Traffic Control Devices Pooled Fund Study

Evaluation of Elongated Pavement Marking Signs

Final Report

To:

Federal Highway Administration
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Washington, DC 20590

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Foreword

The objective of the Transportation Pooled Fund Program's Traffic Control Device (TCD) Consortium is to assemble a consortium of regional, State, local entities, appropriate organizations and the FHWA to 1) establish a systematic procedure to select, test, and evaluate approaches to novel TCD concepts as well as incorporation of results into the MUTCD; 2) select novel TCD approaches to test and evaluate; 3) determine methods of evaluation for novel TCD approaches; 4) initiate and monitor projects intended to address evaluation of the novel TCDs; 5) disseminate results; and 6) assist MUTCD incorporation and implementation of results.

This report documents an FHWA evaluation of the effectiveness of symbolized pavement markings that are elongated (horizontal) versions of the post-mounted signs they complement. Specifically, the study evaluated the effectiveness of Speed Limit regulatory (R2-1), Curve warning (W1-2), and Pedestrian Crossing warning (W11-2) signs as elongated pavement marking signs when used to complement the corresponding posted-mounted signs. The effect of elongated pavement marking signs on operating speeds of vehicles was studied in a driving simulator and at seven field installations.

This report is of interest to engineers, other researchers and practitioners who are concerned with improving safety at certain locations by providing additional emphasis on warning or regulatory signs. Information on the effectiveness of elongated pavement marking signs may also be of interest to local, regional, and State authorities.

Monique R. Evans
Director, Office of Safety
Research and
Development

Notice

Quality Assurance Statement

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16. Abstract: The goal of this study was to evaluate the conspicuity, legibility, and effectiveness of symbolized pavement markings that are elongated (horizontal) versions of the post-mounted signs they complement. Towards this goal, a comprehensive literature and state-of-the-practice review was performed followed by a driving simulator evaluation and field evaluation of elongated pavement markings. Research shows that elongated pavement marking letters and arrows significantly improve recognition distance; however, the effect of elongated pavement marking signs has not been evaluated. Based on a comprehensive literature review and feedback from the Traffic Control Devices Pooled Fund Study members, speed limit (R2-1), curve (W1-2), and pedestrian crossing (W11-2) signs were chosen for the driving simulator evaluation. Results from the driving simulator evaluation indicate that recognition distance increased quadratically as elongation ratio increased. Data suggested an elongation ratio of 5:1 provided maximum visibility distance for drivers. Driving simulator results also showed that operating speeds of drivers in conditions with elongated pavement marking signs complimenting post-mounted signs were similar or lower than operating speeds in locations with only post-mounted signs. The field evaluation was limited to speed limit and curve signs. Field evaluations were conducted in Kansas, Missouri and Wisconsin using the 5:1 elongation ratio for speed and curve warning signs. Operating speed of free flowing vehicles was used as the measure of effectiveness and speed data were collected upstream of-, at-, and downstream of the corresponding post-mounted sign. The speed limit sign was tested at four sites (at least one in each state) and was found to effectively reduce operating speeds at three of the sites. A curve sign was tested at three sites in Kansas and Wisconsin and found operating speed reductions at two of the sites. Research findings demonstrate a measureable effect in operating speed reduction with installing elongated pavement marking regulatory and warning signs to compliment the adjacent post-mounted signs.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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EXECUTIVE SUMMARY

The Manual on Uniform Traffic Control Devices (MUTCD) states that regulatory and warning signs should be placed on posts or mountings and located on the right-hand side of the roadway where they are easily recognized and understood by road users. In certain geometric and operational conditions, post-mounted signs may not be easily recognized or provide adequate information for passing road users. When these geometric and operational conditions occur, complementary pavement markings might be helpful when used with warning, regulatory, or guide signs. These conditions may include reduced speed zones, certain turn prohibitions, pedestrian crossings, right of way regulations, destination names, and route numbers.

The objective of this study was to evaluate the conspicuity, legibility and effectiveness of symbolized pavement markings that are elongated (horizontal) versions of the post-mounted signs they complement. Specifically, the study evaluated the effectiveness of Speed Limit regulatory (R2-1), Curve warning (W1-2) and Pedestrian Crossing warning (W11-2) signs as elongated pavement marking signs when used to complement the corresponding posted-mounted signs. A literature and state-of-the-practice review was conducted followed by a driving simulator and field evaluation of elongated pavement marking signs.

All factors being equal, pavement marking signs are more likely to be detected by drivers than post-mounted signs given their targeted location within the drivers' path. Drivers spend most of the time looking at the roadway directly ahead. As a result, objects on the side of the road may be less likely to be detected by drivers. Additionally, distracted drivers may be focused in other directions or on other tasks and may miss important traffic control information. Several studies have shown that post-mounted signs have a low registration rate (i.e., some drivers do not attend to or notice them) and their registration can be further hampered by the presence of heavy vehicles and other traffic as well as visual clutter in urban environments. Past studies have shown that pavement marking signs are effective from both operations and safety perspectives. The use of curve warning and speed limit pavement marking signs were reported in the literature.

Elongated pavement marking letters and arrows have been shown to significantly improve recognition distance when compared to non-elongated pavement marking letters and arrows. Current practice in the US is to elongate at a ratio of 2.5:1. Elongated pavement marking signs and words are widely used in Europe and Australia; however, the elongation ratio (height to width ratio) differs from country to country. In some instances, elongation ratio of as much as 10:1 is recommended. Furthermore, some countries use different elongation ratios based on posted speed limit, with greater elongation ratios on roadways with higher speeds, while other countries use a single elongation ratio regardless of the speed limit of the roadway. As a result, there is little international consistency on pavement marking elongation ratios.

Based on literature and state-of-the-practice review, and a survey of the Traffic Control Devices Pooled Fund Study members, speed limit regulatory (R2-1), curve warning (W1-2) and pedestrian crossing warning (W11-2) sign were selected for the driving simulator evaluation. Field evaluation was limited to speed limit regulatory and curve warning signs.

The objectives of the driving simulator evaluation were to evaluate the:

1. Effect of elongation on recognition distance while driving at two different operating speeds.
2. Effectiveness of elongated pavement markings with complimentary post-mounted signs.

The two objectives were evaluated in two stages of a driving simulator study which was approved by the University of Wisconsin-Madison Institutional Review Board (IRB).

Stage 1 of the driving simulator evaluation was performed to evaluate the effect of elongation on recognition distance of pavement marking signs. Three sign types (speed limit, curve, and pedestrian) and five elongation ratios (ranging from 1:1 to 10:1) were included in the driving simulator scenario. Sixteen drivers between the ages of 21 and 54 participated in the study. Driver perception-reaction time was accounted for in computing maximum recognition distance. Statistical analysis was performed to analyze the effect of elongation ratio on maximum recognition distance through a random effects linear model. Through a backwards stepwise procedure, it was found that age, gender, years of driving experience, if the participant wore corrective lenses, and speed were not statistically significant terms in the model. The elongation ratio and sign type were found to be statistically significant. Results confirm that maximum recognition distance increases quadratically with increase in elongation ratio. The marginal increase in maximum recognition distance reduces as elongation ratio increases, especially beyond a 5:1 ratio. Therefore, a 5:1 ratio was recommended for the field evaluation.

The Stage 2 of the driving simulator evaluation was performed to study the effectiveness of elongated pavement marking signs (on driver speeds) placed near traditional post-mounted signs. Speed limit, curve, and pedestrian signs were studied. For the curve sign, placement of the elongated pavement marking sign relative to the post-mounted sign was also evaluated. Results indicated that speeds of drivers in conditions with elongated pavement marking signs were similar or lower than speeds in conditions with post-mounted signs only. Furthermore, placing the elongated pavement marking sign downstream of the post-mounted sign was more effective than placing it adjacent to the post-mounted sign. Similarly, placing the elongated pavement marking sign at the post-mounted sign was more effective than placing it upstream of the post-mounted sign.

Three states, Kansas, Missouri, and Wisconsin, participated in the field evaluation of elongated pavement marking signs. Each state determined the type of material used for the elongated pavement marking signs. Considerations were based on individual state's experience with materials, concerns about possibility of skidding for motorcycles in wet pavement conditions, and minimizing pavement damage if the sign were to be removed. Kansas used thermoplastic pavement marking material while Missouri used paint, and Wisconsin used tape. Since the elongated pavement marking signs are not in the MUTCD, Requests for Experimentation (RFEs) in accordance with the MUTCD guidelines for each state were submitted by the individual agencies to the Federal Highway Administration (FHWA) for approval. Following the approval of the RFEs, signs were procured and installed. A before-after study approach was used and speeds were measured at three locations: upstream of the post-mounted sign, at the post-mounted sign and downstream of the post-mounted sign. Data were collected for a minimum of one week in the before and after conditions. Data for the after period were collected a minimum of one week following the installation of the sign to avoid any novelty effect.

The speed limit sign was tested at two locations in KS, one location each in MO and WI. The sign was effective at reducing operating speeds at three out of the four sites studied. The speed limit sign was effective in reducing mean speeds during most of the time periods at the sign and downstream in Branson West, MO. In Andale, KS the sign reduced mean speed, 85th percentile speed, and percentage of drivers exceeding the speed limit by more than 10 mph at the sign and downstream location. Percentage of drivers complying with the speed limit increased at both locations. At Bentley, KS, mean and 85th percentile speeds increased at the sign but remained similar downstream. The sign was not effective in reducing speeding vehicles at either locations. In Brooklyn, WI, the sign was effective at the location of the sign, but not downstream. Mean and 85th percentile speeds were reduced at the sign but remained same downstream. Vehicles speeding by more than 10 mph were reduced and percentage of vehicles complying with speed limit increased at the sign location. The sign had little effect at downstream location.

The curve sign was tested at two locations in KS and one location in WI. The sign was effective at reducing operating speeds at two of the three sites. At both the sites in Lecompton, KS the sign reduced mean speed, 85th percentile speed, and percentage of drivers exceeding the advisory speed limit by more than 10 mph at the sign and downstream locations. The percentage of drivers complying with the advisory speed limit remained similar at both locations. Therefore, it was concluded that the sign was effective at both the locations in Lecompton, KS. In Jefferson, WI, the sign was not effective. Mean speeds and the percentage of drivers exceeding advisory speed limit by more than 10 mph remained similar, while 85th percentile speeds increased marginally at the sign and downstream.

This research confirms that elongation increases the recognition distance of pavement marking signs. The relationship between maximum recognition distance and elongation ratio is quadratic. Furthermore, field and driving simulator evaluations show that the evaluated regulatory and warning elongated pavement marking signs reduced operating speeds demonstrating that they can be effective in reinforcing a warning or a regulatory message to drivers.

Recommendations resulting from this research are:

- Elongation ratio of 5:1 for pavement marking signs.
- Elongated pavement marking signs be used to supplement post-mounted signs when speed reduction or other operating speed changes are needed.
- Based on the driving simulator evaluation, placing the pavement marking sign downstream of the post-mounted sign for curve applications may be more effective than placing it at the sign. Future research should confirm this through field evaluation of various placement positions.

Future Research recommendations include:

- This study did not evaluate long term impact of the signs. It is strongly recommended that future research examine the long-term effectiveness of these signs.
- This research used speed as a surrogate measure for safety. A safety evaluation of these locations would further establish the effectiveness of elongated pavement

marking signs and is highly recommended. Safety evaluations could include evaluating effect of the sign on crashes as well as monitoring driving behavior immediately after sign installation.

- Future research should study the durability of EPMS and also consider using narrower (5 feet or less) EPMS to reduce wear from vehicle tires.
- Ongoing Kansas DOT study on EPMS should be considered in deciding sign effectiveness.

This research was limited to the three sign types discussed on two lane roadways. Therefore, future evaluations should also consider other sign types and roadway types.

CHAPTER 1. INTRODUCTION

The Manual on Uniform Traffic Control Devices (MUTCD) states that regulatory and warning signs should be placed on posts or mountings and located on the right-hand side of the roadway where they are easily recognized and understood by road users. (3) In certain geometric layouts, post-mounted signs may not be easily recognized or provide adequate information for passing motorists. One of these geometric scenarios is horizontal curves and the associated post-mounted 'Curve' horizontal alignment warning sign (W1-2). 'Curve' warning signs are recommended when the difference between the posted speed limit and curve advisory speed is 5 mph, and required (along with an advisory speed plaque) when the speed difference exceeds 10 mph. (3) Like with all warning signs, the 'Curve' warning sign is intended to inform drivers of the horizontal curve ahead and the possible need for a reduction in operating speed. It has been well documented that excessive speed in a horizontal curve increases the probability of driver error and run-of-the-road crashes.

Research by Puvanachandran found that drivers approach speed to horizontal curves often differs from the desired speed within the curve as a function of the degree of curvature. (1) It can be argued that this finding may be due to drivers' disregard for 'Curve' and other warning signs, or the lack of emphasis and conspicuity provided by a single post-mounted sign on the right-hand side of the roadway in these complex scenarios. One way to provide stronger emphasis of the 'Curve' warning sign and desired operating speed on the horizontal curve is to include complementary pavement markings. Figure 1 presents an example of an elongated 'Curve' warning sign used together with a post-mounted warning sign. Complementary pavement markings might be helpful when used with warning, regulatory, or guide signs. These may include reduced speed zones, certain turn prohibitions, pedestrian crossings, right of way regulations, destination names, and route numbers.

Figure 1. Photo. Example of Elongated Curve Warning Sign

Previous research has considered pavement markings at horizontal curves focusing on the speed reductions which could be achieved by adding pavement markings prior to a curve. Chrysler, Schrock and Williams explored the effects of using pavement signing to help reduce speed on horizontal curves. (2) Although their study did not use a combination of post-mounted and pavement signing to warn of an impending curve, it did find speed reductions resulting from the use of both a curved arrow and an advised speed on the pavement prior to the start of the horizontal curve.

Retting, McGee and Farmer studied the effect of pavement markings on freeway exit ramps, which included horizontal curves. (34) While their research did not have specific post-mounted signs warning for curves ahead, there were advisory speed signs located on the freeway exit ramps. A 'before and after' research methodology led to two relevant findings from Retting et al. First, they found a significant reduction in the amount of vehicles that exceeded the speed limit posted on the advisory sign. Second, they also found that the usage of tapered edge lines on freeway exit ramps generally reduced the speed of both passenger vehicles and large trucks.

The objective of the present study is to evaluate the conspicuity, legibility and effectiveness of symbolized pavement markings that are elongated (horizontal) versions of the post-mounted signs they complement. Specifically, the study evaluates the effectiveness of Speed Limit regulatory (R2-1), Curve warning (W1-2) and Pedestrian Crossing warning (W11-2) signs as elongated pavement signs when used to complement the corresponding posted-mounted signs.

The report that follows contains the following chapters:

- Chapter 2: Literature and state of the practice review.
- Chapter 3: Simulator evaluation results.
- Chapter 4: Field evaluation results.
- Chapter 5: Conclusions and recommendations.

CHAPTER 2. LITERATURE AND STATE-OF-THE-PRACTICE REVIEW

The primary objective of the literature and state-of-the-practice review was to summarize current research findings and known practice on the topic of pavement markings, post-mounted signs and pavement signs supplemented by post-mounted signs. The secondary objective of this task was to develop a list of sign types that would most benefit from complementary pavement markings. The research team performed a comprehensive search to gather literature on pertinent topics, including human factors issues associated with signs and pavement markings, applications of pavement marking signs in the United States (US) and other parts of the world, and pavement marking sign policy/practices of US and other countries. Sources include archival journals, online searches, and obtaining information through personal correspondence with national and international agencies.

A summary of this chapter is presented first, followed by discussions of:

- Relevant human factors issues.
- Two applications of pavement marking signs reported in the US and international literature.
- The benefits of elongation of pavement marking signs.
- US practice of pavement marking signs as presented in the Manual on Uniform Traffic Control Devices (MUTCD) follows. [3]
- And, the relevant practices of Australia, Canada, Germany and the UK.

The chapter concludes with key findings of the literature and state-of-the-practice review.

SUMMARY

Drivers spend most of the time looking at the roadway directly ahead. As a result, objects on the side of the road may be less likely to be detected by drivers. Additionally, distracted drivers may be focused in other directions or on other tasks and may miss important traffic control information. Several studies have shown that post-mounted signs have a low registration rate (i.e., some drivers do not attend to or notice them) and their registration can be further hampered by the presence of heavy vehicles and other traffic as well as visual clutter in urban environments (see references 8, 9, 10, 11, 12, 13, and 14.) All factors being equal, pavement marking signs are more likely to be detected by drivers than post-mounted signs given their targeted location within the drivers' path. Past studies have shown that pavement marking signs are effective from both operations and safety perspectives (see references 15, 18, 19, and 20). The use of curve warning and speed limit pavement marking signs were reported in the literature (see references 15, 16, 17, 18, 19, and 20). For instance, the Pennsylvania Department of Transportation has been using an Advance Curve Warning Marking for over a decade at curves on two-lane rural highways with positive results. [17] Additionally, In the United Kingdom (UK), speed limit pavement marking signs are regularly used and are recommended in their traffic control policy. [23, 24, 25]

Elongated pavement marking letters have been shown to significantly improve recognition distance when compared to non-elongated pavement marking letters. Current practice in the US is to elongate at a ratio of 2.5:1. Elongated pavement marking signs and words are widely used in Europe and Australia; however, the elongation ratio (height to width ratio) differs from country to country. In some instances, elongation ratio of as much as 10:1 is recommended. Furthermore, some countries use different elongation ratios based on posted speed limit, with greater elongation ratios on roadways with higher speeds, while other countries use a single elongation ratio regardless of the speed limit of the roadway. As a result, there is little international consistency on recommended or applied pavement marking elongation ratios.

HUMAN FACTORS ISSUES

Information gathered for driving is predominantly visual. Therefore, a brief explanation of the human visual system is necessary to understand driver perception and comprehension of signing. The visual field of human eyes is approximately 55° above the horizontal, 70° below the horizontal and 90° to the left and right. (4) However, the structure of the human eye is such that the foveal region, located in the center of the retina, is responsible for sharpest vision, which is necessary for visual detail. The area of foveal vision includes a cone of approximately 2° to 4° from the focal point. All other vision outside of this region is considered peripheral vision. Peripheral vision usually extends to about 90° on either side of the line of sight. However, the peripheral cone decreases with speed to about 50° at 30 km/h (~19 mph), 40° at 60 km/h (~37 mph), and 20° at 100 km/h (~62 mph). (5) Detection of movement in the peripheral vision can draw attention and prompt an eye and/or head movement to get the object within foveal vision. All factors being equal, the further from the fovea the image falls, the less likely it is to be detected and more likely it is to be overlooked all together. (6) Rockwell studied driver eye movements under normal driving conditions and reported that most eye movements were less than 6° from the focus of expansion (point where roadway meets the horizon). (7) In other words, drivers spend most of their time scanning the roadway directly ahead. With these findings in mind, it is important to note that post-mounted signs first appear in driver's peripheral vision and when noticed, require an eye and/or head movement to bring the sign into foveal vision. The location of pavement marking signs allows the sign to first appear in foveal vision and remain in foveal vision until the sign is passed. Therefore, pavement marking signs are expected to be more successful than post-mounted signs in being detected by drivers.

Research has also shown that visual clutter can negatively impact sign traffic detection. For instance, the ability of drivers to recognize post-mounted signs is adversely affected by other vehicles, especially trucks, which can occlude the sign entirely. (8, 9) Akagi et al. studied the influence of cluttered visual environments on driver ability to detect traffic signs on urban arterials. (10) As one might expect, a statistically significant negative correlation was found between the amount of visual clutter (such as billboards and buildings along roadsides) and the distance at which a traffic sign was first observed.

The literature is replete with evidence that post-mounted signs can have a low recognition rate among drivers, depending on the sign type. To measure recognition, Johansson and Rumar stopped Swedish motorists 710 m after they passed different signs on the road and asked the drivers to recall the last road sign they passed. (11) The recall rate was between 17% and 78% depending on the sign's content. Signs indicating police patrol or change in speed limit had higher recall rate than general warning signs. In a follow-up study, Johanssen and Backlund studied 5,000 drivers and found an average recall/recognition rate of less than 50%. (12) The rates varied based on the urgency of the message in the sign. Drory and Shinar used a similar methodology in Israel and obtained lower recognition rates ranging from 5% to 12%. (13) Researchers also report evidence of low attentional value of warning signs. Shinar et al. analyzed eye movements of drivers as they drove through curves on rural roads and found that direct fixations on warning signs were relatively rare. (14) It is not clear if the low fixation rate was due to the content of the sign (e.g., warning) or the location (e.g., shoulder post-mounted).

Human factors research supports the notion that pavement marking signs have great potential to be detected by drivers, which supports the need for further evaluation. However, pavement marking signs can have durability issues due to vehicle traffic as well as snow clearance operations causing wear. Additionally, inclement weather such as snow and ice can occlude pavement marking signs. For these reasons, post-mounted signs used in conjunction with or in proximity of pavement marking signs, especially when used for regulatory purposes, may be the most desirable implementation.

APPLICATIONS OF PAVEMENT MARKING SIGNS

Two applications of pavement marking signs have been described in the literature: curve warning (warning) and speed limit (regulatory). The following sections document the literature on these two applications of pavement marking signs.

Curve Warning Applications

Retting and Farmer examined the effectiveness of a special pavement marking at one sharp horizontal curve (approximately 90°) located on a suburban two-lane roadway in Northern Virginia. (15) There were post-mounted regulatory and advisory signs near the pavement marking that was tested. The posted speed limit was 35 mph and the test location had an advisory speed of 15 mph posted about 500 feet before the curve using standard signs. The experimental pavement marking (Figure 2) was installed 220 feet upstream of the curve and consisted of the following features:

- The word “SLOW” in eight-foot long white letters.
- The left curve arrow was eight feet long and white in color.
- Transverse lines eighteen inches wide were marked at both the beginning and the end of the text/symbol message.
- Glass beads were used to enhance retroreflectivity and nighttime visibility.
- Average daily traffic on the roadway was 5,000 vehicles per day.
- Thermoplastic pavement marking material was used.

A speed study was performed before and after the pavement marking described above was installed. Speeds were measured on the tangent section 90 feet prior to the point of curvature (PC) and 650 feet upstream of the curve at the test location, as shown in Figure 2. Two road tubes spaced 20 feet apart were used to measure speed. Data were collected after installation for a period of two weeks, which allowed time for the drivers to adapt to the sign. Analysis was limited primarily to passenger cars as there were a limited number of trucks. A minimum gap of three seconds between vehicles was used to assure vehicles were free flowing. Data from three time periods were analyzed: daytime (10:30 AM – 5: 00 PM), evening (9:00 PM – 12:00 AM) and late night (12:00 AM – 3:00 AM). Measures used for analysis included average speed, 90th percentile speed, and percentage of vehicles exceeding given speed thresholds.

Results show that the pavement marking installation was associated with a reduced mean speed and 90th percentile speed downstream of its location at the curve; this reduction occurred under all the three time periods. Specifically, the reductions in mean speed were 1.1 mph, 1.6 mph and 3.4 mph, for the day, evening and late night periods, respectively. Percentages of drivers exceeding 35 mph, 40 mph and 45 mph were also reduced. Overall, the experimental pavement marking resulted in a decrease in speeding of about 6% and 7% during daytime and late night periods, respectively.

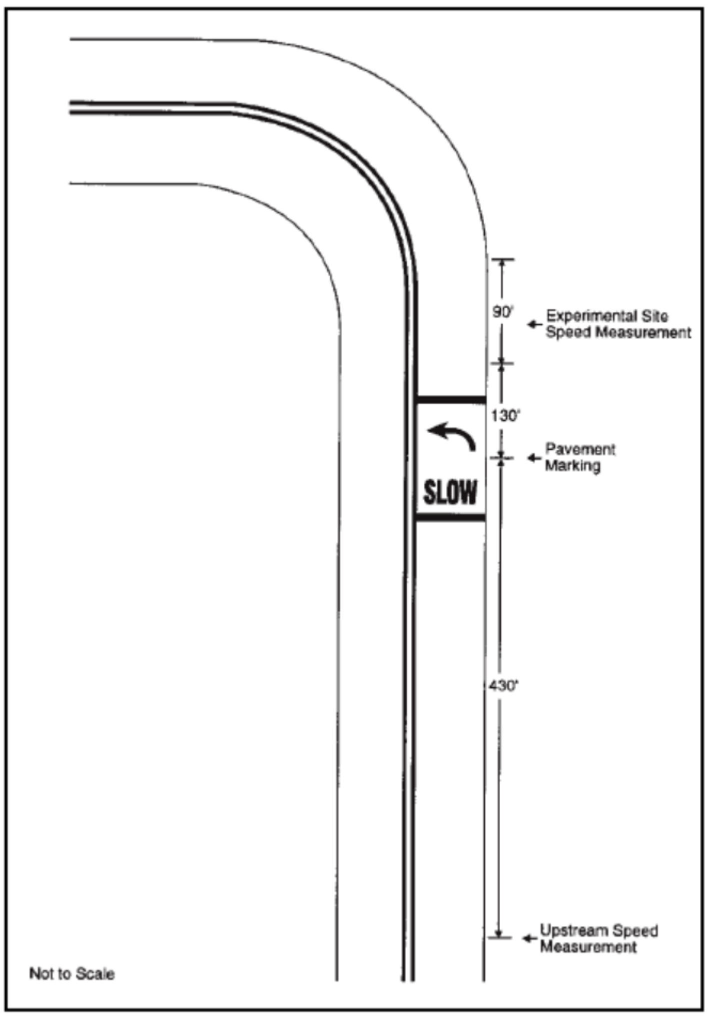


Figure 2. Illustration. Experimental Pavement Marking & Speed Measurement Locations. [15]

Similar to the pavement marking sign evaluated by Retting and Farmer [15], the Pennsylvania Department of Transportation (PennDOT) developed the PennDOT Advance Curve Warning Marking (ACWM) pavement sign (Figure 3) to alert motorists to the presence of a curve and the need to slow down. [16] The PennDOT ACWM is designed for two-lane locations with a high number of curve-related crashes. The sign is 8 ft wide while the length of the sign depends on the posted speed limit. The larger pavement marking sign (50 feet long) is used for speeds of 40 mph or greater and a 35.5 ft long pavement marking sign is used for speeds below 40 mph. Distance of the pavement marking from the PC varies based on posted speed and advisory speed as shown in Table 1.

Figure 3. Photo. PennDOT Curve Advance Marking. [16]

Table 1 Distance of the ACWM Marking from PC in Feet. [16]

Posted Speed (mph)	Advisory Speed (mph)								
	10	15	20	25	30	35	40	45	50
20	50	35							
25	70	60	40						
30	100	85	70	45					
35	135	120	105	80	50				
40	175	160	140	120	90	55			
45	220	205	185	165	135	100	60		
50	270	255	235	210	185	150	110	70	
55	325	310	290	270	205	205	165	120	80
60	385	375	350	330	265	265	225	180	135

Several thousand of these ACWM have been installed in Pennsylvania since 2001. In 2008, a safety evaluation of a large subset of these ACWMs (429 segments), installed between 2000 and 2004, found a 33% (expected range of 21% - 46%) decrease in crashes. [18] Police-reported crashes were used for the evaluation. The decrease was observed for crashes related to curve negotiation and those involving “driver error on curve” as a contributing factor to the crash. Hallmark et al. evaluated pavement curve warning signs in Iowa at two rural two-lane roadway sites with posted speed limits of 55 mph. [20] The pavement sign was similar to the PennDOT ACWM pavement sign. Speed data were collected before installing the pavement sign and twice in the after period: 1 month and 12 months after installation. Mean speed, 85th percentile speed, and percentages of vehicles traveling 5, 10, 15, or 20 mph over the advisory speed (if present) or the posted speed were used for the evaluation. Hallmark et al. concluded that the treatments were moderately effective in reducing mean and 85th percentile speeds. [20] The markings were installed at the PC as opposed to upstream of the PC, as in all the other studies described hereinbefore; therefore, a potential reason for the difference in performance when compared to the Retting and Farmer study.

The pavement marking sign used in Retting and Farmer, Pennsylvania ACWM, and Hallmark et al. are very similar. Conversely, Chrysler and Schrock evaluated the effectiveness of three different pavement markings on reducing speeds on curves at two rural locations and one urban location. [19] The markings tested are shown in Figure 4 through Figure 6 and include: CURVE AHEAD for one rural curve, CURVE 55 MPH at the other rural curve, and a curve symbol with 50 MPH at one urban curve. The pavement marking text was 8 feet long. The markings were applied approximately 400 feet downstream of a standard post-mounted curve warning sign (i.e., MUTCD curve sign W1-2). Traffic speeds were measured upstream of the post-mounted curve warning sign, at the curve warning sign and at the PC of the horizontal curve. The CURVE AHEAD pavement marking sign did not have the intended effect on lowering vehicle speeds. In fact, operating speeds significantly increased by 1 mph. The CURVE 55 MPH treatment increased the drop in speeds between the upstream location and the PC by 4 mph, although this was not statistically significant. For the combined curve arrow and advisory speed treatment at the urban road location, speeds at the PC were reduced by a statistically significant 7 mph. Also, the percentage of vehicles exceeding the speed limit were reduced by 11% to 20% depending on vehicle type and time of day. Pavement markings with advisory speeds were more effective than those which simply warned of an impending curve.

Figure 4. Photo. CURVE AHEAD Treatment on a Rural Road. [19]

Figure 5. Photo. CURVE 55 MPH Treatment on a Rural Road. [19]

Figure 6. Photo. Curve Arrow and Advisory Speed Treatment
on Urban Road. (19)

All of the studies mentioned thus far were field-based evaluations. An Australian study used a driving simulator to compare the relative effectiveness of various types of warnings on drivers' speed selection at curves. (21) Three types of curve warnings at three different curve types were tested using a desktop driving simulator. Details of the driving simulator experiment include:

- A 28.5 km long driving scenario with predominantly rural road with an open road speed of 100 km/h.
- Oncoming cars and trucks traveling between 75km/h and 100 km/h.
- Twelve 45° curves of varying radii: four each with advisory speeds of 45 km/h, 65 km/h and 85 km/hr.
- Curves were marked with one of the following three curve warnings (shown in Figure 7 through Figure 9) or had no warning:
    - Post-mounted diamond warning sign with a curve advisory speed.
    - Chevron warning sign with a curve advisory speed.
    - Advisory speed pavement marking sign and a series of transverse lines at decreasing intervals.
- Curve speeds were measured at four locations: 64 m upstream of the curve, at the entry point of the curve, midway through the curve, and at the end of the curve.

The pavement marking sign was the most effective of all the signs evaluated for the most severe curve (the lowest advisory speed of 45km/h), although the other two warning signs were also effective. For the 65 km/h and 85 km/h curves, the pavement marking sign with advisory speed did not lead to a speed reduction at the entry to the same degree as the other treatments, yet it contributed to lower speeds at the midpoint and exit point of the curve compared to the diamond warning sign and the chevron sign. The post-mounted signs were found to impact drivers speeds further upstream of the curve when compared to the pavement marking sign, possibly because the post-mounted signs were visible to drivers at greater distances than the pavement marking sign.

Figure 7. Photo. Diamond Warning Sign. [21]

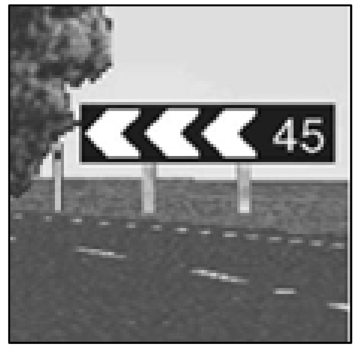


Figure 8. Photo. Chevron Warning Sign. [21]

Figure 9. Photo. Pavement Marking Sign. [21]

In summary, both field studies and the simulator study indicate that pavement marking signs for curve warning can be effective in reducing speeds of drivers in curves. Furthermore, the Pennsylvania study shows that safety can also be improved at locations where curve pavement marking signs are used. The next application of pavement marking signs reported in the literature is of speed limit sign and is discussed next.

Speed Limit Applications

Speed limit pavement markings are used widely in the UK. Speed limit roundels (elongated circles with speed limit numerals in the center laid in white thermoplastic on road surface) are used for traffic calming purposes and also as part of gateway treatments for villages. Figure 10 shows a speed limit roundel outside Heathrow airport in London. Barker and Helliar-Symons evaluated the effectiveness of roundels paired with post-mounted signs on reducing speeds. [22] A statistically significant 3 mph reduction was found with 40 mph roundels. Alternatively, a 30 mph roundel did not produce a statistically significant effect. Post-mounted signs are required with roundel use to maintain the legalities of speed enforcement. Roundels and other pavement marking signs can be covered by snow or could have deteriorated resulting in poor comprehensibility by drivers and therefore are not deemed enforceable. However, the most recent UK guidelines permit every English authority to place a 20 mph roundel marking without an accompanying post-mounted sign at locations within 20 mph speed zones. [23] The requirement for a vertical sign was relaxed to reduce the signing costs in 20 mph zones.

Figure 10. Photo. A Speed Limit Roundel Outside
Heathrow Airport, London, UK.

Figure 11. Photo. Speed Limit Roundel as
Traffic Calming Measures in UK. [25]

Figure 11 shows an installation of speed limit roundels using colored pavement surfaces as part of traffic calming in villages in the UK. Although roundels can be applied independently in 20 mph speed zones outside of villages, within villages these guidelines require that all roundels are accompanied by post-mounted repeater signs because weather, wear and tear can render pavement roundels difficult to see and cause enforcement difficulties for police [24].

In the U.S., Hallmark et al. evaluated effectiveness of speed limit pavement markings as traffic-calming treatments on major roads through small communities in Iowa. [20] The gateway entrance treatments in Roland, IA (shown in Figure 12 and Figure 13) consisted of converging chevrons, lane narrowing by widening painted shoulders, and a “25 MPH” on-street pavement marking. Results of this study showed that decreases in speeds after the treatments were installed remained constant over the yearlong data collection period. The effect of individual treatments could not be ascertained because all three treatments were used in conjunction; nevertheless, the combined effects of the pavement marking treatments proved to effectively reduce operating speeds.

Figure 12. Photo. East Gateway Entrance Treatment used in Roland, IA. [20]

Figure 13. Photo. West Gateway Entrance Treatment used in Roland, IA. [20]

A modified European entrance treatment that consisted of red pavement surface markings with the speed limit number in white was installed at three locations In Dexter, IA. Figure 14 shows a picture of the treatment immediately after installation. Figure 15 shows a picture of the treatment nine months after installation, illustrating how a painted pavement marking sign deteriorates due to traffic and snow plowing operations. The treatments were effective in reducing speeds at all three of the test locations, although the effectiveness varied over time. Only two of the sites maintained the observed speed reductions nine months after installing the treatments.

Figure 14. Photo. Dexter, IA Treatment After Installation. [20]

Figure 15. Photo. Dexter, IA Treatment Nine Months After Treatment. [20]

In summary, the use of speed limit pavement markings in the UK is commonplace and has been found to be effective in reducing speeds. The Iowa study demonstrates that pavement marking applications can be effective in speed reduction, but also illustrates the challenges with long-term durability of a pavement marking sign. The next section documents benefits of elongating pavement marking signs.

BENEFITS OF ELONGATION OF PAVEMENT MARKING SIGNS

MacDonald and Hoffman performed four experiments to investigate the effects of letter size, word order and spacing between words on the perception of pavement messages. [26] One of the significant results applicable to pavement marking symbols is with increasing driving speed, recognition distance decreased linearly. They evaluated 5 ft and 10 ft long letters (average width of 2.25 ft) and found that the longer letters were recognized at a greater distance than normal letters of same width. [27]

Zwahlen, Schnell and Miescher tested the visibility of five designs for pavement marking arrows at both full scale and half scale. [28] Two designs were standard arrows (Figure 16, and Figure 17) and three were elongated arrows (Figure 18, Figure 19, Figure 20). A field study was conducted for both daytime and nighttime conditions. The Australian arrows are elongated more (H/W of about 7) than the Federal (H/W of 1.28) and Ohio arrows (H/W of 1.25). Experimental results clearly showed that elongated full scale arrows provided significantly longer recognition distances than their standard full scale counterparts.

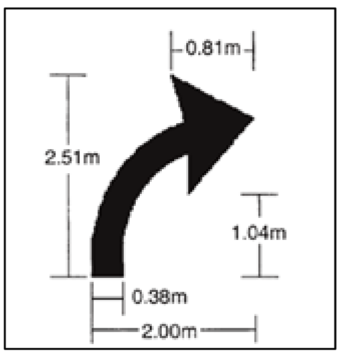


Figure 16. Illustration. Ohio Arrow Design Evaluated by Zwahlen et al. [28]

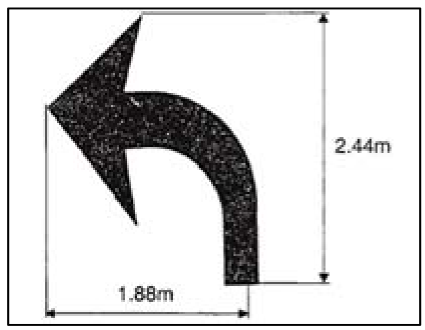


Figure 17. Illustration. Federal Arrow Design Evaluated by Zwahlen et al. [28]

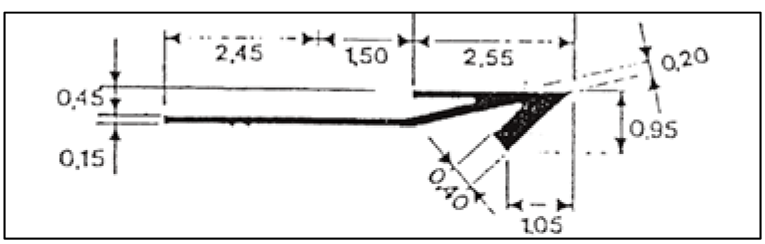


Figure 18. Illustration. Pavement Marking Swiss Arrow Design Evaluated by Zwahlen et al. [28]

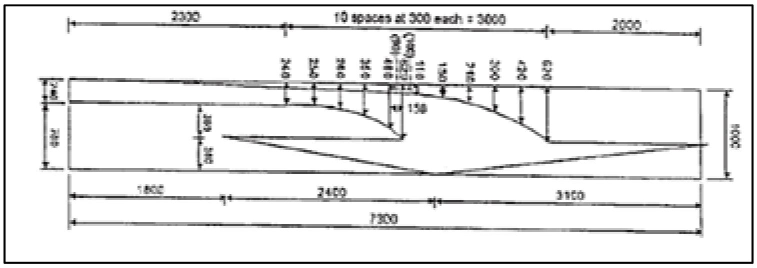


Figure 19. Illustration. Pavement Marking Australian Arrow Design Evaluated by Zwahlen et al. (28)

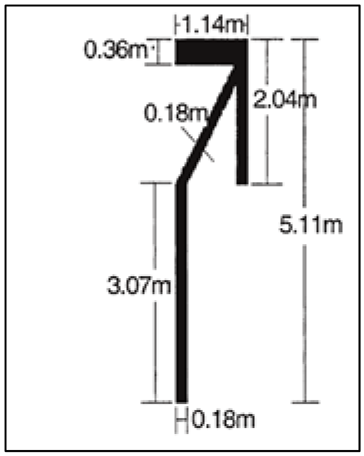


Figure 20. Illustration. Pavement Marking New Arrow Design Evaluated by Zwahlen et al. (28)

Several international manuals and/or guidelines explicitly state that elongation improves the legibility distance of pavement markings. The Queensland (Australia) MUTCD notes that the legibility distance is increased by increasing the length of characters, and the benefit of increasing elongation diminishes if the elongation ratio exceeds about 10:1. (29) The UK Traffic Signs Manual states that the oblique angle at which the pavement markings are viewed causes poor legibility. (30) Therefore, to counter this effect, the manual recommends using elongated markings and indicates that the use of greater elongation ratio results in a greater legibility distance and should be used on higher speed roads. The different elongation ratios recommended vary by sign type are discussed in detail in Appendix B.

Based on the experimental results presented in the literature, one can conclude that elongated pavement marking signs have greater legibility distances. Although the recommended elongation ratios vary, legibility distances can improve when the elongation ratios are correlated to posted speeds. Excessive elongation can result in distortion and therefore a balance between maximizing legibility distance and distortion of the pavement marking sign is required. The next sections briefly summarize the practices in the United States and internationally.

PRACTICE IN THE UNITED STATES AND ABROAD

The Manual on Uniform Traffic Control Devices (MUTCD) Section 3B.20 states that based on engineering judgment, word, symbol, and arrow markings may be used to supplement signs and provide additional emphasis. [3] The MUTCD specifically states:

> "*Word, symbol, and arrow markings on the pavement are used for the purpose of guiding, warning, or regulating traffic. These pavement markings can be helpful to road users in some locations by supplementing signs and providing additional emphasis for important regulatory, warning, or guidance messages, because the markings do not require diversion of the road user's attention from the roadway surface. Symbol messages are preferable to word messages.*"

The word, symbol, and arrow markings including those in the *Standard Highway Signs and Markings* book can be used for this purpose. Some of the word, symbol, and arrow markings that may be used are listed explicitly in the MUTCD and are shown in
Table 2. Information on elongated pavement markings is provided only for route shields and arrows. The H/W (height to width) ratio for the elongated route shield signs is 2.5:1 in the MUTCD. The length of the letters for elongated pavement markings is 8 feet.

Table 2. Word, Symbol and Arrow Markings on Pavements to Supplement Signs. [3]

A. Regulatory	1. STOP 2. YIELD 3. RIGHT (LEFT) TURN ONLY 4. 25 MPH 5. Lane-use and wrong-way arrows 6. Diamond symbol for HOV lanes 7. Other preferential lane word markings
B. Warning	1. STOP AHEAD 2. YIELD AHEAD 3. YIELD AHEAD triangle symbol 4. SCHOOL XING 5. SIGNAL AHEAD 6. PED XING 7. SCHOOL 8. R X R 9. BUMP 10. HUMP 11. Lane-reduction arrows
C. Guide	1. Route numbers 2. Cardinal directions 3. TO 4. Destination names or abbreviations thereof

The research team conducted an online search, as well as contacted transportation and research agencies in Europe, Australia, and New Zealand, to obtain international standards or guidelines for pavement marking signs. In general, elongated pavement markings are widely used in Europe, Australia, Canada, and New Zealand. The research team compiled tables comparing the dimensions used in Australia, Canada, Denmark, Finland, Germany, Netherlands, Norway, Sweden, United Kingdom, and United States for some of the commonly used pavement marking signs. These tables are included in Appendix A.

The major finding is that many countries use elongated pavement marking signs and the extent of elongation depends on roadway speeds. Also, the speed thresholds at which greater elongation ratios are used is not the same across different countries. Appendix B summarizes the practices of some of the countries for which the research team was able to obtain detailed guidance.

KEY FINDINGS OF LITERATURE AND STATE-OF-THE-PRACTICE REVIEW

The objectives of the literature and state-of-the-practice review were to summarize current research on the topic of pavement markings to supplement post-mounted signs as well as the current state-of-the-practice. Additionally, sign types that would most benefit from complementary pavement markings were comprehensively explored.

Key findings of the literature and state-of-the-practice review are:

- From a human factors perspective, pavement marking signs have a better likelihood of being detected by drivers than post-mounted signs.
- Applications of pavement marking signs have been focused on curve warning and speed limit.
- Pavement marking signs (not necessarily identical to post-mounted signs) have been shown to be effective from both the operations and safety perspective.
- Elongated pavement markings have significantly longer recognition distances than non-elongated pavement markings.
- Elongated pavement markings are widely used in Europe and Australia for roadways and are standard for airport runway/taxiway markings.
- Elongation ratios (length or height to width ratios) vary between countries.
- Some countries use greater elongation ratios for roadways with higher speed limits. The speed thresholds at which greater elongation ratios are used also varies.

CHAPTER 3. DRIVING SIMULATOR EVALUATION

This chapter describes the driving simulator evaluation of elongated pavement marking signs. The objectives of the driving simulator study were to evaluate the:

3. Effect of elongation on recognition distance while driving at two different operating speeds.
4. Effectiveness of elongated pavement markings with complimentary post-mounted signs.

The objectives were evaluated in two stages of a driving simulator study and presented in the following sections. The University of Wisconsin-Madison Institutional Review Board (IRB) approved this research.

Driving Simulator Evaluation: Stage 1

In the first stage of the driving simulator study, the effect of elongation on recognition distance was evaluated by placing signs of various elongation ratios on the pavement. Pavement marking signs were placed on longitudinal sections of roadway without any curves in the scenario's visual world. Road curvature was not used in this stage of driving simulator research since it could bias research results by providing a cue regarding what type of sign is present (e.g., curves imply curve signs).

Methods

Participants:
Sixteen drivers, between the ages of 21 and 54, participated in the driving simulator study for this stage of the research (Table 3). Recruitment was completed through a variety of local mediums, including local advertisement on campus, through campus and community organizations, and using databases of past participants. Drivers willing to participate were screened for a valid driver's license in addition to basic demographic categorization. All demographic data were recorded via a short questionnaire completed by the driver. Given the small number of drivers included in the experimental design of this study, drivers selected for participations were not entirely representative of the general driver population.

Table 3. Participant Demographics for Stage 1.

Subject ID	Gender	Years of Driving Experience	Corrective Lenses	Age
417201401	Male	4	Yes	28
417201402	Female	7	Yes	23
417201403	Male	8	Yes	24
418201401	Female	16	Yes	34
418201402	Male	11	Yes	31
418201403	Female	9	Yes	24
418201404	Female	5	Yes	21
418201405	Female	8	Yes	29
423201401	Male	6	No	22
423201402	Male	8	Yes	24
423201403	Female	10	Yes	30
424201401	Male	40	Yes	54
424201402	Male	21	No	37
424201403	Female	10	No	29
425201401	Female	8	No	28
425201402	Female	18	No	36

***Materials*:**

Based on literature and state-of-the-practice review and a survey of the Traffic Control Devices Pooled Fund Study members, speed limit regulatory (R2-1), curve warning (W1-2) and pedestrian crossing warning (W11-2) sign were selected for the driving simulator evaluation. Details of the survey are presented in Appendix C. The research team evaluated each sign at five elongation ratios: 1:1, 2.5:1, 5:1, 7.5:1 and 10:1 resulting in 15 conditions. These ratios were chosen to cover the minimum (1:1, no elongation) and maximum ratio (10:1) and intermediate ratios to study the effect of intermediate elongations. The ratio of 2.5:1 is the current recommended ratio in the MUTCD for highway signs. [3] Australian guidelines indicate that elongation ratios greater than 10:1 distort pavement sign markings. Therefore, a maximum of 10:1 ratio was tested in the driving simulator.

A simulator scenario was created with a roadway network that contained the 15 sign type and elongation ratios combinations. Participants drove the roadway network at two different speeds: 35 mph and 55 mph (Figure 21). The reason for choosing 55 mph as the higher speed is because several countries use 55 mph as the threshold for using a greater elongation ratio and typically two lane highways have a posted speed limit of 55 mph. [31] For the lower experimental speed, 35 mph was chosen because Pennsylvania uses 35 mph as the threshold for using smaller elongation ratio. [17] The total experimental driving distance was in the range of 10 to 15 miles, with a spacing of at least one-half mile between each sign.

Three drivers pilot tested the simulator visual environment prior to conducting the experiment. The purpose of the pilot test was to identify necessary modifications that can only become apparent after administering the experiment. No necessary edits were identified.

Figure 21. Illustration. Driving Course Layout for Stage 1.

Procedures:
Participants were provided with an overview of the experimental procedure and asked to sign an Informed Consent Form (see Appendix D). By signing the Informed Consent Form, participating drivers indicated their understanding of the proposed experiment, willingness to continue, and that compensation would be provided at the end of the experiment. Participants were asked to repeat their understanding of what they were being asked to do before proceeding. Once consent was obtained and understanding confirmed, drivers were seated in the driving simulator and given instructions regarding the procedure. Drivers were asked to fasten their seatbelt, adjust mirrors, and adjust the radio as they would in their own vehicle. Drivers were told that vehicle engine noise will be simulated (along with a small amount of vehicle vibration) and a circulating fan was used to simulate wind through the driver's side window. Subject drivers who prefer to have the window closed were instructed to do so.

The driving portion of the experiment began with a practice module that provided the opportunity for drivers to familiarize themselves with the operational characteristics of the vehicle. Drivers were asked to drive the simulator vehicle as they would drive their own vehicle. Specifically, "don't drive overly conservative nor drive extremely aggressive". At this stage of the experiment, the driver's wellbeing was closely observed for early signs of simulator motion sickness. Drivers who successfully completed the practice course, free of any sickness, were asked to continue with the simulator experiment.

Following the practice course, subjects drove through the experimental scenarios. Drivers started from different positions within the driving scenario to eliminate experimental bias and assure that no driver observed the same sequence of experimental conditions. Drivers were asked to observe speed limit signs and other traffic controls built into the scenarios. Additional signs and marking were included in the experimental scenario to provide a higher level of realism and speed control. While driving, participants were asked to indicate through a verbal 'flag' (i.e., speak out) what sign type they see once they are able to distinguish the pavement marking sign. The timestamp of the moment when the subject indicates recognition was used to determine recognition distance. This process continued until the participating drivers observed all elongation and sign combinations under both speed conditions. On average, the driving portion of the experiment, including the practice module, required 15 to 20 minutes to complete.

Research team members were present to observe and record the results of the driving simulation. Driver responses to each experimental scenario were manually and electronically recorded. Video recordings of all drives were completed and reviewed to confirm driver responses. After completing the experiment, drivers were asked to complete a Payment Voucher and were compensated $20 for their participation in the research study.

Analyses:

Recognition distance was calculated as the distance between the location of the pavement sign and the location of the vehicle when the driver verbally indicated a correct recognition of the pavement sign. However, this methodology did not account for driver's perception and reaction time (PRT) to each sign. Therefore, maximum recognition distance, which takes into account the PRT of drivers, was computed. Distance traveled during PRT was added to the verbal recognition distance to determine the maximum recognition distance. Considering the work done by Dewar et al. and Shoptaugh and Whitaker, a PRT of 0.7 seconds was used to compute maximum recognition distance for elongated horizontal pavement markings. [35, 36]

Statistical analysis was performed to analyze the effect of elongation ratio on maximum recognition distance through a random effects linear model. A random effects linear model was selected to account for the correlation in responses from the drivers. Specifically, this type of model accounts for variance in the dependent variable. [37] Variance can introduce bias in the estimates of the dependent coefficient (β), but the variance can be constrained, leading to estimates that are closer to the true value in any particular sample. [38] The model takes on the form shown in Figure 22.

$$y = X\beta + Zb + \varepsilon$$

Figure 22. Equation. Random Effects Linear Model

Where
y: Response vector
X: Fixed effects design matrix
β: Fixed effects vector
Z: Random effects design matrix
b: Random effects vector
ε: Observation error vector

A model representing the experimental results was built through the backwards stepwise procedure where all variables were initially included. Variables were tested to determine whether they were significant in the model based on the likelihood-ratio test. [39] If the variables were shown to not be significant, they were removed from the model, and the resulting model was tested again until only significant variables ($\alpha = 0.05$) remained.

Results

Recognition distance and maximum recognition distance for each sign type and elongation ratio at 35 and 55 mph are shown in Table 4. Through the backwards stepwise procedure it was found that age, gender, years of driving experience, if the participant wore corrective lenses, and speed were not statistically significant terms in the model. The elongation ratio and sign type were found to be statistically significant, so three different models were found, one for each sign type represented by the generic equation 1, with elongation ratio as the independent variable. The values of A, B and Intercept are shown in Table 5. All the three relationships are quadratic in nature, although the coefficients differ slightly. Figure 23 through Figure 28 show the individual drivers maximum recognition distance as well as the model developed for each sign type. It should be noted since speed was not a significant factor that the model for each sign type could be applied to both the speed scenarios. In order to generalize the model, a model was built that encompasses all the three sign types and is represented by equation 1 and is shown in Figure 29.

$$\text{Recognition Distance} = A * \text{Ratio}^2 + B * \text{Ratio} + \text{Intercept} \qquad (1)$$

Table 4. Recognition distances for each sign type and elongation ratio at 35 mph and 55 mph.

Driver Speed	Sign		Max. Recognition Dist. (ft)				Recognition Dist. (ft)			
	Type	Ratio	Avg.	S.D.	Min	Max	Avg.	S.D.	Min	Max
35	Pedestrian (W11-2)	1 : 1	66	23	14	106	31	19	0	69
		2.5 : 1	103	29	46	158	66	30	0	121
		5 : 1	131	34	55	190	95	34	20	154
		7.5 : 1	161	37	91	229	123	38	55	194
		10 : 1	153	37	84	207	117	37	49	171
	Speed (R2-1)	1 : 1	54	17	13	81	19	13	0	42
		2.5 : 1	105	28	73	176	69	27	40	138
		5 : 1	134	28	85	194	96	30	40	158
		7.5 : 1	165	36	99	247	127	37	51	210
		10 : 1	186	41	116	253	148	41	78	217
	Turn (W1-2)	1 : 1	59	32	0	100	29	19	0	63
		2.5 : 1	91	28	26	139	54	25	0	96
		5 : 1	139	48	56	215	101	50	5	178
		7.5 : 1	167	45	74	244	130	45	37	209
		10 : 1	176	47	91	263	139	49	54	227
55	Pedestrian (W11-2)	1 : 1	54	27	0	89	10	12	0	35
		2.5 : 1	95	38	5	160	43	32	0	103
		5 : 1	131	36	77	194	74	35	21	137
		7.5 : 1	151	50	56	235	95	50	3	176
		10 : 1	160	44	100	242	103	44	41	184
	Speed (R2-1)	1 : 1	59	27	10	110	13	16	0	56
		2.5 : 1	115	40	58	200	64	41	3	143
		5 : 1	144	38	96	220	88	37	40	163
		7.5 : 1	172	51	49	251	116	48	5	192
		10 : 1	210	49	122	288	153	47	67	222
	Turn (W1-2)	1 : 1	51	35	10	130	12	22	0	73
		2.5 : 1	94	40	22	174	42	33	0	113
		5 : 1	144	44	85	219	88	45	26	163
		7.5 : 1	180	32	126	235	123	31	68	176
		10 : 1	181	42	96	264	125	42	38	206

Table 5. Coefficients for Relationship between Maximum Recognition Distance and Elongation Ratio.

Sign	A	B	Intercept
Pedestrian	-1.57	27.94	33.94
Speed	-0.99	25.36	39.42
Curve	-1.66	32.19	23.40
All Signs	-1.41	28.53	32.14

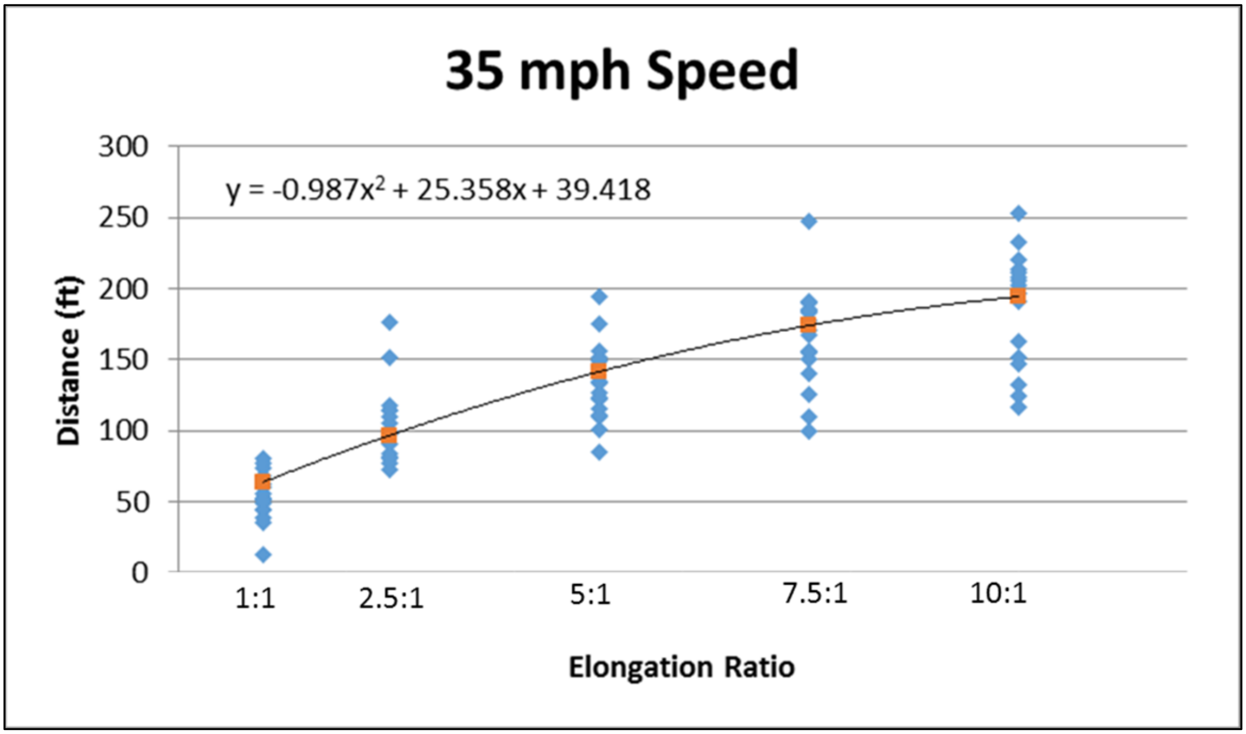


Figure 23. Chart. Relationship between Maximum Recognition Distance and Elongation Ratio for Speed Limit Sign at 35 mph.

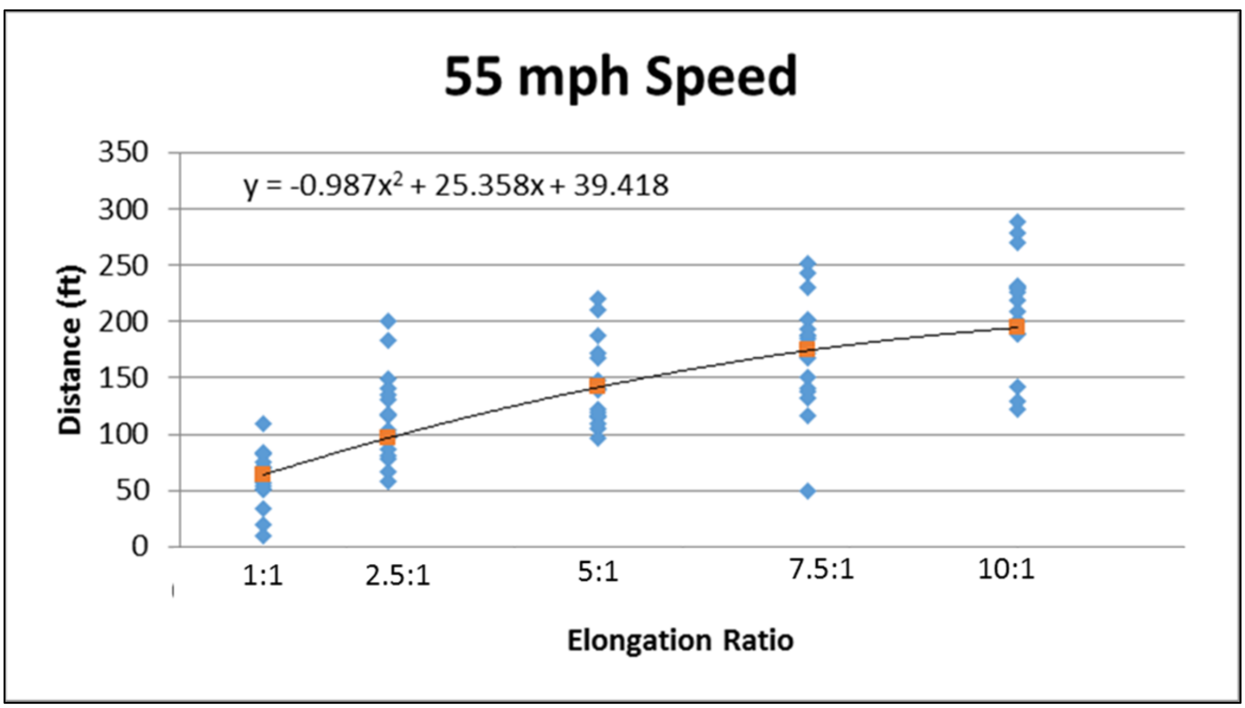


Figure 24. Chart. Relationship between Maximum Recognition Distance and Elongation Ratio for Speed Limit Sign at 55 mph.

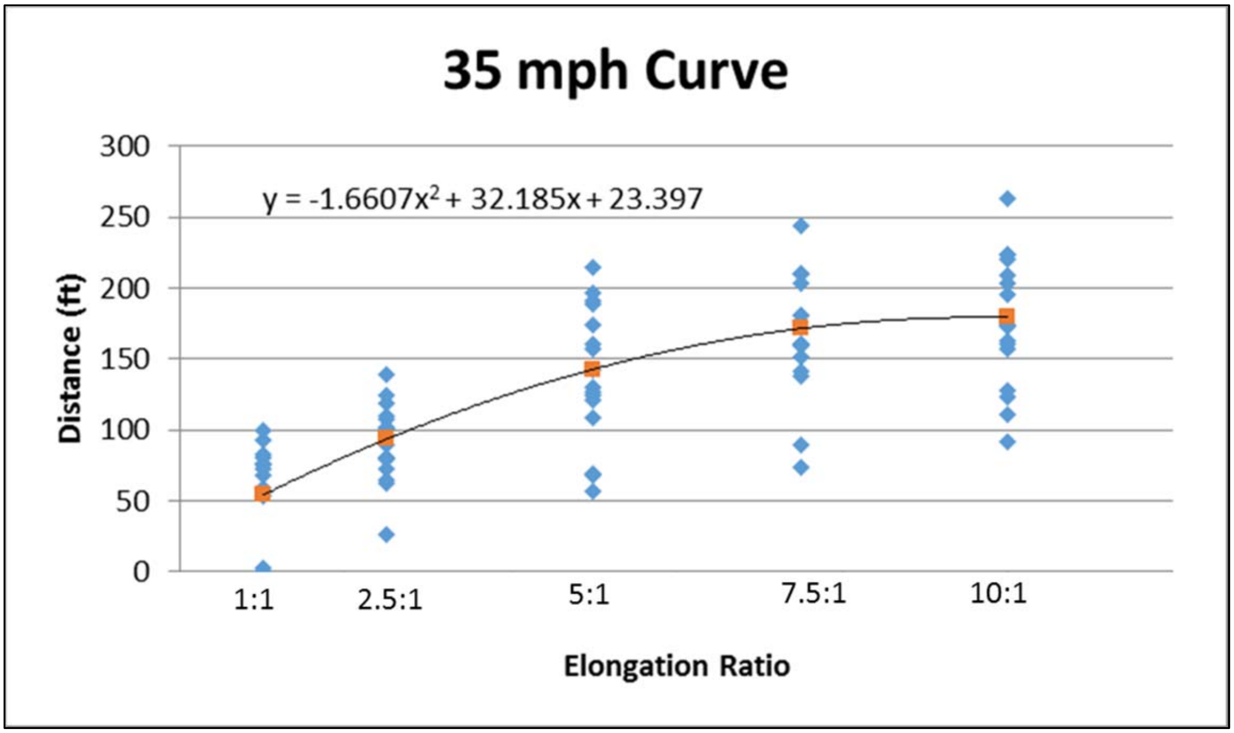


Figure 25. Chart. Relationship between Maximum Recognition Distance and Elongation Ratio for Curve Sign at 35 mph.

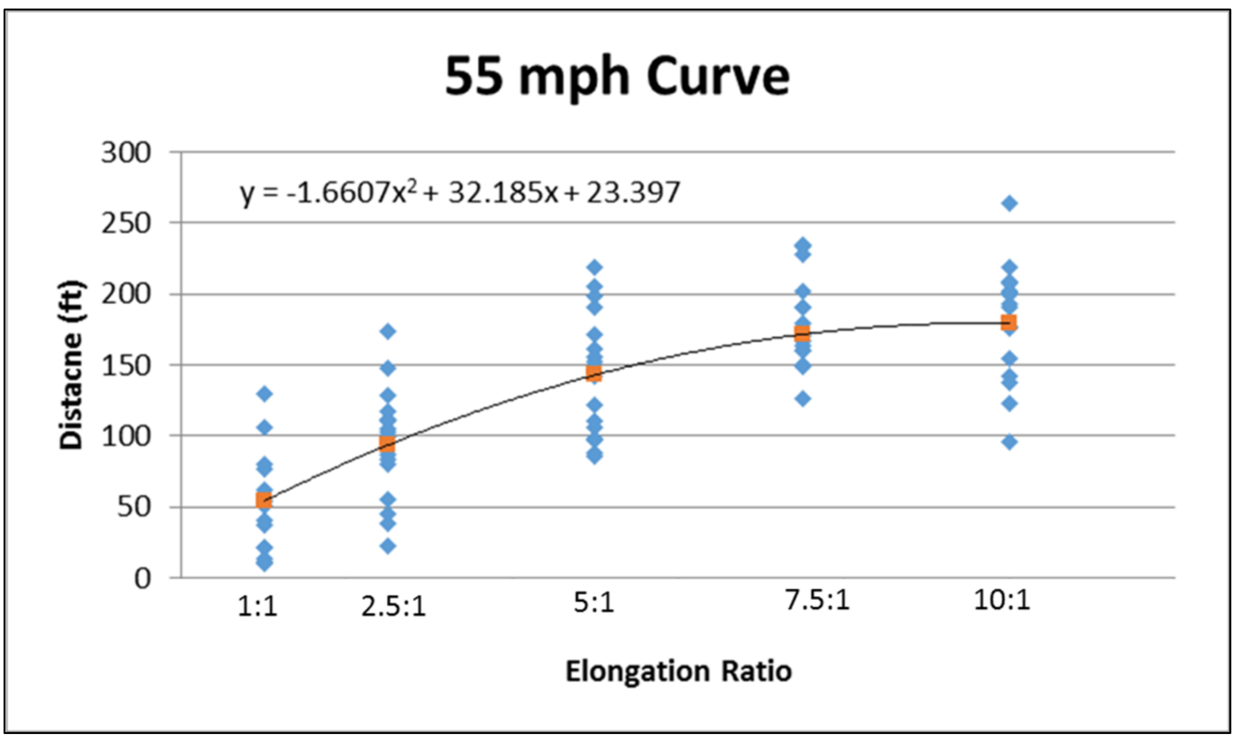


Figure 26. Chart. Relationship between Maximum Recognition Distance and Elongation Ratio for Curve Sign at 55 mph.

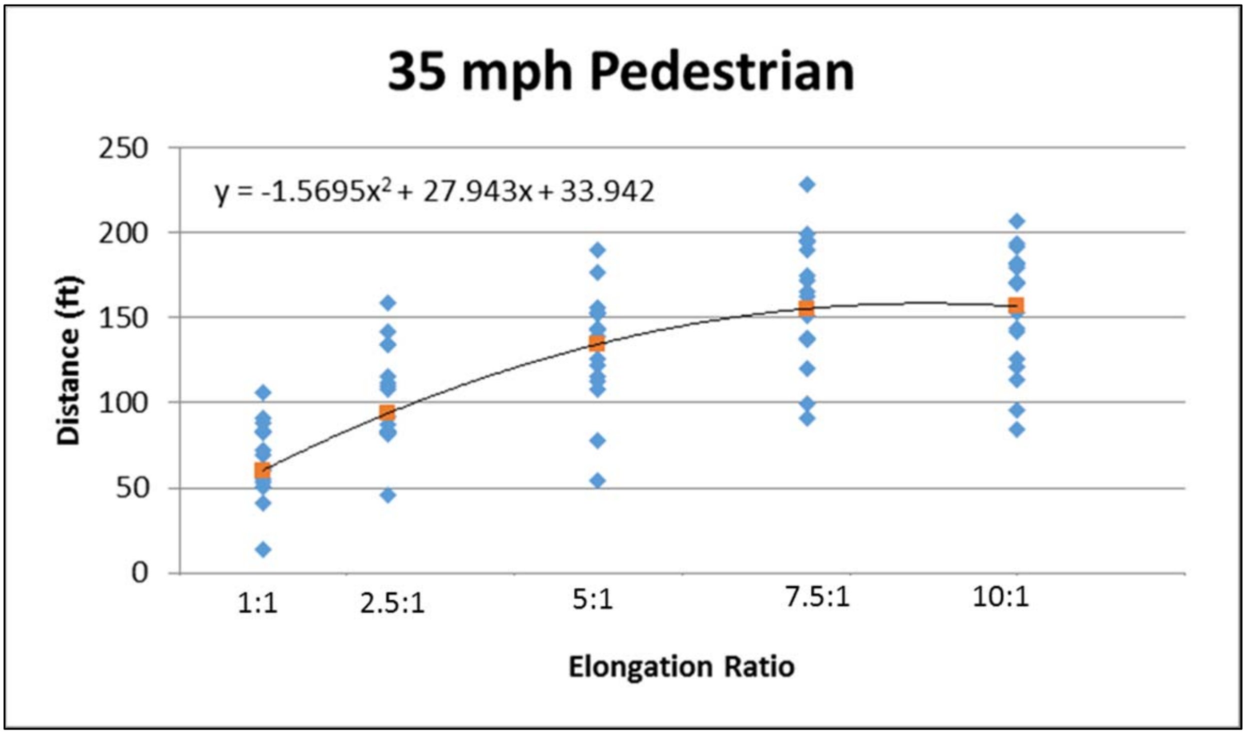


Figure 27. Chart. Relationship between Maximum Recognition Distance and Elongation Ratio for Pedestrian Crossing Sign at 35 mph.

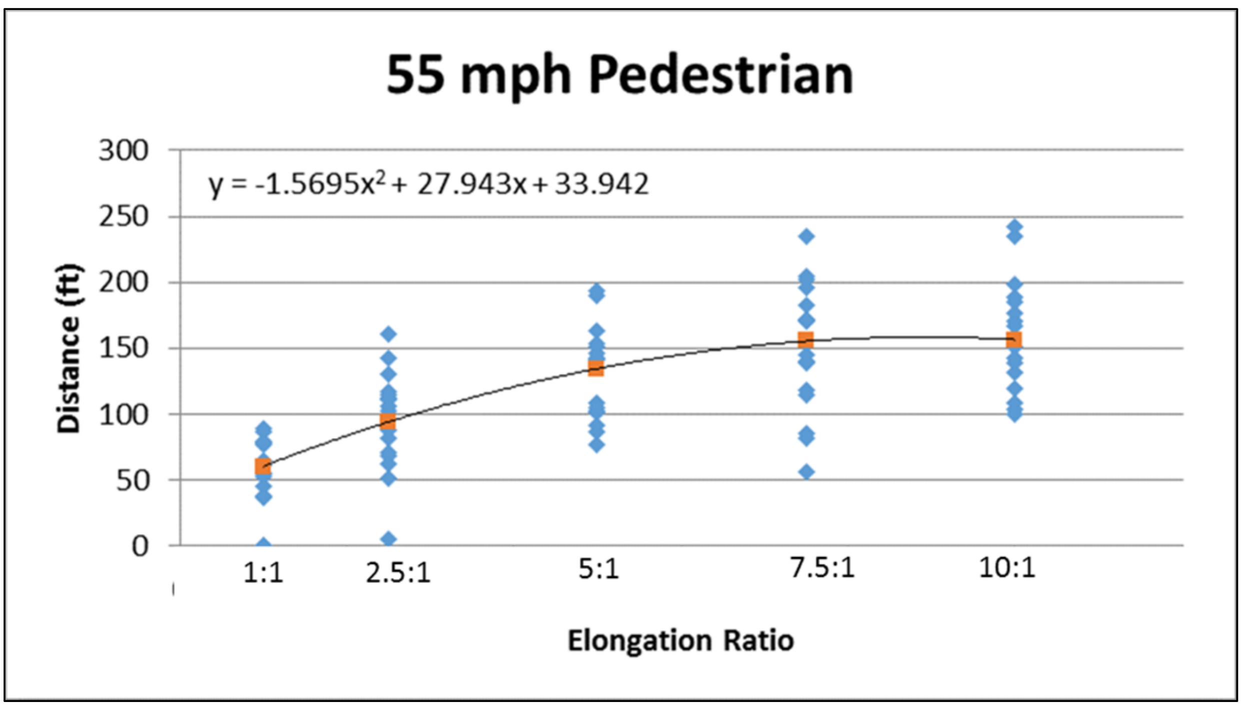


Figure 28. Chart. Relationship between Maximum Recognition Distance and Elongation Ratio for Pedestrian Crossing Sign at 55 mph.

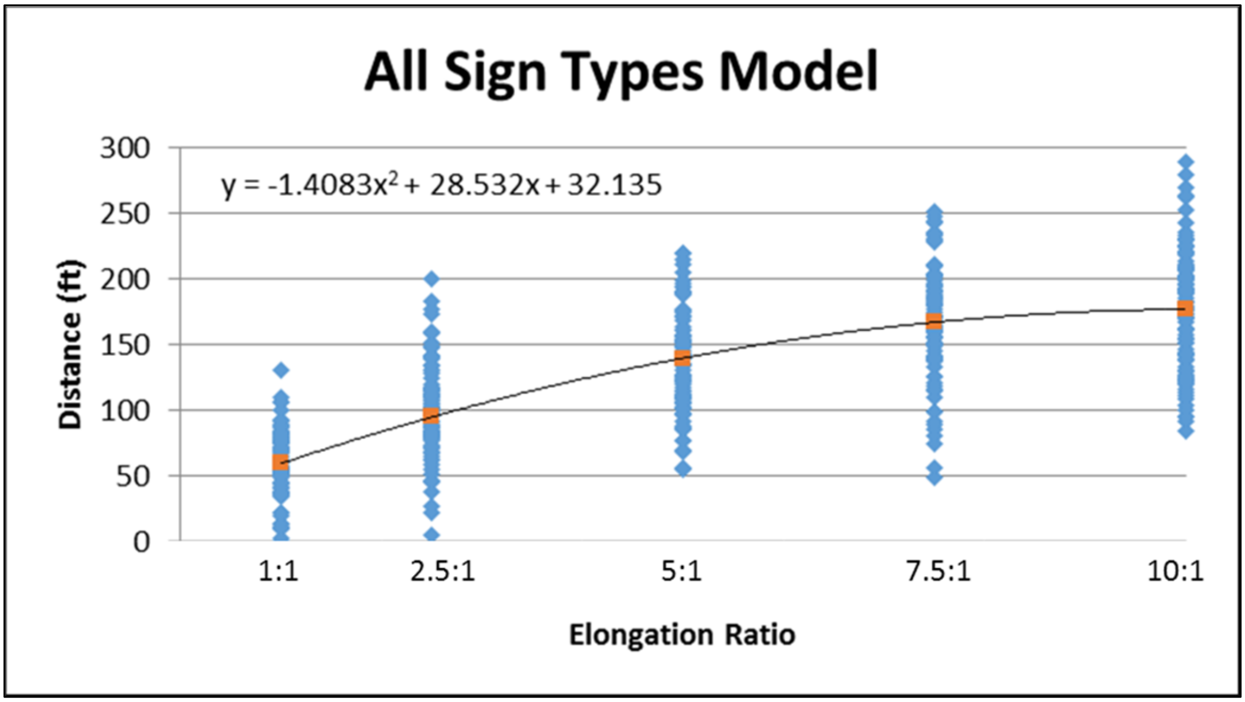


Figure 29. Chart. Relationship between Maximum Recognition Distance and Elongation Ratio for All Sign Types.

Discussion

As shown in Figure 29, maximum recognition distance increases quadratically with increases to elongation ratio up to a ratio of 10:1. A random effects linear model was built from a backwards stepwise procedure to determine that the relationship between recognition distance and elongation ratio is a quadratic function. These results are in line with research findings of MacDonald and Hoffman who reported that relationship between recognition distance of elongated pavement marking letters and letter height (surrogate for elongation ratio) is nearly quadratic. [27]

A very important consideration in the use of any field-based pavement marking sign application is cost and safety. A greater elongation ratio results in a larger sign leading to higher cost of the elongated sign. Therefore, a tradeoff was considered between cost practicality and maximum recognition distance. While elongation ratio of 10:1 has the highest maximum recognition distance in Figure 23 through Figure 29, the cost of installing signs at this elongation ratio were significantly higher and provided a number of installation challenges. Figure 29 shows that the marginal increase in maximum recognition distance reduces beyond the elongation ratio of 5:1. The 5:1 elongation ratio also was found to provide a significant improvement in recognition distance over the currently used 2.5:1 ratio. Therefore, a 5:1 elongation ratio was recommended for stage 2 of the driving simulator evaluation as well as the field evaluations.

Driving Simulator Evaluation: Stage 2

During the second stage, a different group of participating drivers were asked to drive through a road network designed to study the effectiveness of elongated pavement markings placed in conjunction with traditional post-mounted signs. Having a different set of drivers ensured that they had no expectations related to the pavement marking signs biasing the results of this stage. Two types of conditions were presented in the driving simulator visual world: 1) Conditions that included post-mounted sign only, and 2) Conditions that included both pavement and complimentary post-mounted signs. These two conditions allowed a comparison of the effect of elongated pavement marking signs with and without complimentary post-mounted signs.

The research team also explored the location effect of the elongated pavement marking 'Curve' sign relative to the post-mounted sign. All previous field applications of the 'Curve' pavement marking sign were located either at the point of curvature (PC) of the horizontal curve or at a location in between the PC and the post-mounted sign. [25, 19, 20] Therefore, in addition to adjacent to the post-mounted sign, the curve pavement marking sign was placed downstream and upstream of the post-mounted sign to explore the impact of offset signing.

Methods

Participants:
Nineteen drivers, between the ages of 19 and 63, participated in the experimental stage. Similar to Stage 1, recruitment was done through a variety of local mediums, including local advertisement on campus, through campus and community organizations, and using databases of past subjects. Drivers were screened for a valid driver's license, in addition to age/gender group categorization. All demographic data were obtained through a questionnaire completed by the participating drivers. Given the small number of drivers included in the experimental design of this study, drivers selected for participations were not entirely representative of the general driver population. A complete overview of participant demographics is shown in Table 6.

Table 6. Participant Demographics for Stage 2.

Subject ID	**Gender**	**Years of Driving Experience**	**Corrective Lenses**	**Age**
815201401	Female	40	No	60
815201402	Male	40	No	63
815201403	Female	18	No	34
815201404	Male	40	No	63
826201401	Male	13	No	30
827201401	Male	3	No	19
827201402	Male	4	No	20
827201403	Male	6	No	23
827201404	Male	8	No	21
827201405	Male	16	No	29
827201406	Male	9	No	20
827201407	Male	11	No	28
829201401	Female	5	No	24
904201401	Female	4	No	21
904201402	Female	8	No	23
905201401	Female	24	Yes	41
905201402	Female	9	Yes	25
905201403	Female	20	No	36
905201404	Female	13	No	28
905201405	Female	15	Yes	37
905201406	Female	14	No	30

Materials:

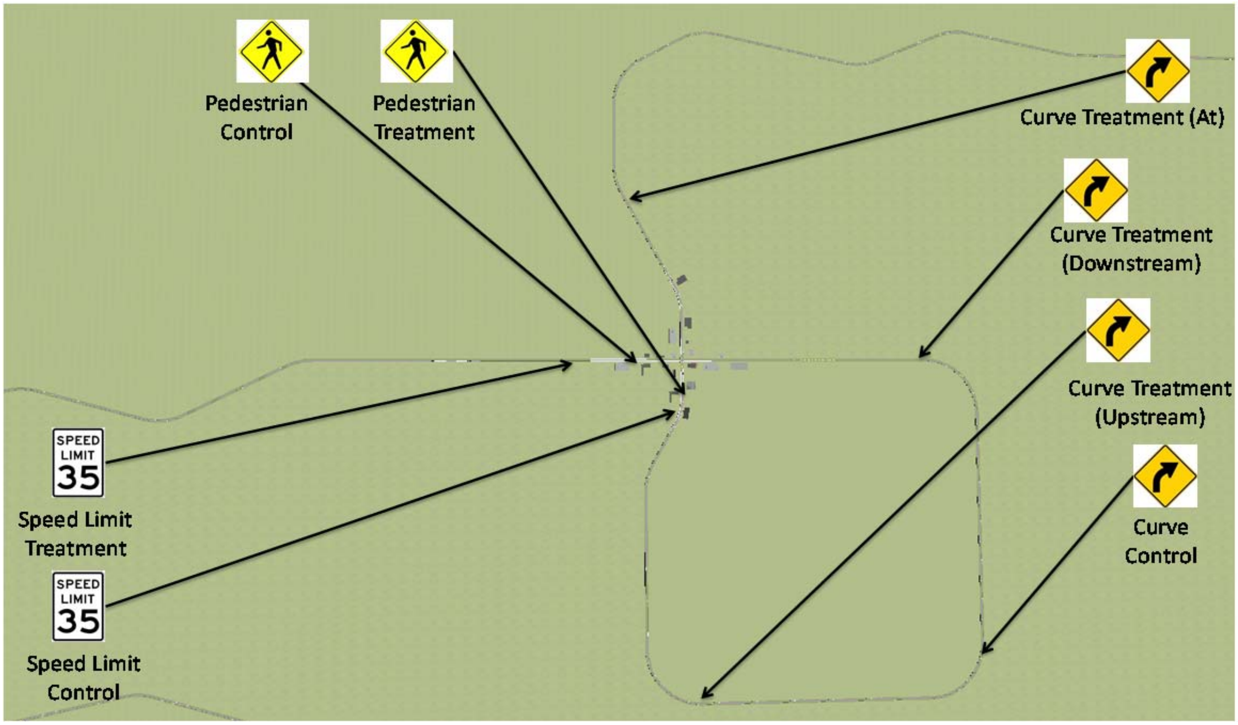


Figure 30 shows the driving course layout and Figure 31 through Figure 33 illustrate the three elongated signs in the driving simulator.

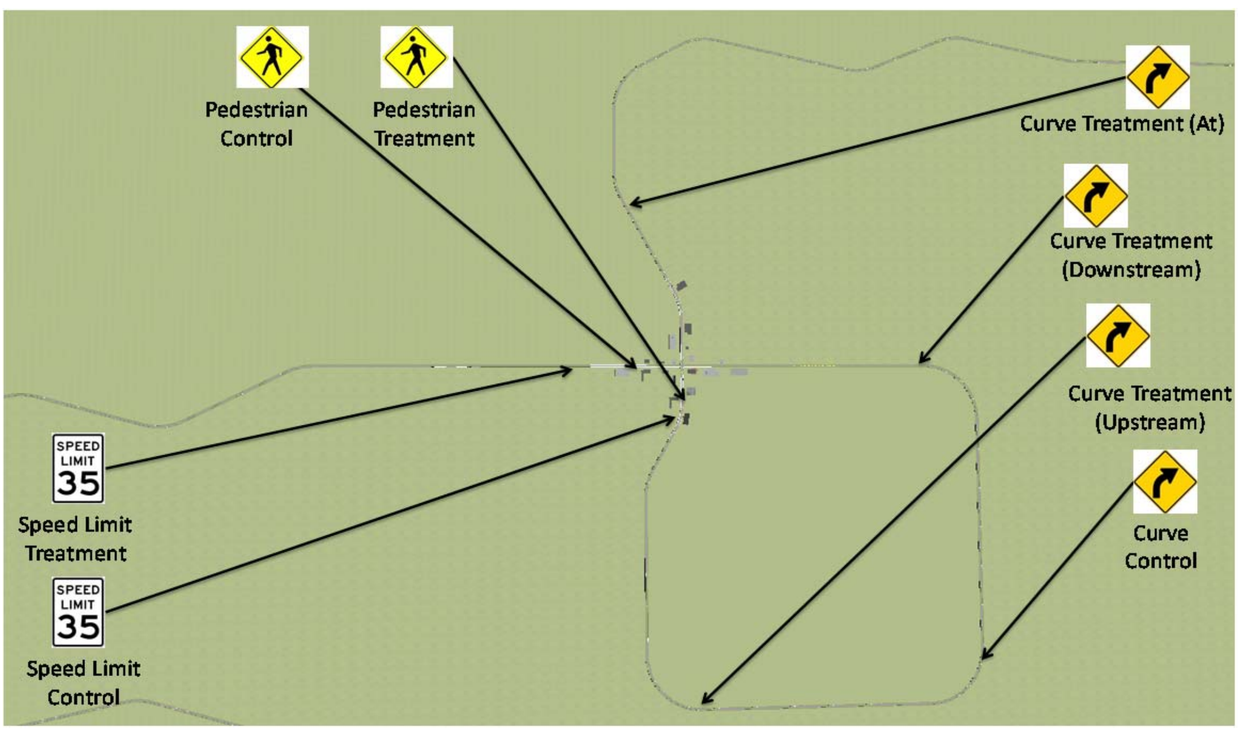


Figure 30. Illustration. Driving Course Layout for Stage 2.

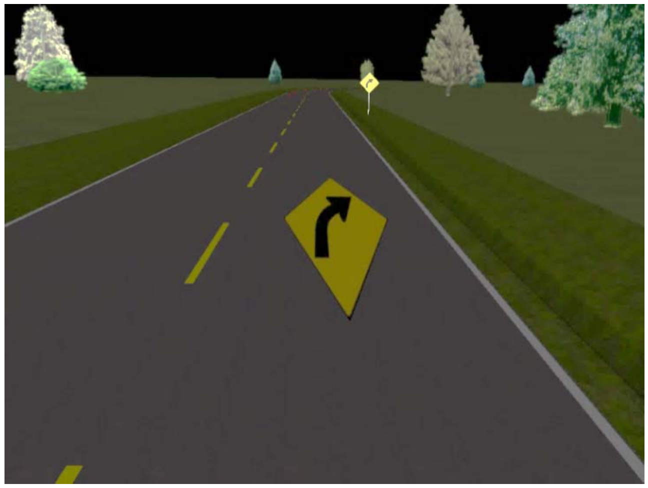


Figure 31. Photo. Snapshot of Elongated Curve Sign in Simulator.

Figure 32. Photo. Snapshot of Elongated Speed Limit Sign in Simulator.

Figure 33. Photo. Snapshot of Elongated Pedestrian Sign in Simulator.

After creating the simulator scenarios, but prior to conducting the experiment, three drivers tested the simulator visual environment. The purpose of the pilot test was to identify necessary modifications that can only become apparent after administering the experiment. No additional changes were identified.

Procedure:

Table 7 summarizes the eight conditions that comprised the experimental design for Stage 2. Two scenarios each with the eight conditions were created and are referred to as Scenario 1 and Scenario 2. Two scenarios were used to ensure that each participant was exposed to two repetitions of all conditions. Total driving distance was in the range of 10 to 15 miles, with spacing of one half mile or longer between each condition. Experimental counterbalance was provided through different starting positions within each driving scenario. The simulator evaluation was limited to daytime conditions. Nighttime conditions were not considered given the difficulty of simulating the impact of vehicle headlight types and impact on sign visibility.

Table 7. Experimental Design for Stage 2 of Simulator Study.

Sign	Scenarios
Curve Warning	• Post-mounted only (Control). • Elongated Pavement Marking at the post-mounted sign. • Elongated Pavement Marking halfway between post-mounted sign and PC. • Elongated Pavement Marking 100 ft upstream of post-mounted sign.
Speed Limit	• Post-mounted only (Control). • Elongated Pavement Marking at the post-mounted sign.
Pedestrian Crossing	• Post-mounted only (Control). • Elongated Pavement Marking upstream of the post-mounted sign.

Driver speeds at three locations were used for the evaluation of effectiveness of speed limit and curve signs. For the pedestrian sign, downstream location was not used since drivers are not expected to maintain reduced speed once they passed the pedestrian crossing. The three locations were:

- Upstream: approximately 1000 ft upstream of the post-mounted sign.
- At the post-mounted sign.
- Downstream at the point of horizontal curvature (PC) for curve sign or 500 ft downstream for speed limit sign.

The procedure followed in stage 2 was essentially identical to the procedure followed in stage 1. The only difference is that drivers did not have to verbally indicate what sign type they observed. Rather, drivers simply had to drive through the scenario responding to signing, marking, and other roadway information as they normally would.

Results

The dependent variable in each scenario was operating speed. Considering the limited sample size statistical analyses were not performed. Rather trends in operating speed were studied to ascertain the effectiveness of elongated pavement marking signs. Figure 34 through Figure 36 illustrate that speed profiles of individual vehicles in the treatment conditions are similar or lower than speeds in the control conditions at all the signs and downstream of the sign. Control group refers to post-mounted sign only and treatment group refers to addition of an elongated pavement marking sign. Additionally, even in conditions where speeds may have been higher in the after period, speed trends generally show speed reduction as drivers approach the treatment location and then further downstream. Individual driver speed shown in Figure 34 also shows the effect of elongated pavement marking curve sign placement relative to the post-mounted sign. Placing the elongated pavement marking curve sign downstream of the post-mounted sign was most effective at reducing speeds followed by placing it at the post-mounted sign and upstream of the post-mounted sign.

Figure 37 through Figure 39 show average operating speeds with their 95% confidence intervals by location and by sign type for the control and treatment conditions.

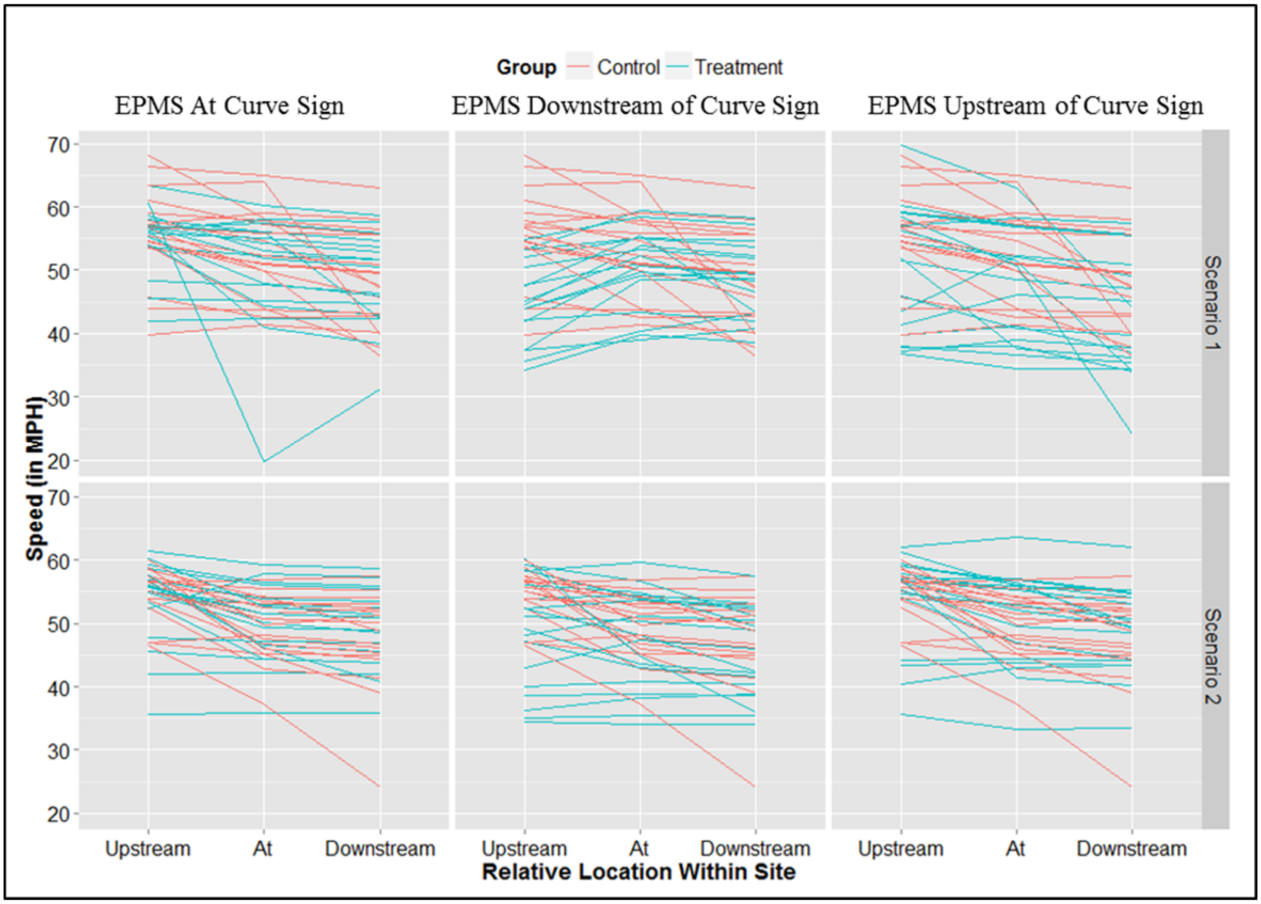


Figure 34. Chart. Individual Driver Speed Behavior by Location for Curve Sign

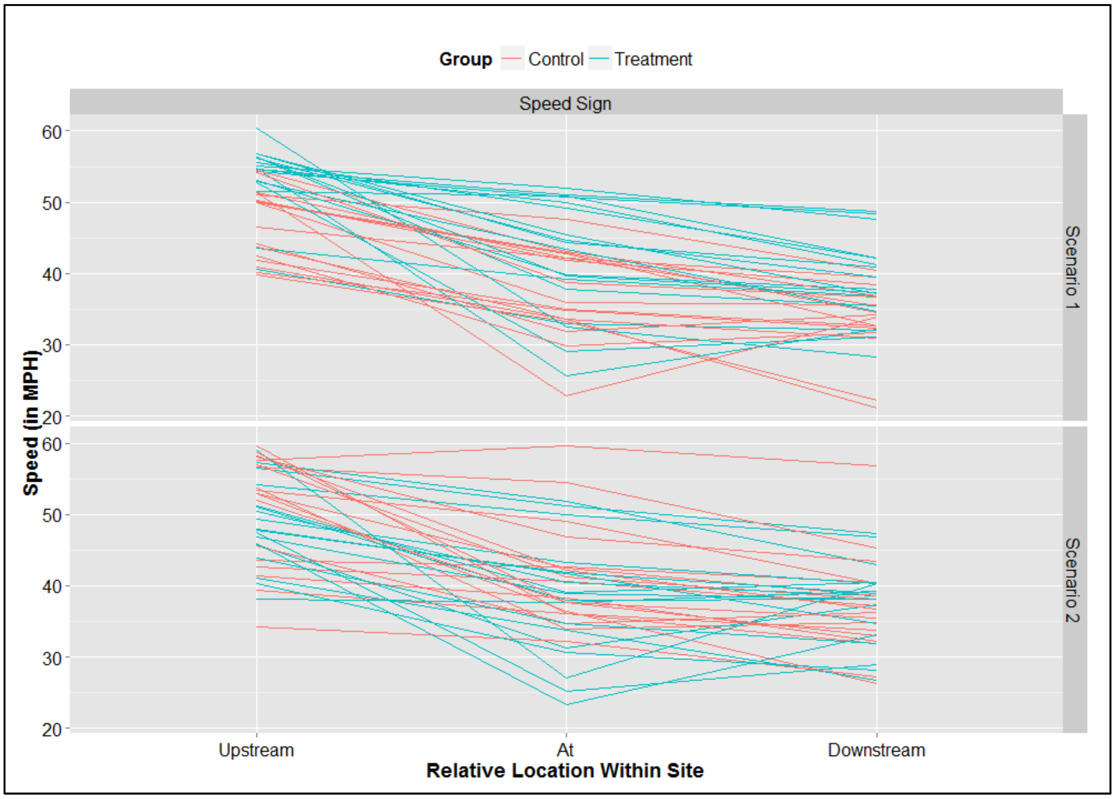


Figure 35. Chart. Individual Driver Speed Behavior by Location for Speed Limit Sign.

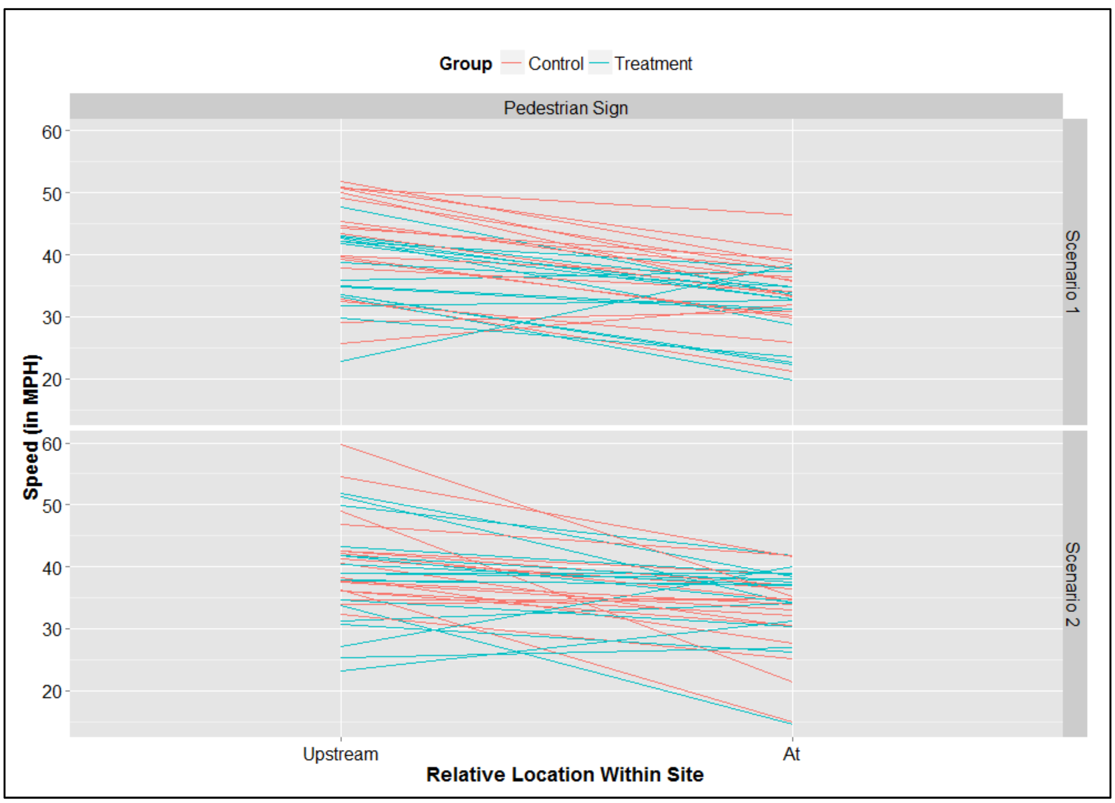


Figure 36. Chart. Individual Driver Speed Behavior by Location for Pedestrian Sign.

Figure 37 shows that average speeds for the speed limit sign in treatment condition were similar to or greater than speeds in the control condition.

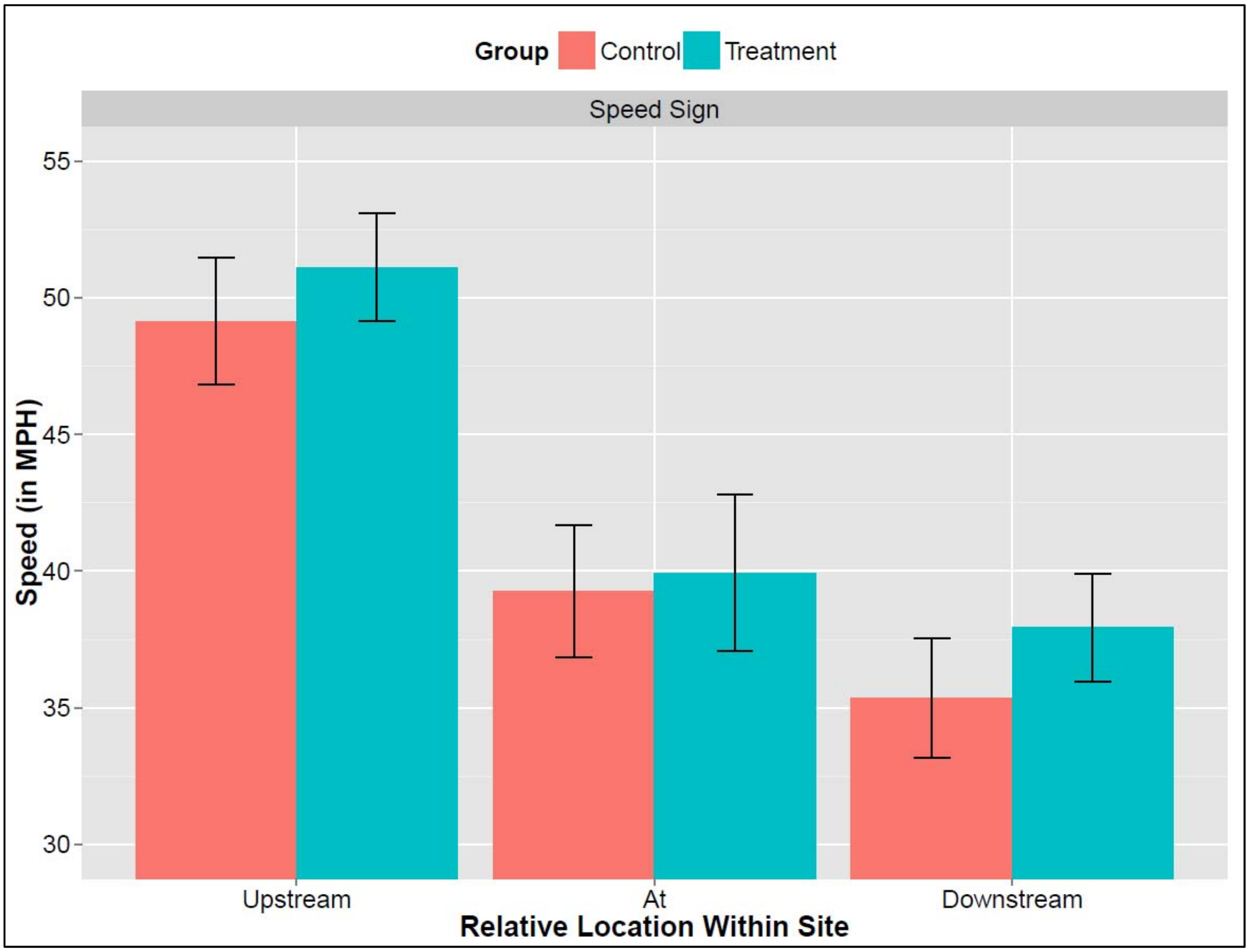


Figure 37. Chart. Average Driver Speed by Location for Speed Limit Sign.

Figure 38 and Figure 39 show that for curve and pedestrian signs, average speeds in treatment condition were generally lower than in the control condition. Figure 38 shows that the reduction in average speed at the PC, when the pavement sign was placed downstream of the post-mounted sign was higher than the reduction when placed “at the sign”. When the elongated pavement marking sign is placed upstream of the post-mounted sign the speed at PC was higher than the control condition.

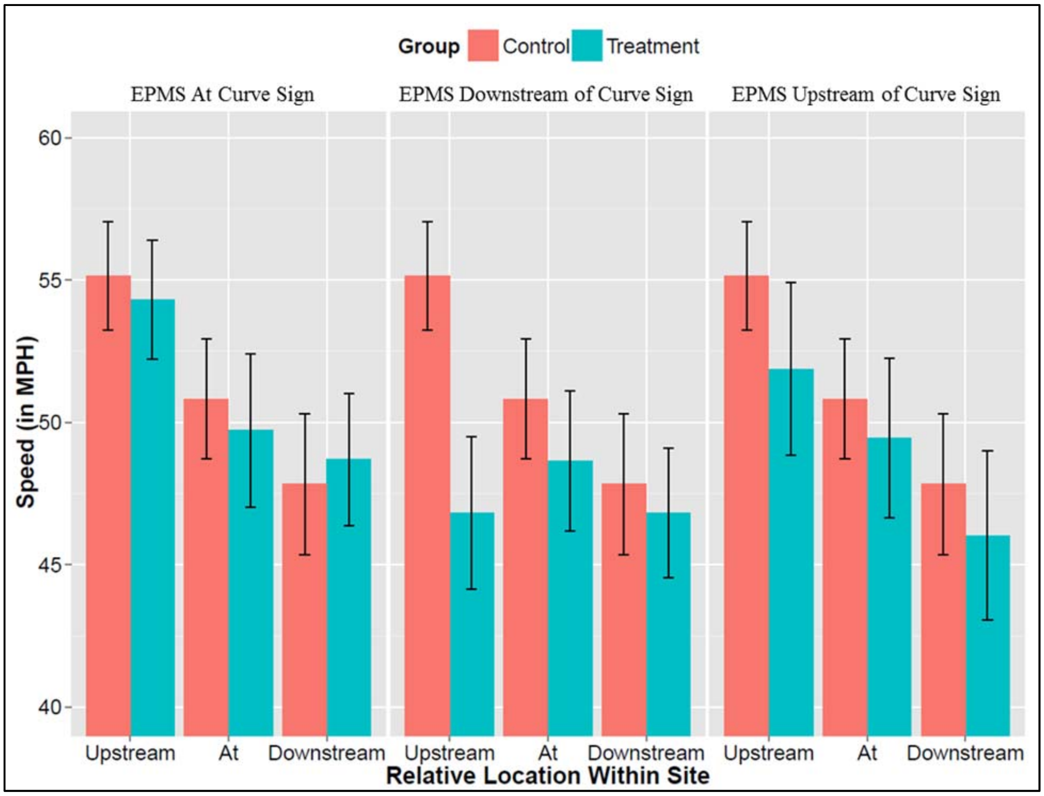


Figure 38. Chart. Average Driver Speed by Location for Curve Sign.

Figure 39. Chart. Average Driver Speed by Location for Pedestrian Sign.

SIMULATOR EVALUATION CONCLUSIONS

Stage 1 of driving simulator evaluation was performed to evaluate the effect of elongation on recognition distance of pavement marking signs. Three signs types (speed limit, curve, and pedestrian) and five elongation ratios (ranging from 1:1 to 10:1) were included in the driving simulator scenario. Sixteen drivers between the ages of 21 and 54 participated in the study. Driver perception reaction time was accounted for in computing maximum recognition distance. Statistical analysis was performed to analyze the effect of elongation ratio on maximum recognition distance through a random effects linear model. Through the backwards stepwise procedure it was found that age, gender, years of driving experience, if the participant wore corrective lenses, and speed were not statistically significant terms in the model. The elongation ratio and sign type were found to be statistically significant. Results confirm that maximum recognition distance increases quadratically with increase in elongation ratio. The marginal increase in maximum recognition distance reduces as elongation ratio increases, especially beyond 5:1 ratio. Therefore 5:1 ratio was recommended for the field evaluation.

The Stage 2 driving simulator evaluation was performed to study the effectiveness of elongated pavement marking signs (on driver speeds) placed near traditional post-mounted signs. Speed limit, curve, and pedestrian signs were studied. Speed limit, curve, and pedestrian signs were studied. For the curve sign, placement of the elongated pavement marking sign relative to the post-mounted sign was also evaluated. Results indicated that speeds of drivers in conditions with elongated pavement marking signs were similar or lower than speeds in conditions with post-mounted signs only. Furthermore, placing the elongated pavement marking sign downstream of the post-mounted sign was more effective than placing it adjacent to the post-mounted sign. Similarly, placing the elongated pavement marking sign at the post-mounted sign was more effective than placing it upstream of the post-mounted sign.

CHAPTER 4. FIELD EVALUATION

This chapter describes the field evaluation of elongated pavement marking signs. The objective of the field evaluation was to measure the effectiveness (i.e., impact on vehicle operating speeds) of elongated pavement marking signs within an actual driving environment. An elongation ratio of 5:1 was chosen based on the results of the driving simulator phase. The research team worked with a sign manufacturer for procuring the elongated pavement marking signs. The regulatory speed limit sign (R2-1) and the curve warning sign (W1-2) were evaluated. Kansas, Missouri and Wisconsin participated in the field evaluation. Elongated ‘Curve’ and ‘Speed Limit’ pavement marking signs were installed at one site each in Wisconsin, at two sites each in Kansas. ‘Speed Limit’ pavement marking sign was installed at one site in Missouri.

METHODS

Materials:
Individual states in consultation with the research team chose data collection sites based on the following criteria:

- Two-lane highway.
- Lower volume (so that traffic is free-flowing).
- Rural or urban.
- Preferably sites with commuter and recreational traffic.
- No confounding factors such as intersections, significant vertical grade, or access points in the vicinity.

Pavement marking versions of the regulatory speed limit sign (R2-1) and the curve warning sign (W1-2) were installed at seven sites in three states (Table 8) as per MUTCD requirements. Each state determined the type of material for the elongated pavement marking signs. Considerations were based on individual state’s experience with materials, concerns about possibility of skidding for motorcycles in wet pavement conditions, and minimizing pavement damage if the sign were to be removed. Kansas used thermoplastic pavement marking material while Missouri used paint, and Wisconsin used tape. Table 8 lists the sign installed, states, sites, highway/road name, average daily traffic (ADT), posted/advisory speed and material used for each elongated pavement marking signs.

Since the elongated pavement marking signs are not in the MUTCD, the research team prepared Requests for Experimentation (RFEs) in accordance with the MUTCD guidelines for each state. RFEs were submitted by the individual state agencies to the Federal Highway Administration (FHWA) for approval. Following the approval of the RFEs, signs were procured and installed. The cost of painted EPMS was about $1,000, while the thermoplastic and tape-based EPMS were between $2,000 and $3,000 each. Figure 40 shows the installation of thermoplastic curve sign in Lecompton, KS. Figure 41 through Figure 47 show the elongated pavement marking signs installed at each of the sites. EPMS installation required lane closure and flagger control. For the painted sign in MO, installation time was approximately 1.5 hours and for the other signs installation time ranged from 1.5 to 3 hours per sign.

Table 8. Sites for Field Evaluation.

Sign	State	Site	Highway/Road	ADT	Posted /Advisory Speed	Material
Speed Limit	Kansas	Andale	247^{th} St West	818	35 mph	Thermoplastic
Speed Limit	Kansas	Bentley	151^{st} St West	2415	30 mph	Thermoplastic
Speed Limit	Missouri	Branson West	Missouri 13	5100	50 mph	Paint
Speed Limit	Wisconsin	Brooklyn	Wisconsin 92	1800	25 mph	Tape
Curve	Kansas	Lecompton_1	Route 442	2000	45 mph	Thermoplastic
Curve	Kansas	Lecompton_2	Route 442	2000	40 mph	Thermoplastic
Curve	Wisconsin	Jefferson	Wisconsin 89	4400	40 mph	Tape

Figure 40. Photo. Installation of Curve Sign in Lecompton, KS.

Figure 41. Photo. Speed Limit Sign in Andale, KS. (With permission from Sedgwick Co, KS)

Figure 42. Photo. Speed Limit Sign in Bentley, KS. (With permission from Sedgwick Co, KS)

Figure 43. Photo. Curve Sign-1 in Lecompton, KS. (With permission from Douglas Co, KS)

Figure 44. Photo. Curve Sign-2 in Lecompton, KS. (With permission from Douglas Co, KS)

Figure 45. Photo. Speed Limit Sign in Branson West, MO. (With permission from Missouri DOT)

Figure 46. Photo. Speed Limit Sign in Brooklyn, WI. (With permission from Wisconsin DOT)

Figure 47. Photo. Curve Sign in Jefferson, WI. (With permission from Wisconsin DOT)

Procedure:
In order to determine the effect of elongated pavement marking signs in conjunction with post mounted signs, a 'before and after' experimental approach was employed. Data were collected at three locations at each site. There was an upstream location approximately 1,000 ft upstream of the post-mounted sign; and speed was measured at the post-mounted sign, and at downstream locations at variable distances. The exact locations of the down-stream locations were site dependent to avoid placing the data collection equipment at driveways, intersections or other roadway features that might impact speeds Figure 48 shows the spots for the aforementioned zones.

For the 'Curve' sign, the downstream location was the point of horizontal curvature. For the 'Speed Limit' sign, the downstream location was approximately 500 feet inside the speed zone. Participating states ensured that the post mounted signs at the data collection sites were in compliance with the MUTCD standards to ensure that results were due to the pavement markings themselves and not the change from a non-compliant to a compliant post-mounted sign.

Research team members or the participating agencies collected data before and after the installation of the elongated pavement marking signs. Data were collected using pneumatic tubes (in WI and KS) and Nu-metric pads (in MO) for up to one week in both the before and after conditions. Except for the Missouri location, speed, vehicle type, and timestamp data were collected for individual vehicles. In Missouri, average vehicle speed and number of vehicles were collected in bins of 30 minutes. Data collection after the installation of the pavement marking signs commenced a minimum of one week after the installation to eliminate any potential novelty effect in the data. Dates of data collection and sign installation for all the seven sites are presented in Table 9.

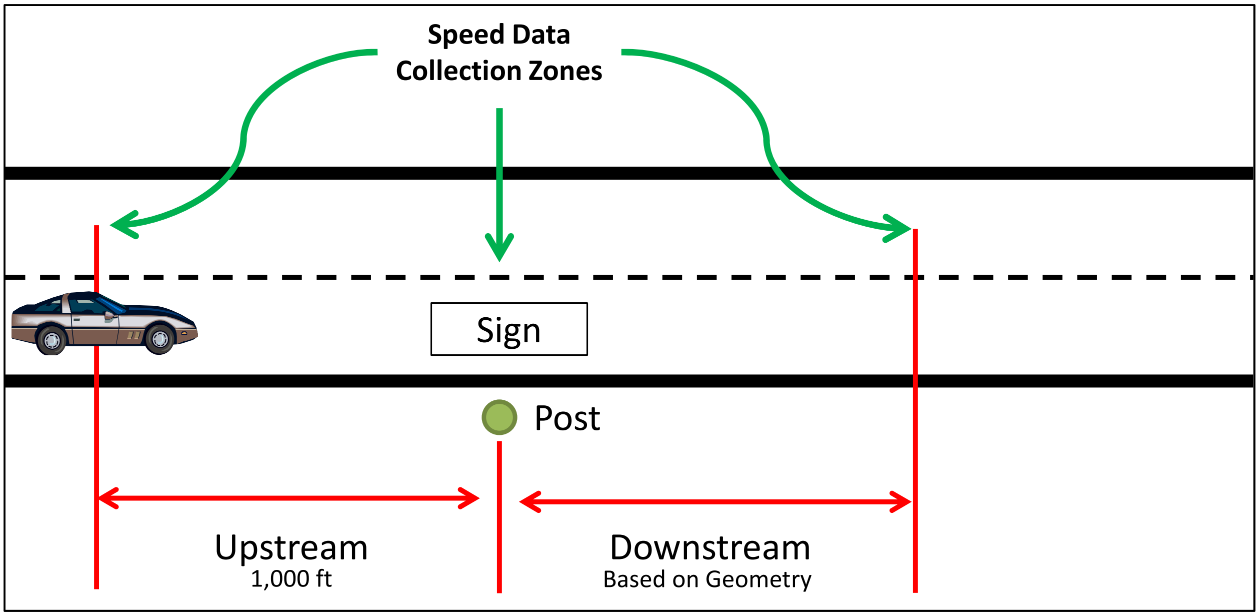


Figure 48. Illustration. Zones for Speed Data Collection

Table 9. Dates of Installation, Before and After Data Collection.

State	Site	Before Start	Before End	Installation Date	After Start	After End
Kansas	Andale	6/9/2014	6/17/2014	8/7/2014	8/18/2014	8/26/2014
Kansas	Bentley	6/17/2014	6/25/2014	8/11/2014	8/18/2014	8/26/2014
Kansas	Lecompton-1	6/16/2014	6/23/2014	8/7/2014	8/14/2014	8/21/2014
Kansas	Lecompton-2	6/23/2014	7/1/2014	8/7/2014	8/21/2014	8/28/2014
Missouri	Branson West	7/10/2014	7/17/2014	7/28/2014	8/7/2014	8/12/2014
Wisconsin	Brooklyn	6/5/2014	6/13/2014	8/4/2014	8/13/2014	8/20/2014
Wisconsin	Jefferson	6/16/2014	6/27/2014	8/4/2014	8/22/2014	8/29/2014

Analyses:

Free flow vehicle speed was evaluated for the data from KS and WI since individual vehicle speeds were collected. Free flow vehicles are vehicles with minimum time headway of 4 seconds between them and the previous vehicle, with the assumption that drivers operating speed is not impacted by other vehicles or congestion. For the MO site, average speed in 30 min durations were collected and were used for the analysis.

Following quality checks, data analysis was performed to quantify the effect of signs on driver speed. It was hypothesized that the 'Curve' sign and the 'Speed Limit' pavement marking signs will lead to decreased operating speeds at both the post-mounted sign location and downstream location. Statistical analyses was performed to determine the statistical significance of the change in speeds. A statistically significant decrease in speed meant that the elongated pavement marking sign was effective in reinforcing the message (warning or regulatory) to drivers. Student's t-test was performed to determine the statistical significance of changes in mean speed.

Results and Discussion

***Speed Limit Sign at the Kansas and Wisconsin Sites*:**
Mean, standard deviation, and sample sizes of free flowing vehicles at sites in KS and WI are shown in Table 10. T-test p-values are also shown in Table 10. Mean speed reduced by 1.9 mph at the sign and by 2.5 mph downstream of the sign in Andale, KS. In Bentley, KS, mean speed increased by 2.1 mph and reduced by 0.2 mph at the sign and downstream, respectively. In Brooklyn, WI, mean speed reduced by 4.7 mph at the sign and increased by 1.5 mph downstream. All the changes in mean speed were statistically significant.

It should be noted that Wisconsin Department of Transportation (WisDOT) installed a sign (shown in Figure 49) warning drivers about the presence of an experimental sign on pavement shortly after the pavement marking sign was placed. Apparently, WisDOT staff observed drivers trying to avoid driving over the newly placed elongated pavement marking sign by swerving to the right or left. Assuming a potential safety issue, WisDOT installed the sign. It is unclear if this sign impacted operating condition; nevertheless, the presence of this sign could have contributed to the decrease in mean speed observed at the elongated pavement marking sign location in Brooklyn, WI.

Table 10. Mean Speed, Standard Deviation and Sample Size of Free Flowing Vehicles at Sites with Speed Limit Sign.

Site	**Location**	**Mean speed (mph)**				**Standard deviation (mph)**		**Sample size**	
		Before	**After**	**Change**	**p-value**	**Before**	**After**	**Before**	**After**
Andale, KS	Upstream	53.7	52.1	-1.7	<0.0001	6.2	5.7	1692	1625
	At	38.7	36.8	-1.9	<0.0001	6.5	5.8	1806	1683
	Downstream	35.4	32.8	-2.5	<0.0001	6.6	5.1	1936	1648
Bentley, KS	Upstream	52.4	56.4	4.1	<0.0001	5.6	5.8	5407	5786
	At	33.8	35.9	2.1	<0.0001	5.1	6.1	5359	5736
	Downstream	33.3	33.1	-0.2	0.0364	4.5	4.2	3783	4184
Brooklyn, WI	Upstream	46.6	48.9	2.2	<0.0001	7.4	8.0	4991	4369
	At	36.2	31.5	-4.7	<0.0001	6.5	5.7	4992	4327
	Downstream	26.1	27.6	1.5	<0.0001	3.6	3.7	1886	4357

Figure 49. Photo. Sign Installed by Wisconsin DOT in Brooklyn, WI.

Median speed, 85^{th} percentile speed, and sample sizes of free flowing vehicles for the KS and WI sites are shown in Table 11. Eighty-fifth percentile speeds reduced by 2 mph and 5 mph at the sign and downstream locations respectively in Andale, KS. In Bentley, KS, 85^{th} percentile speeds increased by 3 mph at the sign and remained same at the downstream location. In Brooklyn, WI, the 85^{th} percentile speed reduced by 5 mph at the sign and increased by 1 mph at the downstream location.

Table 11. Median Speed, 85^{th} Percentile and Sample Size of Free Flowing Vehicles at Sites with Speed Limit Sign.

Site	**Location**	**Median speed (mph)**		**85th percentile speed (mph)**		**Sample size**	
		Before	**After**	**Before**	**After**	**Before**	**After**
Andale, KS	Upstream	54	52	60	58	1692	1625
	At	38	36	45	43	1806	1683
	Downstream	36	33	42	37	1936	1648
Bentley, KS	Upstream	53	57	58	62	5407	5786
	At	34	35	39	42	5359	5736
	Downstream	33	33	37	37	3783	4184
Brooklyn, WI	Upstream	47	50	54	56	4991	4369
	At	36	31	43	38	4992	4327
	Downstream	26	27	30	31	1886	4357

In order to ascertain the effectiveness of the elongated pavement marking sign on extent of speeding, proportions of free flowing vehicles complying with speed limit and exceeding speed limit by 5, 10, and more than 10 mph were computed. Figure 50 through Figure 52 show the proportions of free flowing vehicles complying or exceeding the speed limit at Andale, Bentley and Brooklyn, respectively.

In Andale, KS, percentage of free flowing vehicles complying with speed limit increased from 29% to 39% at the sign and from 45% to 66% downstream. Percentage of free flowing vehicles exceeding the speed limit by more than 10 mph dropped from 16% to 9% at the sign and from 6% to less than 1% downstream (Figure 49).

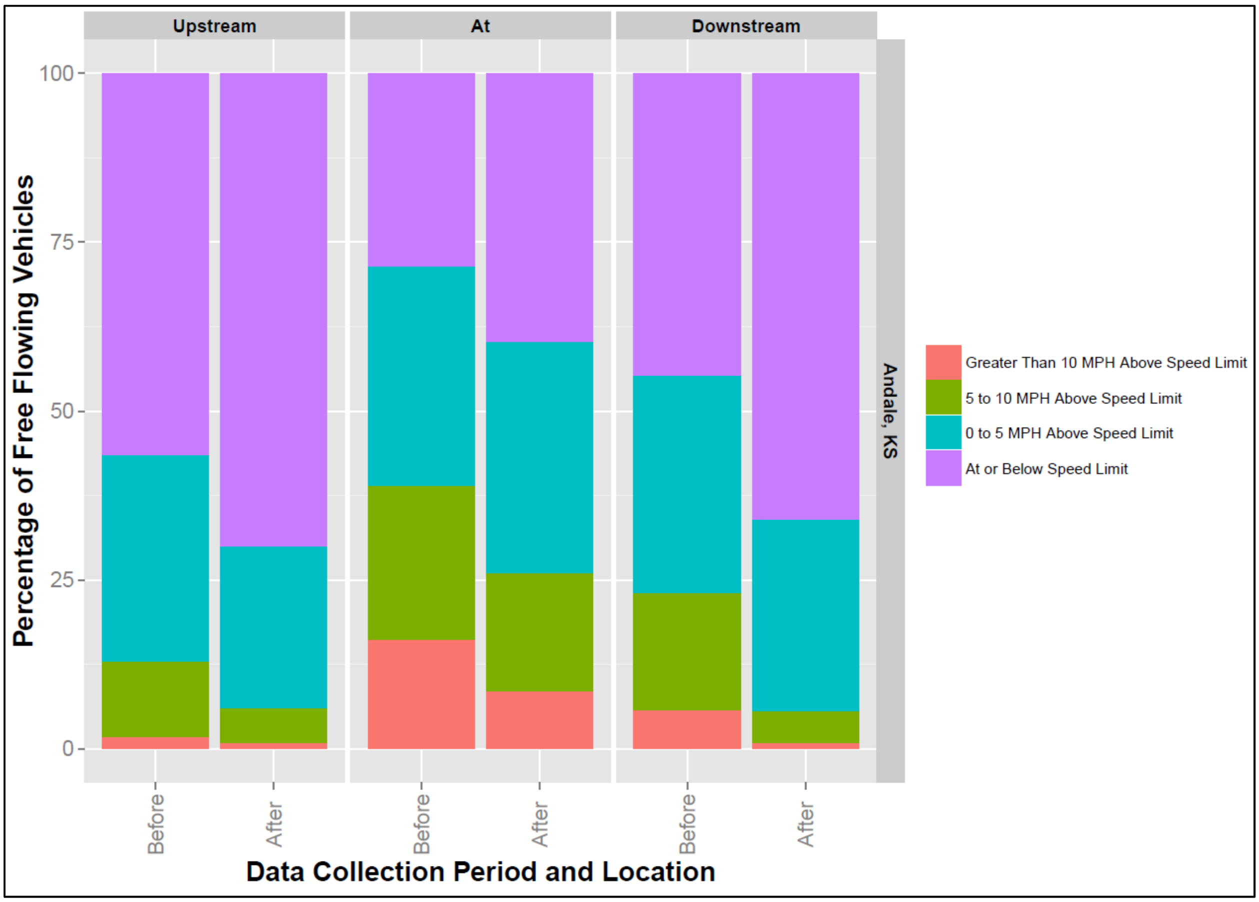


Figure 50. Chart. Proportions of Vehicles Complying or Exceeding Speed Limit in Andale, KS.

In Bentley, KS, percentage of free flowing vehicles complying with speed limit decreased from 24% to 16% at the sign and from 20% to 18% downstream. Percentage of free flowing vehicles exceeding the speed limit by more than 10 mph increased from 11% to 23% at the sign and marginally decreased from 7% to 5% downstream (Figure 50).

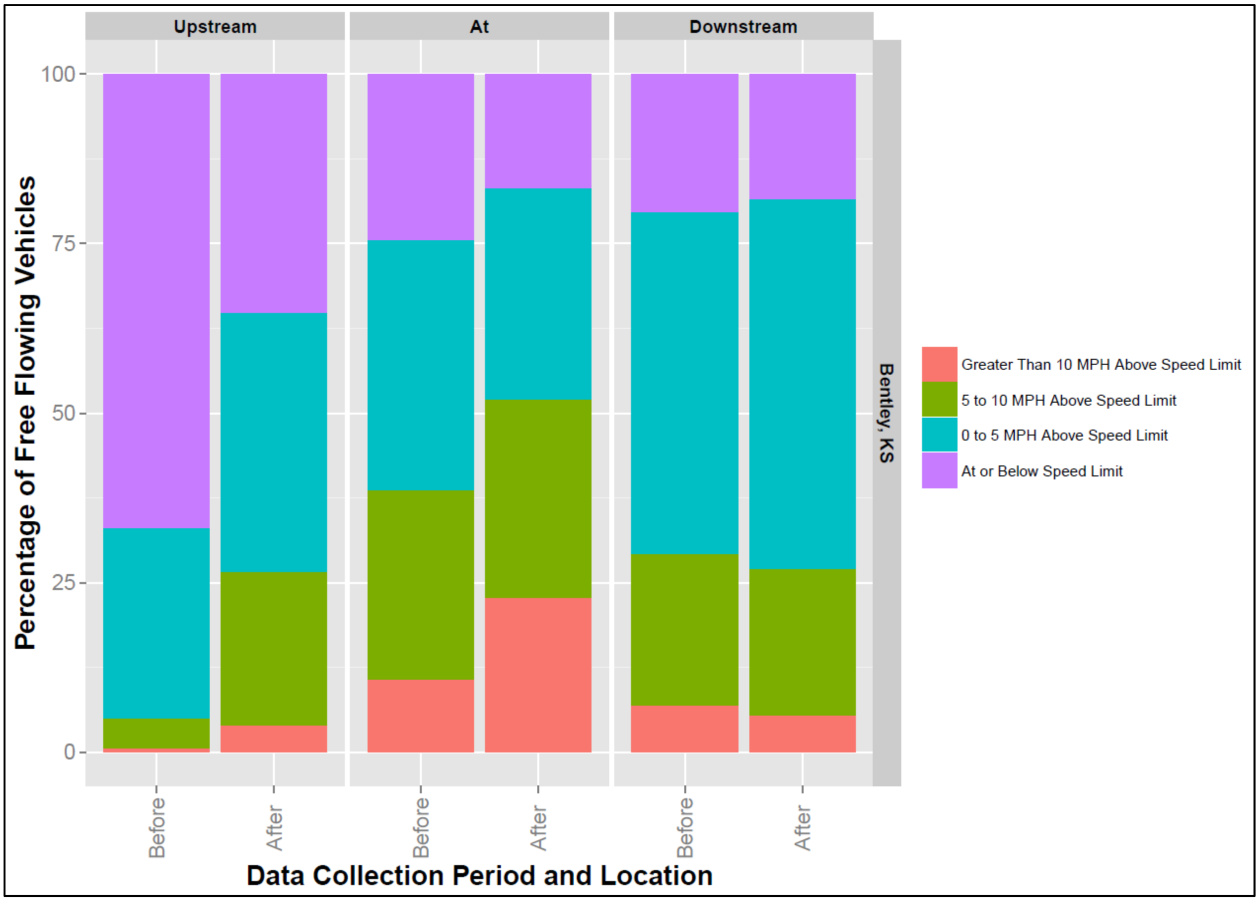


Figure 51. Chart. Proportions of Vehicles Complying or Exceeding Speed Limit in Bentley, KS.

In Brooklyn, WI, percentage of free flowing vehicles complying with speed limit increased from 4% to 14% at the sign and decreased from 47% to 28% downstream. Percentage of free flowing vehicles exceeding the speed limit by more than 10 mph decreased from 52% to 23% at the sign and marginally increased from 2% to 3% downstream (Figure 51).

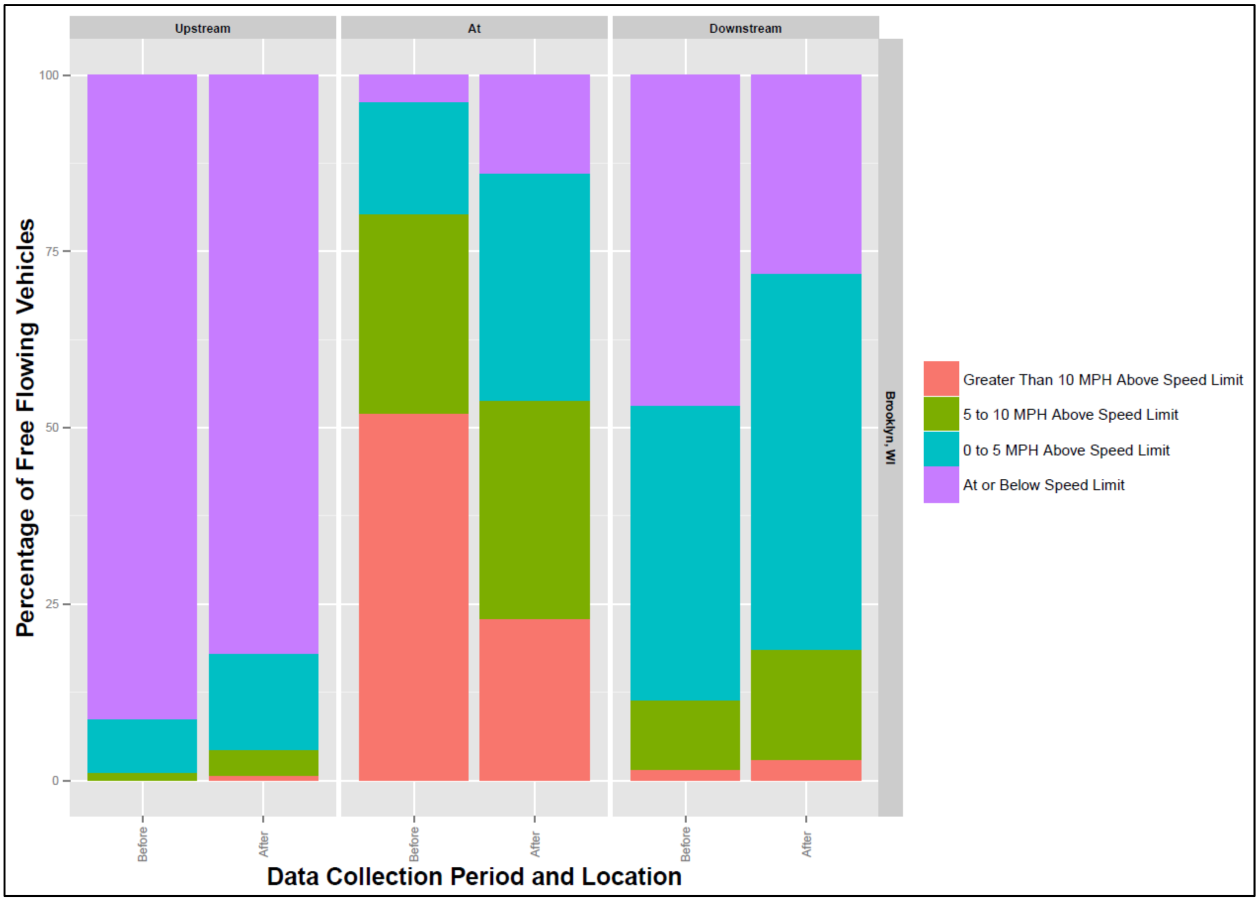


Figure 52. Chart. Proportions of Vehicles Complying or Exceeding Speed Limit in Brooklyn, WI.

Speed Limit Sign: Missouri Site:

Vehicle speed data from the site in Missouri were collected and averaged into 30 minutes bins. Figure 53 shows average speed for each 30 minute period on different days in the before and after period. For the most part, average speeds in the after period are lower than in the before period. Figure 54 shows the speed averaged over multiple days by time of day in the before and after conditions at Branson West, MO. The average speeds in the after conditions were lower than the before conditions for most of the time periods at the sign as well as downstream of the sign. Average speed is directly related to traffic volume. In order to ensure that the decrease in average speeds is not due to traffic volume, average traffic volume in every 30 minute period in the before and after condition were compared. As shown in Figure 55, traffic volumes were similar in the before and after condition. Figure 56 shows that the change in average speeds for most of the time periods were negative indicating that the after speed was lower than the before speed. Average decrease over all the time periods was 1.1 mph at the sign and 2.2 mph at the downstream location.

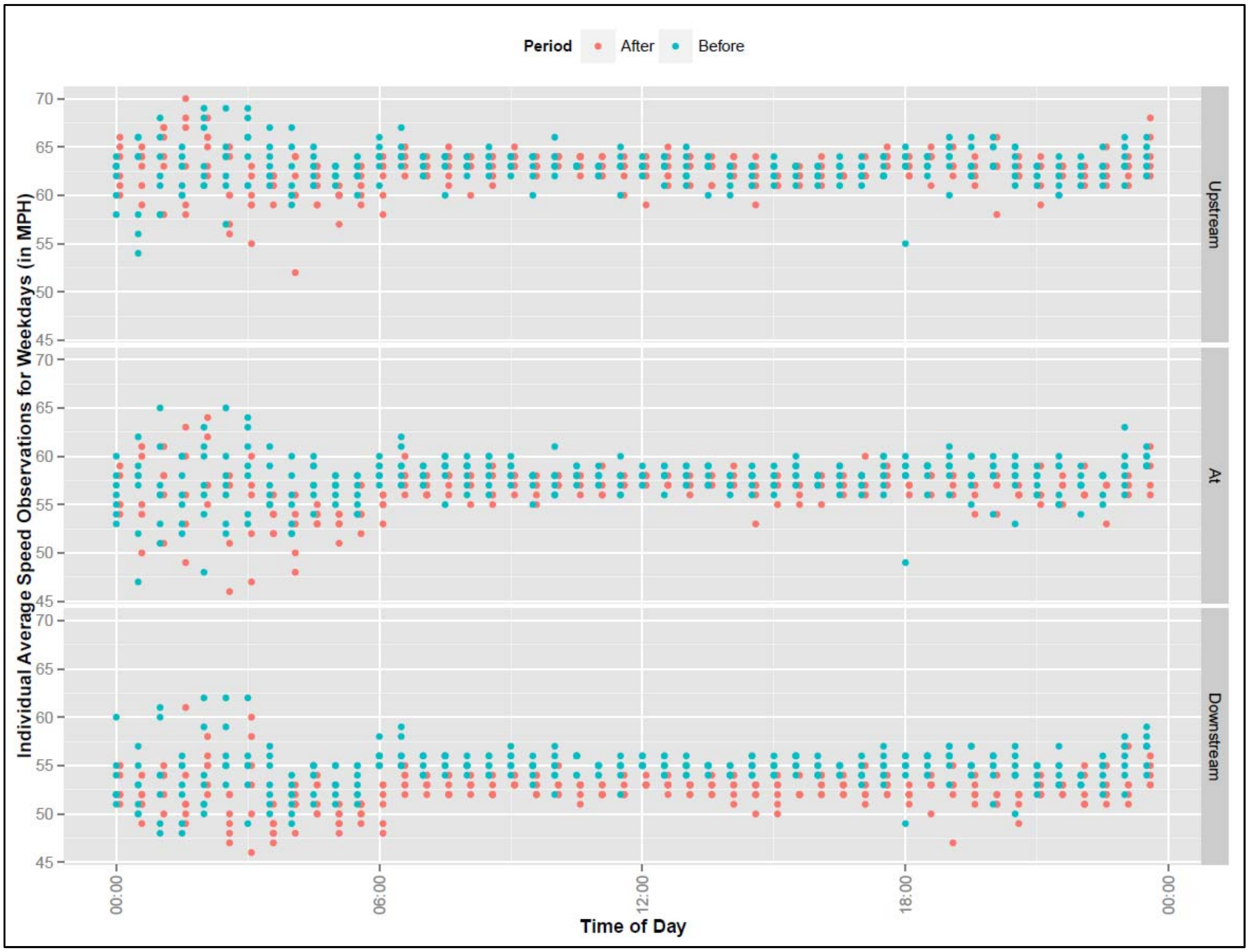


Figure 53. Chart. Average Speeds on Individual Days at Branson West, MO.

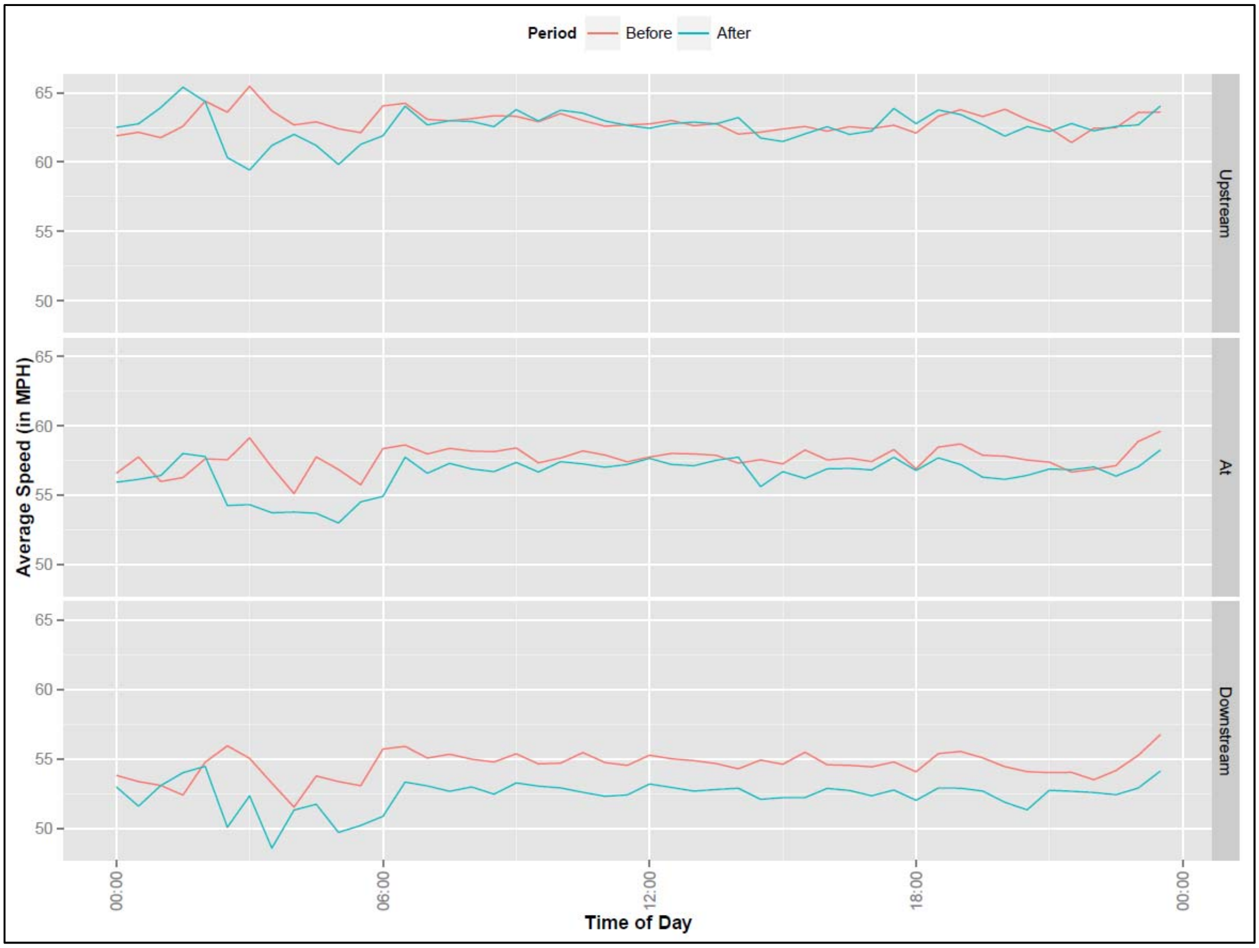


Figure 54. Chart. Average Speeds in the Before and After Conditions at Branson West, MO.

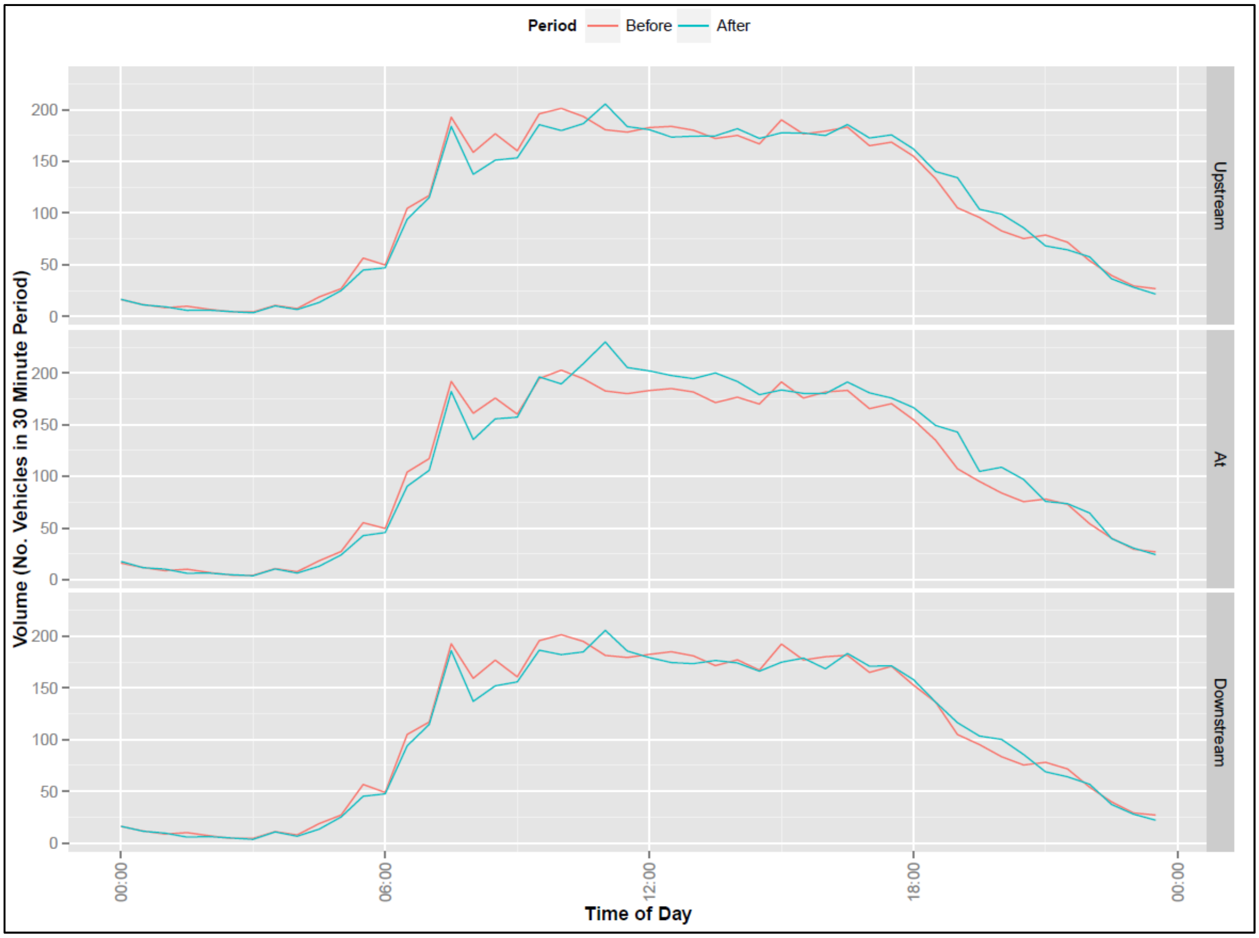


Figure 55. Chart. Average Traffic Volume in the Before and After Conditions at Branson West, MO.

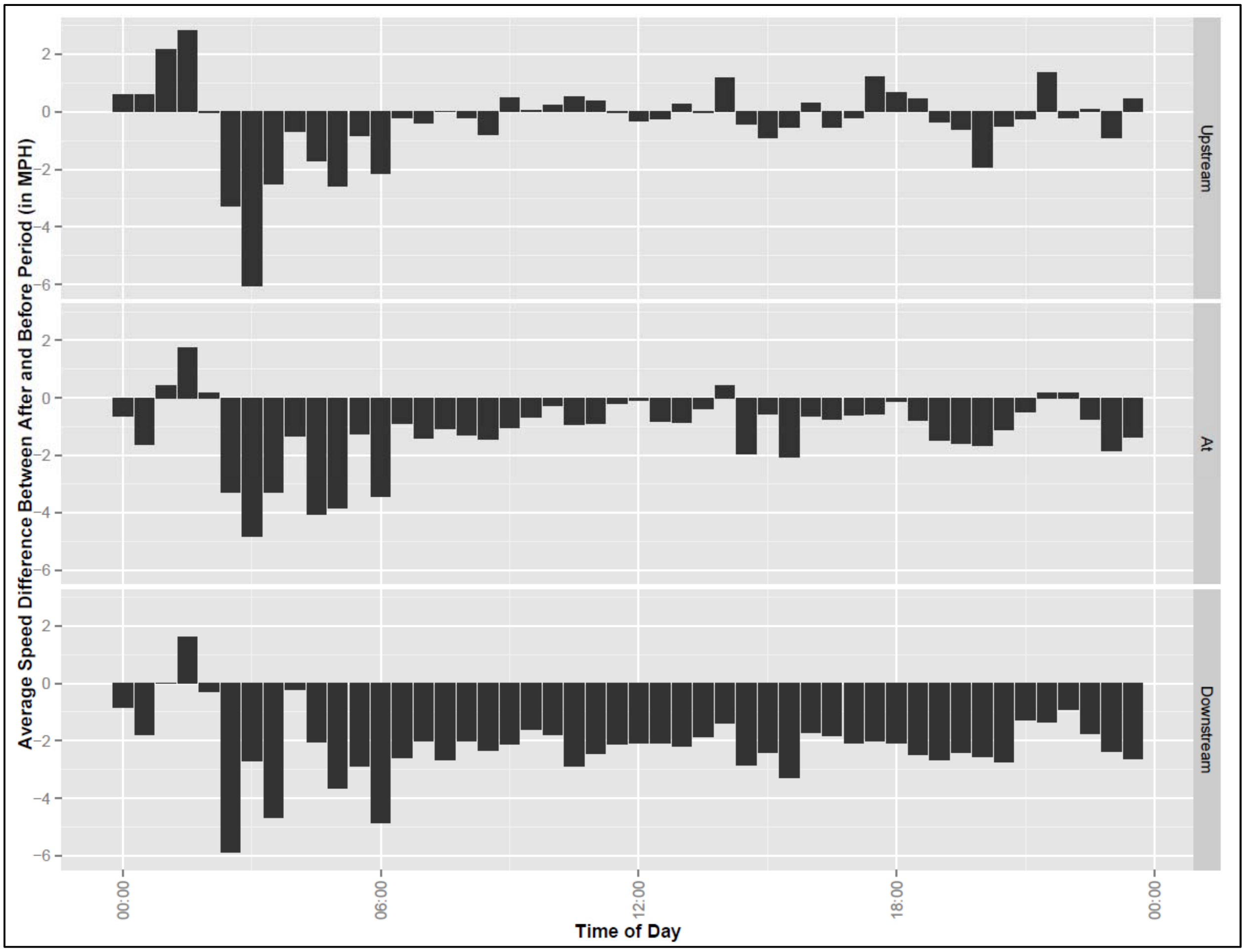


Figure 56. Chart. Change in Average Speed at Branson West, MO.

Curve Sign

Mean, standard deviation, and sample sizes of free flowing vehicles at sites in KS and WI are shown in Table 12. Student's T-test was performed to determine the statistical significance of changes in mean speed. Corresponding p-values are also shown in Table 12. Mean speed reduced by 4.1 mph at the sign and by 2.9 mph downstream of the sign at Lecompton site1. At site 2 in Lecompton, mean speed decreased by 2.0 mph and 0.3 mph at the sign and downstream, respectively. All the changes in mean speed at the Lecompton sites were statistically significant. In Jefferson, WI, mean speed increased by 0.7 mph at the sign and 0.4 mph downstream. Both the speed changes in Jefferson were not statistically significant. As previously mentioned, WisDOT installed a sign (shown in Figure 57) warning drivers about the presence of an experimental sign on pavement. It is unclear if this sign impacted operating condition; nevertheless, the presence of this sign could have affected the results from Jefferson.

Table 12. Mean Speed, Standard Deviation and Sample Size of Free Flowing Vehicles at Sites with Curve Sign.

Site	Location	Mean speed (mph)				Standard deviation (mph)		Sample size	
		Before	After	Change	p-value	Before	After	Before	After
Lecompton-1	Upstream	57.0	55.3	-1.7	<0.0001	6.0	5.9	3821	2332
	At	62.2	58.0	-4.1	<0.0001	6.0	5.0	4238	3987
	Downstream	60.2	57.2	-2.9	<0.0001	7.9	7.2	4164	3923
Lecompton-2	Upstream	50.3	51.6	1.3	<0.0001	8.6	8.6	3930	3437
	At	57.0	55.0	-2.0	<0.0001	6.3	6.0	3687	3243
	Downstream	51.4	51.1	-0.3	0.0302	5.5	5.7	3219	2294
Jefferson	Upstream	56.2	48.5	-7.7	<0.0001	7.0	5.3	9704	6162
	At	54.6	55.2	0.7	1.0000	5.8	6.5	10570	6433
	Downstream	48.2	48.7	0.4	1.0000	5.3	5.5	10352	6447

Figure 57. Photo. Sign Installed by Wisconsin DOT in Jefferson, WI.

Median speed, 85th percentile speed, and sample sizes of free flowing vehicles are shown in Table 13. The 85th percentile speeds reduced by 5 mph and 4 mph at the sign and downstream locations, respectively, at site 1 in Lecompton, KS. At site 2 in Lecompton, KS, 85th percentile speeds decreased by 3 mph at the sign and remained same at the downstream location. In Jefferson, WI, 85th percentile speed increased by 2 mph at the sign and by 1 mph at the downstream location.

Table 13. Median Speed, 85th Percentile, and Sample Size of Free Flowing Vehicles at Sites with Speed Limit Sign.

Site	Location	Median speed (mph)		85th percentile speed (mph)		Sample size	
		Before	After	Before	After	Before	After
Lecompton-1	Upstream	57	56	63	61	3821	2332
	At	62	58	68	63	4238	3987
	Downstream	61	58	66	62	4164	3923
Lecompton-2	Upstream	52	53	57	59	3930	3437
	At	57	55	63	60	3687	3243
	Downstream	51	51	57	57	3219	2294
Jefferson	Upstream	56	49	63	54	9704	6162
	At	55	56	60	62	10570	6433
	Downstream	48	49	53	54	10352	6447

In order to ascertain the effectiveness of the elongated pavement marking sign on extent of speeding proportions of free flowing vehicles complying with speed limit and exceeding speed limit by 5, 10, and more than 10 mph were computed. At the sign and downstream, advisory speed was used as the threshold, while posted speed limit was used at upstream location for these computations. Figure 58 through Figure 60 show the proportions of free flowing vehicles complying or exceeding the speed limit at the two sites in Lecompton, KS and Jefferson, WI, respectively.

At site 1 in Lecompton, percentage of free flowing vehicles complying with the advisory speed limit remained unchanged at about 1% at the sign and increased marginally from 4% to 5% downstream. Percentage of free flowing vehicles exceeding the advisory speed limit by more than 10 mph dropped from 90% to 74% at the sign and from 85% to 74% downstream. At site 2 in Lecompton, percentage of free flowing vehicles complying with advisory speed limit remained unchanged at about 2% at the sign and 3% downstream. Percentage of free flowing vehicles exceeding the advisory speed limit by more than 10 mph dropped from 88% to 81% at the sign and from 57% to 55% downstream. In Jefferson, percentage of free flowing vehicles complying with the advisory speed limit remained unchanged at about 1% at the sign and 6% downstream. Percentage of free flowing vehicles exceeding the advisory speed limit by more than 10 mph remained unchanged at 79% at the sign and increased from 34% to 38% downstream.

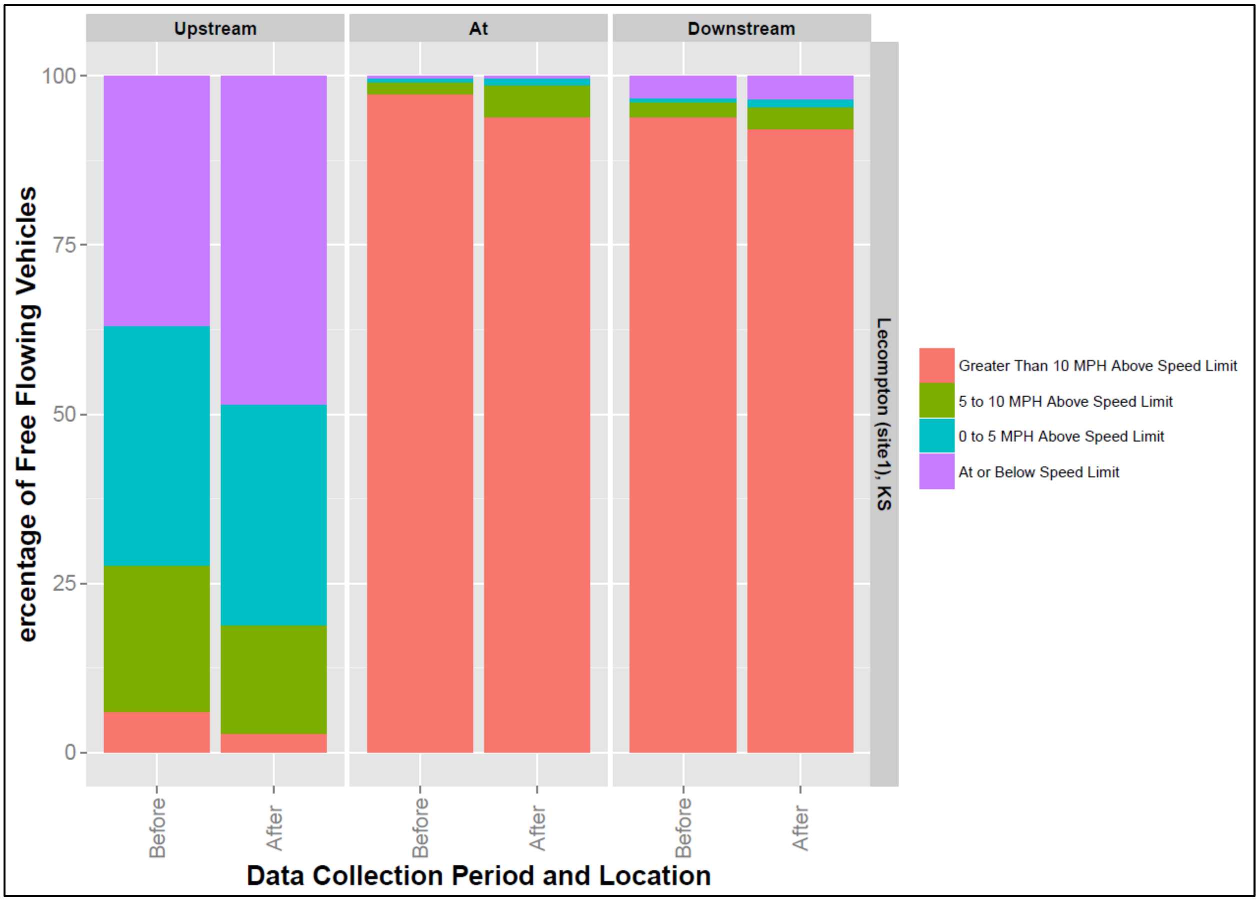


Figure 58. Chart. Proportions of Vehicles Complying or Exceeding Speed Limit at Site 1 in Lecompton, KS.

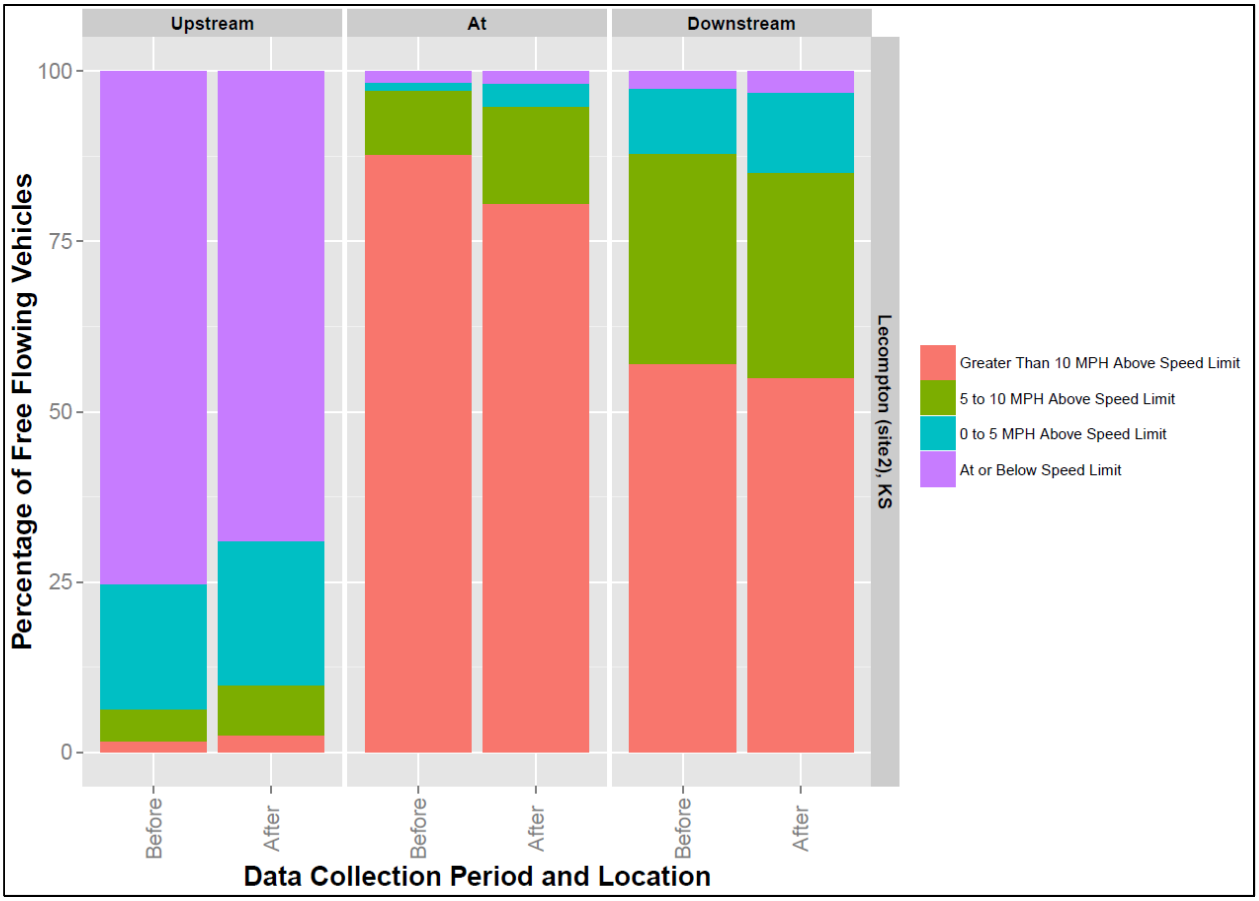


Figure 59. Chart. Proportions of Vehicles Complying or Exceeding Speed Limit at Site 2 in Lecompton, KS.

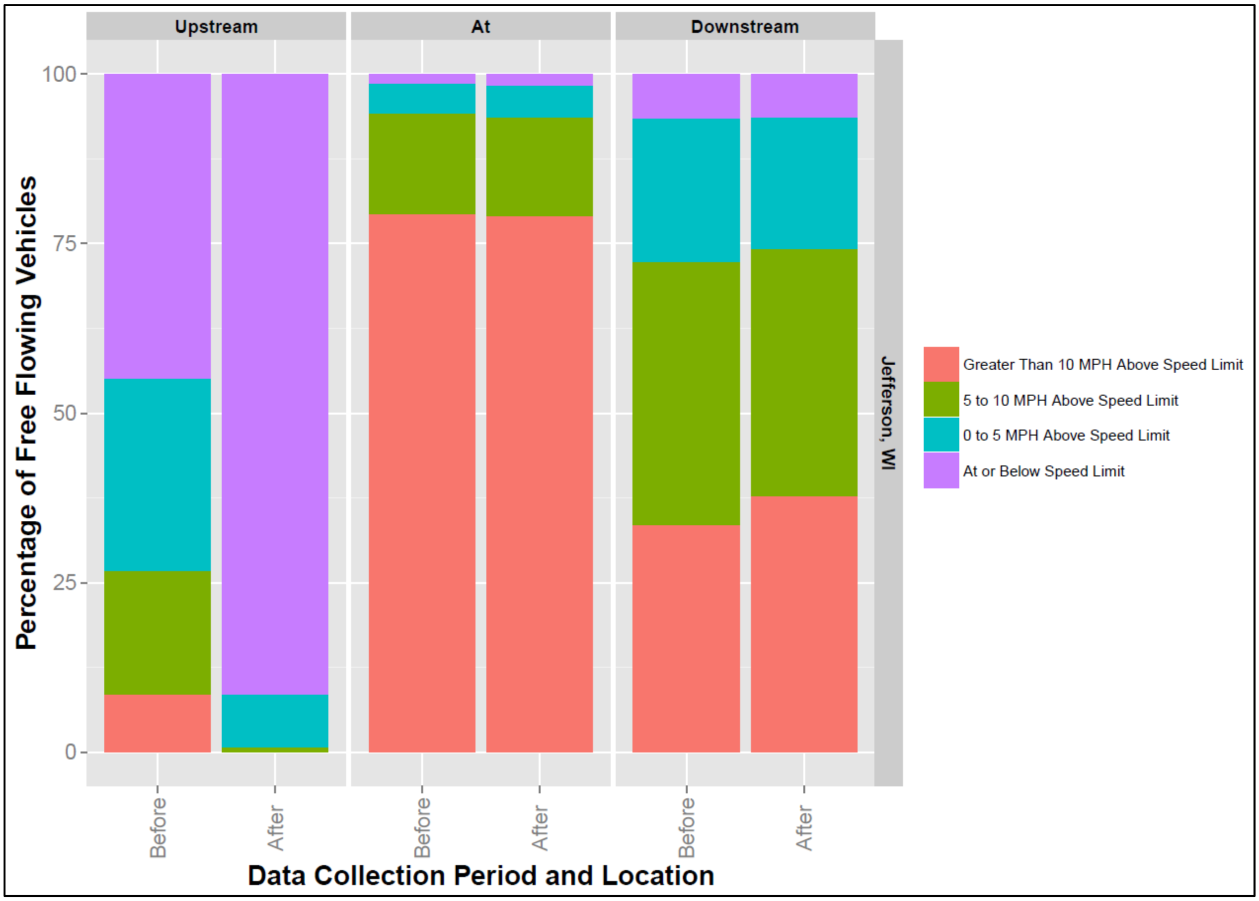


Figure 60. Chart. Proportions of Vehicles Complying or Exceeding Speed Limit in Jefferson, WI.

FIELD EVALUATION CONCLUSIONS

Speed Limit sign was tested at two locations in KS, one location each in MO and WI. The sign was effective at reducing operating speeds at three out of the four sites studied. The speed limit sign was effective in reducing mean speeds during most of the time periods at the sign and downstream in Branson West, MO. In Andale, KS the sign reduced mean speed, 85th percentile speed, and percentage of drivers exceeding the speed limit by more than 10 mph at the sign and downstream location. Percentage of drivers complying with the speed limit increased at both the locations. At Bentley, KS, mean and 85th percentile speeds increased at the sign but remained similar downstream. The sign was not effective in reducing speeding vehicles at either locations. In Brooklyn, WI the sign was effective at the location of the sign, but not downstream. Mean speed, 85th percentile speeds reduced at the sign remained same downstream. Vehicles speeding by more than 10 mph were reduced and percentage of vehicles complying with speed limit increased at the sign location. The sign had little effect at downstream location.

Curve sign was tested at two locations in KS and one location in WI. The sign was effective at reducing operating speeds two of the three sites studied. At both the sites in Lecompton, KS the sign reduced mean speed, 85th percentile speed, and percentage of drivers exceeding the advisory speed limit by more than 10 mph at the sign and downstream location. Percentage of drivers complying with the advisory speed limit remained similar at both the locations. Therefore, the sign was effective at both the locations in Lecompton, KS. In Jefferson, WI the sign was not effective. Mean speeds and percentage drivers exceeding advisory speed limit by more than 10 mph remained similar, while 85th percentile speeds increased marginally at the sign and downstream.

CHAPTER 5. CONCLUSIONS & RECOMMENDATIONS

RESEARCH SUMMARY

The goal of this study was to evaluate the conspicuity, legibility, and effectiveness of symbolized pavement markings that are elongated (horizontal) versions of the post-mounted signs they complement. Towards this goal, a comprehensive literature and state-of-the-practice review was performed followed by a driving simulator evaluation and field evaluation of elongated pavement marking signs.

Elongated pavement marking letters have been shown to significantly improve recognition distance when compared to non-elongated pavement marking letters. However no research describing evaluations of elongated pavement marking signs was found. Elongated pavement marking signs and words are widely used in Europe and Australia. The extent of elongation differs from country to country. Based on literature review and feedback from the Traffic Control Devices Pooled Fund Study members, speed limit, curve, and pedestrian sign were chosen for simulator evaluation. Field evaluations were limited to speed limit and curve signs.

The driving simulator evaluation was performed in two stages to:

1. Determine the relationship between elongation ratio and recognition distance.
2. Evaluate the effectiveness of elongated pavement marking signs.

In stage 1 of simulator research, three sign types and 5 elongation ratios were evaluated by sixteen subjects. Maximum recognition distance was computed for each subject by considering the effect of perception reaction time. Simulator results confirmed that maximum recognition distance increases quadratically with increase in elongation ratio. Results showed that the increase in maximum recognition distance reduces beyond 5:1 elongation ratio. Therefore 5:1 ratio was recommended for the field evaluation.

In stage 2 of the driving simulator research, the effectiveness of speed limit, curve, and pedestrian signs was evaluated. Furthermore, the effect of curve sign placement relative to post-mounted sign was tested. Nineteen different subjects participated in this stage. Simulator results indicated that speeds of drivers in conditions with elongated pavement marking signs were similar or lower than speeds in conditions with post-mounted signs only. Furthermore, placing the elongated pavement marking sign downstream of the post-mounted sign was more effective than placing it adjacent to the post-mounted sign. Similarly, placing the elongated pavement marking sign at the post-mounted sign was more effective than placing it upstream of the post-mounted sign.

Kansas, Missouri and Wisconsin participated in the field evaluations. A Before-After experimental approach was used for the field evaluations. Speed was used as the measure of effectiveness and speed data were collected upstream, at, and downstream of the post-mounted signs. Requests for Experimentation were submitted by the agencies to the Federal Highway Administration for approval. Following the approval of RFEs signs were procured and installed. After data were collected a minimum of one week after the installation.

Speed limit sign was tested at four sites: two in Kansas, one each in Missouri and Wisconsin, and was found to be effective at three of the four locations. In Andale, KS, mean speed of free flowing vehicles was reduced by 1.9 mph and 2.5 mph while 85th percentile speeds were reduced by 2 mph and 5 mph at the sign and downstream location, respectively. Percentage of free flowing vehicles complying with speed limit increased and percentage of free flowing vehicles speeding by more than 10 mph decreased at both the locations. In Bentley, KS, mean speed increased by 2.1 mph and reduced by 0.2 mph, while 85th percentile speeds increased by 3 mph and remained same at the sign and downstream location, respectively. Percentage of free flowing vehicles complying with speed limit decreased and percentage of free flowing vehicles exceeding the speed limit by more than 10 mph increased.

In Brooklyn, WI, mean speed reduced by 4.7 mph and increased by 1.5 mph while 85th percentile speeds reduced by 5 mph and increased by 1 mph at the sign and downstream location, respectively. Percentage of free flowing vehicles complying with speed limit increased at the sign and decreased downstream. Percentage of free flowing vehicles exceeding the speed limit by more than 10 mph decreased at the sign and marginally increased downstream. In Branson West, MO the sign reduced 30 minute average speeds for most of the time periods in a day. The average reduction in 30 minute speeds was 1.1 mph and 2.2 mph, respectively, at the sign and downstream of the sign.

Curve sign was tested at three sites: two in Kansas and one in Wisconsin. At site 1 in Lecompton, KS, mean speed reduced by 4.1 mph and 2.9 mph and 85th percentile speeds reduced by 5 mph and 4 mph at the sign and downstream location, respectively. At site 2 in Lecompton, KS, mean speed reduced by 2.0 mph and 0.3 mph and 85th percentile speeds reduced by 3 mph and remained unchanged at the sign and downstream location, respectively. At both the sites in Lecompton, KS, percentage of drivers exceeding the advisory speed limit by more than 10 mph decreased at the sign and downstream. In Jefferson, WI, mean speeds were not affected by the sign, while 85th percentile speeds increased by 2 mph at the sign and by 1 mph at the downstream location. Percentage of free flowing vehicles exceeding advisory speed limit by more than 10 mph remained unchanged at the sign and increased marginally downstream.

CONCLUSIONS

This research confirms that elongation increases the recognition distance of pavement marking signs. The relationship between maximum recognition distance and elongation ratio is quadratic. Furthermore, field evaluation and simulator evaluation show that the evaluated regulatory and warning elongated pavement marking signs reduced speeds of vehicles demonstrating that they can be effective in reinforcing a warning or a regulatory message to drivers.

RECOMMENDATIONS

Present research is unique and the first of its kind. This research has demonstrated that elongated pavement marking signs of speed limit and curve signs are effective in reducing operating speeds of vehicles. Recommendations resulting from this research are:

- Elongation ratio of 5:1 for pavement marking signs.
- Elongated pavement marking signs be used to supplement post-mounted signs when speed reduction or other operating speed changes are needed.
- Based on the driving simulator evaluation, placing the pavement marking sign downstream of the post-mounted sign for curve applications may be more effective than placing it at the sign. Future research should confirm this through field evaluation of various placement positions.

Research limitations include:

- This study did not evaluate long term impact of the signs. It is strongly recommended that future research examine the long-term effectiveness of these signs.
- This research used speed as a surrogate measure for safety. A safety evaluation of these locations would further establish the effectiveness of elongated pavement marking signs and is highly recommended. Safety evaluations could include evaluating effect of the sign on crashes as well as monitoring driving behavior immediately after sign installation.
- Future research should study the durability of EPMS and also consider using less wide (5 feet or less) EPMS to reduce wear from vehicle tires.
- Ongoing Kansas DOT study on EPMS should be considered in deciding sign effectiveness.
- This research was limited to the three sign types discussed on two lane roadways. Therefore, future evaluations should also consider other sign types and roadway types.

CONSIDERATIONS IN USING EPMS

This research demonstrated that speed limit and curve warning EPMS are effective in reducing speeds. However, things to consider before using EPMS are:

- EPMS are substantial in size, and painted markings of this size may have reduced friction when wet. The effect of wet elongated pavement marking materials on motorcycle and vehicle safety was not considered. An evaluation of material types should be considered to address this potential concern..
- Although traffic control was used in the field evaluations during the installation process, the extent of necessary traffic control for field installations was not considered. Installations may require simple flagger control to full traffic control and lane closure for installation, depending on the location.
- Durability of EPMS, especially in states with winter maintenance operations. Snow plow blades and other pavement maintenance operations may prematurely reduce the effectiveness of the pavement marking sign.
- Need for public outreach to avoid potential driver confusion when EPMS are newly installed, as was reported in Jefferson, WI.

APPENDIX A: DIMENSIONS OF ELONGATED SIGNS IN DIFFERENT COUNTRIES

The dimensions of some of the commonly used pavement marking signs in different countries are compared here. The information for Denmark, Finland, Germany, Netherlands, Norway, Sweden, and United Kingdom is based on a recently released Swedish National Road and Transport Research Institute report. [31] The information for US is from the MUTCD [3], for Canada is from City of Edmonton guidelines, [32] and Australia is from the Queensland MUTCD. [29] The figures accompanying each of the tables in this sub-section are from Fors et al. [31]

Table 14 through Table 18 present the dimensions for speed limit signs (Figure 61), yield signs (Figure 62), stop signs (Figure 63), lane arrows (Figure 64), and lane change/merge arrows (Figure 65). The primary message from this comparison is that elongated pavement markings are commonly used in Europe and Australia and in some other countries; the extent of elongation depends on the speed limit of the roadway. Greater elongations are used for roadways with higher speed limits. Interestingly, different countries have different speed limit thresholds for using the greater elongation ratio.

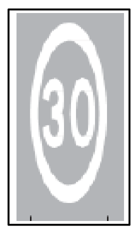


Figure 61. Speed Limit Sign.

Table 14. Dimensions for Speed Limit Signs.

Country	Speed (Km/h)	Length (cm)	Width (cm)
Netherlands	≤ 50	≥ 160	N/A
Netherlands	> 50	≥ 400	N/A
Sweden	≤ 60	≥ 160	N/A
Sweden	≥ 70	≥250	N/A
United Kingdom	≤ 65	430	150
United Kingdom	> 65	750	150

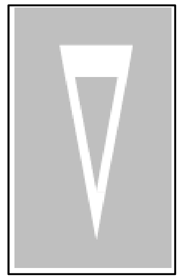


Figure 62. Yield Sign.

Table 15. Dimensions for Yield Signs.

Country	Speed (Km/h)	Length (cm)	Width (cm)
Canada (BC)	N/A	N/A	N/A
Denmark	≤ 60	200/400	100/200
Denmark	> 60	600	200
Finland	All	500	200
Germany	All	500	200
Netherlands	≤ 60	400	100
Netherlands	≥ 50	800	200
Norway	All	300	100
Sweden	≤ 60	300	200
Sweden	≥ 70	600	200
United Kingdom	All	375	125
United States	< 45 mph	13 ft	6 ft
United States	≥ 45 mph	20 ft	6 ft

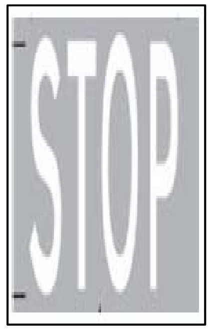


Figure 63. STOP Sign.

Table 16. Dimensions for STOP Signs.

Country	Speed (Km/h)	Length (cm)	Width (cm)
Australia	≤ 80	260	30-90
Australia	> 80	525	30-90
Denmark	N/A	160	< 70
Denmark	N/A	400	< 70
Finland	≤ 50	160	40-60
Finland	> 50	400	40-60
Germany	All	400	≤ 105
Netherlands	≤ 50	≥ 160	< 70
Netherlands	> 50	≥ 400	≤ 70
Norway	≤ 60	160	N/A
Norway	≥ 70	400	N/A
Sweden	≤ 60	160	N/A
Sweden	≥ 70	250	N/A
United Kingdom	≤ 65	160	N/A
United Kingdom	>65	280	N/A
United States	N/A	8 ft	5.9 ft

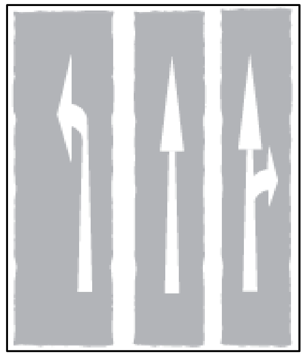


Figure 64. Lane Arrows.

Table 17. Dimensions for Lane Arrows.

Country	Speed (Km/h)	Length (cm)	Width (cm)
Australia	N/A	600	60 - 160
Canada (BC)	N/A	415 - 420	110 - 180
Denmark	≤ 60	500	55-100
Denmark	> 60	500/750	65-110
Finland	≤ 50	500	75-145
Finland	> 50	750	75-145
Germany	N/A	500	50-120
Germany	N/A	750	60-145
Netherlands	≤ 50	500	75-135
Netherlands	≥ 70	750	75-135
Norway	≤ 50	400	75-105
Norway	≥ 60	500	75-105
Sweden	≤ 60	≥ 500	N/A
Sweden	≥ 70	≥ 750	N/A
United Kingdom	≤ 65	400	50-85
United Kingdom	65-100	600/900	50-85
United States	N/A	9.5 - 12.75 ft	N/A

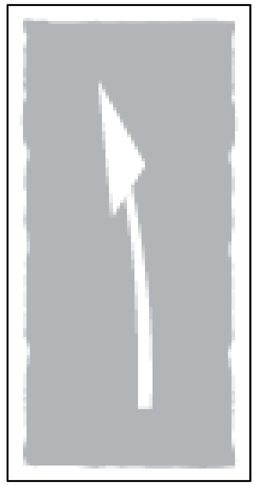


Figure 65. Lane Change/Merge Arrows.

Table 18. Dimensions for Lane Change/Merge Arrows.

Country	Speed (Km/h)	Length (cm)	Width (cm)
Australia	N/A	580	155
Denmark	≤ 60	300	43
Denmark	> 60	500	85
Finland	≤ 50	500	100
Finland	> 50	750	150
Germany	All	500	45
Netherlands	≤ 50	500	81
Netherlands	≥70	750	121
Sweden	≤ 60	500	N/A
Sweden	≥70	750	N/A
United Kingdom	N/A	450	52.5
United Kingdom	N/A	600	70
United States	N/A	17 ft.	5.5 ft.

APPENDIX B: INTERNATIONAL PRACTICES

Appendix B summarizes the practices of some of the countries for which the research team was able to obtain detailed guidance.

Australian Practice

Use of elongated pavement markings is documented in the Queensland Manual on Uniform Traffic Control Devices [29] as an approved traffic control device under certain conditions, "Words, numerals, and symbols may be marked on pavements to convey guiding, warning or regulatory messages to drivers. They shall be elongated in the direction of traffic movement to make them legible at the maximum distance. [29]" Figure 66, Figure 67, and Figure 68 show the Queensland MUTCD design of elongated pavement marking of characters.

The size requirement was noted as "The length of letters and numerals shall be 2.5 m where the speed limit is up to 80 km/h and 5.0 m at higher speed limits." The QMUTCD explicitly notes that the legibility distance is increased by enlarging the length of characters, and the benefit obtainable with increasing elongation diminishes if the distortion ratio exceeds about 10:1. The QMUTCD also allows painting of elongated numerals adjacent to the Speed Restriction Sign in the following circumstances:

- At the start of a lower speed zone where the difference in adjacent speed zones is 20 km/h or higher, with the exception of the start of a school zone or other time based speed zone.
- At repeater signs at major intersections only.
- On undivided multilane roads, at the start of the speed zone.

Elongated numerals may be painted on the road surface in each lane adjacent to the sign. Their use is generally restricted to locations where the provision of signs alone is not adequate, such as where the impact of the sign is reduced by the nature of the roadside environment, and it is considered that the sign needs to be augmented to increase driver perception. The length of numerals should be not less than 2.5 m where traffic approaching them is in a speed zone of 80 km/h or less. At higher speeds, numeral lengths up to 5 m may be required. Intersection arrows are also allowed to be elongated in order to increase their recognition distance. Standard designs for pavement arrows are shown in Figure 69. A H/W ratio of 10 is used for the through arrow. Arrows are elongated similarly to letters or numerals in order to increase their recognition distance.

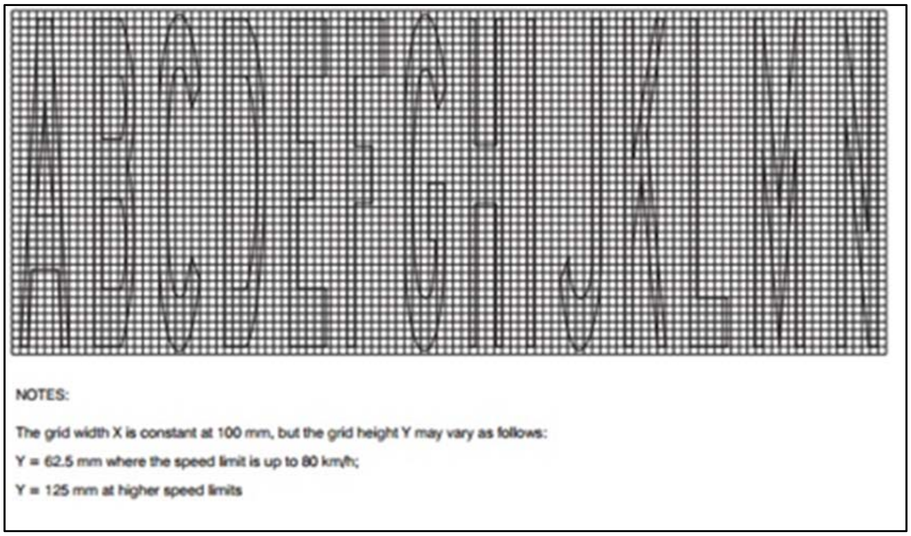


Figure 66. Example of Elongated Characters A Through N on Pavement. [(29)]

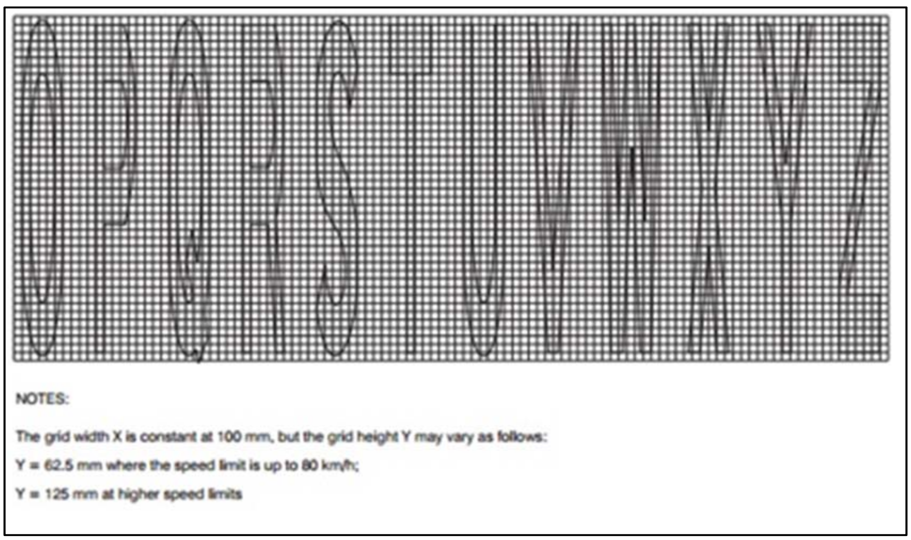
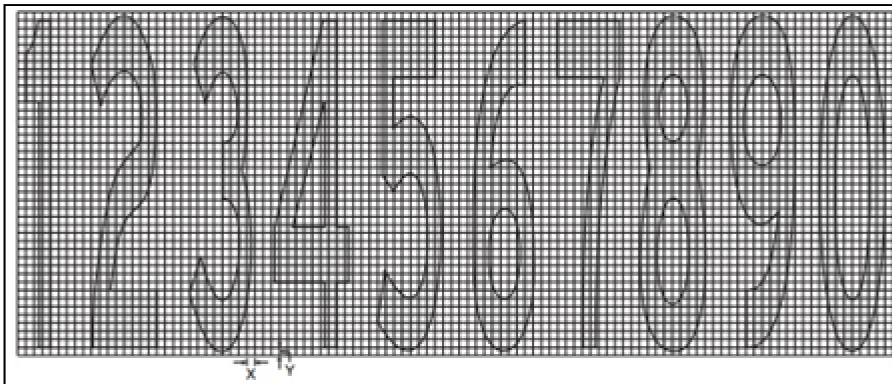


Figure 67. Example of Elongated Characters N Through Z on Pavement. [(29)]



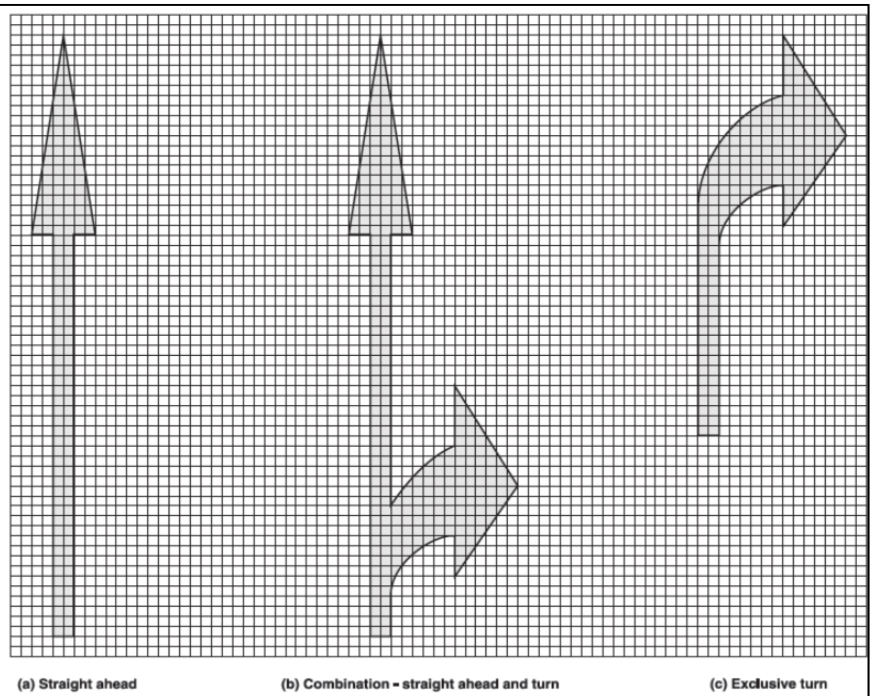
NOTES:

The grid width X is constant at 100 mm, but the grid height Y may vary as follows:

Y = 62.5 mm where the speed limit is up to 80 km/h;

Y = 125 mm at higher speed limits

Figure 68. Example of Elongated Characters 0 Through 9 on Pavement. (29)



NOTES:

1 Minimum length of arrow:
   (a) Straight ahead arrow and combined arrow = 6 m.
   (b) Turn arrow = 4 m.

2 The width of grid squares is constant at 100 mm. The height of the grid squares is 100 mm minimum.

Figure 69. Elongated Intersection Arrows. (29)

Canadian Practice

Elongated pavement markings are allowed for use by City of Edmonton, Canada as specified in Volume 8 of the Design and Construction Standards published by the city. (32) The approved markings are a supplementary diamond shape for reserved lane pavement marking, an elongated arrow to supplement the speed limit ahead symbol, a bicycle symbol, or a bicycle lane arrow. Detailed information including conditions of use and dimension specification of these markings is given below.

- Reserved Lane Pavement Markings:
  - Marking should be along with an elongated diamond shape of 20 cm wide white lines for lane identification. Figure 70 shows an example of elongated diamond for reserved lane. (32)
  - Because of the low angle at which such markings are viewed, they must be elongated in the direction of traffic movement to provide adequate legibility.
  - Reserved lanes are identified by a white elongated diamond symbol pavement marking. For reserved bicycle lanes, the stroke width of the diamond symbol is a minimum of 75mm. The diamond symbol is used with accompanying signing for reserved lanes. The H/W ratio is 4.

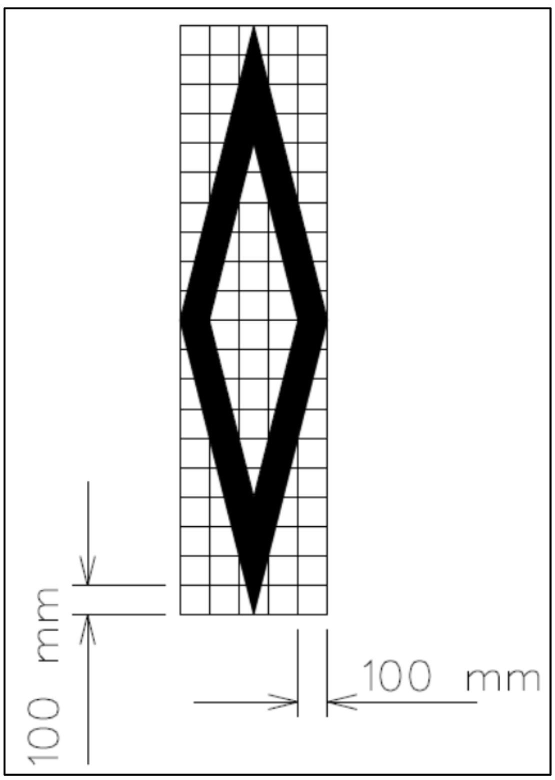


Figure 70. Example of Elongated Diamond for Reserved Lane. (32)

- Speed Limit Ahead Symbol:
  - Speed limit ahead pavement markings (the lower speed limit with an arrow in the travel direction) are only used on high speed roadways where the speed limit

decreases by 20km/h or more (a high speed roadway has a speed limit of 100 km/h or more), and where a high rate of accidents and speed violations warrant their placement.
  - Speed Limit Ahead pavement markings consist of the numeric digits of the lower speed limit and an elongated arrow pointing in the direction of travel.

- Bicycle Symbol:
  - Bicycle lanes are identified by a white elongated bicycle pavement marking. This symbol is 1.0 m wide, with an elongated length of 2.0 m resulting in a H/W ratio of 2. Figure 71 shows an example of elongated bicycle symbol.

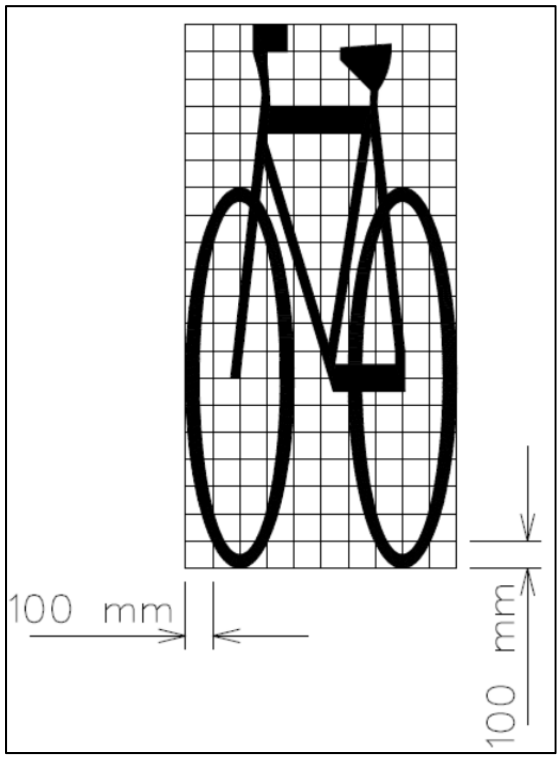


Figure 71. Example of Elongated Bicycle Symbol. (32)

- Bicycle Lane Arrow:
  - The use of a directional arrow on a reserved bicycle lane may be used to designate the direction of travel where this may not be clear. Where a motorist must see and interpret the cyclist directional arrow, a full-sized elongated motorist directional arrow is used. Figure 72 shows an example of elongated bicycle lane arrow. The H/W ratio is about 2.75.
  - Where motorists are not required to see the sign, reduced-size cyclist directional arrows may be used.

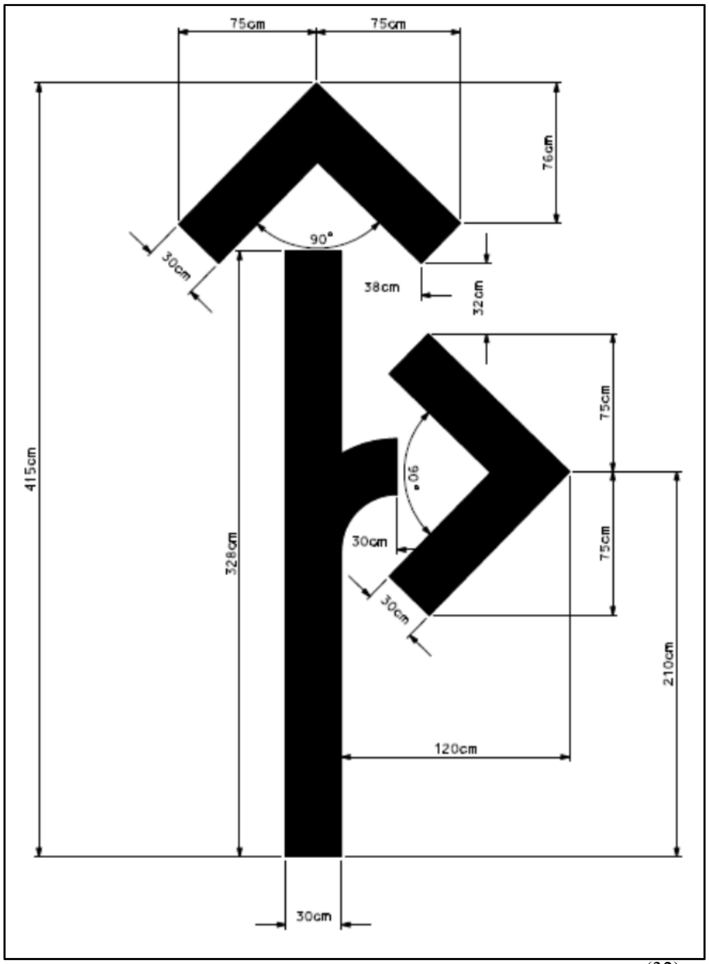


Figure 72. Example of Elongated Bicycle Lane Arrow. [32]

German Practice

In Germany, pavement marking pictograms or the horizontal reproduction of vertical traffic signs can only be used in combination with the vertical sign and have to be located closely to the vertical sign. [33] The horizontal pictogram reproduction of a vertical traffic sign has no independent legal meaning without the accompanying vertical sign. Guidelines for pavement markings (in revision) require that characters, figures/numerals, horizontal reproductions of vertical traffic signs, and pictograms have to be three times elongated in direction of travel. In contrast to the UK, Germany does not have speed dependent elongations.

United Kingdom Practice

Pavement marking signs in the UK are regulated by the Traffic Signs Manual (TSM) Chapter 5. [30] Guidance is provided for the use of worded and diagrammatic markings on roadways. TSM 2003 has the standard widths defined for each capital letter and numerals as shown in Table 19. Figure 73 shows the base dimensions of pavement markings. The length of the letters or numerals depends on the speed of the roadway: 1600 mm for speed limits of 40 mph as shown in Figure 74 and lower and 2800 mm for speed limits over 40 mph as shown in Figure 75. The

H/W ratios range from 2.2 to 5.5 for characters at lower speeds and range from 3.8 to 9.6 for characters at higher speeds.

Table 19. Widths for Letters and Numbers. [30]

Letter	Width (mm)	Letter	Width (mm)	Letter	Width (mm)	Letter	Width (mm)	Letter	Width (mm)
A	544	I	292	Q	632	Y	492	7	416
B	588	J	372	R	564	Z	476	8	520
C	592	K	552	S	548	1	316	9	512
D	616	L	428	T	436	2	480	0	532
E	528	M	736	U	616	3	508	'	156
F	476	N	672	V	520	4	528	&	504
G	620	O	624	W	732	5	488	/	312
H	640	P	520	X	512	6	504		

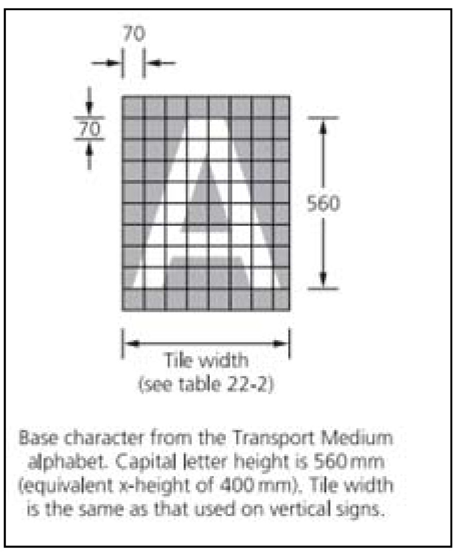


Figure 73. Elongation of Letters for Pavement Markings. [30]

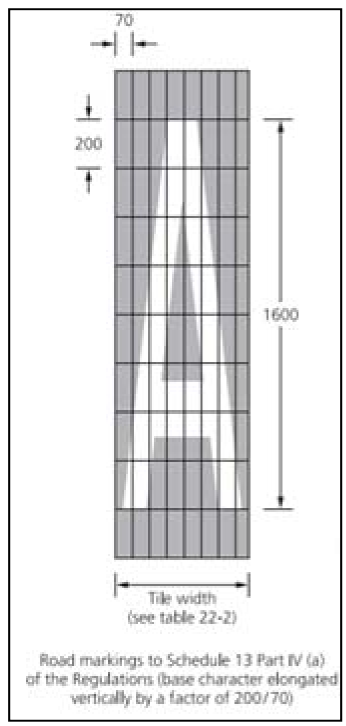


Figure 74. Elongation of Pavement Markings for Speeds Under 40 mph. [30]

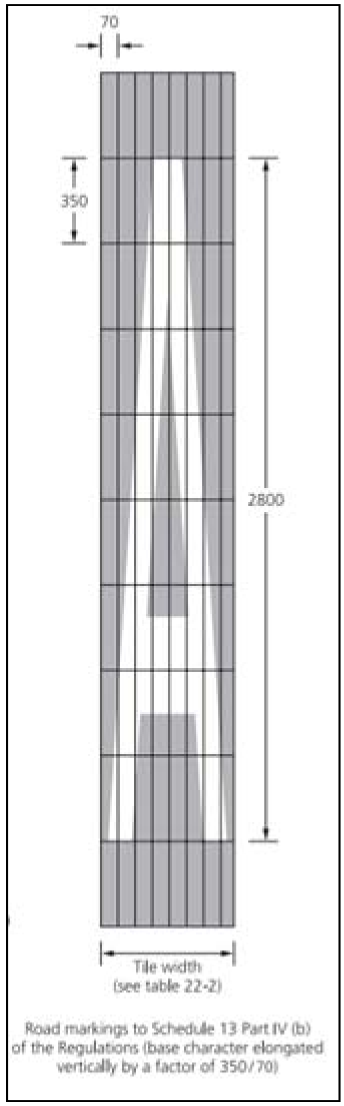


Figure 75. Elongation of Pavement Markings for Speeds Over 40 mph. [30]

The TSM also provides guidance on the use of speed limit signs (called speed limit roundels in the UK) on roadways. Speed limit roundels are elongated in the direction of travel. The TSM provides two specifications for the speed limit roundel depending on the speed limit. Larger elongated speed limit roundel marking is used if the approach speed is higher than 40 mph as shown in Figure 76, and the smaller marking is used if the approach speed is 40 mph or lower (shown in Figure 77). The H/W ratios are 2.9 and 5, respectively. Roundels are commonly used in the UK, generally in conjunction with a posted speed sign. However, the most recent guidelines from the UK permit every English authority to place a 20 mph roundel marking as a repeater without the accompanying posted (vertical) sign in 20 mph speed zones or 20 mph speed limits. [23]

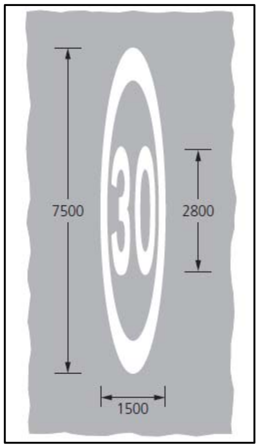


Figure 76. UK Speed Limit Roundel Pavement Marking for Speeds Above 40 mph. (30)

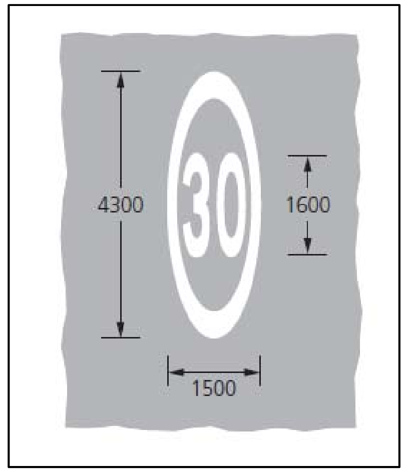


Figure 77. UK Speed Limit Roundel Pavement Marking for Speeds of 40 mph or Below. (30)

The TSM recommends that elongated lane arrows be used on a busy multi-lane approach in order to give drivers advanced warning of the correct lane. (30) Normally two arrows are recommended to be used in sequence although three arrows may be needed in some situations. Dimensions of the arrows are shown in Figure 78, Figure 79, and Figure 80. The H/W ratios range from 8 to 18 for a through arrow depending on the speed limit. The size of the arrows and spacing between them depends on the speed limit, as shown in Table 20. Words can be used with arrows for the purpose of guiding drivers. Characters follow the guidelines shown in Table 19 and Figure 73. TSM also provides standards on arrows for guidance, deflection, and bifurcation. For details, the reader is referred to the TSM.

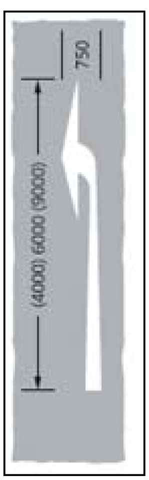


Figure 78. UK Left Turn Lane Arrow Dimensions. (30)

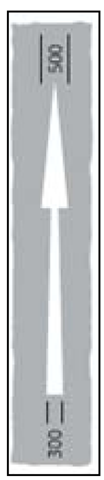


Figure 79. UK Through Lane Arrow Dimensions. (30)

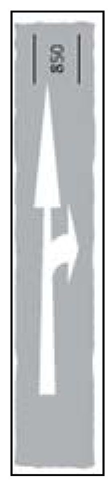


Figure 80. UK Through and Right Turn Lane Arrow Dimensions. (30)

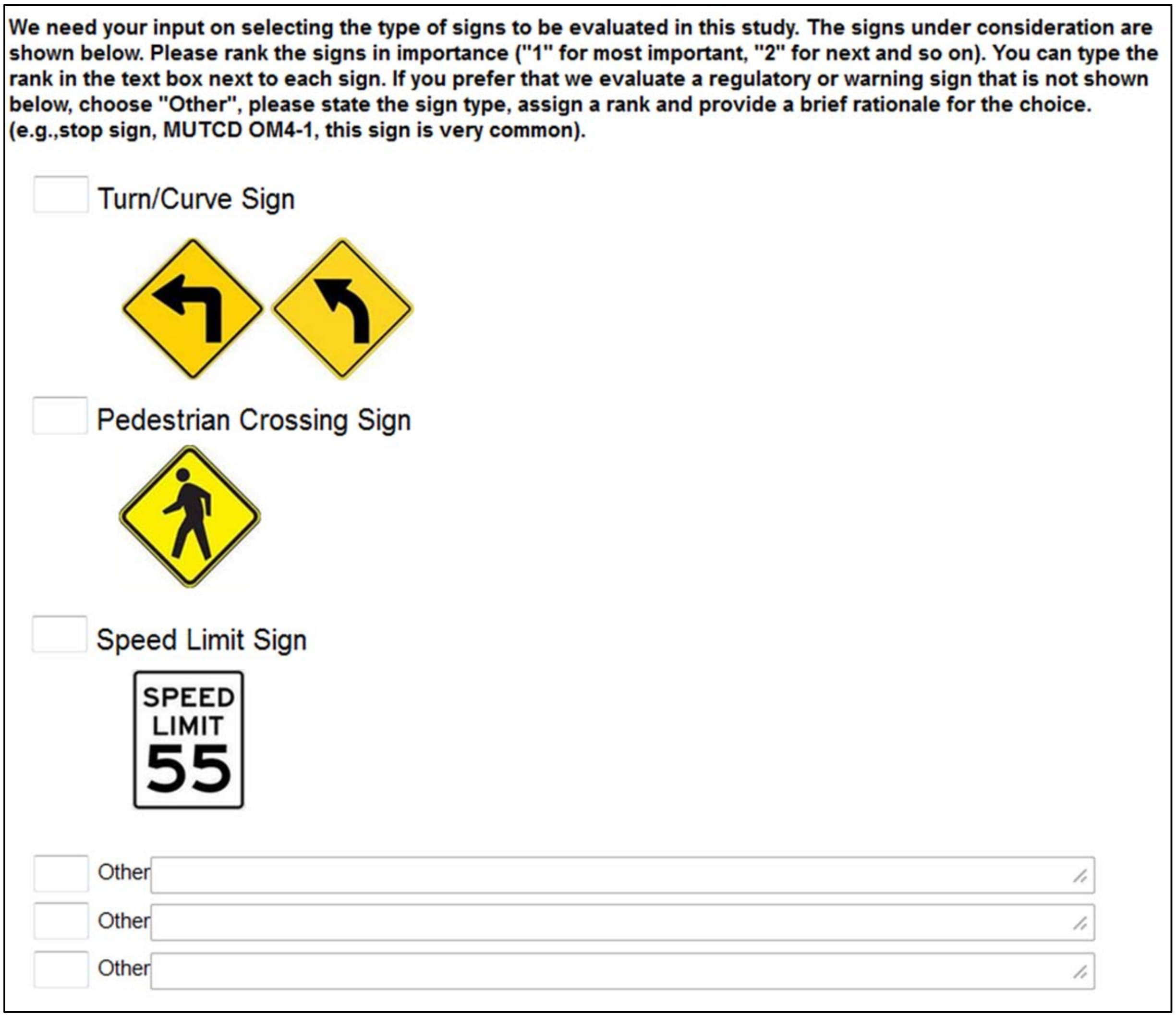
Table 20. UK Lane Arrrow Dimensions and Spacing. [30]

Speed limit (mph)	Arrow length (m)	Distance of first arrow from Stop/Give Way (m)	Distance of second arrow from first (m)	Distance of third arrow from second (m)
40 or less 50 or 60	4 6	15 to 25	30 to 50	30 to 50
70	9	Up to 1.5 times the above distances		

APPENDIX C: TCD-PFS MEMBER ONLINE SURVEY AND RESULTS

Based on the literature and state-of-the-practice review, research team recommended that Turn/Curve warning sign (W1-1, W1-2) and Speed Limit regulatory sign (R2-1) be evaluated in this research. The research team developed a survey for the TCD-PFS member states and they were asked to rank a set of signs in order of importance to be tested in this research (e.g., Turn/Curve sign, Pedestrian Crossing sign, Speed Limit sign, or other). Figure 81 shows a screenshot of the survey. Sixteen survey responses were received. To compute a rank value for each sign, the scores 5,3,1,1, and 1 were applied to the rank values 1,2,3,4, and 5, respectively, then the scores were summed for each sign. Table 21 shows the results of the survey. The Turn/Curve warning sign received the highest score of 70. The Speed Limit regulatory sign was second with a score of 39, followed by Pedestrian Crossing warning sign, which had a score of 21. The combined score for all “Other” signs was 19, and thus none of the other signs mentioned by responders are considered for inclusion for our evaluations. The following “Other” signs were mentioned by the survey respondents:

- STOP (R1-1) regulatory sign.
- W13 series.
- Reduce Speed Ahead (W3-5) warning sign.
- Stop Ahead (W3-1) warning sign.
- Roundabout Ahead (W2-6) warning sign.
- School Crossing Ahead (S1-1) warning sign.
- Advisory speed for Curve or Turn (W13-1P) supplemental plaque.
- Stop/Yield/Signal Ahead warning signs.
- Do Not Enter/Wrong Way regulatory signs.



We need your input on selecting the type of signs to be evaluated in this study. The signs under consideration are shown below. Please rank the signs in importance ("1" for most important, "2" for next and so on). You can type the rank in the text box next to each sign. If you prefer that we evaluate a regulatory or warning sign that is not shown below, choose "Other", please state the sign type, assign a rank and provide a brief rationale for the choice. (e.g.,stop sign, MUTCD OM4-1, this sign is very common).

Turn/Curve Sign

Pedestrian Crossing Sign

Speed Limit Sign

SPEED
LIMIT
55

Other

Other

Other

Figure 81. Screenshot of the Online Survey for TCD-PFS Members

Table 21. Results of TCD-PFS Survey.

Sign	# of votes for each Rank					Score
	1	2	3	4	5	
Turn/Curve Sign	12	3	0	0	1	70
Pedestrian Crossing Sign	0	3	10	1	1	21
Speed Limit Sign	2	8	2	2	1	39
Other	2	1	3	2	1	19

Based on the literature and practice review and the scores from the survey, the 'Curve' (W2-1) warning sign and the 'Speed Limit' (R2-1) regulatory sign were evaluated in the field. For the simulator evaluation, pedestrian crossing warning sign was also included.

APPENDIX D: RESEARCH PARTICIPANT CONSENT FORM

UNIVERSITY OF WISCONSIN-MADISON
Research Participant Information and Consent Form

Title of the Study: Evaluation of Elongated Pavement Markings Signs

Principal Investigator:

David A. Noyce, Ph.D., P.E.

Phone: (608) 265-1882

Email: noyce@engr.wisc.edu

<u>DESCRIPTION OF THE RESEARCH</u>

You are invited to participate in a research study about the characteristics of traffic signs that have been painted on the pavement instead of positioned on the side of the road. You will participate in the study by either ‘driving’ on a driving simulator or observing images as part of a computer simulation. The research will be conducted in the Driving Simulation Laboratory, located in the Mechanical Engineering Building at the University of Wisconsin-Madison, 1513 University Avenue. Computer-based surveys may be conducted at an adjacent facility.

You have been asked to participate in this study because you are a licensed driver over the age of 18.

The position of your feet and your hands might be recorded as part of the research. Your face will not be videotaped. The videotape recording of the driving simulator experiment will be reviewed by the Principal Investigator and his research associates and graduate students. No other person outside of the research group will review. The tapes will be kept for 7 years. It is likely that the videotape will be observed after the research is completed and used for other research. After the 7 year period the videotapes will be destroyed.

<u>WHAT WILL MY PARTICIPATION INVOLVE?</u>

If you decide to participate in this research you may be asked to 'drive' the driving simulator or to participate in a computer simulation.

If you are asked to ‘drive’ the driving simulator you will be asked to drive the simulator as if it was your own vehicle or a vehicle familiar to you. Everything on the vehicle operates just like a real vehicle. In other words, the gas pedal, brake pedal, steering, and so on are all the same. The scene presented to you will include different roads. You will drive a practice course before driving in the study; therefore, you will have time to become familiar with the vehicle and what we are asking you to do.

If you are asked to participate in the computer simulation you will be asked to look at images in the computer simulating different distances and indicate when you are able to read what is displayed in the image.

Your participation will last approximately 30-60 minutes per session and will require only one session of 30-60 minutes in total.

ARE THERE ANY RISKS TO ME?

Some who drive the driving simulator experience something similar to motion sickness. Like with motion sickness, slight dizziness or nausea symptoms may develop. If you experience any of these symptoms, we will not proceed further in the study and you will be free to go. Also, if you have recently experienced motion sickness in a motor vehicle, you should not participate. No other risks are anticipated.

ARE THERE ANY BENEFITS TO ME?

There are no direct benefits for participating in this research.

WILL I BE COMPENSATED FOR MY PARTICIPATION?

You will receive $20 in the form of a gift card for participating in the driving simulator portion of this study. If you do withdraw prior to the end of the driving simulator study, you still will receive the $20 compensation.

If you participate in the computer simulation you will not be compensated. Parking will be provided or reimbursed if necessary for both the driving simulation as well as for the computer simulation.

HOW WILL MY CONFIDENTIALITY BE PROTECTED?

While there will probably be publications as a result of this study, your name will not be used. Only group characteristics will be published.

WHOM SHOULD I CONTACT IF I HAVE QUESTIONS?

You may ask any questions about the research at any time. If you have questions about the research after you leave today you should contact the Principal Investigator David A. Noyce at (608) 265-1882.

If you are not satisfied with the response of research team, have more questions, or want to talk with someone about your rights as a research participant, you should contact the Education Research and Social & Behavioral Science IRB Office at 608-263-2320.

Your participation is completely voluntary. If you decide not to participate or to withdraw from the study you may do so without penalty.

Your signature indicates that you have read this consent form, had an opportunity to ask any questions about your participation in this research and voluntarily consent to participate. You will receive a copy of this form for your records.

Name of Participant (please print):______________________________

____ _______________

Signature Date

ACKNOWLEDGEMENTS

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REFERENCES

1. Puvanachandran. (1995). Effect of Road Curvature on Accident Frequency: Determining Design Speeds to Improve Local Curves. Road and Transportation Research, 4, 76-83.
2. Chrysler, Schrock and Williams (2006). Research Recommendations for Pavement Marking Words and Symbols. Texas Transportation Institute.
3. MUTCD. (2009). Manual on Uniform Traffic Control Devices, U.S. Department of Transportation, Federal Highway Administration.
4. HSM. (2010). Highway Safety Manual. American Association of State Highway and Transportation Officials.
5. Lay,M.G. (2004). Design of Traffic Signs. Chapter 3 of the Human Factors of Transport Signs. Edited by Castro, C. and Horberry, T. CRC Press.
6. Olson, P. L. (2010). Forensic aspects of driver perception and response (3rd ed.). Tucson, Ariz: Lawyers & Judges Pub.
7. Rockwell, T.H. (1972). Eye Movement Analysis of Visual Information Acquisition and Driving: An Overview, Proceedings of the 6th Conference on the Australian Road Research Board, Vol. 6, pp. 316-331.
8. Al-Kaisy, A., Bhatt, J., & Rakha, H. (2005). Modeling the effect of heavy vehicles on sign occlusion at multilane highways. Journal of Transportation Engineering, 131(3), 219–228.
9. Ullman, G., and Dudek, C. (2001). Effect of Roadway Geometrics and Large Trucks on Variable Message Sign Readability. 80th Annual Meeting of the Transportation Research Board, Washington, D.C
10. Akagi, Y., Seo, T., & Motoda, Y. (1996). Influence of visual environments on visibility of traffic signs. Transportation Research Record: Journal of the Transportation Research Board, 1553(1), 53–58.
11. Johansson, Gunnar, & Rumar, K. (1966). Drivers and Road Signs: A Preliminary Investigation of the Capacity of Car Drivers to get Information from Road Signs. Ergonomics, 9(1), 57–62. doi:10.1080/00140136608964342
12. Johansson, G., & Backlund, F. (1970). Drivers and Road Signs. Ergonomics, 13(6), 749–759. doi:10.1080/00140137008931202
13. Drory, A., & Shinar, D. (1982). The effects of roadway environment and fatigue on sign perception. Journal of Safety Research, 13(1), 25–32.
14. Shinar, D., Rockwell, T. H., & Malecki, J. A. (1980). The effects of changes in driver perception on rural curve negotiation. Ergonomics, 23(3), 263–275. doi:10.1080/00140138008924739
15. Retting, R.A. and Farmer, C.M. (1998). Use of Pavement Markings to Reduce Excessive Traffic Speeds on Hazardous Curves. ITE Journal, September, pp. 30-36.
16. McGee, H.W. and Hanscom, F.R. (2006). Low-Cost Treatments for Horizontal Curve Safety. Federal Highway Administration, FHWA-SA-07-002.
17. Modi,G. (2013). Personal Communication with Girish Modi, Chief, Highway Safety, Risk Management and Crash Data Analysis, Bureau of Maintenance and Operations, Pennsylvania Department of Transportation.
18. Golembiewski,G., Haas, R., Katz, B. and Bryer, T. (2008). Evaluation of the Effectiveness of PennDOT's Low Cost Safety Improvement Program (LCSIP), Science Applications International Corporation.

19. Chrysler, S. T., & Schrock, S. D. (2005). Field Evaluations and Driver Comprehension Studies of Horizontal Signing: By Susan T. Chrysler and Steven D. Schrock. Texas Transportation Institute, Texas A&M University System.
20. Hallmark, S. L., Peterson, E., Fitzsimmons, E., Hawkins, N., Resler, J., & Welch, T. (2007). Evaluation of Gatewayand Low-Cost Traffic-Calming Treatments for Major Routes in Small Rural Communities. Retrieved from http://www.ctre.iastate.edu/reports/traffic-calming-rural.pdf
21. Charlton, S. G. (2004). Perceptual and attentional effects on drivers' speed selection at curves. Accident Analysis & Prevention, 36(5), 877–884. doi:10.1016/j.aap.2003.09.003
22. Barker J. and Helliar-Symons, R.D., (1997).Countdown signs and Roundel Markings Trials. TRL Report 201, Transportation Research Laboratory, UK.
23. DFT. (2013). Setting Local Speed Limits. Circular 01/2013, Department for Transport, UK.
24. DFT. (2004). Village Speed Limits. Traffic Advisory Leaflet 1/04, Department for Transport, UK.
25. DFT. (2000). Traffic Calming in Villages on Major Roads. Traffic Advisory Leaflet 1/00, Department for Transport, UK.
26. Macdonald, W. A., & Hoffmann, E. R. (1972). Factors Affecting the Design of Road Pavement Messages. Proc., 6th Conference Australian Road Research Board, Vol. 6, Pt. 3, pp. 273–285.
27. Macdonald, W. A., & Hoffmann, E. R. (1973). The recognition of road pavement messages. Journal of Applied Psychology, 57(3), 314.
28. Zwahlen, H. T., & Schnell, T. (1999). Recognition Distances of Different Pavement Arrow Designs during Daytime and Nighttime. Transportation Research Record: Journal of the Transportation Research Board, 1692(1), 106–118.
29. QMUTCD. (2012). Queensland Manual of Uniform Traffic Control Devices. 2003 Edition, Issue 4, Queensland Department of Transport and Main Roads, Australia.
30. TSM. (2003). Traffic signs manual. Chapter 5, TSO. Great Britain, Department for Transport.
31. Fors, C., Ihlström, J. and Nygårdhs, S. (2012). Road marking symbols – A compilation of the existing regulations in Denmark, Finland, Norway, Sweden, the Netherlands, Great Britain and Germany (report in Swedish, summary in English). VTI (Swedish National Road and Transport Research Institute).
32. City of Edmonton.(2012). Design and Construction Standards, Volume 8 Pavement Marking, City of Edmonton, Canada.
33. Gail, A, (2013). Personal Communication with Annette Gail, Highway Equipment Section V4, Federal Highway Research Institute (BASt), Germany.
34. Retting, R. A., McGee, H.W., and Farmer, C.M. (2000). Influence of Experimental Pavement Markings on Urban Freeway Exit-Ramp Traffic Speeds. Transportation Research Record 1705, pp. 116 – 121.
35. Dewar, R., Kline, D., Scheiber, F., and Swanson, A. (1997). Symbol Signing Design for Older Drivers. Federal Highway Administration.
36. Shoptaugh, C. F., and Whitaker, L. A. (1984). Verbal Response Times to Direction Traffic Signs Embedded in Photographic Street Scenes. Human Factors: The Journal of the Human Factors and Ergonomics Society, 235-244.

37. Littell, R., Stroup, W., and Freund, R. (2002). SAS for Mixed Models, Fourth Edition, Chapter 4. SAS Institute.
38. Clark, T., and Linzer, D. (2012). Should I Use Fixed or Random Effects? http://polmeth.wustl.edu/mediaDetail.php?docId=1315 Accessed May 1, 2014.
39. Agresti, A. (1990). Categorical Data Analysis. Wiley Publishers.