Evaluation of Delineation Systems for the New Jersey Barrier

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A prototype delineation system developed for installation on concrete median barriers is described. The visibility of the reflective devices used was evaluated with respect to the following factors: the effect of weathering on the reflectivity of the reflectors; the effect of weathering and other destructive forces on the durability of the reflectors; and the effects of vertical placement, opposing headlight glare, and wet nighttime conditions on the visibility of an installation. Mounting materials and techniques were evaluated to determine those that were most durable with respect to weathering and other destructive forces. To document permanently the effects of headlight glare and wet nighttime conditions on the visibility of the system, 8-mm color motion pictures were taken of an experimental installation.

The New Jersey type of concrete median barrier, known as a center barrier, has proved to be an effective countermeasure in head-on collisions. Although the barrier offers reduced accident severity to motorists, it may create a visibility problem at night for some drivers. In 1975, 258 single-automobile accidents that involved striking the center barrier occurred on 112 km (70 miles) of US-1 in New Jersey—135 at night and 52 under wet nighttime conditions. It is likely that other single-automobile strikings of the barrier go unreported, especially at night, since no other vehicle is involved and since the purpose of the median barrier is to redirect a colliding vehicle back into its own lane of travel.

Single-automobile center-barrier accidents result from what Alexander and Lunenfeld (1) describe as a "catastrophic system failure" of the "guidance level of driver performance." This performance level refers to the "drivers' task of selecting a safe speed and path on the highway." This selection involves evaluating the immediate situation, making appropriate speed and path decisions, and translating these decisions into vehicle-control actions. To perform these functions, the motorist needs to be provided with a sufficient number of unambiguous messages that are functional under a variety of weather conditions.

Delineation of median barriers will provide motorists with two guidance inputs to aid safe passage along the road. Immediately in front of the vehicle, such delineation will show where not to drive; that is, the median barrier will be perceived as a fixed, continuous, physical object to be aware of and avoided. Farther ahead of the vehicle, the reflectors will provide positive delineation by outlining the path of the barrier.

The necessity for delineation of median barriers is evident during nighttime driving conditions and especially during wet nighttime conditions. The visual contrast between the barrier and the roadway that supplies near and advance guidance information during daylight conditions is reduced during dry nighttime conditions and vanishes almost altogether in wet nighttime situations. The addition of a white pigment to the molded concrete has increased the contrast between the barrier and the road surface at night but is ineffective on wet nights. Delineators are needed to give the barrier a line of discrete visual cues that would replace or supplement the greatly diminished guidance information that exists under wet nighttime conditions.

STUDY DESIGN

The purpose of this study was to develop and test a delineator system that performs adequately on the median barrier after years of weathering. The characteristics that would affect the adequacy of the system were the visibility of the total system and the durability of its various parts.

Experimental variables were chosen for study if they were thought to affect the visibility or durability of the system. To study these variables, environmental factors that affected delineator performance were identified. The relation between these factors and the experimental variables was observed by means of performance measures developed and used during the study.

EXPERIMENTAL VARIABLES

Types of Reflective Devices

Various types of reflective devices were obtained from an extensive survey. The list of materials was narrowed down to six amber devices used in the major evaluations by using the relative reflectivity of new devices and adaptability to barrier application as acceptance criteria. The following devices were selected for the major tests (Figure 1):

Reflector	Type	Trade Name
1	Vinyl microscopic cube corner	Reflexite
2	Acrylic encapsulated lens sheeting	3M BD-21
3	Acrylic cube corner	Stimsonite 975
4	Silvered convex glass lens	Swareflex 3290
5	Wide-angle silvered acrylic cube corner	Stimsonite 2400
6	Low-profile acrylic cube corner	Stimsonite 960

Vertical Position on the Barrier

Three vertical positions were investigated during the project: on top of the barrier, on the side of the barrier 12.7 cm (5 in) from the top, and on the side of the barrier 35.6 cm (14 in) from the top. Originally, it was thought that headlight glare would render only the top-mounted devices ineffective, and therefore more emphasis was initially placed on the side-mounted locations.

Mounting Materials and Techniques

Mounting brackets consisted of steel, ethylene vinyl acetate (EVA), and scrap rubber. The EVA mount shown in Figure 2 is 10.2 by 10.2 by 5 cm (4 by 4 by 2 in), with 0.38-cm (0.15-in) thickness and holes 0.96 cm (0.375 in) in diameter. The EVA and scrap rubber were expected to be superior because of their flexibility and reduced potential danger on impact. Attachment materials studied included concrete studs (Figure 3) and butyl adhesives.

The mounting techniques used consisted of combinations of the various brackets and attachment materials. Only concrete studs were used on metal brackets, either studs or butyl adhesive were used

Figure 1. Median-barrier reflective devices.

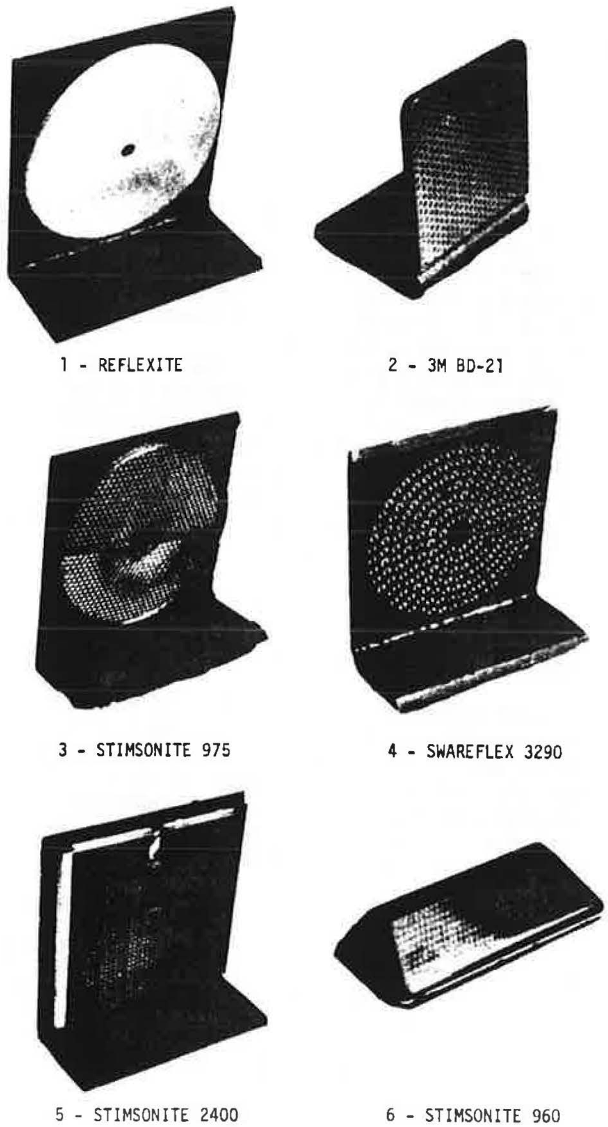

Figure 2. Ethylene vinyl acetate mount.

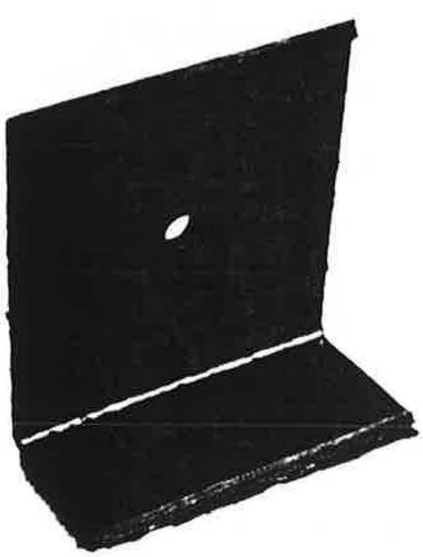

Figure 3. Concrete stud.

on EVA brackets, and only butyl adhesive was used on scrap-rubber brackets.

ENVIRONMENTAL FACTORS

Five environmental factors that could affect the visibility and durability of the experimental variables were chosen for study:

1. Weather conditions—The effect of rain on the reflectivity of the retroreflectors was considered important since the prime function of the system is to provide adequate visibility in inclement weather.
2. Dirt accumulation—It was expected that a layer of dirt on the surface of the reflectors would seriously degrade their reflectivity. How the individual devices were affected by this and whether any gross differences were discernible at the various vertical positions were considered to be important.
3. Wear from windblown particles—The scratching and pitting effect of windblown debris was monitored for the same reasons for which dirt accumulation was monitored.
4. Glare from opposing traffic—The effect of headlight glare on the visibility of the devices at the various vertical positions was studied.
5. Destructive forces—Whether any of the various reflector types or mounting materials or techniques were destroyed, lost, or rendered unusable was studied. Possible damaging forces were wet, plowed snow; impacts from vehicles or flying objects; and vandalism.

MEASURES OF PERFORMANCE

Dynamic Visibility Studies

The six test reflectors were mounted in groups on the barrier on US-1 in Trenton, New Jersey, so that the relative brightness of the individual devices at the vertical positions could be determined. A team of observers were to choose the brighter reflectors from a vehicle traveling in the left lane of traffic. The speed was about 64 km/h (40 mph), and low headlight beams were used. The team of observers consisted of engineers in the areas of traffic engineering, maintenance, quality control, and research. (The participating engineers' normal job responsibilities were related to delineation, but they were not familiar with this particular setup.) Groups of three or four raters were driven through the area and asked to fill out a questionnaire developed for the study.

Ratings were made (a) when the reflectors were new, (b) after one winter of weathering, and (c) after two winters of weathering (16 months of exposure on the barrier). The mounting configuration and the questionnaire were structured so that the following information was obtained:

1. The brightness rating of each device was compared against that of each of the others. The choices from all comparisons were totaled, and a final rating and a relative ranking were determined for each device.
2. The rater's direct preference for the various vertical positions was obtained by driving past a long stretch of the various reflectors at the different heights and considering them as a whole.
3. The rater's opinions on the adequacy of the devices as median-barrier delineators were obtained from consideration of each type of reflector over short stretches of highway.

Photometric Measurements

Specific intensity values of the six test reflectors were determined for three conditions: (a) when the reflectors were new, (b) after two winters of weathering when the reflectors were covered by dirt, and (c) after two winters of weathering when the reflectors had been cleaned. In addition, samples from each existing vertical position were removed and tested for the latter two conditions. All photometric tests were performed on an ESNA reflex photometer at incidence angles of 0° and 30° and divergence angles of 0.1°, 0.2°, and 0.5°.

Motion Pictures and Visual Observations

Eight-millimeter color motion pictures were taken of an installation over a long stretch of highway in both dry and wet nighttime conditions. A Kodak XL360 camera with Ektachrome ASA160, type G film was used. The driver and the camera operator also made visual observations of the effect of glare and the number of reflectors that could be seen in advance of the vehicle. These observations were later compared with similar observations taken from the developed film so that the reality of the motion pictures could be gauged. The film was used to allow all the staff engineers to review the installation under both wet and dry conditions.

Durability Survey for Mounts and Mounting Techniques

All analyses for durability were performed by visual observations. The various test locations were surveyed, and the devices were inspected for the following types of damage: permanent deformation of the bracket, looseness of the concrete bolts, rusting of bolts or rivets, missing reflectors or brackets, rusting of metal mounts, cracking of plastic mounts, and lifting and buckling of the butyl adhesive pads.

RESULTS

Effect on Reflectivity of Wet Nighttime Conditions

The reflectivity of devices used in an installation at New Brunswick, New Jersey, appeared to be enhanced during rain. This result was evident in both motion-picture analysis and visual observations made after 1 year of exposure. Project engineers reported that approximately five devices could be seen in advance of the automobile during dry nighttime conditions whereas 15 or more reflectors could be seen in the rain. Both observations were made while low headlight beams were being used. The visibility of the devices in the rain was limited by glare and geometry but not by reduced reflectivity.

The increase in the number of devices visible in the rain is thought to be caused by the following phenomena:

1. The rain may wash some of the dirt from the surface of the reflector and thus increase its reflectivity.
2. Decreased visibility of barriers and pavement markings may cause the barrier delineators to contrast more with the background.

Effect on Reflectivity of Dirt and Windblown Debris

As weathering or exposure time increased, the relative brightness of reflector 4 (convex glass lens) increased to the point that it was rated as the brightest after two winters of exposure (Table 1). (Ratings were calculated as follows: number of times selected as most reflective ÷ total number of comparisons with other reflectors.) This result was attributable to the dirt covering and the scratching and pitting from windblown particles observed on the surface of the reflectors. Documentation of this effect was also found in the photometric measurements. The glass reflector had a considerably smaller percentage reduction in specific intensity in all vertical positions when it was covered by dirt and when it was cleaned. The reduction in the photometric measurements after cleaning was caused by the scratching and pitting of the reflector surface by windblown particles.

The following percentages of original specific intensity for the six reflector devices resulted after two winters (16 months) of exposure at 0° incidence angle and 0.5° divergence angle:

Reflector	Top Side	Top Side Cleaned	Bottom Side	Bottom Side Cleaned
1	1	3	0	2
2	8	16	3	3
3	5	11	1	2
4	33	68	15	29
5	6	13	3	7
6	11	25	4	4

Some indication does exist that reflector 3 (the acrylic cube corner device) may retain superior reflectivity during rain. The results after one winter of weathering, given in Table 1, show that an acrylic cube corner received the highest rating when viewed in the rain and that reflector 4 (the convex glass lens device) was rated highest under dry conditions.

Adequacy of Retroreflectors as Median-Barrier Delineators

The raters viewed groups of reflectors at three vertical positions and determined whether they performed adequately as median-barrier delineators. A 50 percent threshold was chosen as a division between adequacy and inadequacy. The results indicated that after two winters of exposure all devices with the exception of the vinyl cube corner were considered adequate at the top and top-side positions. At the bottom-side position, one acrylic cube corner (reflector 3) and the convex glass lens (reflector 4) were judged adequate.

Effect of Dirt Accumulation and Windblown Particles at Various Vertical Positions

The first dynamic study, which rated unweathered reflectors, resulted in the bottom-side position being

Table 1. Comparison of retroreflectors in dynamic visibility studies.

Reflector	After Two Winters of Weathering (dry conditions)[a] Rating (¢)	Rank	After One Winter of Weathering: Rain[b] Rating (¢)	Rank	Dry Conditions[c] Rating (¢)	Rank	New Reflectors (dry conditions)[a] Rating (¢)	Rank
1	16	6	0	6	0	6	42	2
2	28	5	6	5	23	5	17	6
3	57	2	95	1	75	2	78	1
4	77	1	37	3	86	1	40	3
5	33	3	28	4	32	4	34	4
6	32	4	41	2	43	3	22	5

[a]13 raters. [b]4 raters. [c]8 raters.

Table 2. Comparison of vertical positions of reflectors.

Position	Percentage of Comparisons in Which Position Was Chosen Most Reflective[a]: New	After One Winter	After Two Winters	Number of Times Position Was Chosen More Reflective[b]: New	After One Winter	After Two Winters
Top				0	10	13
Top side	30	48	47	2	0	0
Bottom side	44	32	24	8	0	0

Note: "Equal" judgments were not counted.
[a]Composite of results from seven locations comparing the six test devices.
[b]Results of single question concerning one location where a device was mounted at all three vertical positions.

selected as the most reflective. This was true not only for the reflectors judged collectively but also for each device individually. After exposure to the environment, the top-side and top positions were selected as the most reflective in all situations where they were used. In addition, as the exposure time increased, the trend toward higher ratings with increased height of mounting became more pronounced (Table 2).

These results can be attributed to the decreased amount of dirt covering and scratching and pitting experienced by the higher mounted devices. This effect is substantiated by the photometric data given previously, where the top-side position had a consistently smaller percentage reduction in specific intensity both when covered with dirt and when cleaned.

The following results, obtained from photometric evaluation of a location where the same device was mounted at all three vertical positions, proved informative:

Position	Reflectivity (percentage of original specific intensity after 30 months of exposure): Dirty	Cleaned
Top	31	47
Top side	3	6
Bottom side	2	3

The top-side position showed slightly less reduction in reflectivity than the bottom-side position; the top position was much less affected than the other two. It has been hypothesized that dirt and debris channeled down the side of the barrier by natural wind or the slipstream wind of vehicles account for the much greater wear and dirt covering of the side-mounted reflectors.

Effect of Opposing Headlight Glare on Reflectors at Various Vertical Positions

In the study performed at the Trenton site, the raters were asked what effect headlight glare had on their ability to view the reflectors. In the first study, 10 raters said the top- or top-side-mounted devices were affected more by glare than the bottom-side ones. One rater noted an equal effect, and 2 did not respond. In the second study, 10 raters said the top and top-side positions were affected more than the bottom-side position, and 2 reported an equal effect. At this site, the traffic volume was very low and the glare effects were intermittent.

At the New Brunswick site, three researchers viewed the reflectors at the peak evening hour in both dry and wet conditions. The effect of glare here was more dramatic. Platoons of cars traveling in the opposing direction "washed out" long stretches of the reflectors. Although all reflectors were mounted at the top-side position and no evaluation could be made of the effect of glare on the other positions, the extreme "blacking out" of barrier visibility appears to preclude the effectiveness of barrier-mounted reflectors under such conditions.

Effect of Destructive Forces on Mounting Materials and Techniques

The most durable mounting technique found in the study was a butyl adhesive pad attached to a low-profile marker. In 16 months of exposure at the northbound Trenton site and 12 months of exposure at the New Brunswick site, none of the reflectors were found to be missing (Table 3). At the New Brunswick site, however, part of the butyl pad was lifting off the barrier under nine of the reflector mounts.

After 16 months of exposure, 2 percent of the mounts that used a flexible bracket (EVA) attached to the barrier with a concrete stud were missing at the northbound Trenton site. Several of the mounts, however, did not remain taut against the barrier, and the mounting bracket rotated around the stud, causing a loss of view of the reflective device.

Flexible mounts (EVA or scrap rubber) attached with a butyl adhesive had a higher rate of loss than flexible mounts with concrete studs. At the northbound Trenton site, 7 percent were missing, and 7 showed a lifting of the butyl pad. At New Brunswick, 21 percent of the mounts were missing, and the butyl pad was lifting on 43. At the southbound Trenton site, 11 percent were lost in the 30 months of exposure, and lifting was not investigated.

The metal mount attached with a concrete stud experienced the highest loss rate. At the northbound Trenton site, 53 percent were missing, and seven of the remaining mounts were bent after 16 months of exposure.

The reason for the high loss of metal mounts was thought to be their inflexibility when they are impacted by some object or force, such as a vehicle, a flying object, or wet snow from plowing operations. When hit, the metal mounts apparently suffered deformation of the L-shaped bracket or failure of the concrete stud in the concrete or both, which diminished their continued effectiveness. A possibility also exists that metal mounts that have fallen off their barriers may pose a danger to motorists if kicked up into the air by vehicle tires.

The flexible mounts do not pose the same danger to motorists as metal mounts since they are plastic or

Table 3. Durability of mounts and reflectors.

Site	Type of Mount	Mounts Installed	Mounts Missing Number	Mounts Missing Percentage	Mounts Bent	Mounts With Butyl Pad Lifting Off	Damaged Reflectors
Northbound Trenton after 16 months exposure	Metal with concrete stud	45	24	53.3	7	-	6
	EVA with concrete stud	47	1	2.1	0	-	0
	EVA with butyl adhesive	2	1	50.0	0	0	0
	Butyl adhesive	20	0	0.0	0	0	0
	Scrap rubber mount with butyl adhesive	12	0	0.0	0	7	0
Southbound Trenton after 30 months exposure	Scrap rubber mount with butyl adhesive	148	17	11.5	-	-	-
New Brunswick after 12 months exposure	EVA with butyl adhesive	75	16	21.3	0	43	0
	Butyl adhesive	57	0	0.0	0	9	0

scrap rubber and apparently remain longer on the barrier. The flexible mounts that use concrete studs appear to be more durable than those that use a butyl adhesive pad, but rotation of the bracket around the stud could be a problem. This may result from loosening of the stud or nut when a flexible bracket bends under impact and puts a stress on the attachment mechanism.

Improper installation technique, the stress put on a butyl adhesive pad during impact, and vandalism are thought to be responsible for failures of the butyl adhesive pad method. During installation, the primer must be dry before the mount is attached to the barrier. If the primer is not dry or if insufficient force is applied to the base of the bracket during mounting, premature failure may result. Mounting the L-shaped bracket toward or away from oncoming traffic may make a difference in the amount of buckling or lifting caused by impacts. It is not known whether contraction-expansion effects during freeze-thaw cycles cause any lifting of the butyl pad.

Vandalism was apparent in one area of the southbound Trenton test site. The scrap-rubber mounts suffered a higher attrition rate in an illuminated interchange area than anywhere else. It has been reported to project personnel that there is pedestrian traffic at this section of US-1 even though a safer path is available. One reflector was found dangling from the barrier as if a vandal stopped before completing the act. Vandalism is suspected since mounts that use a butyl pad can be removed from the barrier by a slow, steady force whereas the large, instantaneous force of a vehicle impact apparently temporarily flattens the flexible bracket but does not rip the pad off the barrier. This occurrence was noted in New Brunswick where an EVA-butyl adhesive mount remained on the barrier even though a force from an impacting vehicle ripped the reflector off and forced the rivet and washer through the mount. The hole through which the reflector was riveted to the bracket was enlarged and elongated, but the butyl pad and mount were otherwise unaffected.

DISCUSSION AND SUGGESTED RESEARCH

The visibility of the retroreflective devices was enhanced during wet nighttime situations. Whether this was due to increased reflectivity or increased contrast with the road is not known. In either case, the motorist is supplied with the guidance information needed to perceive the barrier hazard. However, the effectiveness of the delineators is diminished when there is opposing headlight glare. The erection of glare screens may be a solution to this problem. Research into the use of delineators on barriers topped by glare screens would be necessary since the screen may, like the barrier, channel dirt into the face of the reflector. Moving the reflector to the top of the screen may cause a reduction in the visibility of the delineators since headlight intensity may drop off rapidly with increased height. Cook (2) found that 1.2-m (4-ft) high mountings resulted in shorter detection distances than did heights of 0.75 m (2.5 ft)—the approximate height of both car headlights and the center barrier. The cost of maintaining a center-barrier installation over a more extended period of time also needs investigation. Included in such a study could be possible cleaning methods, determination of the effective life of delineators and mounts, and whether a delineator similar to the glass convex lens reflector could be less costly if manufactured in the United States (thus saving on the original installation costs).

After two winters (16 months) of exposure on the barrier, all retroreflectors would be adequate at the top position (with the exception of the vinyl cube corner). Future studies might determine whether this trend would continue, that is, whether many types of retroreflectors would remain straight at the top position and for how long. A continuance of this result might allow considerations other than initial brightness to be primary in choosing a retroreflector. Such other factors could be cost, vulnerability, and resistance to vandalism.

A study of the varying rates at which harder surface materials of reflectors are affected by the elements may be useful. The dynamic visibility study performed in this project indicates that vinyl surfaces are most quickly affected and glass surfaces least quickly. Acrylic surfaces fall in between. Whether this trend would continue as exposure time increased is not known.

Further research is also needed in developing a more durable and inexpensive mounting technique. As a result of this work, it has been recommended that a concrete stud and a butyl adhesive pad be used for mounting. Although this combination of attachment methods was not studied, it is recommended over methods that use two concrete studs, one concrete stud, or the butyl adhesive pad alone for the following reasons:

1. The butyl pad would protect the barrier surface from spalling where the mount was attached. Two studs alone would not do this.
2. The butyl pad would protect the concrete stud from rusting.
3. The butyl pad would prevent rotation of the bracket around the stud.
4. The use of the concrete stud would prevent failure of the system as a result of the butyl pad lifting off the barrier.
5. The use of the concrete stud would offer more resistance to vandalism.

Documentation of these possible advantages is necessary. In addition, whether or not a steel or aluminum rectangular plate covering the entire face of the bracket base would be necessary to prevent lifting around the edges should be studied.

The longitudinal spacing of reflectors in this study was 24.4 m (80 ft) on tangents and 12.2 m (40 ft) on curves. Increased spacing would certainly lower installation and maintenance costs, but what effect this would have on the overall effectiveness of an installation is not known. Shorter spacing would result in increased costs but might help combat the effect of glare. Shorter spacing may also be necessary in areas of extremely high dirt accumulation such as intersections. Research into these areas may prove helpful. It could be hypothesized that extremely bright reflective devices could in themselves cause a glare problem if they were spaced too closely. However, none of the products evaluated in this study were found to cause such a problem.

Whether a highly visible, durable center-barrier installation has any beneficial effects on road safety could be studied to further justify general use of such devices. Before-and-after accident analysis and other traffic performance measurements, such as lateral placements and lane volumes under wet nighttime conditions, might be used in this endeavor. The installation of center-barrier delineators along with reflective pavement markers meant to perform in inclement weather might have a beneficial effect.

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The contents of this report reflect my views, and I am responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the New Jersey Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Abridgment

Evaluation of Yellow-on-Brown Road Signs for the Adirondack Park

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In 1892, a state park was established in northern New York. This 23 413-km^2 (9000-mile^2) area, known as the Adirondack Park, is guaranteed by the state constitution to remain "forever wild." The Adirondack Highway Council, which is composed of several representatives of state agencies and the public, was convened in 1974 to formulate and implement a state policy of enhancing the appearance of park highways in the Adirondacks. In 1976 and 1977, the work of the council focused on the aesthetic appearance of road signs. They recommended that certain types of highway signs be colored yellow on brown rather than a standard white on green, blue, or brown. This combination was recommended because, over a 40-year period, these have come to be recognized as Adirondack Park colors. Thousands of brown wooden signs with yellow letters have been used throughout the park by the New York Environmental Conservation Department to identify camping areas, hiking trails, ski slopes, and other places of interest. In addition, because of a 1924 state law governing commercial signing, many private organizations and businesses in the park area have chosen to adopt these colors in their advertising.

Before a color change could be implemented, it was necessary to obtain a variance from nationally mandated signing standards. To obtain such a variance, it had to be shown that the new combination would perform as well as standard colors.

A review of existing literature showed several studies that related directly to the proposed research. Unfortunately, although each was complete within its own objectives, not enough information had been collected to answer our question: Would yellow on brown perform as well as standard color combinations for the general driving population? We also wished to survey the opinions of the motoring public on the proposed colors.

The study was divided into two phases: (a) aesthetic appraisal (both by photographic documentation and an opinion survey) and (b) measurements of visibility and legibility. This research is described in greater detail elsewhere (1).