For three construction seasons, these changes were used in approximately 30 installations, most of which were failed sites. After 3 years, all sites are still operational except for a few damaged by highway reconstruction.

Except for the introduction of encased wire and cold-applied sealants, change in materials is less important than emphasis on correct, uniform methods of signal-wire installation. A survey of the department's regional offices indicated that installation techniques varied among locations because of different interpretations of specifications and availability of materials. Major specification changes were

1. Use of No. 14 AWG stranded, single-conductor wire encased in a continuous vinyl or polyethylene plastic tube;
2. Use of improved roadway loop-embedding sealer; and
3. Use of chipped-out or cored corners instead of diagonal sawcuts at the corners of the loop slot cutouts.

Use of state-specified encased signal wire makes it necessary to saw a 3/8-in.-wide slot. The corner diagonal saw cuts have been replaced with chipped or cored corners. Hot bituminous-based sealants have been replaced by an approved list of cold-applied sealers. However, these changes are less critical to loop longevity and operation than the proper loop installation method, which should be standardized throughout the state.

In an attempt to standardize installation methods, a loop-wire informational seminar was conducted. Representatives from various regional construction and maintenance crews attended a 1-day presentation and a 1-day demonstration of field techniques. A special report was prepared for this seminar (1). This special report and the final report (2) are available from NYSDOT for those seeking more details. A video tape (3) that shows correct installation techniques has been prepared by NYSDOT for FHWA and is now available as a training film.

ACKNOWLEDGMENT

The research reported here was conducted in cooperation with FHWA, U.S. Department of Transportation.

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Publication of this paper sponsored by Committee on Traffic Control Devices.

Evaluation of Reflectorized Sign Sheeting for Nonilluminated Freeway Overhead Guide Signs

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ABSTRACT

A comparative evaluation of various combinations of reflective sheeting (Level 1 = high-intensity, super-engineering grade; and Level 2 = engineering grade) on nonilluminated freeway overhead guide signs was made under road test conditions. A panel of nontechnical observers was used in a subjective evaluation of the signs. Luminance measurements were made by using a telephotometer at the front passenger's eye position using low-beam headlights together with traffic stream headlight illumination. Cost analyses were also performed. The study concluded that, pending the results of further tests on high-intensity versus super-engineering grade for sign message and border, the recommended course of action for freeway overhead guide signs was to implement high-intensity foreground (legend and border) on engineering-grade background.

There has been much recent debate and study of the most cost-effective combinations of external illumination and sign sheeting reflectivity to provide adequate nighttime visibility of freeway overhead guide signs. Sign sheeting is available in three reflectivity levels:

- Reflectivity Level 1 [high-intensity grade (HI)]--highest reflectivity; encapsulated lens reflective sheeting.
- Reflectivity Level 2 [engineering grade (EG)]--lowest reflectivity.
- Super-Engineering grade (SEG)--between Levels 1 and 2 in reflectivity.

In the mid-1970s the Ontario Ministry of Transportation and Communications (MTC) adopted use of both external sign illumination and high-intensity reflective sheeting for freeway overhead guide signs. After a trial period through the winter of 1981-1982, the external sign illumination was discontinued, except in specific critical locations, which resulted in associated savings in energy and maintenance costs. There has been no detectable increase in the number of accidents because of discontinuance of sign illumination, nor have there been public complaints.

The decision to use high-intensity sheeting, applied to both the sign foreground (message and border) and the background, had been based on an expectation of a 15-year life for the material, which, despite its higher capital cost as a single-source product, would result in an equal or better life-cycle cost than engineering-grade sheeting (assumed 7- to 8-year life) and would provide higher reflectivity. Super-engineering-grade sheeting was not available in 1977, but entered the market later as a competitor to high-intensity sheeting.

Recent unit prices of sign sheeting for MTC have been as follows (note that 1 m^2 = 0.0929 ft^2):

	Price ($/$m^2$)	Ratio
HI CDN	39.60	4.00
SEG CDN	23.60	2.83
EG CDN	9.90	1.00

By 1983 high-intensity sheeting durability problems had become apparent and were considerably reducing the effective life of the material. The failure occurred primarily in the large expanses of sign background material. It was decided to test whether more cost-effective combinations of sign sheeting materials could be used for overhead signs without sacrificing nighttime visibility.

It is worth noting here that MTC neither endorses nor condemns commercial products, and it is not the Ministry's intent to do so here. Laboratory tests, field experiments, field experience, and cost comparisons will, from time to time, lead to changes in application decisions. This should not be interpreted as a rejection of a given material or product, but rather as a decision based on cost-effectiveness assessment of a combination of factors at a particular time.

OBJECTIVE AND SCOPE

The objective of the study was to determine the most cost-effective combinations of sign sheeting materials for freeway overhead guide signs without external sign illumination.

Forty-seven signs located in metropolitan Toronto and the surrounding area were used in the study. Twelve were practice signs used to familiarize the subjects with the study procedure, and they were not included in the analyses. Roadway illumination was present throughout the test area, but signs were not illuminated by sign luminaires.

Three different reflective sign sheeting materials were used on the overhead signs. Original signs were constructed of reflective sheeting on extruded aluminium panels. Some of the test signs were refurbished signs that used reflective sheeting on a 1.2-mm (0.040 in.) aluminium overlay that was pop-rivetted to the original aluminium extrusion signs. Except for one sign, no signs were more than 4 years old. The data in Table 1 summarize the relevant parameters of the signs used in the study.

TABLE 1 Parameters of Signs in Study

Material Combination (paired signs)	No. of Signs	Position	Avg Age (months)	Avg Text (no. of letters)	Contrast Ratio[a]
HI/HI	7	Left	29	26	5
HI/HI	9	Right	25	14	5
HI/EG	5	Left	7	19	19
HI/EG	2	Right	8	14.5	19
SEG/SEG	2	Left	20	15.5	3.3
SEG/EG	2	Right	5	12.5	9.5
EG/EG	1	Left	5	12.5	7.4
EG/EG	2	Right	2	16. 5	7.4

[a]As measured in weatherometer tests with an observation angle of 0.2 and an entrance angle of -4 after 1,000 hr of exposure.

The primary comparisons in the test were between signs that use HI/HI and HI/EG sheeting materials. Test signs that use SEG sheeting materials were too few in number to permit more than speculative interpretations.

Most of the test signs were refurbished in the summer of 1983. The sign evaluation was carried out in the spring of 1984, after the signs were exposed to one winter of weathering.

A panel of nontechnical observers was employed in a subjective evaluation of the signs. Luminance measurements were also made by using a telephotometer at a front passenger's eye position and low-beam headlights together with traffic stream headlight illumination.

SUBJECTIVE EVALUATION

Methodology

Nineteen full- and part-time MTC employees took part in the study. None of the observers had any direct involvement with traffic signs in their jobs. They ranged in age from 20 to 60; six were 30 or younger, nine were between 31 and 50, and four were 51 or older. Both males and females took part in the study, and all of the observers were licensed drivers.

The sign evaluation took place on four nights in late April. An evening's evaluation session was cancelled if it was raining at the start of the session. As a result, all of the sessions took place in dry weather. At the beginning of each session the group of observers was given approximately 15 min of instruction about the study procedure. Shortly after it was completely dark (about 7:45 to 8:00 p.m.), the observers began traversing a preset route that required close to 2.5 hr to complete. Two observers rode in a car as front seat passengers with a trained driver. Training for the drivers consisted of learning the test route and practicing it a number of times so that each test sign could be passed at a constant speed of 100 km/h (62 mph) and in the same driving lane. The lane driven in was selected so that the car would pass under the left-most sign of the paired sign(s) to be evaluated. Identical full-sized station wagons were used, and the alignment of their low-beam headlights was set to a standardized specification.

Markers were placed on the roadside 210 m (700 ft) before each sign or pair of signs. The messages on the signs that were evaluated were composed of 38-cm (16-in.) letters. By using the accepted legibility distance of 6 m/cm (50 ft/in.) of letter height, the signs would be legible at approximately 245 m (800 ft). A marker distance of 210 m was used to ensure that observers would be able to read the sign at or near the beginning of the observation period. As each marker was passed, the driver instructed the observers to start observing and forming their judgments of the signs. Therefore, the observation period was more than 7.5 sec. The observers scored the left and right signs immediately after the signs were passed.

The signs were scored on four 7-point scales for brightness, legibility, adequacy, and glare. Brightness (conspicuity) was defined as how well each sign being evaluated stood out as a whole. The brightness scale ranged from 1 (not bright) to 7 (very bright). Legibility was defined as how easy it was to read each sign. The scale ranged from 1 (not legible) to 7 (very legible). Adequacy was defined as how well each sign informed the observer and whether the sign could be used comfortably. The intent was to obtain observers' subjective evaluations of the acceptability of a sign without reference to other signs. The adequacy scale ranged from 1 (not adequate) to 7 (very adequate). Glare was defined as how shiny each sign was or how much reflection of unwanted light there was. The glare scale ranged from 1 (no glare) to 7 (excessive glare).

Finally, for each pair of signs the observers were asked to indicate which sign they preferred: left, right, or no preference; thus single signs did not receive preference ratings.

Analysis

For each observer, an average rating for each of the four 7-point scales was calculated for signs of the same combination of sheeting materials. Average ratings for the left and right signs were calculated separately. These data were submitted to within-subjects analyses of variance (ANOVAs). Signs in the left and right overhead positions were analyzed separately. In each analysis the material combinations were treated as the independent variables and the observers' responses on the four rating scales were treated as the dependent variables.

The assumption underlying the averaging of observers' ratings for signs of the same sheeting-material combination while controlling for overhead position (e.g., left, HI/HI) was that a measure would be obtained that was a more stable indicator of the performance of the sign combination across the driving environment of the test than would be obtained by analyzing each sign individually.

The data in Tables 2 and 3 give the mean ratings for the measures of perceived brightness, legibility, adequacy, and glare for the sheeting materials occurring, respectively, in the left and right overhead positions. The ANOVAs for the signs in the left overhead position indicated that observers did not perceive differences between the signs in terms of brightness, legibility, or adequacy ($p > 0.05$). However, a significant difference occurred for the measure of glare ($p < 0.001$). A Newman-Keuls test,

TABLE 2 Overhead Guide Signs in Left Position

	HI/HI	HI/EG	SEG/SEG	EG/EG
Brightness	5.27	4.98	5.00	4.89
Legibility	5.08	5.20	5.37	5.32
Adequacy	4.93	5.20	5.24	5.26
Glare[a]	4.57	3.67	3.66	3.37

Note: Data for 19 observers.
[a]$p < 0.001$.

TABLE 3 Overhead Guide Signs in Right Position

	HI/HI	HI/EG	SEG/EG	EG/EG
Brightness[a]	5.23	5.18	3.71	4.53
Legibility[a]	5.21	5.86	4.50	5.00
Adequacy[a]	5.05	5.55	4.24	4.74
Glare[a]	4.09	2.87	3.08	3.82

Note: Data for 19 observers.
[a]$p < 0.001$.

carried out to determine where differences between signs existed, indicated that the HI/HI combination was judged to have significantly more glare than any of the other three combinations ($p < 0.05$, for all combinations).

The ANOVAs for the signs in the right overhead position revealed significant differences in observers' judgments for all four measures ($p < 0.001$, for all measures). Newman-Keuls tests were performed to further explore these differences. The HI/HI and HI/EG signs were judged to be better than the SEG/EG and EG/EG signs ($p < 0.05$), whereas for both legibility and adequacy the HI/EG signs were judged to be superior to the other three sheeting material combinations ($p < 0.05$). As with the left overhead signs, the HI/HI (and EG/EG) signs were rated as having more glare than the HI/EG and SEG/EG signs ($p < 0.05$).

The foregoing analyses indicate that observers prefer signs with an HI foreground (legend and border) and an EG background, especially for signs in the right overhead position. Additional analyses were conducted to further explore this interpretation.

Because the average age of the HI/HI signs was higher than that of the other four combinations (see Objectives and Scope section), the data were reanalyzed excluding the data for HI/HI signs that had been erected more than 1 year before the study. The average age of the HI/HI signs in these analyses was 7.5 months for those in the left position ($n = 2$ signs) and 8.25 months for those in the right position ($n = 4$ signs). The results mirrored the results of the previously reported analyses. That is, in the left position the HI/HI signs were rated as having more glare than the other three signs; in the right position the HI/EG combination was perceived to be more legible and adequate than the other three signs, and again HI/HI was judged to have more glare. (All of the foregoing comparisons were statistically reliable with $p < 0.05$.) The mean ratings for the left and right overhead signs are given in Tables 4 and 5, respectively.

Data were collected in the test that required observers to indicate directly a preference between pairs of signs (not all of the possible combinations of pairs of signs were represented in the study). The preference judgments between pairs of signs of different sheeting materials were analyzed by using χ^2 tests. The preference ratings involving HI/EG signs consistently favored the HI/EG sign. Specifically, HI/EG signs were preferred over HI/HI signs when the HI/EG sign was in the left position (and the HI/HI

TABLE 4 Overhead Guide Signs Corrected for Age in Left Position

	HI/HI	HI/EG	SEG/SEG	EG/EG
Brightness	4.95	4.98	5.00	4.89
Legibility	5.16	5.20	5.37	5.32
Adequacy	5.21	5.20	5.24	5.26
Glare[a]	4.11	3.67	3.66	3.37

Note: Data are for 19 observers.
[a]$p < 0.05$.

TABLE 5 Overhead Guide Signs Corrected for Age in Right Position

	HI/HI	HI/EG	SEG/EG	EG/EG
Brightness[a]	5.32	5.18	3.71	4.53
Legibility[a]	5.18	5.86	4.50	5.00
Adequacy[a]	5.14	5.55	4.24	4.74
Glare[a]	3.97	2.87	3.08	3.82

Note: Data are for 19 observers.
[a]$p < 0.001$.

in the right) ($p < 0.001$, for three comparisons) as well as when the positions were reversed ($p < 0.001$, for one comparison). Also, in the single comparison of an HI/EG sign in the left position with an SEG/EG sign in the right, the HI/EG sign was preferred ($p < 0.001$). The HI/HI sign in the left position was preferred over both the SEG/EG sign ($p < 0.05$) and the EG/EG signs ($p < 0.05$) in the right position (both tests involved one comparison). However, no systematic preference was expressed between HI/HI signs in the right position and SEG/SEG signs in the left position (involved two comparisons).

The several analyses consistently indicate that the observers had a marked preference for HI/EG signs. This conclusion is especially warranted when HI/EG signs are compared with HI/HI signs, because both types of sheeting material combinations were adequately represented in the study.

LUMINANCE MEASUREMENTS

All measurements were made with a Pritchard Spectrum Photometer Model No. 1980A, which was able to measure target areas contained within an angle range (angle of acceptance) from 0° 2' to 3° 00'. The instrument panel has a digital readout in candelas per square meter (cd/m²), with the sensitive range (measuring span) from 10^{-4} to 10^{8} cd/m² with photopic color correction, calibrated within ±4 percent of reading or 2 percent full-scale accuracy, whichever is greater. The smallest 2-minute angle of acceptance was selected because the target area contained within this angle could fit onto the narrow width of the letters of the legend at the maximum distance of 50 m (164 ft). The instrument was mounted with a specially designed mount on the passenger side with lens height at the eye level. Two operators carried out the measurements. One (passenger) aligned the optical head with the object in the field of view, while the other (driver) recorded the measurements.

The test vehicle was a standard domestic Chrysler Panel Van 198. Before the readings the windshield and headlamp surfaces were cleaned. The vehicle was positioned on the right shoulder of the roadway 50 m in front of the sign.

The background luminances were measured at four corners within the borders of available space and in the center of the sign. The sign-legend luminance was taken on the crown and arrow (if present) and the first and the last letter of each string of the message.

The luminance readings were taken while the sign was illuminated with the combination of ambient illumination (roadway lighting and so forth), vehicles moving on the roadway, and the headlights of the test vehicle (low beams only).

The average luminance values (cd/m²) for each sample reading were grouped by facing material type for background and legend of each sign for each type of facing material. Measurements could not be undertaken safely for all the signs used in the subjective evaluation because of the roadway geometrics of some sign locations.

Traditionally, contrast and luminance levels are among the parameters considered as major factors affecting legibility of a sign. These parameters, in turn, are dependent on reflectivity characteristics, color, and size of legend.

The definition of contrast used in this paper is based on the following requirements and rationale, where contrast equals the luminance ratio:

$$C = L_2/L_1 \qquad (1)$$

where

C = contrast,
L_1 = background luminance, and
L_2 = legend luminance.

The relationship between legibility distance and the legend-to-background-luminance ratios has been developed by Forbes et al. (1,2). This relationship defines, for white legend and green background, that with 20/20 vision and position between the light source and the sign, a maximum legibility distance of 6.0 to 7.2 m/cm (50 to 60 ft/in.) of letter height can be generally obtained. To achieve such conditions, typical legend-to-background-luminance ratios lie within the range of 6:1 to 13:1.

However, Forbes et al. (1,2) also state that in practice the luminance ratios cannot be achieved and the ratios that can be expected will be within the range of 3:1 to 7:1, which when translated into legibility distance correspond to 5.4 to 6.0 m/cm (45 to 50 ft/in.) of letter height.

The average contrast ratios for the HI/HI and HI/EG material combinations are given in the following table:

	Position	
Material	Left	Right
HI/HI	5.5	4.9
HI/EG	5.8	6.4

The test results indicate that either HI/HI or HI/EG will provide satisfactory contrast ratios for legibility, with high-intensity foreground (legend and border) on engineering-grade background giving somewhat better contrast ratios. This finding supports the subjective test results. The conclusion drawn from the luminance measurements is that the substitution of engineering-grade background for high-intensity background will not reduce sign legibility, provided that the legend of the sign is made of high-intensity reflective material.

COST ANALYSIS

For the cost assessment based on empirical experience over the past several years, the following assumptions were made:

1. Cost of HI/HI sign, including material and labor, equals $70.00/m² ($6.50/ft²);

2. Cost of HI/EG sign, including material and labor, equals $43.00/m² ($4.00/ft²);
3. Area of freeway overhead guide signs in Ontario on provincial freeways equals 13,940 m² (150,000 ft²);
4. Expected life of engineering-grade material equals 10 years; and
5. Expected life of high-intensity material (when used as background) equals 5 years.

The result of using high-intensity material for both foreground and background and having to refurbish signs every 5 years (on average) would be an annual refurbishing cost of about $195,000 per year. When using high-intensity foreground and engineering-grade background, there are two extreme cases to be considered:

1. The life of high-intensity material when used as foreground is 5 years, which necessitates refurbishing of the complete sign at the 5-year point; the annual refurbishing cost is $120,000 per year.
2. The life of high-intensity material when used as foreground is 10 years, which necessitates complete sign refurbishing after 10 years; the annual refurbishing cost is $60,000 per year.

Annual savings resulting from use of HI/EG rather than HI/HI on overhead freeway guide signs would appear to lie between $75,000 and $135,000. Other possibilities, falling between these two extremes, include high-intensity foreground life between 5 and 10 years; engineering-grade background life less than 10 years; and partial refurbishing before 10 years without having to scrap useful life of the engineering-grade background.

SUMMARY AND CONCLUSIONS

Three sources of information were employed in the comparative evaluation of various combinations of reflective sheeting on freeway overhead guide signs: observers' judgments, luminance measures, and cost analysis. These three sources converged in recommending, on balance, the use of high-intensity foreground (legends and borders) on engineering-grade background for freeway overhead guide signs.

Observers favored the HI/EG combination both in rating the features of these signs (more legible, more adequate, and less glare) and in consistently choosing the HI/EG combination over each of the other combinations when stating their preference judgments. The analysis of cost between HI/HI and HI/EG clearly favors the latter combination, and luminance measurements indicate that HI/EG provides contrast ratios for legibility that are at least as satisfactory as those for HI/HI.

The present study has some limitations that should be addressed. First, as mentioned previously, the evaluation focused on a comparison between high-intensity and engineering-grade backgrounds, when both had high-intensity foregrounds. The combination of HI/SEG was not represented, although it could be considered as having the potential to be a satisfactory overhead guide sign.

A second limitation results from the practical considerations of testing under clear weather conditions. Previous research (3) has identified the importance of testing under degraded visual conditions when assessing a sign's content (i.e., verbal versus symbolic messages). It would appear reasonable to extend this concern to evaluations of sign sheeting reflectivity. It has been suggested, however, that in wet or rainy conditions, sign conspicuity may be improved because of the additional light reflected from the wet roadway onto the sign. Currently there is no evidence to suggest that a particular combination of sheeting materials would perform better under degraded visual conditions.

Finally, although the sample of observers did range in age from 20 to 60, there were not enough observers in the different age categories (e.g., younger than 30, 31 to 50) to analyze for the effect of age. Research by Sivak et al. (4,5) has identified age as an important variable in tests of nighttime legibility of signs. Specifically, this research indicates that younger observers enjoy an advantage over older observers in distance of legibility. However, the more recent research by these investigators (5) found that the age-related decrement in performance was eliminated with increased contrast ratios for the letter-background combinations of signs. This latter result appears consistent with favoring an HI/EG combination with its higher contrast ratio over an HI/HI combination.

In conclusion, any decision on use of sign materials should be based on an evaluation of observers' reactions to the sign and its cost-effectiveness. It is recognized that certain potential limitations exist on the evaluations of the observers, and it is acknowledged that cost-effectiveness is based on a constantly changing equation that is affected by initial cost, product durability and life, and reflectivity. Having addressed both issues, this study reached a recommendation about sign sheeting. Specifically, pending further research, it is recommended that for freeway overhead guide signs a high-intensity foreground (legend and border) on an engineering-grade background be used.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance and support of the staff in the Traffic Surveys Section for serving as drivers, Chris Blamey for helping design the route and train the drivers, Susan Williams for analyzing the data and her constructive contributions in the preparation of this paper, and, especially, to the employees of MTC who volunteered their time to serve as observers in the study.

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Publication of this paper sponsored by Committee on Traffic Control Devices.