Retroreflective Road Signs: Visibility at Night

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The legibility of retroreflective road markings, and in particular of signs, depends on many parameters, notably the luminance contrast between the message and the ground of the sign. For a given level of illumination, the luminance contrast itself depends on the retroreflection coefficients (R') of the materials used. There are a number of retroreflective products, which have different values of R', on the market. The present study was aimed at determining how variations in R' affect visibility distance (d) at night for a driver at the wheel of his vehicle, the headlights of which illuminate the sign. In the first stage, a small-scale experiment (approximately 1/10th scale) was conducted in the laboratory to identify the variables. Legibility thresholds were determined by presenting different combinations of the alphabets and colors used on road signs to observers at different luminance contrast levels. In the second stage, working from these results, simulations were carried out to quantify the influence of the various parameters, in particular R' and d. It was found that R' is only one of the parameters that affect d. Most often, multiplying R' by 3 increases d by only 30 percent. But the dimensions of the letters used for the messages play a preponderant and limiting role because of their direct relationship to visual acuity. According to earlier experiments, other parameters that are harder to quantify (incident illumination of the signs by vehicle headlamps; dirt on the headlamps, on the signs, on the windscreens; and weather conditions) are important and may require a correction of d ranging from 0 to 100 percent. The results are compared with those of similar studies carried out in the Federal Republic of Germany, the United States, and Japan.

In recent years there have been substantial developments in directional road signs, which must be visible and legible both by day and by night. Such road signs may be internally illuminated bollards, retroreflective signs with or without external lighting, and sometimes still the old enameled or painted sign. In France signs, including overhead ones, with retroreflective film are being increasingly used. Two different types of retroreflective products, Class-I films and the Class-II films, are available on the market. To clarify the importance of the factor "film quality" for sign legibility, a study was undertaken in 1984 in connection with the Organisme National de la Sécurité Routière *(1,2)*.

The luminance of white film on signs lit by vehicule headlights was calculated, and an experiment using observers was conducted to determine the maximum legibility distance, in terms of the calculated luminance levels, for a given height of letter. Simulations using the experimental results were carried out to study the effect of the various parameters, in particular film quality, on legibility distance.

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LUMINANCE OF RETROFLECTIVE FILMS ON SIGNS

The luminance of retroreflective films depends on the retroreflective characteristics of the film and on the degree of illuminance that strikes the sign; both of these parameters are functions of the geometric conditions of lighting and observation.

Geometric Conditions

Two angles determine geometric conditions (Figure 1):

- The angle of observation (α), which is the angle between the lighting and observation directions, and
- The angle of incidence (β), which is the angle between the lighting direction and a line perpendicular to the sign plane.

These angles change with the distance between the vehicle and the sign and with the type of vehicle (truck or light vehicle)

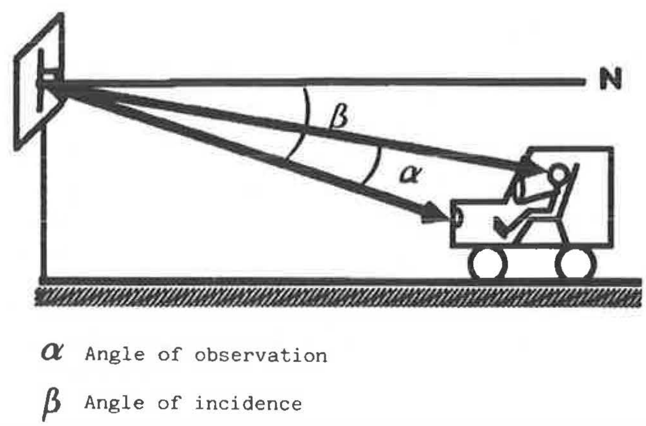

FIGURE 1 Geometric conditions of lighting and observation.

because the height of the observer's eyes varies with these two conditions. Calculations are developed assuming that

- The headlamps are at a height of 0.70 m for a light vehicle and 0.90 m for a truck and
- The observer's eyes are at a height of 1.2 m in a light vehicle and 2.5 m in a truck.

Figure 2 shows this change for an overhead sign. These angles are never large; α varies from around 0.8 to 0.2 degree for a distance of 50 to 250 m in the case of a light vehicle and from

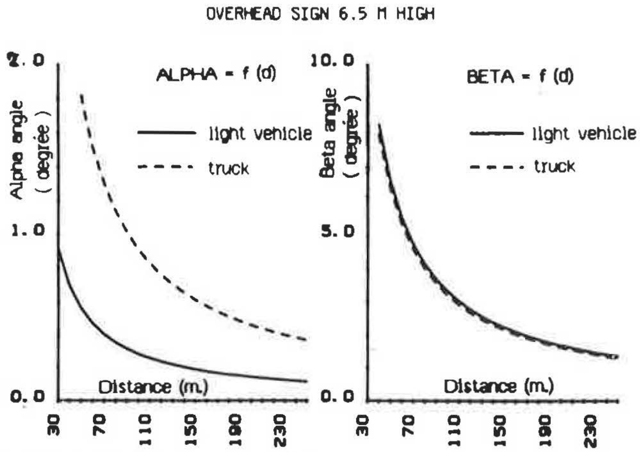

FIGURE 2 Changes in observation and incidence angles white distance between a vehicle (light or truck) and an overhead sign.

1.9 to 0.4 degree for the same distance in the case of a truck. β is identical for a light vehicle and a truck and falls between 7 and 2 degrees when the distance increases from 50 to 250 m for a sign placed perpendicular to the traffic axis. If the sign is placed diagonally across this axis either in a bend or at a crossroads, β is increased by the same amount and may attain values on the order of 40 degrees.

Retroreflective Coefficient

The retroreflective coefficient (RC) defines the intensity of the light reflected per unit of film surface for a certain degree of illumination received. This coefficient varies in terms of β (2 and 40 degrees). A comparison of the performance of a Class-II film and a Class-I film is shown in Figure 3. The Class-I film has the smallest characteristics measured on new film. For a small angle of incidence (β = 2 degrees) and for a small angle of observation (α = 20 min), corresponding to the observation conditions for an overhead sign lit by a light vehicle at 100 m, the Class-II film has an RC approximately three times as large as the Class-I film. For a high angle of incidence (40 degrees), corresponding to a sign placed diagonally across the traffic direction of the vehicle and a small angle of observation (α = 20 min), the ratio between the Class-II film and the Class-I film is approximately 7. Films exist that have intermediate performance characteristics under the conditions studied.

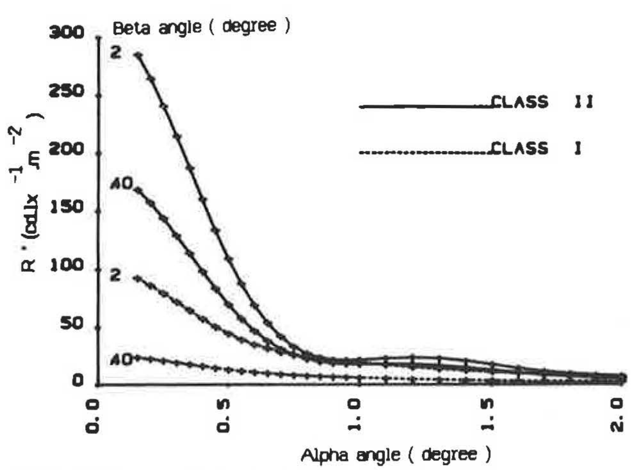

FIGURE 3 Coefficient of retroreflection of Class-I or Class-II white films as a function of the observation angle, for two angles of incidence, β = 2° and β = 40°.

Degree of Illuminance

The degree of illuminance that results from vehicle headlights varies considerably from one vehicle to another. Figure 4 shows the distribution of illuminance measured with a "regloscope" type of device for the angles corresponding to an overhead sign (6.50 m high in the vehicle axis) and a sign, 1.42 m high and 1.40 m from the right side of the roadway, placed 100 m from a vehicle with low-beam headlights *(3)*. The light distribution is based on the study of 100 vehicles the headlights of which were measured before and after adjustment, giving a total of 374 measurements.

For an overhead sign, the extreme values of light distribution are separated by a factor of approximately 10. For a shoulder sign (the position of which is closer to the cutoff line of the low-beam headlights), the dispersion is still greater, and the extreme values are separated by a factor of approximately 70.

For a given vehicle (Citroen GS), the change in the illuminance on the sign in terms of the distance between the vehicle and the sign was determined in situ (Figure 5). Two sign positions were studied, overhead and on a shoulder mast (2.30 m high and 1.40 m from the right side of the roadway). The illuminance on the shoulder sign (at a height of 2.30 m) is slightly less than that on a sign 1.42 m high: approximately 10 percent less at 100 m *(4)*. According to Figure 5, the overhead sign receives about half as much light as the shoulder sign; these values were used in the subsequent calculations.

Luminance

The luminance of the film can be calculated by multiplying the illuminance on the sign by the RC of the film, taking into account the geometric conditions of lighting and observation that change with distance. Figure 6 shows this calculation for an overhead sign lit by a light vehicle or a truck. The retroreflective films are white Class I and Class II.

Luminance is plotted on a logarithmic scale in order to better represent the visual sensation and consequently the legibility, which is proportional to the logarithm of the luminance for the range of luminance under study. The general shape of the curves is identical to that obtained during the in situ measurements *(5)*.

The luminance of the Class-II film is approximately three times that of the Class-I film for the light vehicle. The luminance of the sign observed by a truck driver is smaller than that observed by the driver of a light vehicle because the angle of observation is less favorable for truck drivers. The straight line labled "85%" in Figure 6 will be explained later.

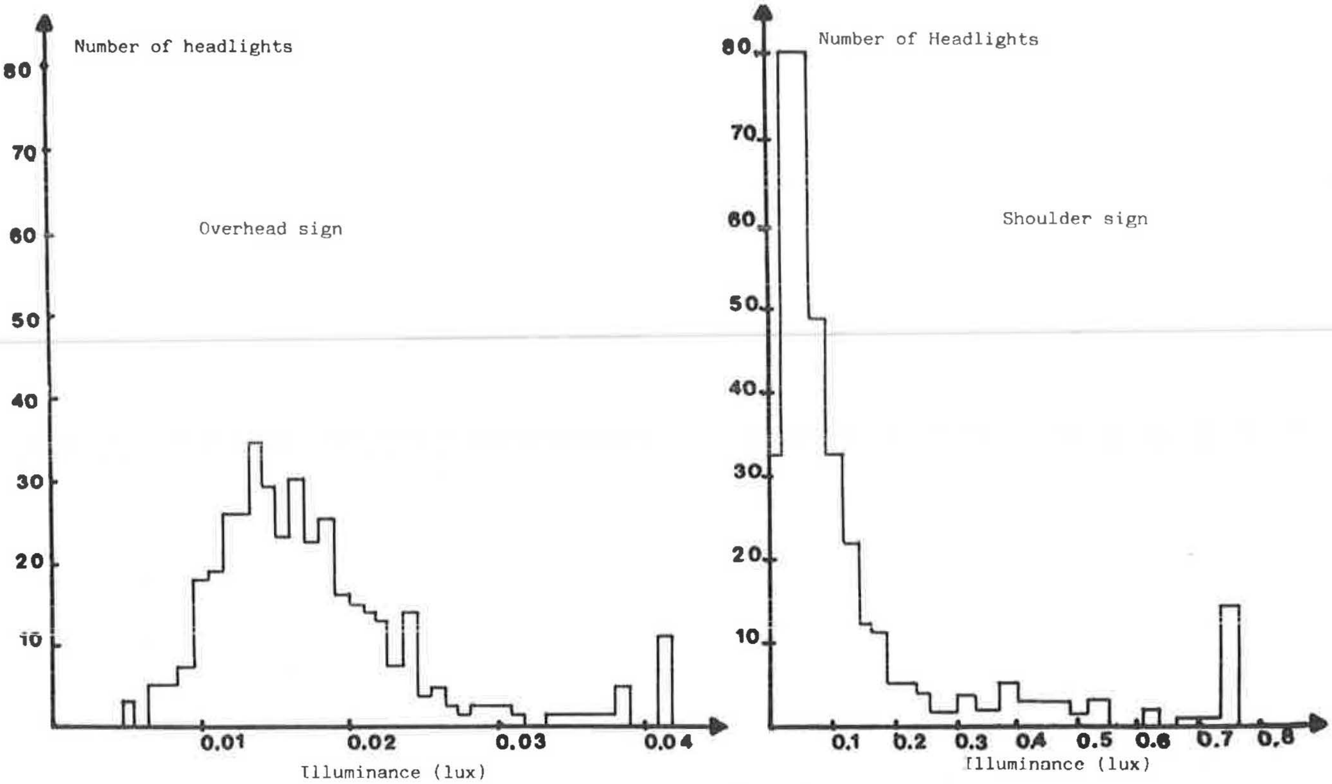

FIGURE 4 Distribution of illuminance received at 100 m by an overhead sign and a shoulder sign—measurement on 374 headlights (low beams).

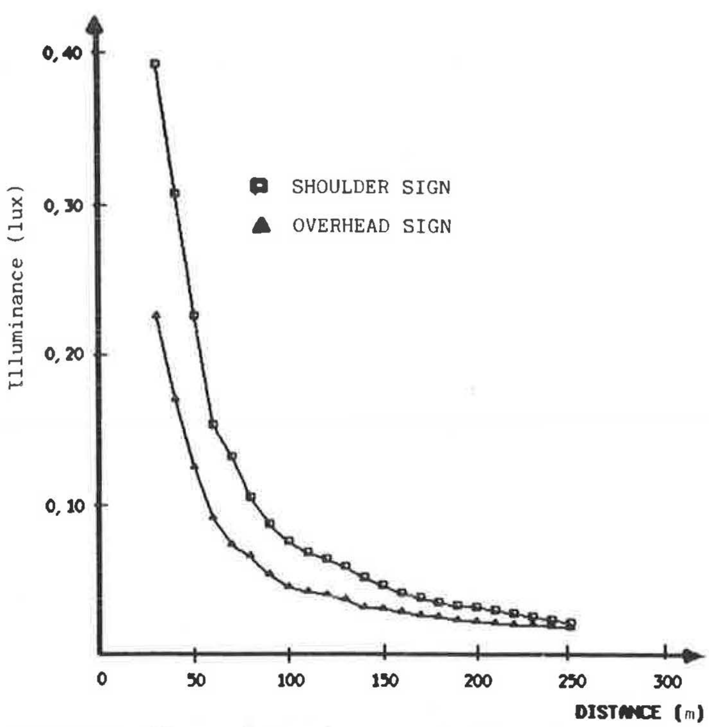

FIGURE 5 Changes in illuminance received by a sign (overhead or shoulder) as a function of the distance between the vehicle and the sign (commas should be understood as decimal points).

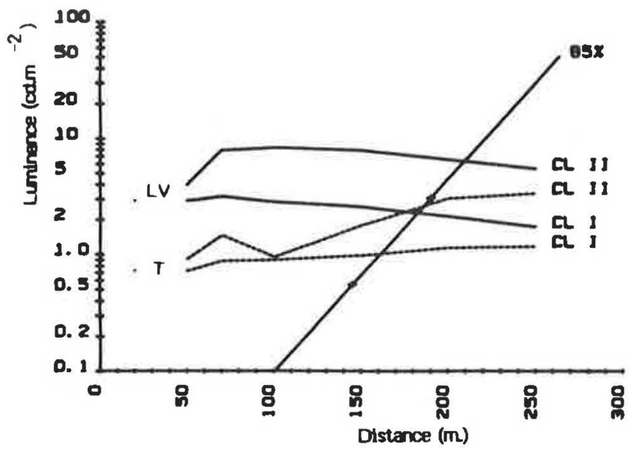

FIGURE 6 Changes in the luminance of white films (Class I and II) on an overhead sign lit by a light vehicle or truck with headlights on low beam.

DETERMINING THE LUMINANCE NECESSARY FOR LEGIBILITY

The luminance necessary for legibility was determined in the laboratory in order to master the parameters involved in legibility.

Experimental Procedure

The signs used were on a scale of approximately 1/10th of their actual dimensions given in the following table:

Sign	*Alphabet*	*Letter Height (cm)*
Shoulder	L1	12.5
	L2	16
Overhead	L1	32
	L2	40

The observation was made at 18 m, and the letter height was 4, 3, and 2 cm, which corresponds to angles of 8, 6, and 4 min. The color and shape of the letters were in accordance with current regulations *(6)*. The line width of the letter is about 1/5th of the letter height.

The three color combinations were

- White retroreflective letters on a nonretroreflective blue background (Alphabet L2),
- White retroreflective letters on a green retroreflective background (Alphabet L2), and
- Black nonretroreflective letters on a white retroreflective background (Alphabet L1).

The contrast between the letters and the background was calculated by

$$C = (L - L_F)/L_F$$

where L is the luminance of the letter and L_F is the luminance of the background. The values obtained were

C (white on blue) = 28,
C (white on green) = 5, and
C (black on white) = 0.96.

Various symbols were studied: words, series of letters, and Landolt rings (Figure 7).

The signs were lit in such a way that the luminance of the sign film was comparable to that in situ. The range of luminance examined varied from 0.1 to 5 cd/m^{-2} in 10 logarithmic stages. Two ambient-lighting situations were simulated, one rural and the other semiurban. The illumination levels received at eye level were 0.06 and 3 lux, respectively. The signs were randomly presented for enough time to allow the observer to read them and note the results.

A letter chart was used to determine the visual acuity of the 45 observers, who were between 23 and 60 years of age, for both photoptic and mesoptic vision. The distribution of their visual acuities is shown in Figure 8. Those participating in this study all had a daytime visual acuity greater than 8|10; 87 percent had acuity of 12|10 or more.

Visual acuity in mesoptic vision had lower values: 65 percent of participants had acuity of 8|10 or more. In mesoptic vision an overall reduction of acuity of approximately 4|10 was found compared with daytime conditions. This reduction varied from person to person, depending on age and visual characteristics.

Results of Measurements

The results were expressed as a percentage of correct replies in terms of the luminance of the white film. Because the white

FIGURE 7 Example of sign messages.

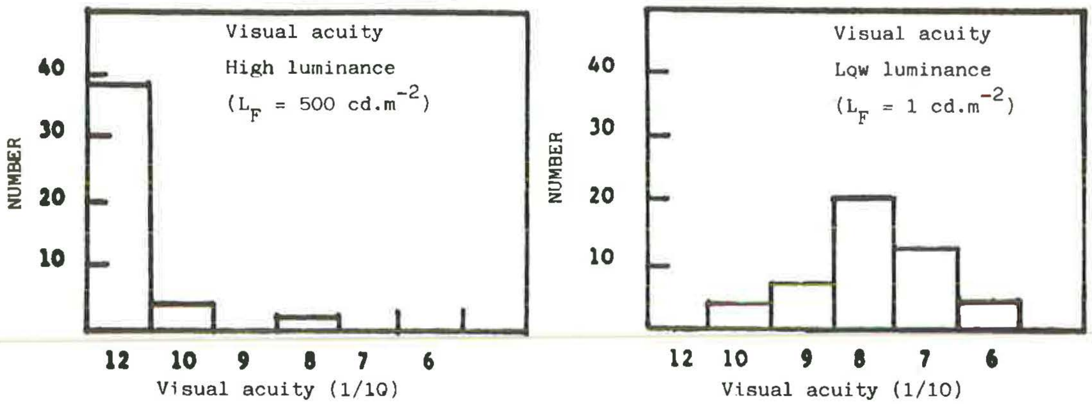

FIGURE 8 Distribution of visual acuity for day and night conditions.

film appeared on all of the signs, either on the background or on the letters, it was chosen as a reference. The principal results follow.

- There was no significant difference in legibility among the three types of message with large symbol dimensions (angle of 8 min). For smaller symbol dimensions (angles of 6 and 4 min) reading became generally more difficult, and under these conditions the Landolt rings were better read than words and letters. These results corroborate those obtained by A. Arnulf (Mieux voir, Comité National de la Division, 1962) who described the ring test as an orientation test, which is easier than an identification test involving letters.
- As was found previously, there was little difference in legibility among the three colors used in the case of large symbols (angle of 8 min).
- However, the following classification was observed for a smaller symbol dimension: the white-on-blue signs were better read than the white-on-green and the black-on-white signs. In other words, greater contrast facilitates reading for a given letter height.

The results are quite sensitive to changes in the dimension of the symbols because reading is linked to the visual acuity of the observer.

Only one example of the curves obtained for the different messages and colors will be presented. The results shown in Figure 9 apply to black rings of 4, 3, and 2 cm on a white background observed at 18 m under rural ambient-light conditions. Observation under urban conditions led to identical results; the curves were displaced by 0.3 cd/m^{-2} toward higher luminance levels because of the additional illumination received by the sign through diffuse lighting.

For each dimension, the percentage of correct replies increases with the luminance of the white film. For dimensions of 3 and 4 cm, the growth is rapid up to L = 1 cd/m^{-2}, and then the percentage tends toward a maximum.

If the luminance of the white film is 1 cd/m^{-2},

- Eighty-six percent of observers have acuity sufficient to read the 4-cm symbols, which correspond to an overhead sign at 144 m;
- Sixty-two percent of observers have an acuity sufficient to

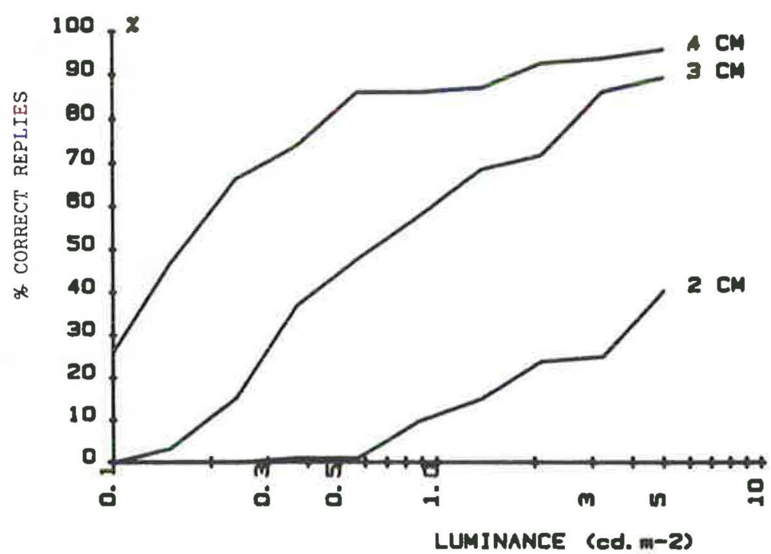

FIGURE 9 Percentage of correct replies obtained during a presentation of black-on-white Landolt rings of 4, 3, and 2 cm as a function of the luminance of the white background.

read the 3-cm symbols, which correspond to an overhead sign at 192 m; and

- Twelve percent of observers have an acuity sufficient to read the 2-cm symbols, which correspond to an overhead sign at 288 m.

LEGIBILITY DISTANCE OF MESSAGES ON SIGNS

When the luminance required for reading a given size of character at a given distance is known, the legibility distance limit, which increases with the luminance and is valid for a certain proportion of the population under study, can be established. Comparison of this legibility distance limit with the luminance of the signs observed on the road makes it possible to establish a maximum legibility distance for the observation conditions.

Establishing the legibility distance line involved deciding what proportion of correct replies should be taken into account. A value of 50 percent appeared to be too small, and a value of 95 percent, although satisfactory for most people, is difficult to attain because of the technological limits governing the dimensions. Therefore an intermediary value of 85 percent, which according to Figure 9 corresponds to realistic luminance levels, is used. (This percentage is often used to define the performance of a population in psychophysical experiments.) The legibility distance indicated hereafter will therefore be representative of 85 percent correct readings.

Figure 9 shows that, for symbols 4 and 3 cm high, corresponding to an overhead sign with letters 32 cm high observed at 144 and 192 m, to give 85 percent correct replies, the luminance of the white film has to be 0.55 and 3.07 cm/m^{-2}, respectively.

In Figure 10 these two luminance values are plotted in terms of the observation distance of an overhead sign with black-and-white rings. The two values are joined by a continuous line the extension of which is then extrapolated. This result was compared with those obtained in other studies with Landolt rings.

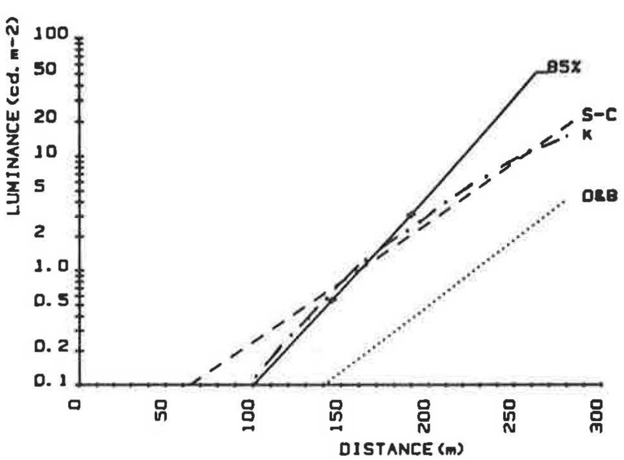

FIGURE 10 Comparison of the curves of extreme legibility distance obtained during various studies: S-C = Schmidt-Clausen (*1*), K = Kaneko (*3*), O&B = Olson and Bernstein (2), and 85 % = the present study (the limit was fixed at 85 % of correct replies).

A study by Schmidt-Clausen *(7)* establishes a relation of the same type between luminance and legibility distance. If the Schmidt-Clausen relation is applied to an overhead sign with characters 32 cm high, the straight line (S-C) plotted on Figure 9 is obtained. A study by Olson and Bernstein *(8)* results in the straight line (O&B) on Figure 9. The curve labeled K is obtained by calculation from Kaneko's *(9)* formula, which gives visual acuity in terms of luminance and contrast, and from the relation between visual acuity and the observation distance of the characters.

Comparison of the four curves shows that only line O&B gives observation distances greater than the others. This is probably because the seven observers used by Olson and Bernstein had good visual acuity at low luminance levels (11|10) whereas in the present study the acuity of the 45 observers at low luminance was about 8|10. The shifted position of this curve is thus quite justified. The similarity between the three other curves is satisfactory and suggests that the results obtained in the three different studies are reasonably representative of the actual situation.

In the rest of the study the 85 percent line, obtained under experimental conditions for determining legibility distances, will be used. (Because of experimental errors, accuracy is about 10 percent.) In Figure 6 the 85 percent line is plotted as well as the curves showing the change in the luminance of the white film as a function of the different distances between vehicle and sign.

Comparison of these last curves with the 85 percent line shows that, in the case of an overhead sign lit by a light vehicle,

- The luminance of the white film, calculated for a Class-I film, is greater than the limit values given by the 85 percent line up to a distance of 180 m and
- For the Class-II film, the limit distance is 210 m.

Therefore this example proves that two films, the retroreflective characteristics of which are separated by a factor of 3, lead to a difference of 30 m in legibility distances at about 200 m from the sign (i.e., a relative difference of about 15 percent). For the other examples not treated here (shoulder sign, light vehicle or truck) the relative differences are of the same order. This low value of relative difference is due to the logarithmic change in the legibility distance with luminance values.

In addition, it is known that the legibility distance is directly proportional to the height of the characters. Thus, if it is desired to increase the legibility distance by 15 percent with a constant luminance level, it is only necessary to increase the character height by 15 percent (i.e., to change from 32 to 37 cm in the case of an overhead sign).

In Figure 11 a 37-cm-limit legibility line is plotted, on the assumption that character height is 37 cm, in addition to the 85 percent line, marked here as "32 cm," because it was calculated under this hypothesis. It can be observed that for an almost constant luminance level (film Class I) the legibility distance increases from approximately 180 to 210 m when the character height is increased from 32 to 37 cm.

Thus, to obtain an identical gain in legibility distance (for this example), multiplying the luminance level by a factor of 3 or multiplying the height of the characters by a factor of 1.15 is equivalent.

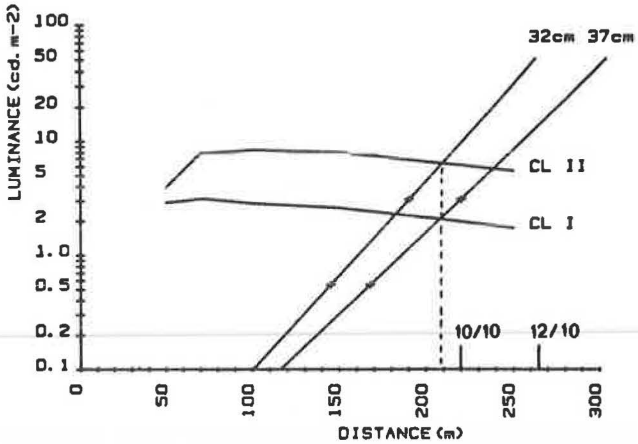

FIGURE 11 Extreme legibility distances obtained with an overhead sign with letters 32 and 37 cm high; vertical lines give the extreme legibility distance obtained by day with observers who had a visual acuity of 10| 10 or 12| 10.

Comparison with Daytime Legibility Distance

Photopic (daylight) vision relates to higher luminance levels (>10 cd/m^{-2}), but legibility distance still depends on visual acuity. If the visual daylight performance of the population that took part in the experiment is considered, 85 percent of the persons concerned have a daylight acuity of approximately 12| 10. Under such conditions, the daytime legibility distance is 264 m for a character height of 32 cm. For these persons, night legibility distance (210 m) is thus about 50 m shorter than daytime distance.

The population used in this study has a higher-than-average daytime acuity. Average daytime acuity is usually taken as 10| 10. For people of 10| 10 acuity, the legibility distance is 220 m. These two distances are marked on Figure 11 with their corresponding visual acuity. It would be interesting to know the nighttime visual performance of all drivers; the results here are only representative of the population under study.

Influence of Other Factors

Under actual driving conditions, other factors may influence the legibility distance in a positive or negative sense:

1. Retroflective film
   - Age of the film
   - Dirt
   - Dew deposit
2. Luminous intensity from headlights
   - Level of this intensity
   - Dirt on the headlights
3. Additional illumination from the environment, other headlights, or from reflection on the damp roadway
4. Geometry of the lighting and observation
5. Absorption of light by the windshield, which may also be tinted or dirty
6. Visual acuity of the drivers, which is a function of the contrast between the letters and the background for a certain luminous ambient situation.

Legibility Distances Under Good Conditions and Poor Conditions

An attempt has been made to give an idea of the range of variation of legibility distance with the help of all of these parameters. A simulation, for calculation purposes, of two extreme realistic cases is shown in Figure 12.

The case of good conditions was calculated using the following assumptions:

- New, clean film (Class I and Class II);
- Direct illuminance from headlights three times higher than the average illuminance value used in the study;
- Additional illuminance identical to the direct illuminance;
- No absorption by the windshield; and
- Clean headlights.

The case of poor conditions was calculated using the following assumptions:

- Old, dirty film (Class I and Class II) with a 20 percent lower retroreflective coefficient;
- Poor direct illuminance equal to one-third of the average illuminance used in the study;
- Twenty percent absorption by the windshield of the luminous flux arriving at the driver's eye; and
- Dirty headlights, which reduce by 50 percent the illuminance received by the sign.

If the good and poor conditions are applied to an overhead sign 6.50 m above the roadway lit by a light vehicle and observed by a driver (visual characteristics of 85 percent of the population presented previously), the curves for luminance changes of the white film on the sign as a function of distance (Figure 12) are obtained.

Compared with Figure 11, the favorable case corresponds to

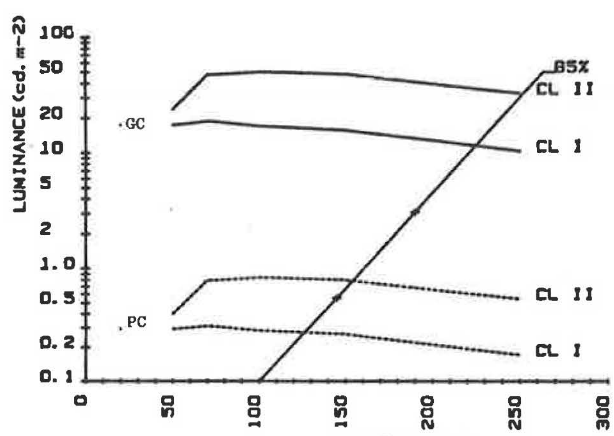

FIGURE 12 Comparison of extreme legibility distances obtained under good conditions (GC) and poor conditions (PC).

multiplying the luminance by 6, and the unfavorable case corresponds to dividing it by 10. For the favorable case, the legibility distance is 225 m for Class-I film and 250 m for Class-II film; for the unfavorable case, the legibility distance is 125 m for Class-I film and 155 m for Class-II film.

In both cases the Class-II film gives gains of 25 and 30 m, respectively. These two extreme conditions lead to a difference of 100 m in the legibility distance for a luminance ratio of 60.

CONCLUSIONS

This study shows that the legibility of road signs depends on numerous parameters. Film quality, like a number of other factors, has a limited influence on legibility distance because of the logarithmic variation of this distance with film luminance. In the case of an overhead sign, the use of Class-I or Class-II film, the characteristics of which are separated by a factor of 3, only leads to a difference of approximately 15 percent in the legibility distance.

On the other hand, the height of the characters used appears to have a preponderant and limiting effect on the legibility distance because of its direct dependence on visual acuity. An evaluation of the illuminance received on the signs shows that this parameter can lead to variations in the legibility distance that may be twice as large as those due to the film characteristics. The range of variation of this parameter is quite wide because of the present great differences in the values of luminous flux provided by the headlights of vehicles in France.

According to other experiments, other factors that are more difficult to quantify such as dirt (on the headlights or on the signs) and meteorological conditions are also of great importance for sign legibility because they weight the other parameters by a coefficient that may vary between 0 and 100 percent.

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