Exact Road Geometry Output Program for Retroreflective Road Sign Performance

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The angles used for the laboratory testing of retroreflective sign sheeting that are set forth in specifications are well defined and are well understood in the laboratory test setting. Not well known is exactly what values of these angular parameters, especially observation angle, occur for actual signs on the roadway. The mathematics for a complete vector structure incorporating the location data for headlamps, driver's eye, the sign, and the vehicle-to-sign (road) distance has been set up. These inputs define all locations exactly; there are no assumptions. The mathematics has been incorporated into a computer program, ERGO (Exact Road Geometry Output), which computes the exact angles at which the sign is actually seen by approaching drivers. The observation angle for actual signs is shown to be two separate values—one for each headlamp—and not simply the eye height over the headlamps. Eye setback is also shown to be a critical factor under some conditions. The ERGO data demonstrate that observation angle is a direct function of road distance: as road distance becomes less, observation angle becomes greater. Specific observation angles correspond to specific road distances. Graphs of the observation and entrance angle correlates are given for STOP and near-roadside signs, overhead guide signs, and signs at a large offset from the road edge. The effect of different size vehicles on observation angle is shown. The relationship of time to observation angle is demonstrated: as the approaching driver observes a sign at observation angles greater than 0.5 degree, these angles are traversed in fractions of a second. Both the ERGO program and its mathematical basis will be made available to others so that it can be applied to other experimental and theoretical data to better correlate laboratory test values and actual road performance of retroreflective material.

Road signs at night require some minimum level of luminance in order to be seen effectively and in time by an approaching driver who is dependent on reading such signs for certain essential information. Retroreflective sheeting is used on road traffic signs as a means to provide this luminance in the absence of internal or external illumination. Specifications for minimum reflectivity values in laboratory tests of this sheeting have the ultimate objective of providing the required level of effective performance (i.e., luminance) for such signs at the distances and for the time that the driver requires. The efficiency of retroreflective sheeting is specified by setting reflective efficiency (coefficient of retroreflection) values (R_A) for certain laboratory test points determined by designating values for those angular parameters that have been carefully defined for laboratory tests (1; ASTM Standard E808-91; AASHTO Standard Method of Test T257-86). The angular parameters that are recognized as the primary determinants of reflective efficiency and are set forth in every specification are observation angle and entrance angle. These angular pa-

rameters must be carefully determined and accurately set up in the laboratory to ensure accurate and valid measurements of the reflectivity (as well as to achieve correlation between laboratories). An R_A-value associated with a certain reflective sheeting has meaning only in the context of the *pair* of these angular values at which it is measured: one exact observation angle and one exact entrance angle. (The "one entrance angle" may be defined by the two angular coordinates B_1 and B_2, which, taken together, define a single entrance angle condition.) These angles are well defined and well understood for laboratory test purposes. What is not well understood is what the actual observation and entrance angles are that occur on the roadway in specific sign situations. How are these angles determined for actual road signs seen by the driver of a vehicle? How do these angles change as the vehicle approaches the sign? What angular values are important to a driver approaching a particular sign? How are these values different for drivers of different types of vehicles?

In a recently published National Cooperative Highway Research Program (NCHRP) Report (2), it was pointed out that the federal standard (then FP-85) does provide minimum specific intensity per unit area (SIA) (R_A) standards for new material. These standards, however, were developed by sheeting manufacturers as purchase specifications, not based on drivers' needs. Therefore, in order to set a new standard for sheeting based on the driver's actual minimum visibility requirements, the report stated:

> The FHWA project on 'Minimum Visibility Requirements for Traffic Control Devices,' is to determine the minimum visibility distances for signs and markings. Based on these minimum visibility requirements, it will be possible to determine the retroreflectivity necessary to make a sign or marking visible at a given distance.

A parallel effort is under way by the European Committtee for Coordination of Standards CEN to develop a standard based on the luminance requirements for reading actual road signs. This effort is equally dependent on accurate values for the observation and entrance angles at which those signs are actually seen by drivers if it is to arrive at specification values that correlate with the actual performance as planned.

A method is needed that can readily provide accurate observation and entrance angle correlates for given sign situations and at different viewing distances. These measurement parameters can then easily be included in study data and considered in arriving at conclusions relating reflectivity levels and other variables. Although some researchers may be computing these values accurately, the basis of such values is never certain and almost never is it adequately described.

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Thus computational error or the dimensional basis cannot be determined or verified. A search of the literature reveals no data on any such method generally available to accurately determine these angular values. There does not appear to be any detailed compilation of these values for actual road sign locations and viewing distances.

Consequently, the computer program ERGO (Exact Road Geometry Output) has been developed to determine the exact observation and entrance angle correlates that actually occur for signs and traffic control devices at different locations and distances, as well as values for several other angular parameters of retroreflectivity. ERGO is available at no charge to qualified personnel interested in the use or study of retroreflective sheeting. Its structure and formulas are available for analysis and proof. It can be used as a common reference for other experimental data.

The data obtained with ERGO are discussed in this paper. Summaries in the form of graphs of the observation and entrance angle correlates for some typical signs are shown. These "applications" of ERGO data illustrate how the data can be useful in studying how the angular parameters change in real road sign situations. In turn, this may be essential in the determination of valid measurement values for minimum levels of retroreflectivity. Given a sufficient range of retroreflectivity data, the program may be used to accurately compare the efficiency of different retroreflective materials for particular applications.

ERGO OPERATION

To calculate the exact road geometry, a simple mathematical vector structure was created together with the formulas to compute all angles precisely and accurately. The computer program was written to accommodate all dimensions in the three coordinate planes that prescribe the locations of the different elements and, in turn, the retroreflective geometry of a specific road sign situation. The program then computes the defined angles determined by those inputs. (The complete mathematical analysis of the vector structure and the derivations of the defined angles by D. Couzin are available on request from the author.)

ERGO easily determines exact, not approximate, retroreflective geometry for any set of input data desired. Each set of correlates generated by this program is specific to the one corresponding set of input dimensions that exactly locate the eye, headlamps, and sign relative to each other. The values are absolute; the only subjectivity is in the selection of the input dimensions, or range of dimensions, to represent any generic designation such as typical STOP sign, large-offset guide sign, standard car, and so forth.

The parameters of location for car headlamps, driver's eye, and sign location that are inputs for ERGO are as follows (all input dimensions are entered in meters or, in an alternative menu choice, a version is available in which all inputs are in feet):

ROAD DISTANCE to Sign: _____
SIGN: Offset from Road Edge: _____
              Height above Roadway: _____

VEHICLE DIMENSIONS (STANDARD CAR):	Meters	Feet
Separation between headlamps	1.042	3.42
Headlamp height over roadway	.661	2.17
Eye height over headlamps	.466	1.53
Eye setback behind headlamps	2.057	6.75
Eye displacement left of vehicle centerline	.330	1.08

Dimensions were measured for a wide variety of vehicles in many models. The dimensions above are the mean of a relatively narrow range of data for compact and mid-size cars and thus well represent the universe of such cars. These mean values have been dubbed the "standard car" and are included as default values in ERGO. Of course, any values can be entered to override the defaults. Separate dimensions were determined for such vehicle groups as large cars, small vans, large vans [recreational vehicles (RVs)], and large trucks with maximum eye-headlamp displacements, dubbed "MAX trucks."

OBSERVATION ANGLE: LABORATORY AND ROAD DEFINITIONS

An accurate understanding of the observation angle is critical both to understanding the effects of the different inputs on the geometry and to using the output data correctly. For laboratory test purposes, observation angle can be defined as follows:

The angle that is formed at the reference center on the test sample between a line to the light source (the illumination axis) and a line to the receiver (observation axis) (see Figure 1a).

It is useful to observe that its measure is a function of the displacement distance from the light source to the receptor (measured perpendicular to the illumination axis) and the distance measured along the illumination axis. This is as defined (in slightly different terminology) in ASTM E808-91.

In the actual road situation where the driver of an approaching vehicle observes a road sign illuminated by the car's headlamps, determining the observation angle at which the sign is seen is a bit more complicated. In the literature, even as recently as the reports by Black et al. (2) and by McGee and Mace (3), the observation angle for the driver has consistently been presented as if it were simply the vertical displacement of the eye above the level of the headlamps. However, this is not correct.

Note that in Figure 2a (which diagrams the eye-headlamp relationships for the standard car), the vertical distance down from the eye is a dimension from the eye to nothing.

In truth, the observation angle, whether it is measured in the laboratory or on the road, is the angle intercepted (at the particular road or test distance) by the straight-line displacement of the receptor (or eye) from the light source illuminating the reflector sample or sign. In the road situation, the receptor is the human eye; the two eyes are sufficiently close together that they can be considered one point at the centerline of the driver. The light source is a headlamp.

Unfortunately for the cause of simplicity, (a) there are two headlamps, that is, two separate light sources illuminating signs; (b) the headlamps are unequally displaced on either
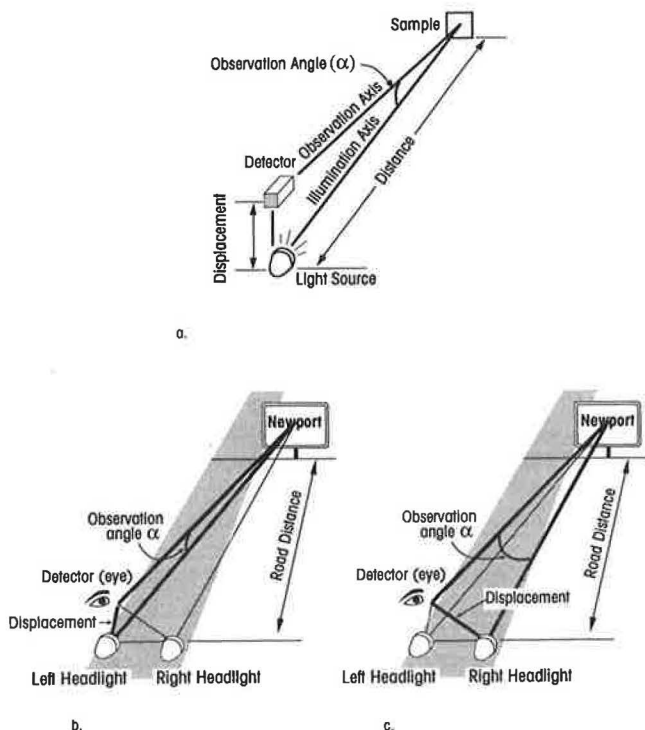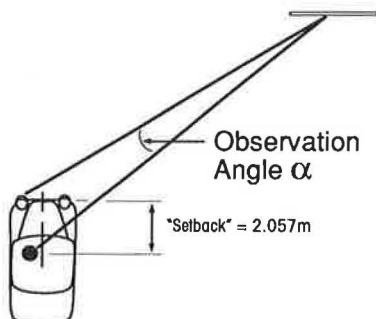
FIGURE 1 Observation angle: (*a*) laboratory test setup per specifications; (*b*) road to left headlamp; (*c*) road to right headlamp.
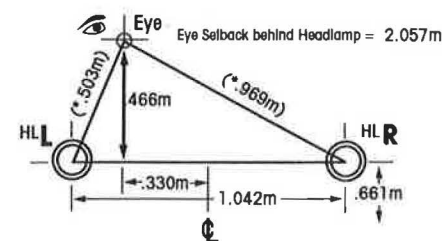
*Not an ERGO input value but shown for the "Standard Car."

(1 meter = 3.28 ft.)

FIGURE 2 Vehicle dimensions in ERGO (primarily affecting observation angle): (*a*) standard car dimensions; (*b*) setback dimension and effect on observation angle.

side of the driver; and (*c*) the headlamps are at a substantial separation. This means that in order to be accurate and mathematically specific, two different observation angles are in effect for each road sign situation. One is the angle intercepted by the displacement to the left (driver's side) headlamp and the other is the angle intercepted by the displacement to the right headlamp. [The necessity of computing the angles to each headlamp separately has also been recognized by Johnson (*4*).]

Figure 1b (to left headlamp) and Figure 1c (to right headlamp) illustrate how these two observation angles are formed between the respective headlamp, the eye, and the sign. Note the correspondence of the elements to the laboratory setup (Figure 1a).

Another factor, which appears to have often been overlooked, can also substantially complicate observation angle calculations under certain conditions. It is automatically included in ERGO's complete computation. This involves the setback distance. In all vehicles the eye is set back behind the headlamps by a substantial distance; the standard car setback averages 2.06 m (6.75 ft). For a driver viewing signs at very small offsets (off the road) and at substantial distance, the setback occurs more or less parallel to the observation axis and thus does not enter into the determination of the observation angle.

However, as a vehicle approaches close to a sign that is substantially offset to one side or the other, or as it turns away from the sign even slightly, as on a curved approach, the setback becomes an increasingly significant component of the eye-headlamp displacement that produces significantly larger observation angles. The rate of increase accelerates at very close distances, producing extremely large observation angles, sometimes even completely out of the effective range of retroreflected light. The principle is illustrated in Figure 2b.

APPLYING ERGO DATA AND DATA SUMMARY GRAPHS

Analysis of data from ERGO can yield substantial information on how retroreflective signs are actually seen. It can be used to determine which observation and entrance angles should be specified for any particular application. As a part of studies of the parameters of effectiveness of signs—legibility distance, detection distance, and so on—it can be useful in indicating where effective retroreflectivity is required, namely, at the observation angle that corresponds to some determined distance having an important function.

The few graphs summarizing ERGO-derived data shown here illustrate how some useful principles can be deduced. Following are a few guidelines for interpreting the ERGO data presented here.

First, plots of angular data can apply to many different sizes and types of signs if the signs are mounted at offsets and heights similar to those shown. However, the point at which a particular sign is usefully seen or detected may not start or end at the endpoints of the plot shown on a given graph. The beginning and end of the useful viewing time for a sign must be independently determined and then the angles corresponding to those distances should be noted.

In using ERGO to evaluate the performance of a given material for a particular type of sign, certain criteria should be separately evaluated: (*a*) the distance at which a particular sign needs to be detected, (*b*) the distance at which it should be read, (*c*) the span of distance during which it continues to be usefully read (and thus also the reading "time" based on a given approach speed), and (*d*) the distance between the approaching driver and the sign when the driver can no longer be expected to read the sign or no longer needs the information. Then, using ERGO, the observation and entrance angle correlates should be noted for those various determined distances.

In the opinion of this author, a determination should also be made in using the above series of data points, although its evaluation is not strictly a part of geometry-limited ERGO. It applies to reflectivity values (and luminance data, if available) at the "far" and "near" limits, especially in the selection between materials of different characteristics. This determination is whether the sign luminance at the far distance limit is less than, more than, or equally as important as that at the near distance limit (at which the sign viewing is actually terminated). Note that the near distance limit is reached after the sign has been observed and read during the entire span of time after the initial reading until reaching the near limit.

ERGO DATA OUTPUTS

The ERGO program output provides values for all the defined angles of retroreflectivity that the input values determine. An example of the actual output for a single road sign situation as reported by ERGO is shown below:

	Left Headlight	Right Headlight
Alpha (α)	0.33	0.52
Beta (β)	2.97	2.42
Gamma (γ)	39.29	121.09
Epsilon (ϵ)	29.98	−56.89
Omega (ω)	69.24	64.23
Beta 1	2.30	−1.25
Beta 2	1.88	2.07
Beta V	1.05	1.05
Beta H	2.78	2.18

In this example, the inputs defined a point on a sign that is offset 2.5 m (8.2 ft) from the edge of the road at a height of 2.5 m (8.2 ft) viewed from the standard car at a road distance of 100 m (328 ft). Output values of ERGO are given for the geometric parameters, which are defined for the laboratory test setup by ASTM E808-91. Two other parameters have been created for the road situation only. The geometric parameters output by ERGO are as follows:

Alpha: Observation angle
Beta: Entrance angle
Gamma: Presentation angle
Epsilon: Rotation angle (ASTM E808-91)
Omega: Orientation angle (ASTM E808-91)
Beta 1: Entrance angle component as defined
Beta 2: Entrance angle component as defined

Apply to ROAD environment ONLY: (not ASTM, not prior CIE)

Beta V: Entrance angle vertical component
Beta H: Entrance angle horizontal component

The analyses in this paper are principally concerned with the observation and entrance angle values, but other values can be important to laboratory tests or specifications intended to correlate with actual road performance, or to both.

The ERGO data presented in the balance of this paper consist of the observation and entrance angle outputs for particular signs over a range of approach distances. These data present the range of these angles that actually occurs for given signs as seen by drivers of approaching vehicles. The data are presented in graphs that plot observation angle (on the vertical scale) against road distance (on the horizontal scale). Since road distance is linear, it is very important to note that the plot is also one of time, given a specific vehicle approach speed. Since the driver's information and decisions are primarily defined by time, this type of graph best represents the rate of change in observation angle as the observing vehicle approaches the sign. Shown below the graphed data is the time in seconds before the vehicle passes the sign at various distances and for speeds of 50 kph (30.1 mph), 75 kph (46.6 mph), and 100 kph (62.1 mph).

Of course, there is an entrance angle correlate for every observation angle in the data. In the lower right-hand corner of most of the graphs is a separate plot of entrance angle against the common horizontal road distance scale. The scale for increments of entrance angle is the short vertical scale along the lower right side of the graph. To avoid confusion with the observation angle plots, the entrance angle output is only plotted when it exceeds 5 degrees. This is acceptable because any entrance angle of 5 degrees or less is considered equivalent to zero degrees. In fact, sheeting is actually tested at 4 or 5 degrees to avoid front surface reflection. The entrance angle plots are short because entrance angle does not exceed 5 degrees until the approaching vehicle is very close to the sign.

An alternative type of graph would plot observation angle against entrance angle. Thus, that plot is the compilation of specific sets of correlates of observation and entrance angles. The correlates of any specification can also be shown as specific points. This type of graph provides the best comparison of specification test points with the actual geometry, especially for unusual or extreme situations.

Road distance can be marked on the actual plots on this second type of graph but it is very nonlinear, with increments of distance very compressed for the longest distances and then increasing to longer and longer spans as the vehicle approaches the sign.

ERGO DATA GRAPHS

Several graphs summarizing ERGO-produced data are shown. The examples were selected to demonstrate a variety of circumstances in which the data from this program can be useful. Analysis of the summarized and plotted data for particular signs can reveal important relationships between the angular

variables (primarily observation angle) and other variables (primarily road distance).

STOP Signs and All Near-Roadside Signs

STOP signs have very specifically defined locations, one component of which is very small offsets from the road edge. In Figure 3, the solid-line plots represent a minimal urban offset of 0.6 m (2 ft). The dashed-line plots represent a large rural offset of 3.65 m (12 ft). The majority of right-edge roadside signs are located within this range.

The plots, virtually identical for either offset, demonstrate that this difference in offsets has essentially no effect on the observation angle value. The data also show that the mean entrance angle is only 13 degrees, even for the larger offset when the approach distance is only 25 m (82 ft) and the mean observation angle is 2.2 degrees.

Zwahlen (5) has shown that drivers approaching a STOP sign looked away from their final viewing ("last look") of the STOP sign at a mean distance of 47.6 m (156 ft) for the worst condition studied and this was after they had viewed the sign

for 148 m (484 ft); presumably they no longer needed the information. Thus the effective distances for STOP signs involve observation angles of 1 to 0.5 degrees and entrance angles of 10 degrees or less.

Overhead Sign

Figure 4 is the plot for an overhead sign centered over the driver's lane at a height of 7 m (23 ft). Overhead signs are mounted at a very limited range of locations relative to the driving lane, which requires them to be considered a significant and separate category. They are always designed to be read at significant distances, and their fixed position above observing vehicles and perpendicular to the vehicles' direction determines that the observation and entrance angles differ very little from site to site. Assuming initial detection in the range of 200 to 300 m (656 to 984 ft) for a very significant span of time after initial detection and viewing, the observation angle in effect for the approaching driver is very small; the entrance angle is negligible. More than any other type, this sign functions during its useful viewing distance at very
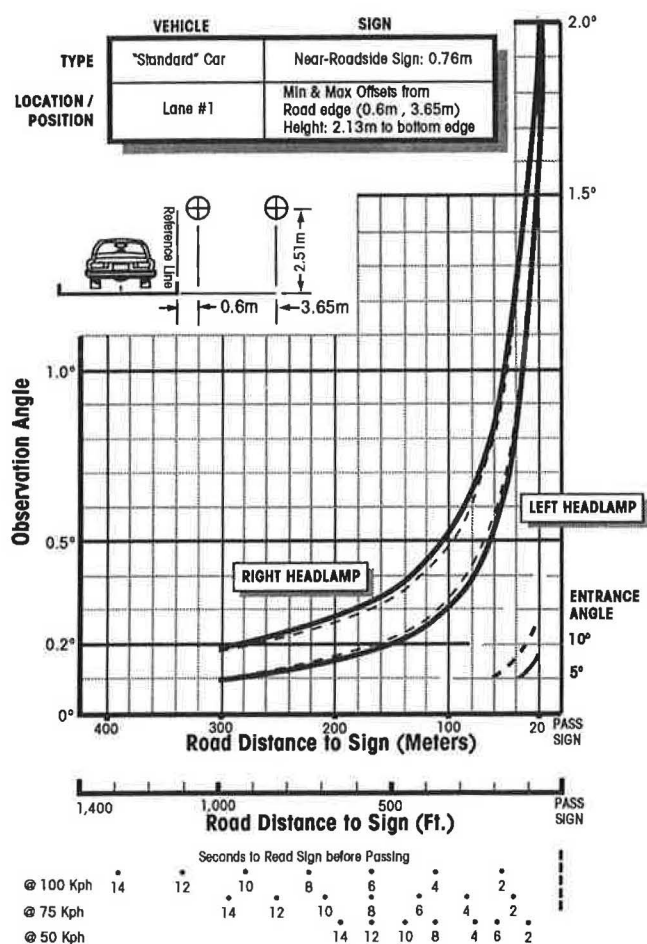

FIGURE 3 Observation angle versus road distance for STOP signs and all near-roadside signs, regulatory and other. Entrance angle shown where 5 degrees or more (to lower right vertical scale).
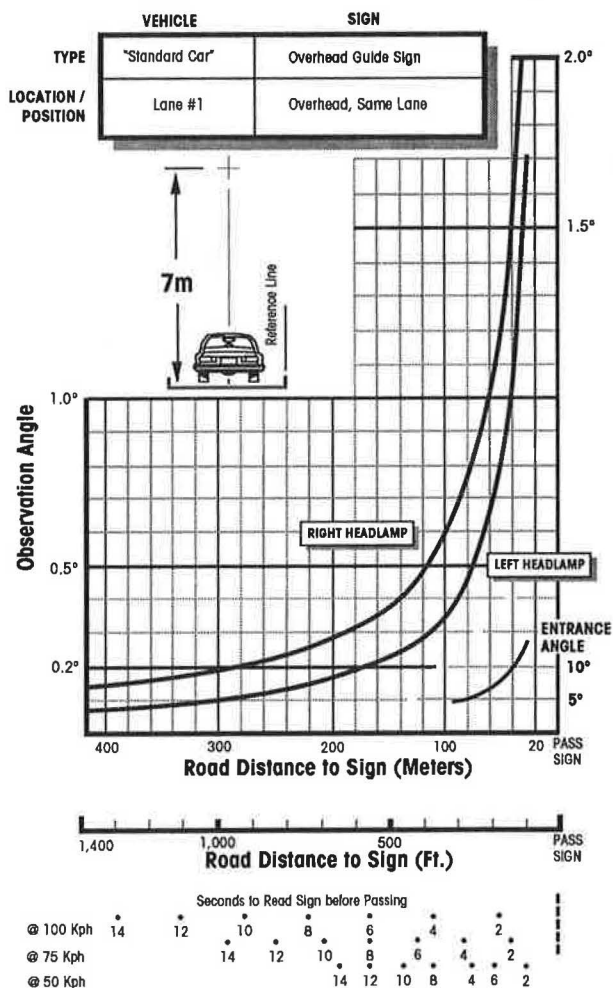

FIGURE 4 Observation angle versus road distance for overhead guide signs. Entrance angle shown where 5 degrees or more (to lower right vertical scale).

small observation and entrance angles. As close as 30 m (98 ft), where the observation angles are about 1.5 degrees and the driver has probably terminated viewing of the sign, the entrance angle is still only 13 degrees.

Large-Offset Signs

Figure 5 shows the observation and entrance angle correlates both to the center of a very wide sign [5.5 m (18 ft)] and at a very large offset from the road edge [9.1 m (30 ft)]. Thus the entrance angle computations are to a point offset 14.6 m (48 ft) from the road edge at a height of 3.34 m (11 ft). Note that for signs at such a large offset, the observation angle curves for left and right headlamps cross over as the line of sight passes over the right headlamp when the vehicle is close to the sign.

Comparison of Vehicles with Different Eye-Headlamp Displacements

Figure 6 is a comparison of the differing observation angles at which drivers of certain types of vehicles with different eye-headlamp displacements view typical road signs at successive approach distances. The vehicles represented are as follows:

1. "Standard car" represents the mean dimensions of the compact, mid-size, and medium cars. The majority of cars fit well into this category.

2. "Large car" represents the mean dimensions of cars such as the Lincoln Town Car, the Chevrolet Caprice (mid-1980s style), and similar cars. Cars in this category are rapidly disappearing.

3. Large vans (RVs).

4. "MAX truck" represents the approximate dimensions of the largest truck-tractors with a maximum eye height of about 2 m (6.6 ft) above the headlamps.

Actually, of course, there is a continous range of trucks having various eye-headlamp displacements so as to create a continuum of plots of observation angle from that shown for large vans to that shown for the MAX truck.

[Note: To avoid having to present excessive data on one graph, only the observation angle data for the left headlamp are shown. The sign position used for the ERGO computations is offset from the road edge by 6.08 m (20 ft) and at a height of 2.13 m (7 ft). Changes in vehicle parameters have no effect on the entrance angle; therefore no entrance angle data are shown.]
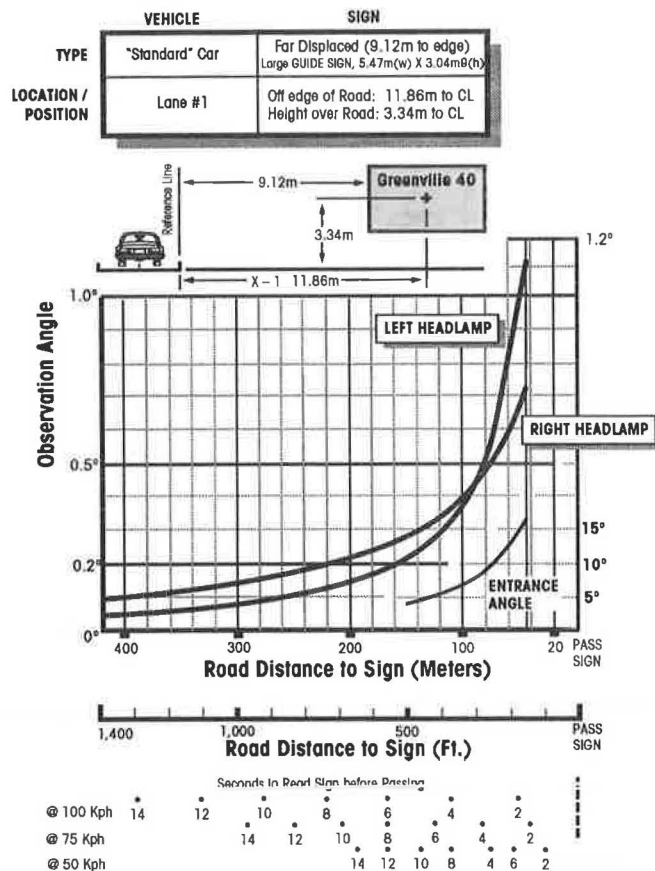

FIGURE 5 Observation angle versus road distance for signs at large offset from highway. Entrance angle shown where 5 degrees or more (to lower right vertical scale).
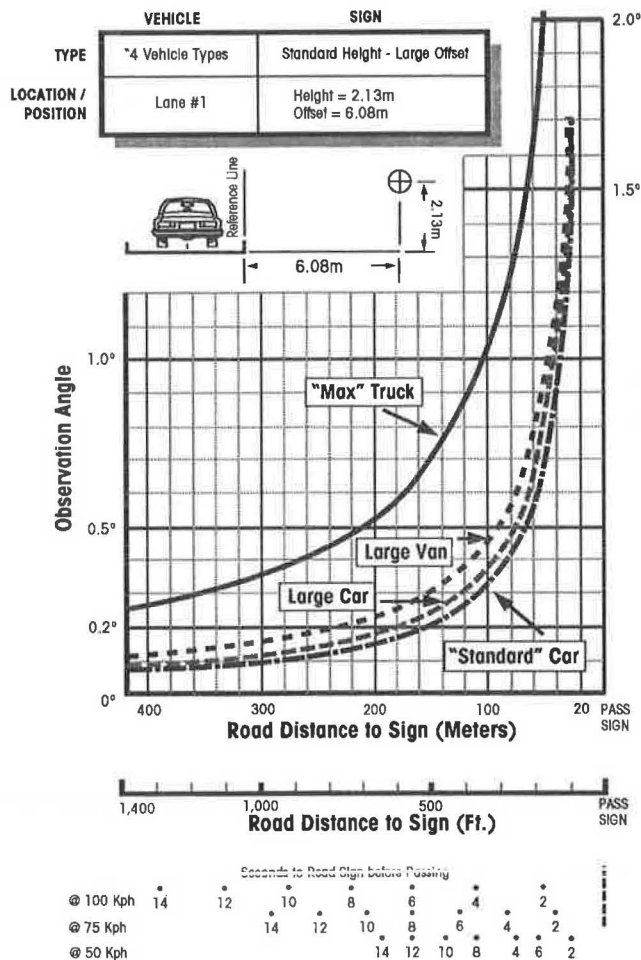

FIGURE 6 Observation angle versus road distance from different vehicles (left headlamp only) to same sign; right side, 2.13 m high.

RETROREFLECTIVE SIGNS: EFFECTIVE PERFORMANCE PRINCIPLES

Some significant principles relating to the effective performance of retroreflective sheeting on road signs can be noted in or deduced from ERGO data. The data developed in ERGO can also be a valuable addition to other experimental data and observations in correlating particular charateristics of reflective sheeting performance with the effectiveness of road signs at night. The four ERGO graphs relating to the geometry of signs (Figures 3–6) apply to and demonstrate the points discussed below. The graphed data are from ERGO calculations.

The most important determinant in the performance of retroreflective sheeting materials for any given application is the direct (although nonlinear) relationship of observation angle and road distance:

1. A specific observation angle value equals a specific road distance (for a given vehicle).
2. Observation angle increases as road distance decreases.

As shown on the three plots of ERGO data for different signs (Figures 3–5), the observation angle is very small (about 0.1 degree) when the road distance is as long as 280 m (919 ft) or more. As the vehicle approaches the sign from a great distance, the observation angle changes very slowly. Depending on the vehicle speed and the size of the sign, the approaching driver may see the sign for 10 sec at 0.1-degree observation angle. The observation angle begins to change more quickly as the driver passes 0.2 degree at 156 m (512 ft) to the sign. If the rate of travel is 75 kph, only 3 sec will elapse before the driver reaches 69 m to the sign and a 0.5-degree observation angle. Now the angle is changing rapidly: in only 1.5 sec the driver is at a 1.0-degree observation angle and in 0.8 sec at a 2.0-degree observation angle. ERGO computations show that at 2.0 degrees nominal, the driver passes through 1.3 degrees of observation angle in 0.5 sec (1.5 to 2.8 degrees).

Table 1 gives carefully computed road distance values corresponding (exactly, for the left headlamp) to the specific observation angle test points of various specifications. Also shown is the time before passing the sign and the time before the next given test point. The data are computed for geometry

to a point on a sign offset at 2.5 m (8.2 ft) and at a height of 2.5 m (8.2 ft) viewed from the standard car.

The purpose of the summary in Table 1 is to provide an easy reference for the sign distances that correspond to particular observation angle test points. The left headlamp is used because it is generally the primary source, the observation angle for the right headlamp being generally larger. Table 1 is applicable to virtually all sign displacements (both offset and height).

All the plots of observation angle versus road distance (Figures 3–6) display this reality: observation angle is a direct function of road distance. Since the displacement distance from a headlamp to the eye is relatively fixed until approach distances quite close to the sign are encountered, the relationship is direct and occurs within a very narrow range for all cars and even for small trucks. In other words, a specific observation angle defines a specific distance to a sign. It follows that studies attempting to accurately correlate distance with some measure of actual sign performance (detection, legibility, etc.) for any or for several retroreflective materials and to draw conclusions from their data must recognize this relationship: different road distances involve different observation angles. For example, an R-value at 0.2 degree cannot correlate with performance at 60 m (197 ft), since at that distance the observation angle is about 0.6 degree. Review of test data (6) for different materials reveals that the relationship between materials at 0.2 degree is substantially different from the relationship between them at 0.6 degree. The objective of arriving at valid conclusions from these studies requires taking into account the actual observation angles that occur on the road as revealed by ERGO. The effective application of this method would require having reflectivity (R_A) data at all observation angles, that is, an observation angle curve (0.1 to 2.0 degrees at least).

Therefore, it would also follow that different retroreflective materials cannot be accurately characterized or referenced by a single R_A-value, as if the reflected light was an amorphous, uniform blob centered around the light source. This implies that the ratios between these single-number values hold for all road distances. However, test data studied (Stimsonite photometric laboratory data, 1992, unpublished) demonstrate that Material A can be substantially lower than Material B in its 0.2-degree observation angle laboratory values but nevertheless produces higher sign luminance than Material B at certain distances (7). Nevertheless, the use of single values is quite common in characterizing the relative retroreflectivity of materials.

Reflectivity values at the very small observation angles correspond to the longer distances and thus determine initial detection and overall reading time for most signs. Equal sign luminance is not equally important at all road viewing distances. In order to provide adequate reading time and so forth, which includes all the considerations that are used to select the size of a sign and its legend for daytime viewing, the distance at which initial detection and subsequent "primary" reading of a sign occur is the most important distance to see a sign, day or night. This distance involves correlates of very small observation and entrance angles. Subsequent continued reading as the driver approaches close to the sign at large observation angles must be, in the author's opinion, far less "necessary." Note the distances given by Zwahlen at which drivers no longer looked at the signs.

TABLE 1 Observation Angle Nominal Points (Exact for Left Headlamp) Versus Road Distance and Travel Time at 75 kph

Observation Angle Specification Points (degrees)	Distance from Sign (m)	Time Before Passing[a] (sec)	Distance and Time to the Next Observation Angle	
			Distance (m)	Time[a] (sec)
0.1	306	14.6	148	7.1
0.2	156	7.5	57	2.7
0.333	99	5	30	1.4
0.5	69	3.3	30	1.5
1.0	38.7	1.8	10.5	0.5
1.5	28.2	1.3	5.5	0.3
2.0	22.6	1.1		

[a]At 75 kph.

In addition to the common angles (observation and entrance angles), which have been emphasized in the data derived from ERGO and presented in this paper, ERGO data can also demonstrate what changes do or do not actually occur for the other angles of retroreflective geometry at different distances for a variety of sign locations. These other angular parameters also have an effect on the effective R_A-value and on actual road performance. ERGO data collected for this study for signs at various locations show that if a given material that is rotationally nonuniform is mounted with a uniform predetermined material orientation for all signs, it will simply result in maximum performance of the material at some sign locations and minimal performance at others. True orientation values range from -90 degrees to +90 degrees for actual signs.

CONCLUSIONS

The ERGO program data developed by users in support of their study requirements can contribute to the knowledge of the characteristics of effective performance of retroreflective sheeting on road signs. Since the values are absolute, they can contribute to valid conclusions from data relating study variables and retroreflectivity. Thus, soundly based and accurate data can replace blanket applications of simplistic beliefs about what geometries fully characterize the effective performance of retroreflective sheeting for road signs.

ERGO can be applied by users to any road viewing situation and any viewing distance. Successive increments of selected variables can be entered, the output geometry determined, and the resultant change in the correlates of observation and entrance angle can be evaluated. To that data, R-values resulting from laboratory tests at exactly the sign correlates given by ERGO can be added for a more accurate comparison of different retroreflective materials.

It is hoped that ERGO will be useful to those studying the application of retroreflective materials and that it will contribute to the accurate use of retroreflectivity data with other visibility parameters to promote the development of accurate and valid conclusions.

The ERGO program, including the complete mathematical basis, will be made available to all interested parties studying retroreflectivity. Requests should be sent to the author.

REFERENCES

1. *Instrumental Photometric Measurements of Retroreflective Material and Retroreflective Devices.* Federal Test Method 370. General Services Administration, March 1977.
2. Black, K. L., et al. *NCHRP Report 346: Implementation Strategies for Sign Reflectivity Standards.* TRB, National Research Council, Washington, D.C., 1992.
3. McGee, H. W., and D. L. Mace. *Retroreflectivity of Roadway Signs for Adequate Visibility: A Guide.* Report FHWA/DF-88/001. FHWA, U.S. Department of Transportation, 1987.
4. Johnson, N. L. Measuring the Appearance of Retroreflectors by Application-Oriented Goniophotometry. In *Review and Evaluation of Appearance: Methods and Techniques,* ASTM STP-914, Philadelphia, Pa., pp. 49–61.
5. Zwahlen, H. T. Stop Ahead Signs and Their Effect on Driver Eye Scanning and Driving Performance. In *Transportation Research Record 1168,* TRB, National Research Council, Washington, D.C., 1988, pp. 16–24.
6. Woltman, H. L., and T. J. Szczech. Sign Luminance as a Methodology for Matching Driver Needs, Roadway Variables, and Signing Materials. In *Transportation Research Record 1213,* TRB, National Research Council, Washington, D.C., 1989, pp. 21–26.
7. Zwahlen, H. T., Q. Li, and J. Yu. Luminance Measurements of Retroreflective Warning Signs Under Lowbeam and Highbeam Illumination at Night Using the CapCalc System. In *Transportation Research Record 1316,* TRB, National Research Council, Washington, D.C., 1991, pp. 31–38.