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_0. 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_0, 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_0 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_0 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, the intensity distribution of the test luminaires (J-table) and the detailed reflection properties of a test road surface (r-table), together with positioning of lighting columns and road layout to calculate the luminance pattern which would appear in front of a driver.

The limitations of the standard program are that it provides only numerical output, is not interactive, and has limited viewpoints. The advantage is that correct and detailed luminance patterns are calculated.

The first stage of combining these two programs required the modification of STAN to an interactive form, and then using its output as input for VIGIL, to define the luminance of patches of road surface. It was not found possible at this stage to draw perspective views within the interactive program, but plan views were made, with the luminances shown as from the driver's position. A perspective view could be produced quite quickly outside the main program, once the values of spacing, overhang, etc. had been decided.

To draw the screen color and luminance correctly, it is necessary to calibrate the TV monitor photometrically. Fortunately, the non-linear correction required between calculated luminance and video voltage can be easily applied through the use of a look-up-table (LUT), linking the values written in the digital image store with the TV display.

The limitations of the combined system were the viewpoint constraints of STAN, the "tiled" appearance of the road surface, columns were not included in the luminance calculations, and glare was not portrayed. Also, since STAN calculates only one lighting span, the display "cheats" by showing the same span at various distances, and is thus limited to long straight roads only. The advantage was that it provided a quick visual output for a visual problem.

A new program (VOSCO) is now in use which eliminates most of the disadvantages previously encountered. The viewpoint is unlimited, the tiles are shaded, and the luminance and color of all parts of the scene are calculated (including columns, houses, trees, vehicles, pedestrians, etc.). Any shape of model is possible, including large areas of landscape produced from aerial survey, with constructed objects added. The only disadvantage seems to be that it does not yet use J-tables for luminaires or r-tables for road surfaces, so the nighttime road luminance calculation is not as good as the CIE program. However, for the situations where this system is at its best, say for designing lighting for complex junctions, the exact luminance levels are not so important as the overall pattern of luminance produced by placement of individual lights.

The user requires no knowledge of any computer language, or operating system, as the program is "command" based, with easily understood names, and "help" available at all levels.

Some idea of the modeling realism can be gained from a description of how the lighting of a model is defined. For daylight, a sky is used, consisting of the sun and the sky itself. The position and intensity of the sun is determined by the latitude, time of day and month of the year. Each of these can be set by a simple command, which not only sets the sun in the correct position, but also calculates the sky luminances, according to the CIE clear sky distribution. The CIE overcast sky distribution is also calculated, and a weighted mean of the two formed according to the amount of cloud cover, also set by a simple command (e.g., !CLOUD[0.4]). There are also objects called /SUN and /SKY, which may be drawn and show behind any other scene.

The program is completely interactive, producing new perspective views very quickly, and allowing both construction and modification of models held within the data base, so that new models and alterations are easily visualized. Future expansions are expected to allow the use of J and r-tables, and to calculate the effect of retro-reflectors, glare and atmospheric haze.

MEASURING THE VISUAL COMPLEXITY OF NIGHTTIME ROADWAYS

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The research described here was sponsored by the Federal Highway Administration and concerns the difficulty of interpreting complex nighttime road scenes. Subjectively, sometimes a driver's view of the road ahead is more difficult to interpret or utilize than at other times. Cues to the path ahead may be low-contrast, diffuse, or ambiguous. Additional elements of the scene may complicate the visual information processing problem: concepts such as visual noise, clutter, information load, and complexity have been applied to this issue. We describe an effort to measure and model the visual difficulty of the view ahead for the motorist.

It is difficult to describe adequately the visual "signal" and "noise" for the driving scene. A motorist is confronted with the task of identifying, abstracting, and structuring relevant information from the scene ahead of him. Information arrays are both spatially and temporarily arranged. These include diffuse and informal cues, as well as purposeful elements such as lane delineation or signs. Much of the information in view may be irrelevant for driving, and even that which may be considered relevant is not immutably so. The relevancy depends on the transient needs of the viewer. Once utilized, an information element may become functionally irrelevant and even contribute to the background noise against which subsequent information must be identified. Informal delineation, such as roadside foliage, luminaires, other traffic, building lines, etc., may serve as useful cues to path features, but may also contribute to the complexity of the scene. Information elements important for inexperienced drivers, or those unfamiliar with the road, may be unimportant for experienced or familiar drivers. All of these issues indicate the problems of objectively specifying where the view ahead is visually demanding for the driver. Yet being able to identify problem areas would be an important aid to improving road safety and directing countermeasures.

In this project we conducted a number of laboratory studies on the difficulty of driving scenes; we developed a preliminary mathematical model to capture aspects of scene difficulty; we conducted