Recognition Distance and Elongation Ratio for Elongated Horizontal Pavement Markings: A Simulator Study

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Abstract

All factors being equal, pavement marking signs are more likely to be detected by drivers than post-mounted signs. Several international manuals/guidelines explicitly state that elongation improves the legibility distance of pavement markings. Furthermore, some countries use greater elongation ratios on roadways with higher speed limits, while some others use a single elongation ratio regardless of the speed limit of the roadway. Therefore, research is needed to explore the relationship between speed and elongation ratio. Most of the available research on this topic has used stationary observers rather than subjects driving at posted roadway speeds, which makes a full-scale driving simulator an invaluable tool to study the effects of sign elongation on recognition distance while driving.

Sixteen drivers, between the ages of 21 and 54, participated in the driving simulator study. Five elongation ratios that were tested in the driving simulator, 1:1, 1:2.5, 1:5, 1:7.5 and 1:10. The 'Curve' (W1-2) sign, 'Speed Limit' (R2-1) sign, and 'Pedestrian Crossing' (W11-2) sign were chosen for this research.

Statistical analysis was performed to analyze the effect of elongation ratio on recognition distance through a random effects linear model. All variables were initially included and through the procedure it was found that age, gender, years of driving experience, and if the participant wore corrective lenses were not statistically significant covariates. It was found

that elongation ratio, sign type, and speed were statistically significant factors when perception response time is not taken into account. The relationship between recognition distance and elongation ratio was found to be a quadratic function. While sign type is statistically significant, it is not meaningful for real world applications, therefore, the model was adjusted to be useful for all sign types. This research yielded a relationship between recognition distance and elongation ratio for drivers in a driving simulator:

$$Distance = -1.4 * Ratio^2 + 28 * Ratio + Constant \qquad (14)$$

The constant term is affected by speed and whether a perception reaction time is used. Other considerations, such as cost of installation and maintenance, should be taken into account before an elongation ratio is selected for application.

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1. Introduction

1.1. Background

Drivers spend most of the time looking at the roadway directly ahead. Any object on the side of the road is first detected in the peripheral vision and requires a head/eye movement to gather information. Several studies have shown that post-mounted signs have a low registration rate and their registration can be further hampered by presence of heavy vehicles and other traffic as well as visual clutter in urban environments. All factors being equal, pavement marking signs are more likely to be detected by drivers than post-mounted signs. Pavement marking signs are copies of pole-mounted signs that are instead painted onto the roadway at a certain elongation ratio.

In certain geometric layouts, post-mounted signs may not provide adequate information for passing motorists. One of these scenarios is a post-mounted 'Curve Ahead (W1-2)' sign. Excessive speed in a horizontal curve is more dangerous than on a straight section of roadway. Puvanachandran (1995) found that the speed of vehicles entering a horizontal curve was much closer in relation to the speed of the vehicle's approach as opposed to the desired speed based on the design degree of curvature. One way to provide a stronger emphasis of the desired operating speed on the horizontal curve is to include complementary pavement marking signs. Other instances where complementary pavement markings might be helpful may include reduced speed zones, certain turn prohibitions, right of way regulations, destination names and route numbers. One of the key components to complimentary pavement marking signs is that they are elongated to increase recognition distance.

1.2. Benefits of Elongation Pavement Marking Signs

MacDonald and Hoffman (1972) performed four experiments to investigate the effects of letter height, word order and spacing between words on the perception of pavement messages. One of the results applicable to pavement marking symbols is that with increasing driving speed, recognition distance decreased linearly. MacDonald and Hoffman (1973) found that elongated letters were recognized at a greater distance than normal letters of same width. The increase in recognition distance was significantly less than would be expected if the subtended vertical visual angle was the lone determining factor.

Several international manuals/guidelines explicitly state that elongation improves the legibility distance of pavement markings. The Queensland (Australia) MUTCD notes that the legibility distance is increased by enlarging the length of characters, and the benefit of increasing elongation diminishes if the distortion ratio exceeds about 10:1 (QMUTCD, 2013). The UK Traffic Signs Manual states that the oblique angle at which the pavement markings are viewed, they are heavily foreshortened (TSM, 2003). Therefore, elongated pavement marking signs have been used and shown to significantly improve the recognition distance when compared to non-elongated pavement marking signs. However, the extent of elongation (height to width ratio) differs from country to country. Excessive elongation can result in distortion and therefore a balance needs to be struck between increasing the legibility distance and distorting the pavement marking sign. Furthermore, some countries use greater elongation ratios on roadways with higher speed limits, while some others use a single elongation ratio regardless of the speed limit of the roadway. Therefore, research is needed to explore the relationship between speed and elongation ratio.

1.3. Research Objective

The objectives of this research are to:

- Identify the current state of practice and use of elongated horizontal pavement markings.
- Determine the relationship between elongation ratio and recognition distance through the use of a driving simulator.

1.4. Thesis Organization

This thesis contains 6 chapters. Chapter 1 introduces elongated horizontal pavement markings by explaining their background and benefits, while also describing the need to find appropriate elongation ratios. Chapter 2 reviews relevant literature surrounding elongate pavement markings and the use of driving simulators. The study parameters and method are described in Chapter 3. Chapter 4 discusses the statistical analysis performed and the results of the analysis. Chapter 5 summarizes the work done in this study, while Chapter 6 describes future work to be done with elongated horizontal pavement markings.

2. Literature Review

2.1. Human Factors Issues

2.1.1. Vision and Pavement Marking Signs

Information gathered for driving is predominantly visual. Therefore, an understanding of the human visual system is necessary to understand driver perception and comprehension of any signing or markings. The visual field of human eyes is approximately 55° above the horizontal, 70° below the horizontal and 90° to the left and right (HSM, 2010). 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 about 2° to 4° from the focal point. All other vision outside of this region is considered peripheral vision. Peripheral vision usually operates 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, 40° at 60 km/h and 20° at 100 km/h (Lay, 2004). Detection of movement or something interesting in the peripheral vision will 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 (Olson, 1996). Rockwell (1972) 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). In other words, drivers spend most of their time scanning the roadway directly ahead. Post-mounted signs first appear in peripheral vision and when noticed, require an eye and/or head movement to bring the sign into foveal vision. Pavement marking signs are expected to appear in foveal vision directly. Therefore, pavement marking signs are expected to be more successful than post-mounted signs in being detected by the drivers.

Research has shown that the ability of drivers to recognize post-mounted signs is adversely affected by other vehicles, especially trucks (Al-Kaisy et al, 2001; Ullman and Dudek, 2001). Akagi et al. (1996) studied the influence of cluttered visual environments on driver ability to detect traffic signs. Study was performed on urban arterials in Japan. As one might expect, researchers found a statistically significant negative correlation between the visual noise ratio (measure to quantify visual clutter) and the distance at which a traffic sign was observed.

Furthermore, the literature is replete with evidence that post-mounted signs can have a low registration rate among drivers, depending on the sign type. Johansson and Rumar (1966) stopped Swedish motorists 710 m after they passed different signs on the road and asked the drivers to recall or recognize the last road sign they passed. The recall/recognition 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 (1970) studied 5,000 drivers and found an average recall/recognition rate of less than 50%. The rates varied based on the urgency of the message in the sign. Drory and Shinar (1982) used a similar methodology in Israel and obtained lower recognition rates ranging from 5% to 12%. Researchers also report evidence of low attentional value of warning signs. Shinar et al. (1980) analyzed eye movements of drivers as they drove through curves on rural roads and found that direct fixations on warning signs were relatively rare.

Considering all these factors, pavement marking signs have greater potential to be perceived by drivers and should be explored. However, pavement marking signs can have durability issues, due to vehicle traffic, as well as snow clearance operations. For these reasons, post-mounted signs may be used in conjunction with or in proximity of pavement marking signs, especially when used for regulatory purposes.

2.1.2. Perception Response Time

In order to determine the maximum recognition distance for elongated horizontal pavement markings, the perception response time (PRT) needs to be known. The perception response time is the time it takes for a driver to identify an object (in this case a sign), comprehend its meaning and/or necessary action to take, and execute a response (verbally state the sign).

During the literature review, no studies were found that analyzed the perception response time for pavement markings. Therefore, perception response studies for pole mounted signs were reviewed. In a study done by Shoptaugh and Whitaker (1984), 60 students, were asked to verbally respond to stimuli presented to them as quickly as possible. The stimuli were classified as control stimuli or embedded stimuli. The control stimuli consisted of a single word (left, right, or no) placed on a white field at the central fixation point. The embedded stimuli consisted of black and white photographs of residential and business areas with directional signals (from the U.S. Highway Department Sign Handbook) inserted into each photograph, either to the left or right of the central fixation point, as shown in Figure 1.

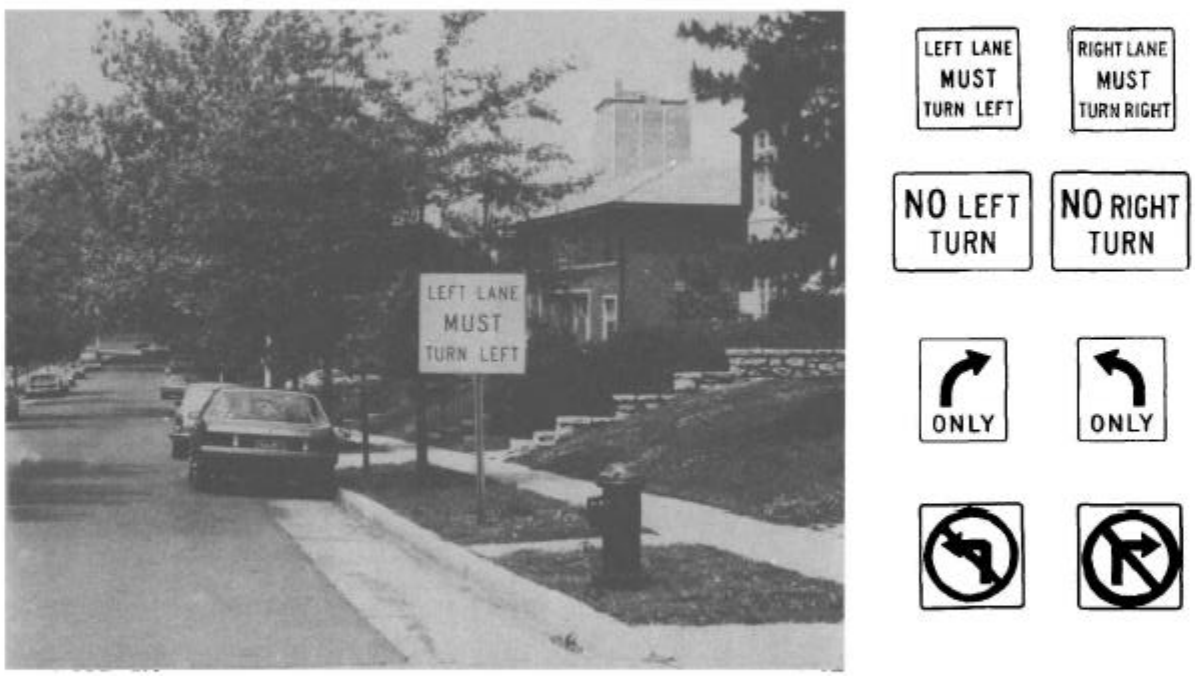


Figure 1. Example of residential photograph with signs from handbook.

Participants were instructed to concentrate on a black x (the central fixation point) on a white background, signal for the stimulus to appear, and verbally respond to the stimulus. The response time was recorded, as well as the accuracy, for each stimulus. The average response time for the control stimuli was 0.639 seconds, which is the most applicable of the stimuli groups due to the low stimulus environment of the driving scenario.

A different study, by Dewar et al. (1997), used 18 standard symbol signs that varied greatly in their tested legibility distance and ease of comprehension. The signs were compared in regard to the ability of young, middle-aged, and older drivers to identify them when they were briefly presented on a computer screen. This study looked at the perception response time for each of the three different volunteer age groups: young group (age range 19 to 33, 6 men and 6 women), middle-aged group (age range 39 to 60, 6 men and 6 women), and older group (age range 61 to 75, 9 men and 9 women). All participants were tested for visual acuity, and although not significantly different, the young and middle-aged drivers had better visual acuity than the older drivers.

A set of 18 MUTCD symbol “test” signs, along with corresponding “foil” signs, were selected to test the participant’s perception reaction time. The “foil” signs were alternative symbol signs selected based on similarity to their corresponding MUTCD sign in order to test comprehension. For each trial, the name of a sign would be shown on the screen, thereafter the participant advanced the test and a sign would be presented. The participant would identify if the sign present was the same as the name previously shown, a “test” sign, or if it was different, a “foil” sign. During the testing, participants were asked to sit 32.7 inches away from the monitor, with the use of a chin rest to maintain distance, to simulate a “real-world” scenario based on the scale of the signs presented on the screen. Along with the monitor, a control console with three keys ("SAME", "DIFFERENT", and "NEXT") was used by the participants to complete the tests. The mean reaction times for each age group for the best, intermediate, and worst signs are shown in Table 1. The designation of best, intermediate, and worst signs came from previous studies and do not necessarily coincide with the results from this study.

Table 1. Mean reaction time (ms) for best, intermediate, and worst signs among driver groups.

Sign	Young	Middle-Aged	Older	Overall Means
Best	542.4	727.6	951.4	740.5
Intermediate	545	696.2	891.2	710.8
Worst	505.9	653.3	888.1	761.7

From Table 1, the overall mean reaction times were in the 0.7 second range. Also, Dewar et al. suggest that contextual variables may be more important determinants of reaction time than the characteristics of the individual sign. These variables could include familiarity of the sign, similarity between the "test" sign and its "foil", and the similarity between "test" signs.

2.2. 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.

2.2.1. Curve Warning Applications

Insurance Institute for Highway Safety (IIHS) Study

Retting and Farmer (1998) examined the effectiveness of a special pavement marking at one sharp horizontal curve (approximately 90°) location on a suburban two-lane roadway in Northern Virginia. 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. About 220 feet upstream of the curve, the experimental pavement marking shown in Figure 2 was installed using thermoplastic material. Glass beads were used to enhance nighttime retro-reflectivity. The word "SLOW" was written in eight-foot high white letters and the left curve arrow was eight foot high and white in color. Eighteen inch wide transverse lines were marked at both the beginning and ending of the text/symbol message. Figure 3 shows the pavement marking and the speed measurement locations.

Figure 2. Experimental Pavement Marking Sign (Retting and Farmer, 1998)

A control site was chosen for the study on the same roadway about a quarter of a mile away. The curve at the control site was an approximately 45° left turn. Average daily traffic on the roadway was 5,000 vpd. A before/after speed study was performed at the test and control locations. 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 3. At the control site, speeds were measured approximately 100 feet upstream of the PC. Two road tubes spaced 20 feet apart were used at each site. Baseline measurements were taken in August 1996 and the marking was installed in January 1997. Data for the after period was collected 2 weeks after installation, allowing time for the drivers to adapt to the sign. The duration of after-treatment collection was one week. Analysis was limited to passenger cars, as there was a limited number of trucks. A minimum gap of three seconds between vehicles was used. Data analysis was performed for three time periods: 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.

The pavement marking was effective in reducing mean speed and 90th percentile speed at the experimental site under all the three time periods. Reductions in mean speed were 1.1 mph, 1.6 mph and 3.4 mph, for the day, evening and late night periods, respectively. Contrastingly, speeds increased at both the upstream and control sites. Percentages of drivers exceeding 35 mph, 40 mph and 45mph were all reduced as well. Overall the experimental pavement marking resulted in a decrease in speeding of about 6 percent and 7 percent during day time and late night periods, respectively.

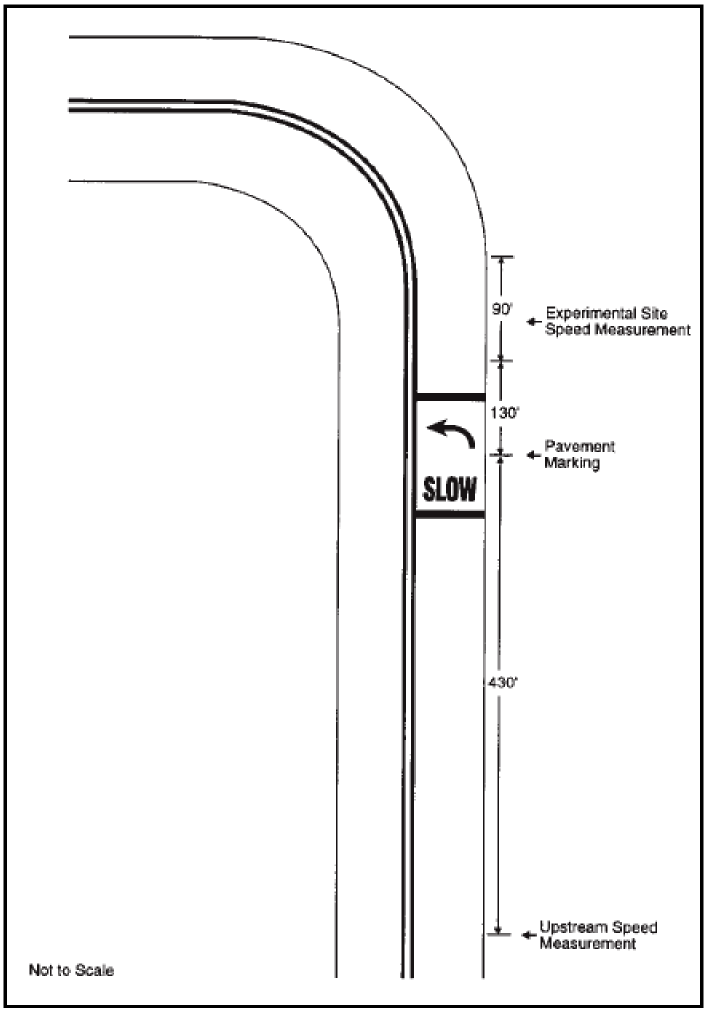


Figure 3. Experimental Pavement Marking & Speed Measurement Locations (Retting and Farmer, 1998)

Pennsylvania Department of Transportation Advance Curve Warning Marking

Similar to the pavement marking sign evaluated by Retting and Farmer (1998), Pennsylvania Department of Transportation (PennDOT) developed the PennDOT Advance Curve Warning Marking (ACWM) pavement sign (shown in Figure 4) to alert motorists to the presence of a curve and the need to slow down (McGee and Hanscom, 2006). The PennDOT ACWM is designed for two-lane locations with a high number of curve-related crashes. Two ranges of posted speed are used to determine the design layout of the sign. Figure 5 shows the layout for low speed limits (35mph or lower) and high speed limits (40 mph or greater). Distance of the marking from the PC is based on posted speed and posted warning speed, as shown in Figure 6.

Figure 4. PennDOT Curve Advance Marking (McGee and Hanscom, 2006)

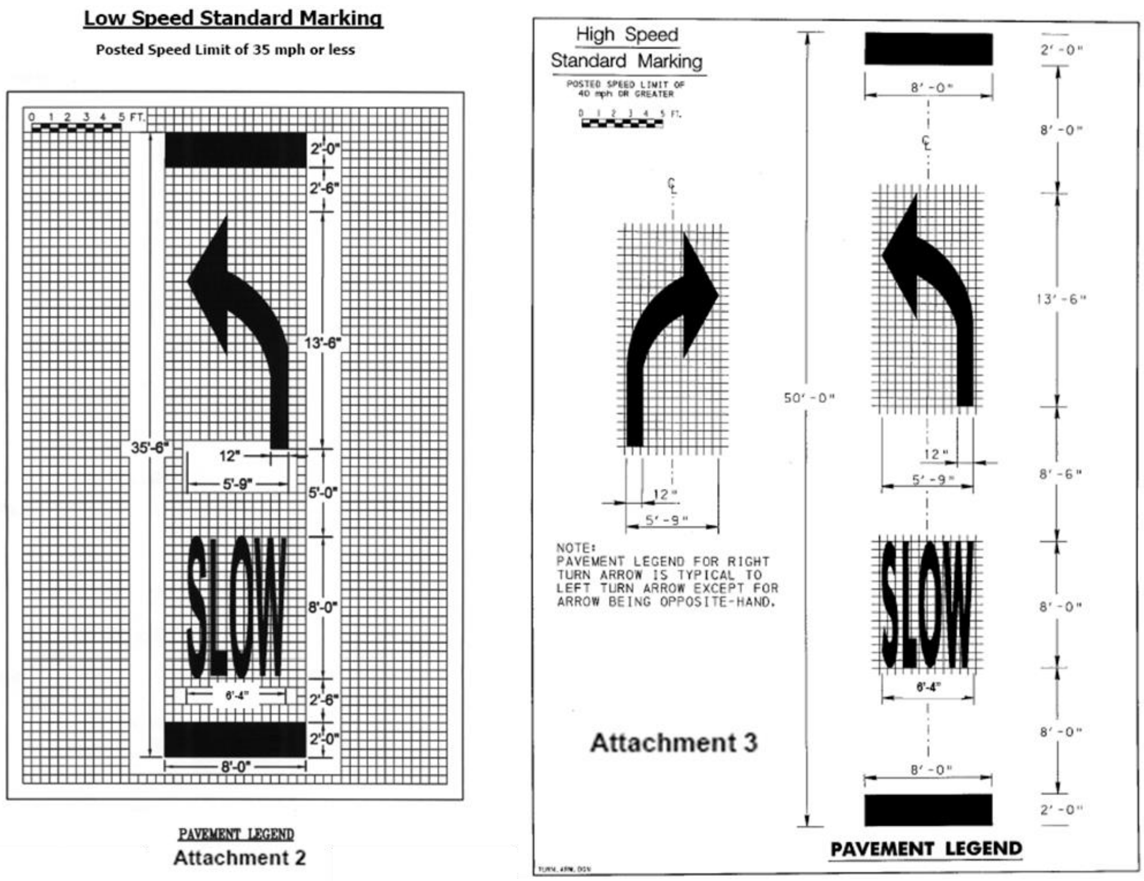
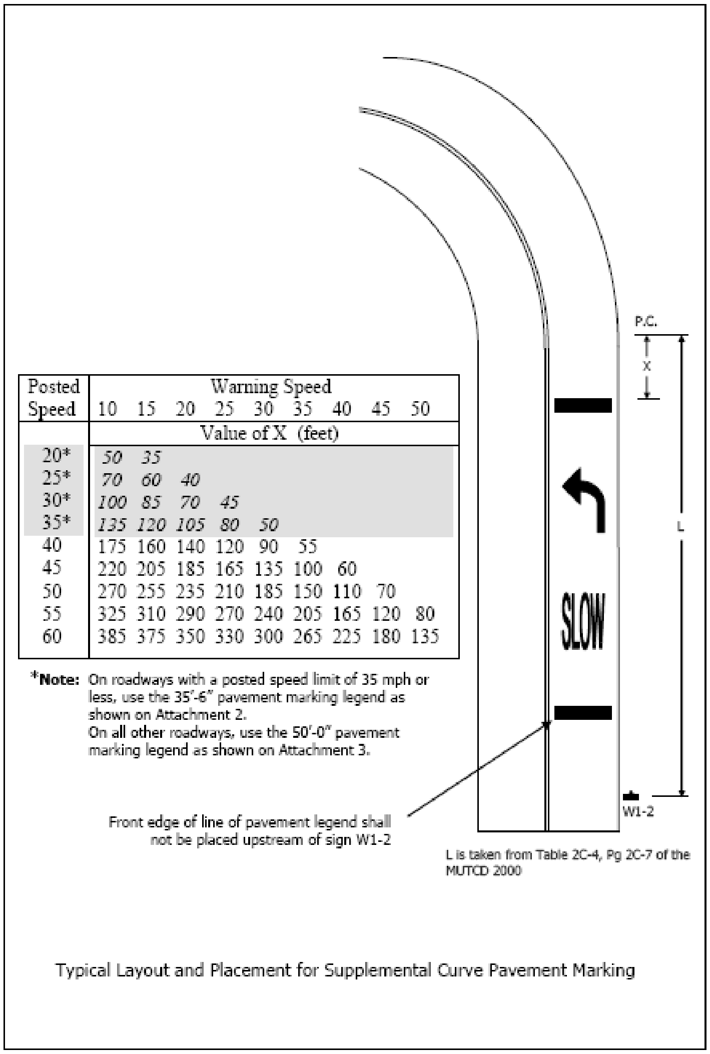


Figure 5. PennDOT ACWM Detailed Design Layout for Different Speeds (Modi, 2013)

Attachment 1



Posted Speed	Warning Speed 10	15	20	25	30	35	40	45	50
	Value of X (feet)								
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	240	205	165	120	80
60	385	375	350	330	300	265	225	180	135

Figure 6. Distance of the Sign from the Point of Curvature (Modi, 2013)

Several thousand ACWM have been installed in Pennsylvania since 2001. Safety evaluation of multiple low-cost safety improvements was conducted for PennDOT in 2008. ACWM installed on 429 segments between 2000 and 2004 were included in the safety analysis. ACWM were found to be very effective and showed a 33% (expected range of 21% - 46%) decrease in crashes (Golembiewski et al., 2008). The decrease was observed for crashes related to curve negotiation and that involved “driver error on curve” as a contributing factor to the crash.

Texas Curve Pavement Marking Study

Chrysler and Schrock (2005) evaluated the effectiveness of three different pavement markings on reducing speeds on curves at two rural locations and one urban location. The markings tested are shown in Figure 7 through Figure 9 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 markings were applied about 400 feet downstream of the standard curve warning sign and a few hundred feet upstream of the PC and the text was approximately 8 feet tall. Speeds were measured at a control point (upstream of the post-mounted curve warning sign), near the curve warning sign and at the PC.

The CURVE AHEAD treatment did not have the intended effect on vehicle speeds. Analysis of variance confirmed that the difference in before and after installation/treatment speeds was statistically significant but the speeds increased about 1 mph. The CURVE 55 MPH treatment increased the drop in speeds between the control point and the PC by 4 mph, although not statistically significant. For the combined curve arrow and advisory speed treatment at the one urban road location, speeds at the PC were reduced by a statistically significant 7 mph. Also, the percentage of vehicles exceeding the speed limit was reduced by 11% to 20% depending on vehicle type and time of day.

Figure 7. CURVE AHEAD Treatment on a Rural Road (Chrysler and Schrock, 2005)

Figure 8. CURVE 55 MPH Treatment on a Rural Road (Chrysler and Schrock, 2005)

Figure 9. Curve Arrow and Advisory Speed Treatment on Urban Road (Chrysler and Schrock, 2005)

Iowa On-Pavement Curve Marking Study

Hallmark et al. (2012) evaluated on-pavement curve warning signs at two rural two-lane roadway sites in Iowa (shown in Figure 10). The pavement sign was similar to the PennDOT ACWM pavement sign. Speed data were collected before installing the pavement sign and then one and twelve months after installation. Mean speed, 85^{th} 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.

Figure 10. Iowa On-Pavement Curve Markings Study Sites (Hallmark et al., 2012)

In general, the mean and 85th percentile speeds reduced by 1 or 2 mph. At one site, the mean and 85th percentile speeds showed mixed results. The percentage of vehicles exceeding the posted speed limit increased by up to 10% north of the PC, but decreased significantly at the center of the curve and south of the PC. The pavement sign treatment did not seem to affect those who exceeded the speed limit by 15 to 20 mph. At the second site, the mean and 85th percentile speeds reduced by up to 2 mph. Up to a 7% reduction was observed in the percentage of vehicles exceeding the advisory speed by 5, 10, 15, or 20 mph at the north and south PCs and up to 16 % at the center of the curve. Hallmark et al. (2012) concluded that the treatments were moderately effective in reducing mean and 85th percentile speeds. The markings were installed at the PC as opposed to upstream of the PC, as in the cases of the Penn DOT sign and the Retting and Farmer study. This change in installation locations could be the reason for the difference in performance when compared to the Retting and Farmer study.

Simulator Evaluation of Advisory Speed Pavement Marking Signs at Curves

Charlton (2004) compared the relative effectiveness of various types of warnings on drivers' speed selection at curves. Three types of curve warnings at three different curve types were tested in a desktop driving simulator. The driving scenario was a 28.5 km recreation of an actual road that was predominantly rural with an open road speed of 100 km/h. The simulation had oncoming cars and trucks traveling between 75km/h and 100 km/h. The road geometry was modified to contain twelve curves, four each with advisory speeds of 45 km/h, 65 km/h and 85 km/hr. Each curve was marked with one of the three curve warnings or had no warning. The three types of warnings (shown in Figure 11) are: diamond warning sign with a curve advisory speed, chevron warning and a pavement marking warning with the advisory speed and a series of transverse lines at decreasing intervals.

Curve speeds were measured at four locations: 64 m upstream of the curve, entry, midway and end of the curve. Results are shown in Figure 12. All three curve warnings were found to be reasonably effective for severe curves (advisory speed of 45km/h) with the road marking being most effective. For the 65 km/h and 85 km/h curves, the road marking warning did not reduce the speed as much as the other treatments at the entry, but the speeds at the midpoint and exit were lower than the diamond and very similar to the chevron scenarios. Charlton reported that chevron markings typically slowed drivers sooner than the road marking warning. The diamond warning (when it worked) affected drivers' speeds earlier than the road marking warnings, possibly because post-mounted signs were visible to drivers at greater distances than the pavement marking warning.

Designation	Configuration	Example
Diamond warning (permanent warning sign PW-18 and curve advisory speed sign PW-25)[a]	PW-18: 1200 mm × 1200 mm, 1800 mm above road surface. PW-25: 1200 mm × 800 mm, 980 mm above road surface. Located 64 m prior to curve[b]	
Chevron warning (chevron sight board RC-4)	3200 mm × 600 mm, 1000 mm above road surface. Located at curve tangent point directly ahead of approach lane	
Road marking warning (transverse line warning)	Numbers were 1200 mm × 4000 mm. Treatment 58 m long, beginning 64 m prior to curve. From numbers, 18 m to line 1 (510 mm wide), 16 m to line 2, 12 m to line 3, 8 m to line 4, ending 6 m prior to curve entry	

Figure 11. Three Curve Warnings Evaluated by Charlton (2004)

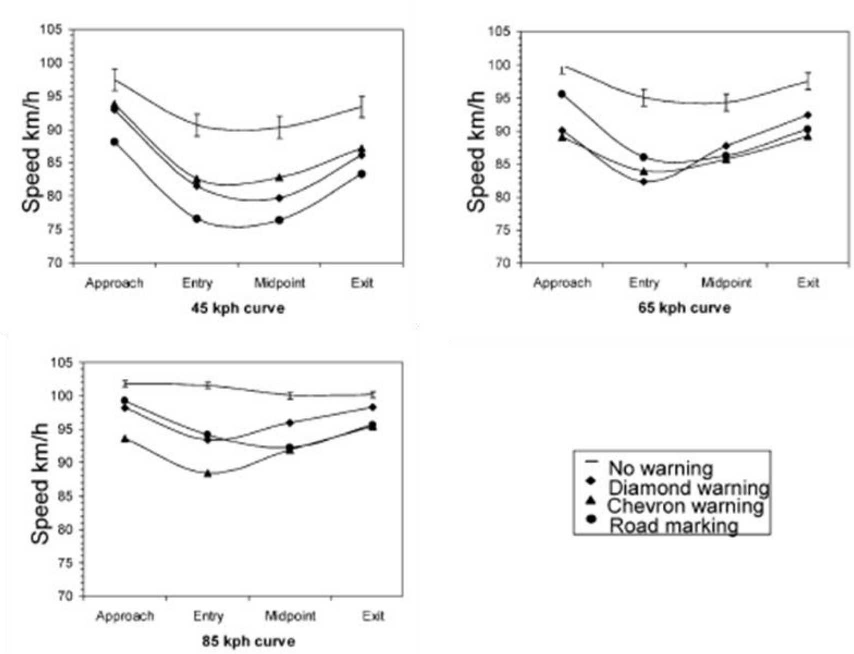


Figure 12. Mean Speeds Under Different Scenarios (Charlton, 2004)

2.2.2. Speed Limit Applications

This section summarizes the use of pavement marking signs for speed limits in the UK and an evaluation of pavement markings for speed limits conducted in Iowa.

Speed Limit Pavement Markings in UK

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) in the UK. Barker and Helliar-Symons (1997) evaluated the effectiveness of roundels on reducing speeds. A 3 mph reduction was found with the 40 mph roundel which was statistically significant, while the 30 mph roundel did not have a statistically significant effect. The most recent guidelines from the UK permit every English authority to place a 20 mph roundel marking as a repeater without the accompanying post-mounted sign in 20 mph speed zones or 20 mph speed limits (DFT, 2013). Requirement for a vertical sign to accompany the roundel was relaxed to reduce the signing and costs in 20 mph zones. Figure 13 shows a speed limit roundel outside Heathrow airport in London.

Figure 13. Speed Limit Roundel outside Heathrow Airport, London, UK

Figure 14 shows installations of speed limit roundels on colored pavement surfaces as part of traffic calming in villages in the UK. The Department for Transport leaflet on “Village Speed Limits” provides guidance for the use of speed limit roundels in villages (DFT, 2004). The guidance requires that roundels are accompanied by post-mounted repeater signs. Roundels are not independently authorized in villages because adverse weather and wear and tear can render them difficult to see and cause enforcement difficulties for police.

Figure 14. Speed Limit Roundels as Traffic Calming Measures in UK (DFT, 2000)

Iowa Speed Limit Pavement Markings Study

Hallmark et al. (2007) evaluated several traffic-calming treatments on major roads through small communities in Iowa. Seven different low-cost traffic treatments were implemented and evaluated in five rural communities of Iowa. The evaluation of on-street speed limit pavement markings is summarized in this section.

Three treatments were used as part of a gateway treatment on east and west sections of County Road E-18 in Roland, IA. The gateway entrance treatments (shown in Figure 15) consisted of converging chevrons, lane narrowing by widening painted shoulders and a “25 MPH” on-street pavement marking. Speeds decreased for all speed metrics for all of the after treatment periods, and decreases 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.

Figure 15. Gateway Entrance Treatments used in Roland, IA (Hallmark et al., 2007)

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 16 shows a schematic of the treatment, a picture of the treatment after installation and nine months after installation. Fading of the treatment is clearly visible in the pictures. The treatments were effective in reducing speeds at all three of the testing locations, although the effectiveness varied over time. With the exception for one location during the nine-month after period, when the markings had faded somewhat, the treatments remained effective.

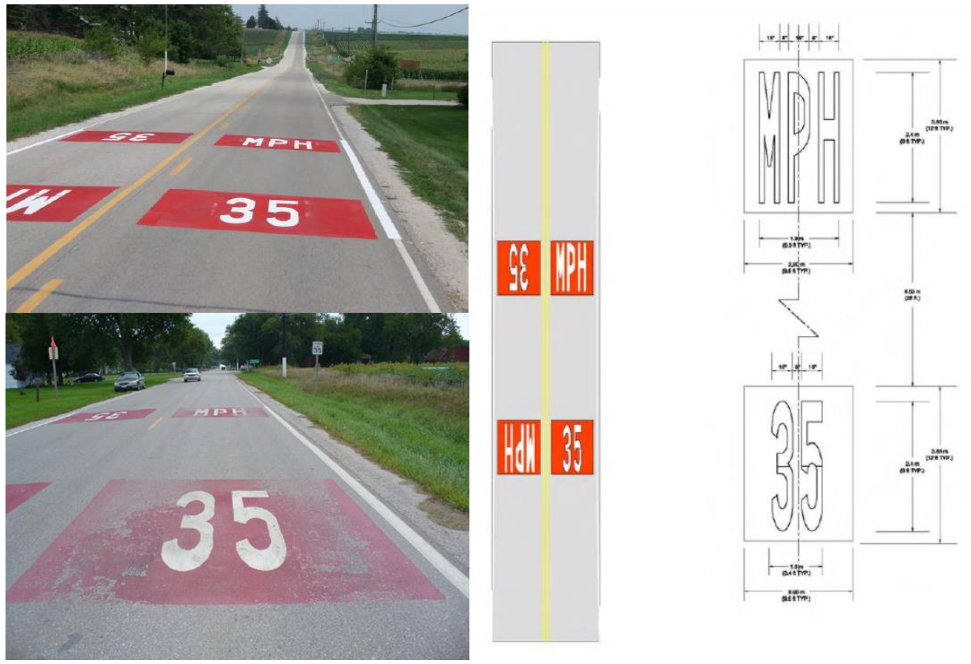


Figure 16. Schematic of Dexter, IA treatment (Hallmark et al., 2007)

2.3. United States Practice

The Manual on Uniform Traffic Control Devices (MUTCD, 2009) Section 3B.20 states that based on engineering judgment, word, symbol and arrow markings may be used to supplement signs and provide additional emphasis. Specific language from the MUTCD regarding this:

> "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.

Table 2. Word, Symbol & Arrow Markings on Pavements to Supplement Signs (MUTCD, 2009)

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

Information on the elongated pavement markings is provided only for route shields and arrows. As shown in Figure 17, the H/W (height to width) ratio for the elongated route shield signs is 2.5:1 in the MUTCD. Figure 18 shows the different examples of standard arrows for pavement markings in the MUTCD. Figure 19 shows that the lengths of the letters for elongated pavement markings is 8 feet.

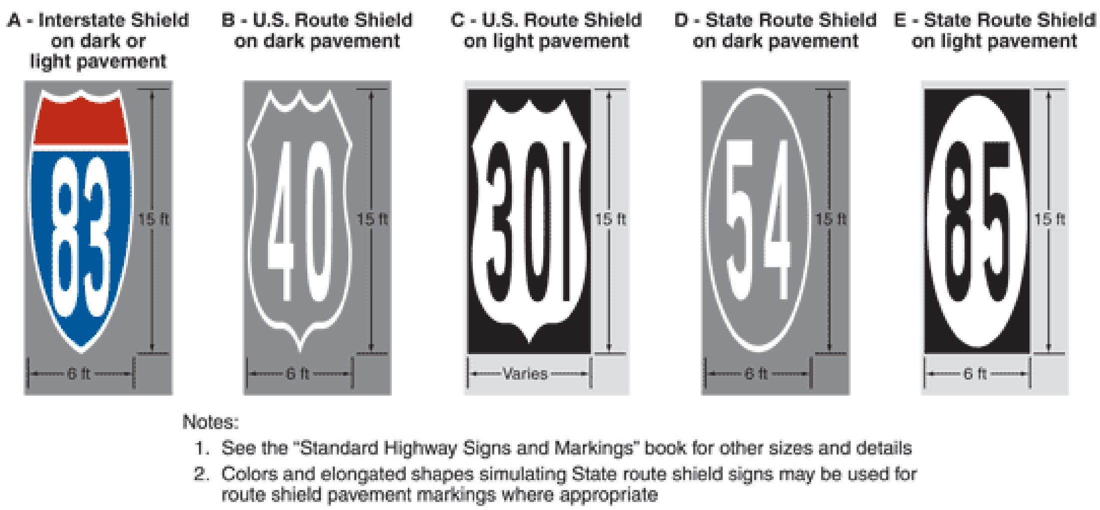


Figure 17. MUTCD Examples of Elongated Route Shields for Pavement Markings (MUTCD 2009)

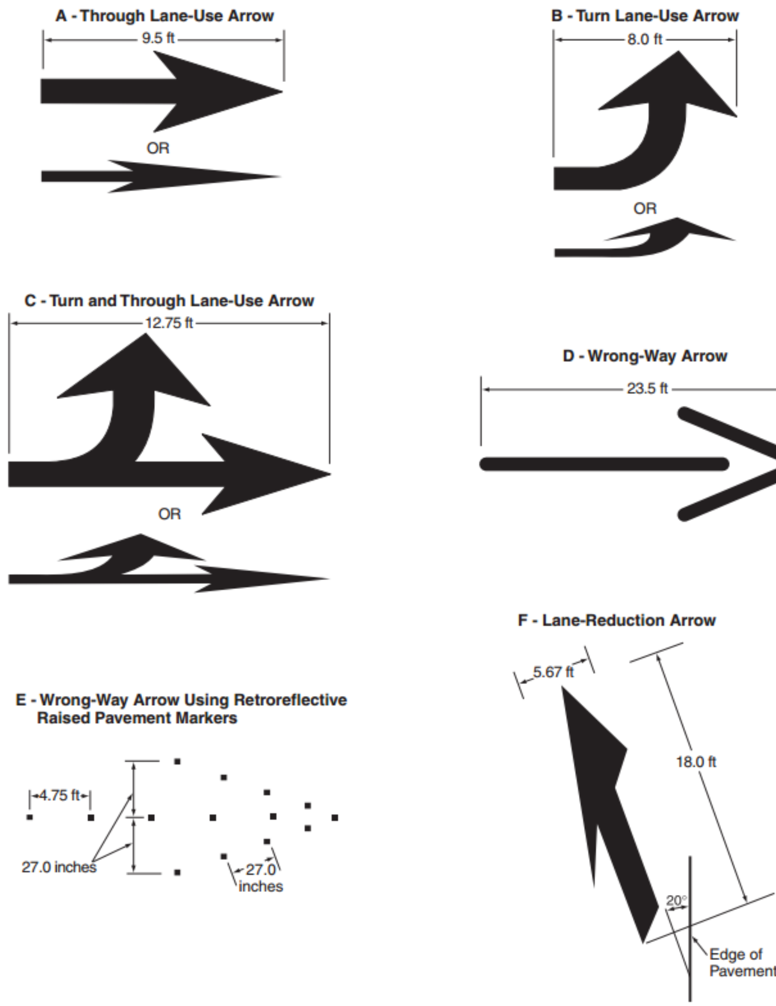


Figure 18. MUTCD Examples of Standard Arrows for Pavement Markings (MUTCD 2009)

Figure 19. MUTCD Example of Elongated Letters for Word Pavement Markings (MUTCD 2009)

2.4. International Practice

In general, elongated pavement markings are widely used in Europe, Australia, Canada and New Zealand. The major finding is that several 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. This section summarizes the practices of some of the countries for which detailed guidance was obtained.

2.4.1. Comparison of Pavement Marking Signs of 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 (Fors et al., 2012). The information for US is from the MUTCD (MUTCD 2009), for Canada is from City of Edmonton guidelines (2012) and Australia is from the Queensland MUTCD (QMUTCD, 2012). The figures accompanying each of the tables in this sub-section are from Fors et al., 2012.

Table 3 through Table 7 present the dimensions for speed limit signs, yield signs, stop signs, lane arrows, and lane change/merge arrows. The primary message from this comparison is that elongated pavement markings are commonly used in Europe and Australia and in some 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.

Table 3. 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

Table 4. 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

Table 5. 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

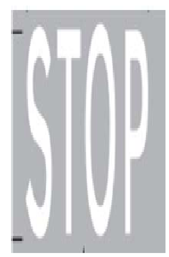


Table 6. Dimensions for Lane Arrows

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

Table 7. 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.

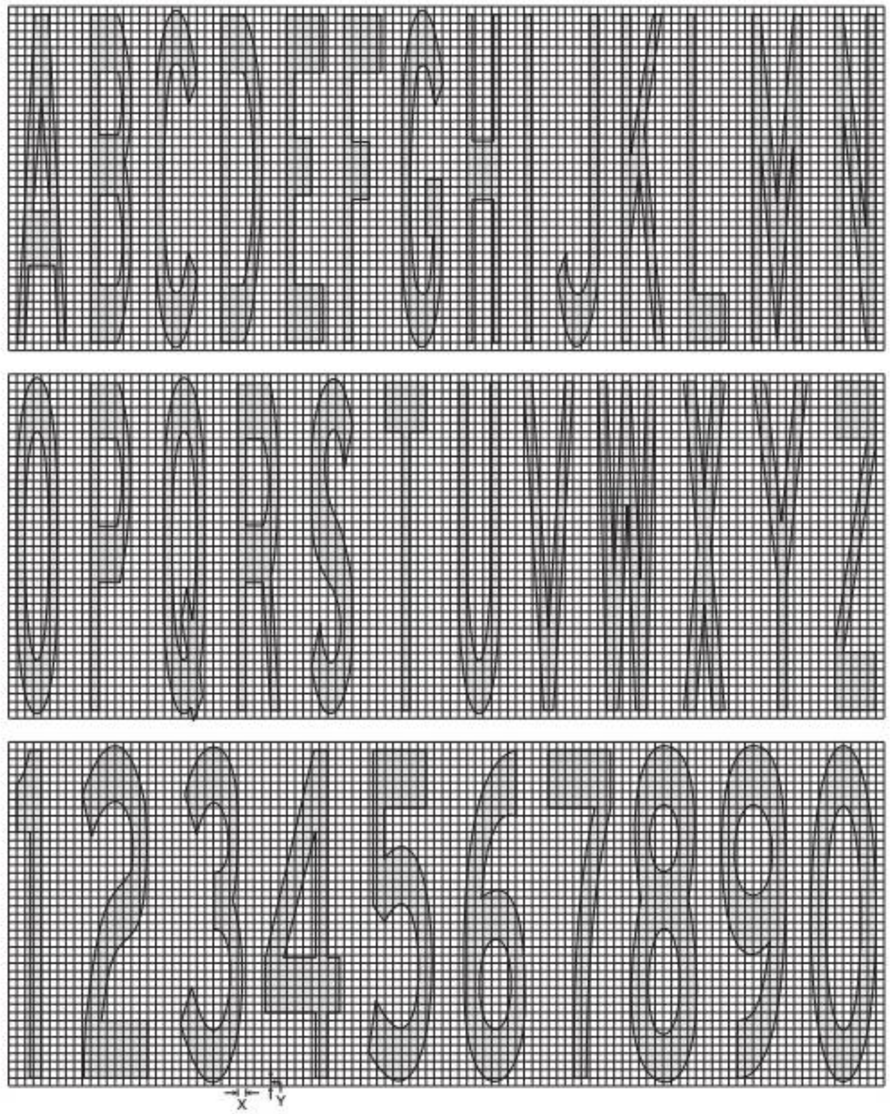
2.4.2. Australian Practice

Use of elongated pavement markings is documented in the Queensland Manual on Uniform Traffic Control Devices (QMUTCD, 2012) 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 (QMUTCD, 2012).” Figure 20 shows 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:

1) 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;
2) At repeater signs at major intersections only; and
3) 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 21. An 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.



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 20. Example of Elongated Characters on Pavement (QMUTCD, 2003)

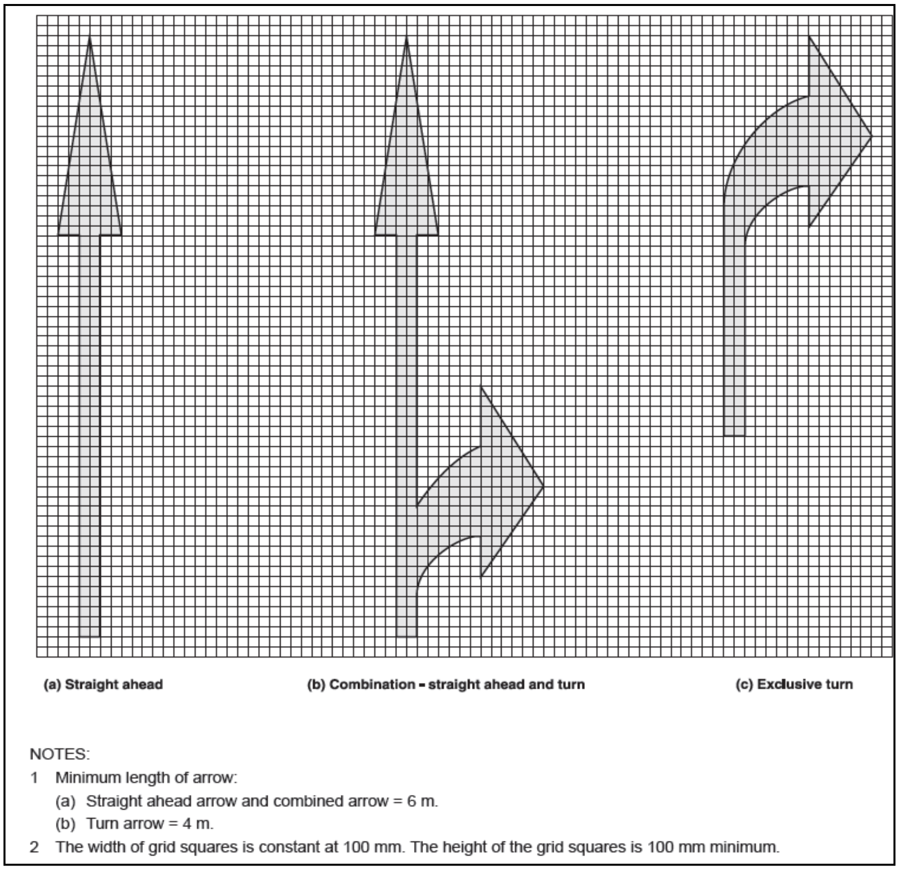


Figure 21. Elongated Intersection Arrows (QMUTCD, 2003)

2.4.3. 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 (City of Edmonton, 2012). 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 22 shows an example of elongated diamond for reserved lane (City of Edmonton, 2012).
- 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.

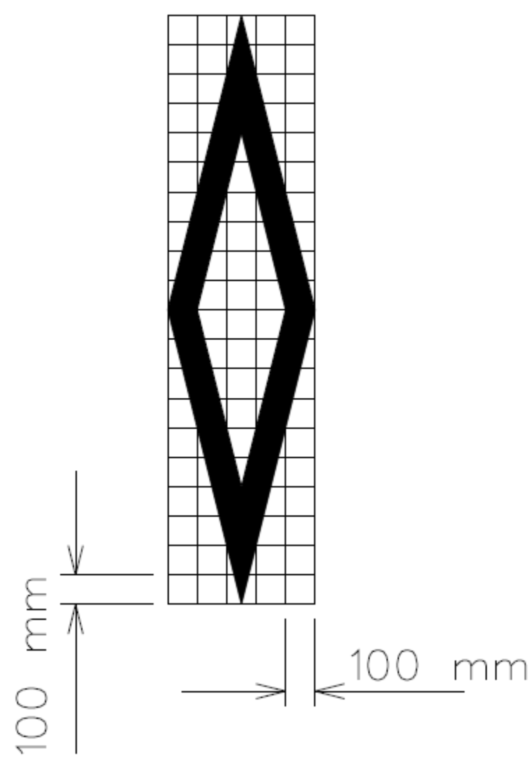


Figure 22. Example of Elongated Diamond for Reserved Lane (City of Edmonton, 2012)

- 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 23 shows an example of elongated bicycle symbol.

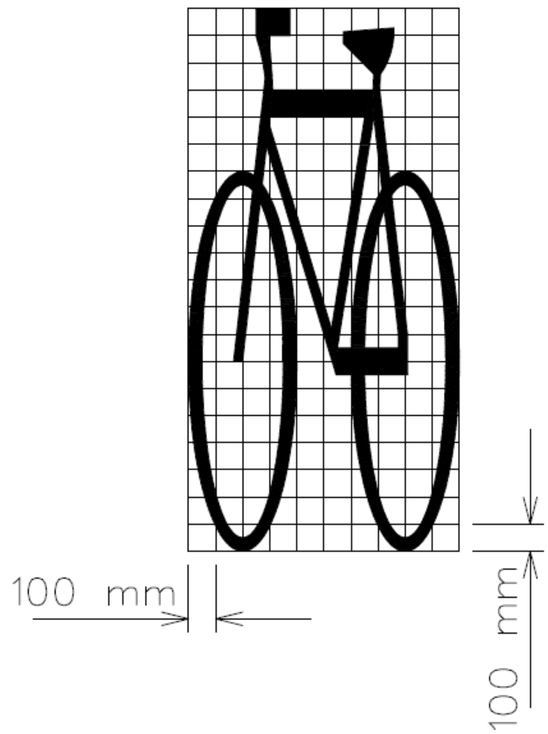


Figure 23. Example of Elongated Bicycle Symbol (City of Edmonton, 2012)

- 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 24 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.

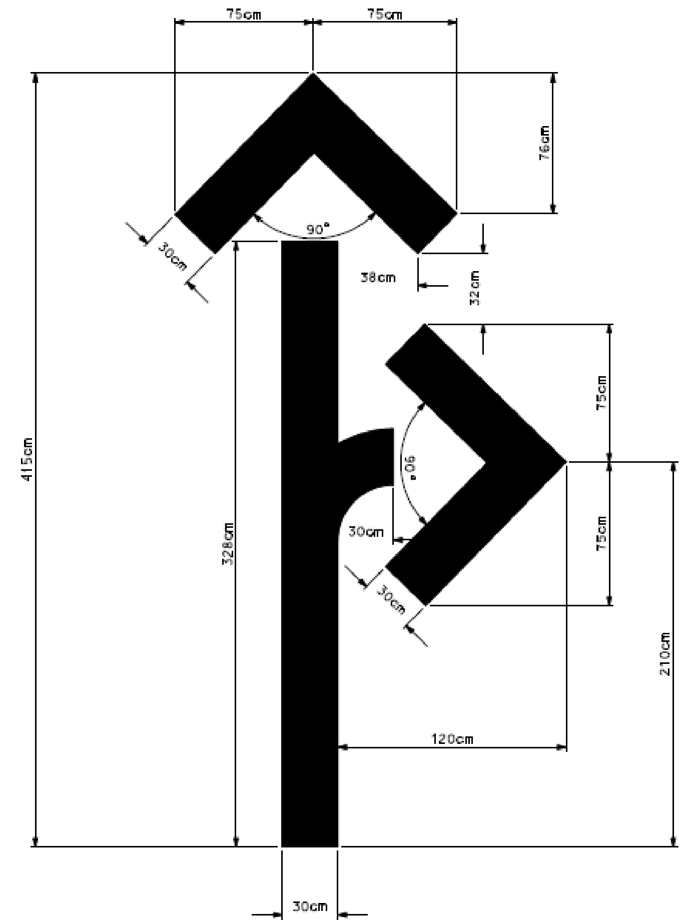


Figure 24. Example of Elongated Bicycle Lane Arrow (City of Edmonton, 2012)

2.4.4. 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 (Gail, 2013). 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.

2.4.5. United Kingdom Practice

Pavement marking signs in the UK are regulated by the Traffic Signs Manual (TSM, 2003) Chapter 5. 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 8. The length of the letters or numerals depends on the speed of the roadway: 1600 mm for speed limits of 40 mph and lower and 2800 mm for speed limits over 40 mph as shown in Figure 25. 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 8. Widths for Letters and Numbers (TSM 2003)

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		

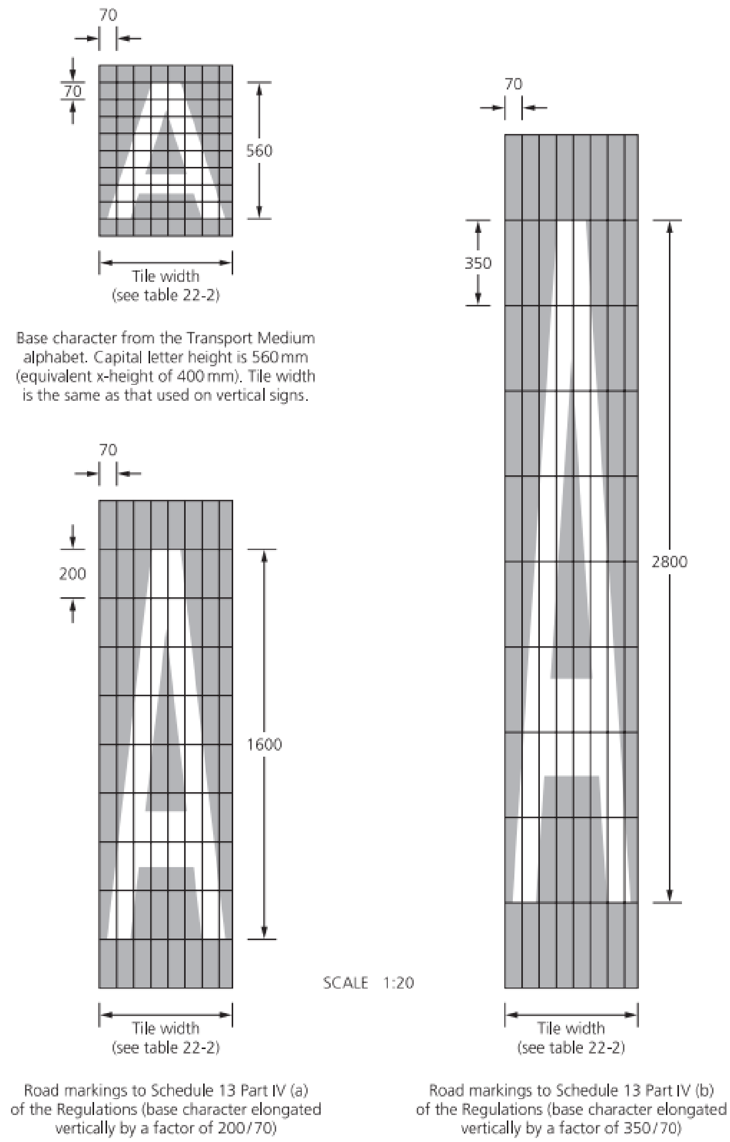


Figure 25. Elongation of Letters for Pavement Markings

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, and the smaller marking is used if the approach speed is 40 mph or lower (shown in Figure 26). 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 (DFT, 2013).

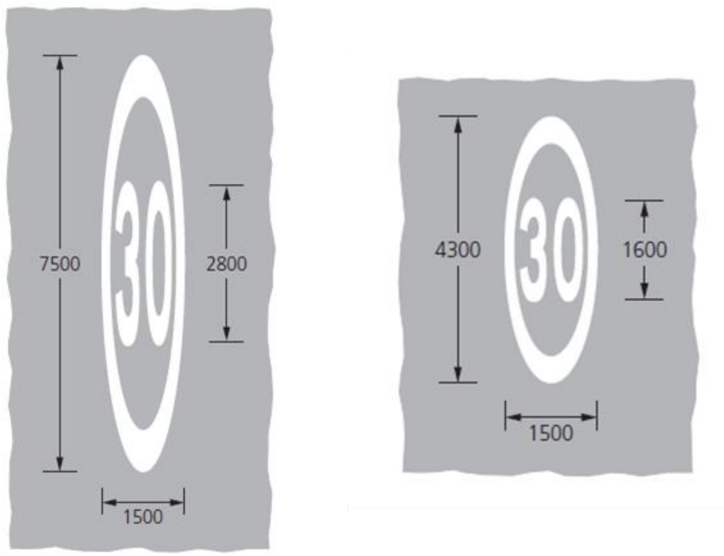


Figure 26. UK Speed Limit Roundel Pavement Marking (TSM 2003)

The TSM (2003) recommends that elongated lane arrows be used on a busy multi-lane approach in order to give drivers advanced warning of the correct lane. 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 27. 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 9. Words can be used with arrows for the purpose of guiding drivers. Characters follow the guidelines shown in

Table 8 and Figure 25. TSM also provides standards on arrows for guidance, deflection and bifurcation. For details, the reader is referred to the TSM.

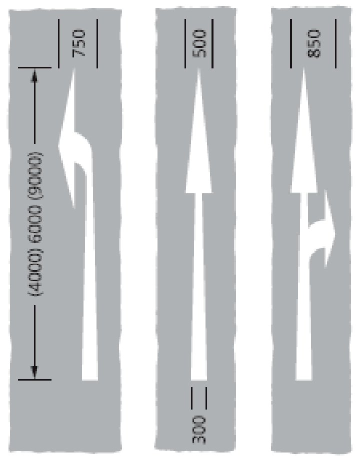


Figure 27. UK Lane Arrow Dimensions (TSM 2003)

Table 9. UK Lane Arrrow Dimensions and Spacing (TSM 2003)

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		

2.5. Simulator Validation

Driving simulators have been around since before the 1960's, initially used for training military personnel. In a report by Blana (1996), the main applications of today's driving simulators have been to train drivers, investigate innovative road designs, evaluate safety, research driver behavior, and study vehicle dynamics. In driving simulators, participants are piloting vehicles that have the same controls (steering well, pedals, gear shift, etc.) as real vehicles. The intent of having as realistic environments as possible in a simulator is to evoke behavior consistent with driving in reality. The degree to which the driver's behavior in the simulator matches that in the real world reflects the validity of the simulator (Kaptein et al., 1996).

In a validation study conducted by Blaauw (1982), two types of validity are presented: relative validity and absolute validity. Relative validity is when the performance differences, between the driving simulator and real world driving, are of the same order and direction. If, instead, the performance differences have about equal values, then the simulator is said to have absolute validity. Examples of both relative and absolute validity can be seen in Figure 28 (Godley et al, 2002). Absolute validity is achieved in the control scenario for Panel A, but the treatment scenario in Panel A has neither absolute nor relative validity. Relative validity is achieved for both the treatment and control scenarios in Panel B.

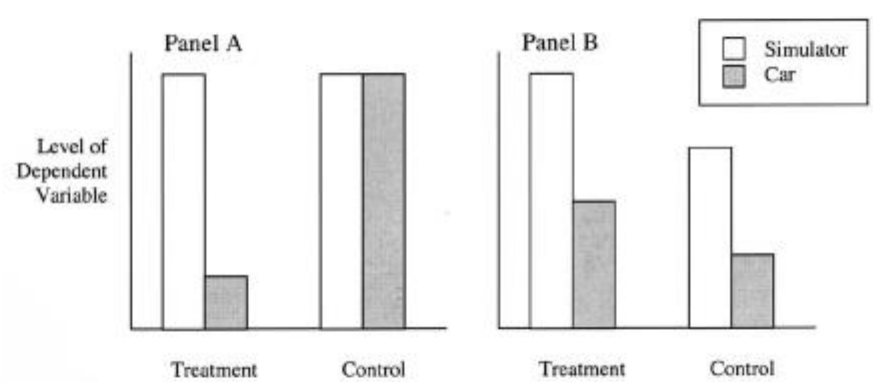


Figure 28. Hypothetical examples of absolute and relative validities (Godley et al, 2002)

In Blaauw's validation study for straight road driving, 48 subjects (24 experienced and 24 inexperienced) between 18 and 36 years old were asked to drive on a segment of four-lane highway in both a real car and a simulator. Half of the participants started driving the real car first, while the other half started by driving the simulator. During the drive, participants were asked to perform one of the four following tasks:

1. Free driving: Instructed to drive at normal highway speed.
2. Forced Lateral Control: Instructed to drive at normal highway speed and informed that lateral movement was being recorded, therefore subjects should drive as straight as possible.
3. Forced Longitudinal Control: Informed that variations in velocity were being recorded, therefore subjects should concentrate on driving at a constant 100 kph.
4. Forced Lateral and Longitudinal Control: Instructed to drive as straight as possible with a constant speed of 100 kph.

The tasks were to elicit a particular behavior out of the subjects, including lateral and longitudinal control. Comparing the performances of subjects for the simulation and real vehicle driving, shown in Table 10 and Table 11, would indicate whether the simulator proved to be a valid method of study.

Table 10. Mean Values of Lateral Vehicular Control (Blaauw, 1982)

Performance Index		Instrumented Car		Simulator	
		Inexperienced	*Experienced*	*Inexperienced*	*Experienced*
Lateral Position	(cm)	178.4	171.2	190.6	194.2
SD Lateral Position	(cm)	19.4	16.6	36.4	24.3
SD Yaw Rate	(deg/s)	0.32	0.32	0.31	0.26
SD Steering-Wheel Angle	(deg)	1.6	1.4	1.8	1.2

Table 11. Mean Values of Longitudinal Vehicular Control (Blaauw, 1982)

Performance Index		Instrumented Car		Simulator	
		Inexperienced	*Experienced*	*Inexperienced*	*Experienced*
Velocity	(km/h)	104.3	109.7	104.9	103.4
SD Velocity	(km/h)	1.1	0.8	1.3	1.0
SD Accelerator	(%)	1.4	1.1	2.3	1.3

Since the performances of the participants were consistent for both the instrument car and simulator, Blaauw concluded that the "simulator offers a valid method for studying straight-road driving". Also, the longitudinal vehicle control has both absolute and relative validity, while the lateral vehicle control has relative validity. In a different study, conducted by Godley et al (2002), that looked at speed and speeding countermeasures using a simulator, relative validity was established for mean speed. It also concluded that the simulator is a valid tool for speed and speeding countermeasures.

Simulators have also been used to evaluate recognition distances for pole mounted signs. In two studies conducted by Allen et al., (1980 and 1994), sign recognition distance can vary from 50-450 ft. In these studies, subjects were split into four age groups and then into three sub-groups, which received different training. Each subject drove the simulation three times, the first time without any training, the second right after training, and the third a week after training. For each simulation trial, subjects drove for 25 minutes while controlling steering and speed. During this time, 72 symbolic signs from the MUTCD were randomized and presented to the driver. Drivers indicated sign recognition by depressing a foot switch which extinguished the sign. Drivers verbalized their understanding of the symbol meanings and the computer measured the driver's response time and distance from the foot switch activation.

Age and learning effects on recognition response distance are illustrated in Figure 29. Sign response distance improves with symbol training and degrades with age (Allen et al., 1980). Also, bold and familiar symbols tended to result in the longest response distances (i.e. shortest response time after appearance), more complex symbols suffered in response distance (Allen et al., 1994).

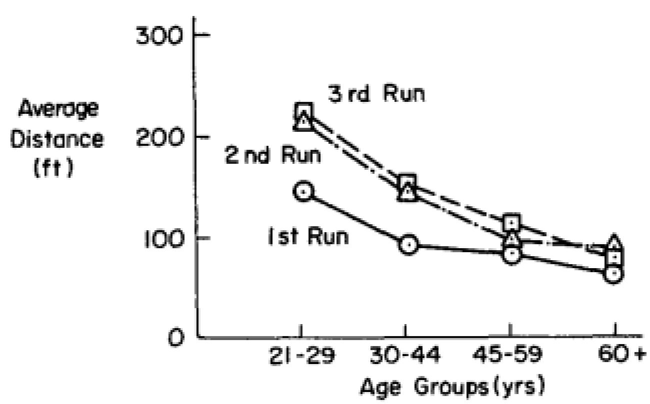


Figure 29. Average Sign Recognition Response Distance (Allen et al., 1980)

Legibility distance in a driving simulator was studied by Ting et al. (2007), which was compared to recognition distance in a test vehicle. Two different scenarios were tested, the first was quasi-static driving where the subjects drove at a walking pace (5 km/h), and the second was dynamic driving where subjects drove at 40, 60 and 80 km/h. Participants were instructed not to guess, but only respond when they knew what the sign was. Results from the dynamic driving scenarios, shown in Figure 30, indicate that as speed increases the legibility distance decreases, almost linearly.

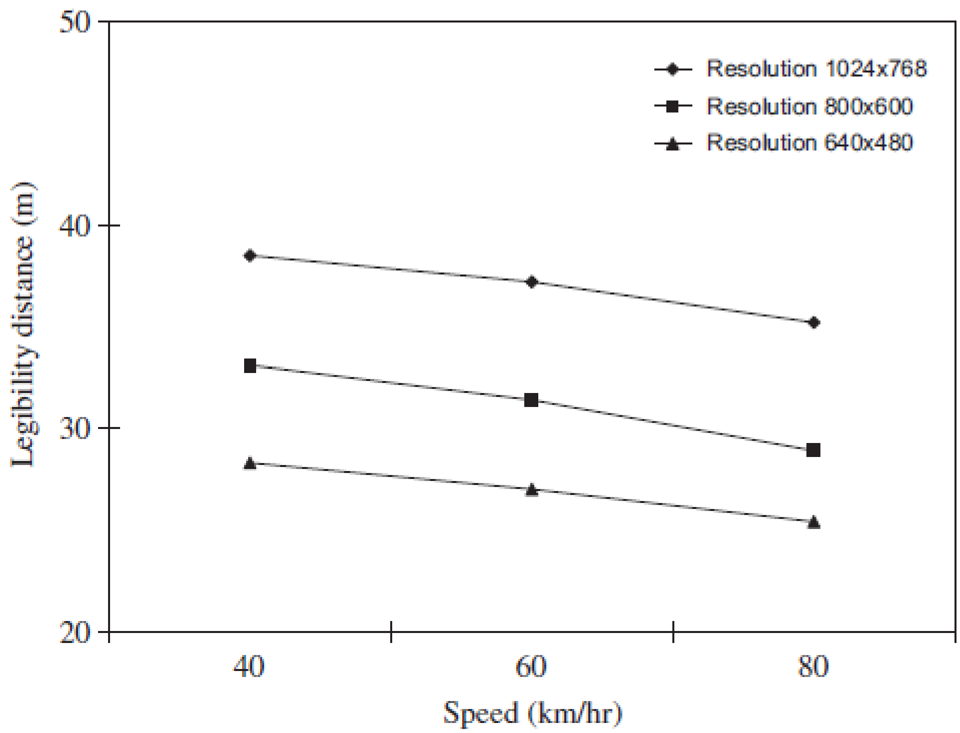


Figure 30. Legibility distances under dynamic driving conditions (Ting et al., 2007)

2.6. Literature Review Summary

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

- From a human factors perspective, pavement marking signs have better likelihood of being detected by drivers than post-mounted signs.
- Applications of pavement marking signs reported in the literature are for curve warning and speed limit.
- Pavement marking signs (not necessarily identical to post-mounted signs) have been shown to be effective from operations and safety perspectives.
- 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 (height to width ratios) used in different countries varies.
- Some countries use greater elongation ratios for roadways with higher speed limits. The speed thresholds at which greater elongation ratios are used vary between countries.
- Driving simulators are valid tools for research.
- Perception response time varies by age group.

3. Methodology

Research that shows how elongation of pavement marking signs affects recognition distance is limited. Most of the available research on this topic has used stationary observers rather than subjects driving at posted roadway speeds and daytime light conditions (MacDonald and Hoffman, 1972; Zwahlen and Schnell, 1999). Therefore, a full-scale driving simulator is an invaluable tool to study the effects of sign elongation on recognition distance while driving.

3.1. Driving Simulator Characteristics

The vehicle cab of the University of Wisconsin driving simulator is a full-sized Ford Fusion, which the driver operates just as he or she would on the road. One rear-facing and five forward-facing projectors display the visual world on a 24-foot screen wrapped 240 degrees around the vehicle and on an additional screen spanning the rear of the vehicle. LCD screens installed in each of the side-view mirrors bring the total number of projectors contributing to the simulation environment to eight. As the driver turns the wheel, brakes, or accelerates, the roadway that is visible to the driver changes appropriately. A network of eight advanced RTI servers update the images 60 times per second. High-end multimedia video allows the servers to process the images at the same resolution as the human eye. Image resolution on each screen can be as high as 1080p. Logitech Dolby 2.1 Surround Sound speakers with subwoofer comprise the simulator's sound system. Realistic road, vehicle, and wind noise, along with appropriate direction, intensity and Doppler shift effects, enhance the virtual environment experience. Computer screens replacing the interior vehicle dashboard and center console allow testing of vehicle enhancements currently under development. Other capabilities include a dynamic messaging system, as well as haptic feedback for applications such as rumble strip evaluation. Finally, the vehicle is positioned in a front-to-back motion base capable of one degree of motion in any direction for movement tracking.

Figure 31. University of Wisconsin-Madison driving simulator

Figure 32. University of Wisconsin-Madison driving simulator

Data obtained from the driving simulator came in several forms. Computers models tracked X, Y, and Z plane coordinates throughout each simulator experiment. Velocity and acceleration data were captured, along with corresponding data from the vehicle components (brakes, steering, etc.). Video cameras were used to capture physical driver maneuvers within the experiment and associated vehicle position and driver behavior data. As depicted in Figure 34, researchers collect and analyze these data in real time.

Figure 34. Driving simulator data collection

3.2. Participant Demographics

Sixteen drivers, between the ages of 21 and 54, participated in the driving simulator for this research. The drivers were screened for a valid driver's license, in addition to age/gender group categorization. All demographic data was recorded via questionnaires filled out by participants. Drivers under the age of 18 could not participate without parental consent and elderly drivers were less likely to participate. Also, many of the participants were from the surrounding community, which was primarily a college campus. Therefore, the age ratios may vary from that of the general driver population. A complete overview of participant demographics is shown in Table 12.

Table 12. Participant Demographics

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

3.3. Driving Simulator Procedure

The effect of elongation on the driver's recognition distance was evaluated by using the driving simulator. Five elongation ratios that were tested in the driving simulator, 1:1, 1:2.5, 1:5, 1:7.5 and 1:10. These ratios were chosen to cover the minimum (1:1, no elongation) and maximum ratio (1:10), as per Australian guidelines, and intermediate ratios to study the effect of intermediate elongations. The ratio of 1:2.5 is the recommended ratio in the

MUTCD (2009) for highway signs. ‘Curve’ (W1-2) sign, ‘Speed Limit’ (R2-1) sign, and ‘Pedestrian Crossing’ (W11-2) sign at five elongation ratios result in 15 conditions, shown in Table 13.

Table 13. Combinations of Sign and Elongation Ratios of Simulator Study

<table>
<tr><th>Sign</th><th>Elongation Ratios</th></tr>
<tr><td>
(W1-2)</td><td>1:1, 1:2.5, 1:5, 1:7.5, 1:10</td></tr>
<tr><td>

(R2-1)</td><td>1:1, 1:2.5, 1:5, 1:7.5, 1:10</td></tr>
<tr><td>
(W11-2)</td><td>1:1, 1:2.5, 1:5, 1:7.5, 1:10</td></tr>
</table>

Before driving in the simulator, participants were provided with an overview of the experimental procedure and asked to sign an Informed Consent Form. By signing the Informed Consent Form, subject drivers indicated their understanding of the proposed experiment and willingness to continue. Participating drivers were asked to repeat their understanding of what they are being asked to do. Once consent was obtained, drivers were seated in the simulator and given a specific set of instructions regarding the procedure. Drivers are asked to fasten their seatbelt, adjust mirrors, and adjust the radio as they would in their own vehicle. Again, the idea is to replicate their normal driving environment as much as possible. Drivers are told that vehicle engine noise will be simulated (along with a small amount of vehicle vibration) and a circulating fan may be used to simulate wind through the driver's side window. Subject drivers who prefer to have the window closed are instructed to do so.

Drivers are asked to *drive* the simulator vehicle as they would drive their own vehicle. Specifically, "don't drive overly conservative nor drive extremely aggressive". The driver's wellbeing is closely observed for signs of simulator motion sickness, and they have been instructed to stop the simulation via an emergency shut off button if they cannot proceed at any point. Subjects drove through the experimental scenarios, and to avoid the need for verbal communication during the evaluation, any additional navigation instructions were embedded within the visual world of the scenario. Test subjects drove through a roadway loop containing the 15 sign type and elongation ratios at two different speeds: 35 mph and 55 mph. The total driving distance was in the range of 10-15 miles, with a spacing of at least half a mile between each sign. The reasons for choosing 55 mph as the higher speed are that 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 (Fors et al, 2012). For the lower speeds 35 mph was chosen because Pennsylvania uses 35 mph as the threshold for using smaller elongation ratio (Modi, 2014).

During their drive, subjects were asked to indicate through a verbal flag what they see once they are able to distinguish the pavement marking sign. More than one version of each sign was used and the drivers were asked to indicate which version is present. For example, left and right curve signs and speed limit signs of 35 and 55 mph were used. The timestamp of the moment when the subject indicates recognition, along with adjustments based on their location in the scenario, were used to determine recognition distance. The driving portion of each scenario requires an average of 15 to 20 minutes to complete.

The results of the simulation were recorded, including the responses at each elongated pavement marking and other driving related factors such as indecision, unnecessary braking, or any pertinent verbal comments made. Driver responses to each experimental scenario were manually and electronically recorded. Video recordings of all drives were reviewed to confirm driver responses.

4. Analysis and Results

4.1. Calibration of Driving Simulator

For each subject that participated in the driving simulator, study data were collected from the driving simulation data output and from a video camera. These data was used to identify the moment when the participant verbally recognized the signs while driving in the simulation. Since two recording devices were used it was necessary to synchronize the times. First, the simulation was started. Then, the simulation time was recorded on the video camera before the subject started driving. However, the demand the simulation software placed on the computer processor caused the simulator to drop frames and in turn run more slowly than real time. To correctly asses the recognition distance for each subject, the rate at which the simulator was dropping frames needed to be determined.

In order to calculate the rate at which the simulator was dropping frames, the simulation time and video time needed to be compared when the vehicle was at known locations. This was achieved by first obtaining the coordinates for different observable points in the simulation. These coordinates where then searched for in the simulation data in order to retrieve the simulation time at which the vehicle was at that location. The video footage was then reviewed to determine the video time at which the vehicle was at the location specified by the coordinates for the observable point. This meant that there were two times, the simulation time and the video time, at which the vehicle was at the same location. The difference between these times was calculated for each observable point and plotted against the video time, as seen in Figure 35.

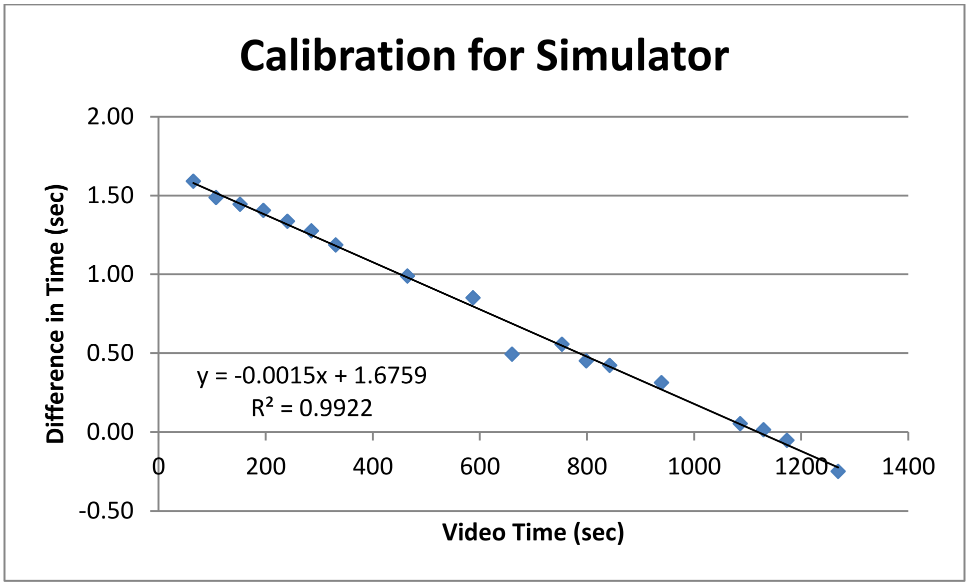


Figure 35. Example of calibration for simulator data

The recognition distance for each sign was calculated using both the coordinates of the sign and the vehicle, both of which had a corresponding simulation time. However, the verbal flag from the subject driving in the simulator corresponds to a time in the video recording, not the simulation. Thus, the equation from Figure 35 could be used to determine the simulation time from the video time. The slope equals the rate at which frames are dropped and the intercept corresponds to the time elapsed in the simulation before the video camera began recording. A calibration equation was created for each scenario for each participant.

4.2. Recognition Distance

For this research, two different recognition distances were used. The first is the recognition distance when the verbal flag is heard. The second is the maximum recognition distance, which takes into account the perception response time. Considering the work done by Dewar et al. and Shoptaugh and Whitaker, a perception response time of 0.7 seconds was used for the maximum recognition distance for elongated horizontal pavement markings. Recognition distance was calculated from the distance between the sign and the vehicle based on simulation time, which required using the calibration curves for each trail to convert the video time of the verbal flag into simulation time. The average recognition distance for each sign type and elongation ratio at both speeds can be seen in Table 14, while the raw subject data is in the Appendix.

Table 14. Recognition distances for each sign type and elongation ratio at 35 mph and 55 mph

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

4.3. Statistical Analysis

Statistical analysis was performed to analyze the effect of elongation ratio on recognition distance through a random effects linear model. A random effects linear model was selected to account for the correlation in the responses from the subjects. This type of model accounts for variance in the dependent variable (Littell et al., 2002). This variance can introduce bias in the estimates of the dependent coefficient (β in Figure 36), but the variance can be constrained, leading to estimates that are closer to the true value in any particular sample (Clark and Linzer, 2012).

$$y_i = \alpha_{j[i]} + \beta x_i + \varepsilon_i; \qquad \alpha_j \sim N(\mu_\alpha, \sigma_\alpha^2); \qquad \varepsilon_i \sim N(0, \sigma_y^2).$$

Figure 36. Random Effects Linear Model (Clark and Linzer, 2012)

The model was built through the backwards stepwise procedure where all variables were initially included in the model. Variables are tested to determine whether they are significant in the model or not based on the likelihood-ratio test (Agresti, 1990). 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.

4.4. Results

4.4.1. Maximum Recognition Distance - Perception Response Time

A random effects linear model was built using the previously described backwards stepwise procedure for the maximum recognition distance, which takes into consideration a perception response time (PRT) of 0.7 seconds. The goal of the model is to explain the trend in the PRT data.

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 equations were found, one for each sign type shown in Figure 37, with elongation ratio as the independent variable. Since speed was not significant, the model for each sign type could be applied to both scenarios, as can be seen in the graphs in Figure 38. Differentiating between sign type would not be meaningful in application; therefore, a model was built that encompasses all sign types, shown in Figure 37 and graphed in Figure 39.

Maximum Distance Equations (PRT Data)

Distance =	Coeff. A	*	Ratio^2	+	Coeff. B	*	Ratio	+	Intercept	
Pedestrian =	-1.56951	*	Ratio^2	+	27.94329	*	Ratio	+	33.94228	Eq. (1)
Speed =	-0.98704	*	Ratio^2	+	25.35805	*	Ratio	+	39.41801	Eq. (2)
Turn =	-1.66074	*	Ratio^2	+	32.18542	*	Ratio	+	23.39733	Eq. (3)
All Types =	-1.4083	*	Ratio^2	+	28.5319	*	Ratio	+	32.1353	Eq. (4)

Figure 37. Maximum Recognition Distance Equations

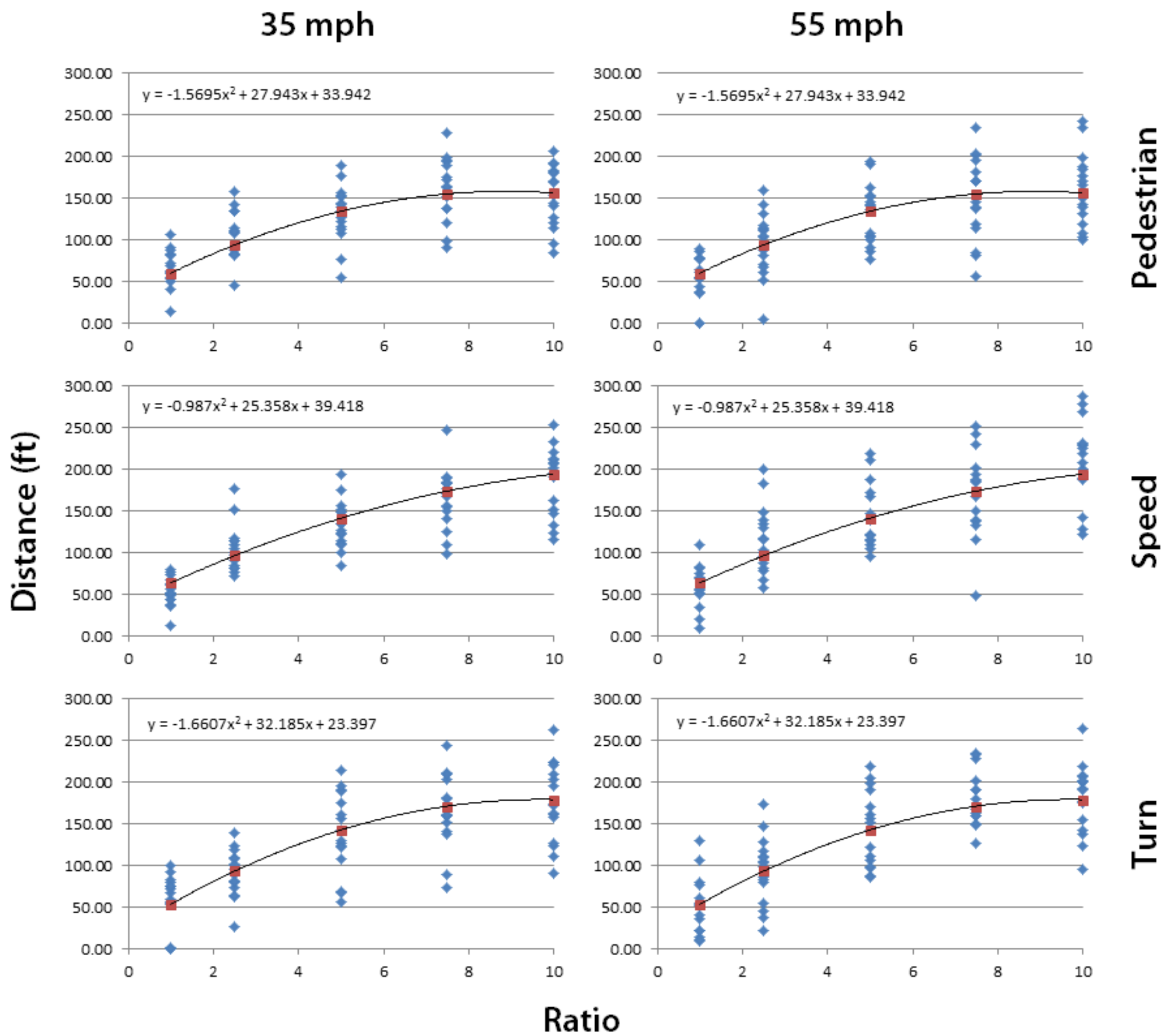


Figure 38. Graphs of PRT data with model equations.

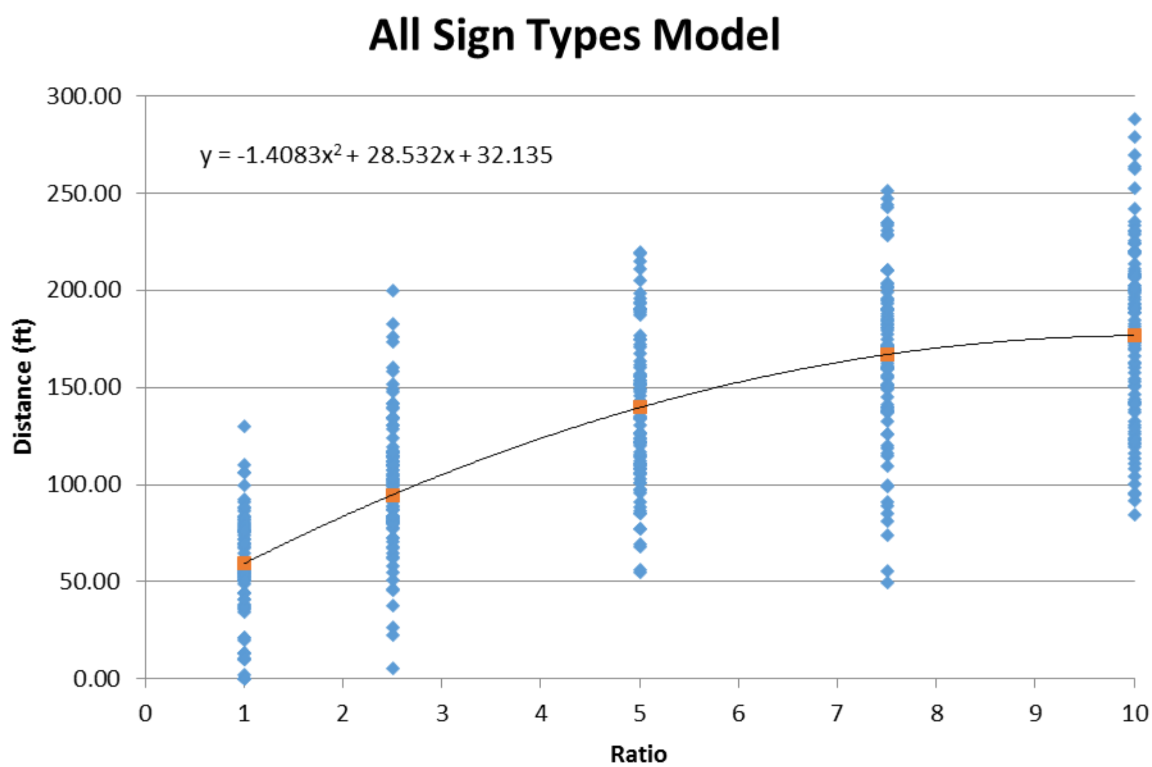


Figure 39. Graph of PRT data with all sign types model

4.4.2. Recognition Distance – Without Perception Response Time

Again, a random effects linear model was built using a backwards stepwise procedure to model the data without including the effects of a perception response time and determine the recognition distance associated with each elongation ratio. All variables were initially included and through the procedure it was found that age, gender, years of driving experience, and if the participant wore corrective lenses were not statistically significant covariates. It was found that elongation ratio, sign type, and speed were statistically significant factors. With the addition of speed as a significant factor, there are now six different equations, one for each sign type at each speed, which are graphed in Figure 40. Again, differentiating between sign type would not be meaningful in application, therefore, a model was built that encompasses all sign types for each speed. This yields two equations that have the same trend (both of the dependent variable coefficients are the same) but are different due to the intercept, which is affected by the speed. It was found that speed has an effect on recognition distance, where the great the speed, the lower the recognition distance. All model equations can be seen in Figure 41.

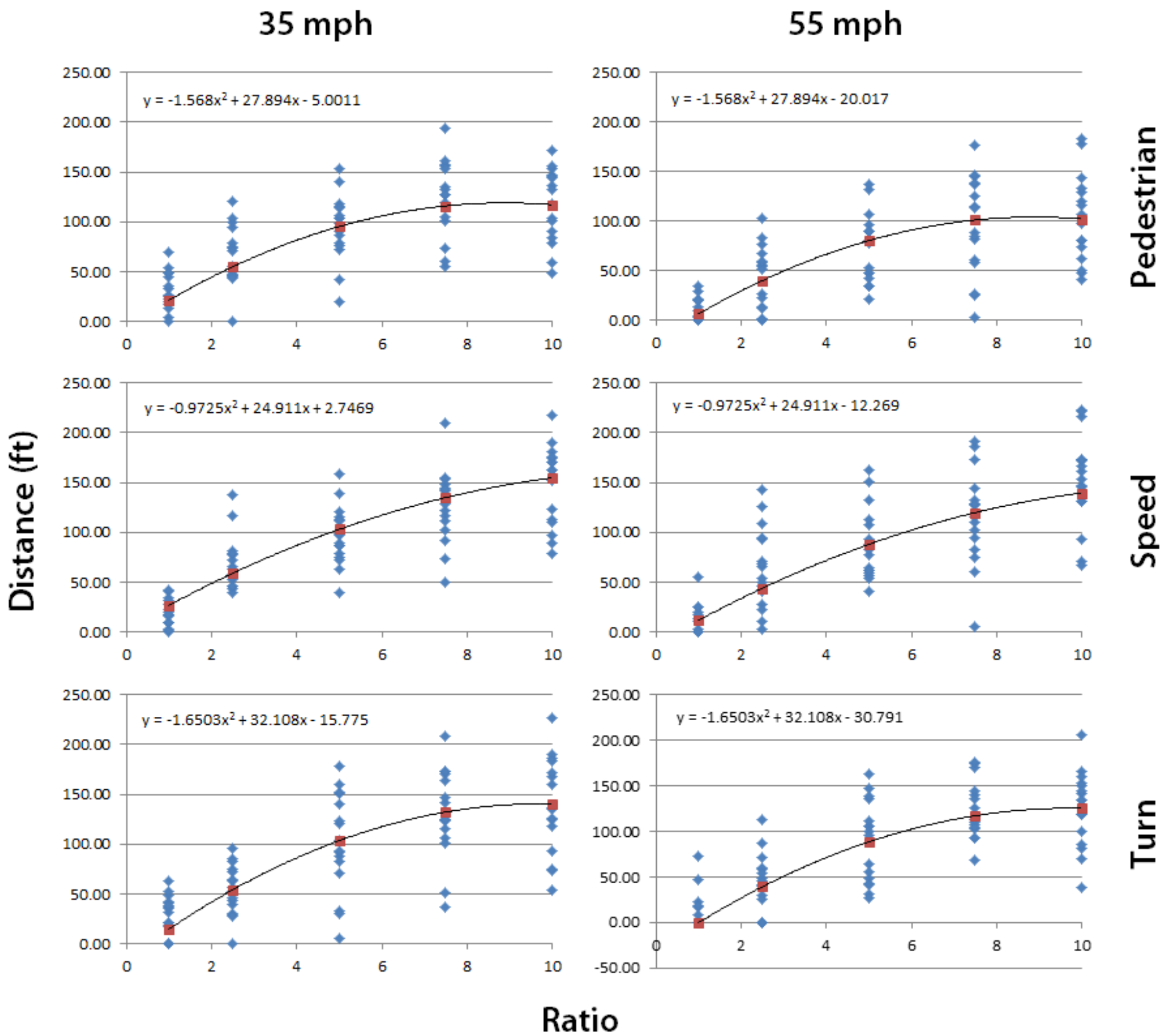


Figure 40. Graphs of No PRT Data with model equations

Recognition Distance Equations (no PRT Data) 35 mph

Distance	=	Coeff. A	*	Ratio^2	+	Coeff. B	*	Ratio	+	Intercept	
Pedestrian	=	-1.56802	*	Ratio^2	+	27.89382	*	Ratio	+	-5.0011	Eq. (5)
Speed	=	-0.97253	*	Ratio^2	+	12.87812	*	Ratio	+	2.74692	Eq. (6)
Turn	=	-1.65029	*	Ratio^2	+	24.91106	*	Ratio	+	-15.7754	Eq. (7)
All Types	=	-1.4002	*	Ratio^2	+	28.3519	*	Ratio	+	-6.1476	Eq. (8)

Recognition Distance Equations (no PRT Data) 55 mph

Distance	=	Coeff. A	*	Ratio^2	+	Coeff. B	*	Ratio	+	Intercept	
Pedestrian	=	-1.56802	*	Ratio^2	+	27.89382	*	Ratio	+	-20.0168	Eq. (9)
Speed	=	-0.97253	*	Ratio^2	+	12.87812	*	Ratio	+	-12.2688	Eq. (10)
Turn	=	-1.65029	*	Ratio^2	+	24.91106	*	Ratio	+	-30.7911	Eq. (11)
All Types	=	-1.4002	*	Ratio^2	+	28.3519	*	Ratio	+	-21.1983	Eq. (12)

Recognition Distance Equation (no PRT Data) both Speeds

Distance	=	Coeff. A	*	Ratio^2	+	Coeff. B	*	Ratio	+	Intercept	
All Types	=	-1.393	*	Ratio^2	+	28.256	*	Ratio	+	-13.415	Eq. (13)

Figure 41. Recognition Distance Equations for Data without a PRT

The effect of speed on the model equations is graphically shown in Figure 38, where model equations 8, 12, and 13 correspond to No PRT 35, No PRT 55, and No PRT, respectively.

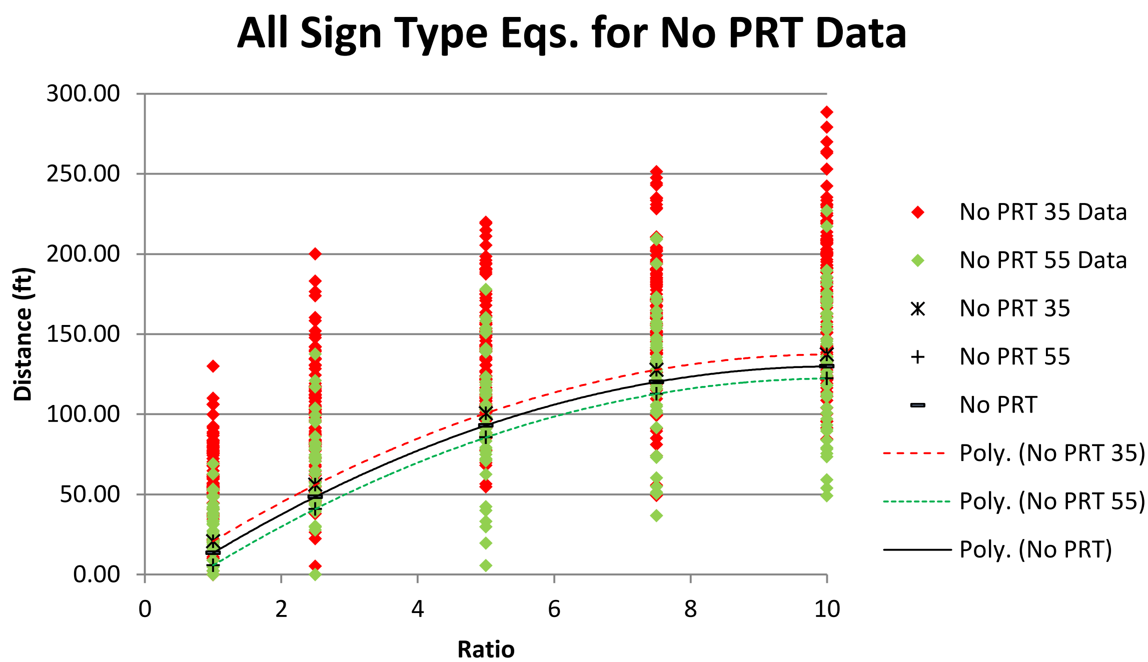


Figure 42. Graph of model equations 8, 12, and 13

4.4.3. Comparison between Models

The statistical analysis of both data sets (with and without the use of a PRT), yielded equations that relate recognition distance and elongation ratio. These equations (Eq. 4, 8, 12, and 13) are graphed in Figure 43.

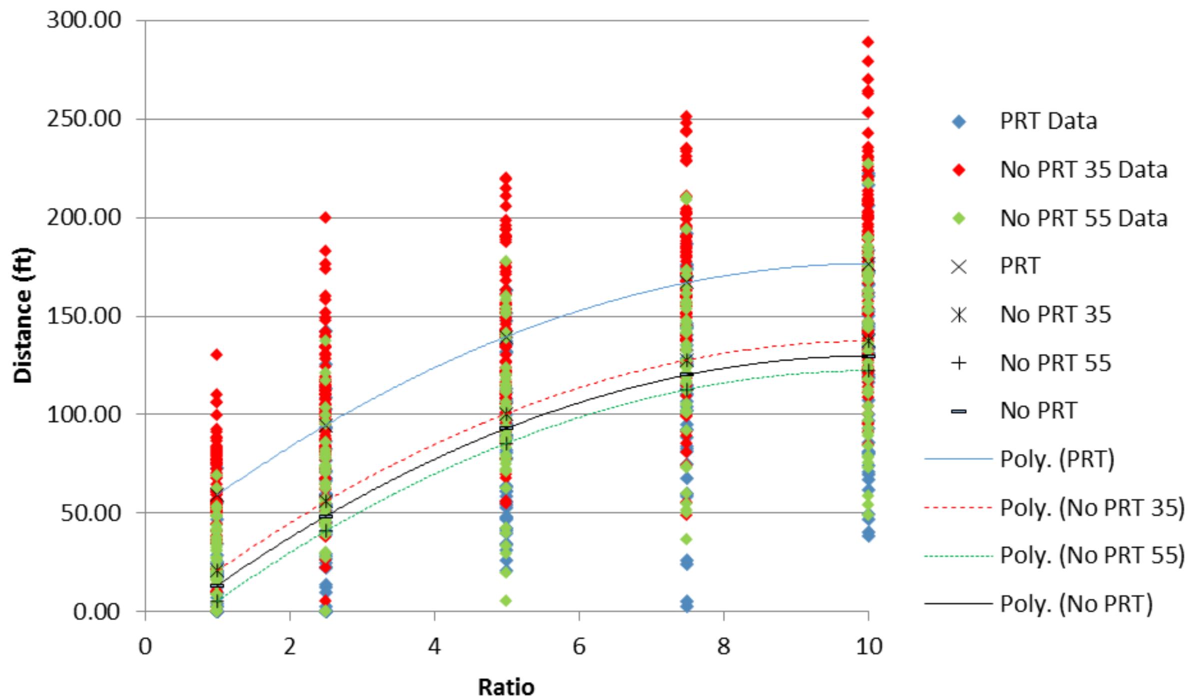


Figure 43. Comparison of model equations

From the graph, it can be seen that the trend holds for all equations. The difference between equations is due to either speed (differences between No PRT equations) or the inclusion of a PRT (difference between No PRT and PRT equations). The difference between the equations is mainly due to the constant term. Therefore, it is reasonable to state that the relationship between recognition distance and elongation ratio is:

$$Distance = -1.4 * Ratio^2 + 28 * Ratio + Constant \qquad (14)$$

Where the constant term varies based on speed and PRT.

5. Conclusion

Based on the analysis conducted, a relationship between recognition distance and elongation ratio was found. A random effects linear model was built from a backwards stepwise procedure to determine that the relationship is a quadratic function. If a perception response time is used, the statistically significant covariates are elongation ratio and sign type. If a perception response time is omitted, speed becomes statistically significant. While sign type is statistically significant, it is not meaningful for real world applications, therefore, the model was adjusted to be useful for all sign types. The resulting equations (Eq. 4, 8, and 12) had nearly the same values for the coefficients of the dependent variable (ratio) and only differed in the intercept. Therefore, it is reasonable to state that the relationship between recognition distance and elongation ratio is:

$$Distance = -1.4 * Ratio^2 + 28 * Ratio + Constant \qquad (14)$$

Using equation 14 with a perception reaction time of 0.7 second, yields equation 15.

$$Distance = -1.4 * Ratio^2 + 28 * Ratio + 32 \qquad (15)$$

As seen in Table 15, equation 15 has a maximum recognition distance with an elongation ratio of 10.

Table 15. Recognition distances for equation 15

Ratio	Distance (ft)
1 : 1	59
1 : 2.5	93
1 : 5	137
1 : 7.5	163
1 : 10	172
1 : 12.5	163

While this research yielded a relationship between recognition distance and elongation ratio for drivers in a driving simulator, other considerations should be taken into account before an elongation ratio is selected for practice. The biggest factor that was not included in this research is the relationship between cost and elongation ratio. As the elongation ratio increases, so does the pavement marking, meaning the cost to implement and maintain the pavement marking increases.

6. Future Work

This research focused on the relationship between recognition distance and elongation ratio for elongated horizontal pavement markings in a driving simulator. However, this work could be expanded to look at driver behavior and real world applications of elongated pavement markings.

6.1. Simulator Study

A second driving simulator experiment could be conducted with a road network designed to study the effectiveness of elongated pavement markings placed in conjunction with traditional post-mounted signs. There could be two types of scenarios presented in the driving simulator visual world: 1) Scenarios that include post-mounted sign only and 2) scenarios that include both pavement and complimentary post-mounted signs. These two conditions allow a comparison of the effect of elongated pavement marking signs with and without complimentary post mounted signs.

The effect of location of elongated pavement marking 'Curve' sign relative to the post-mounted sign could also be explored. 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 (Retting and Farmer, 1998; Chrysler and Schrock, 2005; Hallmark et al., 2007). Therefore, scenarios where the Curve pavement marking sign is downstream and upstream of the post-mounted sign could be included.

6.2. Field Experiments

A field evaluation study could be conducted to measure the effectiveness (i.e., impact on vehicle operating speeds) of elongated pavement marking signs within the actual driving environment using an elongation ratio based on the results of this research. A sign stencil will need to be created for each elongated pavement marking sign in order to test them at different locations. The following possible site specifications for identifying prospective sites for field evaluations:

- Two-lane highways;
- Lower volumes (so that traffic is free flowing and not congested);
- Rural or urban;
- Preferably sites with commuter and recreational traffic; and
- No confounding factors such as intersections, significant vertical grade, or access points in the vicinity.

Data collection after the installation of the pavement marking signs should not commence for a minimum of two full calendar weeks after the installation to eliminate any potential novelty effect in the data. The post mounted signs at the data collection sites should be in compliance with the MUTCD standards to insure that results are due to the pavement markings themselves and not the change from a non-compliant to a compliant post-mounted sign.

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APPENDIX

SubjectID	04172014_01

Video Observations (Scenario 1) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	35.6	62.2	65.7	62.9	66.4	2.4
Pede	10	153.1	108.3	111.7	109.0	112.4	118.1
Turn	2.5	62.7	208.3	211.6	209.0	212.3	29.6
Spee	5	149.1	256.0	259.3	256.7	260.0	115.1
Pede	1	41.0	306.8	310.0	307.5	310.7	4.6
Pede	5	121.9	353.4	356.5	354.1	357.2	87.2
Turn	7.5	141.4	504.1	507.0	504.8	507.7	105.8
Spee	10	206.3	635.4	638.1	636.1	638.8	170.0
Spee	2.5	77.2	716.1	718.7	716.8	719.4	43.7
Turn	1	59.5	861.8	864.1	862.5	864.8	20.7
Turn	5	157.1	905.3	907.5	906.0	908.2	120.2
Spee	7.5	185.3	1,004.3	1,006.4	1,005.0	1,007.1	147.8
Pede	2.5	83.2	1,159.7	1,161.6	1,160.4	1,162.3	47.9
Pede	7.5	151.4	1,206.5	1,208.3	1,207.2	1,209.0	115.8
Turn	10	195.0	1,253.8	1,255.5	1,254.5	1,256.2	160.1

Video Observations (Scenario 2) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	102.9	52.6	54.5	53.3	55.2	50.3
Turn	1	53.5	115.0	116.8	115.7	117.5	0.0
Turn	5	190.8	144.8	146.5	145.5	147.2	135.7
Spee	7.5	139.9	175.7	177.4	176.4	178.1	83.1
Pede	2.5	70.6	207.6	209.3	208.3	210.0	13.9
Pede	7.5	138.5	236.6	238.2	237.3	238.9	81.5
Turn	10	208.5	330.1	331.5	330.8	332.2	152.3
Spee	1	57.1	467.3	468.6	468.0	469.3	3.2
Pede	10	166.5	529.8	531.0	530.5	531.7	107.5
Turn	2.5	45.3	592.4	593.4	593.1	594.1	0.0
Spee	5	140.8	658.3	659.3	659.0	660.0	88.2
Pede	1	78.8	757.6	758.4	758.3	759.1	20.9
Pede	5	135.6	786.1	786.9	786.8	787.6	77.3
Turn	7.5	159.6	815.8	816.5	816.5	817.2	102.3
Spee	10	199.7	879.6	880.3	880.3	881.0	145.7

SubjectID	04172014_02

Video Observations (Scenario 1) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	109.9	48.3	49.8	49.0	50.5	55.6
Pede	10	188.5	76.3	77.7	77.0	78.4	129.5
Turn	2.5	104.5	137.8	139.2	138.5	139.9	48.6
Spee	5	187.4	167.4	168.8	168.1	169.5	132.0
Pede	1	86.6	199.4	200.7	200.1	201.4	29.1
Pede	5	105.3	228.8	230.0	229.5	230.7	47.9
Turn	7.5	163.5	318.7	319.9	319.4	320.6	107.0
Spee	10	229.1	402.1	403.1	402.8	403.8	172.7
Spee	2.5	183.1	450.2	451.2	450.9	451.9	126.0
Turn	1	36.8	545.1	545.9	545.8	546.6	0.0
Turn	5	106.3	573.6	574.3	574.3	575.0	48.2
Spee	7.5	186.8	635.9	636.6	636.6	637.3	128.0
Pede	2.5	142.0	734.2	734.7	734.9	735.4	82.9
Pede	7.5	171.2	763.3	763.8	764.0	764.5	114.4
Turn	10	175.3	793.8	794.2	794.5	794.9	119.1

Video Observations (Scenario 2) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
Turn	1	68.0	149.6	151.1	150.3	151.8	31.7
Turn	5	108.6	194.9	196.3	195.6	197.0	70.8
Spee	7.5	155.0	239.0	240.4	239.7	241.1	117.3
Pede	2.5	87.2	286.1	287.3	286.8	288.0	50.1
Pede	7.5	137.6	330.8	332.0	331.5	332.7	100.7
Turn	10	111.1	472.0	473.0	472.7	473.7	75.4
Spee	1	56.3	676.3	677.0	677.0	677.7	19.6
Pede	10	141.5	770.0	770.5	770.7	771.2	104.2
Turn	2.5	89.4	862.8	863.1	863.5	863.8	52.1
Spee	5	134.7	961.1	961.3	961.8	962.0	97.5
Pede	1	59.7	1,114.5	1,114.6	1,115.2	1,115.3	22.3
Pede	5	108.2	1,160.7	1,160.6	1,161.4	1,161.3	72.2
Turn	7.5	137.9	1,208.2	1,208.1	1,208.9	1,208.8	101.2
Spee	10	211.2	1,303.2	1,302.9	1,303.9	1,303.6	174.9

SubjectID	04172014_03

Video Observations (Scenario 1) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	80.7	64.4	65.9	65.1	66.6	40.3
Pede	10	191.4	104.8	106.3	105.5	107.0	153.0
Turn	2.5	101.4	195.2	196.5	195.9	197.2	62.7
Spee	5	100.9	239.7	241.0	240.4	241.7	62.5
Pede	1	91.3	285.0	286.2	285.7	286.9	53.4
Pede	5	156.2	328.8	329.9	329.5	330.6	118.1
Turn	7.5	180.5	462.8	463.8	463.5	464.5	141.7
Spee	10	190.9	585.6	586.3	586.3	587.0	152.8
Spee	2.5	117.6	658.4	659.1	659.1	659.8	81.0
Turn	1	75.7	799.0	799.4	799.7	800.1	37.2
Turn	5	190.7	840.7	841.1	841.4	841.8	150.7
Spee	7.5	170.6	937.1	937.3	937.8	938.0	133.6
Pede	2.5	134.2	1,084.7	1,084.7	1,085.4	1,085.4	94.9
Pede	7.5	174.8	1,127.7	1,127.7	1,128.4	1,128.4	135.5
Turn	10	173.5	1,171.9	1,171.8	1,172.6	1,172.5	136.0

Video Observations (Scenario 2) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	140.0	51.1	52.6	51.8	53.3	93.2
Turn	1	40.7	112.1	113.5	112.8	114.2	0.0
Turn	5	205.4	139.9	141.2	140.6	141.9	147.9
Spee	7.5	201.9	169.4	170.7	170.1	171.4	144.3
Pede	2.5	160.2	200.4	201.6	201.1	202.3	102.6
Pede	7.5	234.9	228.3	229.5	229.0	230.2	176.4
Turn	10	200.1	317.3	318.3	318.0	319.0	140.9
Spee	1	69.1	444.3	445.2	445.0	445.9	10.2
Pede	10	235.3	501.9	502.7	502.6	503.4	177.5
Turn	2.5	173.8	562.0	562.7	562.7	563.4	113.1
Spee	5	167.9	622.7	623.3	623.4	624.0	108.1
Pede	1	77.7	717.0	717.5	717.7	718.2	19.6
Pede	5	190.3	744.6	745.1	745.3	745.8	131.3
Turn	7.5	234.5	773.3	773.7	774.0	774.4	174.1
Spee	10	188.6	835.5	835.8	836.2	836.5	131.7

SubjectID	04182014_01

Video Observations (Scenario 1) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	20.1	56.3	57.8	57.0	58.5	0.0
Pede	10	185.0	87.4	88.9	88.1	89.6	133.3
Turn	2.5	86.8	158.0	159.4	158.7	160.1	39.2
Spee	5	109.8	191.9	193.2	192.6	193.9	61.4
Pede	1	61.0	227.4	228.6	228.1	229.3	13.2
Pede	5	141.1	260.7	261.9	261.4	262.6	89.3
Turn	7.5	190.3	362.8	363.8	363.5	364.5	140.3
Spee	10	142.5	456.5	457.4	457.2	458.1	92.9
Spee	2.5	78.1	512.6	513.4	513.3	514.1	28.3
Turn	1	54.3	654.5	655.2	655.2	655.9	17.5
Turn	5	141.9	698.5	699.1	699.2	699.8	106.0
Spee	7.5	138.1	801.5	801.9	802.2	802.6	102.5
Pede	2.5	102.6	959.9	960.0	960.6	960.7	67.9
Pede	7.5	171.4	1,006.5	1,006.6	1,007.2	1,007.3	137.7
Turn	10	200.0	1,054.5	1,054.5	1,055.2	1,055.2	165.7

Video Observations (Scenario 2) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	83.9	74.9	76.6	75.6	77.3	52.9
Turn	1	2.1	151.4	152.9	152.1	153.6	0.0
Turn	5	56.4	185.4	186.9	186.1	187.6	5.5
Spee	7.5	99.4	219.7	221.2	220.4	221.9	50.5
Pede	2.5	46.2	255.4	256.8	256.1	257.5	0.0
Pede	7.5	120.2	289.2	290.6	289.9	291.3	74.0
Turn	10	123.1	399.9	401.1	400.6	401.8	73.3
Spee	1	13.0	550.3	551.2	551.0	551.9	0.0
Pede	10	143.7	624.2	625.1	624.9	625.8	100.5
Turn	2.5	80.8	697.5	698.3	698.2	699.0	30.1
Spee	5	85.1	773.4	774.0	774.1	774.7	40.0
Pede	1	53.9	931.1	931.5	931.8	932.2	20.3
Pede	5	133.9	977.5	977.9	978.2	978.6	97.9
Turn	7.5	160.1	1,024.7	1,024.9	1,025.4	1,025.6	123.8
Spee	10	124.1	1,126.1	1,126.2	1,126.8	1,126.9	89.4

SubjectID	04182014_02

Video Observations (Scenario 1) Speed 35 MPH

Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	44.5	75.9	77.2	76.6	77.9	8.7
Pede	10	113.7	122.9	124.2	123.6	124.9	79.1
Turn	2.5	73.0	224.4	225.5	225.1	226.2	39.0
Spee	5	121.8	274.3	275.3	275.0	276.0	88.7
Pede	1	83.8	324.8	325.8	325.5	326.5	48.2
Pede	5	115.3	374.2	375.1	374.9	375.8	79.3
Turn	7.5	181.0	521.3	522.0	522.0	522.7	146.4
Spee	10	132.8	656.9	657.4	657.6	658.1	97.0
Spee	2.5	91.2	735.6	736.0	736.3	736.7	57.7
Turn	1	75.8	892.0	892.1	892.7	892.8	40.8
Turn	5	123.9	940.4	940.4	941.1	941.1	88.1
Spee	7.5	126.0	1,044.1	1,044.0	1,044.8	1,044.7	91.7
Pede	2.5	107.9	1,202.9	1,202.6	1,203.6	1,203.3	74.6
Pede	7.5	137.3	1,252.8	1,252.4	1,253.5	1,253.1	104.7
Turn	10	127.4	1,302.6	1,302.1	1,303.3	1,302.8	93.2

Video Observations (Scenario 2) Speed 55 MPH

Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	100.9	46.9	47.7	47.6	48.4	53.5
Turn	1	9.9	112.3	113.0	113.0	113.7	0.0
Turn	5	161.4	141.3	141.9	142.0	142.6	106.1
Spee	7.5	171.7	171.5	172.1	172.2	172.8	115.2
Pede	2.5	130.8	203.8	204.4	204.5	205.1	77.0
Pede	7.5	182.0	233.7	234.2	234.4	234.9	125.1
Turn	10	207.0	327.6	327.9	328.3	328.6	150.4
Spee	1	75.2	466.0	466.2	466.7	466.9	19.4
Pede	10	150.7	530.5	530.6	531.2	531.2	97.2
Turn	2.5	111.9	594.6	594.6	595.3	595.3	58.3
Spee	5	147.8	659.4	659.3	660.1	660.0	93.8
Pede	1	54.6	763.4	763.1	764.1	763.8	4.1
Pede	5	163.6	793.9	793.6	794.6	794.3	106.8
Turn	7.5	170.3	824.6	824.2	825.3	824.9	113.5
Spee	10	200.7	891.6	891.1	892.3	891.8	146.5

SubjectID	04182014_03

Video Observations (Scenario 1) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	54.5	51.6	52.5	52.3	53.2	12.7
Pede	10	119.1	84.1	85.0	84.8	85.7	62.1
Turn	2.5	22.4	145.1	145.9	145.8	146.6	0.0
Spee	5	114.3	174.4	175.1	175.1	175.8	56.3
Pede	1	55.2	205.0	205.7	205.7	206.4	3.1
Pede	5	102.7	234.6	235.2	235.3	235.9	47.2
Turn	7.5	126.2	324.3	324.8	325.0	325.5	67.9
Spee	10	129.0	405.6	406.0	406.3	406.7	71.3
Spee	2.5	80.9	452.8	453.1	453.5	453.8	22.8
Turn	1	21.5	544.3	544.5	545.0	545.2	0.0
Turn	5	122.1	572.3	572.4	573.0	573.1	63.5
Spee	7.5	132.5	635.3	635.3	636.0	636.0	75.0
Pede	2.5	112.4	731.7	731.6	732.4	732.3	53.8
Pede	7.5	118.6	760.8	760.7	761.5	761.4	60.3
Turn	10	192.9	789.3	789.1	790.0	789.8	134.6

Video Observations (Scenario 2) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	97.8	58.3	58.8	59.0	59.5	55.6
Turn	1	53.1	152.3	152.6	153.0	153.3	17.1
Turn	5	69.5	199.9	200.1	200.6	200.8	33.1
Spee	7.5	140.2	243.6	243.7	244.3	244.4	102.2
Pede	2.5	82.4	291.8	291.9	292.5	292.6	46.5
Pede	7.5	91.0	338.8	338.8	339.5	339.5	54.9
Turn	10	91.5	481.3	481.1	482.0	481.8	53.9
Spee	1	60.5	683.3	682.8	684.0	683.5	22.4
Pede	10	121.1	777.7	777.1	778.4	777.8	83.9
Turn	2.5	79.6	871.0	870.2	871.7	870.9	43.2
Spee	5	115.0	969.0	968.1	969.7	968.8	78.2
Pede	1	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
Pede	5	54.6	1,166.6	1,165.4	1,167.3	1,166.1	19.5
Turn	7.5	74.1	1,215.1	1,213.8	1,215.8	1,214.5	36.7
Spee	10	151.1	1,306.9	1,305.5	1,307.6	1,306.2	112.6

SubjectID	04182014_04

Video Observations (Scenario 1) Speed 35 MPH

Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	38.3	54.5	55.7	55.2	56.4	2.1
Pede	10	95.4	97.1	98.3	97.8	99.0	59.0
Turn	2.5	26.3	195.3	196.3	196.0	197.0	0.0
Spee	5	111.0	241.2	242.1	241.9	242.8	74.8
Pede	1	62.2	290.3	291.2	291.0	291.9	26.6
Pede	5	139.4	336.7	337.5	337.4	338.2	104.0
Turn	7.5	159.7	483.0	483.6	483.7	484.3	124.1
Spee	10	146.8	615.5	615.9	616.2	616.6	110.7
Spee	2.5	80.8	691.9	692.2	692.6	692.9	45.9
Turn	1	56.7	838.8	838.8	839.5	839.5	20.9
Turn	5	127.0	885.3	885.3	886.0	886.0	91.9
Spee	7.5	156.5	988.3	988.1	989.0	988.8	121.4
Pede	2.5	115.1	1,145.3	1,144.9	1,146.0	1,145.6	79.2
Pede	7.5	162.5	1,191.8	1,191.3	1,192.5	1,192.0	126.6
Turn	10	202.8	1,238.3	1,237.7	1,239.0	1,238.4	167.9

Video Observations (Scenario 2) Speed 55 MPH

Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	87.2	48.5	49.2	49.2	49.9	40.3
Turn	1	13.5	112.1	112.7	112.8	113.4	0.0
Turn	5	155.8	141.3	141.8	142.0	142.5	100.3
Spee	7.5	150.9	171.6	172.1	172.3	172.8	94.8
Pede	2.5	110.5	203.8	204.3	204.5	204.9	54.8
Pede	7.5	145.3	233.5	233.9	234.2	234.6	88.7
Turn	10	137.3	326.0	326.3	326.7	327.0	81.3
Spee	1	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
Pede	10	176.5	516.6	516.6	517.3	517.3	120.4
Turn	2.5	99.1	579.0	578.9	579.7	579.6	41.1
Spee	5	121.4	643.7	643.5	644.4	644.2	63.7
Pede	1	37.8	743.9	743.5	744.6	744.2	0.0
Pede	5	108.0	772.9	772.5	773.6	773.2	52.6
Turn	7.5	167.0	803.7	803.3	804.4	803.9	110.7
Spee	10	219.4	866.7	866.1	867.4	866.8	161.7

SubjectID	04182014_05

Video Observations (Scenario 1) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	48.9	56.0	70.1	56.7	70.8	15.7
Pede	10	171.3	102.3	116.3	103.0	117.0	136.2
Turn	2.5	110.2	200.6	214.5	201.3	215.2	74.6
Spee	5	133.9	247.5	261.3	248.2	262.0	98.2
Pede	1	60.8	297.9	311.6	298.6	312.3	25.3
Pede	5	190.0	343.0	356.6	343.7	357.3	153.9
Turn	7.5	244.2	486.9	500.3	487.6	501.0	209.0
Spee	10	196.4	620.9	634.1	621.6	634.8	162.4
Spee	2.5	114.2	697.3	710.4	698.0	711.1	77.9
Turn	1	83.0	844.5	857.3	845.2	858.0	48.2
Turn	5	174.6	891.3	904.1	892.0	904.8	139.9
Spee	7.5	190.9	993.3	1,006.0	994.0	1,006.7	155.4
Pede	2.5	134.7	1,151.3	1,163.7	1,152.0	1,164.4	99.4
Pede	7.5	228.7	1,197.5	1,209.9	1,198.2	1,210.6	193.8
Turn	10	262.8	1,244.5	1,256.8	1,245.2	1,257.5	227.0

Video Observations (Scenario 2) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	134.4	42.8	43.2	43.5	43.9	94.0
Turn	1	129.9	106.5	106.8	107.2	107.5	73.1
Turn	5	218.9	135.9	136.1	136.6	136.8	163.3
Spee	7.5	243.0	165.5	165.7	166.2	166.4	186.7
Pede	2.5	114.6	198.2	198.3	198.9	199.0	58.6
Pede	7.5	202.1	227.5	227.6	228.2	228.3	145.4
Turn	10	154.5	321.0	321.0	321.7	321.7	100.4
Spee	1	81.8	454.0	453.7	454.7	454.4	25.5
Pede	10	242.3	513.2	512.8	513.9	513.5	183.5
Turn	2.5	128.4	574.1	573.7	574.8	574.4	71.6
Spee	5	219.7	637.3	636.8	638.0	637.5	163.1
Pede	1	76.9	737.3	736.6	738.0	737.3	20.1
Pede	5	153.4	766.2	765.5	766.9	766.2	96.0
Turn	7.5	190.6	796.6	795.8	797.3	796.5	135.6
Spee	10	269.9	864.5	863.7	865.2	864.4	216.5

SubjectID	04232014_01

Video Observations (Scenario 1) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
Pede	10	142.6	87.9	88.9	88.6	89.6	80.8
Turn	2.5	147.8	144.2	145.1	144.9	145.8	86.8
Spee	5	139.0	172.6	173.5	173.3	174.2	78.1
Pede	1	52.6	201.4	202.3	202.1	203.0	0.0
Pede	5	151.5	227.9	228.7	228.6	229.4	89.8
Turn	7.5	228.2	310.1	310.8	310.8	311.5	169.8
Spee	10	230.4	392.1	392.6	392.8	393.3	172.0
Spee	2.5	130.4	439.1	439.6	439.8	440.3	71.0
Turn	1	106.1	525.8	526.2	526.5	526.9	47.3
Turn	5	170.9	554.2	554.5	554.9	555.2	111.5
Spee	7.5	193.5	614.9	615.1	615.6	615.8	132.6
Pede	2.5	61.9	706.8	706.9	707.5	707.6	1.2
Pede	7.5	204.1	734.3	734.3	735.0	735.0	146.6
Turn	10	218.8	763.5	763.5	764.2	764.2	159.9

Video Observations (Scenario 2) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	109.7	52.8	53.7	53.5	54.4	72.7
Turn	1	79.9	145.5	146.3	146.2	147.0	42.0
Turn	5	160.6	189.7	190.4	190.4	191.1	123.4
Spee	7.5	151.0	234.5	235.1	235.2	235.8	111.9
Pede	2.5	111.8	280.4	281.0	281.1	281.7	73.4
Pede	7.5	194.4	323.9	324.4	324.6	325.1	157.5
Turn	10	224.0	463.2	463.6	463.9	464.3	185.6
Spee	1	50.9	658.4	658.4	659.1	659.1	8.7
Pede	10	193.0	742.9	742.8	743.6	743.5	156.0
Turn	2.5	139.2	832.1	831.8	832.8	832.5	96.4
Spee	5	126.8	920.7	920.4	921.4	921.1	86.0
Pede	1	82.2	1,061.1	1,060.6	1,061.8	1,061.3	44.0
Pede	5	143.3	1,104.1	1,103.4	1,104.8	1,104.1	104.1
Turn	7.5	203.1	1,148.1	1,147.4	1,148.8	1,148.1	164.5
Spee	10	162.5	1,240.2	1,239.4	1,240.9	1,240.1	123.9

SubjectID	04232014_02

Video Observations (Scenario 1) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	77.3	59.2	60.8	59.9	61.5	41.8
Pede	10	169.5	102.9	104.3	103.6	105.0	132.3
Turn	2.5	80.8	200.1	201.5	200.8	202.2	46.6
Spee	5	155.8	245.1	246.3	245.8	247.0	120.1
Pede	1	69.2	295.4	296.6	296.1	297.3	33.0
Pede	5	152.4	340.1	341.3	340.8	342.0	115.2
Turn	7.5	151.8	473.8	474.8	474.5	475.5	115.8
Spee	10	233.3	584.5	585.3	585.2	586.0	189.6
Spee	2.5	151.8	649.6	650.3	650.3	651.0	116.9
Turn	1	99.7	788.7	789.1	789.4	789.8	62.6
Turn	5	188.6	832.6	833.0	833.3	833.7	152.3
Spee	7.5	183.9	922.8	923.1	923.5	923.8	144.4
Pede	2.5	158.3	1,068.9	1,068.9	1,069.6	1,069.6	121.0
Pede	7.5	195.2	1,111.4	1,111.4	1,112.1	1,112.1	155.9
Turn	10	224.0	1,154.8	1,154.7	1,155.5	1,155.4	189.6

Video Observations (Scenario 2) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	117.1	69.9	72.0	70.6	72.7	66.3
Turn	1	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
Turn	5	110.6	158.8	160.6	159.5	161.3	55.3
Spee	7.5	184.8	187.6	189.3	188.3	190.0	126.7
Pede	2.5	5.2	218.8	220.4	219.5	221.1	0.0
Pede	7.5	55.7	247.7	249.2	248.4	249.9	2.5
Turn	10	142.2	338.0	339.2	338.7	339.9	86.0
Spee	1	51.3	467.1	467.9	467.8	468.6	0.0
Pede	10	100.1	526.5	527.1	527.2	527.8	40.7
Turn	2.5	54.6	586.7	587.1	587.4	587.8	0.0
Spee	5	140.6	647.2	647.4	647.9	648.1	82.1
Pede	1	54.3	742.1	742.0	742.8	742.7	0.0
Pede	5	142.9	769.9	769.7	770.6	770.4	81.0
Turn	7.5	179.5	799.7	799.4	800.4	800.1	125.6
Spee	10	288.5	858.5	858.0	859.2	858.7	222.4

SubjectID	04232014_03

Video Observations (Scenario 1) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
Pede	10	104.0	87.8	88.9	88.5	89.6	47.0
Turn	2.5	79.6	151.6	152.5	152.3	153.2	29.5
Spee	5	105.5	184.6	185.5	185.3	186.2	54.0
Pede	1	44.5	217.5	218.3	218.2	219.0	0.0
Pede	5	86.4	248.8	249.5	249.5	250.2	34.4
Turn	7.5	159.7	344.4	345.0	345.1	345.7	104.5
Spee	10	121.7	432.5	433.0	433.2	433.7	67.3
Spee	2.5	67.3	480.4	480.8	481.1	481.5	10.2
Turn	1	61.4	579.8	580.1	580.5	580.8	7.7
Turn	5	97.1	610.9	611.1	611.6	611.8	42.3
Spee	7.5	49.3	678.9	679.0	679.6	679.7	5.3
Pede	2.5	105.5	780.0	780.0	780.7	780.7	51.3
Pede	7.5	114.9	810.2	810.1	810.9	810.8	58.6
Turn	10	123.1	842.1	842.0	842.8	842.7	69.5

Video Observations (Scenario 2) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	102.9	52.6	54.5	53.3	55.2	50.3
Turn	1	53.5	115.0	116.8	115.7	117.5	1.2
Turn	5	190.8	144.8	146.5	145.5	147.2	135.7
Spee	7.5	139.9	175.7	177.4	176.4	178.1	83.1
Pede	2.5	70.6	207.6	209.3	208.3	210.0	13.9
Pede	7.5	138.5	236.6	238.2	237.3	238.9	81.5
Turn	10	208.5	330.1	331.5	330.8	332.2	152.3
Spee	1	57.1	467.3	468.6	468.0	469.3	3.2
Pede	10	166.5	529.8	531.0	530.5	531.7	107.5
Turn	2.5	45.3	592.4	593.4	593.1	594.1	10.2
Spee	5	140.8	658.3	659.3	659.0	660.0	88.2
Pede	1	78.8	757.6	758.4	758.3	759.1	20.9
Pede	5	135.6	786.1	786.9	786.8	787.6	77.3
Turn	7.5	159.6	815.8	816.5	816.5	817.2	102.3
Spee	10	199.7	879.6	880.3	880.3	881.0	145.7

SubjectID	04242014_01

Video Observations (Scenario 1) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	52.5	54.3	76.4	55.0	77.1	16.7
Pede	10	207.1	100.1	122.1	100.8	122.8	171.5
Turn	2.5	124.4	195.0	216.9	195.7	217.6	85.9
Spee	5	151.2	239.3	261.1	240.0	261.8	112.9
Pede	1	87.9	285.9	307.7	286.6	308.4	49.1
Pede	5	153.5	328.2	349.9	328.9	350.6	114.1
Turn	7.5	210.4	458.0	479.5	458.7	480.1	170.7
Spee	10	202.6	576.6	597.9	577.3	598.6	162.8
Spee	2.5	104.9	645.8	667.1	646.5	667.8	65.1
Turn	1	92.3	778.8	799.8	779.5	800.5	52.5
Turn	5	142.9	820.9	841.9	821.6	842.6	103.0
Spee	7.5	167.7	912.2	933.0	912.9	933.7	127.9
Pede	2.5	110.1	1,054.0	1,074.6	1,054.7	1,075.3	70.4
Pede	7.5	172.0	1,095.8	1,116.3	1,096.5	1,117.0	132.2
Turn	10	157.5	1,139.1	1,159.6	1,139.8	1,160.3	117.7

Video Observations (Scenario 2) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	96.1	44.4	45.4	45.1	46.1	45.5
Turn	1	51.1	103.9	104.8	104.6	105.5	0.0
Turn	5	97.9	133.5	134.4	134.2	135.1	41.5
Spee	7.5	115.9	163.4	164.2	164.1	164.9	60.0
Pede	2.5	68.1	195.4	196.2	196.1	196.9	12.6
Pede	7.5	139.9	225.1	225.8	225.8	226.5	84.4
Turn	10	201.2	316.1	316.7	316.8	317.4	144.3
Spee	1	34.5	451.8	452.2	452.5	452.9	0.0
Pede	10	170.2	515.9	516.2	516.6	516.9	116.3
Turn	2.5	102.9	578.5	578.7	579.2	579.4	45.0
Spee	5	116.6	641.1	641.2	641.8	641.9	58.9
Pede	1	64.7	742.2	742.1	742.9	742.8	9.0
Pede	5	145.7	771.3	771.2	772.0	771.9	89.3
Turn	7.5	201.5	801.4	801.3	802.1	802.0	144.1
Spee	10	208.8	864.6	864.4	865.3	865.1	153.9

SubjectID	04242014_02

Video Observations (Scenario 1) Speed 55 MPH

Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	70.3	49.8	50.8	50.5	51.5	17.1
Pede	10	138.6	77.9	78.9	78.6	79.6	80.0
Turn	2.5	83.7	137.5	138.5	138.2	139.2	25.2
Spee	5	172.4	165.4	166.3	166.1	167.0	113.3
Pede	1	36.1	196.8	197.6	197.5	198.3	0.0
Pede	5	101.0	224.8	225.6	225.5	226.3	42.2
Turn	7.5	171.0	313.5	314.2	314.2	314.9	113.2
Spee	10	225.5	396.0	396.5	396.7	397.2	166.7
Spee	2.5	199.9	442.5	443.0	443.2	443.7	142.5
Turn	1	79.4	535.0	535.4	535.7	536.1	23.1
Turn	5	152.0	564.6	564.8	565.3	565.5	95.3
Spee	7.5	251.3	627.4	627.6	628.1	628.3	192.1
Pede	2.5	116.9	727.4	727.5	728.1	728.2	58.9
Pede	7.5	170.9	756.4	756.4	757.1	757.1	113.4
Turn	10	190.8	786.8	786.8	787.5	787.5	134.5

Video Observations (Scenario 2) Speed 35 MPH

Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	99.9	52.3	53.7	53.0	54.4	62.7
Turn	1	72.1	147.7	148.9	148.4	149.6	35.9
Turn	5	130.5	194.3	195.5	195.0	196.2	93.5
Spee	7.5	177.4	238.0	239.1	238.7	239.8	141.0
Pede	2.5	83.8	286.6	287.6	287.3	288.3	45.9
Pede	7.5	164.8	330.9	331.8	331.6	332.5	127.8
Turn	10	172.6	470.5	471.2	471.2	471.9	135.4
Spee	1	44.6	674.3	674.8	675.0	675.5	9.0
Pede	10	182.7	768.7	769.0	769.4	769.7	146.8
Turn	2.5	119.2	866.3	866.5	867.0	867.2	82.1
Spee	5	148.8	965.0	965.0	965.7	965.7	111.6
Pede	1	72.3	1,118.1	1,117.8	1,118.8	1,118.5	35.6
Pede	5	142.3	1,162.5	1,162.2	1,163.2	1,162.9	105.9
Turn	7.5	160.1	1,209.1	1,208.7	1,209.8	1,209.4	124.2
Spee	10	208.0	1,306.4	1,305.9	1,307.1	1,306.6	170.8

SubjectID	04242014_03

Video Observations (Scenario 1) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	62.4	32.4	33.6	33.1	34.3	27.4
Pede	10	181.6	77.0	78.0	77.7	78.7	145.5
Turn	2.5	107.7	174.8	175.7	175.5	176.4	72.0
Spee	5	194.1	221.0	221.9	221.7	222.6	158.3
Pede	1	106.0	271.9	272.6	272.6	273.3	69.1
Pede	5	176.8	317.8	318.5	318.5	319.2	141.0
Turn	7.5	210.6	457.5	458.0	458.2	458.7	173.1
Spee	10	220.4	578.5	578.8	579.2	579.5	181.1
Spee	2.5	176.4	652.6	652.8	653.3	653.5	137.6
Turn	1	75.8	793.7	793.7	794.4	794.4	38.2
Turn	5	214.8	837.2	837.1	837.9	837.8	177.9
Spee	7.5	247.5	935.9	935.6	936.6	936.3	209.8
Pede	2.5	142.0	1,083.8	1,083.3	1,084.5	1,084.0	103.8
Pede	7.5	199.1	1,127.7	1,127.2	1,128.4	1,127.9	161.4
Turn	10	220.6	1,173.1	1,172.5	1,173.8	1,173.2	183.3

Video Observations (Scenario 2) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	149.2	29.0	30.6	29.7	31.3	108.9
Turn	1	76.7	90.8	92.2	91.5	92.9	18.3
Turn	5	198.4	118.6	120.0	119.3	120.7	139.1
Spee	7.5	230.8	146.8	148.2	147.5	148.9	173.7
Pede	2.5	88.2	177.6	178.9	178.3	179.6	26.8
Pede	7.5	196.1	204.8	206.1	205.5	206.8	137.8
Turn	10	263.8	291.3	292.5	292.0	293.2	205.9
Spee	1	83.5	421.6	422.6	422.3	423.3	24.6
Pede	10	198.8	480.7	481.6	481.4	482.3	143.1
Turn	2.5	116.9	540.5	541.3	541.2	542.0	60.1
Spee	5	210.9	602.4	603.1	603.1	603.8	151.4
Pede	1	88.8	699.5	700.1	700.2	700.8	34.7
Pede	5	193.6	728.8	729.3	729.5	730.0	137.0
Turn	7.5	233.4	758.9	759.4	759.6	760.1	175.6
Spee	10	279.1	820.9	821.2	821.6	821.9	221.3

SubjectID	04252014_01

Video Observations (Scenario 1) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	67.6	53.9	54.7	54.6	55.4	31.1
Pede	10	126.1	99.7	100.4	100.4	101.1	90.5
Turn	2.5	100.6	196.4	197.0	197.1	197.7	64.8
Spee	5	175.1	242.1	242.7	242.8	243.4	138.8
Pede	1	13.6	294.4	294.9	295.1	295.6	0.0
Pede	5	112.2	340.5	340.9	341.2	341.6	76.6
Turn	7.5	160.8	483.2	483.4	483.9	484.1	124.6
Spee	10	252.9	612.2	612.2	612.9	612.9	217.1
Spee	2.5	114.1	689.0	688.9	689.7	689.6	78.1
Turn	1	0.0	837.4	837.0	838.1	837.7	0.0
Turn	5	196.0	880.5	880.1	881.2	880.8	160.3
Spee	7.5	190.0	980.7	980.1	981.4	980.8	153.6
Pede	2.5	91.6	1,136.9	1,136.1	1,137.6	1,136.8	55.1
Pede	7.5	189.9	1,182.6	1,181.8	1,183.3	1,182.5	153.8
Turn	10	162.8	1,230.8	1,229.8	1,231.5	1,230.5	126.3

Video Observations (Scenario 2) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	116.3	51.2	52.8	51.9	53.5	67.9
Turn	1	10.9	112.8	114.3	113.5	115.0	0.0
Turn	5	88.3	141.6	143.1	142.3	143.8	31.5
Spee	7.5	167.8	169.9	171.3	170.6	172.0	110.2
Pede	2.5	51.0	201.8	203.1	202.5	203.8	0.0
Pede	7.5	81.1	231.4	232.7	232.1	233.4	24.5
Turn	10	95.6	322.1	323.3	322.8	324.0	38.5
Spee	1	50.2	451.0	452.0	451.7	452.7	0.0
Pede	10	130.9	511.3	512.2	512.0	512.9	74.0
Turn	2.5	110.2	570.8	571.6	571.5	572.3	53.9
Spee	5	96.0	633.8	634.5	634.5	635.2	40.1
Pede	1	0.0	732.2	732.8	732.9	733.5	0.0
Pede	5	77.3	761.0	761.5	761.7	762.2	20.9
Turn	7.5	149.6	791.0	791.5	791.7	792.2	92.5
Spee	10	230.9	851.9	852.2	852.6	852.9	173.2

SubjectID	04252014_02

Video Observations (Scenario 1) Speed 55 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	1	9.8	58.4	60.2	59.1	60.9	0.0
Pede	10	108.6	86.2	88.0	86.9	88.7	49.8
Turn	2.5	37.8	146.1	147.8	146.8	148.5	0.0
Spee	5	119.8	174.3	175.9	175.0	176.6	61.2
Pede	1	0.0	206.3	207.9	207.0	208.6	0.0
Pede	5	91.3	234.7	236.3	235.4	237.0	34.2
Turn	7.5	148.8	328.6	330.0	329.3	330.7	92.6
Spee	10	188.6	413.2	414.5	413.9	415.2	131.1
Spee	2.5	58.3	462.0	463.2	462.7	463.9	2.6
Turn	1	21.6	553.7	554.8	554.4	555.5	0.0
Turn	5	85.5	581.9	583.0	582.6	583.7	26.3
Spee	7.5	187.8	642.5	643.4	643.2	644.1	128.7
Pede	2.5	81.2	739.1	739.9	739.8	740.6	22.6
Pede	7.5	85.1	768.0	768.8	768.7	769.5	26.2
Turn	10	177.5	796.0	796.7	796.7	797.4	118.5

Video Observations (Scenario 2) Speed 35 MPH							
Sign		With Perception Response Time			Without Perception Response Time		
Type	Ratio	Recogntion Distance (ft)	Video Time (sec)	Simulation Time (sec)	Video Time (sec)	Simulation Time (sec)	Recognition Distance (ft)
Spee	2.5	81.8	44.5	45.4	45.2	46.1	46.5
Turn	1	0.0	141.1	141.8	141.8	142.5	0.0
Turn	5	121.4	183.0	183.7	183.7	184.4	83.2
Spee	7.5	182.7	228.2	228.7	228.9	229.4	143.2
Pede	2.5	81.5	278.0	278.5	278.7	279.2	43.9
Pede	7.5	155.7	321.2	321.6	321.9	322.3	119.2
Turn	10	209.5	457.1	457.3	457.8	458.0	171.9
Spee	1	52.4	656.6	656.6	657.3	657.3	17.4
Pede	10	179.6	749.7	749.5	750.4	750.2	143.6
Turn	2.5	95.2	842.2	841.8	842.9	842.5	57.1
Spee	5	123.4	939.0	938.5	939.7	939.2	86.2
Pede	1	50.7	1,087.7	1,087.0	1,088.4	1,087.7	13.7
Pede	5	126.2	1,134.0	1,133.2	1,134.7	1,133.9	90.8
Turn	7.5	210.3	1,179.9	1,179.0	1,180.6	1,179.7	172.9
Spee	10	213.5	1,272.6	1,271.6	1,273.3	1,272.3	175.4