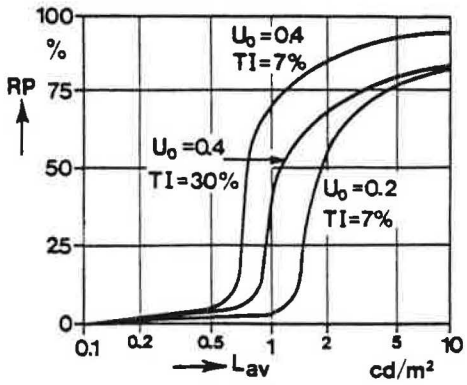
performed. For example, the results of revealing power calculations, as illustrated in Figure 1, have also been checked out in the open-air laboratory.

Figure 1 - Revealing Power (RP) at the darkest location on the road as a function of the average road-surface luminance (L_{av}) for different values of overall uniformity (U_o) and threshold increment TI (glare). Revealing power is defined as the percentage of objects (4') visible out of a set of objects, each of which has a reflectance value typical of the clothes worn by pedestrians. (ref: W. J. M. van Bommel; J. B. de Boer, "Road Lighting", 1980.)



Of course, the driving task involves rather more than just avoiding obstacles on the road. The general task of each road user is to get to the appointed destination as safely as possible, and to accomplish this the driver is constantly required to make decisions. Many of these decisions are based on the interpretation of the visual information available. This includes, amongst other things, details of the roadway, its alignment and immediate surroundings; the run of the road ahead; other vehicles such as cars and bicycles; pedestrians on or close to the roadway; and, of course, possible obstacles. The total range of visual information may therefore be of great complexity, especially when the scene is viewed dynamically.

Preparations are in hand for a series of investigations to be conducted at the open-air laboratory in which the relation between some of the above-mentioned aspects and the lighting will be examined. For this purpose, a measuring and recording setup is being prepared for installation in a normal motorcar to enable the detection speed of a motorist to be measured while he is performing a normal driving task.

REFLECTIVE CHARACTERISTICS OF ROADWAY PAVEMENTS DURING WET WEATHER

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Although the inclusion of pavement reflectance properties under wet weather conditions in the design of fixed lighting installations has been considered as necessary, it has been studied by fewer researchers and somewhat less systematically than dry pavement reflectance. The reasons are readily apparent when one considers what is required for such an investigation. One of the major problems is that measuring accuracy is much inferior to that for dry road surfaces, even in a laboratory, owing to the dynamically changing wetness of the pavement. Hence, among the tasks of this ongoing study are to explore techniques to characterize and predict, as well as accurately and rapidly measure, the reflectance properties of pavement surfaces in wet weather conditions.

Three fundamental tasks must be conducted to satisfy the goals of this study. These are 1) predict actual, full-scale roadway luminance patterns under dry and a variety of wet conditions using r-table data; 2) describe, measure, and track pavement wetness; and 3) classify reflectance characteristics by simple measurements of pavement physical properties. By and large, only preliminary data are available at this time but the hypotheses and techniques developed to address these tasks are briefly described here.

Frequently, when measured full-scale luminance patterns are compared with those predicted using laboratory generated r-tables, the results are less than satisfactory. For example, Keck and Odle found that field measurements were, on average, 50% to 75% greater than those predicted using r-tables derived from core samples. The reasons for these discrepancies are unclear and could possibly lead to erroneous conclusions about the validity of either the full-scale measurements, laboratory measurements, or both. Factors such as variations in the condition of the road surface (or wetness in the present case, e.g., puddles) and deviations from the design candlepower distributions of the luminaires can result in unaccounted-for variance in the full-scale data. Other factors, such as disagreements among various computer programs in calculating pavement luminance or the potential lack of validity due to the removal of cores from the roadway, and/or the reduced scale of the laboratory measurements, can cause further difficulty in pinpointing the source of error.

For this study, there will be four sources of reflectance data available from which to predict full-scale luminance patterns: 1) CIE classification R- or W-tables; 2) existing r-table atlases such as Erbay's or LTL's; 3) laboratory measurements obtained from extracted core samples; and 4) measurements obtained using the FHWA's prototype, Colorado Gonio-reflectometer.

In order to validate these sources of reflectance data, an apparatus has been constructed which will permit the rapid and accurate placement of a light source of known intensity distribution into desired geometric positions about a fixed spot on an actual roadway. The measuring photometer is then placed 70.5 feet from the spot (1/4 of the standard CIE viewing distance) to measure luminance with a 1° viewing angle. By using such an apparatus, it is possible to eliminate all the sources of variation noted above and to validate each of the four sources of r-tables by using the 1/4-scale values as the standard against which to compare the other sources. If one or more sources of r-table data can be shown to be valid using this technique but still fail to accurately predict full-scale luminance patterns, it will be concluded that the source of error lies with some component of the field measurements rather than with the validated r-table sources. Alternatively, if the r-table data obtained from the above sources do not correlate with the 1/4-scale data, it will then be concluded that small-scale, laboratory generated

data cannot be used as a valid representation of full-scale roadway reflectance parameters.

The ability to describe, measure, and track the level of pavement wetness is also crucial to this and any future work in lighting research. Preliminary experiments have shown that measuring and tracking the CIE specularity parameter, S1, may provide the non-contact, real time, and repeatable methodology needed to monitor the wetness level of a pavement. That is, it has been found that immediately after a target spot is flooded with water, S1 will assume a relatively low value. Then, over the course of approximately 5-6 minutes, S1 rises to a peak value before exponentially decaying to its dry value. Furthermore, it appears that the peak S1 value may be associated with the macrotexture of the pavement surface. If these two relationships can be convincingly demonstrated by additional experiments during this investigation, there will be a potential basis for completely describing and predicting pavement specularity changes as pavement conditions change from being fully flooded to totally dry.

Finally, an important objective of this study is aimed at developing a technique for placing the selection and scaling of r-tables on a more objective level while still being simple enough for an engineer to use without elaborate photometric equipment. The current CIE recommended practice is based on the classification of road surfaces into groups or classes according to their S1 or S1' values. A number of "typical" surface materials and pavement condition descriptions are then associated with each of these classes. A design engineer is required to match his surfaces as closely as possible to these descriptions in order to select the appropriate r-tables, thereby accepting a certain amount of imprecision.

Since analyses conducted for this study have confirmed earlier findings that it does not seem possible to predict reflectance classification and scaling parameters using measurements of simple physical properties, alternative methodologies have been proposed. These alternatives are being explored in this study. As noted above, one possibility for predicting the specularity of wet pavements is based on the relationship of peak S1 values with pavement texture measured by the sandpatch technique. Another possibility being explored is to quantify Q_0 by photographing a gray scale lying on the surface of a pavement and correlating the calibrated gray scale reflectance values with Q_o. Here, it is assumed that Q_0 is closely correlated with the lightness or albedo of a surface matched to a gray scale of reflectance.

PAVEMENT REFLECTION STUDIES

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In 1978, in anticipation of the adoption in North America of the CIE recommended luminance method for the design of fixed roadway lighting, a research program was initiated by the Ontario Ministry of Transportation and Communications and Transport Canada to study the reflection characteristics of typical road surfacing materials used in Canada. An automated reflectance measuring facility was designed and built at the University of Toronto to carry out these studies.

The facility was designed so that the light source could be moved along a straight line at a constant height above the sample, and the sample and luminance meter could be rotated together to allow the light to fall on the sample at the recommended angles of altitude and azimuth. The system is calibrated manually, the sample set in place and leveled and the measuring cycle initiated. A dedicated computer controls the measuring cycle, records and stores the luminance measurements, processes the data and prints out the r-table, and the reflectance parameters Q_o, S1 and S2.

To facilitate the removal and transportation of road samples from existing roadways, a sample size smaller than recommended by the CIE was desirable. A pilot study of the reliability of measurements using 150 mm (6 inch) core samples was undertaken; the 65 mm by 115 mm field-of-view was centrally located. The results of this study indicated that if three samples were taken within the same area, the use of the small sample was statistically valid. Two areas (between and within the wheel path) should be selected to account for traffic wear.

An extensive study of 400 samples from 36 different pavement types from Ontario was made to determine if the reflectance parameters agreed with the CIE classification system established from measurements of European materials. The results plotted as log S1 vs log S2 were within the Erbay Atlas boundaries. There was a significant variation along the log S1 axis for a specific pavement type, depending on the condition of the surface texture.

An analysis of the statistical variation of the reflectance parameters was also made to establish the heterogeneity of the pavement characteristics. Several specific experiments were designed to study two scales of heterogeneity; microscale and macroscale. The microscale related to the sample size and the macroscale to the number of samples required to obtain a meaningful average. The statistical significance of any measurement errors was also included and found to be insignificant in relation to the heterogeneity variations, as for instance, variations along the wheel path of a pavement section.

The statistical results obtained from this rather extensive Ontario study formed the basis of a measuring program sponsored by the Road and Transportation Association of Canada (RTAC) to obtain data on the reflection properties of pavement materials used on Canadian roads. A total of 151 samples provided by nine provinces were measured. The results of these measurements confirmed the validity of the use of the CIE classification system for Canada road surfacing materials. The aggregate composition had a major effect on Q_o values and further systematic studies of this aspect of the problem would provide more reliable information for scaling the standard r-tables used in the CIE classification system. The effect of changes to Q_o with time and traffic wear should also be considered.

All measurements made to date pertain to dry samples. Work is in progress to extend the program to wet surfaces.

Results

The specularity parameter S1 (not S2) is used to determine the specularity class of pavement types,