Legibility and Contrast Requirements of Variable-Message Signs

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New technologies such as optic fibers and light-emitting diodes are now used for information matrix signs. A field study was carried out to evaluate the best conditions for the legibility of these signs during the day and at night. For legibility criteria, the contrast between the letters and the sign background is chosen for daylight conditions and the luminance of the letters for night conditions. The performance of some commercially available signs is compared with the study results.

The variable-message sign (VMS) is being used increasingly on main roads and motorways. On those signs, optical fibers are not being followed by light-emitting diodes. The special characteristics of these products call for a revision of the French specifications to complete the recommendations on their luminous intensities and colors. The focus here is on the photometric aspects of signs delivering alphanumeric messages made up of 5- by 7-point dot matrix characters. An initial investigation was carried out by simulation on video monitors (*1*), but the luminosity limits of the monitors were such that only night visibility conditions could be simulated. Hence, an experimental study has been carried out on a prototype sign to determine, in a more realistic manner, the conditions of optimum visibility both in daylight and at night.

REVIEW OF LITERATURE ON VMS LEGIBILITY

There is a tendency to characterize a fiber optic or diode VMS consisting of luminous points by the luminous intensity emitted by each point of the matrix. But, if such signs are observed from a long distance (100 to 200 m), the characters exhibit a continuous appearance under most traffic conditions.

Which photometric property should then be chosen to characterize the legibility of such signs? Luminous intensity is closest to technological reality, but luminance and contrast are more closely correlated with human vision and with the criteria of legibility applied to other signs (*2*).

The latter two factors were chosen. Kerr et al. (*3*) have carried out an experiment on the legibility of VMS through laboratory simulation. By analyzing the observers' response times, they found that reading performance was best with a contrast of approximately 7.

Moreover, reading is generally dependent on the visual acuity of the observers. This factor varies substantially with the luminance of the character displayed and with the contrast between the character and its background (*2*). Van Meeteren et al. (*4*) have found that a luminance ratio of approximately 10 between the letter and the background provides optimum visual acuity.

The results of this investigation, obtained in daylight conditions, are presented in terms of contrast C', equal to luminance ratio L/Lf, where L is the luminance of the letter and Lf is the luminance of the background. This relation takes ambient luminosity into account in the luminance of the background of the sign.

Other authors, among them Padmos et al. (*5*), have chosen the luminance of the characters as the VMS legibility criterion, stated as a function of the luminance of the horizon, both in daylight and at night. This factor also takes ambient luminosity into account. On the basis of this investigation, carried out at an actual site at an observation distance of 100 m, two levels are recommended for day and night conditions: a luminance of 4000 cd/m² in daylight and 100 cd/m² at night. At night, the luminance of the backgrounds, of the VMS tends toward zero, so the luminance of the character was chosen as the criterion, as used for other types of sign.

For example, for comfortable reading of illuminated signs, Allen et al. (*6*) recommend a luminance of 30 to 300 cd/m² in rural areas (where there is little or no illumination) and 300 to 1500 cd/m² in highly illuminated urban areas. For retroreflecting signs, Woltman and Szczech (*7*) report an optimum character luminance of 75 cd/m² to ensure good legibility at night. Reading becomes just possible at only a few cd/m².

The previous study of the legibility of dot matrix characters carried out by simulation on video monitors (*1*) indicated more than 70 percent responses with a luminance of between 30 and 230 cd/m². Therefore, the criterion of character luminance is used to provide the night results.

EXPERIMENTAL INVESTIGATION

Description of Sign

The experimental investigation used a prototype sign built for that purpose by the optronics laboratory of the University of Poitiers. It has a single block of diodes, 320 mm high, on which any of the 26 letters of the alphabet can be displayed (see Figure 1). Each letter is defined by a 5- by 7-point array.

Each point of the matrix may consist of a variable number of diodes: 1, 4, 9, 16, 25, or 36. The luminous intensity of each point of the matrix varies according to the number of diodes lit and according to the electric power delivered to each diode. In practice, the luminous intensity was varied

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FIGURE 1 Experimental sign displaying the letter E, with each point of the matrix consisting of nine diodes.

from approximately 0.02 to 1.5 cd per point under the night observation conditions and from 0.2 to 8 cd per point under the daylight observation conditions.

During the tests, the vertical illumination received by the sign and the background luminance of the sign when off were measured. On the different test days, the vertical illumination ranged from 5000 to 60 000 lx and the background luminance from 100 to 500 cd/m^2.

Experimental Procedures

The sign was shown to 27 observers, in groups of 3 from a stopped vehicle 200 m away. The 26 letters of the alphabet were presented in random order at six different matrix point sizes and six different levels of luminous intensity. Altogether, 180 configurations were displayed, each for 2 sec. After each presentation, the observers recorded the letter read on a form. The same procedure was followed both for daylight and for night conditions. The observers consisted of 8 women and 19 men, between 22 and 65 years old. The drivers' vision was checked by measuring visual acuity and sensitivity to contrast.

Daylight Results

The answer forms were analyzed by counting correct answers, incorrect answers, and failures to answer for all individuals and each luminous level and size of matrix point. As a result of the thinking about readability criteria discussed previously, the daylight results were reported by the percentage of correct answers versus contrast C' (see Figure 2), so that they could be compared with the results given in the literature.

In daylight the true luminance (L) of the character is the sum of the internal luminance (Li) of the sign and the external luminance (Le) resulting from ambient illumination, which is equal to the background luminance (Lf). Internal luminance (Li) is calculated from the luminous intensity measured in the photometrics laboratory by the following equation:

$$\text{Li} = (\text{Ip} \times 35)/S \qquad (1)$$

where Ip is the luminous intensity per point of the matrix and S is the area of the block of diodes containing the 35 points. Thus,

$$C' = L/\text{Lf} = (\text{Li} + \text{Lf})/\text{Lf} \qquad (2)$$

Because the background luminance was not measured continually in the course of the tests and varied with the ambient illumination, the average value of Lf = 200 cd/m^2 was used for the contrast calculation. The true luminance of the letters ranged from approximately 280 to 4090 cd/m^2.

The various symbols of Figure 2 represent the six sizes of the points of the matrix.

The experiment did not reveal any substantial influence of point size on reading performance, whereas the influence of contrast C' can be seen in the rapid increase in correct answers: from 10 to 50 percent as C' increases from 1.5 to approximately 3. The percentage of correct answers continues to rise with increasing contrast, leveling off at about 85 percent for a contrast between 8 and 20. No values were measured beyond 20. The corresponding luminance (L) of the character is between 1500 and 4000 cd/m^2. These values are perfectly compatible with the results of Padmos et al. (*5*).

Night Results

In accordance with the thinking about night legibility criteria, the results are given as the percentage of correct answers by the observers versus the luminance of the character. At night there is little illumination of the experimental site and no oncoming vehicles. The results were obtained by the same procedures as for daylight. The various symbols on Figure 3 represent the different matrix point sizes. At night, as in daylight, the experiment did not reveal any significant influence of this factor. During the night experiments, the luminance ranged from 9 to 730 cd/m^2. Overall performance was 60 percent, with a large dispersion, and revealed no significant change in the percentage of correct answers with increasing luminance. This performance level, lower than in daylight, is probably explained by the observers' loss of visual acuity at night.

Most of the observers judged the highest luminance levels to be uncomfortable, but this perceived discomfort did not affect reading performance, probably because each letter was presented long enough for the individuals' vision to adapt to these slightly more difficult reading conditions.

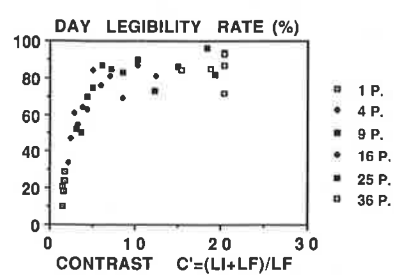

FIGURE 2 Percentage of letters correctly read in daylight versus contrast.

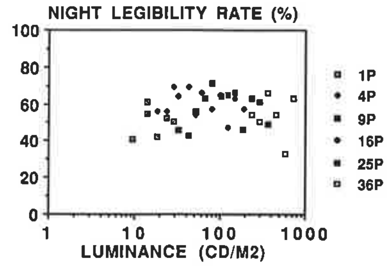

FIGURE 3 Percentage of letters correctly read at night versus luminance.

The night results do not allow precise values of luminance required for reading to be determined. The previous study by Mazoyer and Colomb (*1*), in which a simulation was used, indicated a narrower range of luminances ($30 < L < 230$ cd/m²) that are perfectly compatible with the other data examined.

PHOTOMETRIC PERFORMANCE OF THE VMS

In this section the results of this experiment and the results reported in the literature are compared with the actual performance of the products.

Measurement Method

A testing method to evaluate the luminous performance of products subject to approval was developed in the photometric laboratory. The measurement includes a number of steps.

First, a prototype sign capable of displaying three characters is placed on a rotating table. A photometric cell that can move on a column is used to measure the luminous intensity of the characters and, hence, to deduce the luminous intensity per matrix point (see Figure 4). The measurement is automated; it begins on the axis perpendicular to the plane of the sign and is continued to ± 16 degrees horizontally. The data (angle, luminous intensity) are transmitted to the microcomputer-controlled acquisition system, and the results are printed out immediately as tables or graphs.

Second, the background luminance of the sign is measured (see Figure 5). The sign is once again placed on the rotating table. It is kept off and is illuminated by a light source simulating the sun, from a direction 20 degrees above the normal to the sign in the vertical plane. The measurement of luminance L is made in the axis of the sign by a luminancemeter at a given vertical illumination (EV). Unfavorable illuminance conditions are defined by EV = 80,000 lux. The corresponding background luminance is calculated using the following relationship:

$$Lf = (L \times 80\,000)/EV \qquad (3)$$

Finally, the color of the luminous message is measured on the illuminated panel using a spectrophotometer in the axis perpendicular to the front of the sign.

Performance in Daylight

By setting a minimum contrast threshold and determining the background luminance of the sign, it is possible to calculate the luminance that a character should have to be readable and, from that value, to deduce the luminous intensity per matrix point for a given character height.

Assume a contrast threshold of 3, corresponding to 50 percent correct answers in the investigation. Under unfavorable conditions of illumination, with a vertical illumination of 80 000 lux, the background luminance of signs can easily be as much as 1500 cd/m² with a diffusing front surface. Under these conditions the luminance of the character must exceed 4500 cd/m² and the internal luminance 3000 cd/m². Assuming a character height of 400 mm, the corresponding luminous intensity per matrix point must be greater than 10 cd.

The luminous intensity values vary with the technology. The values per matrix point Ip as measured in the photo-

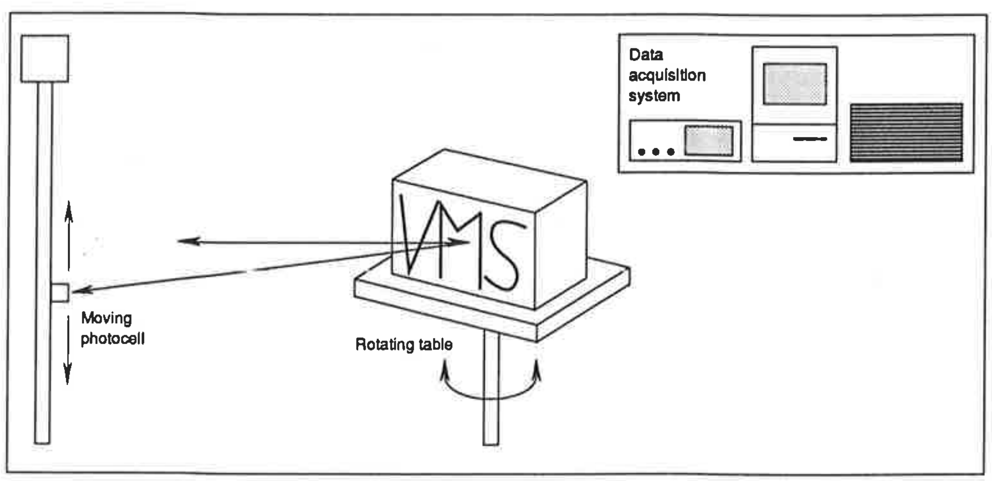

FIGURE 4 Measurement of luminous intensity.

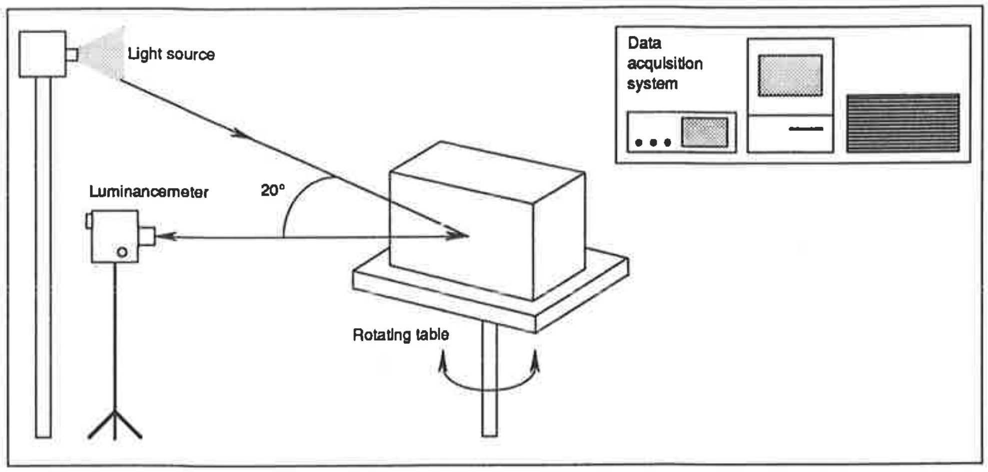

FIGURE 5 Measurement of luminance of front of sign.

metrics laboratory in the direction perpendicular to the front of the sign are as follows:

- For fiber optic signs, Ip ranges from 10 to 40 cd according to the power of the source, the number of fibers per matrix point, and the color of the filter used (yellow in some cases).
- For diode signs, Ip is a few candela and varies with the number of diodes per point and their color (red diodes are more powerful than the others).

A value of 3.6 cd was measured on a sign for which each matrix point consisted of 8 red diodes and 8 green diodes. A value of 4.3 cd was measured on a sign for which each matrix point consisted of 20 yellow diodes and 20 green diodes.

The luminous intensity of the diodes decreases with increasing temperature; at constant ambient temperature, it decreases after the diodes are switched on because of heating. The values given are for the standard measurement conditions, with a temperature of 20°C and measurement made 20 min after lighting.

Judged by the design assumptions stated, only the fiber optic technology provides adequate legibility, with Ip greater than 10 cd.

To consider another example, the initial assumption concerning contrast (contrast threshold equal to 3) is retained, but assumptions concerning the front of the sign are changed. Consider a sign having a front that diffuses very little, measured under the same conditions of illumination or with weaker illumination. The background luminance is only about 500 cd/m^2. If a character height of 400 mm is assumed, the luminous intensity per point must exceed about 3 cd. In this example, fiber optic and light emitting diodes are both satisfactory.

Thus, when the siting of a VMS is being considered, the natural conditions of illumination to which the sign may be exposed (unfavorable conditions) must be examined along with the photometric properties of the sign (i.e., its luminous intensity), in conjunction with the optical properties of the front of the sign.

Performance at Night

From the luminance ranges given, it is possible to calculate the corresponding luminous intensity for characters of a given height. If, for example, the two luminance ranges specified by Allen (*6*) are used for the two ambient luminosities, with a character height of 400 mm, the luminous intensity per dot, at night, must be between 0.1 and 1 cd in a zone of little or no illumination and between 1 and 5 cd in a highly illuminated urban zone. Most of the signs available on the market provide a luminous intensity that is greater than the required values. Indeed, care should be taken to reduce these intensities for night operation.

CONCLUSIONS

The criteria of contrast and luminance can be used to specify the conditions that a VMS must satisfy to be readable in daylight and at night. A review of the literature revealed overall agreement among the ranges of values obtained in the various investigations.

In practice there may be a problem of legibility in daylight with some VMSs. An overall photometric analysis of the sign can help correct this problem by considering not just the emitted luminous intensity but also the luminance of the front of the sign.

The photometric problems posed by this new type of sign have been reviewed. It now remains to settle the question of color raised by the use of diodes, which display spots of color outside the ranges traditionally accepted by the International Commission on Illumination for other luminous signaling equipment.

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