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VERTICAL ILLUMINANCE AS A CRITERION FOR TUNNEL LIGHTING DESIGN

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From experiments conducted at the Ministry of Transportation and Communications' (Ontario) laboratory, and measurements taken at the Thorold and East Main Tunnels (Ontario), it was concluded that lighting geometrics which favor vertical illuminance will result in enhancement of visibility conditions with respect to the eye adaptation process at the threshold zone and object detection in the tunnel interior.

From the findings of these investigations it was concluded that with respect to drivers' visibility needs, a tunnel should not be isolated from the rest of the traffic system. A motorist, in performing his driving task, should consider a tunnel as an integral part of a complex scene.

It is understood that data required for steering and vehicle guidance are drawn from the immediate surroundings; however, in planning the overall trip strategy a driver requires visual contact with 3-dimensional space. In that case, the road surface forms only part of the complex scene and data on contrast are only part of the visual information.

At a distance of approximately 80-100 m from the tunnel portal all drivers are concentrating on the tunnel portal, at which time the eye adaptation process begins to take place.

The most difficult visibility obstacle for a driver is to overcome the sudden drop in luminance level at the tunnel threshold zone. The main factors of this phase contributing to eye adaptation are vertical planes ahead of him -- tunel portal and tunnel walls. Therefore it is very important in designing a tunnel lighting system to ensure that the luminances of these vertical planes are properly coordinated and related to eye adaptation requirements.

From our observations conducted at many tunnels we have noticed an important phenomenon which is very easy to check in the field: as soon as a driver crosses the threshold into the tunnel eye adaptation takes place very quickly. The problem of visual difficulty disappears, even under mediocre lighting conditions. (We have experienced this phenomenon under luminance levels as low as 30 cd/m^2). This phenomenon indicates that the contrasts between objects and their backgrounds are factors of lesser importance than that of luminance of walls.

From experiments conducted in laboratories and in the field, using asymmetrical directional light distribution, the following conclusions were drawn:

a. When the main light beam is directed at an angle of 30-50 degrees to the driver's line of vision, it assures adequate vertical object illuminance for visibility by positive contrast (better in object identification than those of silhouette viewing).

b. It provides a high value of vertical illuminance on the walls, making eye adaptation less difficult to the approaching driver at the most critical time.

Using similar lighting sources, and with the main beam directed against the driver's line of vision, the contrast between test objects and pavement were found to be of lower values and considerable glare from the light sources interfered with the driver's visibility.

The counterbeam system advocates assume that the only visibility problem in a tunnel interior is to detect relatively small objects; therefore, they concentrate their efforts on creating a high brightness on the tunnel pavement. From our investigations we have concluded that counterbeam lighting, although by using directional light creates better contrasts on the pavement, at the same time ignores the more important aspect in the visual process by neglecting to emphasize the wall luminance.

From data obtained in these investigations it was concluded that asymmetrical directional light distribution offers better visibility (compared with lateral or counterbeam methods) by increased vertical wall and object illuminance, and offers the possibility of reduction in energy requirements in tunnel lighting design.

A SYSTEMS APPROACH TO THE OPTIMIZATION OF VISUAL CONDITIONS IN LOW BEAM ILLUMINATION

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The beam pattern of the low beam is designed to illuminate the road in front of the vehicle as well as possible and at the same time to cause as little glare as possible for oncoming drivers. The net effect of the beam pattern should be an optimized visibility of the road and of objects on the road in opposing situations.

In order to optimize visibility, all beam patterns of the low beam have a strong light intensity directed towards the road surface and the near edge of the road and a weak light intensity directed towards the lane of opposing traffic. Between these areas of strong and weak light intensities there is a more or less steep gradient of light.

On straight level roads the optimum beam pattern should not be much of a problem. But this is not the normal appearance of a road. On the contrary, there are horizontal as well as vertical curves of different radius. Besides this variation there is a large variation in low beam aiming. The important vertical aiming varies to a high degree as a consequence of vehicle attitude deviations due to load.

Road geometry, low beam aiming and beam pattern interact in a complex way. These parameters are at the same time most important for the illumination of the road scene, and for the amount of glare on opposing drivers. In order to optimize the beam pattern it is necessary to study the effect on visibility when these parameters vary simultaneously as they do on the road. Computer simulations are the only way to do this. The results of such simulations should give clear information about how visibility should be improved.

Whether or not an object on the road is visible depends on three main conditions:

1. The conditions of illumination and glare on the road, as defined by beam pattern, aiming and road geometry.

2. The visual target condition as defined by the object and its background.

3. The visual ability of the driver exposed to the situation.

A computer model must simulate each of these conditions in one way or another. The natural variation on the road in each of these main conditions can be regarded as three populations of situations. An ideal model should choose random samples from each of these three populations for simulation. But such a model would be too complex.

What qualities, then, should a computer model have for optimizing low beam visibility?

1. The computer model must simulate the variation in illumination and glare on the road as defined by beam pattern, aiming and road geometry. This should be done by drawing a random sample from this population of situations.

2. The computer model should simulate one or a very small number of design targets chosen from the population of targets.

3. The computer model must simulate the visual ability of a design driver by specifying a valid criterion of driver visual ability.

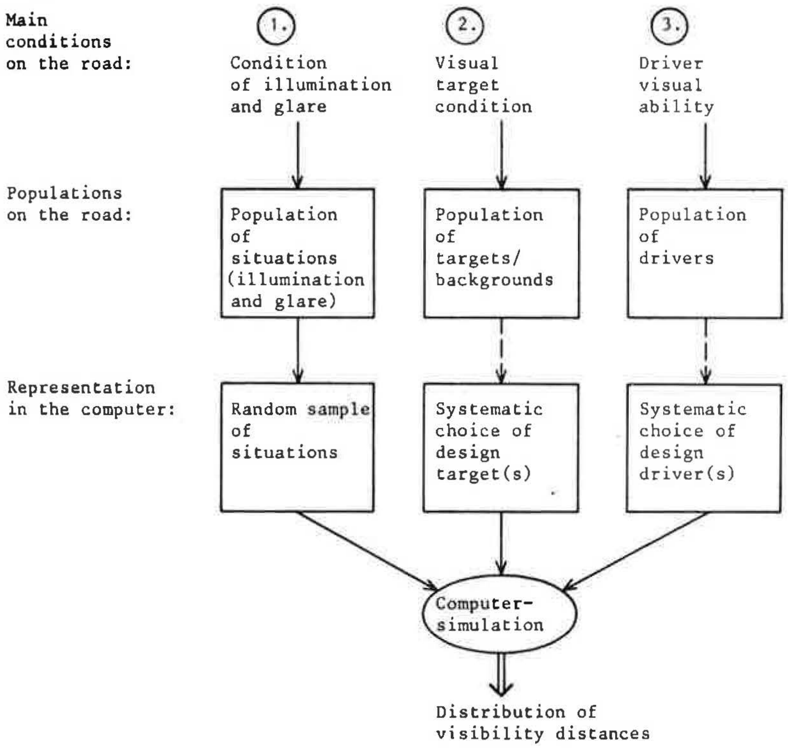
Then the computer can simulate a random sample of opposing situations and calculate a measure of visibility which can be generalized to this population of situations. But this generalization will only be valid for the design target and the design driver. Consequently, a good choice of those is very important.

The model must simulate the ability of the design driver to discover significant changes in the road and to detect objects on the road.

The most valid measure of visibility should be the distance in front of the vehicle at which the criterion of visibility is just reached. One strong reason for this is that visibility distances in low beam opposing situations on the road are often shorter than the stopping distances and therefore unsafe.

In all work on optimization, the question of which situation type we should make the optimization in must be addressed. In the case of the low beam the optimization should be made in situations with opposing traffic on roads without public lighting. The main reason for this is that the beam pattern of the low beam is created with the aim of maximizing visibility in these situations.

Figure 1 - A description of the main structure of the proposed computer model.



Visibility distances should be calculated by the computer for a large sample of low beam situations randomly drawn from the population. The data will constitute a distribution of visibility distances with a large variation. By analysis of variance the total variance in the data can be assigned to the independent variables in proportion to importance as main effects and as interactions between two or more independent variables.

In this way the relative importance of the beam pattern, the aiming and the geometry of the road can be shown. This would be a useful tool in the choice between possible measures of improvements.

The computer model must draw a random sample from the population of situations of illumination on the road. This population is created by the variation in beam pattern, low beam aiming and road geometry. The distribution of variation in each parameter must be collected in a statistically correct way, by drawing random samples from the traffic environment to which the results are to be generalized.

Besides beam pattern, low beam aiming and road geometry, there are some other parameters which influence the conditions of illumination, e.g., low beam mounting height, mounting distance between the two headlights on the car and reflection properties of the road surface. These parameters should also be considered.

The variation in beam patterns is an important parameter in optimizing low beam visibility. There are primarily two types of variation concerning the beam pattern of new headlights. The first one is the extra-type variation which is the variation in beam pattern between makes and types of headlights. The second is the intra-type variation which is the variation in beam pattern between low beams of identical make and type. Then, there is another source of variation introduced in traffic as an effect of age and dirt. In the work on optimizing the low beam pattern the importance of these sources of variation must also be studied.

THE LIGHTING OF ROAD CURVES

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Introduction

The work reported here is a contribution to a major revision of the Australian Road Lighting Standard (SAA 1973). The revision will use the CIE light technical parameters (LTPs) as criteria of qualtiy (CIE 1977). Luminaire manufacturers will be required to provide tabulations of the maximum spacings possible for their products on straight roads to meet specific values of these criteria, derived from standard CIE computation (CIE 1982).

The question to be answered is whether a simple rule can be formulated that allows the spacings on curves to be derived from the spacings provided for the straight sections. At present, in the Australian Code, it is recommended that the spacing be closed up and the luminaires be mounted in the outside of the curve; the exact spacing is derived by multiple application of a simple template which crudely approximates the light patch formed on the road from a luminaire.

Calculations

Two series of calculations, using CIE LUCIE (CIE 1982), were made to determine the LTPs for a range of practical installations, viz:

Series 1

Road width W_k(m)	Mounting height H(m)	Radius of Curvature R_c(m)
7.55 (2 lane)	9, 10.5	100, 200
15 (4 lane)	13.5, 15	150, 200, 600

Overhang: Zero for all H, plus H/4 for H = 13.5 and 15 m

Spacing: 3 values of S between 2.5 H and 5 H

Arrangement: Single-sided on inside and outside of curve

Luminaires: Two production types, of semi-cut-off distribution, one with 3^0 toe-in and the other with 13^0 toe-in, with flux commensurate with W_k and H.

Road surface: CIE R3

Calculation field: Two situations were examined, (i) approaching the curve in which the curve reversal point was included in the calculation field, the length of which depended on R_c and (ii) in the curve where a constant calculation field of one span was used. In both cases the observer was positioned in the center of the road, 60 m from a luminaire which started the calculation field.

Series 2

Same installations as in series 1, but on a straight road with one spacing only of 5 H (conventional value in present Code).

Analysis

The LTP average road luminance (L) was found to be systematically related to radius of curvature and spacing. Therefore the necessary spacings on the curves were deduced by interpolation between the three spacings used in series 1, which gave the same values of L as on the straight in series 2 for each installation. Only the in-curve situation has been used further in the analysis, since it appeared impossible to achieve required luminance uniformities with any reasonable spacing at the approach to the curve. However, values of L were always high.

Regression analysis gave the following relationships:

(a) Mounting on the inside of the curve
$S/H = 2.50 \log R_c - 3.03$ ($r^2 = 0.89$, $p < 0.001$)