Entrance Angle Requirements for Retroreflectorized Traffic Signs

MICHAEL S. GRIFFITH, JEFFREY F. PANIATI, AND RICHARD C. HANLEY

The primary objective of this study was to examine the validity of the maximum specification (30 degrees) for entrance angles of retroreflective traffic signs, which is considered to be the widest angle for signs. However, the 45-year-old specification is not substantiated by empirical data. Accurate data are necessary to evaluate the need for a new specification. The amount of light returned from a sign to a driver determines retroreflectivity; therefore, research was conducted from the driver's perspective. Measurements of sign entrance angles were made and their distribution was analyzed. A customized computer software program, SEAMS (Sign Entrance Angle Measurement System), was used to measure entrance angles for over 1,100 in-service traffic signs on several roadway types. After examination of previous research and consideration of other factors, it was decided to take sign entrance angle measurements at 30.5 and 61.0 m (100 and 200 ft). Using the 61.0-m (200-ft) distance for freeways and the 30.5-m (100-ft) distance for nonfreeways provided a conservative estimate of sign entrance angles. The empirical distributions show that approximately 95 percent of the sign entrance angles measured are less than 21 degrees and approximately 99 percent are less than 27 degrees. The study results indicate that the current 30-degree specification covers nearly all signs and provides a margin of safety to compensate for signs that are twisted, bent, or leaning out of plumb. However, the data also show that a lower specification (20 degrees) would cover 99 percent of the freeway signs and 96 percent of all signs measured.

Traffic signs are designed to provide the motorist with the warning, regulation, and guidance necessary to move safely and efficiently through the highway network. To meet this goal, these signs must be clearly visible to the driver both during the day and at night. Nighttime visibility of most traffic signs is provided through the use of retroreflective sheeting. Retroreflection occurs when light rays from an automobile's headlamps strike the surface of a sign and are redirected back toward the driver (see Figure 1). The measure of retroreflectivity is termed the coefficient of retroreflection (R_A).

The amount of light reflected back to the driver varies, depending on two important angles: the entrance angle and the observation angle. The entrance angle is that between a light beam striking the surface of the sign and a line perpendicular to the sign surface [see Figure 2 (*top*)]. There are two components of the entrance angle: β_1 corresponds to the horizontal part of the angle and β_2 corresponds to the vertical part of the angle. The horizontal component of the entrance angle is shown in Figure 2 (*top*). The entrance angle β may be derived from the expression $\cos \beta = \cos \beta_1 \cos \beta_2$ (*1*).

M. S. Griffith and J. F. Paniati, Office of Safety and Traffic Operations R&D, Federal Highway Administration, McLean, Va. 22101. R.C. Hanley, Office of Research and Materials, Connecticut Department of Transportation, Rocky Hill, Conn. 06067.

Figure 2 (*bottom*) shows the vertical component of the entrance angle.

The observation angle is that between a light beam striking the surface of the sign and the line of sight of the driver. This angle is a function of the height of the driver's eyes with respect to the vehicle headlamps. Both the entrance angle and the observation angle change as the distance between the vehicle and the sign changes (*2*). This study did not examine observation angles.

Current specifications for minimum R_A values for new sign sheeting are contained in ASTM D 4956-89. These specifications are given for different sign colors at two entrance angles and two observation angles. The entrance angles specified are −4 degrees and +30 degrees. The −4-degree angle is intended for signs that are close to a straight road but turned slightly away from traffic to avoid glare from the smooth sign surface. The +30-degree angle has traditionally been considered to be the widest angle at which signs would commonly be seen on curved roadways. Recently, the basis for the +30-degree entrance angle requirement has been questioned. Investigation into this specification has revealed that it is 45 years old and not substantiated by empirical data.

Presented here are the results of a research study to collect empirical data to evaluate the need for a new maximum specification for sign entrance angles. This study was conducted using a customized computer software program, SEAMS (Sign Entrance Angle Measurement System) (*3*), developed for use with the Connecticut Department of Transportation (ConnDOT) photolog laser videodisc (PLV) retrieval system. This program allowed the measurement of entrance angles for a large sample of in-service traffic signs in an office environment.

APPROACH

The amount of light returned from a sign to a driver determines retroreflectivity; therefore, research was conducted from the driver's perspective. Measurements of sign entrance angles were made and their distribution was analyzed. The implementation of this type of approach required several key components:

1. An efficient method to collect sign entrance angle data for a large group of signs;
2. A definition of the "last-look distance," the distance before the sign after which the driver no longer obtains information from the sign; this is the distance at which the maximum entrance angle would be measured; and

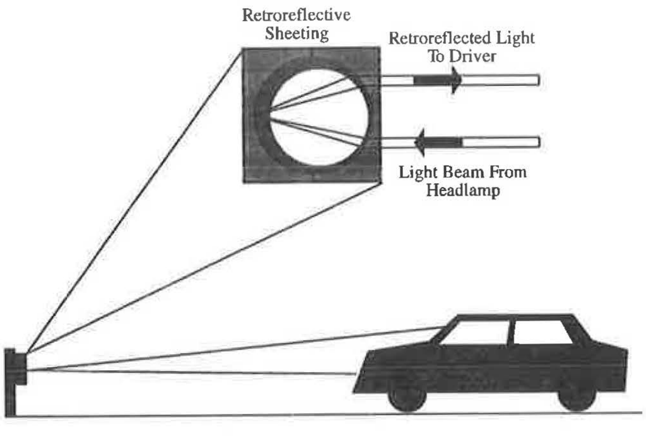

FIGURE 1 Principle of retroreflection.

3. A sampling plan that provides a representative sample accounting for differences in sign classes, sign placements, roadway types, and so forth.

The current literature on the last-look distance and how this research was applied to this study are outlined in the next section, followed by a discussion of the PLV retrieval system and the development of the SEAMS software to allow collection of entrance-angle data in an office environment. Then the sampling plan and data collection and the analysis of the data are presented. Last, the results of the field data collection and a validation analysis of the results are discussed.

LAST-LOOK DISTANCE

Measurement of sign entrance angles requires a distance specification. Entrance angles are a function of the distance between the driver and the sign. On a straight road, the entrance angle of a sign increases as a driver gets closer to a sign. Last-look distance is defined as the distance from the sign to the point at which the driver moves his or her eyes from the sign and does not look at it again (*4*). This is the last distance at which the driver acquires information from the sign. It is not the only point at which a driver looks at a sign. Generally, a driver will look at a sign several times before his or her last look. Figure 3 shows an example for an urban street sign with

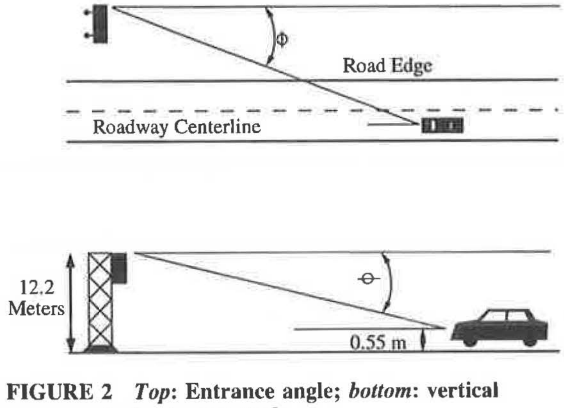

FIGURE 2 ***Top*: Entrance angle; *bottom*: vertical component of entrance angle.**

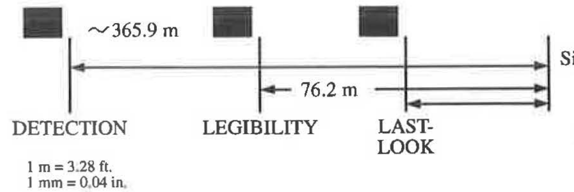

FIGURE 3 Last-look distance.

a 101.6- to 152.4-mm (4- to 6-in.) legend. This sign is detected on average at a distance of 365.9 m (1,200 ft) by the driver, and it becomes legible to the driver on average at 76.2 m (250 ft) (Douglas Mace, unpublished data). Between 76.2 m (250 ft) and a last-look distance of less than 76.2 m (250 ft), the driver may look at the sign several times. Most drivers last look at a nonfreeway sign at a distance of less than 76.2 m (250 ft) (*4,5*).

Study of the current literature on last-look distance was required to determine the distance at which entrance angles would be measured. The objective of the first of two studies by Zwahlen (*4*) was to determine the effectiveness of the STOP AHEAD sign in warning drivers of an upcoming, unexpected, partially concealed STOP sign and intersection during daytime and nighttime conditions. The driving performance and eye-scanning behavior of 39 subjects were studied as they approached an intersection of two-lane rural roads where they were required to stop. The objective of another study (*5*) was to determine the effectiveness of advisory speed signs used in conjunction with curve warning signs in Ohio. A total of 40 drivers were used to drive an unfamiliar test route on a two-lane rural road that included two typical curves equipped with curve warning signs. Eye-scanning data ("first- and last-look distances") were collected for stop signs with and without the STOP AHEAD sign and for curve signs with and without the advisory speed sign. Each study collected this data to identify any differences in driver eye-scanning behavior.

Detailed eye-scanning results for individual subjects and groups for both of the aforementioned studies are given by Zwahlen (*6*). The combined number of last-look distance measurements collected in the studies was 240 under daytime conditions and 141 under nighttime conditions. In both experiments, subjects performed tasks in a group. There was a total of 44 subject groups. The average operating speeds of the subjects ranged from 48.6 km/hr to 89.1 km/hr (30 to 55 mph). Means and standard deviations of last-look distance were computed to find the 99 percent confidence interval for both conditions. The 99 percent confidence interval for the population mean, μ, is (63.4 m, 78.4 m) (208 ft, 257 ft) for daylight conditions and (49.4 m, 61.3 m) (162 ft, 201 ft) for nighttime conditions. Minimum last-look distance results were computed to examine the statistics of the shortest distances for all 44 subject groups. The 99 percent confidence interval for the population mean of minimum last-look distances, μ, is (23.8 m, 33.8 m) (78 ft, 111 ft) for daytime conditions and (27.7 m, 37.8 m) (91 ft, 124 ft) for nighttime conditions.

Last-look distances for signs vary depending on driver characteristics; the function of the sign (signs that require lane changes with merging activity and those that require a complete stop must be detected and read at considerable distances from the sign); environmental conditions (signs are read at distances very close to the sign under nighttime inclement weather conditions); and the placement of the sign (signs that are further from the shoulder line have longer last-look distances). For example, older drivers as a group exhibit a significant decrease in perceptual, cognitive, and psychomotor abilities, all of which are related to safe driving performance. The U.S. population is aging. By 2030, the number of people older than 65 will more than double (*7*). The night legibility distances for older drivers are significantly lower than those for younger drivers for all sign types, as shown by the following (1 m = 3.28 ft; 1 mm = 0.04 in.):

	Legibility Distance (m) by Age (years)		
Letter Size (mm)	*Sign Type*	*<40*	*>65*
101.6	Street name	73.2	36.6
152.4	Regulatory	106.7	54.9
203.2	Warning	137.2	73.2
304.8	Guide	213.4	109.8

Placement of signs is generally greater on freeways than on nonfreeways. Vehicle speeds also tend to be greater on freeways, especially in rural areas. Generally, longer last-look distances can be found for signs on freeways because of the combination of the greater placement of the signs and the higher speeds. A longer last-look distance will usually result in a lesser entrance angle.

On the basis of the results of the analysis of the Zwahlen data and consideration of these other factors, it was decided to collect sign entrance angle measurements at 30.5 and 61.0 m (100 and 200 ft). It was believed that using the 61.0-m (200-ft) distance for the freeways and the 30.5-m (100-ft) distance for the nonfreeways would provide a conservative estimate of sign entrance angles.

SIGN ENTRANCE ANGLE MEASUREMENT SYSTEM

ConnDOT, in cooperation with the Federal Highway Administration (FHWA), has developed the software SEAMS for the measurement of entrance angles for in-service highway signs. SEAMS allows measurement of these angles in an office environment using the PLV retrieval system to access highway images stored on laser videodiscs. A photolog is a series of sequential images taken from a moving vehicle at approximately driver's eye level to provide a permanent record of the state-maintained roadway network. ConnDOT uses two automated vehicles to annually film the entire state highway system in both directions on 35-mm color film. A photograph is taken every 0.016 km (0.01 mi) or 16.1 m (52.8 ft).

During the filming, on-board sensors simultaneously collect and store an array of data including route number, direction of travel, cross slope, compass reading, date, time, horizontal and vertical curvature, long-term and short-term roughness, grade, side friction, and vehicle speed. Currently, Connecticut is the only state that collects and stores the photolog images and the corresponding geometric data. The 35-mm film used to collect the images is developed, edited, and recorded onto videotapes, which are then shipped to a videodisc mastering facility where the images are transferred to double-sided laser videodiscs. The final product is a library of 15 videodiscs, each disc side containing 429 km (265 mi) of highway images. The advantages of the videodisc over film are random accessibility, storage density, durability, and the ability of the player to accept computer input.

Measuring entrance angles with SEAMS is fairly simple for the user. The process requires that the selected sign be visible in at least two photolog images, at least two corresponding points on the sign be visible in each image, and the corresponding highway geometric data be available. The user first uses the menu-driven software to move to the image closest to the sign. Then by operating a five-button cursor, the user places four points on the outer edges of a sign. The task of placing points on the sign is repeated one image farther back from the sign, which enables SEAMS to reconstruct the path of the vehicle. SEAMS then calculates the coordinates of these points in relation to the road alignment provided by grade, cross slope, and azimuthal geometric data acquired by the instrumented photolog vehicle. This process is a complex form of parallax. An algorithm within the software computes the entrance angle for a sign at different distances. The distance from the photolog van to the sign is measured along the centerline of the roadway. The output from SEAMS shows entrance angles for Points 1 and 2. Point 1 is at the top edge of the sign and Point 2 is at the edge of the sign furthest from the driver. Taking the conservative approach, Point 2 was selected as the one at which all sign entrance angle measurements would be collected. In the majority of cases, measurements at Point 2 will result in a greater angle than those at Point 1. It is also important to note that the legend of a sign never reaches this outer edge (Point 2). It is the sign legend that contains the information the driver must acquire.

Connecticut's photolog van generally takes all pictures and measurements from the right lane for the nonfreeway system and from the right lane or one of the center lanes for the freeway system. Measurements of signs were taken from the lane in which the photolog van traveled at each location. Clearly, all motorists do not drive in the right lane on the nonfreeway system or in one of the center lanes on the freeway system. Therefore, taking the conservative approach, adjustments were made to all measurements to compute the entrance angle in the lane furthest from the sign except in certain cases. These cases include locations where the same sign is mounted on both sides of the highway (the majority of these cases exist on the freeway system) and for particular signs (e.g., MERGE) where the sign is intended primarily for the motorist in the right lane. For each lane of travel further in distance from a sign, 3 degrees was added to the initial angle for measurements taken at 61.0 m (200 ft) and 7 degrees was added for measurements taken at 30.5 m (100 ft). These adjustments are based on measurements taken in the field.

Using SEAMS has many benefits over conventional taping or surveying techniques. Since measurements are done in an office environment, the need for field work (aside from the collection of the photolog images) is eliminated, thus saving time and field trips and removing personnel from the hazardous highway working environment. The actual measurement operation can be performed by one person, reducing personnel costs associated with a survey crew. Measurements using SEAMS do not impair traffic flow.

Measurements with SEAMS are based on the following assumptions:

1. The photolog van always tracks in the center of the lane, with no erratic maneuvers;
2. The photolog camera is located in the center of the truck;
3. The plane of a sign is always at a right angle to a point on the roadway shoulder line; and
4. The vertical component of the entrance angle is insignificant.

Assumptions 1 and 2 are believed to be reasonable and representative of the conditions when the photologs are obtained in the field. Assumption 3 is valid if signs are installed and maintained in accordance with the *Manual on Uniform Traffic Control Devices* (MUTCD), which states that signs should be mounted approximately at right angles to the direction of, and facing, the traffic that they are intended to serve (*8*). Additional discussion concerning the validity of this assumption in the real world is included later in the paper.

Assumption 4 was made because the horizontal component of the entrance angle dominates the vertical component in its effect on the overall entrance angle, as can be demonstrated through the following example. Figure 2 (*bottom*) illustrates a worst-case scenario for a freeway sign. The driver is approaching a sign 12.2 m (40 ft) high (approximate maximum height of a sign from the roadway surface) and in most cases last looks at the sign 61.0 m (200 ft) or more before it. The distance of 0.55 m (1.8 ft) represents the average height of passenger-car headlamps above the road surface (49 CFR, Section 571.108, Table II, Oct. 1991). The software used in this study (SEAMS) only calculated entrance angles based on the first component. Referring to the bottom part of Figure 2, the second component of the entrance angle is $\tan^{-1}$ 38.2/200 = 10.8 degrees. If the first component is 30 degrees, then entrance angle ß = (cos 30 degrees)(cos 10.8 degrees) = 31.7 degrees. Therefore, in the worst case the entrance angle estimate will be off by less than 2 degrees. On average, it is expected that the "error" will be less than 1 degree.

In the nonfreeway scenario, a driver approaches a sign no greater than approximately 4.6 m (15 ft) high and in most cases last looks at the sign at a distance of 30.5 m (100 ft) or more before it. In this case, the second component of the entrance angle is $\tan^{-1}$ 13.2/100 = 7.5 degrees. If the first component is 20 degrees, then entrance angle β = (cos 20 degrees)(cos 7.5 degrees) = 21.5 degrees. The computations indicate that the first component of the entrance angle (the horizontal part) has much greater influence on the overall entrance angle than the vertical part. Therefore, disregarding the second component (vertical part) of the entrance angle in this study did not have a significant impact on the final results.

SAMPLING PLAN AND DATA COLLECTION

A sampling plan was developed to collect sign entrance angle data with the SEAMS software. The plan was based on Connecticut's system of approximately 12 636 bidirectional km (7,800 mi) of state-maintained highways. Connecticut's system has a range of terrain conditions including hilly and flat, and other topographical features. Entrance angle data were collected for essentially all types of permanent signs including regulatory, warning, and guide signs located on the right side of the roadway. Data were not collected for temporary work zone devices, overhead guide signs, milepost signs, street name signs, and NO PARKING signs.

SEAMS was not validated for construction work zone devices such as drums, cones, and A-frame barricades. Therefore, it was not reasonable to make entrance angle measurements on work zone devices. In addition, the sample of work zone services available on Connecticut's videodisc photolog system is too small to capture the cumulative distribution of entrance angles for these devices. Given the unique characteristics of work zone devices, it may be appropriate to have a separate (possibly higher) specification for these materials.

It was unnecessary to collect and examine the distribution of entrance angles for overhead guide signs. This is because physical limitations such as windshield cutoff and dynamic visual acuity cause an overhead sign to become illegible approximately 53.4 m (175 ft) before the vehicle reaches the sign (*9*). Also, since overhead signs are located directly above the roadway, the effect of the first component of the entrance angle, β_1, is minimal. Therefore, the second component (the vertical part), β_2, dominates the overall entrance angle, β, for overhead signs. The maximum height of an overhead guide sign above the headlamps of a passenger vehicle is assumed to be 11.6 m (38.2 ft) if the sign is 12.2 m (40 ft) high. The entrance angle of this overhead guide sign at a distance of 53.4 m (175 ft) is $\tan^{-1}$ 38.2/175 = 12.3 degrees. This angle does vary depending on the driver characteristics and vehicle type. However, the maximum entrance angle requirement for overhead signs is well below that needed for roadside signs.

Sample size was determined to estimate the number of signs required for data collection. Data had to be collected on a sufficient number of signs to capture a valid cumulative distribution of sign entrance angles. Sample size was estimated by drawing inference on the population mean (population average of sign entrance angles) as the parameter of interest. If the desired accuracy of the sample mean is denoted by d and the test level of significance by α, the formula for sample size (n) is (*10*)

$$n = \frac{(Z_{1-\alpha/2})^2}{d^2} \tag{1}$$

The value of z is a probability extracted from the standard normal probability table. To estimate the population mean to within 15 percent with a probability of .95, the required sample size is

$$n = \frac{(z_{.975})^2}{(.15)^2} = \frac{(1.96)^2}{.0225}$$

$$n = 171 \text{ signs} \tag{2}$$

The data collection goal for each roadway type was 200 signs.

A stratified random sampling plan was developed to collect sign entrance angle data for all roadway types across the entire state of Connecticut. Specific sampling schemes were developed for five roadway types: Interstate, other freeways, principal arterial, other urban (urban arterials and collector roads), and other rural (rural arterials and collector roads). Entrance angle data were collected in 1.62-km (1-mi) samples. The number of miles and the average number of traffic signs per mile were calculated for each roadway type. Dividing 200 signs by the average number of signs per mile indicated roughly the number of 1-mi samples to collect for each roadway type. The overall sampling plan implemented provides a representative sample accounting for differences in sign types, sign locations, roadway types, and so forth.

A special collection effort was completed for signs situated to the left side of the roadway on freeway facilities. These facilities generally have the most signs situated on the left side of the roadway and were believed to provide a reasonable worst-case scenario for left-mounted signs.

The total number of signs collected is shown below:

Roadway Type	*No. of Signs*
Interstate	212
Other freeways	195
Freeways (left)	192
Principal arterial	182
Other urban	187
Other rural	174
Total	1,142

DATA ANALYSIS

The focus of the analysis was to examine the upper percentiles of the sign entrance angle data. This examination would indicate how the highest entrance angles compare with the current specification (+30 degrees) and provide an indication of the impact of changing this specification. The data were analyzed separately for each roadway type. The sign locations at the 75th, 85th, 90th, 95th, and 99th percentiles for the different roadway types at 30.5 m (100 ft) for nonfreeways and at 61 m (200 ft) for freeways are shown in Tables 1 and 2, respectively.

The average sign location for freeway roads at the 99th percentile is 20 degrees and that for nonfreeway roads is 27 degrees. Table 1 shows for the nonfreeway system that approximately 95 percent of all sign entrance angles are less than 21 degrees and approximately 99 percent are less than 27 degrees. Table 2 shows for the freeway system that approximately 95 percent of all sign entrance angles are less than 16 degrees and approximately 99 percent are less than 20 degrees. The percentage of signs that have entrance angles greater than 20, 25, and 30 degrees for each roadway type is as follows:

Roadway Type	*>20 degrees*	*>25 degrees*	*>30 degrees*
Interstate	0.5	0	0
Other freeways	1	0	0
Interstate and other freeways (left)	0	0	0
Principal arterial	13	3	0
Other urban	5	1	0
Other rural	3	1	0

None of the 1,142 signs measured have entrance angles greater than 30 degrees and only 10 of the signs measured have entrance angles greater than 25 degrees.

Other signs were studied that have the potential of having high entrance angles. In particular, ONE WAY and DO NOT ENTER signs positioned at the end of one-way freeway exit ramps were examined. These signs are needed to prohibit traffic from the cross road that intersects the exit ramp from entering the restricted road section (*8*). Sign entrance angles of eight ONE WAY signs mounted on both sides of the roadway were measured. The angles at 30.5 m (100 ft) range from 10 degrees to 24 degrees. DO NOT ENTER signs on these exit ramps that do not directly face the traffic on the cross road were not measured. The DO NOT ENTER signs that face in this direction are typically supplemented with a ONE WAY sign that faces the traffic on the cross road. The ONE WAY sign displays the required information to the driver on the cross road.

The results show that the effect of using a lower requirement (20 degrees) would not be significant on freeways (0 to 1 percent of the entrance angles are greater than 20 degrees) and moderate on nonfreeways (3 to 13 percent of the entrance angles are greater than 20 degrees) but would not include a margin of safety. The results also show that there is little benefit to be gained from using a higher maximum entrance angle.

TABLE 1 Percentiles of Entrance Angle Measurements at 30.5 m

Roadway Type	75th	85th	90th	95th	99th
Principal Arterial	17°	19°	22°	24°	29°
Other Urban	14°	16°	16°	20°	26°
Other Rural	12°	13°	15°	19°	26°
Average	14°	16°	18°	21°	27°

1 m = 3.28 ft

TABLE 2 Percentiles of Entrance Angle Measurements at 61 m

Roadway Type	75th	85th	90th	95th	99th
Interstate	12°	14°	14°	16°	19°
Other Freeways	12°	14°	15°	18°	24°
Interstate and Other Freeways (Left)	11°	12°	13°	14°	17°
Average	12°	13°	14°	16°	20°

1 m = 3.28 ft

FIELD DATA COLLECTION AND VALIDATION ANALYSIS

Entrance angle data were collected in the field to verify the accuracy of SEAMS. It was determined that measurements on 75 signs would be sufficient to do a valid statistical analysis. Signs were selected for all roadway types in a preferred area around Rocky Hill, Connecticut, to minimize travel time. (ConnDot's Office of Research and Materials is located in Rocky Hill.) Before data collection, color prints of each sign were produced with the color video printer, a component of the ConnDot photolog laser videodisc system. This allowed for easy identification of the selected signs to be measured in the field. Measurements were attempted on over 100 signs by a survey crew. For various reasons, such as roadway safety, new sign replacement, and sign elimination, data were collected on only 77 signs at 30.5 and 45.7 m (100 and 150 ft).

Entrance angle data were collected with a device designed by an engineer at FHWA. The entrance angle instrument has a telescope that is mounted to an aluminum base with a level and computer-generated protractor attached to the top of the base. A handle is attached to the bottom of the base, which is held when using the instrument.

The measurement process used in the field to collect entrance angle data was fairly simple. First, distances of 30.5 and 45.7 m (100 and 150 ft) from the selected sign were measured with a measuring wheel and marked. Cones were then placed at the lane line and shoulder line at the marked distances. After the required distances from a selected sign were measured and marked, the lane width was measured with a tape. Angle measurements were taken with the entrance angle device by first supporting it level against a sign. The telescope was then turned until the target (a cone) was viewed at the intersection of the crosshairs. At this point, an angle was read from the protractor. The farther the telescope was turned, the greater was the sign entrance angle. This measurement process was completed for all four cones. Through interpolation between the two angles obtained at the lane line and shoulder line, the entrance angle of each sign was calculated at the point 1.4 m (4.5 ft) from the lane line. Assuming that the motorist drives in the middle of a 3.7-m (12-ft) lane and the width of the vehicle is approximately 1.8 m (6 ft), 1.4 m (4.5 ft) to the right of the lane line is the average position where the driver is located. This is the position on the roadway where a motorist views signs at different entrance angles.

Figures 4 and 5 show the cumulative distribution of the SEAMS data and field data for all roadway classifications (Interstate, principal arterial, etc.) combined at 30.5 m (100 ft) and 61 m (200 ft), respectively. The distance measured in the field for the freeways was 45.7 m. This is because at the time of field data collection it was believed that 45.7 m was the most reasonable distance to represent the last-look distance for freeways. After further consideration of all the factors that affect the last-look distance (driver characteristics, function of the sign, environmental conditions, placement of the sign, etc.), it was decided that a distance of 61 m (200 ft) is more appropriate. Both Figures 4 and 5 show that the distribution of the SEAMS data is more conservative than the distribution of the field data. The entrance angles from SEAMS are greater from the lowest percentile to approximately the 80th percentile. In the upper range, 80th percentile and above, the SEAMS and field distributions parallel one another. Since this is the range of interest for the maximum entrance angle requirement, the SEAMS data reasonably represent the greatest entrance angles.

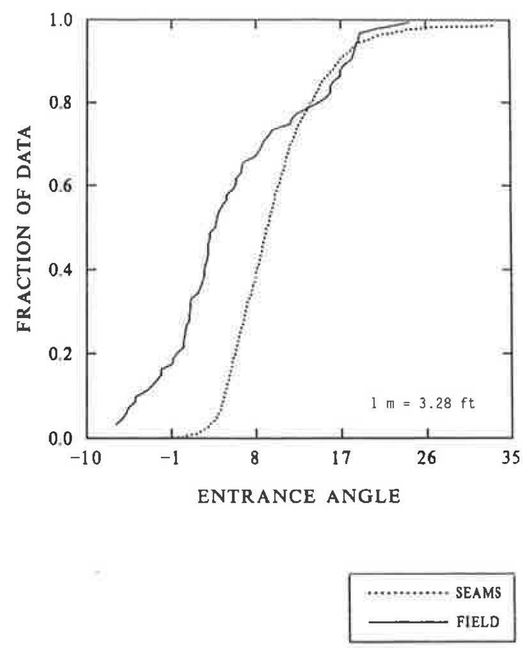

FIGURE 4 SEAMS versus field data at 30.5 m.

The assumption of SEAMS that the plane of a sign is at a right angle to a point on the roadway shoulder line was examined in the field. Normally, signs should be mounted approximately at right angles to the direction of, and facing, the traffic that they are intended to serve. They should be turned slightly away from the road to avoid the specular reflection (in which drivers would see their headlights by mirror reflec-

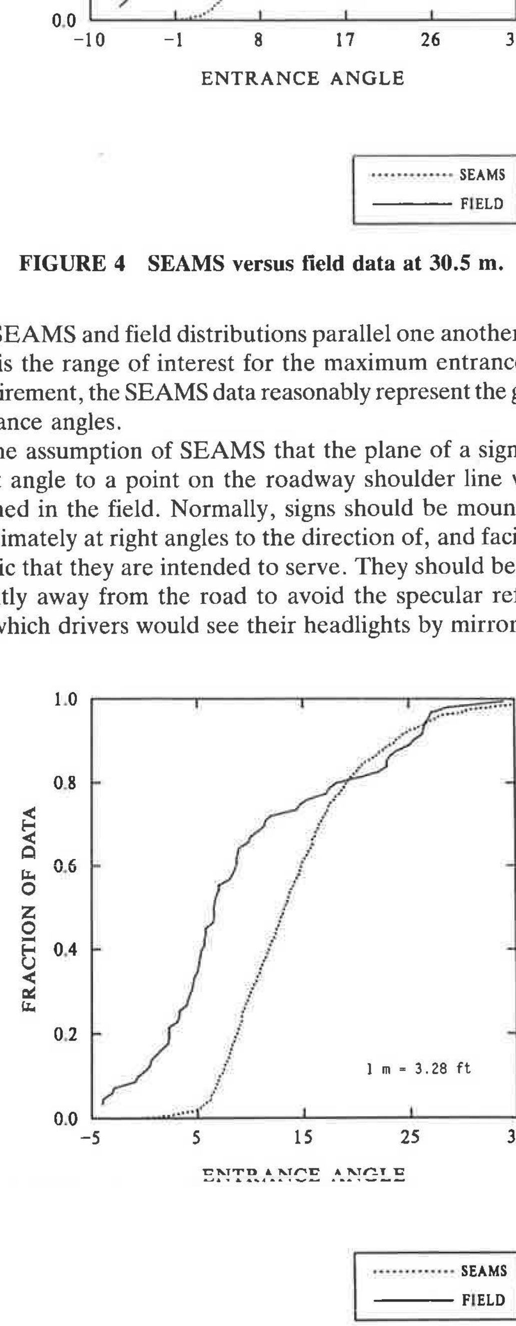

FIGURE 5 SEAMS versus field data at 61 m.

tion on the front surface of the sign sheeting) (8). An estimate of the degree of skewness from the perpendicular was made for each sign in the field. The SEAMS assumption that signs are at a right angle was found to be incorrect for a significant number of signs in Connecticut. Twenty-three signs were estimated to be skewed greater than ±10 degrees to the perpendicular of the roadway. Table 3 shows a comparison of the data at 30.5 m (100 ft) and 61 m (200 ft) between all signs and all signs estimated in the field to be skewed 10 degrees or greater to the perpendicular of the roadway. The majority of the differences between the field and SEAMS data are 5 degrees or less. The largest discrepancies exist between the signs that were measured in the field to be skewed greater than ±10 degrees to the perpendicular of the roadway. This signifies that when the assumptions of SEAMS are satisfied, one can have greater confidence that the results from SEAMS truly represent actual entrance angles that can be found on the nation's highways.

In addition to verifying SEAMS in the field, the repeatability of the SEAMS data was studied. Entrance angle data for 1989 and 1990 were compared to see if measurements can be reproduced over time. Connecticut collects new pictures and highway geometric data each year. Fifteen signs were examined, and discrepancies were found to be 2 degrees or less.

CONCLUSION

The study reported here obtained empirical data that can be used to establish a maximum specification for entrance angles of retroreflectorized traffic signs. Data were collected for a wide range of urban and rural conditions. SEAMS provided a quick and easy method to collect entrance angles on over 1,100 signs. The study results indicate that the current maximum entrance angle requirement, 30 degrees, includes a margin of safety to compensate for signs that are twisted, poorly placed to alignment, bent, or leaning out of plumb. As a general entrance angle specification, 30 degrees is valid. However, the data indicate that a lower specification, 20 degrees, could be used for signing on freeways with no adverse effect. Only 3 freeway signs of the 599 freeway signs measured (0.5 percent) have entrance angles greater than 20 degrees. There are also cases on nonfreeways where a 30-degree requirement is unwarranted. It is important that a jurisdiction examine the signing on their roadways to determine the potential for very high entrance angles before deciding on what maximum specification to use.

The research results from SEAMS are conservative and reasonable for the following reasons:

1. The results are based on a large sample of signs (1,142);
2. The sample selected is representative of the nation, accounting for differences in sign classes, sign placements, roadway types, and so on;
3. All measurements were calculated at the average minimum last-look distance;
4. All measurements were calculated at the point on the sign furthest from the roadway;
5. All measurements were calculated from the lane furthest from the sign except in special cases; and
6. Comparison of the SEAMS and field distributions shows that SEAMS parallels the upper range of the field data, which is the range of interest in this study.

It is believed that the data collected in Connecticut reasonably represent that which can be found in other states. Highway design and geometric characteristics of freeways across the nation are relatively standard. Although the nonfreeway system is not as standard as the freeway system, the results are based on measurements taken at distances very close to the sign and therefore are believed to be representative of the conditions found elsewhere. In addition, since a conservative approach was taken in the measurement of the entrance angle, a factor of safety exists to account for greater sign entrance angles that might exist on other states' nonfreeways.

Although it is believed that the results reported here are representative of the overall conditions encountered by the driver, it is recognized that there are cases where sign entrance angles are over 30 degrees and in special situations they are significantly above 30 degrees. In the authors' opinion, it is not a prudent approach to expect the specification to cover all of these cases. It is incumbent upon the engineer to find other site-specific solutions, such as the installation of supplementary signing.

Although SEAMS was developed for use in the measurement of sign entrance angles, numerous other applications of the technology are envisioned. Currently, two efforts are under way. A videodisc-based sign inventory is being developed to allow users to relate signs to photolog images and use a mod-

TABLE 3 Differences Between the SEAMS and Field Data

		Difference			
Distance	Signs	0°-5°	5°-10°	10°-15°	15° - +
30.5 meters	All signs	48	18	8	3
	All signs > 10° to perpendicular of roadway	8	6	6	3
61 meters	All signs	50	19	4	4
	All signs > 10° to perpendicular of roadway	10	7	3	3

1 m = 3.28 ft

ified version of the SEAMS program to measure sign sizes directly from videodisc. A second effort is generalizing the SEAMS concept for use in measuring heights, offsets, and longitudinal distances. This generalized measurement system has the potential for measuring sign sight distance, passing sight distance, vertical clearances, roadside hazard locations, and many parameters.

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