that supplied the information used in this paper is also acknowledged.

REFERENCE

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Abridgment

Performance of Signs Under Dew and Frost Conditions

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The nighttime legibility and target value of retroreflective traffic-sign legend and background materials are frequently decreased and occasionally lost because of dew or frost formation on the face of the sign. Dew forms when the temperature of the sign face approaches the dew point of the surrounding air; frost forms when this temperature is below the freezing point of water. Certain atmospheric conditions are known to be favorable for dew formation: (a) a clear sky, (b) a still atmosphere, and (c) a supply of moisture in the air around the sign, i.e., high humidity. The frequency and duration of occurrence of dew formation therefore vary with such factors as climate, locale, season of the year, and atmospheric conditions.

Several different types of materials are commonly used as retroreflective surfaces on traffic signs to convey information to motorists under low-visibility conditions. Field experience has shown that formation of dew and frost on such materials occasionally reduces the effectiveness of signs to varying degrees for different types of materials and sometimes even totally obliterates the message under headlight illumination. The distinctive shapes of some of the more important regulatory and warnings signs (STOP, YIELD, CAUTION, RAILROAD CROSSING, SCHOOL) (1) help to overcome such temporary losses of sign-legend effectiveness and have even led to the suggestion of clearly distinctive shapes for other signs, such as a pennant shape for DO NOT PASS and an arrow shape for ONE WAY. However, even these distinctively shaped signs lose varying amounts of target value for the different types of materials when headlight illumination is scattered and diffused by droplets of dew or crystals of frost on the face of the sign. In the case of freeway guide signs, the decrease in the visibility of the legend sometimes represents total loss of the sign message.

Efforts to overcome the effects of this phenomenon have perhaps justifiably been given lower priority than many other more urgent problems that need research. In the experience of many traffic engineers, the fogging over (dew) or frosting over of sign messages occurs only rarely, only after the evening rush hour, and with fairly predictable regularity only during certain seasons of the year. However, recent research suggests that a lessening of the conspicuity (target value) and specificity (clearness of message) of traffic signs has adverse effects on driver behavior (2, 3, 4). Furthermore, commonly accepted engineering and psychological principles for transmitting information to drivers clearly demand as much uniform signing redundancy (distinctive shape, color, and message) and target value as can be maintained under any given weather conditions (5, 6).

In the absence of suitably energy-conservative means of otherwise overcoming the adverse effects of dew and frost on existing signs, the signing materials industry should be encouraged to develop materials that are less subject to these effects. In the meantime, it is expedient to evaluate existing materials and consider the use of the least affected combinations of signing materials currently available.

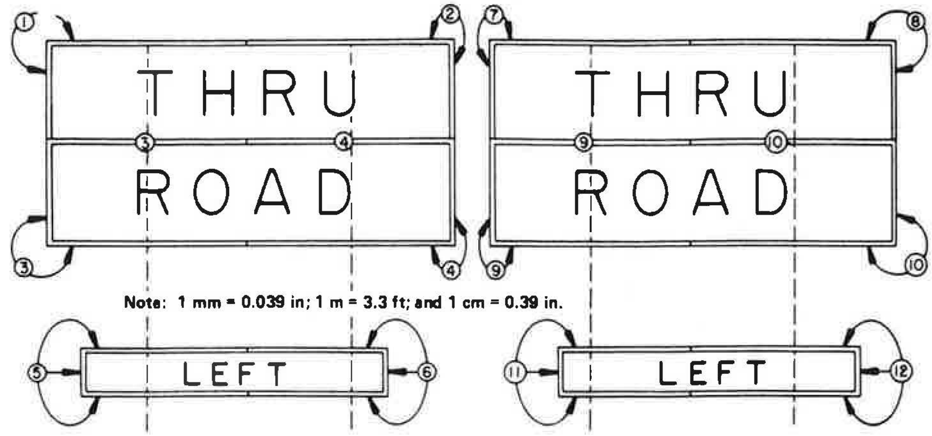
The legibility of signs under dew and frost conditions has been observed to vary with different combinations of legend, background, and mounting materials. The relative performances of different combinations of these materials have also been noted to vary somewhat with age (exposure) of the materials. The purpose of this study was to evaluate the effects of dew and frost on the nighttime legibility of several possible combinations of retroreflective legend and background materials under headlight illumination. Observations were made over an 8-month period, from April through November, in central Kentucky. A total of 31 nights with observed natural dew or frost formation between 9:00 p.m. and midnight were selected for purposes of sign evaluation.

TEST CONDITIONS AND MATERIALS

The observation site was at Blue Grass Field, the Lexington-Fayette County, Kentucky, airport, in a small valley surrounded on three sides by runways, taxiways, and airport service facilities. A National Oceanic and Atmospheric Administration weather service station at the airport provided ready access to needed atmospheric data.

Consideration of reported effects of light source and viewing conditions (7, 8, 9, 10) led to use of a standard automobile headlight system that was mounted on skids for mobility and maintained at constant brightness by a portable gasoline-powered generator and battery charger. Various combinations of encapsulated-lens, enclosed-lens, and button-copy materials were included in the test signs (Figure 1) (11, 12). All direct-applied legend and border materials were mounted in the shop. All demountable, embossed, and button-copy materials

Figure 1. Sign materials.



SIGN LARGE 3 175 mm ALUMINUM
SMALL 3 175 mm ALUMINUM

BACKGROUND TOP HALF ENCLOSED LENS
BOTTOM HALF ENCAPSULATED LENS
SMALL PANEL ENCLOSED LENS

COPY TH ENCAPSULATED LENS DIRECT APPLIED
RU ENCLOSED LENS DIRECT APPLIED
RO BUTTON COPY
AD ENCAPSULATED LENS DEMOUNTABLE
LE ENCLOSED LENS EMBOSSED
FT ENCAPSULATED LENS EMBOSSED

BORDER ① ENCAPSULATED LENS DIRECT APPLIED
② ENCLOSED LENS DIRECT APPLIED
③ BUTTON COPY
④ ENCAPSULATED LENS DEMOUNTABLE
⑤ ENCLOSED LENS EMBOSSED
⑥ ENCAPSULATED LENS EMBOSSED

SIGN LARGE 19.05 mm PLYWOOD, 1.58 mm ALUMINUM OVERLAY
SMALL 3 175 mm ALUMINUM

BACKGROUND TOP HALF ENCLOSED LENS
BOTTOM HALF ENCAPSULATED LENS
SMALL PANEL ENCAPSULATED LENS

COPY TH ENCAPSULATED LENS DIRECT APPLIED
RU ENCLOSED LENS DIRECT APPLIED
RO BUTTON COPY
AD ENCAPSULATED LENS DEMOUNTABLE
LE ENCAPSULATED LENS EMBOSSED
FT ENCAPSULATED LENS DIRECT APPLIED

BORDER ⑦ ENCAPSULATED LENS DIRECT APPLIED
⑧ ENCLOSED LENS DIRECT APPLIED
⑨ BUTTON COPY
⑩ ENCAPSULATED LENS DEMOUNTABLE
⑪ ENCAPSULATED LENS DEMOUNTABLE
⑫ ENCAPSULATED LENS DIRECT APPLIED

LARGE PANELS 1 22 x 2 44 m, COPY 38 1 cm (BUTTON COPY 40.6 cm), BORDER 2.54 cm
SMALL PANELS 1.83 x 0.305 m, COPY 15.2 cm, BORDER 2.54 cm

SIGN HEIGHT TO TOP 3.96 m WITH 45.7 cm SPACE BETWEEN LARGE AND SMALL PANEL

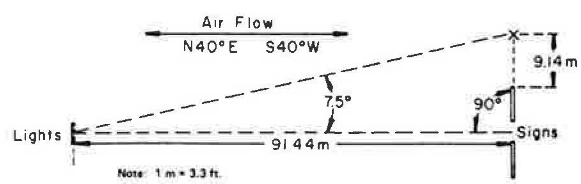
Figure 2. On-site mounting.

were mounted in the field, and the signs were installed at standard mounting height (Figure 2). The headlighting system was installed on a line perpendicular to and centered between the signs so they could be aimed either to a point midway between the signs or to a marker offset 9.144 m (30 ft) from the left-hand sign (Figure 3).

TEST PROCEDURES

Test procedures were varied according to prevalent atmospheric conditions. Normally, observations and photographs were made at 1-h intervals. Some conditions (e.g., a drastic change in the amount of dew)

Figure 3. Layout of test system.



called for the shortening of intervals between observations. The normal period of observations, from 1 h after dark until midnight, was varied to meet conditions and schedules. During early experimental observations in April and May, it was often necessary to wait until after midnight to observe dew or frost conditions. Subsequently, observations were continued only until midnight or until atmospheric and sign conditions stabilized.

Sign positions were interchanged (left to right) in September, approximately at the midpoint of the study, to examine the possibility that the positions of the signs relative to each other were affecting the results.

Sign conditions at the time of each recorded manual observation on each of the 31 nights selected for evaluation were photographed and logged for later corroborative comparison with on-site subjective evaluation of the relative performance of each of the combinations of signing materials. Early experimentation resulted in the selection of photographic techniques that produced color slides of sufficient fidelity to allow experienced viewers to arrive at comparative evaluations nearly identical to those of the on-site observer except in those cases of combinations of signing materials with

Table 1. Total hours of observed dew or frost on test materials.

Item	Hours of Dew or Frost on Material	Percentage of Total Hours of Dew or Frost
Legend		
Direct-applied enclosed lens on enclosed lens, large plywood-backed panel	41	74
Direct-applied enclosed lens on enclosed lens, large aluminum panel	32	58
Direct-applied encapsulated lens on enclosed lens, large plywood-backed panel	24	44
Direct-applied encapsulated lens on enclosed lens, large aluminum panel	18	33
Embossed enclosed lens on enclosed lens, small aluminum panel	35	64
Embossed encapsulated lens on enclosed lens, small aluminum panel	26	47
Embossed encapsulated lens on encapsulated lens, small aluminum panel	20	36
Direct-applied encapsulated lens on encapsulated lens, small aluminum panel	8	14
Button copy on encapsulated lens, large plywood-backed panel	26	47
Button copy on encapsulated lens, large aluminum panel	20	36
Demountable encapsulated lens on encapsulated lens, large plywood-backed panel	18	33
Demountable encapsulated lens on encapsulated lens, large aluminum panel	12	22
Border		
Direct-applied encapsulated lens on enclosed lens, large plywood-backed panel	16	29
Direct-applied enclosed lens on enclosed lens, large plywood-backed panel	24	44
Button copy on encapsulated lens, large plywood-backed panel	49	80
Demountable encapsulated lens on encapsulated lens, large plywood-backed panel	18	33
Embossed enclosed lens on enclosed lens, small aluminum panel	23	42
Embossed encapsulated lens on enclosed lens, small aluminum panel	16	29
Direct-applied encapsulated lens on enclosed lens, large aluminum panel	15	27
Direct-applied enclosed lens on enclosed lens, large aluminum panel	25	45
Button copy on encapsulated lens, large aluminum panel	49	89
Demountable encapsulated lens on encapsulated lens, large aluminum panel	17	31
Demountable encapsulated lens on encapsulated lens, small aluminum panel	16	29
Direct-applied encapsulated lens on encapsulated lens, small aluminum panel	14	25

similar performance. Use of a 2-s exposure of Kodak Ektachrome EH 135 (ASA 160) film and a Bushnell 300-mm lens with blue filter resulted in sign photographic brightness approximating bright headlight illumination at f5.5 and dim headlight illumination at f8.

RESULTS

Total hours of observed dew or frost on each of the combinations of sign materials are given in Table 1. Although 85.5 h of dew or frost occurred at ground level at the test site during the selected periods of observation, only 55 h of dew or frost was observed on one or more of the combinations of sign materials, and a maximum of only 49 h of dew or frost was observed on any single combination. The percentage of total hours of dew or frost on each of the combinations of materials (Table 1) is based on the 55 h of dew or frost formation on the signs. (Temperature, dew point, and humidity data for each of the nights of observation are available on request from the authors.)

One of the most obvious phenomena that recurred throughout the study was the early accumulation of dew on sign materials that had a plywood-backed aluminum panel (see Figure 1, upper right). Dew always formed there first, with greater subsequent total accumulation, and seemed to affect legend performance more seriously. Furthermore, there was a marked difference in subjectively apparent legend performance on the two types of background sheeting material on this sign panel. Legends mounted on the encapsulated-lens reflective materials performed better than legends mounted on the enclosed-lens material.

All combinations of materials appeared to be less affected by frost than by dew. Button copy performed much better under frost conditions than under heavy dew conditions. However, the performance of button copy relative to the performance of the other legend materials degraded with time. It may be that dirt (accretion of atmospheric dust) played a large part not only in the decrease in relative performance of the button-copy materials but also in the noted general degradation in performance of all test materials over time.

A marked difference in the angularity of button and reflective-sheeting materials was noted. The reflective-sheeting legend could be seen easily up to about 30° from center at 91.44 m (300 ft). The button legend showed very little angularity, especially under dew conditions.

At various times, dew- and frost-free areas would appear on the test signs but, unlike the similar bright areas noted on roadside signs, these were almost never in the same places on successive nights. No convincing explanation of this phenomenon or any clear identification of the variables believed to be involved was ever found. Combinations of effects peculiar to the test site and the test installation are believed to have been involved.

Under road conditions, a dew-free area is usually observed on the sign face where the posts are attached to the back of the sign. The posts act as heat sinks. It is possible that air currents and turbulence created by traffic near roadside signs also help to cause the sign face to cool before the posts cool. The experimental signs were generally not exposed to such air turbulence. Furthermore, the size of mounting posts was a factor. For signs of this size, the posts used in practice are usually larger than the ones used in the test installation. The extra heat stored in the larger posts would probably cause this phenomenon to be more stable and pronounced in the case of roadside signs. The noted ephemerally bright (dew- and frost-free) spots were not usually associated with the mounting posts at the test installation.

Forty-five days after the beginning of observations, the relative performances of the various combinations of retroreflective materials were judged to be in the following order (beginning with the last legend to lose reflectability):

1. Button copy (RO) on encapsulated lens, aluminum panel;
2. Button copy (RO) on encapsulated lens, plywood-backed panel;
3. Direct-applied encapsulated lens (FT) on encapsulated lens, aluminum panel;
4. Embossed encapsulated lens (LE) on encapsulated lens, aluminum panel;

5. Demountable encapsulated lens (AD) on encapsulated lens, aluminum panel;
6. Direct-applied encapsulated lens (TH) on enclosed lens, aluminum panel;
7. Demountable encapsulated lens (AD) on encapsulated lens, plywood-backed panel;
8. Embossed encapsulated lens (FT) on enclosed lens, aluminum panel;
9. Embossed enclosed lens (LE) on enclosed lens, aluminum panel;
10. Direct-applied encapsulated lens (TH) on enclosed lens, plywood-backed panel;
11. Direct-applied enclosed lens (RU) on enclosed lens, aluminum panel; and
12. Direct-applied enclosed lens (RU) on enclosed lens, plywood-backed panel.

Final subjective ratings of the legends under light dew conditions after 6.5 months of observation, again in order from best to poorest performance, were as follows:

1. RO on encapsulated lens, aluminum panel;
2. AD on encapsulated lens, aluminum panel;
3. RO on encapsulated lens, plywood-backed panel;
4. FT on encapsulated lens, aluminum panel;
5. LE on encapsulated lens, aluminum panel;
6. TH on encapsulated lens, aluminum panel;
7. AD on enclosed lens, plywood-backed panel;
8. FT on enclosed lens, aluminum panel;
9. LE on enclosed lens, aluminum panel;
10. TH on enclosed lens, plywood-backed panel;
11. RU on enclosed lens, aluminum panel; and
12. RU on enclosed lens, plywood-backed panel.

Two exceptions to these findings were noted during heavier dew formation. The button legend, RO, was about fifth or sixth in order of performance under moderately heavy dew conditions. Under conditions of rapidly forming heavy dew, the button-copy letters exhibited the worst performance (eleventh and twelfth).

Border materials performed very similarly to like legend materials with the notable exception that the button border generally exhibited the worst performance of all the border materials. During the later observations, button-copy borders frequently all but disappeared even under light dew conditions.

Most of the observations under frost conditions occurred during the second half of the study after the sign panels were interchanged (left to right). The superiority of button-copy and encapsulated-lens material was often rather striking. Subjective ratings of legend materials relative to each other under frost conditions, beginning with the last to lose reflectivity, were as follows:

1. RO on encapsulated lens, aluminum panel;
2. RO on encapsulated lens, plywood-backed panel;
3. AD on encapsulated lens, aluminum panel;
4. AD on encapsulated lens, plywood-backed panel;
5. TH on enclosed lens, aluminum panel;
6. FT on enclosed lens, aluminum panel;
7. FT on encapsulated lens, aluminum panel;
8. LE on encapsulated lens, aluminum panel;
9. LE on enclosed lens, aluminum panel;
10. TH on enclosed lens, plywood-backed panel;
11. RU on enclosed lens, aluminum panel; and
12. RU on enclosed lens, plywood-backed panel.

Subjectively rated relative effects of dew and frost on target values of background materials were as follows (the best performance is ranked first):

1. Encapsulated lens on aluminum panel,
2. Encapsulated lens on plywood-backed panel,
3. Enclosed lens on aluminum panel, and
4. Enclosed lens on plywood-backed panel.

CONCLUSIONS

The frequency of some amount of dew or frost formation observed on test sign materials was much greater than expected, i.e., more than 65 nights (9:00 p.m. to midnight) out of the 214 nights (April 18 to November 17) involved. On many selected observation nights when there was noticeable dew on the signs, the formation of ground fog prevented photography essential to the established evaluation procedure. Furthermore, observers frequently could not be present at the test site when atmospheric conditions were suggestive of dew or frost formation. It is conservatively estimated that noticeable dew or frost formation on the test signs, viewed from a distance of 91.44 m (300 ft) under direct headlight illumination, occurred on at least one out of every three nights during the study period. The adverse effects of dew and frost on signs are therefore not frequently imposed on motorists in areas that have climates similar to that of the test site.

Appropriate use of the guidance provided by the following conclusions is thus recommended:

1. Under direct headlight illumination from a distance of 91.44 m and with natural dew formation conditions at the sign face, the performance of encapsulated-lens retroreflective sign materials was found to be far superior to that of enclosed-lens material and equal (for light dew) or superior (for heavy dew) to button copy. Under the same viewing conditions but under natural conditions of frost formation, the performance of button copy was far superior to that of all other test materials; however, viewed from a position offset 1.8 m (6 ft) laterally from the light source, encapsulated-lens material and button copy were almost identical in performance under frost conditions; viewed from greater lateral offset distances, all other test materials were far superior to button copy under both dew and frost conditions.

2. Of the sign materials under study, button-copy legends exhibited the most noticeable continuing degradation in performance under both dew and frost conditions during the 8 months of observations, presumably because of aging (weathering) or accumulation of dirt film or both.

3. The observed decreases in sign legibility and target value because of dew and frost formation were always more pronounced on the plywood-backed sign panel than on the plain aluminum panels.

4. Because of the reduction in dew and frost formation time, encapsulated-lens background material greatly improved the legibility of all legends under all degrees of dew and frost formation observed. This was most noticeable in the case of the directly applied legends: An encapsulated-lens legend on an encapsulated-lens background was far superior to an encapsulated-lens legend on an enclosed-lens background.

5. Subjective ratings of the relative performance of the sign materials under dew and frost conditions were almost imperceptibly affected by aiming the headlights 30° to the left of center of the test sign installation (Figure 3). However, when the headlights were centered on the test sign installation and observers viewed the signs from an angle of 1° to the left or right of center at the light source, both the lack of angularity of button copy and the superiority of the encapsulated-lens materials were quite apparent. Differences in angularity

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