burdens on the driving task in a way that often aggravates drivers' view of roadways, shoulders, roadsides, paths or locations of other vehicles, fixed roadside objects, and traffic control devices.

Using only the light energy emitted from automobile headlights, reflectorized devices have been developed and applied to enhance drivers' views on the highway where it has been believed to be necessary. Many of the decisions to use or not to use reflectorization have been limited by inadequate information on the priority, availability, and effectiveness of current reflective materials and devices. When decisions have been made to use reflectorized devices, the choice between practical, competitive devices for use under the great variety of conditions and purposes is not obvious. Often the need for more competition, lower costs, or new reflectorization systems is evident.

SNOWPLOWABLE RAISED PAVEMENT MARKERS

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A number of states in the northern part of the United States, including the State of Ohio, have regular annual programs to install and maintain large quantities of snowplowable raised pavement markers. These markers provide drivers with additional and effective visual delineation cues during night driving, especially in rain. In the past, the normal spacing for tangent sections and for curves was usually related to existing painted line segment-gap intervals rather than to scientifically established visual needs and capabilities of the driver.

The United States Department of Transportation (DOT), and the Federal Highway Administration (FHWA) have sponsored a number of roadway delineation studies in the past. In one study conducted by Systems Technology, Inc. (STI) (1), an empirical model for painted skip lines was developed on the basis of the results obtained in a driving simulator. This empirical model related lateral lane deviation to speed, delineation visibility, and configuration. Visual range was expressed in terms of delineation contrast and an empirical relationship was expressed between the average standard deviation of the lateral lane deviation and the contrast. In addition, the probability of lane exceedance was defined based on a Gaussian distribution of lane deviations.

The objective of a current study conducted at Ohio University sponsored by the Ohio Department of Transportation, FHWA, and DOT is to modify the empirical STI model for point sources and to determine the optimal spacings and placement for snowplowable raised pavement markers for tangent sections on Interstate highways and for entrance and exit ramps from a visibility and lateral lane deviation point of view. The spacing and placement recommendations obtained with this model will then be tested and validated in the field at night in rain using test drivers and an instrumented test vehicle. The lateral lane position, speed, and the driver's eye scanning behavior will be measured. On the basis of the analytical visibility and lane deviation calculations using the modified STI model, a spacing of 120 ft. for markers placed along skip lines is tentatively recommended for tangent sections on Interstate highways. For entrance and exit ramps with a 24-degree curvature it is tentatively recommended that the markers be placed on the outer edge line at a spacing of 25 ft.

Problems and Issues

Empirical Model

The empirical model developed by STI and modified by Ohio University for point sources is primarily based on driver performance results obtained from driver simulator studies. The degree to which the rather insensitive relationships between the number of markers and the lateral lane deviation apply to real world driving is questionable. It should be noted that the estimated average standard deviations for lateral lane deviation (based on real world night driving results obtained by STI) were about 0.85 ft. for a low-stripe contrast of 0.3 and about 0.60 ft. for a high-stripe contrast of 14. The standard deviation difference of 0.25 ft. between low contrast and high contrast represents only a 42 percent increase and would suggest that lateral lane deviation might not be the most sensitive driver performance measure. The effect of oncoming headlight glare (amplified by the wet pavement) from opposing traffic is not considered in the STI model or the modified STI model. The required point source intensities against wet and reflecting pavement surfaces need to be investigated, as well as the upper value of useful real world driving visibility distance from a lateral and guidance control point of view.

Performance Measures

The ultimate measure of performance would be the number of accidents that occurred at night in rain where delineation, or the lack thereof, was the major causative factor. It would be expected that the use of snowplowable raised pavement markers should result in a decrease of nighttime accidents in wet weather. Because accidents are low probability events and are usually caused by more than one single factor, an investigation of point source intensities against wet and reflecting pavement would require a large-scale experimental effort and large sample sizes to obtain statistically valid results.

Recording lateral lane deviations of regular traffic, or of test drivers in an instrumented vehicle, at night in rain might assist in evaluating the spacing and placement of snowplowable raised pavement markers. However, the average standard deviation of lane deviations might not be the most sensitive performance measure and might require large amounts of experimental data in order to demonstrate statistically significant differences between pavement marker spacings and/or placement schemes.

STI has proposed a measure called the probability of lane exceedance. This measure is based on a Gaussian distribution assumption and is quite sensitive to the average standard deviation of lateral lane deviations for z-values beyond +3 (low tail probabilities). It is, however, questionable whether the Gaussian assumption and the assumption that a driver always drives exactly in the center of the lane holds in the real world. Also, it is unknown how a driver's lateral lane deviation distribution changes as a function of different types of roads (narrow, two-lane rural roads versus Intertates roads; two-lane roads with wide shoulders versus two-lane roads with narrow shoulders; vertical and horizontal curves with different curvatures, etc.). The optimal spacings and placement of snowplowable raised pavement markers need to be determined for other types of roads such as rural two-lane roads.

Another performance measure might be a driver's eye-scanning behavior. It would be expected that a driver's visual information acquisition should be highest when delineation cues are at a minimum. The aspects of a driver's eye scanning behavior that are sensitive to the various levels of road delineation are uncertain.

Speed and possibly speed variability might also be useful as a performance measure if poor delineation can be expected to lead to slower speed and more speed variability. The use of speed or speed variability as a performance measure to determine the effects of various levels of road delineation remains to be seen.

Snowplowable Raised Pavement Markers

For cube-corner type markers, the photometric performance (specific intensity) needs to be known as a function of the observation angle. At present, little is known about the photometric performance of cube-corner type markers as a function of the cube angles, especially the presentation and rotation angles. In addition, the photometric performance of the markers should be known as a function of wear and tear and exposure in the field, and an appropriate methodology should be developed to predict the useful marker life in the field. In order to develop such a methodology, a minimum acceptable level of photometric performance should be scientifically established for the markers in the field. Further, because of the different geometric conditions between tangent sections and curves it might be beneficial to develop and use markers with different photometric performance characteristics.

Delineation System Interactions

The use of snowplowable raised pavement markers should be investigated in the presence and the absence of other delineation elements such as reflective post delineators. The effects of overhead road illumination on the delineation aspects of snowplowable raised markers should be investigated. Questions about the placement of the markers along curves with different radii need to be resolved.

Many of the preceding points involve difficult trade-offs. Not only should driver performance and driver safety be considered, but also the costs and the expected economic benefits need to be considered within the overall delineation system framework.

Reference

1. R. W. Allen, et al., Driver's Visibility Requirements for Roadway Delineation. Volume I: Effects of Contrast and Configuration on Driver Performance and Behavior, November, 1977, Report No. FHWA-RD-88-165.

RESEARCH NEEDS RELATED TO SIGN LIMINANCE AND VISUAL COMPLEXITY OF HIGHWAY SIGNS

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The federal standards for luminance of retroreflective materials for traffic signs are absolute; they provide no differentiation based on driver need. Driver needs for sign luminance are of two types: (a) luminance levels that define sign legibility and (b) luminance levels that define sign conspicuity. A primary reason that the standards do not reflect these fundamental driver needs is the absence of conclusive data supporting practical and reliable guidelines and the fact that available luminance is dependent on several factors other than the specific luminance of sign material.

Research groups that have recently studied sign luminance and conspicuity include Cole and Jenkins, 1980, 1981, and Mace, et al., 1982. Both groups call attention to the importance of background complexity in the study of conspicuity. Cole and Jenkins state: "No object is conspicuous per se. It can only be conspicuous in a certain background; if the background changes, then the object may or may not remain conspicuous." Mace, et al. expanded this observation, giving equal importance to the role of driver motivation and uncertainty.

"Conspicuity, like visibility and legibility, is not an observable characteristic of a sign, but a construct which relates measures of perceptual performance with measures of background, motivation, and driver uncertainty." This definition recognizes that a stop sign is more conspicuous to the driver who is alerted that a sign is imminent, or a guide sign is more conspicuous to drivers traveling to the location indicated on the sign.

Cole and Jenkins, 1980, define a conspicuous object as one ". . . that will for a given background, be seen with certainty within a short observation time, regardless of the location of the object in relation to the line of fixation." Mace, et al. suggest a slightly different definition. "Conspicuity refers to the changes in target or surround or scene (e.g., luminance of target) which will offset the performance decrements associated with both uncertainty and background complexity." This definition agrees with the Cole and Jenkins definition of a conspicuous object, but replaces probability of detection with a stimulus dimension as the scale of measurement. A statement that a sign requiring a 2-ft.-lambert increase in luminance is twice as conspicuous as a sign requiring a 4-ft.-lambert increase in luminance to attain the same level of perceptual performance may have more construct validity than similar statements based on probability of detection.

Few studies have examined the effects of the visual complexity of nighttime highway environments on driver requirements for sign size and luminance. In general, the literature suggests that sign detection can be considered a function of the visual characteristics of the target and its surround. Both Mace and Jenkins have conducted related studies in the laboratory, and Mace has conducted some research in field situations.

On the basis of these studies, Mace, et al. published a hypothetical relationship between visual complexity, sign brightness, and visual performance. It is hypothesized that in low complexity areas, signs below federal luminance standards for Type 2 sheeting may be adequate and in high complexity areas, even new Type 3 sheeting may not be adequate for conspicuity.