SPEED MANAGEMENT IN RURAL COMMUNITIES USING OPTICAL SPEED BARS

By

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Abstract

Speed management has been a challenge, particularly in places where high-speed highways pass through. Due to high rate of fatalities and low budgets available, it is therefore necessary to identify low-cost effective approaches in reducing speeds. Optical Speed Bar (OSB) treatment is one such technique. This research makes an attempt to evaluate the effectiveness of OSBs in reducing approach speeds on two-lane, rural highways approaching small communities. Speed data were collected and analyzed "before" and "after" periods at five sites. Effectiveness of OSBs was evaluated using changes in mean and 85th percentile speeds under different categories by considering all vehicles, vehicle classification (two axles vs. more than two axles), day of the week (weekdays vs. weekends), and time of day (daytime vs. nighttime), as well as proportions exceeding posted speed limit, using t-test mean speeds, F-test for analysis of variance, and Z-test for proportions of vehicles exceeding posted speed limit between "before" and "after" datasets.

Even though motorists were found to slow down on the approaches, in response to speed zones, speeding was noted. "Before" speed data indicated higher speeds than desired at the sites. The 85th percentile speeds were between 50 and 63 mph while the posted speed limits on the approaches were 45 mph at four sites, and the 85th percentile speed was about 42 mph at one site with an approach posted speed limit of 30 mph. The "before" degrees of noncompliance were up to 90 % of free-flowing vehicles at the sites. Speed data analysis showed significant reductions in speeds at ends of OSBs at four test sites. Mean and 85th percentile speeds and standard deviations were found reduced in the after periods. Percent reductions in mean speeds were between 1.2 and 8.2 %, with 85th percentile reductions between 3.2 and 8.9 %. At one site, no notable change in mean and 85th percentile speeds occurred at the end of OSBs, but

significant increases in standard deviations were noted. Speed reductions were higher for two-axle vehicles, during the daytime and on weekdays with few exceptions.

Results of the study showed, as other previous studies did, OSBs may have some minor effects on vehicle speeds. The study provides an indication that it may be possible to create safety improvements as result of using OSBs on the approach to a rural community. However, magnitude of speed reductions was generally small, though the reductions were statistically significant at the 95% confidence level. Because of the non-consistence of the magnitude of speed reductions at the test sites, no conclusion can be drawn as to how much OSB treatment reduced speeds. These results were based on "after" periods up to five months. Therefore, further study would be required to determine whether these safety improvements are sustained over an even longer time period. Even though minor speed reductions occurred, speeds observed at the sites were still higher than the posted speed limits, indicating OSBs were not effective enough in providing the desired speed limit compliance. Additional studies would be helpful to identify combinations of countermeasures, for instance OSBs and other techniques, effective in providing speed limit compliance.

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Chapter 1 Introduction

1.1 Background

Despite considerable safety measures initiated by traffic and transportation engineers, speeding continues to be a significant safety problem on highways. Both U.S. and international studies have recognized it as a major factor in many highway crashes.

In the U.S., effects of speed are considerably costly. The National Highway Traffic Safety Administration (NHTSA) considers it to be one of the most prevalent factors contributing to traffic crashes. For a crash to be speeding-related, an officer must indicate that driving too fast for conditions or exceeding the posted speed limit was a contributing factor in the crash (Traffic Safety Facts, 2008). In 2008, speeding was found to be a contributing factor in 31% of all fatal crashes, with 11,674 people losing their lives in speeding-related crashes. Annual economic costs related to speeding crashes is estimated at a total at $40.4 billion. According to NHTSA, of young male drivers 15 to 20 years old who were involved in fatal crashes, 37% had been speeding.

In Canada, speeding was a factor in about 25% of fatalities and 20% of serious injuries from vehicle crashes between 2002 and 2004, and was increasing faster among younger drivers (Transport Canada, 2008). For instance, 80% of speeding drivers in fatal crashes were under the age of 45 years, and 40% were between 16 and 24. Additionally, single-vehicle crashes accounted for more than 50% of speeding fatalities and serious injuries.

Fields and Lee (1993) indicated excessive speeding accounted for 8% of crashes and was found to be a contributing factor in up to 30% of fatal crashes in Australia. Statistics also showed that speed-related road trauma was likely to cost the Australian community up to a $1 billion AUD annually.

In the U.K., the Royal Society for the Prevention of Accidents (RoSPA) estimated excessive speed contributed to 28% of fatal crashes, 18% of crashes resulting in a serious injury and 12% of all injury crashes (Royal Society for the Prevention of Accidents, 2009). In 2008, 362 people were killed in crashes involving someone exceeding the speed limit and additional 224 people died when someone was traveling too fast for the conditions. The statistics showed that approximately two-thirds of all crashes in which people are killed or injured happen on roads with a speed limit of 30 mph or less. Table 1.1 shows the extent at which speed affects the risk of crash severity. At 35 mph a driver is twice as likely to kill someone as they are at 30 mph.

Table 1.1 Effects of Speed in Crash Severity

Speed at Time of Crash (mph)	Estimated Pedestrian likely Killed	Percent of likely Survivors (%)
20	1 out of 40	97
30	2 out of 10	80
35	5 out of 10	50
40	9 out of 10	10

(Source: RoSPA, 2009)

Several studies have established relationships between speed and crashes. One such relationship is the role of high speeds in crash occurrence and severity. At high speeds, a driver's ability to safely control a vehicle and clearly identify an object or obstacle on the roadway are significantly reduced, and high speeds also lead to shorter reaction times and longer braking distances (Traffic Safety Facts, 2008).

Kloeden et al. (2001) found the risk of involvement in a fatal crash increases exponentially with increasing free travel speed in rural areas. Also, small reductions in traveling speed in rural areas have the potential to greatly reduce fatal crashes. Furthermore, speeding was found to cause a significant proportion of rural crashes. For example, even traveling only 10 km/h (6.2 mph) faster than the average speed of other traffic was found to double the risk of crash involvement.

Studies by Kloeden et al. (2002) about traveling speed and risk of crash involvement found relative risk of a crash approximately doubles for each 5 km/h (3.1 mph) increase in free traveling speed, and even very small reductions in speeds of vehicles in general could be expected to result in a major reduction in frequency of fatal crashes in urban areas.

An earlier study by Kloeden et al. (1997) indicated risk of involvement in a fatal crash doubles with each 5 km/h (3.1 mph) increase in traveling speed above 60 km/h (37.3 mph) when the speed limit at the location is 60 km/h (37.3 mph). Table 1.2 (Kloeden et al., 1997) shows results of their study relating to travelling speed and risk of involvement in a fatal crash relative to travelling at 60 km/h (37.3 mph) in a 60 km/h (37.3 mph) speed limit zone. It can be observed that even a travelling speed of 65 km/h (40.4 mph) doubles the risk of involvement in a fatal crash. The study found none of the travelling speeds below 60 km/h (37.3 mph) to be associated with risk of involvement in a fatal crash statistically significantly different from the risk at 60 km/h (37.3 mph). However, above 60 km/h (37.3 mph) a consistent increase in risk of involvement in a fatal crash exists with increasing travelling speed, such that the risk approximately doubles with each 5 km/h (3.1 mph) increase in speed.

Table 1.2 Travelling Speed and Risk of Involvement in a Casualty Crash Relative to Travelling at 60 km/h in a 60 km/h Speed Limit Zone

Nominal Speed	Speed Range	No. of Cases	No. of Controls	Relative Risk	Lower Limit*	Upper Limit*
35	33-37	0	4	0	-	-
40	38-42	1	5	1.41	0.16	12.53
45	43-47	4	30	0.94	0.31	2.87
50	48-52	5	57	0.62	0.23	1.67
55	53-57	19	133	1.01	0.54	1.87
60	58-62	29	205	1.00	1.00	1.00
65	63-67	36	127	2.00	1.17	3.43
70	68-72	20	34	4.16	2.12	8.17
75	73-77	9	6	10.60	3.52	31.98
80	78-82	9	2	31.81	6.55	154.56
85	83-87	8	1	56.55	6.82	468.77
-	88+	11	0	infinite	-	-
Total		151	604			

- 95% confidence limits of the estimated relative risk (Source: Kloeden et al., 1997)

Moreover, a synthesis of past studies by Stuster et al. (1998) revealed the severity of a crash depends on the change in speed of the vehicle at impact, and the fatality risk increases with the change in speed to the fourth power. Moreover, results from international studies suggested that for every 1 mph change in speed, injury crashes will change by 5% (3% for every 1 km/h) (Stuster et al. 1998). Therefore, crash speed is very important in relation to crash outcome; the higher the crash speed, the more serious the crash impact.

Another relationship exists in the role of speed variance in the occurrence of crashes. Studies have found as speed variance increases, so does likelihood of involvement in crashes. A synthesis of previous studies by Stuster et al (1998) concluded crash risk is lowest near the average speed of traffic and increases for vehicles traveling much faster or slower than average. In these cases, slow-moving drivers have safety issues similar to speeding drivers, as traffic flowing at uniform speeds results in increased safety and fewer crashes. Studies have shown roadway safety and uniform traffic operations are related. As uniformity of traffic operation of a roadway increases, so does safety on that section of roadway. This indicates slower traveling speeds do not necessarily mean safer traffic operation, especially on high-speed highways. Crash rates increase with increasing speed variance, which tends to be at a minimum when the difference between design speeds and posted speeds is between 5 and 10 mph.

Despite the high number of miles travelled in urban areas, more annual traffic fatalities occur in rural areas, which is true for both speeding-related and non-speeding-related crashes. An analysis of data from the Fatality Reporting System (FARS) for the period of 1994 -2003 comparing characteristics of rural and urban fatal crashes found approximately 42% more fatal crashes exist in rural areas compared to urban areas, though fewer vehicle miles are traveled in rural areas. The findings also revealed fatal crashes in rural areas are more likely to involve multiple fatalities, rollovers, and more trucks, and they more often occur on curved roadways with greater vehicle damage. Head-on crashes are also found to be more prevalent in rural than urban areas (NTSHA, 2005). Previous studies by NTSHA (2001) from 1990-2001 crash data and recently from 1998- 2007 crash data (Traffic Safety Facts, 2007) showed the same consistent pattern.

Kansas is no exception to national crash statistics. Table 1.3 presents the percent of urban area crashes and the percent of rural fatal crashes from year 2000 to year 2008.Table 1.3 indicates that though more crashes occurred in urban areas, more fatal crashes were noted in rural areas. This has been true from 2000 through 2008. In 2008, 64.5 percent of crashes occurred in urban areas, but 67.5 percent of fatal crashes occurred in rural areas (KSDOT, 2008).

Table 1.3 Percent of Rural and Urban Crashes in Kansas from 2000 to 2008

Year	Percentage of Crashes in Urban* Areas	Percent of Fatal Crashes in Rural Areas
2000	63.6	78.0
2001	63.2	75.1
2002	64.2	76.4
2003	63.3	75.4
2004	63.6	77.2
2005	64.1	71.9
2006	64.4	67.9
2007	63.4	71.0
2008	64.5	67.5

*Urban: Crashes with the urban area boundary of cities with more than 5,000 in population (source: KDOT, Rural/ Urban, Kansas Traffic Accident Facts)

Speeding has also been a concern on Kansas roadways. From 1998 through 2008, a total of 91,444 speed-related crashes occurred on Kansas roadways, with a total of 1,299 fatalities, as shown in Table 1.4 (KSDOT, 2008). In 2008 alone, speeding contributed to 7,917 crashes, including 97 fatalities. In 2006, even though fewer speed-related crashes were noted, higher fatal crashes occurred.

Table 1.4 Speed-Related Crashes in Kansas from 1998 to 2008

Year	Crashes				People	
	Total	Fatal	Injury	PDO	Fatalities	Injuries
1998	8,498	113	3,086	5,299	123	4,985
1999	8,122	108	3,035	4,979	129	4,801
2000	9,229	106	3,284	5,839	113	5,081
2001	8,587	111	3,053	5,423	134	4,712
2002	8,773	119	2,968	5,686	140	4,541
2003	8,369	112	2,618	5,639	127	3,988
2004	8,156	94	2,690	5,372	114	4,011
2005	8,142	100	2,660	5,382	105	3,793
2006	6,171	111	2,251	3,809	118	3,347
2007	9,480	89	2,755	6,636	99	3,981
2008	7,917	87	2,347	5,483	97	3,329
Total	91,444	1,150	30,747	59,547	1,299	46,569

(Source: KDOT, 2008 Kansas Traffic Accident Facts)

Analysis of crash data from the Kansas Accident Repord System (KARS) showed greater speeding-related fatalities in rural areas. Kansas defines speeding as exceeding posted speed limit (EPSL) or too fast for conditions (TFFC). From 1999 to 2008, Table 1.5 shows a higher number of speeding fatalities in rural areas each year.

Table 1.5 Rural and Urban Speeding Fatalities in Kansas from 1999 to 2008

Year	Rural Fatalities		Rural Fatalities Total (Percent)	Urban Fatalities		Urban Fatalities Total (Percent)	Urban/ Rural Fatalities Total
	Exceeding Posted Speed Limit	Too Fast For Conditions		Exceeding Posted Speed Limit	Too Fast For Conditions		
1999	13	69	82 (57.7)	35	25	60 (42.3)	142
2000	21	67	88 (71.0)	17	19	36 (29.0)	124
2001	32	70	102 (67.5)	26	23	49 (32.5)	151
2002	28	72	100 (68.0)	30	17	47 (32.0)	147
2003	23	60	83 (59.7)	30	26	56 (40.3)	139
2004	16	66	82 (65.6)	25	18	43 (34.4)	125
2005	14	59	73 (67.0)	12	24	36 (33.0)	109
2006	18	47	65 (51.6)	27	34	61 (48.4)	126
2007	13	56	69 (61.6)	22	21	43 (38.4)	112
2008	14	56	70 (70.0)	17	13	30 (30.0)	100

Note: Fatalities with unknown location were discarded.

Plot of percent of speeding fatalities in Figure 1.1 shows differences between rural and urban speeding fatalities, but the difference was reduced in 2006.

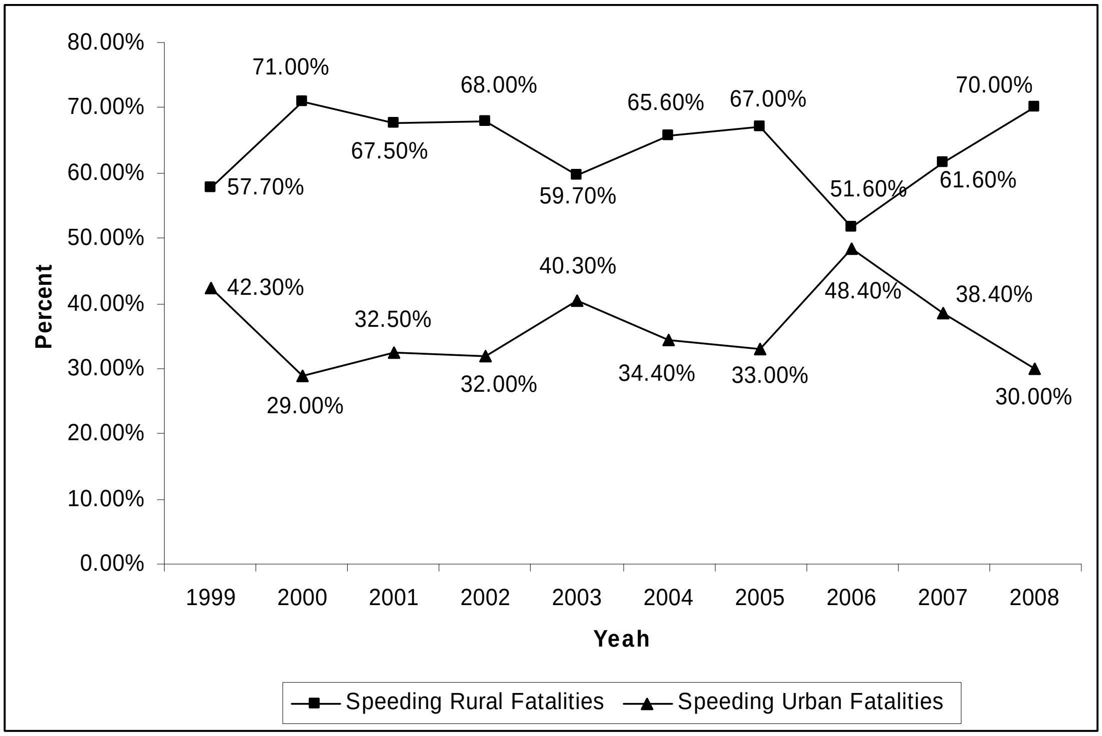


Figure 1.1 Kansas Speeding Fatalities in Rural and Urban Areas from 1999 to 2008

1.2 Speed Management

A variety of approaches have been utilized to control speeding on roadways. Speed management is important for traffic operations and safety, and its effectiveness depends on a combination of many strategies to counteract speeding. The Massachusetts Traffic Safety Research Program (MassSAFE) presents three categories of strategies commonly used in speed management: engineering measures, enforcement, and education (MassSAFE, 2004). Engineering measures consist of establishing rational speed limits, implementation of traffic-calming techniques, employing passive speed-control measures or perceptual techniques such as optical speed bars, and application of advanced transportation technologies such as Intelligent Transportation Systems (ITS). Enforcement includes police engagement in regulating speed, whereas education consists of involving the public through information, consultation, and participation. Speed management works best with an effective and efficient combination of the above speeding countermeasures.

Measures for speed management are essential for limiting negative effects of driving too fast at inappropriate speeds, and speed management begins with a safe and credible speed limit (Institute for Road Safety Research, 2008). The basis for any speed management policy is delimiting speed zones by setting speed limits, which need to reflect the safe speed on the particular roadway environment, related to road function, traffic composition, and road design characteristics. Furthermore, the speed limit adopted needs to rely on engineering judgments based on speed studies at the concerned location, as drivers mostly travel at the speed they feel is safe for the roadway, based on different environmental and geometric conditions. Moreover, speed limits should be credible and logical, based on characteristics of the roadway and road environment. In addition, sufficient and clear information needs to be provided for drivers to know where and what the speed limit is, through consistent roadside signing and road markings.

Even though introduction of speed zones by setting up proper speed limits is important for informing drivers of the safe speeds at which they should travel, this approach alone has not been effective as there are always many drivers who still travel above the speed limit (Fildes et al., 1987). Drivers who exceed the speed limit do so intentionally or due to other reasons, and therefore police enforcement remains necessary to control and alter the speeding behavior of that group of drivers. However, effectiveness of police enforcement will necessitate a constant presence of police patrols at hazardous locations, which is costly and impracticable as it requires hiring a large police force. While these speed-control approaches are always important and necessary in hazardous locations, the fact that a large number of motorists continually drive above the current speed limit suggests this is not a totally sufficient means of speed control.

Another approach to controlling speeding and the volume of traffic is to engineer the road and its immediate surroundings. This approach, usually applied to residential streets and local areas, is generally used to counteract speeding and heavy traffic (FHWA, 2001). In general, the purpose of traffic calming is to slow down cars and increase the visibility of pedestrians and bicyclists. Direct benefits of traffic calming include increased pedestrian awareness, slower moving traffic, and fewer vehicles on the road. Full-street closures, half-street closures, median barriers, and forced-turn islands are often utilized as volume control measures included in traffic-calming techniques to discourage or eliminate cut-through traffic. Though these volume-control measures have been found to be effective, the presence of some of these devices on the roadway does not do anything but introduce additional road hazards, where one problem is just shifted from one place to another. On the other hand, vertical, horizontal, and narrowing techniques are used to control the speed of vehicles on streets and the impact of pedestrian access. Vertical speed-control measures rely on forces of vertical-rise acceleration to discourage speeding. These measures include speed humps, speed tables, raised crosswalks, raised intersections, and textured pavement. Horizontal speed-control measures rely on forces of lateral-shift acceleration to discourage speeding, and these measures are comprised of roundabouts, neighborhood traffic circles, curb extensions, and center island narrowing. Moreover, narrowing speed control measures rely on a "psycho-perceptive sense of enclosure to discourage speeding".

Contrary to conventional measures of speed control which influence a driver's speed choice decision and affect a driver's conscious decisions regarding speed choice (Godley, 2000), and contrary to engineering measures which lead to undesirable changes in travel behavior, perceptual measures for speed control create conditions that lead to a desire by drivers to change their travel behavior (Fildes et al., 1987). This can likely lead to reduced vehicle speeds and ultimately to fewer crashes and improved safety.

The aim of perceptual measures is to alter the driver's perception of what appropriate travel speed is. Their advantages are numerous as they influence the visual information on display to the driver to address the core of the speeding problem (Godley, 2000). The perceptual effect provided by a modified environment is less likely to annoy or frustrate drivers. Also, change in visual perception by creating the illusion of less safe-travel speed is not necessarily perceived by drivers as annoying or obstructing. Furthermore, perceptual countermeasures do not involve introducing additional hazards onto roadways, but only painted lines or additional plastic to the road surface to create the desired effects. Also, perceptual countermeasures are inexpensive and easier to justify in terms of cost/benefit effectiveness.

1.3 Problem Statement

One common problem in rural areas has been the higher rate of fatalities, though total number of crashes is less than compared to urban areas. Another specific problem is the transition between a rural and urban area, especially on main highways that pass through rural communities, which requires reduction in speeds. Moreover, although enforcement is an effective countermeasure to speeding, there are simply not enough law enforcement personnel to adequately enforce speed limits throughout the rural roadway system. Therefore, there is a need to identify one or more non-enforcement countermeasures that will be effective in reducing speeds on highways in rural communities. Use of optical speed bars appears to be one such approach with potential benefits.

Optical Speed Bars (OSBs) are a series of white rectangular markings placed just inside both edges of a driving lane, spaced progressively closer together to create the illusion of traveling faster as well as the impression of a narrower lane (FHWA, 2009).

Theoretically, transverse lines have the characteristic of altering drivers' perceptions of appropriate travel speeds. As spacing of the speed bars is reduced in the direction of travel, drivers traveling at the same speed through the speed bar treatment perceive their speed as increasing, making them feel as if they are speeding instead of moving at the same speed. Similarly, perceptional effects of the bars give decelerating drivers the illusion of not decelerating enough, possibly causing them to further slow down.

1.4 Research Objective

The main objective of this study is to evaluate the effectiveness of using optical speed bars as an innovative low-cost approach for speed management in rural communities. Speeding has become an issue where high-speed roads pass through these areas. To achieve the objective sought in this study, it was necessary to identify measures of effectiveness to evaluate the efficiency of implementing an OSB treatment for approach-speed reductions to rural communities.

1.5 Measure of Effectiveness

Common practice in the evaluation of the effectiveness of a treatment has been to assess a safety improvement in the area where the treatment is being tested. Safety assessment generally includes looking into the reduced number of crashes or how much speeding is reduced after the treatment implementation. Safety assessment is also based on evaluation of a safety improvement in terms of economic benefit and cost improvement.

Due to the fact that gathering crash data necessary for safety analysis requires a long period of time and because there is evidence related to the relationship between speeds and crashes, the measure of effectiveness used in evaluating the OSB treatment for the objectives sought was limited to the speed of motor vehicles.

Accordingly, a comparison was made between speeds of vehicles traveling through the test sites before and after the OSB treatment. Effectiveness of the OSB treatment was assessed by comparing changes in the mean speed, and 85^{th} percentile speed, speed variation, and proportion of vehicles exceeding the posted speed limit. The significance of differences in these speed parameters was statistically analyzed with an appropriate test.

1.6 Evaluation Plan

The evaluation plan included the different steps required to be followed to arrive at the objective sought. These steps followed in the evaluation of OSB treatments: literature review, site selection, OSB design and installation, before-and-after speed data collection, statistical analysis of the data collected, and providing recommendations based on the findings. The purpose of the literature review was to provide a thorough review of previous studies, both international and from the United States (U.S.), concerning OSBs. In the process, different design methods of the optical speed bars and their characteristics were determined in various applications both in the U.S. and other countries where they seem to have been successful. The next step in the evaluation process was selection of sites located on approaches to rural communities where high-speed highways pass through. When potential sites were identified, the next step was to determine the most appropriate traffic data collection methodology to effectively carry out the evaluation. Data collection methodology identifies the number and location of speed data collection points at the sites, as well as the period of time during which the required sample size for statistical analysis was to be collected. Data collection methodology also determines the time periods for which data collections are carried out for the before-and-after OSB periods of data collection. Another purpose of data collection methodology identification is to determine the most suitable equipment needed and its appropriateness for data collection. After the before-and-after speed data collection, the speed data were statistically analyzed and compared.

1.7 Organization of the Report

This report includes six chapters and two appendices. Chapter 1 introduces background information about speeds and crashes, the problem statement, and objectives of the study. Chapter 2 summarizes previous studies, both international and in the U.S., related to OSBs. Chapter 3 presents data collection, site selection, OSB design and installation, statistical methodology used in the analysis of speed data and assessment of the effectiveness of OSB treatment. Chapter 4 introduces the results of the speed data analysis and discussion. Chapter 5 presents the summary, conclusion and recommendations drawn from the findings. The appendices include some considered test sites in appendix A. and the OSB design in appendix B.

Chapter 2 Literature Review

Past studies have attempted to learn more about driver' s tendencies as a result of installing optical speed bars (OSBs). Different types of OSBs have been examined by researchers both international and in the U.S. This chapter presents findings of past studies on the effectiveness of OSBs, as well as treatment patterns, design methodologies, measures of effectiveness, and evaluation techniques utilized by different studies.

The Kansas Department of Transportation (KDOT) and the University of Kansas tested optical speed bars on a rural four-lane divided highway on the approach to a work zone (Meyer, 2004). The considered segment was straight and had a gradient of less than 1%, except for the last 400 ft. The regulatory speed limit was 70 mph, reducing to 60 mph during construction. Objectives of the study were to evaluate the effectiveness of OSBs in reducing speeds and speed variations in highway work zones; determine the extent to which any speed reduction that might be observed could be attributed to a change in driver perception of speed as opposed to simply a warning effect, that is a result of the bars focusing driver attention on the driving task; and determine if bars could be used over a long distance to maintain any reduction in speed that might occur in the initial pattern. The study considered three pattern treatments of OSBs: a primary pattern with varying width and spacing of the speed bars; a leading pattern with constant width and spacing of the speed bars; and a work zone pattern consisting of four sets of six bars with constant spacing between sets. The leading pattern, which has uniform spacing of bars, was used to play the role of warning effects. The primary pattern, with decreasing spacing of bars, provided perceptual effects. Finally, the work-zone pattern was used to maintain speed reductions downstream from the treatment. Figure 2.1 shows the experimental pattern elements of the treatment section.

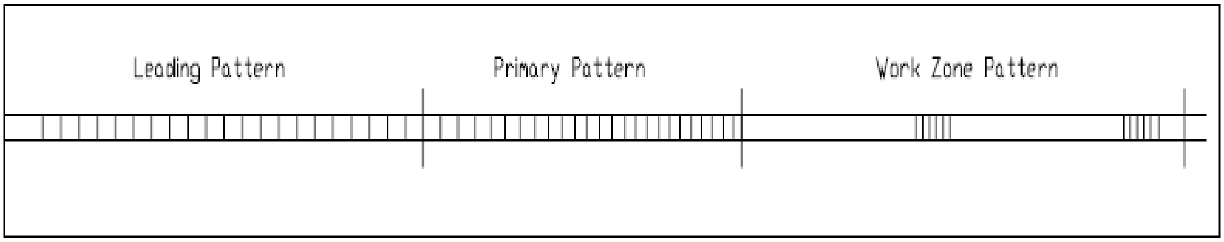


Figure 2.1 Sketch of Experimental Pattern Elements

(Source: Meyer, 2004)

JAMAR Automatic Traffic Recorders were used to collect data at 10 locations simultaneously, and in each direction, for 30 days. The analysis consisted first of comparisons of mean speeds and 85th percentile speeds between data points, time periods, and directions of travel, considering all vehicle classifications. The second analysis consisted of comparing the data over time to analyze temporal changes with all vehicle classifications. The third analysis considered passenger cars and heavy vehicles separately and examined effects of the work zone pattern.

The study concluded optical speed bars effectively cause reductions in mean speed, 85^{th} percentile speed, and speed variation, though the magnitude of speed reduction was small. Both warning and perceptual effects occurred and can be additive. It was found speed reduction dissipated downstream of the pattern, and the work-zone pattern was not effective at maintaining speed reductions obtained in leading and primary patterns. Finally, effectiveness was greatest for passenger cars during daylight hours.

Three characteristics of the road that might have affected results of effectiveness of OSBs include presence of oncoming traffic in an adjacent lane detracted from effectiveness of the speed bars; the original surface site of asphalt overlay and the final implementation on new Portland cement concrete engendered a color difference resulting in a decrease of contrast between the bars and the surface; and data collection was hindered by failure of some pneumatic tubes used for speed data collection.

The study recommended the use of transverse pavement markings on the approach to work zones be considered for adoption as standard practice, and a test installation of this type should be evaluated and compared with an appropriate control site to better quantify benefits that can be expected. Use of a primary pattern was not recommended for the highway work zone but the primary pattern be considered for other applications where speed reductions do not need to be maintained such as in rural intersections or work zones established solely for bridge maintenance. The final recommendation was not to use an intermittent work zone pattern but to include a leading pattern as a frame of reference that enhanced the perceptual effect of the primary pattern and extended the length of the primary pattern.

Arnold and Lantz (2007) conducted a test application of OSBs in Virginia using two sites: Lee Chapel Road in Fairfax County and Route 460 through town of Zuni. Both roads at time were experiencing increases in traffic volume and crash fatalities. At both sites, speeds were collected during three data collection periods: before installation of the OSBs, within 7 days and 90 days after. Lee Chapel Road in Figure 2.2, though the speed limit is 40 mph, a speed study recorded an average speed of 48 mph and an 85th percentile speed of 55 mph for 5,215 vehicles. The overall segment of concern was 1.05 miles long. Traffic volumes and speeds were obtained with traffic counters placed at 10 locations: 5 in the southbound lane and 5 in the northbound lane. Peripheral markings were used for the treatment, and consisted of 31 bars over a length of 530 feet. The spacing between the bars varied from 24 to 12 feet. The bars were of thermoplastic pavement markings, 18 inches by 12 inches extending from both edge line and centerline of roadway.

Figure 2.2 Optical Speed Bars on the North End of Lee Chapel Road

US-460 through Zuni in Figure 2.3 was on a straight alignment with speed limit of 55 mph, which dropped to 45 mph trough town. A speed study recorded an average speed of 47 mph for both directions and 85th percentile speeds of 52 and 51. Thermoplastic pavement markings of 12 inches wide and 8.5 feet long, which run across the lane, were used for the treatment. Traffic volumes and speeds were obtained with traffic counters at four locations before installation and six locations after installation. Before and after comparisons were made for all days, weekdays, weekends, daytime, and nighttime. Before and after data were collected at 15-minute intervals over 7 days. Analysis of variance was used to determine statistical differences at the 95 percent confidence level.

Figure 2.3 Optical Speed Bars on Route 460, East Side of Zuni

The study concluded optical speed bars had an overall positive impact on speed reduction, which may be small. The speed decreases were generally higher in Zuni, where the speed bars were placed in the center of the travel lanes, than on Lee Chapel Road, where the bars were placed on the edges of the travel lanes. Also, the study found, if thermoplastic tape was 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.

The study recommended the use of optical speed bars as a safety countermeasure, 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.

Mutabazi et al. (2008) evaluated effectiveness of optical speed bars installed in 1980 on southbound lanes along Solomon Hochoy highway in the vicinity of Freeport flyover, Trinidad. The road is part of a multilane, divided highway system with two lanes in each direction; the speed limit is 80 kph (49.7 mph); and no posted speed limit signs were along the highway. The pavement consisted of 95 white transverse markings of 1.9 ft x 26.5 ft, spanning both southbound lanes over a distance of 1,262.3 ft. The spacing (exponential) between bars decreased in the direction of travel from 20 ft to 6 ft. Painting of additional lines consisted of broken yellow lines 1 ft x 3¼ ft at spacing of 3¼ ft. MetroCount 5600 and TRAX I Plus Vehicle Classifier Systems were used to collect speed data, which was carried out for two days. The study determined the difference between traffic speeds at entrance and exit points of the markings. The study found the average speed at downstream location was higher than a corresponding value at upstream location. Some geometric factors of the roadway, such as downward vertical alignment, might have a stronger effect than a perceptual speed effect. Downward grade in the vertical alignment, beginning of a horizontal curve at the exit point, and warning effect of markings were three factors considered to affect the results. The study also found that average speed increases with vehicle headway. Also, the higher speed at upstream rather than downstream location, and higher nighttime speeds than daytime speeds at the downstream location, was evident in each headway category.

Katz (2004 and 2007) evaluated effectiveness of pavement markings in reducing vehicle speeds at three study sites: New York (Interstate 690 in Syracuse, speeds drop from 65 mph to 30 mph) shown in Figure 2.4a; Mississippi (two-lane rural roadway in Flowood, speed drop from 45 mph to 40 mph) shown in Figure 2.4b; and Texas (two-lane rural highway in Waller, speed drop from 65 mph to 40 mph) shown in Figure 2.4c. Data collection was conducted before installation, shortly after, and six months after installation. Peripheral bars were used for the study and Jamar Traffic Counters were used to collect data, along with a laser speed gun for accuracy verification and laptop computers for downloading data. Mean, median, variance, and 85^{th} percentile speeds were examined for all vehicles, by vehicle classification, and by vehicle with varying headways. For the three sites, the peripheral bars were12 inches wide and 18 inches long. The study concluded pavement markings were effective in speed reduction, and some factors impacted the magnitude of the effect: driver familiarity, degree of curvature in the road, and visibility of pavement markings. For example, speed reduction was noticed to be higher in New York and Mississippi, where the sites were located on highway and arterial roadways, compared to Texas where the site was on a local road. It was also found speed reduction occurred upstream of the bars in Texas, which was attributed to drivers' familiarity with the roads. It was recommended that pavement markings be used for speed reduction at sites similar to those used in this project. The study did not recommend use of pavement markings on long segments of highways for speed reduction.

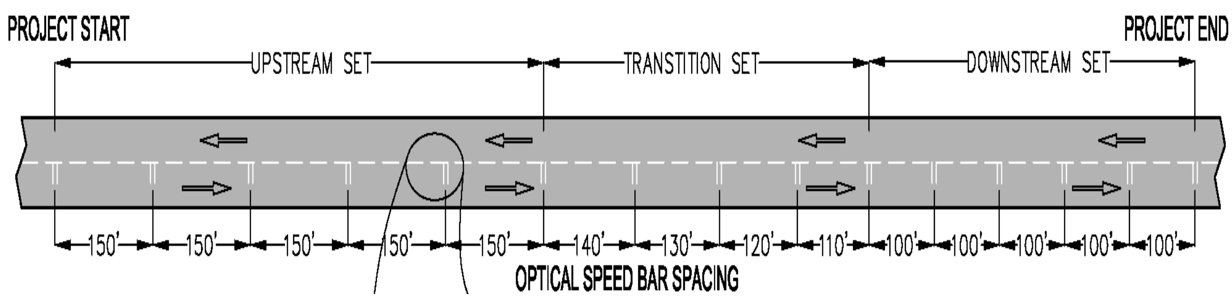
a. Syracuse, New York **b. Flowood, Mississippi** **c. Waller, Texas**

Figure 2.4 Peripheral Transverse Lines Treatment at Test Sites

(Source: Katz, 2004)

Liebel et al. (1984) evaluated OSBs on a major freeway exit ramp in Calgary, Canada, for the purpose of reducing accidents and speeds. The speed drop was from 100 km/h (62.1 mph) to 40 km/h (24.9 mph). The ramp ended at an intersection where numerous collisions had occurred, many of which were attributed to high speeds. Treatment consisted of 90 transverse white lines across 404 meters of the 900-meter freeway exit ramp. Bar spacing was 7.7 meters that reduced to 2.75 meters, and the bars had 0.6 meters of width and 3.5 to 4.0 meters of length. The treatment was observed during five and one-half weeks, and speeds of 106,444 vehicles were recorded using a Stevens PPR11 Print Punch Traffic Classifier, which provided an hourly printout of volume and vehicle speed. The first week following installation, average speed was 60.4 km/h with only 3.19 % of the vehicles traveling over 80 km/h, and 500 fewer vehicles driving under 80 km/h after the lines were painted. A reduction of right-angle accidents on the exit ramp was noted over 22 ½ months, but there was an increase of rear-end crashes. Installation of OSBs was also performed on another exit ramp experiencing a high number of accidents. It was concluded optical speed bars have the greatest impact on first-time users, are inexpensive to install, and have potential to reduce accident severity. It was recommended a period of three to four years to be used to obtain any meaningful accident statistics.

Latoski (2009) tested the applicability of OSBs on a tangent section of a two-lane rural highway in Mohave County, Arizona. The optical speed zone layout, shown in Figure 2.5a, consisted of three parts: an upstream set of equally spaced bars at 150 ft, a transition set of varying spacing from 150 ft to 110 ft, and a downstream set of equally spaced at 100 ft. The segment of interest was on Stockton Hill Road, as shown in Figure 2.5b, 1750 ft. long with 30 thermoplastic transverse bars. The bars consisted of two transverse markings spaced eight inches apart, and each bar had 24 inches of transverse length and eight inches of width. Dimensions of the speed bars were two feet by two feet, and the bars were placed adjacent to the centerline of the road. Spacing of the downstream treatment was determined by multiplying the measured 85th percentile speed by one second and upstream treatment was based on desired sensory speed increases. The length of the pattern was determined based on providing sufficient time to detect the frequency of sequential bars within the optical speed zone bar pattern. A four-bar-per second headway was adapted to slow vehicles from 65 mph to 30 mph. Data collection was conducted before, immediately after, and three months after installation. After speed was measured immediately downstream of the optical speed zone and in the middle of the target hazard segment. Evaluations were conducted before vs. immediately after installation and before vs. three months after installation for both daytime and nighttime. Results showed a statistical significance in speed reduction. Before and immediately after speed comparisons indicated mean and 85th percentile speeds dropped by 2 mph, and nighttime mean and 85th percentile speed dropped by 4 mph. Before and three months comparison showed mean speed dropped over 4 mph; 85th percentile speed dropped 5 mph; and there were similar reductions in speed during nighttime hours.



(Source: Latoski, 2009)

a. Optical Speed Bar Layout

(Source: Latoski, 2009)

b. Optical Speed Bars on SB Stockton Hill Road

Figure 2.5 Optical Speed Bar Layout and Installation at Test Section

Agent (1980) tested optical speed bars on US-60 in Meade County, Kentucky. The site was a high-accident location where 48 accidents had occurred, 36 of which were speeding-related. The study considered a minimum of 750 ft of markings, and warning devices were placed at a distance ahead of the hazardous zone. The speed drop was from 55 mph to 35 mph, and a deceleration rate of 1.67 mph/s was adopted, which led to a length of treatment of 810 ft. Spacing of the markings was a function of desired perception, travel speed, and frequency of two stripes per second, varying according to the distance traveled in 0.5 s. For instance, the spacing for a speed of 25 m/s (55 mph) would be approximately 12 m (40 ft) and drop to 7.6 m (25 ft) for a speed of 16 m/s (35 mph). To increase slowing of vehicles, spacing was decreased to 4.6 m (15 ft), and width of the stripes was also decreased to 0.6 m (2ft). Reflective markings were used, which included 30 stripes over a length of 247 m (810 ft).

Accident data were considered in the study during six years before installation of the treatment and one year after. Accident data were also analyzed for before-and-after periods. Reduction of accidents was noted by comparing only one year before and one year after treatment. Radar speed data was collected before and after (one week and six month later) and at the beginning and end of the treatment. Data included speed for night and day, and vehicle classification. The average, 50th percentile, and 85th percentile speeds at the beginning of the curve were determined. “Before” speed data were compared to both “after” periods, and day and night data were analyzed separately. An overall speed reduction was observed. The study found that transverse stripes can effectively reduce speed, and the warning effect of the transverse stripes is more effective than the warning effect of signing alone. The recommendation was to use transverse stripes as traffic-control devices at locations where high speeds have contributed to accidents, and a distance up to 1200 ft was recommended to increase the warning effect.

Godley et al. (2000) evaluated psychological mechanisms responsible for speed reductions caused by transverse lines using a driving simulator. The methodology consisted of 24 experienced drivers driving on four rural roads, and passing through four intersections on each road. Some of these intersections had their approaches treated with transverse lines at both reducing and constant spacing, with lines extending 0.6 m (2.0 ft) from the lane edges (peripheral transverse lines), and with no lines (control), considering both before and after speed adaptations.

All lines reduced travel speeds in the treatment areas. Transverse lines reduced speeds more than peripheral lines in the initial treatment area, and no speed differences were found between the two transverse-line spacing schemes. It was concluded transverse lines reduce speed by alerting drivers, and also through peripheral perception processes throughout the treatment. However, speed perception was not influenced by decreasing spacing of the lines.

The experiment found transverse lines are effective in reducing speed on the approach to an intersection. Speed reductions were found to be from alerting proprieties of the lines in the initial treatment area, but the main speed-reduction effect appeared to be from the influence on speed perception through peripheral vision. The study indicated the perceptual effect was not due to the decreasing line-spacing scheme distorting speed perception, but was likely due to increased peripheral visual stimulation leading to faster speed estimations. Speed reductions continued throughout the treatment areas until drivers could determine the appropriate deceleration rate from the location of the intersection alone, after which travel speeds were no longer influenced by the treatments. The study found transverse bars have an alerting effect on the participants, and speed can be reduced through peripheral visual perception alone. Therefore, use of peripheral transverse bars was recommended. To further make the case on the role of peripheral vision in producing faster speed estimations and slower speeds, the study suggested testing and comparing transverse lines with central transverse lines.

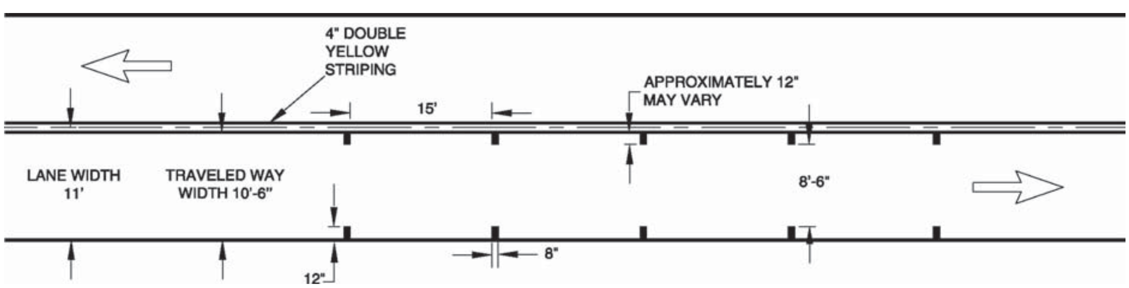
The study revealed since transverse lines influenced speed perception through additional peripheral visual stimulation, it is then probable they will have the largest influence on drivers if used in areas where the contrasting texture for the peripheral visual roadside is limited, which makes them less suitable in urban areas. The study also indicated that uses of transverse lines are not necessarily limited to areas where drivers are expected to be speed adapted. In addition, it was mentioned that it was not necessary for transverse lines to be spaced at exponentially decreasing distances apart. As a final point, the study highly favored peripheral transverse lines to be tested on roads, as they should result in similar road safety benefits to full-lane width lines and receive less wear from tires as only wide vehicles are likely to run over them, which make them a cheaper alternative to transverse lines.

The National Cooperative Highway Research Program Report 613 (NCHRP, 2008) discussed two types of transverse pavement markings installed on approaches to intersections for speed reduction. One site of this case study was the intersection of Whiskey Hill Road (Figure 2.6c) and Meridian Road (Figure 2.6b) in Clackamas County, Oregon. A speed study conducted on both roads of the intersection in August 2005 found the 85th percentile speed to be 48.7 mph, which is 28 % more than the 45 mph speed limit. On Meriden Road, the 85th percentile was found to be 56.2 mph, corresponding to 66% exceeding the 45 mph speed limit. The report indicated, based on crash data and public complaints, a need to reduce speeds in the northbound direction on Meridian Road to eliminate stop sign violations. Based on complex roadway geometry and limited sight distance, there was also a need to reduce speeds in the eastbound direction of Whiskey Hill Road prior to the intersection and school.

In order to address the need for speed reduction, several treatments such as reduced lane width, visible shoulder treatments, speed tables, rumble strips, roadway environment, approach curvature, roundabouts, splitter islands, dynamic warning sign, and longitudinal and transverse pavement markings were considered. After assessing appropriateness and effectiveness of each treatment, transverse pavement markings were adopted.

Two treatment design options were considered: full transverse bars and peripheral transverse bars. Full transverse bars are considered more noticeable to drivers, making them more effective at reducing speeds, but there are reports about motorcycles slipping on the markings while decelerating on full transverse bars. Conversely, peripheral transverse bars require less maintenance, are less expensive to install, and seem to create a narrowing effect of the travel way. Clackamas County, therefore, chose to install peripheral transverse instead of full transverse bars.

The peripheral bars, as presented in Figure 2.6a, were designed to include five pavement markings placed in a series to extend perpendicularly into the travel way from the edge and center lines, while not extending into the wheel path of vehicles. The spacing was 15 ft., and each marking was approximately between 12 to 24 inches in width and 18 to 33 inches in length. Length of each peripheral bar was determined depending on existing lane width and width of the wheel base of vehicles that commonly travel through the area. The traveled way width at the site was 10’6” and the typical wheel base was assumed to be 8’6”, so the peripheral bars were designed to be 12” by 8”. The “before” testing were performed in April 2006, treatment installation occurred in May 2006, and “after” testing was carried out in September 2006. The report did not include whether the treatment was found effective at reducing speeds at approaches to intersections.



a. Typical Optical Speed Bars Installed at Test Site

b. Northbound on Meridian Road **c. Eastbound on Whiskey Hill Road**

Figure 2.6 Peripheral Transverse Pavement Marking Design

The report also mentioned application of peripheral transverse bars, along with dynamic warning speeds, at the approach to the intersection of SR 20 and Marysville Road in Marysville, California. Peripheral transverse bar treatment was chosen for the Marysville Road southbound approach to supplement existing signing and “Stop Ahead” pavement markings. The same design pattern of the peripheral transverse bars in Oregon was adopted in California. At the time of the NCHRP report, peripheral transverse bars had not been installed in California, but there were plans to implement and monitor the treatments to observe their effectiveness at reducing speeds and increasing driver awareness at the intersection.

A study by Gates et al. (2008) addressed the short- and long-term effectiveness of an experimental transverse-bar pavement marking treatment on a curved section of freeway on I-43/I-94 in both northbound and southbound directions in Milwaukee, Wisconsin. The pavement marking treatment was installed in early September 2006 to serve as a low-cost interim safety countermeasure before future realignment construction. Each treatment section was 1,000 ft long, and markings were installed so that 500 ft of the treatment occurred both before and after the point of curvature on the horizontal curve. Each individual marking was a white rectangle, 18 in. in lateral width by 12 in. longitudinally. Typical speed limit along rural sections of I-94 and I-43 in Wisconsin was 65 mph, but the posted curve advisory speed limit and posted speed limit immediately upstream and downstream of the curve was 50 mph. Treatment sections, as shown in Figure 2.7, were designed and installed with continuously decreasing spacing between successive markings. Spacing between successive markings was designed to slow drivers from 65 to 50 mph over the initial 500 ft. of the treatment using a constant frequency of four bars per second. Thus, initial spacing between successive markings was 24 ft., while spacing at 500 ft. and beyond was 19 ft.

Traffic data such as speed, volume, occupancy, and vehicle composition were collected before and after installation of the markings at three locations, in both northbound and southbound directions using three, side-firing Wavetronix radar units.

Figure 2.7 Experimental Marking Treatment

Short-term reductions in marginal mean speeds were observed in both northbound and southbound directions. The ANOVA results confirmed these short-term speed reductions were statistically significant at a 95% confidence level. Short-term reductions in the 85th-percentile speeds were lower in magnitude than the mean speeds. Northbound traffic showed 0.0 to 1.0 mph short-term reductions in the 85th-percentile speed, while 1.0 to 3.0 mph short-term reductions were observed for southbound traffic. The study concluded the experimental pavement marking treatment was effective at reducing curve speeds, especially in the short term, and before–after speed reductions were sustained six months after installation at the northbound location when measured midway through the marking section.

The Kansas Department of Transportation (KDOT) has also experimented with OSBs at two test sites as part of a KTRAN research project. One test was on K-27 in Wallace County just south of Sharon Springs (Russell and Godavarthy, 2010). The purpose of placing these transverse markings was to study whether or not drivers reduce their speed of travel in response to the bars. The OSBs were spaced at gradually decreasing distances with the intent of enhancing the driver's perception of speed, resulting in speed reduction.

Painted white stripes (or bars) were placed on the north and south approaches to the curves on K-27 Highway located six miles south of Sharon Springs in Wallace County, as shown in Figure 2.8a. The speed limit drops from 65 mph to 30 mph at the location, and the speed bars were designed with a deceleration rate of 2.99 ft/s^2 over a distance of 1200 ft. A total of 70 bars were adopted for the treatment, and the 70^{th} bar was at the point of curvature. The second test site was on US-24/US-58 at Midland Junction, north of Lawrence in Douglas County, as presented in Figure 2.8b. The speed limit drops from 55 mph to 45 mph at the location, and the OSBs were designed for a deceleration rate of 2.7 ft/s^2 over a distance of 400 ft. The site leads to curves, inside which there is an intersection. A frequency of four bars per second was used. A total of 23 bars were installed and the 23rd bar was placed at the point of curvature.

a. Optical Speed Bars on K 27 **b. Optical Speed Bars on US-24/ US-59**

Figure 2.8 Installed Optical Speed Bars at Douglas County and Sharon Springs Sites

Results of speed analyses showed, on US-24 in Douglas County, reductions of 0.9 mph, 3.1 mph, and 3.1 mph for eastbound, westbound, and combined eastbound/ westbound traffic, respectively, with the westbound and eastbound/ westbound being statistically significant. On K-27 in Wallace County, analysis of the combined speed data, taken from both directions of traffic, showed a increase in speeds.

The researchers indicated future studies should be conducted using a more rigorous data collection program, and the time frame used in the study was too short for reliable long-term conclusions, stating it was too short for any novelty effects to wear off.

Chapter 3 Methodology

This section describes the main elements of the methodology such as site selection, data collection, optical speed bar (OSB) design and installation, and speed data analysis.

3.1 Site Selection

The main objective of this study was to test effectiveness of OSBs in reducing approach speeds on highways passing through rural communities. Selected sites were therefore located on approaches to rural towns. Kansas maps were used to identify such sites, and Google map was utilized in preliminary identification of initial and reduced posted speeds on highways located at these sites. Working with the Kansas Department of Transportation (KDOT), additional characteristics of potential test sites were proposed. These characteristics included sites on two-lane highways, no maintenance scheduled during the period of experimentation, and similar characteristics for all test sites to the extent possible.

Site visits were performed to further identify characteristics of the sites on the field and confirm the speed drops obtained from Google map. Table 3.1 presents characteristics of the considered test sites.

Table 3.1 Test Section Characteristics

City	Highway	Location	Initial Speed (mph)	Reduced Speed (mph)
Meriden West Test	K-4	West Side	65	45
Meriden East Test	K-4	East Side	65	45
Belvue	US-24	West Side	55	30
Silver Lake	US-24	West Side	65	45
Rossville	US-24	East Side	65	45

All test sites were on two-lane highways with asphalt-paved surfaces. Test sections were approximately straight and had approximately level grades. At the Belvue site shown in Figure 3.1, a reverse horizontal curve leads to the test section approximately 300 feet from the 55 mph speed limit sign. The speed limit on the highway was 65 mph, which first drops to 55 mph and then to 30 mph before entering the city. OSBs were installed on the portion of the roadway between the 55 mph and 30 mph signs. There is one intersecting local roadway just before the 55 mph speed limit sign and another around 50 feet after the 30 mph speed limit sign.

The Rossville test site on US-24 on the east side approach was on a straight segment of the highway and approximately at level grade. An intersecting driveway exists downstream of the test section approximately 1700 feet from the 45 mph speed limit sign. A horizontal curve was approximately 2000 feet from the 45 mph speed limit sign. Figure 3.2 shows the orientation of the Rossville test site.

The Silver Lake test site on US-24 on the west side approach, as presented in Figure 3.3, was also on a straight segment of roadway and at level grade. A horizontal curve exists just before entering the town, considerable distance (roughly 1500 ft) downstream of the test section.

Two test sites were considered on both approaches to the city of Meriden, shown in Figure 3.4. The speed limit on Highway K-4 was 65 mph and reduced to 45 mph at both sites. The highway was a two-lane asphalt-paved road with unpaved shoulders. The segment on the west side of the site was straight, leading to a curve downstream from the test section. The segment on the east side was located on a slight vertical curve and straight. There was a bridge approximately 550 feet from the reduced 45 mph speed limit sign.

Figure 3.1 Belvue Test Site on West Side Approach

Figure 3.2 Rossville Test Site on East Side Approach

Figure 3.3 Silver Lake Test Site on West Side Approach

Figure 3.4 Meriden Test Sites on Both Approaches

3.2 Data Collection

This section describes equipment used during data collection and methodology employed. It also presents data collection points within the test sections. The evaluation plan in testing the OSBs was to collect speed data “before”, “immediately after”, and “long after” for approximately a week for each data collection period. Unfortunately, difficulties were encountered as to availability of equipment for data collection. Consequently, data were collected during two “after” periods for some sites (Silver Lake and Rossville) and only one “after” period for other sites (Belvue and Meriden), where data were not able to be collected during the “immediately after”. The equipment, procedure, and spots at which data were collected are discussed in the following sections.

3.2.1 Equipment

Speed data were collected in each test section using pneumatic road tubes connected to automatic traffic recorders (ATR). The road tubes consisted of mini tubes of 50 feet in length. Each ATR was connected to a set of two mini tubes (TRAX I Plus User’s Manual, 2004 and 2008). Automatic traffic recorders from JAMAR were utilized for data collection, consisting of four TRAX I Plus counters. They are able to collect traffic data in three modes (basic data, volume-only, and binned data), and the basic mode was used in this study. Traffic data collected included speed, gap, vehicle classification, and volume. To properly collect the above mentioned traffic data, the following settings are necessary into the ATR: DBV, DT, and space. DBV is the longest distance between consecutive axles of the largest vehicle expected on the study site. The recommendation was to set the DBV value to 36 feet, and that sets the ATR so that any axles spaced at more than 36 feet apart must be registers as separate vehicles. The DT or dead time or D-bounce is the amount of time the air switch in the ATR waits after recording a pulse before recording another one, and the recommendation was to set its value at 35 milliseconds as the normal setting. This value depends on the volume of traffic at the study site. The space is the distance measured from the center of each tube and is used to evaluate the speed of the crossing vehicle.

During data collection, the road tubes were laid across the roadway lanes at points where data were to be collected and were then connected to the ATR placed at one side of the road. A tape measure was used to measure spacing from the center of each tube to determine proper spacing, which is important for accuracy of the data collected at the site. The tubes were secured at each end of the roadway, knots were tied at the far end of the tubes, and end plugs were used to close the ends of the tubes. The tubes were also secured across the road to maintain the spacing throughout the time of data collection. Figure 3.5 shows the mini tubes installation during traffic data collection.

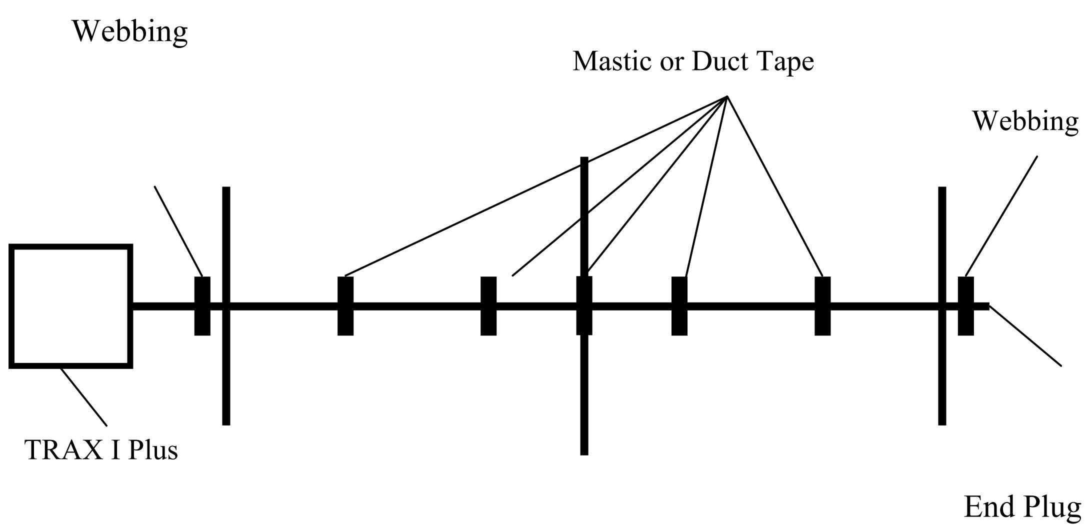


Figure 3.5 Mini Tube Installation across the Roadway

3.2.2 Data Collection Procedure

The procedure for data collection is that when a moving vehicle passes over the tube, an air impulse is transmitted through the tube to the ATR. For speed measurements, two tubes were placed across the lane spaced at a specified distance; in this study, the tubes were two feet apart, based on the recommendation of the manufacturer. An impulse was recorded when the front wheels of a moving vehicle passed over the first tube, and shortly afterwards a second impulse was recorded when the front wheels passed over the second tube. The time elapsed between the two impulses and the distance between the tubes were used to compute the speed of the vehicle. In this case, measuring the correct tube spacing and maintaining it throughout the length of the tubes was critical in collecting accurate speed data. The spacing of two feet was set in the ATR, which recorded the time elapse between the impulses from the first and second tubes. The ATR then used that information to determine the speed of each vehicle. To ensure each impulse travelled the same distance in each tube attached to the ATR, an equal length of 50 feet was set for the tubes, per a recommendation specific to mini tubes. Care was also taken to have the road tubes laid perpendicular to the direction of the roadway to avoid any double counting of vehicles.

Figure 3.6 presents the tube layout used during data collection. Data was recorded for both directions of travel. When a vehicle traveling southbound passed over both the A tube, then the B tube, the ATR recorded the class and speed (or time-stamps) of the vehicle in the first direction. In the same way, a vehicle traveling northbound and passing the B tube then the A tube, was recorded in the second direction (TRAX I Plus User's Manual, 2004 and 2008).

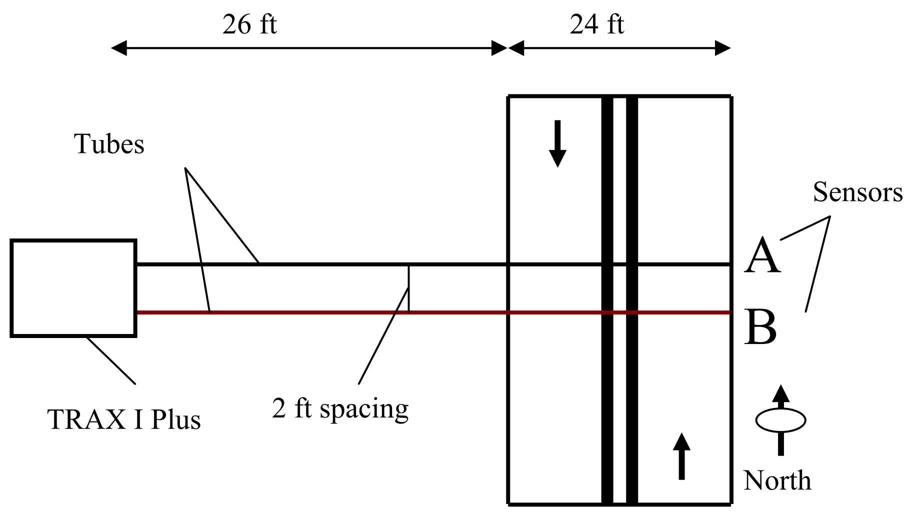


Figure 3.6 Tube Layout for Two-Way Divided Roadway

3.2.3 Data Collection Points

During the "before" period of data collection, traffic data were collected at four data collection points at each test site, but due to ATR malfunction, only three spots had valid data to compare to the "after" period of the data collection, except for the Meriden west side test site.

Figure 3.7 shows data collection spots on K-4 at the Meriden east side test site. Three spots were considered and identified as spot 1, spot 2, and spot 3. Spot 1 was at the warning sign of 45 mph, which also coincided with the beginning of the OSB treatment. Spot 2 was at the reduced speed limit of 45 mph and also at the end of OSB treatment. Spot 3 was downstream from the OSB treatment.

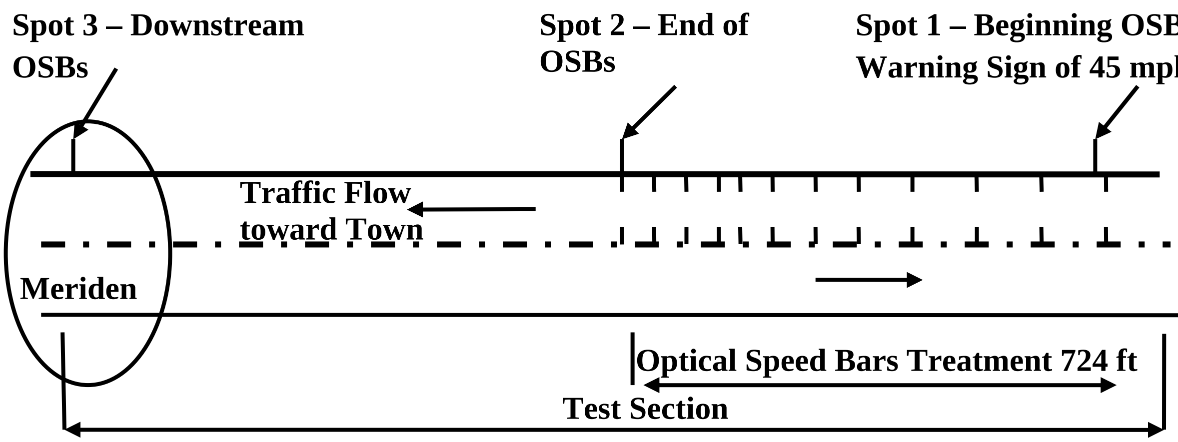


Figure 3.7 Data Collection Points at Meriden East Side Test Site

Figure 3.8 presents data collections points on K-4 at the Meriden west side test site. Traffic data were collected at four spots in both data collection periods. Spot 1 was at the warning sign of 45 mph, which was also at the beginning of the OSB treatment. Spot 2 was at the reduced speed limit of 45 mph, which was also at the end of OSB treatment. Spot 3 was downstream of the OSB treatment. Finally, spot 4 was at a location further downstream of the OSB treatment.

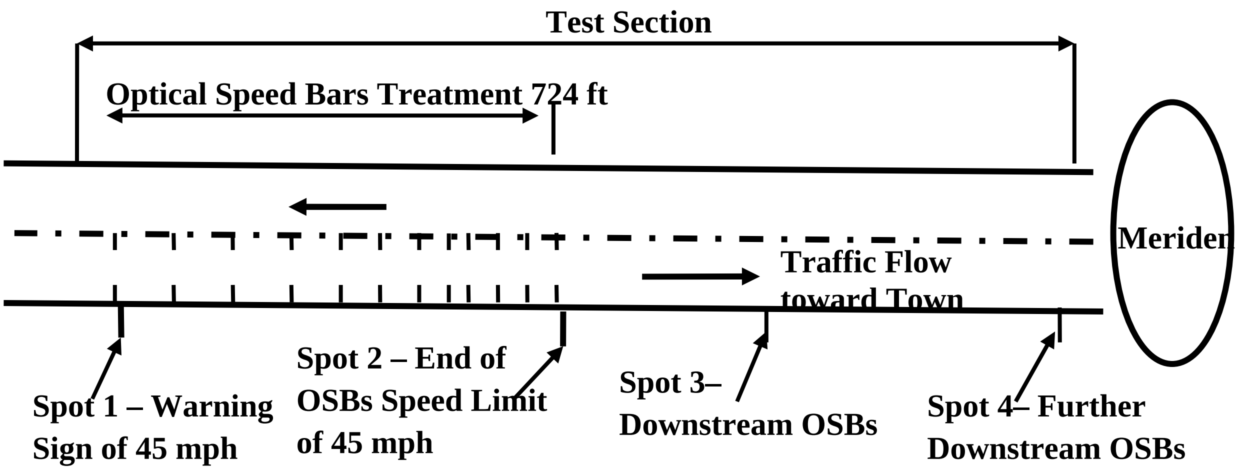


Figure 3.8 Data Collection Points at Meriden West Side Test Site

Figure 3.9 describes data collection points on US-24 at the Belvue test site. Data were collected at three spots: Spot 1 was at the initial speed limit sign of 55 mph in the test section; spot 2 was at the end of the OSB treatment and also at the reduced speed limit of 30 mph; and spot 3 was at a downstream location in town.

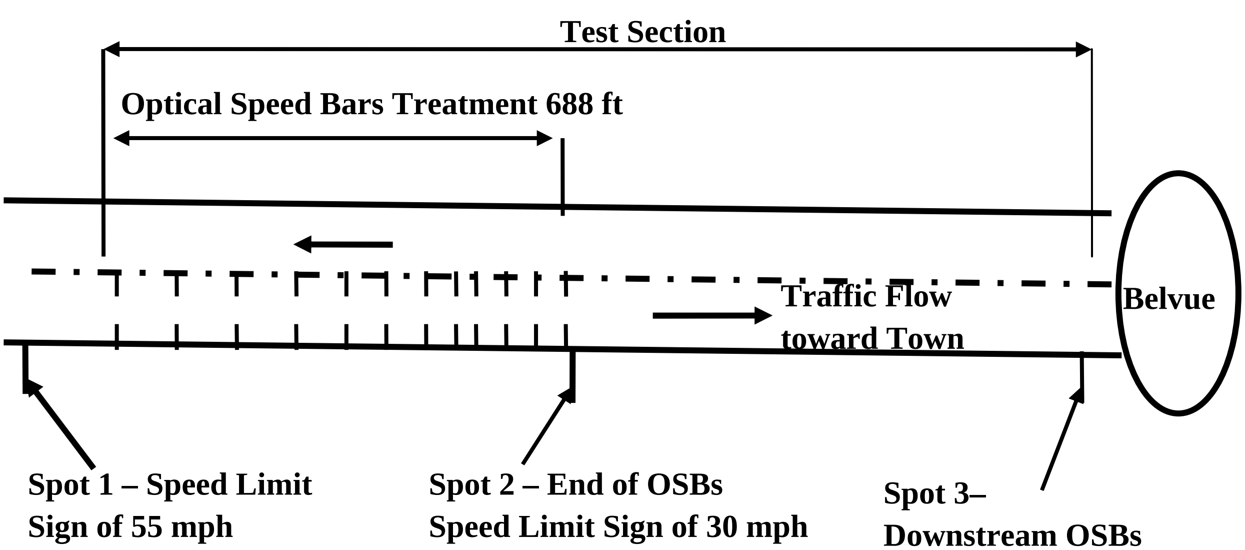


Figure 3.9 Data Collection Points at Belvue Test Site

Data were collected at three spots on US-24 at the Rossville test site as shown in Figure 3.10. Spot 1 was at a location well ahead of the beginning of the OSB treatment at the warning sign of 45 mph. Spot 2 was at the end of the OSB treatment and also at the reduced speed limit sign of 45 mph. A spot 3 was at a location downstream of the OSB treatment.

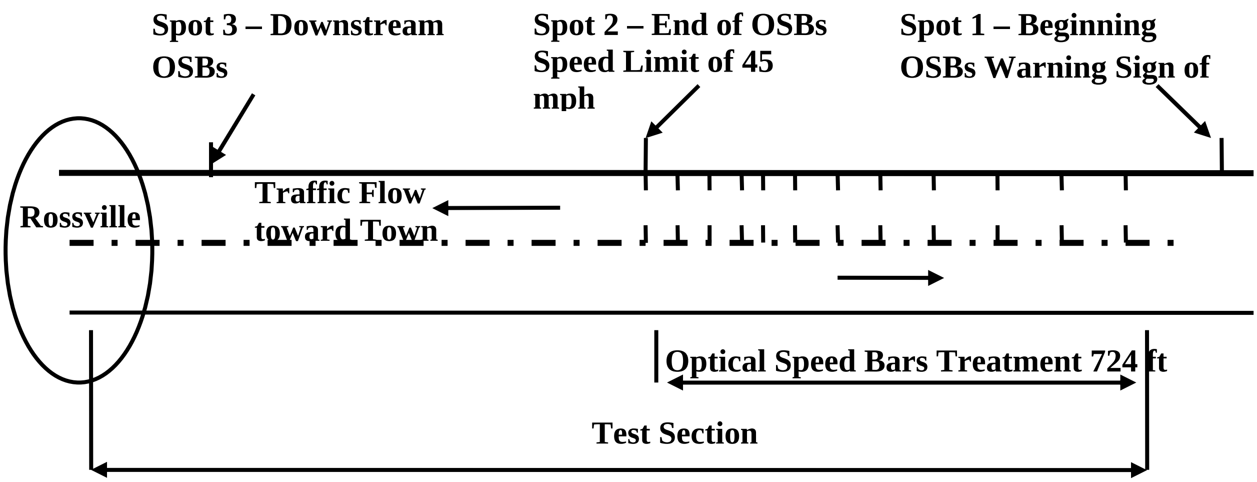


Figure 3.10 Data Collection Points at the Rossville Test Site

Data collection on US-24 in Silver Lake was performed at three spots as presented in Figure 3.11 Spot 1 was at the beginning of the OSB treatment and at warning sign of 45 mph; spot 2 was at the end of OSB treatment and at a reduced speed limit of 45 mph; and spot 3 was at a location downstream of the OSB treatment.

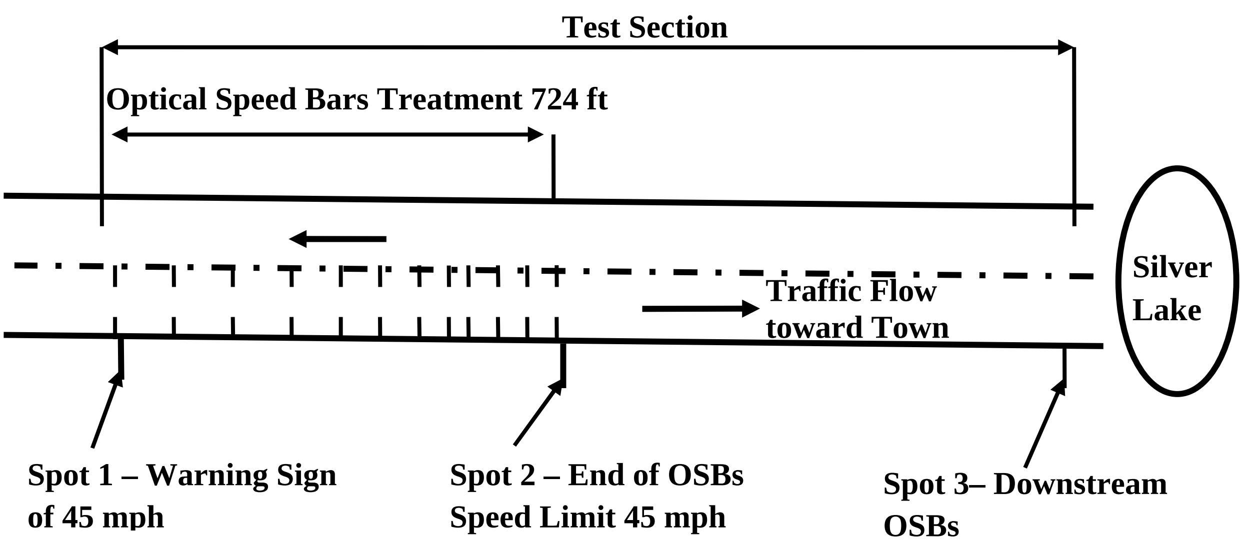


Figure 3.11 Data Collection Points at Silver Lake Test Site

3.2.4 Periods of Data Collection

Four sets of ATRs were available for data collection and all were used at one test site at a time. Table 3.2 summarizes data collection periods at the test sites. OSB treatments were painted at these test sites in early November 2009. Two data collection periods ("before" and "after") were performed at the test sites in Meriden and Belvue. At these sites, speed data were not collected immediately after having the speed bars painted. Instead, the "after" speed data were collected at approximately three and four months after installing the OSB treatments. At the test sites in Rossville and Silver Lake, three data collection periods ("before", "after", and "long after") were performed. Speed data were collected at the Rossville test three weeks after painting the speed bars and a little more than a month after at the Silver Lake test site. At these two sites, an extended data collection was performed as presented in Table 3.2

Table 3.2 Data Collection Periods at Test Sites

Test Sites	Periods of Data Collection		
	Before	After	Long After
Rossville	8/26/2009 to 9/2/2009	11/28/2009 to 12/5/2009	4/2/2010 to 4/9/2010
Silver Lake	8/17/2009 to 8/24/2009	11 /12/2009 to 11/ 16/2009	3/28/2010 to 4/2/2010
Meriden West Side	8/10/2009 to 8/17/2009	2/28/2010 to 3/3/2010	NA
Meriden East Side	8/2/2009 to 8/9/2009	3/16/2010 to 3/19/2010	NA
Belvue	9/19/2009 to 9/26/2009	2/10/2010 to 2/13/2010	NA

NA* - no speed data collected at these sites for the "long after" period

3.2.5 Problems Encountered During Data Collection

Tube perforation was a concern throughout data collection periods. As a result, data were lost in Silver Lake and Rossville during the "after" period at some data collection points. In addition, tubes were cut off for all spots in Silver Lake during the first attempt of data collection during the "after" period, leading to a second attempt. Moreover, road tubes were cut off at spot 3 at the Meriden west side site. Consequently, parts of data collected at that spot were lost.

Another issue encountered was maintaining tube spacing during the time period of data collection. In a few cases, the tape loosened over the flow of traffic, resulting in an increase or decrease of required tube spacing. As that spacing is very important in determining exact speeds at the sites, the ATRs were reset and new counts were performed each time the set tube spacing changed.

3.2.6 Sample Size Determination

Since speeds recorded are generally subjected to statistical analysis, an adequate number of vehicle speeds should be recorded, and the representative speed value at any location is usually taken as the mean of the speeds recorded during a speed study and is assumed to be the true mean of all vehicle speeds at that location (Garber and Lester, 1988). Accuracy of the assumption depends on sample size, and the higher the sample size, the higher the probability the estimated mean is not different from the true mean within acceptable error limits for the study. To ensure sample speeds are representative of true speeds at these locations, a minimum number of vehicles must be observed. As the number of vehicles in the sample increases, variability of vehicle speeds decreases and the confidence level of any subsequent statistical test increases. Statistical procedures are used to determine the minimum sample size, and the basic assumption made in determining the minimum sample size for speed studies is that the normal distribution describes the speed distribution at a given section of highway.

Visual observation of traffic flow at the sites indicated that even one day of data collection would be enough to provide a sufficient sample required for any statistical analysis. To obtain a large sample size for the statistical analysis, a data collection of seven days was adopted for this study.

3.3 Optical Speed Bar Design and Installation

3.3.1 Optical Speed Bar Design

A study by Godley et al. (2000) evaluated peripheral lines and transversal lines versus a non-treated control section of a roadway in a driving simulator. The study concluded peripheral lines performed the same and in some cases better than regular transverse lines at the beginning of the treatment area. Therefore, the study recommended use of peripheral lines as they should result in similar road safety benefits for the full-lane-width lines and should receive less wear from tires as only large vehicles are likely to run over them, which make them a cheaper alternative to transverse lines (Godley et al., 2000). In addition, the Kansas Department of Transportation (KDOT) suggested using peripheral transverse markings for this study for the advantages outlined by Godley et al. (2000), Katz (2004), and NCHRP (2008), in which it was noted peripheral transverse lines have the benefits of 1) being very easy to install and maintain, 2) being very cost effective since only a small amount of pavement marking material is needed, and 3) not being on the wheel path but on the edges, giving the effect of lane width reduction.

The design principle adopted for this study was similar to the design used in studies by Katz (2004) and Arnold et al. (2007). In this design methodology, an initial speed and a desired ending speed at each location are considered. Based on these speeds, length of OSB treatment is determined based on deceleration from the initial to the ending speed, and the bars are spaced such that a driver decelerating at a constant rate from the initial speed to the ending speed crosses four bars per second. Equation 1 is used to determine the required length of the optical speed bar treatment, and Equation 2, developed by Katz (2007), is used to find the spacing of the optical speed bar throughout the treatment.

$$D = \frac{(v_0^2 - v_1^2)}{2a} \qquad 3.1$$

where

D = distance traveled in slowing from v_0 to v_1,

a = deceleration rate,

v_0 = initial speed at the beginning of the treatment, and

v_1 = final speed.

$$x = \frac{1}{2}a(\frac{n}{f})^2 + v_0(\frac{n}{f}) + x_0 \qquad 3.2$$

Where

x = placement of the optical speed bars and

x_0 = initial placement of the first bar. The valued of x_0 is set to zero when a first bar is placed at the beginning of the treatment.

n = number of the optical speed bar for which the placement is determined.

f = required frequency of the bars, which is the number of optical speed bars in a second seen by motorists travelling through the treatment.

Spacing of OSBs should be determined such that motorists have the ability to perceive frequency of the bars. Spacing of the OSBs should not be extended in such a way that motorists are not able to perceive enough bars required for the perceptual effect of speeding when the spacing is in fact reduced (Latoski, 2007). Spacing should neither be reduced to the point that motorists see too many bars that they are unable to capture that perceptual effect.

Katz (2007) investigated the optimal spacing pattern for peripheral transverse bars to reduce vehicle speeds in a controlled environment on the Virginia Tech Smart Road. Spacing patterns of two bars per second and four bars per second were applied to the roadway and compared to baseline conditions with no treatment applied. The study found peripheral transverse lines spaced at four bars per second resulted in a significant decrease in speed at the entrance to the curve compared to both two bars per second and the baseline condition with no markings applied. In the current study, the frequency of four bars per second was adopted for design of OSBs.

3.3.2 Optical Speed Bar Installation

Kansas Department of Transportation (KDOT) performed the installation of OSBs at the test sites, which were located in two KDOT areas. Each area office installed the OSBs in its own area. The KDOT Wamego area office installed optical speed bars on November 5, 2009, at Belvue as shown in Figure 3.12. Spacing of the bars was measured prior to installation of the speed bars. On the day of installation, a red-painted rope was used by two people to mark transverse lines on the pavement to indicate placement of the speed bars. A plaque with shape and dimensions of the speed bars was used to paint bars. A traditional method was used to perform the painting, and reflective material was applied immediately following the painting of each bar. The plaque used was cleaned often to avoid splashing extra paint on the pavement. During installation, the crew was in general divided into three teams. One team of two flaggers was in charge of regulating traffic. One lane was open for traffic while the other was closed for speed bar construction. Two people were in charge of alternating the directions. The second team of two was in charge of marking the placement of bars. The third team of three was in charge of placing the plaque, painting the bars, and applying the reflective material. It took the crew approximately an hour to complete the painting of the speed bars.

The same day the KDOT Topeka area office performed installation of OSBs in Silver Lake. The KDOT Topeka area office was also in charge of installing OSBs at Rossville and Meriden. The KDOT Topeka area office installed OSBs at Rossville using a crew of five people, as presented in Figure 3.13. Spacing measurement and bar painting were done the same day. Two people were in charge of the spacing measurement; two people controlled the traffic; and one person placed the plaques, painting the bars using a more sophisticated method, and applied the reflective product. The painter was later helped by the team in charge of the spacing measurement. The painting was completed in approximately an hour.

Figure 3.12 Placing Optical Speed Bars at Belvue Test Site, Looking East

Figure 3.13 Placing Optical Speed Bars at Rossville Test Site, Looking West

3.4 Speed Data Analysis

Three major tasks were carried out in the analysis of the speed data: 1) descriptive statistics on the speed data and identifying speed characteristics, 2) evaluation of the change in vehicle speeds between “before” and “after” periods of data collection, and 3) evaluation of the change in the proportion of vehicles exceeding the speed limit.

3.5 Free-Flow Speed

A vehicle is considered to be operating under free-flowing conditions when the preceding vehicle has sufficient headway. If the road experiences traffic congestion, there will be certain periods when motorists are impeded by vehicles in front and are therefore unable to travel at their desired operating speeds. If these impeded vehicles are included in determination of the mean or 85th percentile speeds, then speed statistics will not accurately reflect the road’s true operating speed. It is necessary to introduce a headway cutoff value to effectively remove vehicles not operating under free-flow conditions, allowing determination of the true operating speed. Applying the appropriate headway cutoff to the speed data leads to an analysis where motorists are only traveling at their chosen speeds, unimpeded by vehicles in front of them.

Based on previous studies (Meyer, 2004; TAXPRO, 2006; Fontaine et al., 2009; Anthony et al., 2008), a headway cutoff value of five seconds was utilized to identify free flow-speed data.

3.6 Normality Test

Many classical statistical tests (t-test, z-test, etc…) depend on normality assumptions. The normality test verifies whether a given distribution comes from the normal distribution.

Commonly used tests for normality verification were not used in this study due to large sample sizes, since a test’s ability to reject the null hypothesis increases with sample size (SAS

Onlinedoc., 2007). That is, as the sample size becomes larger, increasingly smaller departures from normality can be detected, and small deviations from normality do not severely affect validity of the analysis of variance tests. Furthermore, with very large sample sizes (well over 1000) of speed data, a normality test may detect statistically significant but unimportant deviations from normality. Moreover, the t-test is robust to non-normality with large sample sizes, and therefore may not have a serious effect on the test results if the non-normality is not apparent in the normal probability plot for a large data sample.

In a normality plot, data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line, and departures from this straight line indicate departures from normality (National Institute of Standards and Technology, 2003). If speed variables match the test distribution, the points lie along a straight line; and if some observed values surround the straight line with noticeable deviations, this indicates presence of some outliers in the speed data.

3.7 Descriptive Statistics

Descriptive statistics of interest for defining the observed speed were sample size, mean speed, 85th percentile speed, standard deviation, and percentage of vehicles traveling above the speed limit. Sample mean speed is the most useful measure of central tendency of speed distribution and determines the average speed of vehicles traveling at the test site. The “before” and “after” speed data are used to assess the effectiveness of the OSBs, and as the same drivers in the “before” speed data collection period are not necessarily in the “after” speed data collection period, mean speed was used to evaluate effectiveness of the OSBs. The 85th percentile speed corresponds to the speed at or below which 85% of all vehicles are observed to travel under free flow conditions determined by spot speed studies, and is an important parameter used by traffic and transportation engineers to set speed limits. As such, the 85th percentile speed was also used in assessing effectiveness of the OSBs. The standard deviation provides measures of variability about the mean, and indicates speed variation at the test sites. The standard deviation was also included in the analysis to assess effectiveness of the OSBs.

3.8 Evaluation of Change in Vehicle Speeds between Periods

This evaluation consists of comparing speed parameters between the "before" period of data collection and that of the "after" period of data collection. The comparison was made for all vehicles combined and for categories based on vehicle classification (two axles vs. more than two axles), days of the week (weekdays vs. weekends), and time of day (daytime vs. nighttime.

Speed analysis includes comparison of mean and 85th percentile vehicle speeds during "before" and "after" time periods using the independent, two-sample t-test, comparison of speed variance using the F-test, and comparison of proportions of vehicles traveling over the posted speed limit using the Z-test. The two-sample t-test compares the difference between two sample means against a hypothesized difference between populations. Analysis of the speed variance with the F-test will suggest the equality of variance.

3.8.1 Testing Equality of Two Population Variances

The F-test statistic is determined by the ratio of the sample variances of two independent samples given by equation 3.3 (National Institute of Standards and Technology, 2003; Washington et al., 2003). The null hypothesis that the two sample variances are equal is rejected when $|F| \geq F_{\frac{\alpha}{2}}$ for a two-tailed test or when the p-value is more than the level of significance, which leads to the conclusion that the speed variances are statistically different.

$$F = \frac{S_1^2}{S_2^2} \qquad 3.3$$

Where

F = test statistic of analysis of variances,

S_1= standard deviation of the before speed data, and

S_2 = standard deviation of the after speed data.

3.8.2 Testing Differences between Two Population Means

Random independent samples drawn from two populations are used to test the difference between two population means. It is assumed that large samples are used to test for the difference between two population means because when sample sizes are sufficiently large, then distribution of their means can be considered as approximately normally distributed using the central limit theorem (Washington et al., 2003). This subsection presents analysis of independent samples using the t-test. The null hypothesis that the two sample means are equal is rejected if $t < -t_{(\alpha/2,df)}$ or $t > t_{(\alpha/2,df)}$, $t_{(\alpha/2,df)}$ is the critical value of the t-distribution with df degrees of freedom and level of significance α. The p-value of the test can also be used as an indicator of whether or not the null hypothesis can be rejected. The p-value is the smallest level of significance α that leads to rejection of the null hypothesis, and it quantifies the amount of statistical evidence that exists to reject the null hypothesis in favor of the alternative hypothesis, the larger the test statistic the smaller the p-value. When the p-value of the test is more than the level of significance α, then the null hypothesis cannot be rejected at that level of significance, and there is no evidence to conclude that the means of the two samples are significantly different. If the p-value is less than or equal to the level of significance α, then the null hypothesis is rejected and there is evidence to conclude that the means of the two samples are different. Two types of independent two-sample t-test exist, depending whether or not the sample variances are equal or different.

3.8.3 t-Statistic of Unequal Sample Sizes with Equal Variance

The test statistic of t-test of unequal sample sizes with equal variance is given by Equation 3.4 (Washington et al., 2003).

$$t = \frac{\overline{x_1} - \overline{x_2}}{s_p \sqrt{(1/n_1 + 1/n_2)}} \qquad 3.4$$

where

t = test statistic,

$\overline{x_1}$ = mean of the before speed data,

$\overline{x_2}$ = mean of the after speed data,

n_1 = sample sizes of the before speed data,

n_2 = sample size of the after speed data, and

S_p = pooled standard error.

When two population variances are equal, then the variances are pooled together to obtain a common population variance based on sample variances and sizes of the two sample distributions. The pooled variance is determined by using Equation 3.5.

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_1^2}{n_1 + n_2 - 2} \qquad 3.\ 5$$

Degrees of freedom associated with the pooled estimate of the population variance are determined by $df = n_1 + n_2 - 2$. The confidence interval for a difference in population means is based on the t distribution with $df = n_1 + n_2 - 2$ degrees of freedom.

3.8.4 t-Statistic of Unequal Sample Sizes with Unequal Variances

The test statistic of the t-test of unequal sample sizes with unequal variances is given by Equation 3.6 (Washington et al., 2003).

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad 3.6$$

The degree of freedom associated with unequal variances is determined by Equation 3.7.

$$df = \frac{(s_1^2/n_1 + s_2^2/n_2)^2}{(s_1^2/n_1)^2/(n_1 - 1) + (s_2^2/n_2)/(n_2 - 1)} \qquad 3.7$$

3.8.5 Testing Differences between Two Population Proportions

Differences in proportions of vehicles traveling over the speed limit could be tested using the Z-test for proportions, assuming that sample sizes are sufficiently large and the two proportions are randomly sampled. The two-proportion Z-test determines whether the hypothesized difference between population proportions differs significantly from the observed sample difference (National Institute of Standards and Technology, 2003; Washington et al., 2003). Three proportions were compared between periods of data collection under three scenarios: vehicles traveling over the speed limit, vehicles traveling more than 5 mph above the speed limit, and vehicles traveling more than 10 mph above the speed limit.

When sample sizes are large, as was the case in this study, sampling distributions of the two sample proportions and their difference are approximately normally distributed. The Z-test statistic is determined using Equation 3.8.

$$Z = \frac{(P_1 - P_2)}{SE} \quad 3.8$$

where

P_1 = proportions from sample 1,

P_2 = proportions from sample 2, and

SE = standard error from the sampling distribution determined by using Equation 3.9.

$$SE = \sqrt{P*(1-P)*(\frac{1}{n_1}+\frac{1}{n_2})} \quad 3.9$$

where

n_1= size of the sample 1,

n_2 = size of the sample 2, and

P = pooled sample proportion determined by using Equation 3.10.

$$P = \frac{(n_1 * P_1 + n_2 * P_2)}{(n_1 + n_2)} \quad 3.10$$

The null hypothesis that there is no difference between two population proportions is tested here. Thus, the two-tailed test applies to assess the significance of the difference in proportion by examining the P-values (Washington et al., 2003). The null hypothesis is rejected when the P-value is less than the significance level α of the test and accepted otherwise. Smaller P-values indicate there significance difference between population distributions, and higher p-values state no sufficient evidence exists to assess the difference at the significance level α of the test.

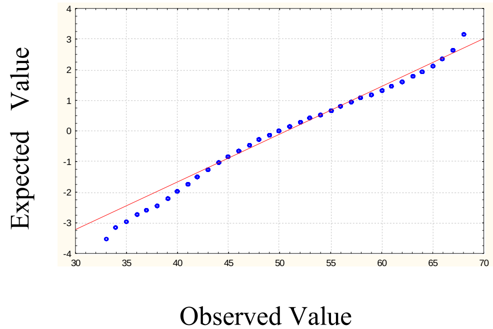
Chapter 4 Results of Speed Data Analysis

4.1 Normality Test

As discussed earlier in the methodology section, the normal probability plot was used to verify whether speed data distribution was in accordance with the normal distribution. Results of the normality observation are presented in Figure 4.1 for all test sites at the end of the treatment after having painted the optical speed bars (OSBs). Visually, the probability plots show strongly linear patterns, and the correlation coefficient (coefficient of determination) of the line fit to the probability plot backs that fact. The correlation coefficient measures strength and direction of a linear relationship between two variables. The coefficient of determination measures proportions of variance or fluctuation of one variable that is predictable from the other variable. Variables here consisted of values of the standard normal distribution and those of speed distributions. The equations presented along with the probability plots of Figure 4.1 represent regression lines that determine the relationship of the variables, and the given coefficient of determination indicates how well the regression line represent the data. All coefficients of determination were high and closer to one, indicating a strong correlation. The fact that the points in the lower and upper extremes of the plot did not deviate significantly from the straight-line pattern indicates there were no significant outliers relative to a normal distribution. In addition to normal probability plots, frequency histogram of speeds, as shown in Figure 4.2, were used to identify any flatness and symmetry of speed distributions.

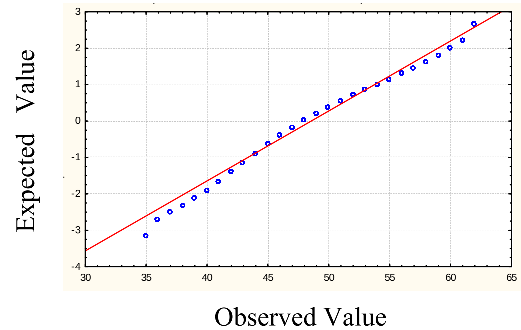
In conclusion, the normal probability plot showed a strongly linear pattern. There were only minor deviations from the line fit to the points on the probability plot, and the normal distribution appeared to be a good model for these data.

$Y = 0.1563x - 7.9212; R^2 = 0.9835$



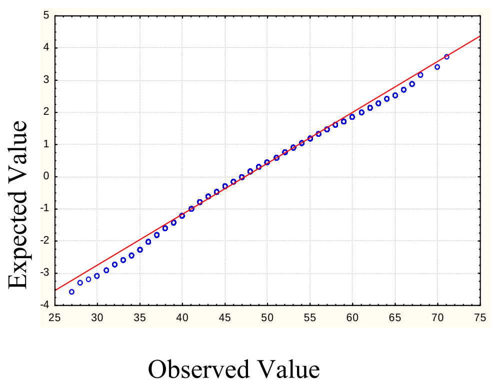
a. Meriden East Side Test Site

$Y = 0.1931x - 9.3771; R^2 = 0.9806$



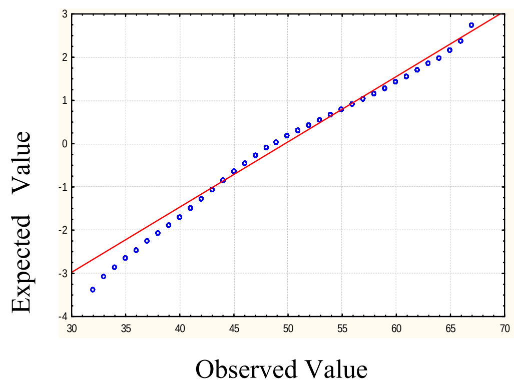
b. Meriden West Side Test Site

$Y = 0.1585x - 7.504; R^2 = 0.9906$



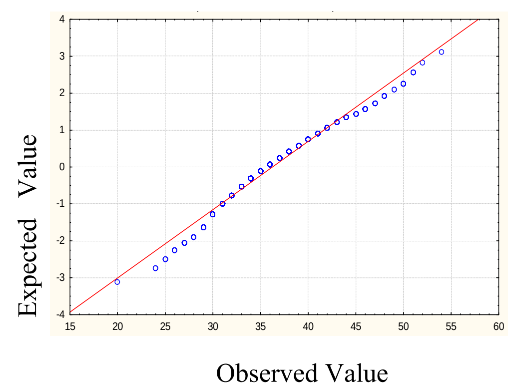
c. Silver Lake Test Site

$Y = 0.151x - 7.5264; R^2 = 0.9808$



d. Rossville Test Site

$Y = 0.186x - 6.7421; R^2 = 0.9775$



e. Belvue Test Site

Figure 4.1 Normal Probability Plot of Speed Distributions at the End of the Optical Speed Bar Treatment at the Test Site

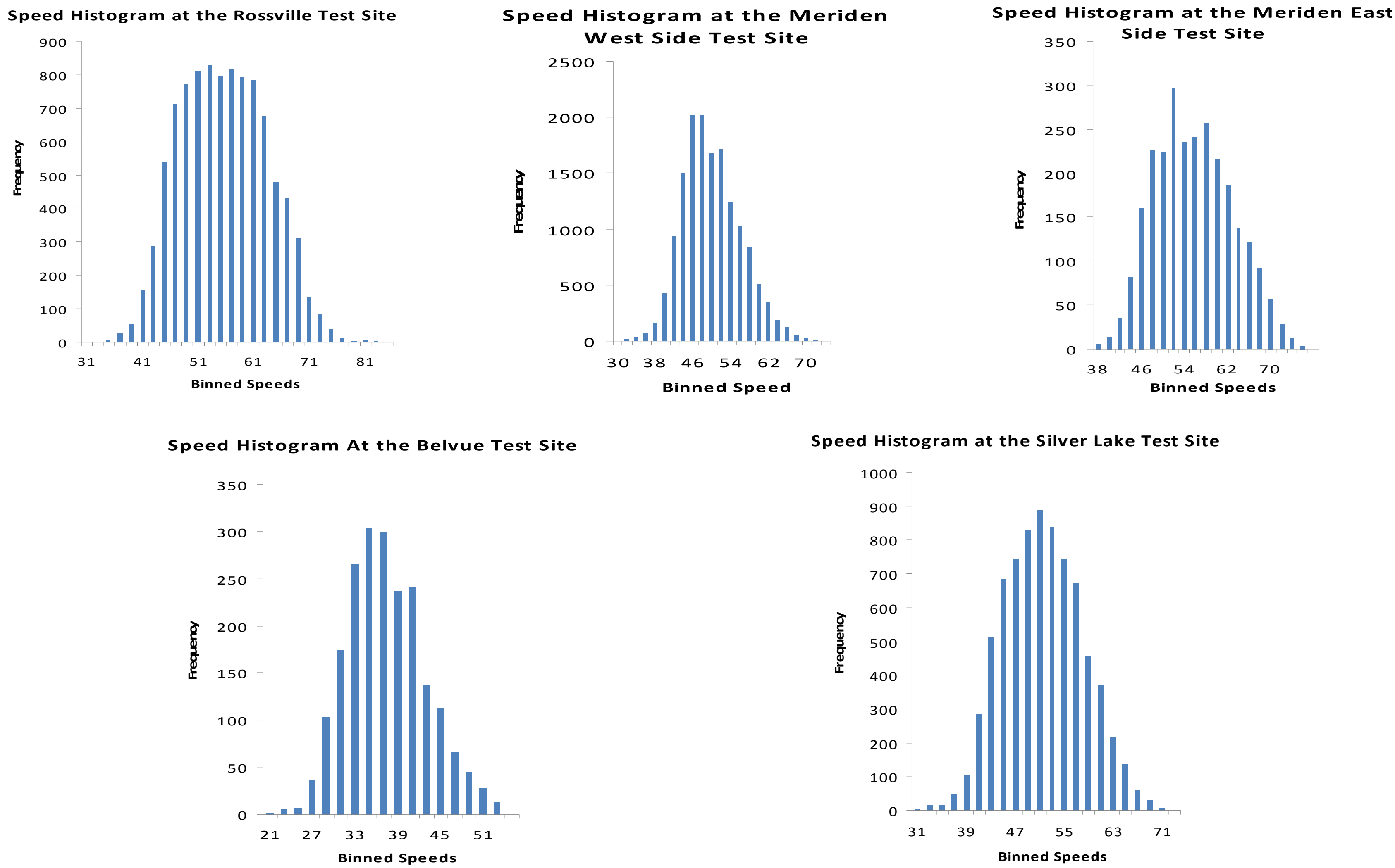


Figure 4.2 Frequency Histogram Plots of Speed Distributions at Ends of Treatments

4.2 Results of Descriptive Statistics of Speed Data

In the analysis of speed data, parameters such as sample size, mean speed, 85^{th} percentile speed, and standard deviation were estimated for speed datasets during both "before" and "after" periods. These speed parameters were determined in the categories of all vehicles, vehicle classification, time of day, and day of the week. This section presents results of that characteristic analysis.

As speed data were collected in both directions of traffic flow, speed analysis was performed for both directions, one of which was the treatment direction where the OSB treatment was installed. Traffic flow in this direction travelled to small towns on the approaches of which the test sites were located. In this direction, speed data were analyzed in all categories. On the other hand, the opposite direction was the direction in which the traffic flow included vehicles leaving the towns. No treatment was applied in the opposite direction. It was hypothesized that vehicle speeds in this direction were not influenced by the OSB treatment, since previous studies (Meyer, 2004 and Godley, 2000) have concluded the influence OSBs have on vehicle speeds comes from warning and perceptual effects. It was considered these effects work only on driver choices of speeds when these drivers travel through the OSB treatment. Speed analysis in the opposite direction therefore will serve as a control direction to see the changes in speeds in both directions between the "before" and "after" time periods. While speed data were analyzed in several categories in the treatment direction, only the all-vehicles category was considered in the opposite direction. That is, the opposite direction was used to see how speeds of all vehicles changed between the "before" and "after" periods of data collection, and the changes were compared to those in the treatment direction.

As indicated in section 3.2.3, data were collected in at least at three spots, and four spots in the case of one site. Spot 1 was placed upstream of the OSB treatment. Since this spot was placed ahead of the OSB treatment, vehicle speeds would not be influenced by the treatment. Drivers could not see the OSB treatment at spot 1 and therefore should not receive any effect (warning or perceptual) from the bars. This was the case for spot 1 in the test sites located on the approaches to Belvue and Rossville. At these two sites, spot 1 was at a location well ahead of the OSB treatment, and drivers could not see the bars. For these sites, spots 1 could well play the role of the control spot. For the other sites (Silver Lake and Meriden), spot 1 was located at the beginning of the OSB treatment. Therefore, due to the warning effect attributed to OSBs by some studies, spot 1 in these sites could not be considered as a control spot. Additionally, these spots were specifically placed at locations where ATRs could be secured, and some spots corresponded at locations where warning and reduced speed signs were installed.

At the Meriden east side test site, analysis was performed on speed data collected at three spots for all vehicles, based on vehicle classification and time of day. Even though speed data were collected at four spots before the OSB treatment, it was only possible to have speed data collected at three spots during the "after" period due to an ATR malfunction. In addition, before the treatment, spacing of the road tubes did not stay the same throughout the week of data collection. The tape used to maintain the spacing between road tubes came off sometime during the data collection and accordingly, some speed data were lost. Therefore, it was not possible to analyze data based on the weekday vs. weekend categorization.

At the Meriden west side test site, speed data were collected and analyzed at four spots. No tube problems or ATR malfunctions were encountered either "before" or "after" the treatment, with the exception of spot 3 where the count was interrupted for a short period of time due to one of the two tubes being cut off. Speed data were collected at four spots in the before period, but due to tubes being cut off through the flow of traffic, data collected at spot 4 were mostly lost. Only a few hours of count was obtained with a sample size of 379 in the treatment direction and 63 in the opposite direction. Though the sample size of 379 may be reasonable for some studies, in this study, it was considered insufficient, as it was much smaller than those collected at the other three spots, which were more than 10,000 vehicles. The other reason was that when processing data collected in the software (TRAXPRO) the percentage of "unclassified" was very much higher than recommended (should be less than 10 %). At spot 4 the percent of "unclassified" was 98 %, meaning the counter recognized only 2 %, indicating an inaccurate situation.

Data were collected at four spots during both "before" and "after" periods at the Belvue test site. However, for unknown reasons, the counter placed at the warning sign (beginning of the OSBs) did not store the data during the "after" period. Therefore, only data collected at the other three spots were included in the analysis.

At the Silver Lake test site, two periods of data collection were performed after installing the OSBs. The first data collection was done immediately after having the OSBs installed and is referred to as "after" period of data collection in the analysis. The second data collection was done in a period long after and is referred to as the "long after" period of data collection.

At the Rossville test site, two periods of data collection were performed after installing the OSBs. The first data collection was done immediately after having the OSBs installed and is referred to as the "after" period of data collection in the analysis. The second data collection was done in a period long after and is referred to in the analysis as the "long after" period of data collection. A similar situation as in Silver Lake occurred in Rossville in the "before" period of data collection. Data collected at spot 4 (well downstream) were lost due to tube cuts, and the percent of "unclassified" was very high, in the range of 95%. The count at spot 2 (at the end of OSB treatment) was also lost due to tube cuts in the "after" period of data collection.

A statistical analysis was performed on speed data collected at the test sites to determine effects of OSB treatment in reducing approach speeds to rural communities. Periods of data collection hereby indicate periods "before", "after" and "long after" implementing OSB treatment at the test sites. Three tests were performed for the purpose of evaluating such effectiveness and to see whether changes were statistically significant. Results of these tests are presented for each test site based on analysis of variance, analysis of differences in sample means, and examination of 85th percentile speeds between periods.

4.3 Analysis of Speed Variation

Analysis of variation indicates whether the difference in speed variances are statistically significant between datasets and also provides an idea about which t-test is to be utilized during the analysis of differences in sample means.

Standard deviations at the Meriden east side test site presented in Figure 4.1 were lower at upstream and downstream locations, while were higher at the end of OSBs. Standard deviations first increased from the upstream location to the end of OSBs and then decreased at the downstream location. The difference in drivers slowing down may explain speed variations observed at the test site. Between the upstream and the end of OSBs, drivers were in the process of breaking down in response to the change in speed zones. As drivers did not necessarily have the same response to the speed zone, the slowing altered the smoothness of traffic flow. Also, differences in standard deviations were higher at the end of OSBs and more so at the downstream location.

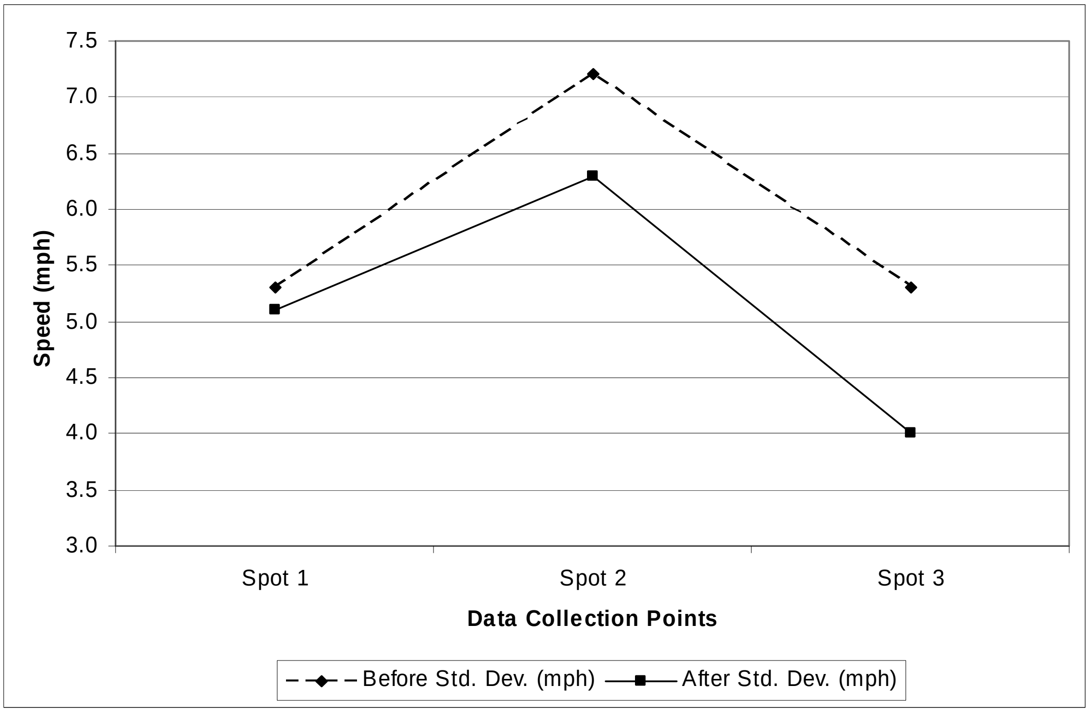


Figure 4.3 Standard Deviation for All Vehicles at Meriden East Side Test Site

Analysis of variance based on a level of significance of 5 % is presented in Table 4.1. Most of the p-values obtained were less than 5 % significance level, indicating statistically significant differences in standard deviations. Reductions occurred in speed variance at all three data collection points and were statistically significant at the 95 % confidence level. The exception was during daytime at the beginning of OSBs and for more-than-two-axle vehicles at the downstream location, with the increases being not significant. The highest statistically significant decreases in speed variances occurred at the end of OSBs and at the downstream location.

Table 4.1 Results of F-Test of Variance at Meriden East Side Test

Categories	Before		After		F-test	Statistical Significance
	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)	P-value	
Treatment Direction						
Spot 1- at beginning of the OSBs						
All Vehicles	4,732	5.3	5,944	5.1	<0.0001	Yes
2 Axles	4,369	5.3	5,360	5.1	<0.0001	Yes
>2 Axles	365	5.2	581	4.8	0.0314	Yes
Daytime	3,755	5.1	4,023	5.2	0.13191	No
Nighttime	973	6.1	1,975	5.2	<0.0001	Yes
Spot 2 – at end of OSBs						
All Vehicles	2,637	7.2	6,037	6.3	<0.0001	Yes
2 Axles	2,447	7.2	5,457	6.3	<0.0001	Yes
>2 Axles	190	6.9	582	6.7	0.283	No
Daytime	1,753	7.1	4,060	6.5	<0.0001	Yes
Nighttime	885	7.3	1,969	5.9	<0.0001	Yes
Spot 3 – at 500 ft downstream OSBs						
All Vehicles	2,396	5.3	5,661	4.0	0.1236	Yes
2 Axles	2,212	5.3	5,159	3.9	0.0147	Yes
>2 Axles	188	5.9	580	6.1	0.2298	No
Daytime	1,618	5.9	3,976	4.8	<0.0001	Yes
Nighttime	866	6.2	1,880	3.8	<0.0001	Yes
Opposite Direction						
Spot 1- at beginning of OSBs						
All Vehicles	8,733	6.0	5,557	5.9	0.0117	Yes
Spot 2 – at end of OSBs						
All Vehicles	8,839	6.5	5,823	6.2	0.0007	Yes
Spot 3 – 500 ft downstream OSBs						
All Vehicles	2,243	6.6	5,619	6.7	0.2429	No

At the Meriden west side test site, standard deviations presented in Figure 4.4 show slight increases from the upstream location to the end of OSBs, then decreases to the downstream location. The decreases continued to the next downstream location during the “before” period, but increases occurred from the first downstream location to the next downstream location during “before” period. Standard deviation reductions between “before” and “after” periods were lowest at the first downstream location but highest at next the downstream location.

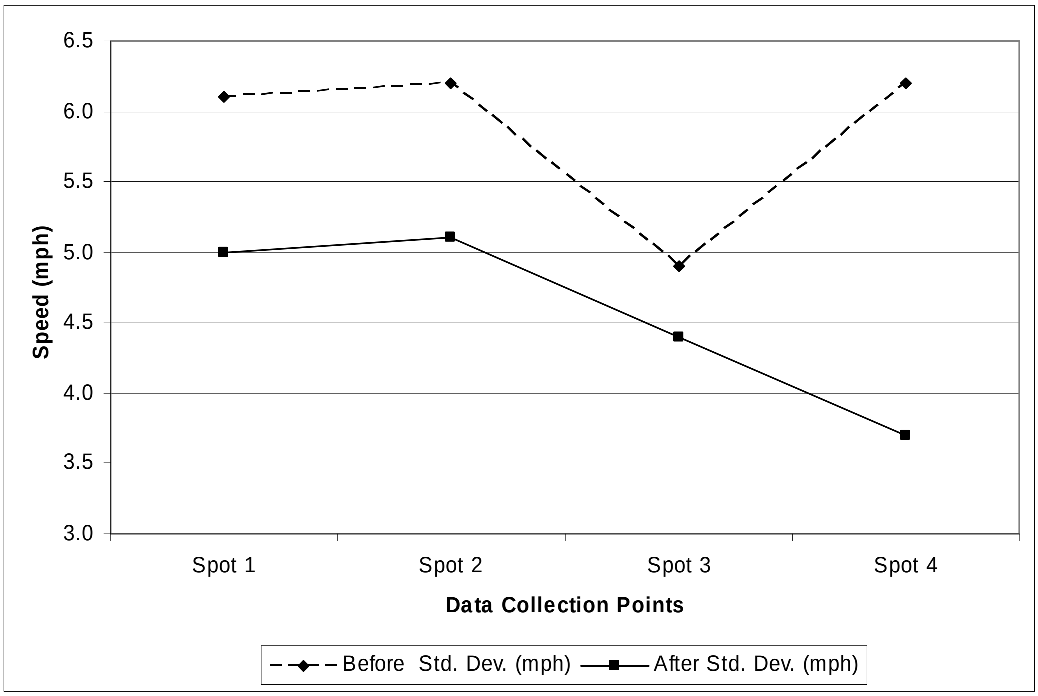


Figure 4.4 Standard Deviations for All Vehicles at Meriden West Side Test Site

Results of the F-test of variance are presented in Table 4.2. Standard deviations decreased at all data collections points and were statistically significant at the 95 % confidence level, as p-values observed were lower than the 5 % significance level. Two exceptions occurred at the beginning of the OSBs and at the first downstream location for vehicles of more than two axles.

Table 4.2 Results of F-Test of Variance at Meriden West Side Test

Categories	Before		After		F-test	Statistical Significance
	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)	P-value	
Spot 1- at the beginning of the OSB						
All Vehicles	14,920	6.1	6,221	5.0	<0.0001	Yes
2 Axles	13,644	6.1	5,694	5.0	<0.0001	Yes
>2 Axles	1,276	5.2	529	4.9	0.0600	No
Daytime	11,357	5.8	4,155	5.0	<0.0001	Yes
Nighttime	3,563	6.3	2,066	5.1	<0.0001	Yes
Weekdays	10,794	5.9	5,291	5.0	<0.0001	Yes
Weekends	4,126	6.2	930	5.0	<0.0001	Yes
Spot 2 – at end of OSB						
All Vehicles	14,991	6.2	6,226	5.1	<0.0001	Yes
2 Axles	13,646	5.9	5,725	5.1	<0.0001	Yes
>2 Axles	1,201	6.2	518	5.7	0.0155	Yes
Daytime	11,400	6.1	4,300	5.2	<0.0001	Yes
Nighttime	3,492	5.5	1,894	4.7	<0.0001	Yes
Weekdays	10,764	5.9	5,235	5.1	<0.0001	Yes
Weekends	4,068	5.9	991	5.3	<0.0001	Yes
Spot 3 – at approximately 250 ft downstream the OSB treatment						
All Vehicles	14,474	4.9	3,424	4.4	<0.0001	Yes
2 Axles	13,464	5.3	3,091	3.9	<0.0001	Yes
>2 Axles	1,280	5.3	264	5.3	0.3925	No
Daytime	11,187	5.3	2,096	4.4	<0.0001	Yes
Nighttime	3,511	4.7	1,281	3.8	<0.0001	Yes
Weekdays	10,647	5.2	2,596	4.3	<0.0001	Yes
Weekends	4,093	5.4	828	4.5	<0.0001	Yes
Spot 4 – at 550 ft from end of OSB						
All Vehicles	14,296	6.2	8,961	3.7	<0.0001	Yes
2 Axles	13,172	6.2	8,399	3.7	<0.0001	Yes
>2 Axles	1,124	6.1	569	4.1	<0.0001	Yes
Daytime	10,947	6.3	5,442	3.8	<0.0001	Yes
Nighttime	3,349	5.5	3,519	3.6	<0.0001	Yes
Weekdays	10,263	6.2	5,295	3.7	<0.0001	Yes
Weekends	4,033	6.1	3,815	4.3	<0.0001	Yes

Table 4.2 Continued

Category	Before		After		F-test	Statistical Significance
	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)	P-value	
Spot 1- at the beginning of the OSBs						
All Vehicles	8,138	5.4	7,283	5.4	0.1524	No
Spot 2 – at end of OSB						
All Vehicles	8,436	5.1	7,596	4.8	<0.0001	Yes
Spot 2 – at end of OSBS						
All Vehicles	8,307	5.5	4,253	5.1	<0.0001	Yes
Spot 3 – at approximately 500 ft downstream OSBs						
All Vehicles	16,964	5.2	10,026	4.4	<0.0001	Yes

Standard deviations at the Belvue test site increased during the “before” period from the upstream location to end of OSBs, then decreased to the downstream location as shown in Figure 4.5. During the “after” period, standard deviations decreased from the upstream location to the end of OSBs and continued the decrease to the downstream location. Decreases were highest from the end of OSBs to the downstream location.

Reductions of standard deviations occurred between the “before” and “after” periods, but the p-values in Table 4.3 indicate the reductions were statistically significant at the 95 % confidence level only at upstream and downstream locations for all vehicles. Reductions were also not significant during daytime and for vehicles of more than two axles at the end of OSBs, and during daytime and nighttime at the downstream location.

In the opposite direction, significant reductions in standard deviations were also found at the upstream location and end of OSBs, with no significant change at the downstream location.

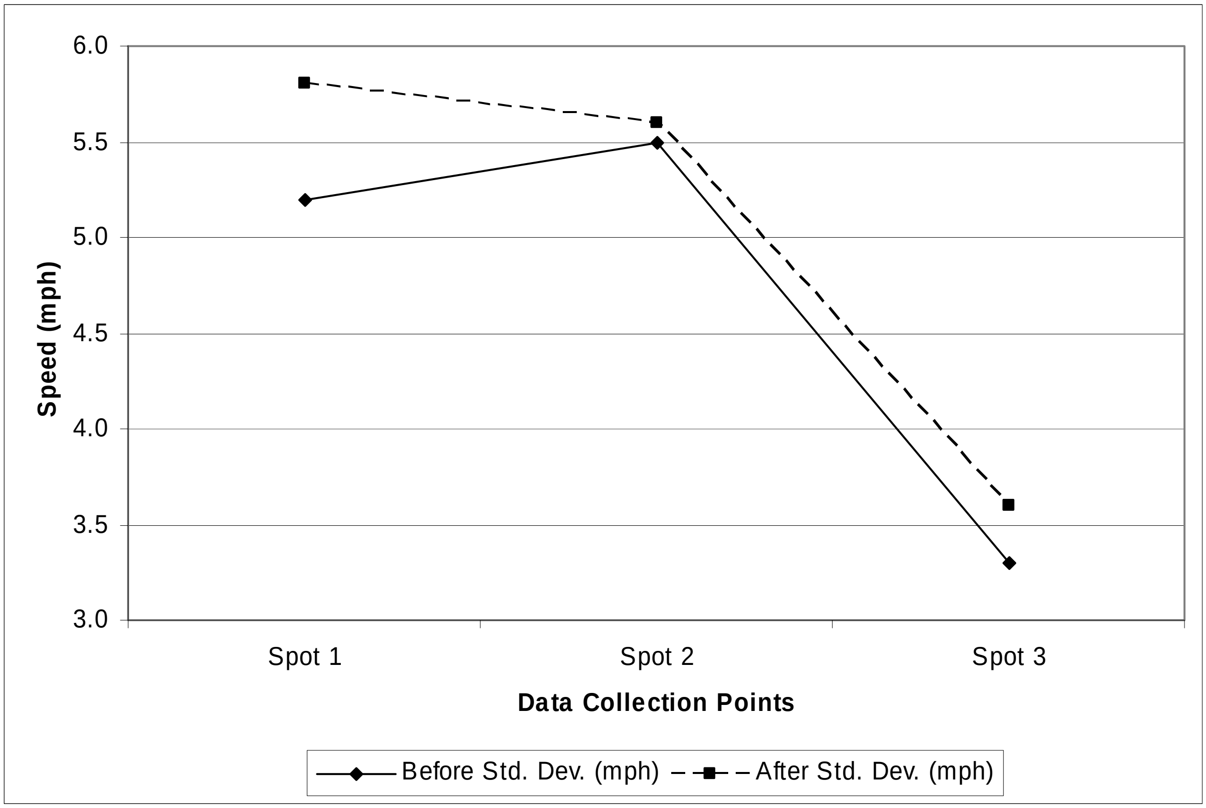


Figure 4.5 Standard Deviations at Belvue Test Site

Table 4.3 Results of F-Test of Variance at Belvue Test Site

Categories	Before		After		F-test	Statistical Significance
	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)	P-value	
Spot 1 – Way before beginning of OSBs						
All Vehicles	2,685	5.2	4,729	5.8	<0.0001	Yes
2 Axles	2,362	5.2	4,042	5.7	<0.0001	Yes
>2 Axles	327	5.2	691	5.7	0.0236	Yes
Daytime	2,057	5.2	3,334	5.6	0.0002	Yes
Nighttime	633	5.3	1,395	6.2	<0.0001	Yes
Spot 2 – at the end of OSBs						
All Vehicles	2,078	5.5	4,792	5.6	0.0670	NO
2 Axles	1,955	5.5	4,070	5.7	0.0199	Yes
>2 Axles	121	5.5	723	5.3	0.3383	No
Daytime	1,531	5.6	3,419	5.8	0.0548	No
Nighttime	546	4.9	1,372	5.3	0.0220	Yes
Spot 3 - 800 ft downstream OSBs						
All Vehicles	1,851	3.3	4,604	3.6	<0.0001	Yes
2 Axles	1,754	3.3	3,943	3.6	<0.0001	Yes
>2 Axles	101	3.7	646	3.1	0.0141	Yes
Daytime	1,505	3.8	3,359	3.9	0.3222	No
Nighttime	418	3.3	1,305	3.4	0.1747	No
Opposite Direction						
Spot 1- at the beginning of the OSBs						
All Vehicles	5,983	5.9	4,447	5.7	<0.0001	Yes
Spot 2 – at end of OSBs						
All Vehicles	5,265	6.3	4,413	4.5	<0.0001	Yes
Spot 3 – at 800 ft downstream the OSBs						
All Vehicles	1,845	3.6	4,286	3.6	0.4391	NO

At the Rossville test site, standard deviations increased from the upstream location to the end of OSBs, then decreased to the downstream location during both the “before” and “long after” periods as shown in Figure 4.6. Standard deviations observed at data collection points were closer during the “after” period than those during “before” period. This supports the fact that standard deviations at the test site were lower.

While increases of standard deviations occurred at the upstream location, reductions happened at the end of OSBs and downstream location during “before”, “after”, and “long after” periods. Increases at the upstream location were not significant at the 95 % confidence level during the “after” period, except for vehicles of more than two axles, and during nighttimes and weekends. However, reductions were statistically significant at the downstream location. During the “long after” period, increases at the upstream location and decreases at the end of OSBs and downstream location were statistically significant.

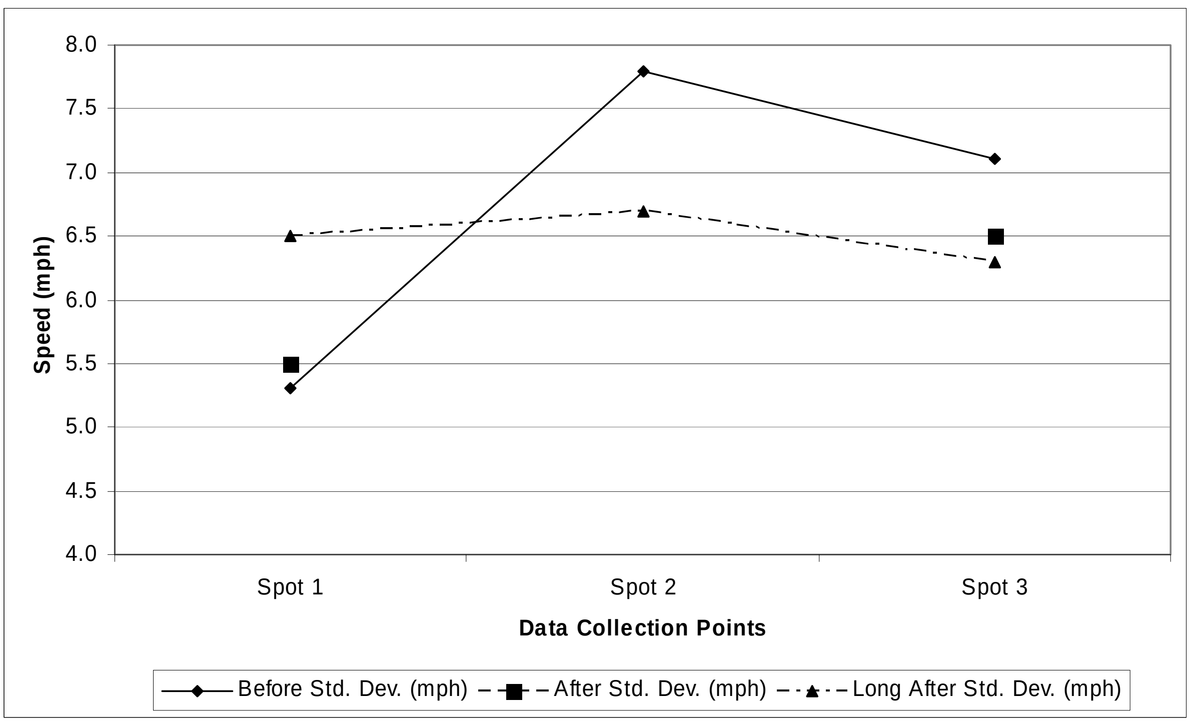


Figure 4.6 Standard Deviations at Rossville Test Site

Table 4.4 Results of F-Test of Variance at Rossville Test Site

Categories	Before		After		Long After		Before vs. After		Before vs. Long After	
	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)	P-value	Statistical Significance	P-value	Statistical Significance
Treatment Direction										
Spot 1 – Way before beginning of OSBs										
All Vehicles	9,404	5.3	9,448	5.5	9,835	6.5	0.2412	No	<0.0001	Yes
2 Axles	8,424	5.3	8,222	5.5	8,588	6.4	0.1285	No	<0.0001	Yes
>2 Axles	976	4.9	1,226	5.2	1,258	6.2	0.0271	Yes	<0.0001	Yes
Daytime	7,529	5.1	5,651	5.3	8,027	5.7	0.3291	No	<0.0001	Yes
Nighttime	1,865	5.7	3,784	5.6	1,678	7.2	<0.0001	Yes	<0.0001	Yes
Weekdays	6,905	5.3	7,152	5.4	7,167	5.5	0.2864	No	<0.0001	Yes
Weekends	2,490	5.2	2,286	5.5	2,296	5.8	0.0061	Yes	<0.0001	Yes
Spot 2 – at the end of OSBs										
All Vehicles	9,575	7.8	NA	NA	9,725	6.7	NA	NA	<0.0001	Yes
2 Axles	8,401	7.9	NA	NA	8,433	6.8	NA	NA	<0.0001	Yes
>2 Axles	1,174	7.0	NA	NA	1,304	6.1	NA	NA	<0.0001	Yes
Daytime	7,179	7.8	NA	NA	8,046	6.7	NA	NA	<0.0001	Yes
Nighttime	2,397	7.9	NA	NA	1,686	6.6	NA	NA	<0.0001	Yes
Weekdays	7,083	7.8	NA	NA	7,190	6.6	NA	NA	<0.0001	Yes
Weekends	2,494	8.0	NA	NA	2,543	7.0	NA	NA	<0.0001	Yes

NA- speed data were lost at the end of OSBs during “after” period.

Table 4.4 Continued

Categories	Before		After		Long After		Before vs. After P-value	Statistical Significance	Before vs. Long After P-value	Statistical Significance
	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)				
Treatment Direction										
Spot 3 – In Town at 500 ft from the end of OSBs										
All Vehicles	9,748	7.1	9,275	6.5	9,552	6.3	<0.0001	Yes	<0.0001	Yes
2 Axles	8,486	7.3	8,082	6.6	8,374	6.4	<0.0001	Yes	<0.0001	Yes
>2 Axles	1,265	6.2	1,192	5.9	1,185	6.2	0.0487	Yes	0.4000	No
Daytime	7,461	7.2	5,571	6.9	7,763	6.3	0.0002	Yes	<0.0001	Yes
Nighttime	2,290	6.9	3,715	5.9	1,798	6.1	<0.0001	Yes	<0.0001	Yes
Weekdays	7,250	7	7,061	6.5	7,023	6.3	<0.0001	Yes	<0.0001	Yes
Weekends	2,489	7.4	2,214	6.7	2,552	6.6	<0.0001	Yes	<0.0001	Yes
Opposite Direction										
Spot 1- at the beginning of the OSBs										
All Vehicles	8,247	5.3	8,196	5	8,291	4.8	<0.0001	Yes	<0.0001	Yes
Spot 2 – at end of OSBs										
All Vehicles	8,643	5.7	NA	NA	8,218	6.3	NA	NA	<0.0001	Yes
Spot 3 – at 500 ft downstream the OSBs										
All Vehicles	8,568	6.1	8,205	6.1	8,154	6.8	0.4785	No	<0.0001	Yes

NA – speed data were lost at the end of OSBs during “after” period

At the Silver Lake test site, standard deviations increased from the upstream location to the end of OSBs, then decreased to the downstream location during the "before" period. During the "after" period, standard deviations decreased from the upstream location to the end of OSBs, then increased at the downstream location. Standard deviations were found the same at the upstream location as at the end of OSBs, but they decreased from the end of OSBs to the downstream location.

At the upstream location, as shown in Figure 4.7, standard deviations increased between periods, but the highest increase occurred during the "after" period. At the end of OSBs, reductions of standard deviations occurred, with the highest reductions seen during the "after" period. At the downstream location, reductions of standard deviations occurred during "long after" period, but increases happened during the "after" period. Differences in standard deviations were statistically significant at the 95 % confidence level, as the p-values in Table 4.5 were less than the significance level of 5 %. Exceptions were at the downstream location for weekend standard deviations during the "after" period and for both weekend and weekday standard deviations during the "long after" period.

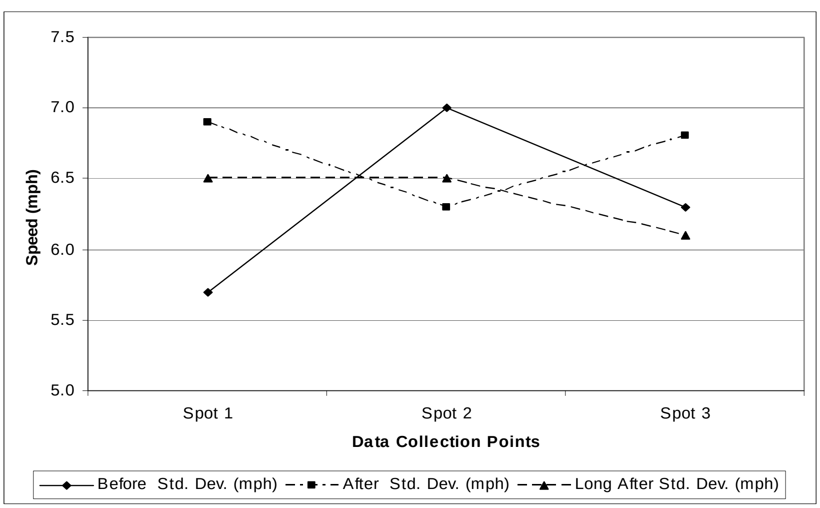


Figure 4.7 Standard Deviations at Silver Lake Test Site

Table 4.5 Results of F-Test of Variance at Silver Lake Test Site

Category	Before		After		Long After		Before vs. After P-value	Statistical Significance	Before vs. Long After P-value	Statistical Significance
	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)				
Spot 1- at the beginning of OSBs										
All Vehicles	10,269	5.7	6,888	6.9	7,838	6.5	<0.0001	Yes	<0.0001	Yes
2 Axles	9,076	5.7	6,141	7.0	6,778	6.4	<0.0001	Yes	<0.0001	Yes
>2 Axles	1,193	5.3	756	5.8	1,046	6.0	0.0014	Yes	<0.0001	Yes
Daytime	7,618	5.6	5,275	6.8	5,791	6.5	<0.0001	Yes	<0.0001	Yes
Nighttime	2,646	5.9	1,620	7.2	2,061	6.7	<0.0001	Yes	<0.0001	Yes
Weekdays	7,560	5.7	4,076	7.2	6,470	6.4	<0.0001	Yes	<0.0001	Yes
Weekends	2,709	5.8	2,819	6.4	1,384	6.4	<0.0001	Yes	0.0100	Yes
Spot 2 – at the end of OSBs										Yes
All Vehicles	10,202	7.0	6,772	6.3	7,668	6.5	<0.0001	Yes	<0.0001	Yes
2 Axles	8,980	7.1	6,077	6.3	6,668	6.5	<0.0001	Yes	<0.0001	Yes
>2 Axles	1,221	6.3	690	5.5	999	6.5	<0.0001	Yes	0.3487	Yes
Daytime	8,368	7.0	5,209	6.3	6,490	6.5	<0.0001	Yes	<0.0001	Yes
Nighttime	1,834	7.2	1,560	6.2	1,181	6.4	<0.0001	Yes	<0.0001	Yes
Weekdays	7,497	7.1	3,970	6.3	7,215	6.5	<0.0001	Yes	<0.0001	Yes
Weekends	2,704	7.0	2,798	6.1	452	6.6	<0.0001	Yes	0.101	Yes
Spot 3 at 500 ft after the end of OSBs										
All Vehicles	10,330	6.3	6,646	6.8	7,852	6.1	<0.0001	Yes	0.0046	Yes
2 Axles	9,108	6.3	5,959	6.9	6,827	6.2	<0.0001	Yes	0.0622	No
>2 Axles	1,211	5.8	682	5.5	1,035	5.7	0.0810	Yes	0.3819	No
Daytime	7,619	6.2	5,072	6.6	6,439	6.1	<0.0001	Yes	0.2543	No
Nighttime	2,697	6.2	1,558	7.0	1,415	5.9	<0.0001	Yes	0.0041	Yes
Weekdays	7,609	6.2	3,849	7.1	5,949	6.3	<0.0001	Yes	0.0868	No
Weekends	2,703	6.1	2,793	6.3	1,946	6.1	0.0665	No	0.3600	No

Table 4.4 Continued

Category	Before		After		Long After		Before vs. After P-value	Statistical Significance	Before vs. Long After P-value	Statistical Significance
	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)	Sample Size	Std. Dev. (mph)				
Opposite Direction										
Spot 1- at the beginning of OSBs										
All Vehicles	9,929	6.2	9,534	7.4	7,626	5.4	<0.0001	Yes	<0.0001	Yes
Spot 2 – at end of OSBs										
All Vehicles	8,262	5.8	6,544	6.2	7,475	6.5	<0.0001	Yes	<0.0001	Yes
Spot 3 – at 500 ft downstream from OSBs										
All Vehicles	9,390	6.0	6,109	5.3	7,389	6.6	<0.0001	Yes	<0.0001	Yes

4.4 Speed Variation Analysis Summary and Discussion

Speed variations (standard deviations) analyzed at test sites indicated as vehicles slowed down along test sections toward towns, speed variations changed. Standard deviations were found to have increased from upstream locations to ends of OSBs, then reduced to downstream locations at all test sites during the “before” period. Standard deviations at upstream and downstream locations were lower than those at ends of OSBs in most cases.

These changes in speed variations were not as consistent at all test sites during the “after” period as they were during the “before” period, with the exception of the Rossville and Meriden east side test sites. At the Belvue test site, standard deviations were found higher at upstream locations and reduced at ends of OSBs, and continued reducing at downstream locations. Standard deviations reduced from upstream locations to the end of OSBs, then increased at downstream locations. At the Meriden west side test, a slight increase in standard deviation were seen from the upstream location to the end of OSBs, then reduced to the first downstream location and increased to the next downstream location.

When examining speed variations between periods, standard deviations were found lower during the “after” period particularly at the end of OSBs where consistent decreases of speed variations occurred. Practically, speed variations decreased at data collection points at which mean and 85th percentile speeds decreased and increased where mean and 85th percentile speeds increased.

4.5 Analysis of Mean and 85th Percentile Speeds

Statistical analysis was performed on speed data collected at test sites to determine effects of OSBs in reducing approach speeds to rural communities, and to see whether changes were statistically significant. The two-sample t-test was used to examine significant differences in means between datasets.

As shown in Figure 4.8, mean and 85th percentile speeds at the Meriden west side test site decreased from the beginning of OSBs to downstream locations during both “before” and “after” periods. The highest decrease occurred between the end of OSBs and the downstream location, which is indicated by the slope of the speed plots. Reductions of mean and 85th percentile speeds were observed during the “after” period for all categories and at all data collection points. Table 4.6 presents mean and 85th percentile speeds as well as results of the t-test, which showed that reductions in mean speeds were statistically significant at the 95 % confidence level. The p-values determined were all less than 5 % significance level. In the opposite direction, mean and 85th percentile speeds increased, and the mean speed increases were found statistically significant at the 95th percentile confidence level.

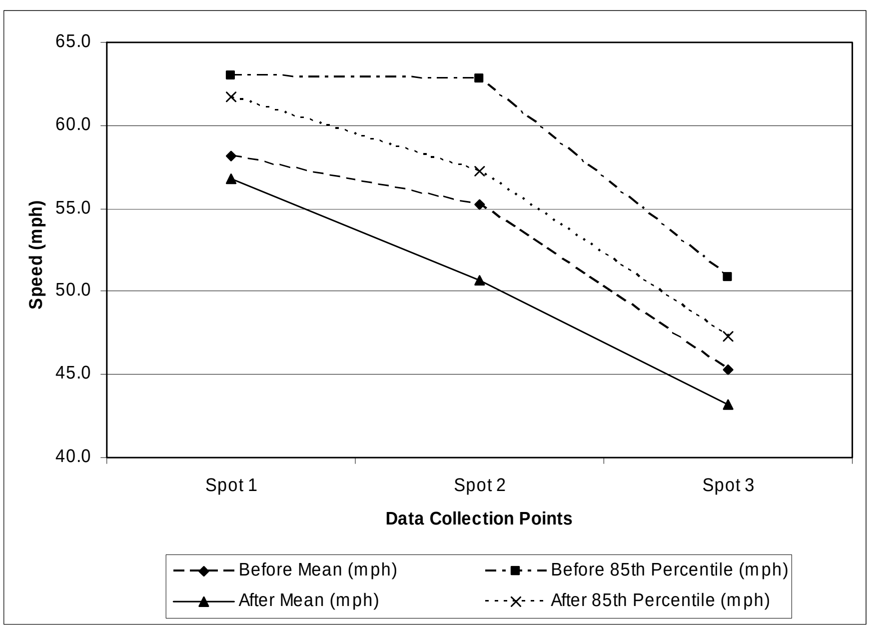


Figure 4.8 Mean and 85th Percentile Speeds for All Vehicles at Meriden West Side Test Site

Table 4.6 Speed Statistics at Meriden East Side Test Site

Categories	Before			After			Before vs. After P-value	Statistical Significance
	Sample Size	Mean (mph)	85th Percentile (mph)	Sample Size	Mean (mph)	85th Percentile (mph)		
Treatment Direction								
Spot 1- at the beginning of OSBs								
All Vehicles	4,732	58.2	63.0	5,944	56.8	61.7	<0.0001	Yes
2 Axles	4,369	58.2	63.0	5,360	56.7	61.6	<0.0001	Yes
>2 Axles	365	57.8	62.3	581	57	61.5	0.0011	Yes
Daytime	3,755	58.3	63.0	4,023	57	61.9	<0.0001	Yes
Nighttime	973	57.7	63.7	1,975	56	61.0	<0.0001	Yes
Spot 2 – at end of OSBs								
All Vehicles	2,637	55.2	62.8	6,037	50.7	57.2	<0.0001	Yes
2 Axles	2,447	55	62.5	5,457	50.5	56.8	<0.0001	Yes
>2 Axles	190	57.2	64.2	582	52.3	59.4	<0.0001	Yes
Daytime	1,753	55.6	63.0	4,060	50.9	57.7	<0.0001	Yes
Nighttime	885	54.4	62.2	1,969	50.1	56.2	<0.0001	Yes
Spot 3 – at 500 ft downstream from OSBs								
All Vehicles	2,396	45.3	50.9	5,661	43.2	47.3	<0.0001	Yes
2 Axles	2,212	45.2	50.7	5,159	43.1	46.9	<0.0001	Yes
>2 Axles	188	47.3	53.7	580	45.7	51.8	0.0012	Yes
Daytime	1,618	45.8	51.3	3,976	43.6	48.3	<0.0001	Yes
Nighttime	866	46.1	52.8	1,880	43.4	47.0	<0.0001	Yes
Opposite Direction								
Spot 1- at the beginning of the OSBs								
All Vehicles	8,733	63.9	69.5	5,557	64.1	69.7	0.029	Yes
Spot 2 – at end of OSBs								
All Vehicles	8,839	58.3	64.5	5,823	59.2	65.5	<0.0001	Yes
Spot 3 – at 500 ft downstream from OSBs								
All Vehicles	2,243	56.8	63.2	5,619	57.7	64.6	<0.0001	Yes

Figure 4.9 shows mean and 85th percentile speeds for all vehicles at the Meriden west side test site for four data collection points. Throughout the test section, mean and 85th percentile speeds reduced from the beginning of OSBs to the first downstream location (spot 3), an indication of drivers slowing down as they approached the town of Meriden. Mean and 85th percentile speeds then picked up at the next downstream location (spot 4), especially during the "after" period.

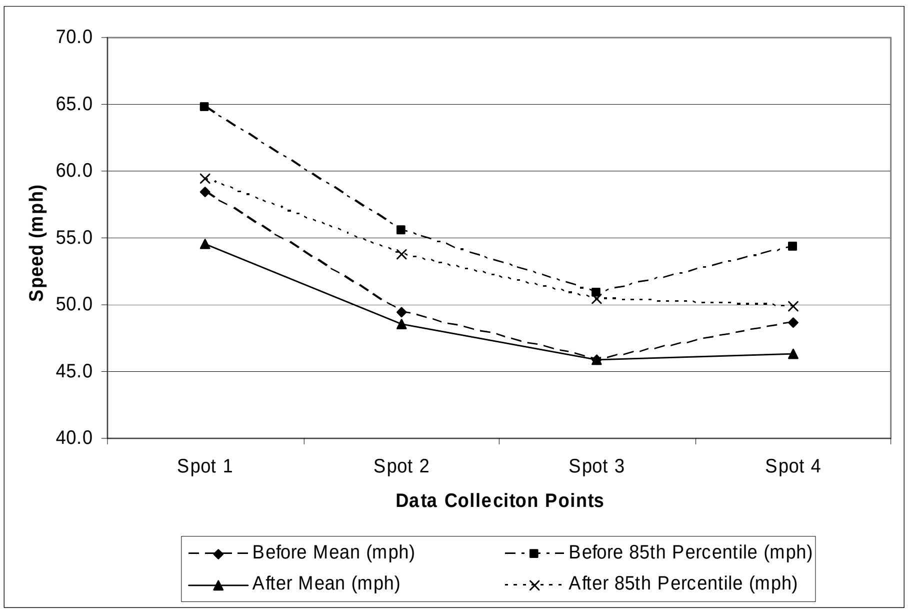


Figure 4.9 Mean and 85th Percentile Speeds for All Vehicles at Meriden West Side Test Site

At the Meriden west side test site, as presented in Table 4.7, reductions of mean and 85th percentile speeds between "before" and "after" periods were observed for all categories and at all four data collection points. Mean reductions were statistically significant at the 95 % confidence level. Exceptions were at the downstream location (spot 3) for all vehicles and during weekend speeds. Reductions in mean and 85th percentile speeds occurred in the opposite direction as well, with mean reductions being statistically significant at the 95 % confidence level.

Table 4.7 Speed Statistics at Meriden West Side Test Site

Category	Before			After			Before vs. After P-value	Statistical Significance
	Sample Size	Mean (mph)	85th Percentile(mph)	Sample Size	Mean (mph)	85th Percentile(mph)		
Treatment Direction								
Spot 1- at the beginning of OSBs								
All Vehicles	14,920	58.5	64.8	6,221	54.6	59.5	<0.0001	Yes
2 Axles	13,644	58.0	63.8	5,694	54.6	59.5	<0.0001	Yes
>2 Axles	1,276	58.3	63.4	529	55.2	59.8	<0.0001	Yes
Daytime	11,357	58.6	64.0	4,155	54.7	59.8	<0.0001	Yes
Nighttime	3,563	56.3	62.7	2,066	54.4	59.5	<0.0001	Yes
Weekdays	10,794	57.8	63.5	5,291	54.6	59.5	<0.0001	Yes
Weekends	4,126	58.6	64.5	930	54.5	59.5	<0.0001	Yes
Spot 2 – at end of OSBs								
All Vehicles	14,991	49.5	55.6	6,226	48.6	53.8	<0.0001	Yes
2 Axles	13,646	49.3	55.2	5,725	48.8	53.5	<0.0001	Yes
>2 Axles	1,201	50.4	56.5	518	51.0	56.8	0.0385	Yes
Daytime	11,400	49.9	56.0	4,300	48.7	54.0	<0.0001	Yes
Nighttime	3,492	47.8	53.4	1,894	47.9	52.8	0.4756	No
Weekdays	10,764	49.4	55.4	5,235	48.6	53.8	<0.0001	Yes
Weekends	4,068	49.1	55.2	991	48.5	53.9	0.0025	Yes
Spot 3 – at 250 ft downstream from OSBs								
All Vehicles	14,474	45.9	50.9	3,424	45.9	50.4	0.7823	No
2 Axles	13,464	46.1	51.3	3,091	45.5	49.6	<0.0001	Yes
>2 Axles	1,280	47.3	52.7	264	48.2	54.0	0.0187	Yes
Daytime	11,187	46.6	51.9	2,096	46.0	50.4	<0.0001	Yes
Nighttime	3,511	44.7	49.2	1,281	45.4	49.3	<0.0001	Yes
Weekdays	10,647	46.2	51.2	2,596	45.8	50.2	0.0006	Yes
Weekends	4,093	46.2	51.6	828	46.1	50.6	0.5528	No

Table 4.7 Continued

Category	Before			After			Before vs. After P-value	Statistical Significant
	Sample Size	Mean (mph)	85th Percentile (mph)	Sample Size	Mean (mph)	85^{th} Percentile (mph)		
Treatment Direction								
Spot 4 – at 550 ft from end of OSBs								
All Vehicles	14,296	48.7	54.3	8,961	46.3	49.9	<0.0001	Yes
2 Axles	13,172	48.6	54.3	8,399	46.3	49.7	<0.0001	Yes
>2 Axles	1,124	49.8	56.3	569	47.5	51.8	<0.0001	Yes
Daytime	10,947	49.0	54.9	5,442	46.4	51.0	<0.0001	Yes
Nighttime	3,349	47.8	52.8	3,519	46.2	49.5	<0.0001	Yes
Weekdays	10,263	48.6	52.5	5,295	46.2	49.5	<0.0001	Yes
Weekends	4,033	48.8	54.3	3,815	46.8	50.8	<0.0001	Yes
Opposite Direction								
Spot 1- at the beginning of OSBs								
All Vehicles	8,138	60.4	65.3	7,283	60.3	65.4	0.0602	Yes
Spot 2 – at end of OSBs								
All Vehicles	8,436	52.5	57.3	7,596	52.2	56.8	0.0002	Yes
Spot 3 – at 250 ft downstream from OSBs								
All Vehicles	8,307	53.0	58.0	4,253	52.8	57.7	0.0035	Yes
Spot 3 – at 500 ft downstream from OSBs								
All Vehicles	16,964	47.3	52.2	10,026	47.9	52.5	<0.0001	Yes

At the Belvue test site, plots of Figure 4.10 show mean and 85th percentile speeds reduced throughout the test section as drivers approached Belvue. These reductions in mean and 85th percentile speeds were the highest between the upstream location and the end of OSBs. It can also be noted there were no apparent changes in mean and 85th percentile speeds at the end of OSBs (spot 2), and the p-values in Table 4.8 back that fact. No significant change in mean speed occurred at the end of OSBs, even though significant increases in mean speeds happened at upstream and downstream locations and in the opposite direction.

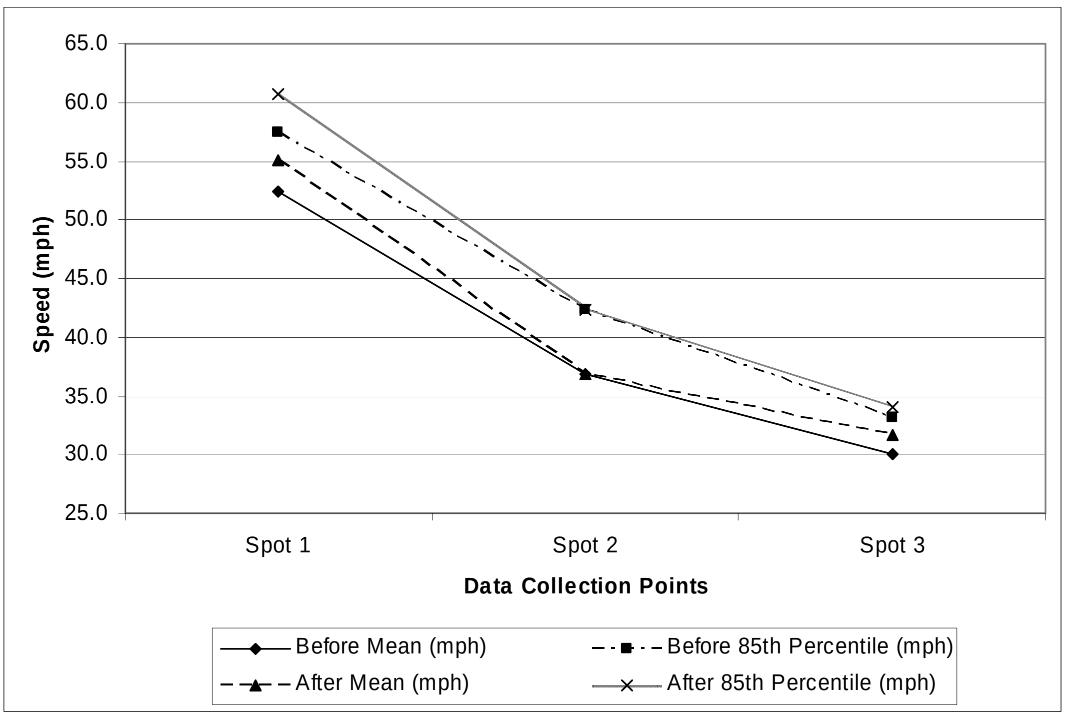


Figure 4.10 Mean and 85th Percentile Speeds for All Vehicles at the Belvue Test Site

Table 4.8 Mean an 85th Percentile Speed Statistics at Belvue Test Site

Categories	Before			After			Before vs. After P-value	Statistical Significant
	Sample Size	Mean (mph)	85th Percentile (mph)	Sample Size	Mean (mph)	85th Percentile (mph)		
Treatment Direction								
Spot 1 – before beginning of OSBs								
All Vehicles	2,685	52.4	57.4	4,729	55.1	60.7	<0.0001	Yes
2 Axles	2,362	52.6	57.6	4,042	55.4	61.0	<0.0001	Yes
>2 Axles	327	50.1	54.8	691	53.0	58.6	0.0236	Yes
Daytime	2,057	52.6	57.5	3,334	55.2	60.6	0.0002	Yes
Nighttime	633	51.5	56.3	1,395	54.9	61.0	<0.0001	Yes
Spot 2 – at end of OSBs								
All Vehicles	2,078	36.9	42.3	4,792	36.9	42.4	0.0670	No
2 Axles	1,955	36.9	42.3	4,070	37.0	42.6	0.0199	Yes
>2 Axles	121	36.9	42.5	723	36.3	41.4	0.3383	No
Daytime	1,531	37.5	43.1	3,419	37.1	42.6	0.0548	No
Nighttime	546	35.3	40.2	1,372	36.3	41.5	0.0220	Yes
All Vehicles	1,851	30.1	33.2	4,604	31.7	34.1	<0.0001	Yes
2 Axles	1,754	30.0	33.2	3,943	31.6	35.2	<0.0001	Yes
>2 Axles	101	30.8	34.3	646	32.1	35.9	0.0141	Yes
Daytime	1,505	30.7	34.2	3,359	32.0	35.5	0.3222	No
Nighttime	418	29.1	32.0	1,305	31.3	34.4	0.1747	No
Opposite Direction								
Spot 1- at beginning of OSBs								
All Vehicles	5,983	57.6	63.4	4,447	59.3	64.6	<0.0001	Yes
Spot 2 – at end of OSBs								
All Vehicles	5,265	38.1	43.8	4,413	39.3	43.5	<0.0001	Yes
Spot 3 – at approximately 500 ft downstream from OSB treatment								
All Vehicles	1,845	31.7	34.8	4,286	32.5	35.8	0.4391	No

Mean and 85th percentile speed plots in Figure 4.11 indicate at the Rossville test site drivers reduced their speeds as they approached Rossville. Speed reductions were higher between the upstream location and the end of the OSBs during the "long after" period, while higher reductions occurred between the end of OSBs and the downstream location during the "before" period.

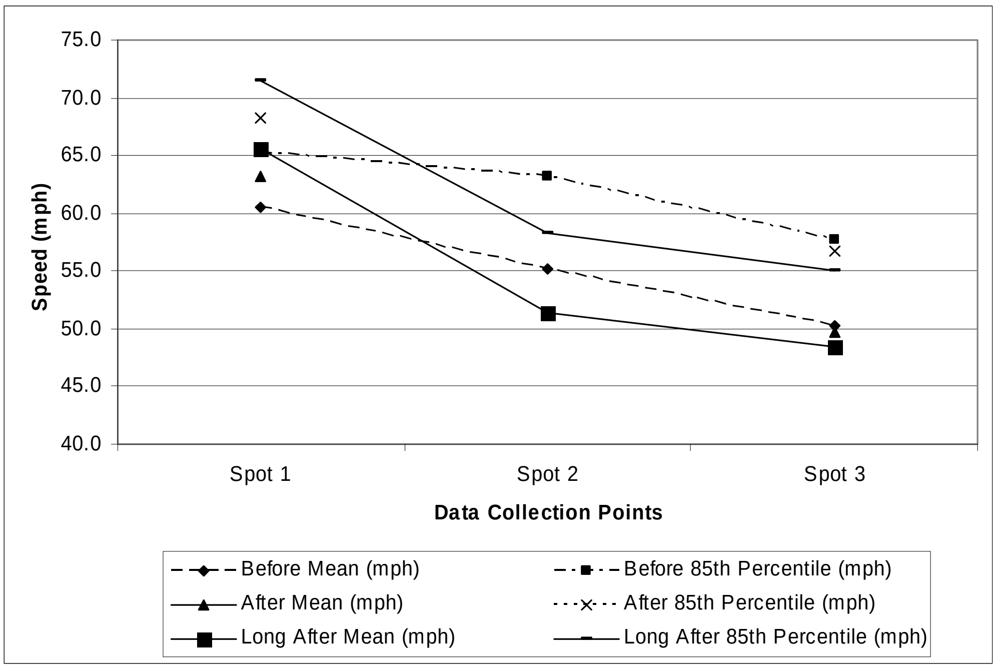


Figure 4.11 Mean and 85th Percentile Speeds for All Vehicles at Rossville Test Site

Mean and 85th percentile speeds increased at upstream locations during both "after" and "long after" periods. The p-values in Table 4.9 indicate significant increases in mean speeds at the upstream location. At the end of OSBs and at the downstream location, mean and 85th percentile speeds decreased during both "after" and "long after" periods. Decreases in mean speeds were statistically significant at the 95 % confidence level.

Table 4.9 Mean and 85th Percentile Speed Statistics at Rossville Test Site

Categories	Before			After			Long After			Before vs. Long After P-value	Statistical Significance	Before vs. After P-value	Statistical Significance
	Sample Size	Mean (mph)	85th (mph)	Sample Size	Mean (mph)	85th (mph)	Sample Size	Mean (mph)	85th (mph)				
Treatment Direction													
Spot 1 – before beginning of OSBs													
All Vehicles	9,404	60.5	65.3	9,448	63.2	68.3	9,835	65.6	71.5	<0.0001	Yes	<0.0001	Yes
2 Axles	8,424	60.7	66.5	8,222	63.4	68.3	8,588	66.0	71.9	<0.0001	Yes	<0.0001	Yes
>2 Axles	976	58.9	63.4	1,226	61.7	66.3	1,258	63.4	69.0	<0.0001	Yes	<0.0001	Yes
Daytime	7,529	60.7	65.4	5,651	63.5	68.0	8,027	66.1	71.5	<0.0001	Yes	<0.0001	Yes
Nighttime	1,865	59.8	65.0	3,784	62.7	68.0	1,678	64.7	71.5	<0.0001	Yes	<0.0001	Yes
Weekdays	6,905	60.4	65.3	7,152	63.0	67.9	7,167	63.5	69.2	<0.0001	Yes	<0.0001	Yes
Weekends	2,490	60.7	65.5	2,286	63.7	68.5	2,296	64.2	70.2	<0.0001	Yes	<0.0001	Yes
Spot 2 – at end of OSBs													
All Vehicles	9,575	55.2	63.2	NA	NA	NA	9,725	51.4	58.3	NA	NA	<0.0001	Yes
2 Axles	8,401	55.2	63.2	NA	NA	NA	8,433	51.5	58.5	NA	NA	<0.0001	Yes
>2 Axles	1,174	55.0	62.0	NA	NA	NA	1,304	50.5	56.6	NA	NA	<0.0001	Yes
Daytime	7,179	55.7	64.0	NA	NA	NA	8,046	51.7	58.6	NA	NA	<0.0001	Yes
Nighttime	2,397	53.7	61.5	NA	NA	NA	1,686	49.5	56.5	NA	NA	<0.0001	Yes
Weekdays	7,083	55.1	63.0	NA	NA	NA	7,190	51.1	58.0	NA	NA	<0.0001	Yes
Weekends	2,494	55.4	64.1	NA	NA	NA	2,543	52.0	59.2	NA	NA	<0.0001	Yes

NA – speed data were lost at end of OSBs during “after” period.

Table 4.9 Continued

Categories	Before			After			Long After			Before vs. After P-value	Statistical Significance	Before vs. After P-value	Statistical Significance
	Sample Size	Sample Size	85th (mph)	Sample Size	Mean (mph)	85th (mph)	Sample Size	Mean (mph)	85th (mph)				
Treatment Direction													
Spot 3 – at 500 ft from the end of OSB													
All Vehicles	9,748	50.2	57.7	9,275	49.7	56.7	9,552	48.4	55.0	<0.0001	Yes	<0.0001	Yes
2 Axles	8,486	50.3	58.0	8,082	49.7	56.8	8,374	48.4	55.0	<0.0001	Yes	<0.0001	Yes
>2 Axles	1,265	49.7	56.2	1,192	49.7	55.7	1,185	48.5	54.8	0.9746	Yes	<0.0001	Yes
Daytime	7,461	50.7	58.0	5,571	50.8	58.0	7,763	48.9	55.5	1.960157	Yes	<0.0001	Yes
Nighttime	2,290	48.7	55.6	3,715	48.1	54.0	1,798	46.3	52.4	0.0007	Yes	<0.0001	Yes
Weekdays	7,250	50.1	57.5	7,061	49.8	56.6	7,023	48.4	55.0	0.0021	Yes	<0.0001	Yes
Weekends	2,489	50.5	58.2	2,214	49.5	56.7	2,552	48.4	55.2	<0.0001	Yes	<0.0001	Yes
Opposite Direction													
Spot 1- at beginning of OSBs													
All Vehicles	8,247	61.6	66.5	8,196	63.1	67.5	8,291	63.9	68	<0.0001	Yes	<0.0001	Yes
Spot 2 – at end of OSBs													
All Vehicles	8,643	55.0	60.4	NA	NA	NA	8,218	58.3	64.4	NA	NA	<0.0001	Yes
Spot 3 – at 500 ft downstream from OSBs													
All Vehicles	8,568	52.7	58.5	8,205	55.4	61.4	8,154	57.0	63.5	<0.0001	Yes	<0.0001	Yes

At the Silver Lake test site, Figure 4.12 shows drivers reduced their speeds as they approached Silver Lake, with higher decreases in speed occurring between the upstream location and the end of OSBs.

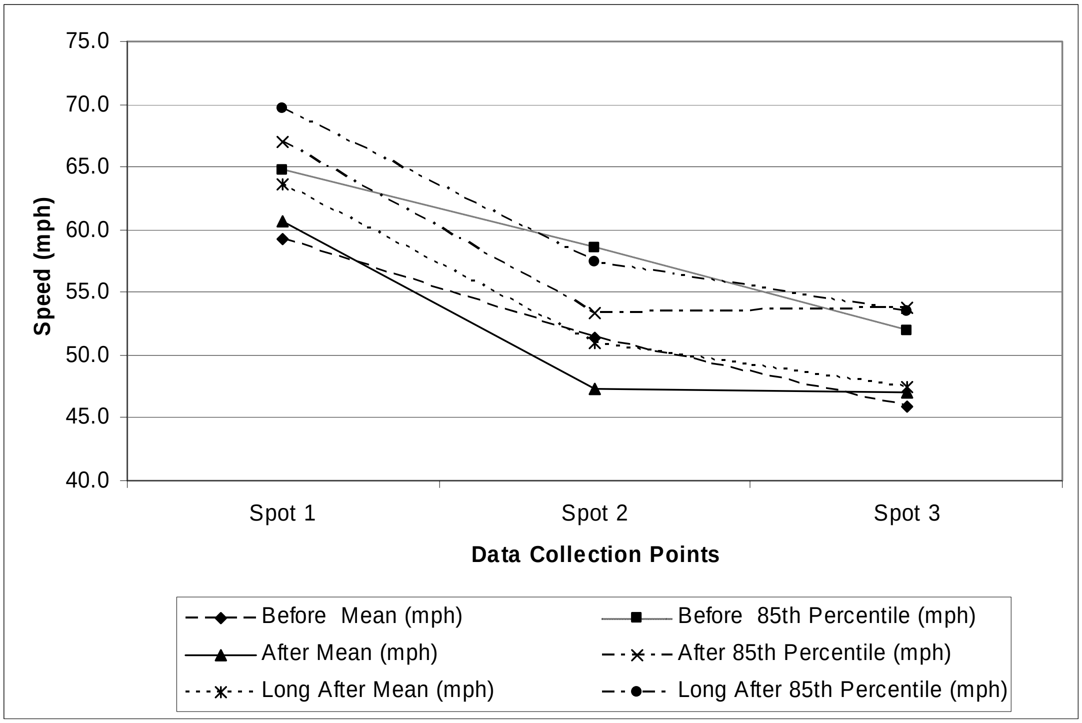


Figure 4.12 Mean and 85th Percentile Speeds for All Vehicles at Silver Lake Test Site

Speed statistics presented in Table 4.10 show mean and 85th percentile speeds increased both at the beginning of OSBs and at the downstream location during both “after” and “long after” periods. Mean speed increases were statistically significant at the 95 % confidence level. At the end of OSBs, reductions in mean and 85th percentile speeds occurred during both “after” and “long after” periods. Mean reductions were found statistically significant at the 95 % confidence level. Reductions obtained during the “after” period were higher than those during the “long after” period.

Table 4.10 Mean and 85th Percentile Speeds for All Vehicles at Silver Lake Test Site

Categories	Before			After			Long After			Before vs. After P-value	Statistical Significance	Before vs. Long After P-value	Statistical Significance
	Sample Size	Mean (mph)	85th (mph)	Sample Size	Mean (mph)	85th (mph)	Sample Size	Mean (mph)	85th (mph)				
Treatment Direction													
Spot 1- at beginning of OSBs													
All Vehicles	10,269	59.3	64.8	6,888	60.7	67.0	7,838	63.6	69.7	<0.0001	Yes	<0.0001	Yes
2 Axles	9,076	59.6	65.0	6,141	61.0	67.5	6,778	64.1	70.3	<0.0001	Yes	<0.0001	Yes
>2 Axles	1,193	57.3	62.4	756	58.1	63.6	1,046	60.7	66.5	0.000924	Yes	<0.0001	Yes
Daytime	7,618	59.1	65.0	5,275	60.9	67.3	5,791	63.5	69.7	<0.0001	Yes	<0.0001	Yes
Nighttime	2,646	58.4	64.3	1,620	59.9	66.7	2,061	63.9	70.3	<0.0001	Yes	<0.0001	Yes
Weekdays	7,560	59.2	64.7	4,076	59.9	66.6	6,470	63.7	69.7	<0.0001	Yes	<0.0001	Yes
Weekends	2,709	59.5	65.1	2,819	61.8	67.8	1,384	63.7	70.5	<0.0001	Yes	<0.0001	Yes
Spot 2 – at end of OSB													
All Vehicles	10,202	51.4	58.5	6,772	47.3	53.3	7,668	51.0	57.5	<0.0001	Yes	0.0002	Yes
2 Axles	8,980	51.6	58.8	6,077	47.5	53.5	6,668	51.3	57.7	<0.0001	Yes	0.0033	Yes
>2 Axles	1,221	49.7	56.3	690	46.4	51.5	999	49.1	55.2	<0.0001	Yes	0.0104	Yes
Daytime	8,368	51.7	58.9	5,209	47.6	53.6	6,490	51.1	57.6	<0.0001	Yes	<0.0001	Yes
Nighttime	1,834	50.2	57.2	1,560	46.5	52.5	1,181	50.5	57.0	<0.0001	Yes	0.2197	Yes
Weekdays	7,497	51.5	58.6	3,970	46.8	53.2	7,215	51.1	57.6	<0.0001	Yes	<0.0001	Yes
Weekends	2,704	51.0	58.2	2,798	48.0	53.8	452	50.0	57.4	<0.0001	Yes	0.0024	Yes

Table 4.10 Continued

Categories	Before			After			Long After			Before vs. After P-value	Statistical Significance	Before vs. Long After P-value	Statistical Significance
	Sample Size	Mean (mph)	85th (mph)	Sample Size	Mean (mph)	85th (mph)	Sample Size	Mean (mph)	85th (mph)				
Treatment Direction													
Spot 3 at 500 ft after end of OSBs													
All Vehicles	10,330	45.9	52.0	6,646	47.0	53.8	7,852	47.4	53.5	<0.0001	Yes	<0.0001	Yes
2 Axles	9,108	46.1	52.3	5,959	47.2	54.0	6,827	47.6	53.8	<0.0001	Yes	<0.0001	Yes
>2 Axles	1,211	44.5	50.4	682	45.3	50.3	1,035	45.7	51.4	0.0038	Yes	<0.0001	Yes
Daytime	7,619	46.1	52.4	5,072	47.5	53.8	6,439	47.6	53.6	<0.0001	Yes	<0.0001	Yes
Nighttime	2,697	45.1	51.3	1,558	45.5	52.3	1,415	46.4	52.5	0.0518	Yes	<0.0001	Yes
Weekdays	7,609	45.9	52.3	3,849	46.8	53.7	5,949	47.4	53.6	<0.0001	Yes	<0.0001	Yes
Weekends	2,703	45.8	52.0	2,793	47.2	53.5	1,946	47.3	53.4	<0.0001	Yes	<0.0001	Yes
Spot 1- at beginning of OSBs													
All Vehicles	9,929	59.7	65.2	9,534	61.5	69.0	7,626	62.0	66.7	<0.0001	Yes	<0.0001	Yes
Spot 2 – at end of OSBs													
All Vehicles	8,262	53.9	59.2	6,544	56.4	62.3	7,475	58.7	65.0	<0.0001	Yes	<0.0001	Yes
Spot 3 – at 500 ft downstream from OSBs													
All Vehicles	9,390	54.7	60.4	6,109	55.9	59.7	7,389	58.2	64.5	<0.0001	Yes	<0.0001	Yes

4.6 Mean and 85th Percentile Speed Summary and Discussion

In analyzing speed data for all five sites in the variable of mean and 85^{th} percentile speeds, and according to categories such as all vehicles, vehicle classification, time of day, and days of week, the following points can be made: drivers slowed down on approaches to towns but did not do so enough to comply with posted speed limits at the sites.

At upstream locations (spot 1), 85^{th} percentile speeds commonly used to set the posted speed limit were lower or near the speed limit at that location. At both locations in Meriden, the 85^{th} percentile speeds taken at the warning sign of 45 mph (posted speed limit of 65 mph), and also at the beginning of OSB treatment, were found to be less than the speed limit, indicating either drivers were not speeding at upstream location (spot 1), or they started slowing down upstream from that spot. At the Rossville and Silver Lake test sites where the upstream location (spot 1) was at a warning sign of 45 mph (posted speed limit of 65 mph), the 85^{th} percentile speeds were higher. At the Belvue test site where the upstream location (spot 1) was at the speed limit sign of 55 mph, the 85^{th} percentile speeds, both the "before" and "after" the treatment were less than the speed limit of 65 mph at the upstream location (spot 1). Thus, as vehicle speeds were less or near the speed limit at the upstream location (spot 1), drivers were slowing down.

However, at ends of OSBs (spot 2), the 85^{th} percentile speeds were higher than the speed limit at all sites and during all periods of data collection. At Meriden, Silver Lake, and Rossville, the posted speed limit at ends of OSBs was 45 mph and was 30 mph at Belvue. "Before" 85^{th} percentile speeds at ends of OSBs (spot 2) and at downstream locations (spot 3), as shown in Table 4.11 and Table 4.12, were higher than the posted speed limits at different sites. Even though driver speeds at end of OSBs (spot 2) dropped compared to speeds at upstream location (spot 1), the drops were not enough to comply with posted speed limits. At downstream locations (spot 3), the 85th percentile speeds were also higher than the speed limit at all test sites and during all periods of data collection. At the further downstream location (spot 4) at the Meriden west side test site, speeds were higher than speed limits both before and after the treatment.

Tables 4.11 and 4.12 also present percent reduction of mean and 85th percentile speeds at data collection points for all vehicles. At ends of OSBs (spot 2) reductions were observed except for Belvue, with highest reduction of 85th percentile at Meriden east side (after) and Silver Lake (long after) of 8.9 %.

Table 4.11 Percent Reductions in Mean and 85th Percentile Speeds for All Vehicles at All Sites between "Before" and "After"

Treatment Direction	Before		After		Mean Speeds Percent Reduction	85th Percentile Speed Percent Reduction
	Mean (mph)	85th Percentile (mph)	Mean (mph)	85th Percentile (mph)		
Meriden East Side						
Upstream	58.2	63.0	56.8	61.7	2.4%	2.1%
End of OSBs	55.2	62.8	50.7	57.2	8.2%	8.9%
Downstream	45.3	50.9	43.2	47.3	4.6%	7.1%
Meriden West Side						
Upstream	58.5	64.8	54.6	59.5	6.7%	8.2%
End of OSBs	49.5	55.6	48.6	53.8	1.8%	3.2%
Downstream	45.9	50.9	45.9	50.4	0.0%	1.0%
Further Downstream	48.7	54.3	46.3	49.9	4.9%	8.1%
Belvue						
Upstream	52.4	57.4	55.1	60.7	-5.2%	-5.7%
End of OSBs	36.9	42.3	36.9	42.4	0.0%	-0.2%
Downstream	30.1	33.2	31.7	34.1	-5.3%	-2.7%
Silver Lake						
Upstream	59.3	64.8	60.7	67.0	-2.4%	-3.4%
End of OSBs	51.4	58.5	47.3	53.3	8.0%	8.9%
Downstream	45.9	52.0	47.0	53.8	-2.4%	-3.5%
Rossville						
Upstream	60.5	65.3	63.2	68.3	-4.5%	-4.6%
End of OSBs	55.2	63.2	-	-	-	-
Downstream	50.2	57.7	49.7	56.7	1.0%	1.7%

Table 4.12 Percent Reductions in Mean and 85th Percentile Speeds for All Vehicles at Rossville and Silver Lake between "Before" and " Long After"

Treatment Directions	Before		Long After		Mean Speeds Percent Reduction	85th Percentile Speed Percent Reduction
	Mean (mph)	85th Percentile (mph)	Mean (mph)	85th Percentile (mph)		
Rossville						
Upstream	60.5	65.3	65.6	71.5	-8.4%	-9.5%
End of OSBs	55.2	63.2	51.4	58.3	6.9%	7.8%
Downstream	50.2	57.7	48.4	55.0	3.6%	4.7%
Silver Lake						
Upstream	59.3	64.8	60.7	67.0	-2.4%	-3.4%
End of OSBs	51.4	58.5	47.3	53.3	8.0%	8.9%
Downstream	45.9	52.0	47.0	53.8	-2.4%	-3.5%

Speed Drop comparisons between data collection points, presented in Table 4.13, showed inconsistency whether higher speed drops occurred in the "after" period. Higher speed drops were noted between upstream location and end of OSBs in the after period at four test sites, with lower speed drops at one (Meriden west side). One thing to note is at Belvue, though no significant change in speeds occurred, higher speed drop happened in the "after" period between upstream location and end of OSBs. Another indication of Table 4.13 is the lower speed drops in the "after" period observed downstream the OSBs at all tests.

Table 4.13 Speed Drop Comparison between Data Collection Points "Before" and "After" Periods

Data Collection Point Comparisons	Before		After	
	Mean (mph)	85th Percentile (mph)	Mean (mph)	85th Percentile (mph)
Meriden East Side				
Upstream vs. Ends of OSBs	3.0	0.2	6.1	4.5
End of OSBs vs. Downstream	9.9	11.9	7.5	9.9
Meriden West Side (Before vs. After)				
Upstream vs. Ends of OSBs	9.0	9.2	6.0	5.7
End of OSBs vs. Downstream	3.6	4.7	2.7	3.4
Downstream vs. Further Downstream	-2.8	-3.4	-0.4	0.5
Silver Lake (Before vs. After)				
Upstream vs. Ends of OSBs	7.9	6.3	13.4	13.7
End of OSBs vs. Downstream	5.5	6.5	0.3	-0.5
Silver Lake (Before vs. Long After)				
Upstream vs. Ends of OSBs	7.9	6.3	12.6	12.2
End of OSBs vs. Downstream	5.5	6.5	3.6	4.0
Belvue (Before vs. After)				
Upstream vs. Ends of OSBs	15.5	15.1	18.2	18.3
End of OSBs vs. Downstream	6.8	9.1	5.2	8.3
Rossville (Before vs. Long After)				
Upstream vs. Ends of OSBs	5.3	2.1	14.2	13.2
End of OSBs vs. Downstream	5.0	5.5	3.0	3.3

While mean and 85th percentile speeds for vehicles of more than two axles were found higher than those of two-axle vehicles at the two Meriden test sites, a reverse observation occurred at the other test sites. At end of Treatment no consistency was found concerning which vehicle classification reduced more speeds between "before" and "after" periods. Tables 4.14 and 4.15 show more reductions in speed for two-axle vehicles occurred at Meriden and Silver Lake ("after" period) at ends of OSBs, but the reverse happened at Belvue, Rossville, and Silver Lake ("long after" period).

Mean and 85th percentile speeds during daytime were found to be higher than those during nighttime, and this occurred consistently at all test sites and during all periods of data collection, with only one exception at spot 3 before treatment at the Meriden east side test site. Daytime mean and 85th percentile speeds were found to decrease more at almost all test sites, as presented in Tables 4.14 and 4.15. Few exceptions occurred; nighttime mean at Rossville decreased slightly higher, and nighttime 85th percentile speed at Meriden east side decreased more.

Table 4.14 Percent Changes in Mean and 85th Percentile for Vehicle Classification, Time of the Day, and Days of the Week between "Before" and "After" at Ends of OSBs

Treatment Directions	Before		After		Mean Speeds Percent Reduction	85th Percentile Speed Percent Reduction
	Mean (mph)	85th Percentile (mph)	Mean (mph)	85th Percentile (mph)		
Meriden East Side						
2 Axles	55.0	62.5	50.5	56.8	8.2%	9.1%
>2 Axles	57.2	64.2	52.3	59.4	8.6%	7.5%
Daytime	55.6	63.0	50.9	57.7	8.5%	8.4%
Nighttime	54.4	62.2	50.1	56.2	7.9%	9.6%
Meriden West Side						
2 Axles	49.3	55.2	48.8	53.5	1.0%	3.1%
>2 Axles	50.4	56.5	51.0	56.8	-1.2%	-0.5%
Daytime	49.9	56.0	48.7	54.0	2.4%	3.6%
Nighttime	47.8	53.4	47.9	52.8	-0.2%	1.1%
Weekdays	49.4	55.4	48.6	53.8	1.6%	2.9%
Weekends	49.1	55.2	48.5	53.9	1.2%	2.4%
Belvue						
2 Axles	36.9	42.3	37.0	42.6	-0.3%	-0.7%
>2 Axles	36.9	42.5	36.3	41.4	1.6%	2.6%
Daytime	37.5	43.1	37.1	42.6	1.1%	1.2%
Nighttime	35.3	40.2	36.3	41.5	-2.8%	-3.2%
Silver Lake						
2 Axles	51.6	58.8	47.5	53.5	7.9%	9.0%
>2 Axles	49.7	56.3	46.4	51.5	6.6%	8.5%
Daytime	51.7	58.9	47.6	53.6	7.9%	9.0%
Nighttime	50.2	57.2	46.5	52.5	7.4%	8.2%
Weekdays	51.5	58.6	46.8	53.2	9.1%	9.2%
Weekends	51.0	58.2	48.0	53.8	5.9%	7.6%

No consistent pattern was found for the category of day of the week, even among data collection points within a test site. In some cases, mean and 85th percentile speeds during weekdays were found to be higher than those during weekends and were reversed in other cases. However, weekday speeds reduced more between "before" and "after" periods at ends of treatment, as shown in Tables 4.14 and 4.15.

Table 4.15 Percent Changes in Mean and 85th Percentile for Vehicle Classification, Time of the Day, and Days of the Week between "Before" and "After" at Ends of OSBs

Treatment Directions	Before		Long After		Mean Speeds Percent Reduction	85th Percentile Speed Percent Reduction
	Mean (mph)	85th Percentile (mph)	Mean (mph)	85th Percentile (mph)		
Rossville						
2 Axles	55.2	63.2	51.5	58.5	6.7%	7.4%
>2 Axles	55.0	62.0	50.5	56.6	8.2%	8.7%
Daytime	55.7	64.0	51.7	58.6	7.2%	8.4%
Nighttime	53.7	61.5	49.5	56.5	7.8%	8.1%
Weekdays	55.1	63.0	51.1	58.0	7.3%	7.9%
Weekends	55.4	64.1	52.0	59.2	6.1%	7.6%
Silver Lake						
2 Axles	51.6	58.8	51.3	57.7	0.6%	1.9%
>2 Axles	49.7	56.3	49.1	55.2	1.2%	2.0%
Daytime	51.7	58.9	51.1	57.6	1.2%	2.2%
Nighttime	50.2	57.2	50.5	57.0	-0.6%	0.3%
Weekdays	51.5	58.6	51.1	57.6	0.8%	1.7%
Weekends	51.0	58.2	50.0	57.4	2.0%	1.4%

4.7 Evaluation of Changes in Proportion of Vehicles Exceeding the Posted Speed Limit

The Z-test was used to compare the proportion of vehicles traveling over the posted speed limit between "before" and "after' installation of OSB treatments at the test sites. Three scenarios were considered in the comparison: (1) vehicles traveling over the speed limit, (2) vehicles traveling more than 5 mph above the speed limit, and (3) vehicles traveling more than 10 mph above the speed limit. “Before” and “after” proportions were compared for the test sites in Meriden and Belvue. Table 5.26 presents the percentage of drivers exceeding the speed limit both “before” and “after” OSB treatment and for each scenario, and the Z-test results at the Meriden and Belvue test sites.

All differences in proportions were compared at the 95 % confidence level for statistical significance. Significant reductions of the percentage of vehicles exceeding the speed limit occurred at the end of treatments and downstream locations at the test sites presented in Table 4.11. All differences in proportion were statistically significant at a 95 % confidence level except for some cases. One case was at the downstream location (spot 3) at the Meriden west side test site for the percentage of vehicles above the speed limit. Another case was at the end of OSBs (spot 2) at the Belvue test site for the percentage of vehicles above the speed limit and those exceeding the speed limit by 10 mph. The final case was at the end of OSBs (spot 2) at the Silver Lake test site for the percentage of vehicles above the speed limit and those exceeding the speed limit by 5 mph above “before” and “long after” OSB treatment. At all test sites, except Belvue during “after” and Silver Lake during “long after” treatments, significant reductions of proportion of vehicles exceeding the speed limit occurred at the end of the OSB treatment (also at data collection point of spot 2) for the scenarios considered (over the speed limit, 5 mph over the speed limit, and 10 mph over the speed limit).

Table 4.16 Z-test Statistics and Percentage of Drivers Exceeding Speed Limit at Meriden and Belvue Test Sites

Scenarios	Spots	Percentage of Speeding Vehicles		Z-Statistic	P-Value	Significance
		Before OSB	After OSB			
Meriden East Side						
Above Speed Limit	Spot 2	92.5	77.1	17.07	< 0.0001	Yes
	Spot 3	43.0	27.0	14.1	< 0.0001	Yes
5 mph Above	Spot 2	71.6	45.0	22.83	< 0.0001	Yes
	Spot 3	18.4	6.2	16.81	< 0.0001	Yes
10 mph Above	Spot 2	45.0	22.8	20.86	< 0.0001	yes
	Spot 3	5.0	0.0	16.96	< 0.0001	Yes
Meriden West Side						
Above Speed Limit	Spot 2	72.5	69.8	4.0	< 0.0001	Yes
	Spot 3	48.0	47.5	0.5	0.587	No
	Spot 4	70.0	56.7	20.7	< 0.0001	Yes
5 mph Above	Spot 2	40.7	32.5	11.2	< 0.0001	Yes
	Spot 3	18.9	16.3	3.5	< 0.0001	Yes
	Spot 4	30.5	19.5	18.6	< 0.0001	Yes
10 mph Above	Spot 2	17.5	10.8	12.3	< 0.0001	Yes
	Spot 3	4.0	3.0	2.7	0.006	Yes
	Spot 4	13.5	1.1	32.6	< 0.0001	Yes
Belvue						
Above Speed Limit	Spot 2	88.0	87.5	0.54	0.587	No
	Spot 3	42.8	62.4	-14.31	< 0.0001	Yes
5 mph Above	Spot 2	56.8	57.3	-4.06	< 0.0001	Yes
	Spot 3	6.5	15.5	-9.78	< 0.0001	Yes
10 mph Above	Spot 2	25.0	26.5	-1.28	0.2	No
	Spot 3	0.0	0.8	-3.87	< 0.0001	Yes

Table 4.12 presents the percentage of vehicles exceeding the speed limit at the end of the treatment and at downstream locations for the Silver Lake and Rossville test sites. Comparisons were conducted between “before” and “after” proportions, then between “before” and “long after” proportions. At both Silver Lake and Rossville test sites, reductions of the proportion of vehicles exceeding the speed limit occurred in the “after” period. However, exceptions were noted in the “long after” period at the Silver Lake test site, as no significant change happened at the end of the treatment for the scenario above and 5 mph above the speed limit. Increases in non-compliance occurred at downstream locations (spot 3) for all three scenarios at the Silver Lake test site. On the contrary, reductions in noncompliance were seen at the end of the treatment.

Table 4.12 also shows the reduction of the proportion of vehicles exceeding the speed limit at the end of the treatment diminished in the “long after’ compared to the “after’ period. However, this was not possible to verify at the Rossville test site due to the loss of speed data in the “after” period.

Table 4.17 Z-test Statistics and Percentage of Drivers Exceeding the Speed Limit at the Rossville and Silver Lake Test Sites

Scenarios	Spots	Percentage of Speeding Vehicles			Before -After			Before- After Long		Sig.
		Before OSB	After OSB	Long After OSB	Z-Statistic	P-Value	Sig.	Z-Statistic	P-Value	
Rossville										
Above Speed Limit	Spot 2	88.8	NA	78.5	NA*	NA*	NA	19.29	<0.0001	Yes
	Spot 3	70.5	72.5	63.1	-3.04	0.002	Yes	10.92	<0.0001	Yes
5 mph Above	Spot 2	68.5	NA	53.7	NA*	NA*	No	21.18	<0.0001	Yes
	Spot 3	49.5	41.3	35	5.13	<0.0001	Yes	14.18	<0.0001	Yes
10 mph Above	Spot 2	47.8	NA	28.5	NA*	NA*	NA	27.65	<0.0001	Yes
	Spot 3	23.9	25.5	15	5.71	<0.0001	Yes	15.71	<0.0001	Yes
Silver Lake										
Above Speed Limit	Spot 2	78.5	58.4	78.2	28.08	<0.0001	Yes	0.48	0.634	No
	Spot 3	50	55.5	59.5	-7.01	<0.0001	Yes	-12.73	<0.0001	Yes
5 mph Above	Spot 2	53.8	29.5	52.5	31.22	<0.0001	Yes	1.72	0.085	No
	Spot 3	24.4	29.4	31.1	-7.31	<0.0001	Yes	-10.15	<0.0001	Yes
10 mph Above	Spot 2	29.5	10.4	25.4	29.44	<0.0001	Yes	6.02	<0.0001	Yes
	Spot 3	7.5	12.5	15.5	-10.87	<0.0001	Yes	-17.1	<0.0001	Yes

NA* - Speed data at the end of the treatment were lost.

Chapter 5 Summary, Conclusions and Recommendations

5.1 Summary

The main objective of this study was to evaluate effectiveness of OSBs in reducing approach speeds to rural communities. To achieve this objective, test evaluations were conducted at five test sites (Meriden (2), Silver Lake, Rossville, and Belvue) located on highways on the approaches to such rural communities. Test sites at which OSBs were installed had approximately similar geometric characteristics, straight and at level grade. At four test sites the speed limit dropped from 65 mph to 45 mph. At the fifth site, the speed limit dropped from 55 mph to 30 mph.

OSB treatment consisted of one pattern with varying spacing. Spacing of the OSBs at the beginning of the treatment was gradually reduced towards the end of the treatment. The OSBs used in this study consisted of peripheral white markings placed across the edge of the travel lane. Similar OSBs were installed at all test sites with the same dimensions and bar frequency. At the four tests with similar speed drop, the OSB treatment had same length and spacing of bars.

Speed data were collected with automatic traffic counters and pneumatic road tubes. Data collections were performed during two periods (before and after) at three test sites in Meriden (2) and Belvue and during three periods (before, after, and long after) at two test sites in Silver Lake and Rossville. “Before” data collection periods occurred in the months of August and September 2009 at all sites. At Rossville and Silver Lake sites, first “after” data collections occurred in early November 2009 and second “after” data collections happened in early April 2010. At Belvue and two Meriden sites, the only “after” data collections were performed late

February and early March 2010. Speed data collection was performed for about one week during each data collection period at all test sites and in both directions of traffic flow.

Speed data were analyzed with use of statistical tests such as the t-test for means to assess statistical significance of differences in mean speeds between periods of data collection. Furthermore, F-test for variances was used to examine equal variances which determined not only statistical significance of changes in speed variation and also the t-test to use in the analysis of mean speeds. Moreover, Z-test for proportions was utilized to examine statistical significance of changes in proportion of drivers exceeding the speed limit at test site. Analysis of speed data was performed by considering all vehicles, vehicle classifications, times of the day, and days of the week in the treatment direction and considering only all vehicles in the opposite direction. Descriptive statistics on speed data included sample sizes, mean and 85th percentile speeds, and standard deviations. Speed characteristics were examined along test sections, by considering changes in mean speed, 85th percentile speed, and standard deviation as motorists travelled trough sections. Effectiveness of OSBs was assessed by comparing speed parameters between "before" and "after" and between "before" and "long after" periods.

In examining speed characteristics at test sites and along test sections, mean and 85th percentile speeds were found to decrease as vehicles approached these rural communities. Even though motorists slow down on the approaches, in response to speed zones, speeding was noted. Analysis of "before" speed data indicated higher speeds than desired at the sites. At Meriden, mean speeds were between 45 and 57 mph at the end and downstream location, with 85th percentile speeds between 50 and 63 mph. At Silver Lake, mean speeds were between 45 and 52 mph, with 85th percentile speeds between 50 and 59 mph. At Rossville, mean speeds were between 49 and 56 mph, with 85th percentile speeds between 56 and 65 mph. The desired posted speed limit at these sites, on the approaches to towns, was 45 mph. At Belvue, where the desired posted speed limit was 30 mph, mean speeds were 30 and 38 mph, with 85th percentile speeds about 44 mph. The "before" speed data collected showed high degrees of noncompliance, with between 43 and 93 % of free-flowing vehicles at Meriden, between 42 and 88 % of free-flowing vehicles at Belvue, between 70 and 90 % at Rossville, and between 50 and 80 % at Silver Lake.

Analysis of speed data collected during "after" and "long after" periods showed reductions of speed, particularly at ends of OSBs at four of the sites except at one where significance change in speeds. Mean speed reductions ranged from 0.0 at Belvue to 8.2 % at Meriden east side and 85th percentile speed increase of 0.2 % at Belvue and reductions up to 8.9 % at Meriden east side and Silver Lake. Reductions in means at the ends of OSBs were found significant at the 95 % confidence level. Standard deviations also decreased at the ends of OSBs at four sites, which were statistically significant at the 95% confidence level. At one site, significant increase in standard deviation was noted. Analysis of proportions of vehicle exceeding the posted speed limits "before" and "after" periods showed similar reductions as with analysis of mean and 85th percentile speeds. With the three scenarios (above speed limit, 5 mph above, and 10 mph above) at ends and downstream of OSBs, statistically significant reductions of proportions of vehicles exceeding the posted speed limits were noted. These proportions were between 40 to 90 % "before" period and between 27 and 78 % "after" period, with exception for Belvue where the proportions at end of OSBs were about 88 % both "before" and "after" periods.

At some test sites, decreases in speeds were consistent throughout test sections, though magnitude of the reductions faded away downstream from the treatment. At the Meriden test sites, speed reductions occurred at almost all data collection points. However, at other test sites

(Rossville and Silver Lake), magnitudes of speed reductions obtained at the end of the treatment were less at downstream locations, with speed increases occurring at Silver Lake. At Belvue, no significant change in speed existed at the end of OSBs, but significant increases in speeds existed upstream and downstream of OSBs. At Meriden east side, significant reductions were observed at all three data collection points in the treatment direction but with significant increases in the opposite direction. At Meriden west side, significant reductions in speeds also occurred at all data collection points with exception of some categories. However, speed reductions at the end of the OSBs were small. At Rossville, speed reductions happened at the end of OSBs and at downstream locations both “after” and “long after” periods, but speeds increased at upstream of OSBs. In addition, speed reductions observed at the end of OSBs were higher than decreases noted at downstream locations. Reductions during the “after” period at downstream locations were lower than reductions during the “long after” period at the same location. However, speed data at the end of OSBs were lost during the “after” period and therefore reductions during the “after” and “long after” can not be compared for novelty purposes. At Silver Lake, speeds increased at upstream and downstream locations both “after” and “long after” periods. Speeds also increased at these corresponding data collection points in the opposite direction. However, speeds decreased at the end of OSBs, with the highest decreases observed during “after” period.

5.2 Conclusions and Recommendations

Results of the study showed, as other previous studies did, OSBs may have some minor effects on vehicle speeds. The study provides an indication that it may be possible to create safety improvements as result of using OSBs on the approach to a rural community. However, magnitude of speed reductions was generally small, though the reductions were statistically significant at the 95% confidence level. Because of the non-consistence of the magnitude of speed reductions at the test sites, no conclusion can be drawn as to how much OSB treatment reduced speeds. These results were based on “after” periods up to five months. Therefore, further study would be required to determine whether these safety improvements are sustained over an even longer time period. Even though minor speed reductions occurred, speeds observed at the sites were still higher than the posted speed limits, indicating OSBs were not effective enough in providing the desired speed limit compliance. Additional studies would be helpful to identify combinations of countermeasures, for instance OSBs and other techniques, effective in providing speed limit compliance.

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Appendices

Appendix A Considered Sites during Selection

Appendix A.1 Preliminary Sites Selected

Cities	Speed Drop (mph)	Cities	Speed Drop (mph)
Lawrence K-30	**70-35**	**Scranton** US-56 **Overbrook** US-56 **Burlingame** 55 **Hugoton** KS-51 **McPherson** US-36	**55-20**
Oskaloosa US-59 **Wamego** US-24	**65-40**	**Hoxie** US-24	**50-35**
Ulysses US-160 **Washington** US-36 **Smith Center** US-36 **Holton** US-75 **Yates Center** K-96	**65-35**	**Leoti** KS-96 **Harper** KS-2 US-160 **Wakeeney** US-283	**50-30**
Herington US-56 **Rossville** US-24 **Ottawa** KS-68 **Burlington** US--75 **Hill City** US-283 **Clay Center** US-24 K-15 **Mankato** US-36 **Ness City** US-283 ***Sharon Springs** K-27	**65-30**	**Leoti** KS-96 **Harper** KS-2 US-160 **Wakeeney** US-283	**50-20**

Table A.1 Continued

Cities	Speed Drop (mph)	Cities	Speed Drop (mph)
Council Grove US-56 **Lacrosse** US-183 **Hoxie** KS-23 **Atwood** US-36 **Phillipsburg** US-36	**65-20**	**Sublette** US-56 **Hoisington** KS-4 US-281	**45-35**
Lacrosse US-4	**60-45**	**Meade** US-54	**45-25**
Galena KS-66	**60-35**	**Fowler** KS-98	**45-20**
Holton K-116	**60-20**	**Hill City** US-24 **Plainville** US-183	**40-30**
Baldwin City US-56	**55-35**	**Hugoton** US-56	**40-25**
Waverly KS-31 **Solomon** US-40	**55-30**	**Lyons** US-56	**40-20**
		***Midland Junction** US-24/US-59	**55-45**

Appendix A.2 Potential Test Locations after Site Visits

Cities	Roadway	Initial Speed (mph)	Next Speed (mph)	Next Speed	Horizontal Characteristics	Vertical Characteristics
Belvue	US-24 W	65	30		Lead to curve	Straight
St. Marys	US-24	45	30		Straight	Small ramp
	K-63					
Rossville	US-24 E	50	30		Straight	Straight
	US-24 W	55	30		Straight	Straight
Silver Lake	US-24 E	65	45		Lead to curve	Straight
Horton	US-159	65	30			
	K-20	55	30		Straight	Vertical curve
Hiawatha	US-73 S	65	35		Straight	Vertical curve at speed limit sign 35
	US-73 N	65	40		Straight	Straight
Seneca	US-36	65	55	45	Straight	Straight
Marysville	US-36 E	50	30		Straight	Straight
	US-77	65	30		straight	Slight vertical curve
Washington	US-36 W E	65	35		Straight	Slight vertical curve
	K-15	50	30		Straight	Straight
Clay Center	K-15 W E	65	35		Straight	
Herington	US-56 BUS	55	30		Straight	Straight
Council Grove	US-56 E	65	35		Straight	Straight
Fairview	US-36 W	65	40		Straight	Straight
Home City	US-36 W	65	40		Straight	Straight after a ramp

Appendix B Design of Optical Speed Bars

Appendix B.1 Meriden (K-4, East Side and West Side), Rossville (US-24 East Side), and Silver Lake (US-24 West Side)

Initial Speed 95.33 ft/s 65 miles per hour

Desired Speed 66 ft/s 45 miles per hour

Treatment Distance 724 feet

Required Deceleration -3.3 ft/s2

Bar Frequency 4 bars/sec.

Marking Number	Cumulative Distance (ft)	Rounded (ft)	Spacing (ft)	Speed ft/s2	Speed mph
1	0.00	0	0	95	65
2	23.73	24	24	95	64
3	47.25	47	24	94	64
4	70.57	71	23	93	63
5	93.68	94	23	92	63
6	116.59	117	23	91	62
7	139.29	139	23	90	62
8	161.78	162	22	90	61
9	184.07	184	22	89	61
10	206.15	206	22	88	60
11	228.02	228	22	87	59
12	249.69	250	22	86	59
13	271.15	271	21	85	58
14	292.41	292	21	85	58
15	313.45	313	21	84	57
16	334.30	334	21	83	57
17	354.93	355	21	82	56
18	375.36	375	20	81	55
19	395.59	396	20	80	55
20	415.61	416	20	80	54
21	435.42	435	20	79	54
22	455.02	455	20	78	53
23	474.42	474	19	77	53
24	493.61	494	19	76	52
25	512.60	513	19	76	52
26	531.38	531	19	75	51
27	549.95	550	19	74	50
28	568.32	568	18	73	50

Table B.1 Continued

Marking Number	Cumulative Distance (ft)	Rounded (ft)	Spacing (ft)	Speed ft/s2	Speed mph
29	586.48	586	18	72	49
30	604.44	604	18	71	49
31	622.19	622	18	71	48
32	639.73	640	18	70	48
33	657.07	657	17	69	47
34	674.20	674	17	68	46
35	691.12	691	17	67	46
36	707.84	708	17	66	45
37	**724.35**	**724**	**17**	**66**	**45**

Note: Marking # 37 is at the reduced speed of 45 mph. The markings are peripherals of 18 inches long by 12 inches wide. Total marking: 111 feet of 12 inches of paint.

Appendix B.2 US-24, Belvue (Eastbound)

Initial Speed 80.67 ft/s 55 miles per hour

Desired Speed 44 ft/s 30 miles per hour

Treatment Distance 688 feet

Required Deceleration -3.3 ft/s2

Bar Frequency 4bars per second

Marking Number	Cumulative Distance (ft)	Rounded (ft)	Spacing (ft)	Speed ft/s2	Speed mph
1	0.00	0	0	81	55
2	20.06	20	20	80	54
3	39.92	40	20	79	54
4	59.57	60	20	78	53
5	79.02	79	19	77	53
6	98.26	98	19	77	52
7	117.29	117	19	76	52
8	136.11	136	19	75	51
9	154.73	155	19	74	51
10	173.15	173	18	73	50
11	191.35	191	18	72	49
12	209.36	209	18	72	49
13	227.15	227	18	71	48
14	244.74	245	18	70	48
15	262.12	262	17	69	47
16	279.30	279	17	68	47
17	296.27	296	17	67	46
18	313.03	313	17	67	45
19	329.59	330	17	66	45
20	345.94	346	16	65	44
21	362.08	362	16	64	44
22	378.02	378	16	63	43
23	393.75	394	16	63	43
24	409.28	409	16	62	42
25	424.60	425	15	61	42
26	439.71	440	15	60	41
27	454.62	455	15	59	40
28	469.32	469	15	58	40
29	483.82	484	14	58	39
30	498.11	498	14	57	39
31	512.19	512	14	56	38

Table B.2 Continued

Marking Number	**Cumulative Distance (ft)**	**Rounded (ft)**	**Spacing (ft)**	**Speed ft/s2**	**Spee d mph**
32	526.06	526	14	55	38
33	539.73	540	14	54	37
34	553.20	553	13	53	36
35	566.45	566	13	53	36
36	579.51	580	13	52	35
37	592.35	592	13	51	35
38	604.99	605	13	50	34
39	617.42	617	12	49	34
40	629.65	630	12	48	33
41	641.67	642	12	48	33
42	653.48	653	12	47	32
43	665.09	665	12	46	31
44	676.49	676	11	45	31
45	687.68	688	11	44	30
46	**698.67**	**699**	**11**	**44**	**30**

Note: Marking # 46 is at the reduced speed of 30 mph. The markings are peripherals of 18 inches length by 12 inches width. Total markings: 138 feet of 12 inches of paint.