



TRC1305

Low-Cost Experimental Treatments for Horizontal Curves

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Final Report

Arkansas State Highway & Transportation Department
Transportation Research Committee

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CHAPTER 1

INTRODUCTION

Horizontal curves are an essential part of highway alignments, but they also are associated with a disproportionate number of crashes. From 2011 thru 2013, on Arkansas' rural two-lane U.S. and State Highways, 13,891 roadway departure crashes occurred, and of those 13,891 run off the road type crashes, 4528 (33%) occurred in horizontal curves. Moreover, from 2011 to 2013, 183 head-on crashes occurred in horizontal curves in Arkansas. This research developed and applied low-cost experimental treatments to reduce crashes in Arkansas' horizontal curves.

BACKGROUND

The American Association of State Highway and Transportation Officials (AASHTO) approved its Strategic Safety Plan in 1998 with the goal of reducing annual highway fatalities by 5,000 to 7,000. Guides for local and state agencies were developed by The National Cooperative Highway Research Program (NCHRP) to help identify ways to reduce injuries and fatalities in targeted areas. One of these target areas is crashes in horizontal curves. "Most of the fatalities attributed to roadway departures and crashes at horizontal curves occur on rural roads, especially two-lane roads." Drivers often speed on these roads, even though they tend to have unforgiven shoulders and roadsides and less access to emergency services (NCHRP 2009).

The crash rate for horizontal curves is about three times higher than other highway segments. Poor visibility, speed, and lane deviations are a few factors contributing to crashes in horizontal curves. Due to these alarming statistics the Federal Highway Administration (FHWA) has made roadway departure one of its three program emphasis areas. After extensive research, FHWA has determined there are several low cost treatments to reduce the crash rates on horizontal curves striving to reduce the likelihood of a vehicle crossing over the centerline or leaving the roadway and minimizing the damage if such were to happen (FHWA 2011).

In 2011, the Arkansas Highway and Safety Steering Committee began the process of updating the Strategic Highway Safety Plan (SHSP), and in 2013 it was decided that the focus should be Toward Zero Deaths, which supports the Toward Zero Deaths National Strategy on Highway Safety. To reach this goal, key safety areas were identified. One of those safety areas

was roadway departure crashes. Arkansas has made positive efforts to reduce fatalities and injuries on roadways, but it is recognized that one fatality is too many. Arkansas' vision is to have zero fatalities on Arkansas' roadways, which includes reducing crashes in horizontal curves.

CHAPTER 2

LITERATURE REVIEW

A review of literature was conducted to identify the various low-cost experimental treatments available. Improving safety at horizontal curves helps achieve one of FHWA's key lifesaving strategies: reducing roadway departures. One approach to implementing this strategy is to provide local agencies, which bear the greatest responsibility for the Nation's vast network of two-lane rural roads, with tools to implement positive changes. FHWA has deployed a variety of low-cost safety improvements that can reduce the risk posed by horizontal curves. Many of these treatments are equally effective in both rural and urban areas. Details of literature that were of assistance in regards to treatments that were used for this research project are provided below.

TREATMENTS

PennDOT Curve Advance Pavement Marking

Pavement markings in advance of horizontal curves provide highly conspicuous, supplementary warning information and the potential to increase safety. The intent of this strategy is to provide advance warning to a driver that the horizontal alignment of the roadway is about to change and that the driver must alter the path and possibly the speed of the vehicle to negotiate the curve safely. Advance warning of alignment changes should be provided to a driver when changes in the alignment are unexpected. This typically occurs in situations where curves are sharper than anticipated or after a long tangent section of roadway (NCHRP 2009).

In a study by Iowa State University, two locations were selected to implement pavement markings. At one location, a change in mean and 85th percentile speeds showed mixed results. The percentage of vehicles traveling 5 or 10 or more mph over the posted speed limit increased by up to 10 percent at the north PC but decreased significantly at the center of the curve and at the south PC. Little change was noted for any location for vehicles traveling 15 or 20 mph over the posted speed limit. At the second site, the mean and 85th percentile speeds decreased by up to 2 mph. Moderate decreases in the percentage of vehicles exceeding the advisory speed by 5, 10, 15, or 20 or more mph resulted for the north and south PC, while significant decreases occurred at the center of the curve for all thresholds. Overall, both treatments were moderately effective in reducing mean and 85th percentile speeds. The treatments had the greatest impact in decreasing the percent of vehicles traveling 5, 10, 15, or 20 mph or more over the posted or advisory speeds (Hallmark).

PennDOT has developed an innovative experimental treatment to alert motorists to slow down as they approach a curve. This treatment is known as the “PennDOT Curve Advance Marking,” and it consists of two transverse bars, a SLOW legend, and an arrow indicating the direction of the upcoming curve (Figure 1). The primary objective is to reduce the number of run-off-the-road crashes. It was specifically designed for two lane roads having a high number of curve-related crashes. Figure 2 shows a detailed design layout. Figure 3 indicates the distance of the marking from the point of curvature based on posted speed and posted warning speed.



Figure 1: PennDOT Curve Advance Pavement Marking (Source: FHWA 2011)

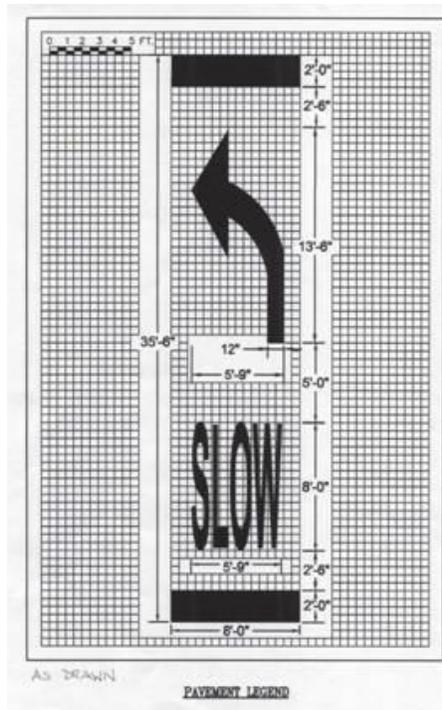


Figure 2: PennDOT Detailed Design (Source: FHWA)

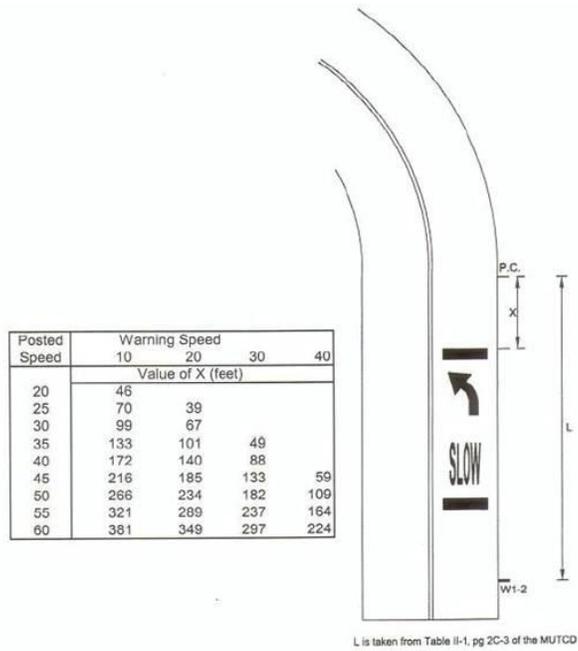


Figure 3: Distance from Point of Curvature Based on Posted Warning Speed (Source: FHWA)

Optical Speed Bars

Another experimental treatment that was designed to reduce speed in horizontal curves is optical speed bars. The goal is to increase the drivers' perception of speed and cause them to reduce speed. This is achieved by the visual effect on drivers' speed as they react to the spacing of the printed lines. In Figure 4, white transverse stripes are spaced at gradually decreasing distances. These white transverse stripes are 18 in long and 12 in wide. It is recommended that thermoplastic is used because of the exposure to traffic volume over time.



Figure 4: Optical Speed Bars Used to Reduce Vehicle Speed (Source: FHWA)

Optical speed bars are typically applied to road segments where speeds should be reduced or where traveling highway speeds are required to slow for curves. This treatment has been used for accident locations or situations where traffic speeds need to be reduced significantly. According to FHWA, agencies should now apply optical speed bars just to reduce traffic speed. Overuse of this treatment could threaten the visual effect of the treatment (FHWA).

Several optical speed bars are designed and spaced to reduce the drivers speed as they approach the curve. The spacing gradually narrowing spacing makes the driver think that they have increased speed and will slow down to keep the 4-bar/sec spacing. The table below shows New York Department of Transportation applied spacing between successive bars designed to cause drivers to reduce vehicle speed from 65 mi/h to 30 mi/h.

Table 1. Example Spacing Between Sequential Pairs of Optical Speed Bars

Bars	Spacing (ft)	Bars	Spacing (ft)	Bars	Spacing (ft)
1-2	24	11-12	19	21-22	15
2-3	23	12-13	19	22-23	15
3-4	23	13-14	19	23-24	15
4-5	23	14-15	18	24-25	14
5-6	22	16-17	18	26-27	13
6-7	22	16-17	18	26-27	13
7-8	21	17-18	17	27-28	13
8-9	21	18-19	16	28-29	12
9-10	21	19-20	16	29-30	12
10-11	20	20-21	16	30-31	12

The pavement-marking segment’s total length depends upon the speed difference the application is designed to produce. The speed difference is from the approach and to the lower curve. The following table suggests approximate lengths. The numbers in the table provide drivers with a minimum 4 seconds of driving time within the painted marking segment. These numbers produce a comfortable speed reduction (FHWA).

Table 2. Guideline for Length (ft) of Speed Bar Segment in Advance of Curve

		Approach Speed, mi/h					
		45	50	55	60	65	70
Curve Speed, mi/h	15	300	385	470	565	670	785
	20	275	350	440	535	640	755
	25	235	315	405	500	600	720
	30		270	360	450	560	670
	35			300	400	500	620
	40				335	440	555
	45					370	480
	50						405

Fluorescent Yellow Sheeting

Another low-cost treatment to possibly reduce crashes in horizontal curves is fluorescent yellow sheeting. Fluorescent yellow increases the visibility of signs, such as warning signs and chevrons. Research has shown that upgrading standard signs to fluorescent yellow enhances driver perception of the signs as the higher intensity makes the signs more visible to the motorists. The motorist will be able to recognize the signs quicker and respond to them earlier than a standard yellow sign. Figure 6 illustrates enhanced chevron visibility from Texas Transportation Institute. The warning signs visibility will be the same as the chevrons in the picture (FHWA).

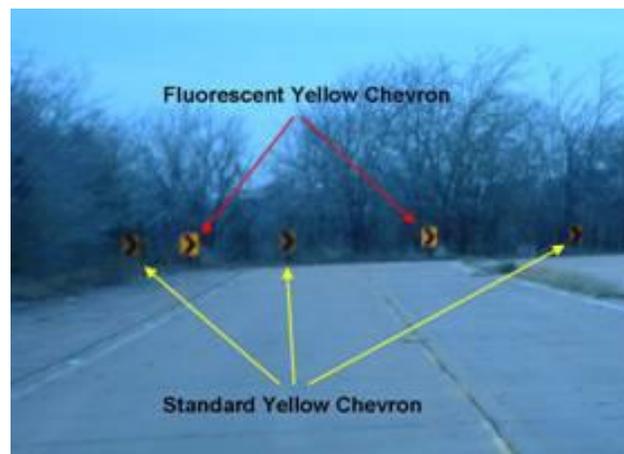


Figure 6: Illustrating Enhanced Chevron Visibility (Source: FHWA)

LED Blinkers

A flashing light-emitting diode (LED) Curve Warning sign warns the driver that they are approaching a curve. The LED sign can be programmed to flash either 24/7 or it can be activated when vehicles approach the sign by a detector in advance of the curve warning sign or on the curve warning sign. The LED blinkers install easy onto any new or existing post, and they can be integrated into an Intelligent Transportation System (ITS). A proprietary circuitry

automatically adjusts light output for maximum visibility and better efficiency. Multiple LED signs can also be synchronized. Figure 6 shows a setup in advance of a curve. The LED curve warning sign was added to the existing post with the advisory speed limit. The LED blinker replaced the existing sign (TAPCO).



Figure 7: LED Curve Warning Blinker Sign

CHAPTER 3

WORK PLAN

The primary objective of this research project was to determine if any low-cost treatments could reduce crashes in horizontal curves in the state of Arkansas. This was done by testing the above literature to see which of the treatments would reduce crashes in the selected curves for this project. Along with crashes, an additional performance measure was speed. Though other treatments exist, this project only tested four treatments on rural two-lane roads. The treatments that were tested were fluorescent yellow sheeting on curve warning signs, optical speed bars, PennDOT curve advance pavement marking and LED blinkers.

Locations were selected on Arkansas rural roads to test these experimental treatments. Areas with horizontal curves were located and evaluated using the current crash data, speed limits versus traveler speeds, and other measures deemed important. Previous improvements to the sites were considered in the site selections, such as locations where Maintenance had already installed warning signs, chevrons, surface friction improvements, etc. After crash data was evaluated for the pool of sites selected, the best locations for this project were determined. After selecting sites, speed data was collected before placing each treatment. Once treatments were placed, speed data was collected for over a year. See Appendix A. The performance of the treatments were monitored and evaluated based on speed data.

CHAPTER 4

SITES AND DATA COLLECTION

Site Selection

A list of high crash segment, horizontal curves sites on two-lane paved roadways in rural Arkansas was compiled based on the latest crash data from 2010. The research team reviewed the Roadway Departure Plan that was done for horizontal curves in rural areas. A query of 0.50 mile segments where the officers noted the crashes happened in each horizontal curve was performed. The segments were ranked by frequency after the query was performed. Many of the locations originally selected were also in the Roadway Departure Plan.

The team narrowed down the sites by looking at locations via Arkansas' Multimedia-Based Highway Information System (MMHIS). Field visits were made to the remaining sites, and additional site attributes were noted. During the site visits, it was noted whether the drivers were going above the posted speed limit and advisory speed limit by using a radar gun.

After site visits, the list was narrowed to those sites that met the following criteria:

- High crash rate (level of importance to traffic safety)
- Demonstrated speeding problems (if a driver's speed was 5 or more over the advisory curve speed)
- Posted speed limit of 55 mph or greater
- Advisory speed the same for at least two sites in order to compare treatments
- No unusual features that would make treatments difficult to install or difficult to collect speed data

Following this criteria, maintenance engineers for each location of the sites were contacted. It was confirmed that no major maintenance improvements had occurred over the last three years and none were scheduled for the duration of this project, which was two years. Of the remaining nine sites, 2 sites were selected to be treated with LED blinkers, 3 sites were selected

for advance pavement markings, 2 sites were selected for fluorescent yellow signs, and 2 sites were selected for optical speed bars.

Description of Test Sites

The information provided in Table 3 describes the 9 sites that were all located on rural two-lane roadways. The location of the sites, log miles, length, posted speed, advisory speed and the treatments used at each location are listed.

Table 3: Site Attributes

District	County	Route	Section	Beginning Logmile	Ending Logmile	Length	Posted Speed Limit (mph)	Advisory Speed (mph)	Treatment
9	Benton	112	2	6.65	6.85	0.2	55	25	LED BLINKERS
6	Saline	5	7	16.55	17.6	1.05	55	25	
6	Lonoke	5	12	6.7	7.3	0.6	55	45	PAVEMENT MARKING
9	Benton	102	2	1.91	6.04	4.13	55	45	
6	Lonoke	5	12	6.7	7.3	0.6	55	45	FLUORESCENT YELLOW SHEETING
9	Benton	102	2	1.91	6.04	4.13	55	45	
6	Saline	5	7	1.92	6.84	4.92	55	30	OPTICAL SPEED BARS
9	Baxter	201	1	4.6	5.15	0.45	55	30	
9	Newton	7	18	19.266	19.912		55	25	PAVEMENT MARKING WITH BARS

Data Collection and Reduction

Prior to installing each treatment, speed data was collected at each test site using the pneumatic road tubes. Data was collected three months prior to installation (referred to as before data). After the treatments were installed, data was collected for approximately a year (referred to as after data).

The drivers' speed was checked to determine whether it was within the confidence interval, which meant that the drivers obeyed the posted speed. If not, data was reduced depending on if the posted speed is less than or greater than the lower and upper limits of the

measured speed. If the confidence interval was close to the advisory curve speed, the driver was influenced by the advisory speed. The before and after speeds were tested to determine if they were significantly different. A z-test was used to compare the two means of the posted and advisory speed and the two means of the before and after mean speeds.

CHAPTER 5

RESULTS

The chapter presents the study results by treatment. Before and after speed data were collected at each site for each treatment. Once crash data is available, more analyses will be performed on all data. This section is an initial step for developing a methodology for analyzing the distribution of data for all sites to determine which treatments will be effective to implement in horizontal curves in Arkansas. The results presented here include traffic speed distribution plots for each treatment. The analyses performed were used to determine which treatments reduced the speed of vehicles in horizontal curves, which could have caused a reduction in the number of crashes. However, this hypothesis will not be confirmed until crash data is analyzed.

Fluorescent Yellow

An analysis was performed on the before and after data at two locations. The posted speed limits at both locations were 55 mph and the advisory curve speed was 45 mph. From Figure 7, it was determined that the means (before and after vehicle speed) of the fluorescent yellow signs were not significantly different, which means that there was no major change in speed after the treatment was installed. Once crash data is analyzed, it can be determined if the signs had an overall effect on reducing crashes in horizontal curves with the attributes listed above in Table 3.

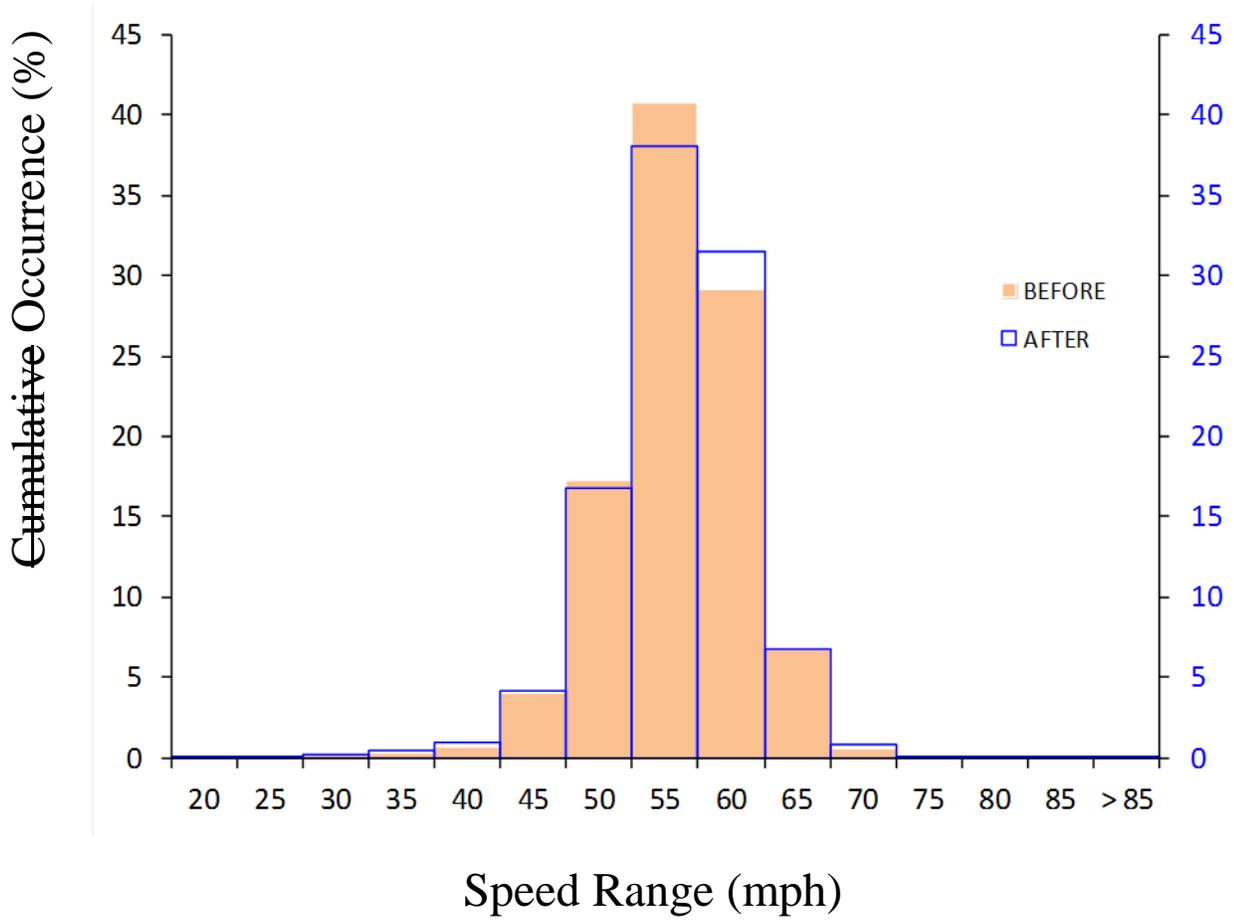


Figure 8: Speed Distribution for before and after installation of Fluorescent Yellow

Optical Speed Bars

An analysis was performed on the before and after data at two locations. The posted speed limits at both locations were 55 mph and the advisory curve speed was 30 mph. From Figure 9, it was determined that the means (before and after vehicle speed) of the optical speed bars were not significantly different, which suggests that there was no major change in speed after the treatment was installed.

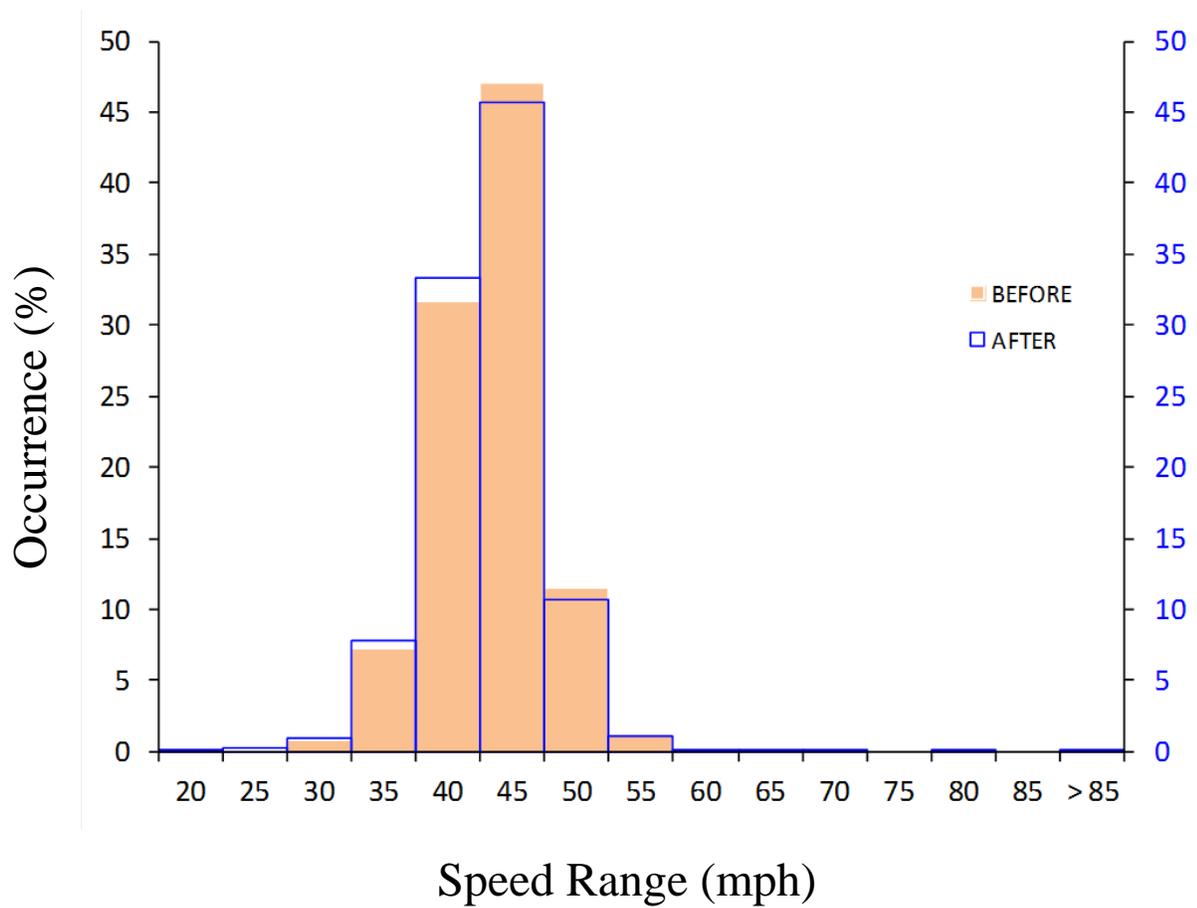


Figure 9: Speed Distribution for before and after Installation of Optical Speed Bars

Advance Pavement Markings

An analysis was performed on the before and after data at two locations. The posted speed limits at both locations were 55 mph and the advisory curve speed was 45 mph. From Figure 10, it was determined that the means (before and after vehicle speed) of the optical speed bars were different. The speed increased after this treatment was installed. A number of factors could be the cause of this increase, which includes weather condition when before and after data was collected, location of counters before and after data was collected and other factors.

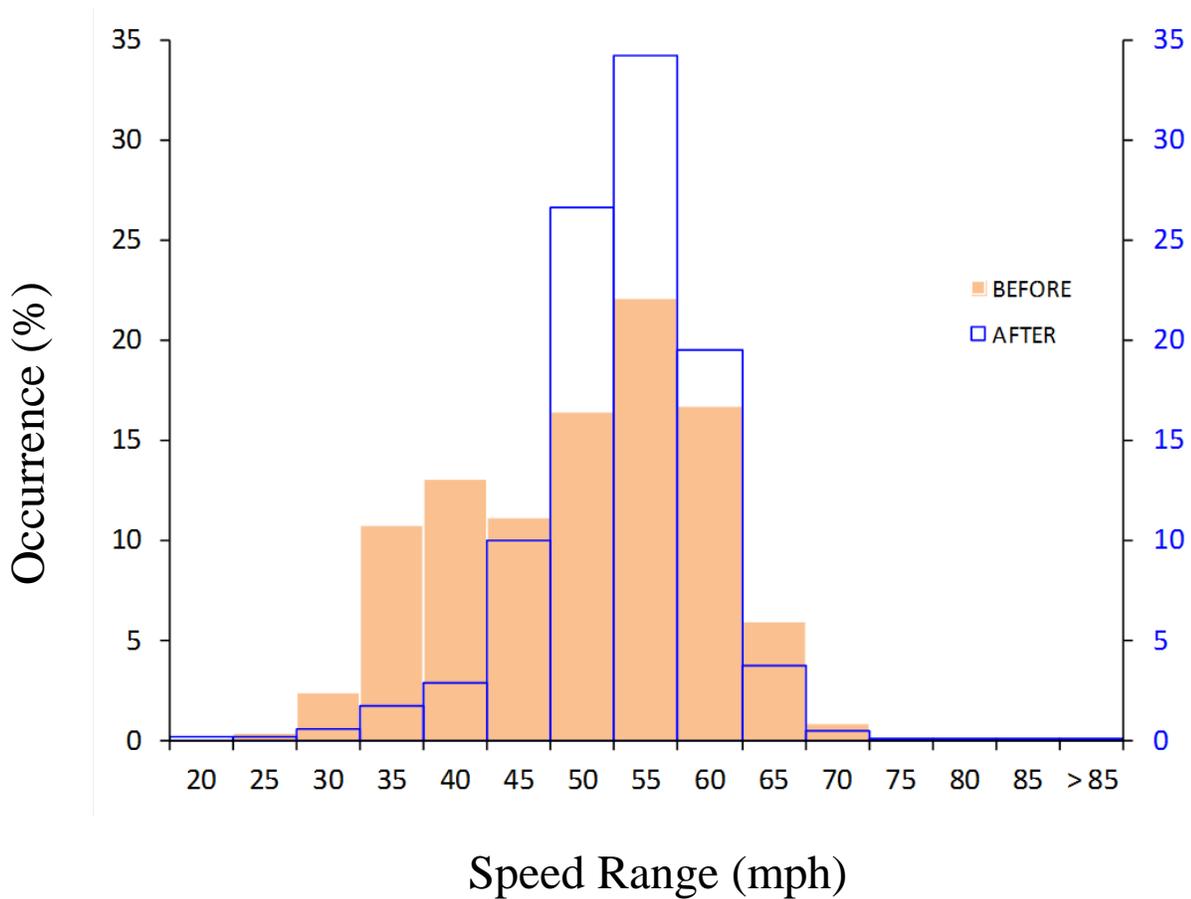


Figure 10: Speed Distribution for before and after installation of Advance Pavement Markings

LED Blinkers

An analysis was performed on the before and after data at two locations. The posted speed limits at both locations were 55 mph and the advisory curve speed was 25 mph. From Figure 11, it was determined that the means (before and after vehicle speed) of the LED blinkers were significantly different, which suggests that there was a change in speed after the treatment was installed.

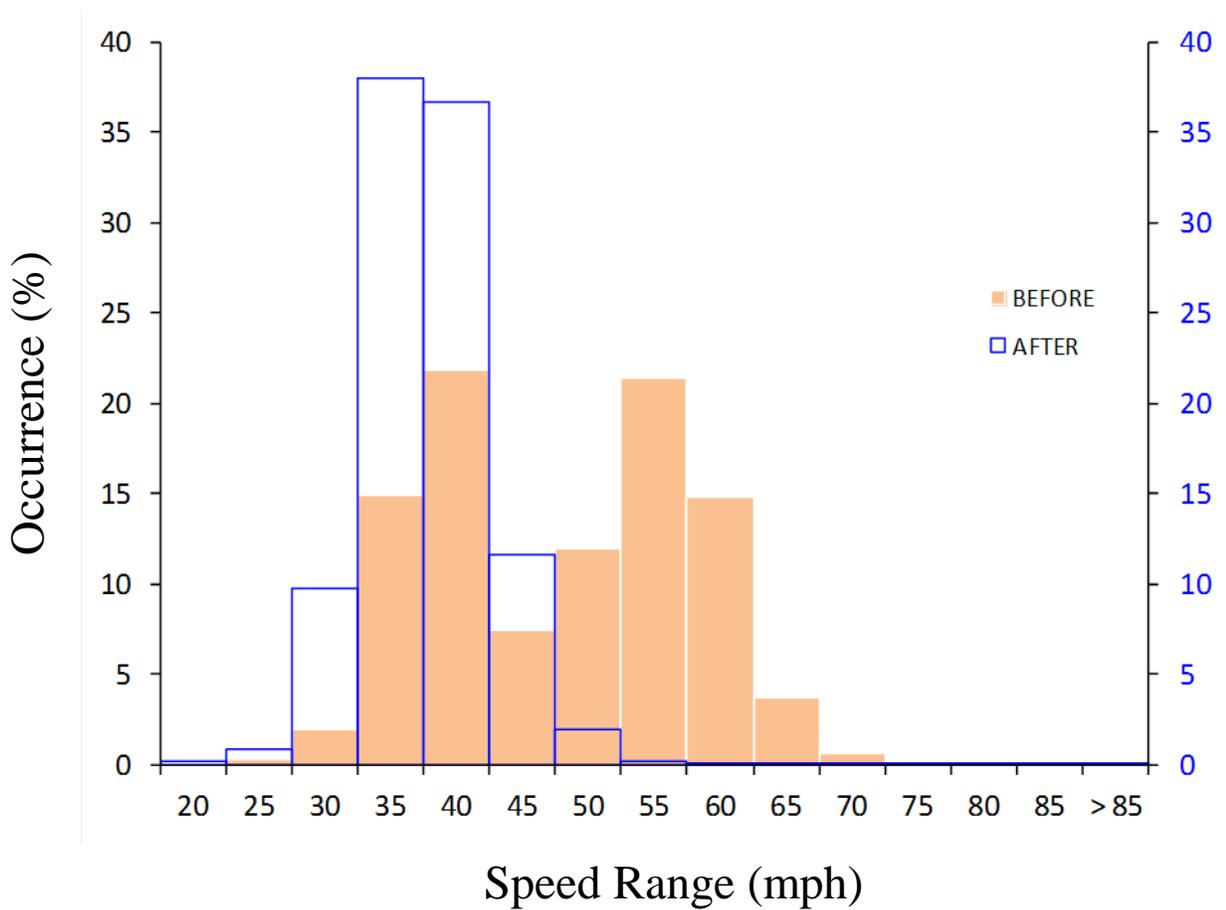


Figure 11: Speed Distribution for before and after Installation of LED Blinkers

Figure 12 summarizes the treatments installed at each site. The results indicate that the LED blinkers reduced speed and other treatments did not have significant effects on the average vehicle speed.

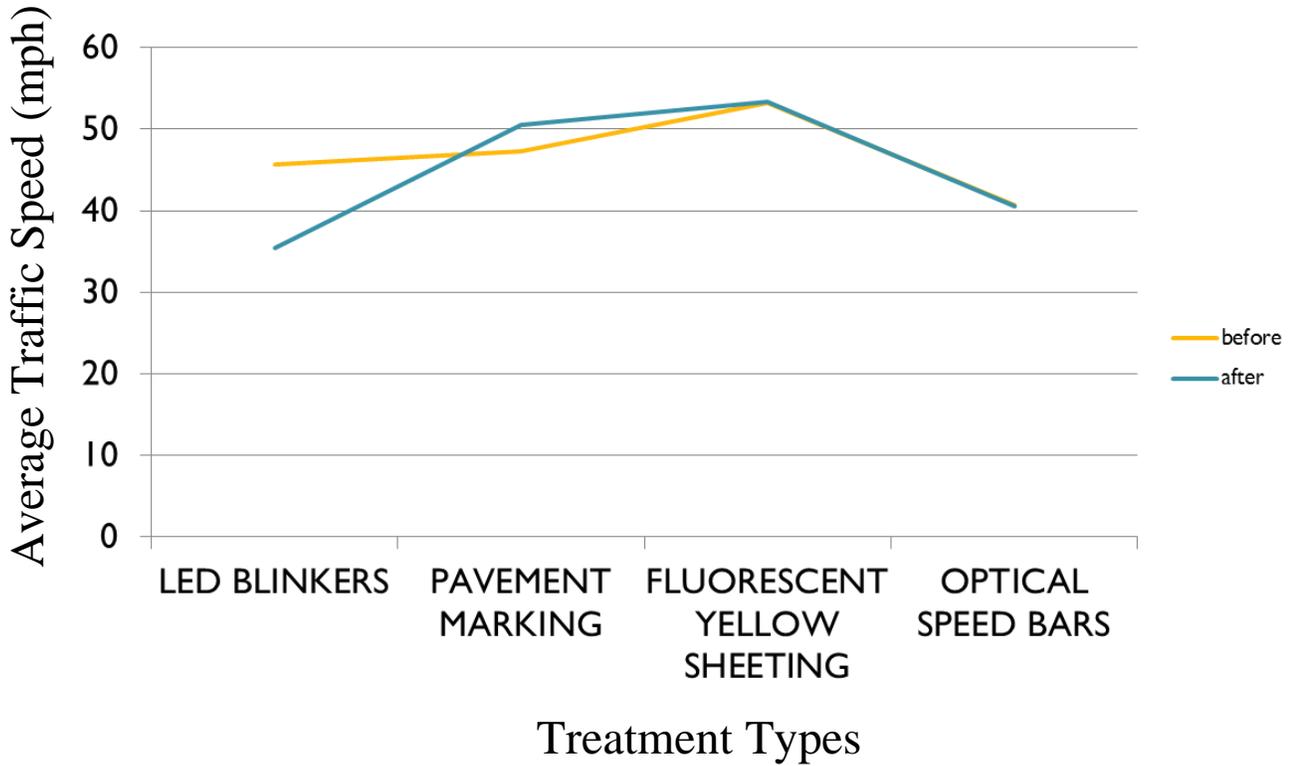


Figure 12: Overall Results of Effects of All Treatments on Vehicle Speed

CHAPTER 6

CONCLUSION

Research was conducted at nine horizontal curves on rural two-lane roads in Arkansas to determine if any of the four selected low-cost treatments could reduce the number of crashes. For this report, only the speed data was analyzed since Arkansas' crash data for 2014 is not available. The criteria for selecting the sites were based on the following:

- High crash rate (level of importance to traffic safety)
- Demonstrated speeding problems (if a driver's speed was 5 or more over the advisory curve speed)
- Posted speed limit of 55 mph or greater
- Advisory speed the same for at least two sites in order to compare treatments
- No unusual features that would make treatments difficult to install or difficult to collect speed data

Before and after speed data were collected at all nine sites. The following sequence of analyses was performed on the speed data.

- Statistical testing of the means of the average vehicle speed for before and after the treatments were installed was conducted using a z-test with a confidence level of 95%.
- The average of the number of vehicles that fell in the range of the posted speed was compared to the mean of the number of vehicles that fell in the range of the advisory speed. If the confidence interval was close to the advisory speed, the vehicles were influenced by the advisory speed and vice versa for posted speed.
- Before and after speeds were tested to determine if they were significantly different.

FINDINGS

The following findings resulted from this research are solely based on the analysis performed on traffic data collected before and after treatments were installed.

- According to all analyses, the mean speed was significantly affected by the installation of the LED Blinkers. The speed decreased after treatments were installed. Therefore, the LED blinkers are effective based on speed data.
- According to the analyses performed, the Pavement Markings did not have significant effect on vehicle speed, since the difference between mean speed before and after treatment installation was still within the 5% margin (significant level).
- According to the analyses performed the mean speed before and after installing optical speed bars and fluorescent yellow signs were not significantly different.
- Overall, no major differences in speed were found for 3 of the 4 treatments (i.e. pavement markings, optical speed bars and fluorescent yellow sign).

These findings are not definitive results of the treatments applied to each site to reduce crashes in horizontal curves. Further research and analyses should be done to include the following:

- Analyze before and after crash data to determine if treatments are effective,
- Double of treatments at locations and analyze the data, and
- Conduct another speed study for the LED blinkers to see if they're still effective.

Overall, this report shows that one treatment was effective based on speed data, which proves that low-cost treatments can be effective in horizontal curves. Once crash data is analyzed, it can be concluded if more treatments used for this research are effective in horizontal curves.

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APPENDIX A

STUDY SITES

Highway 112 Benton County



- Location: Highway 112, Benton County
- Before data collected: July 2013 & October 2013
- Installed: December 2013
- After data collected March 2014, May 2014, November 2014, March 2015

Highway 5, Saline County



- Location: Highway 5, Saline County
- Before data collected: July 2013 & October 2013
- Installed: December 2013
- After data collected March 2014, May 2014, November 2014, March 2015

Highway 102, Benton County



- Location: Highway 102, Benton County
- Before data collected: July 2013 & October 2013
- Installed: March 2014
- After data collected: March 2014, May 2014, November 2014

Highway 7, Newton County



- Location: Highway 7, Newton County
- Before data collected: October 2013
- Installed: February 2015
- After data collected: March 2015, April 2015

Highway 5, Saline County



- Location: Highway 5, Newton County
- Before data collected: October 2013
- Installed: April 2014
- After data collected: March 2015, April 2015