are of concern in cases such as cab-over-engine trucks that have 254-cm (100-in) driver eye height and misaimed or failed left headlight(s).

6. The performance of all combinations of sign materials appeared to be less affected by frost than by dew.

7. An encapsulated-lens legend on an encapsulated-lens background (the small sign at the bottom right of Figure 1) was less than half as much affected by dew or frost in the case of the directly applied legend (FT) as in the case of the embossed legend (LE). However, this comparative advantage from use of direct applied copy was not evident in the relative performances of direct applied versus embossed borders; direct applied, embossed, and demountable borders exhibited only slight differences in performance, most of which could be explained in terms of other variables such as sign backing, background material, and border material.

8. Reversing the positions of the two sign panel combinations (left to right in Figure 1) had no effect on the subjectively rated relative performances of the signing material combinations.

9. Under the conditions of this study, 80 percent of the noted adverse effects of dew or frost on the conspicuity and specificity of enclosed-lens legends on enclosed-lens backgrounds on plywood-backed sign panels (RU, upper right in Figure 1) could have been avoided through the use of encapsulated-lens legends on encapsulated-lens backgrounds on plain aluminum panels (FT, bottom right in Figure 1).

10. Allowing for normal variations in atmospheric conditions (light dew, rapidly forming heavy dew, and frost) and in signing practice (plywood versus aluminum panels and direct applied versus demountable copy), it is estimated that 50 to 80 percent of the adverse effects of dew and frost could be overcome through the use of encapsulated-lens signing materials.

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Relation Between Sign Luminance and Specific Intensity of Reflective Materials

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Recommendations related to nighttime luminance for traffic signing are not readily translatable from specification or photometric descriptions of the reflective brightness of materials. An investigation of a simple means of translation was undertaken to aid in the proper selection and application of materials where a sign luminance level is desired. The study approach used a photometric determination of specific intensity of the reflective material. The two observation angles common to most highway specifications, 0.2° and 0.5° at -4° entrance angle, were used for determining a broad luminance span for a variety of reflective materials in the common traffic colors. These materials were then installed on a test road where field determinations of sign luminance were also made. The many readings were then correlated by linear regression. These expressions, based on direct observational data, are shown for a variety of shoulder and overhead sign positions, for upper and lower beams, and for the two distances most closely approximating the 0.2° and 0.5° observation angles—183 and 91.5 m (600 and 300 ft). The resulting expressions permit simple computation of either sign luminance or specific intensity for a reflective sheeting.

It is acknowledged that nighttime sign performance is dependent on attention value and legibility. Each factor is related directly to the luminance contrast, the sign with its surround providing attention value and the letters with the sign background providing legibility. Literally, contrast is the luminance difference between an object and its background and is a subjective experience that is given to extreme variation, particularly at night. Excessive stimuli from glare sources, such as opposing headlamps, highway luminaires, and electric advertising, contrast with the generally inadequate luminance needed elsewhere for effective nighttime perception.

In recognition of this, the Manual on Uniform Traffic Control Devices (MUTCD) (1) requires reflectorization or illumination of signs, delineators, and pavement markings. Although the MUTCD requirement has done much to improve visibility, no minimal values are specified and no maintenance of minimal luminance is suggested.

Numerous performance levels of reflective materials are available in various federal and state specifications, and a wide variety of lighting designs and luminaire fixtures exist for compliance with the manual requirement. An obvious difficulty arises in translating reflective material specification values to sign luminances suggested by research for various situations. Although such research has yet to be adopted by the MUTCD, desirable and minimum nighttime levels of sign luminance have been suggested by Lythgoe (2), Smyth (3), Allen and Straub (4), Allen and others (5), Forbes (6), Olson (7), Jainski (8), and other researchers. Such research indicates that increasing sign luminance is required where sign surrounds possess increasing luminance and may vary depending on such factors as the color and size of the sign.

The performance recommendations given in luminance terms are not easily equated to photometric values of reflective material specifications. Reflective luminance has been generally quantified for various materials by Youngblood and Woltman (9). This previous work used a telephotometer at driver eye position and a vehicle of standard dimensions that had carefully aligned headlamps. Careful work from study to study has validated the efficacy of this approach. What was lacking was a complete and relatively direct relation between the variety of photometric test points and sign luminance. Many very pertinent factors are involved in this relation.

Since the efficiency of reflective sheeting varies widely over useful observation (divergence) angles, the resulting relation is expressed as specific intensity (called reflective intensity in certain specifications) and is the luminance in absolute terms versus the observation angle for each type of reflective material under consideration. Observation angle (called divergence angle in certain specifications) is the angle subtended by the headlamps, the sign, and the reflective light beam at the observer. This angle undergoes significant change as the motorist approaches the sign and greatly influences the resulting sign luminance. This angle increases substantially as reading distances for signs shorten. Further, the greater lateral distance of the right headlamp makes the luminance contribution from this source approximately half that of the left lamp at shorter distances. Both changes necessitate separate calculation of the luminance for each headlamp and for each observation angle.

Illuminance depends on the alignment of the sign with the headlamp beam, and its determination requires the location of the reflective device in the appropriate area of the headlamp isocandle diagram for both high and low beams and for typical conditions of highway alignment. Calculation for each lamp is required as is change in sign position or distance. Luminance values are then obtained by application of the inverse square law. Inherent differences in individual lamps are to some extent compensated for by the presence of two or four lamps. However, variation in voltage, lamp misalignment, changes in automobile loading, and specularity of the road surface all contribute to variation in illuminance so that results are not always consistent.

DESIGN OF EXPERIMENT

Most specifications (10, 11) use photometric test points at -4° entrance (called incidence angle in certain specifications), which is essentially perpendicular to the sign surface. The negative angle is for elimination of specular glare in the photometric test, but traffic signing materials today vary little in reflectivity up to angles of ±10°. Observation angles of 0.2° and 0.5° are intended to conform to typical eye headlamp height and sign-reading distances of interest and correspond approximately to distances of 183 and 91.5 m (600 and 300 ft) respectively. These distances were chosen for our observations as most representative of the two observation angles most frequently encountered in specifications.

TEST ROAD

The test road facility is 670 m (2200 ft) long and was designed and constructed to represent a one-way portion of an Interstate roadway. The facility is a straight section with a uniform +0.4 percent grade. The road surface is of comparatively fine-textured asphaltic concrete and is essentially unworn.

POSITION OF SAMPLE PANELS

The sample panels were positioned as shown in Figure 1, the centroids for four positions of signs: for overhead guide signs, 6.55 m (21.5 ft) above the crown of the roadway centered over the right lane; for the shoulder-mounted guide sign, 13.72 m (45 ft) to the right of the lane and 3.05 m (10 ft) above the elevation of the pavement: for the rural shoulder-mounted regulatory warning and advisory signs, 1.83 m (6 ft) above and 3.05 m (10 ft) to the right of the lane edge; for urban shoulder-mounted regulatory warning and advisory signs, 2.44 m (8 ft) above and 0.91 m (3 ft) to the right of the lane edge. These locations represent the center of typical signs and closely correspond to the recommended placement as specified in the MUTCD.

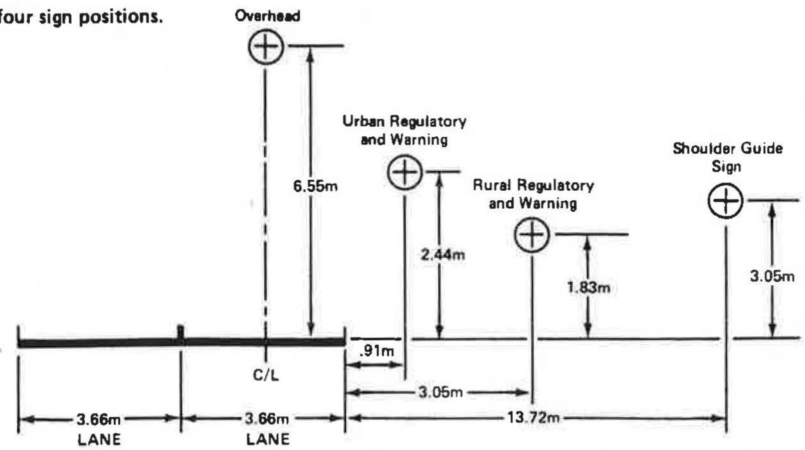
TEST VEHICLE

A full-size station wagon, without tinted glass, was used throughout the test as the primary test vehicle from which measurements were made. Loading conditions of this vehicle were maintained constant throughout the study. The headlamps used were photometrically checked and supplied by General Electric Corporation and conform to the recommended standard for photometrics of the Society of Automotive Engineers (SAE) (12). Two secondary vehicles were also used to check the values obtained with the primary vehicle and to broaden the data base for field luminance. The headlamps of all vehicles were aligned by using the recommended SAE visual aiming method.

SIGNING MATERIALS

The signing materials studied are representative of retroreflective sheeting materials used for traffic-control signs; include silver-white, yellow, orange, red, and green colors; and span a range of specific intensity from 1 to 800 $cd/lx/m^2$ (1 to 800 $cp/fc/ft^2$).

Figure 1. Centroids for four sign positions.



The materials used represented three levels of sheeting: enclosed lens, encapsulated lens, and cube corner prismatic. These sheetings, in each color, were further attenuated with up to 10 thicknesses of clear transparent acrylic plastic for purposes of broadening the luminance range from 3 to 15 determinations/color by adding successive thicknesses of plastic after unobstructed readings had been made.

PHOTOMETRIC INSTRUMENTATION

Determinations of specific intensity per unit area of materials used in the outdoor test, including transparent overlays, were made in a 15-m (50-ft) laboratory darkroom equipped for routine photometric testing. The equipment and the procedure used conform to Federal Test Method Standard 370 (13).

Determinations of specific intensity per unit area were made at observation angles of 0.2° and 0.5° at -4° entrance, corresponding to two reflective intensity specification values most representative of the sign-luminance determinations. The photometric equipment uses a 2856 K source and has a photocell corrected for linearity of response. In the National Bureau of Standards (NBS) collaborative tests of reflective materials (14), this equipment has proved to be very close to the median of values reported by all laboratories in the NBS program.

Luminance measurements were made with a Gamma Scientific model 2000 telephotometer. This instrument, which has a transistorized photomultiplier and electrometer amplifier, independent battery power supply, five acceptance angles, a measurement span from 0.003 to 100 000 cd/m^2 (0.01 to 30 000 ft·L), photopic color correction, and internal standardization and calibration, is suited for such measurements. At the outset and at the conclusion of the tests, the instrument was calibrated with an NBS standard source and over a number of tests averaged ±2.5 percent.

DISCUSSION OF RESULTS

Plotting of sign-luminance measurements versus specific-intensity data reveals a linear relation that differs slightly depending on the chosen shoulder position of the sign and varies quite significantly depending on the beam mode used or if the overhead sign position is used. In the testing, the color of the reflective material was not an apparent variable except that color results in a differing value of specific intensity.

Computer analysis by use of a least squares regression was performed to determine both the linear and exponential fit for a given set of data points. Forty-eight or more pairs of data were analyzed for each linear expression. In each of the sign-luminance specific-intensity determinations given in Table 1, the following expression is used:

$$y = ax + b \quad (1)$$

or

$$x = (y - b)/a \quad (2)$$

where

y = sign luminance (cd/m^2);
a = slope of the line;
x = specific intensity of the reflective material ($cd/lx/m^2$); and
b = constant.

r^2 = quality of fit with the data; it is that portion of the variability in the data that is explained by the regression equation.

As an example, sign luminance is desired for a yellow warning sign in the urban shoulder location when viewed from 91.5 m (300 ft) on low beams. When measured at 0.5° observation and -4° entrance in the laboratory, a material has a specific intensity of 110 $cd/lx/m^2$ (110 $cp/fc/ft^2$). From Table 1, the appropriate formula is $y = 0.13x - 0.45$; thus, $y = 0.13 \times 110 - 0.45 = 13.85$ cd/m^2 (4.0 ft·L) sign luminance.

The 183-m (600-ft) distance is only related to the 0.2° observation angle, and the 91.5-m (300-ft) distance is related to the 0.5° observation angle. These relations are appropriate and must be kept in mind in attempting to predict sign performance.

It should be pointed out that the above relations are appropriate for the typical domestic automobile and headlight and should not be translated to vehicles that have widely differing headlamps or headlamp-to-eye-height distances. The relations hold for colors tested by the authors and dirty and weathered signs but not dirty headlamps or windshields. Dirty or weathered signs must be evaluated with a portable photometer such as a Gamma model 910 or be photometrically evaluated in the laboratory.

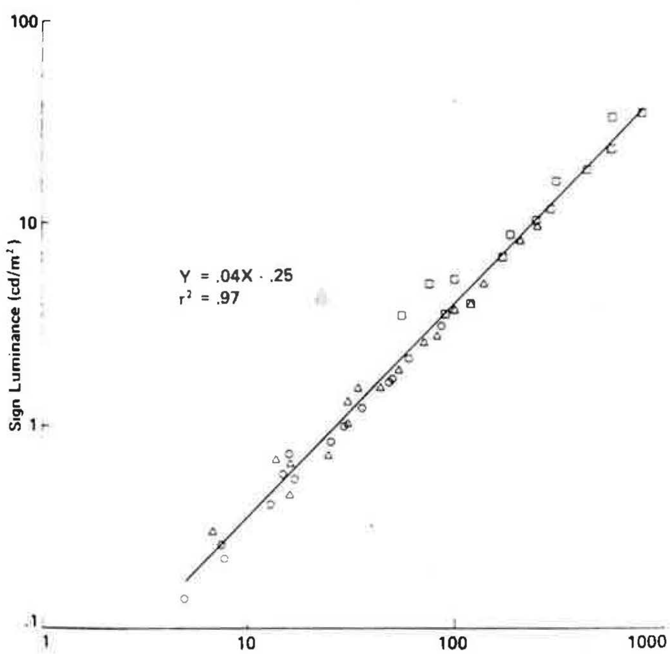
By substituting values and solving for x, the specific intensity of the sheeting can be determined if a predetermined sign luminance is desired. This procedure can aid in the selection of the appropriate reflective material for the sign application. The typical data points that represent sign luminance versus specific intensity of the reflective material for one set of viewings are

Table 1. Equations for sign luminance and specific intensity for various sign locations and beam modes.

Sign Position	Distance (m)	Headlamp Beam	Specific Intensity (cd/lx/m²)	Sign Luminance (cd/m²)	r^2
Urban shoulder	183	Upper	x = 0.86y + 2.99	y = 1.14x - 0.64	0.98
		Lower	x = 23.16y + 9.75	y = 0.04x - 0.25	0.97
	91.5	Upper	x = 0.24y + 7.62	y = 3.92x - 20	0.94
		Lower	x = 7.47y + 4.07	y = 0.13x - 0.45	0.98
Rural shoulder	183	Upper	x = 1.01y - 0.28	y = 0.96x + 3.72	0.97
		Lower	x = 20.42y + 8.22	y = 0.047x - 0.20	0.97
	91.5	Upper	x = 0.25y + 7.43	y = 3.82x - 21	0.94
		Lower	x = 5.84y + 4.03	y = 0.16x - 0.41	0.96
Shoulder guide	183	Upper	x = 3.07y + 4.80	y = 0.32x + 0.36	0.97
		Lower	x = 3.78y - 4.48	y = 0.25x + 3.42	0.96
	91.5	Upper	x = 2.11y + 13.60	y = 0.47x + 6.02	0.99
		Lower	x = 8.84y + 11.86	y = 0.11x - 1.23	0.99
Overhead	183	Upper	x = 3.45y - 9.71	y = 0.29x + 3.66	0.98
		Lower	x = 52.04y - 12.38	y = 0.02x + 0.29	0.98
	91.5	Upper	x = y - 12.65	y = 1.00x + 12.65	0.98
		Lower	x = 33.33y + 1.67	y = 0.03x - 0.05	0.99

Note: 1 m = 3.3 ft, 1 cd/lx/m² = 1 cp/fc/ft²; and 1 cd/m² = 0.29 ft L.

Figure 2. Sign luminance versus specific intensity for urban sign location at sight distance of 183 m (600 ft) using lower beam headlamps.



shown in Figure 2 together with the linear equation that has the calculated best fit.

CONCLUSIONS

To aid in translating from photometric determinations of specific intensity per unit area of reflective sheetings to the reflective performance of the sign in place, the study examined the relations in a field-laboratory series of tests. Determinations of nighttime sign luminance were made from the driver's eye position in a standard-sized passenger automobile with carefully selected normal headlamps. Measurements were made on a smooth tangent roadway by using a laboratory telephotometer at distances of 183 and 91.5 m (600 and 300 ft). Reflective samples were mounted in typical sign positions. The reflective materials used represented specific intensities from 1 to 800 cd/lx/m² (1 to 800 cp/fc/ft²) in silver-white, yellow, orange, red, and green.

Specific intensities per unit area were determined for the same materials by standard laboratory photometric methods. Determinations at the observation angle of 0.2° were correlated with 183-m (600-ft) luminance readings and those at a 0.5° observation angle with 91.5-m (300-ft) luminance readings. A linear regression equation was determined for each viewing condition. The resulting equations established the relation between sign luminance and the specific intensity of reflective materials for each distance, sign, and headlamp position.

Should minimum sign luminances be established, or if the research cited previously is used to establish desirable sign luminances, ready translation from photometric values to sign luminance is available in convenient form.

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Evaluation of Daytime High-Visibility Aids for Motorcyclists

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The results of a survey of consumer attitudes toward such conspicuity aids for motorcyclists as jackets, waistcoats, sleeves, and slipovers are reported, and the results of laboratory and field trials conducted to determine the effectiveness of such conspicuity aids in facilitating the detection of motorcyclists are reported. These results are based on the first three years of a continuing research project. The user attitude survey indicates serious design problems with some types of conspicuity aids and, for most materials, a severe lack of fastness of both color and fluorescence. The laboratory trials indicated an inverse logarithmic relation between the projected area of fluorescent color and mean detection time.

To examine some of the problems associated with the design, use, and effectiveness of high-visibility aids and clothing for daytime use by motorcyclists, the U.K. Transport and Road Research Laboratory has sponsored a 3-year evaluation program that has been carried out by the Institute for Consumer Ergonomics and the Department of Transport Technology at Loughborough University. This paper briefly discusses the three principal research areas investigated in this project:

1. An evaluation of user attitudes to the types of clothing and other conspicuity aids currently in production and the subsequent design of more suitable clothing (1),
2. A laboratory simulation of the effectiveness of high-visibility aids in the daytime detection of motorcyclists (1), and
3. Field trials to determine the effect of such high-visibility aids on gap acceptance by drivers (2).

These research areas carried out over a period of 3 years form three parts of a continuing program of research into the conspicuity of two-wheeled vehicles that in the long term will embrace both motorized and nonmotorized vehicles under both daytime and nighttime conditions.

USER SURVEY

Study Design

There is strong evidence that, although motorcyclists can make themselves more visible by wearing such fluorescent clothing as slipovers, waistcoats, or jackets, there is some consumer reticence toward using these conspicuity aids. Generally the number of riders wearing fluorescent clothing is very small; in an observational survey carried out in conjunction with this work, only 1.5 percent of the sample (N = 2842) were observed to be wearing any type of high-visibility clothing. To examine this problem in greater depth, a series of discussions on attitudes was carried out with groups of motorcyclists. This was followed by a survey of users' opinions on safety clothing. The survey attempted to

1. Establish the perceived effectiveness of different safety clothing,
2. Isolate particular problems of use,
3. Evaluate the acceptability of high-visibility clothing,
4. Determine users' willingness to purchase such garments, and
5. Evaluate the fastness of the fluorescence and color of the clothing.

A number of different styles of safety-related clothing were purchased and distributed free of charge to motorcyclists in four different areas in the United Kingdom. After three months of use, the motorcyclists were requested to complete an evaluation questionnaire. A large range of safety clothing was obtained, and from this range 19 items were selected for evaluation on the basis of the following five criteria:

1. Style—slipover, waistcoats, jackets, and sleeves;
2. Method of fastening—zip, Velcro, ties, buttons, elasticated sides, and press studs;
3. Material—Wavelock PVC, PVC-coated woven fabric, Webb-lite;
4. Color—red-orange to orange range plus Saturn yellow; and
5. Cost.

Altogether, 924 items of clothing were distributed in five population centers: Swindon (290), Peterborough (88), Nottingham (150), Manchester (113), and Loughborough (283). As the clothing was distributed, anthropometric measurements were taken from the users. Because sleeves were an unpopular option, 32 pairs of sleeves were given to respondents who were also given a slipover or a waistcoat. Therefore, only 892 volunteers received the 924 items. Three months after the date of distribution, the volunteers were each sent a copy of the evaluation questionnaire. Three reminders