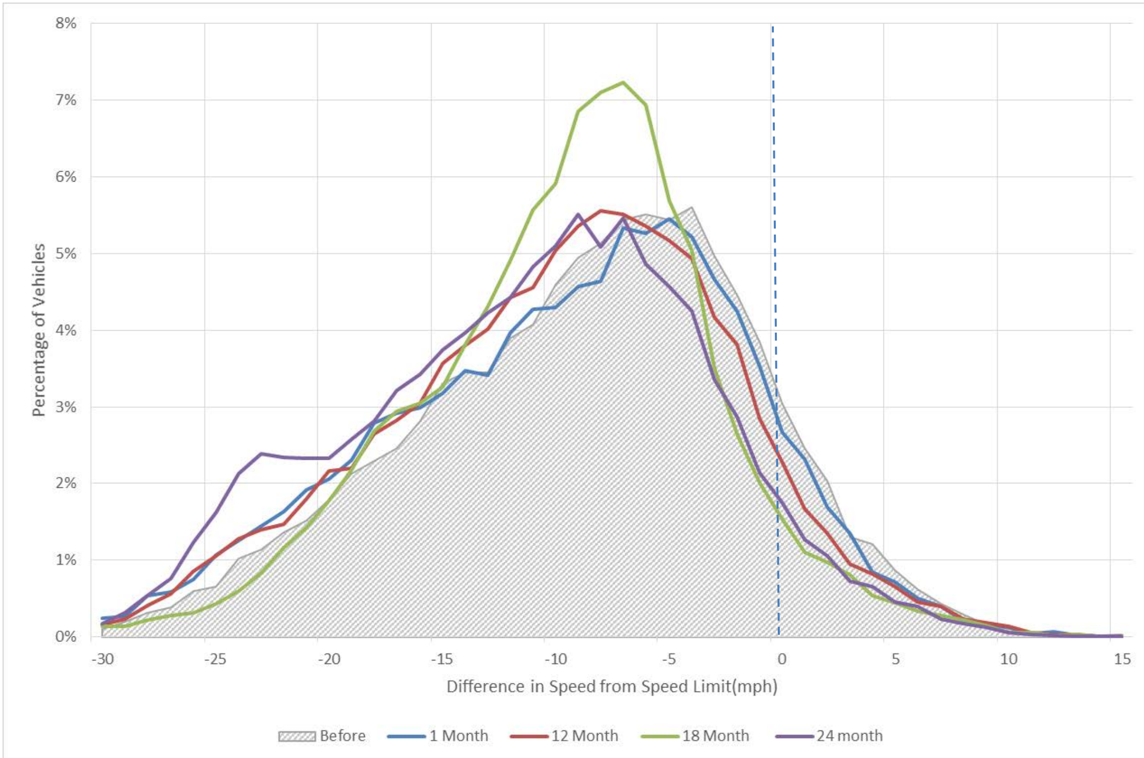

Figure EX.6. Graph. Percentage of vehicles with difference in speed from speed limit at center of curve (CC).

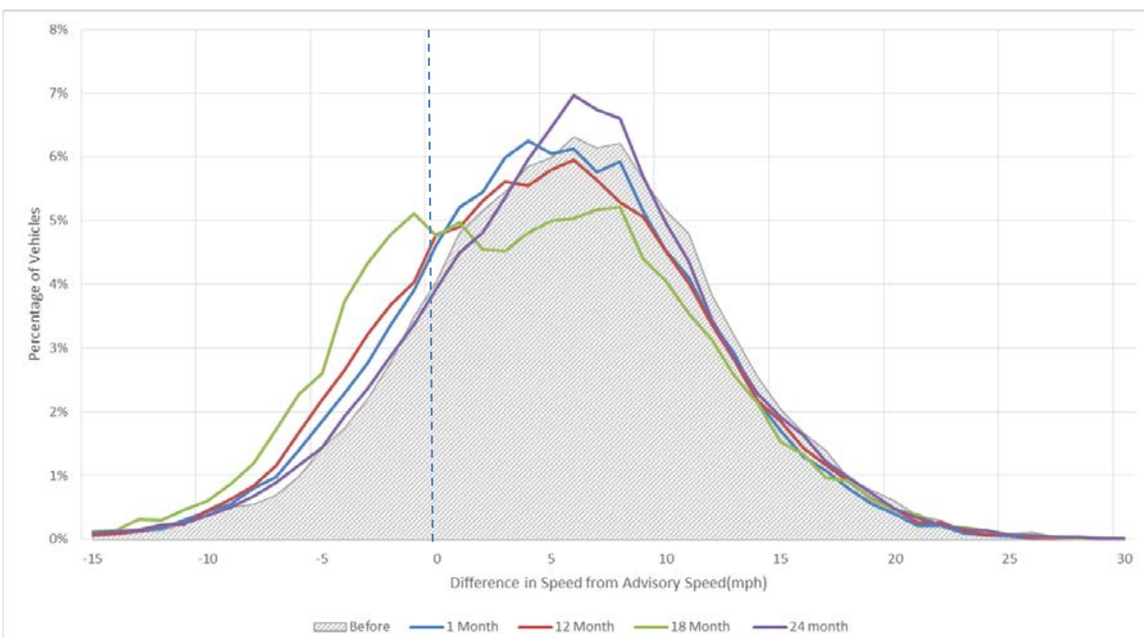

Figure EX7. Graph. Percentage of vehicles with difference in speed from advisory speed at center of curve (CC).

At both the point of curvature and center of curve, the tracked vehicle statistics were slightly higher or similar to the speed statistics for all vehicles. The tracked vehicle removed influences of trailing and following vehicles and showed that the vehicles only influenced by the SDCWS had a larger reduction in speed.

While speed was shown to be reduced, most agencies have a desire to lower the high-end speeds, which can substantially increase the safety of the curve. The results at both the point of curvature and center of curve suggest that the signs had an impact on high-end speeds during all data collection periods. Reductions were found in all vehicles exceeding the advisory speed but the largest decreases occurred in the vehicles exceeding by 20 mph or more. Higher decreases were found at the point of curvature suggesting that vehicles were reducing their speed prior to entering the curve and selecting an appropriate speed to negotiate the curve.

The speed results also indicate that the SDCWS was effective at reducing speed consistently between 1 and 24 months after installation. This suggests the signs may have a long-term impact on the speeds through the curve. With very little change in the mean and 85th percentile speed over time, the human factors impact of having a new or different sign had little effect.

Crash Analysis

The simple crash analysis, which was conducted to help determine the safety benefits, evaluated data 5 years before the SDCWS installation and 2 years after installation. The test sites where the SDCWS signs were installed and the selected control sites were evaluated.

Three of the sites had no crashes documented 2 years after the installation of the SDCWS (IA 141, TX FM 407, and TX FM 530). Reduction in the number of crashes per year was between 17 and 91 percent at seven other sites, while two sites had slight increases of 7 and 11 percent.

Although only a simple analysis of crashes was conducted (there were only two years of after data), the results showed improvement in safety by reducing crashes. A simple analysis cannot account for regression to the mean and other factors which will also affect crashes. Consequently, the results should be used to suggest that the treatment is effective but should be applied cautiously.

Conclusions

Overall, the SDCWS treatment appeared to be effective in reducing speed and crashes. The speed analysis showed small but consistent reductions in mean and 85 percentile speeds. The analysis also showed the reduction in the percent of vehicles exceeding the speed limit or advisory speed limit by 5, 10, 15, or 20 mph, particularly in the higher ranges. This shows the positive impact of the SDCWS in improving curve navigation and safety.

Agencies considering implementing the SDCWS should consider the following factors before installing the devices:

1. Location: Solar power is necessary for proper operation of the SDCWS. Locations should be investigated to ensure a proper view of the southern sky is feasible.
2. Maintenance: During the two year study, very few maintenance issues were encountered. However, it is recommended that agencies pay attention to the operation of the devices to make sure they are functioning.

3. Vandalism: Although devices with solar panels can be the subject of vandalism, the SDCWS solar panel doesn’t attract much attention because of the relatively small size of the solar panel. No vandalism was reported during the two-year study.
4. Threshold settings: Due to the limited number of installations, one threshold setting – recommended by the manufacturer – was used. For operational use, agencies might want to experiment with speed threshold and blinking pattern settings to maximize the effectiveness of the devices.

The results from this research add to the body of knowledge and provide safety engineers with another tool to address curve-related crashes.