those already mentioned, the main visual causes were "wrong estimate of speed or position" (7%) and "indistinct geometric road characteristics" (5%). The two factors may be related, because estimating speed and position may be facilitated by seeing a road user or oneself in relation to the course of the road.

Day/night differences in the pattern of near-accident causes were not obvious, which is an unexpected result in view of the special nighttime problem of indistinct geometric road characteristics. However, indistinct geometric characteristics may contribute indirectly to (near) accidents, because the effort to perceive them may take an important part of the driver's attention at the cost of attention for other road users (Walton, 1975).

Opinions About Public Lighting

In the case of nighttime near-accidents on express highways, only 5% of the subjects thought that (better) public lighting at that place could have prevented the near-accident. For near-accidents on other roads this percentage was 27 percent. In general, subjects also expressed a relatively low priority for lighting on express highways. This is consistent with the much lower incidence of visually critical elements on express highways, found in the first study, and is probably related to the smooth and redundant geometric properties of express highways.

Tentative Conclusions

- On roads where high-speed traffic is separated from other traffic, seeing other road users constitutes no special problem at night. Seeing obstacles on the road surface is also not a problem.

- Indistinct roadway geometrics form a most important visual problem during night driving, especially on non-illuminated highways.

- Difficulty in estimating speed and position was mentioned relatively frequently as a cause of near-accidents. It remains to be studied whether this may be due to a reduced ability to perceive the course of the road and thus to frame other cars in a road context.

- From the above, it follows that seeing a brick-like "critical object" on the road surface is generally not a very adequate quality criterion for public lighting on roads for motorized traffic. Instead, the visually most critical elements belong to the category "geometric road characteristics" and, possibly related to this, "position and speed of other traffic".

- Public lighting must be aimed at improving the visibility of geometric road characteristics. Required lighting levels will probably depend upon the amount of glare from oncoming vehicles, but not least upon the intrinsic visibility and predictability of roadway geometrics. Application of improved reflective road markings (Blaauw and Padmos, 1983) or self-luminous beacons might in many cases form a cost-effective alternative, therefore, or at least an important supplement to general lighting. Studies on the function of these type of markings in vehicle guidance have been performed recently (Godthelp and Riemersma, 1982; Blaauw, 1984).

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REDUCED LIGHTING DURING PERIODS OF LOW TRAFFIC DENSITY

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The object of this research is to determine if fixed roadway lighting on freeways can be reduced or eliminated during low volume nighttime periods without causing significant reductions in the ability of drivers to control their vehicles in a safe and effective manner. Specific project goals include developing alternative reduced lighting tactics, examining the costs and potential energy savings of these tactics, determining the potential legal implications of using these tactics, evaluating the effect of these tactics on driver performance, deriving cost-benefit relationships for these tactics, and preparing guidelines for their use.

A central component of this research was an analytic determination of the relative effectiveness of fixed versus vehicle-based lighting systems in meeting a driver's visual information needs. In general terms, this analysis proceeded according to a human factors model of driver performance, relating the visual inputs provided by the respective lighting systems to specific informational needs and -- through a series of mediating cognitive processes -- to the net response effectiveness of the man-machine system. A preliminary consideration of critical nighttime driving tasks then narrowed the study's focus to the detection of hazards (i.e., obstructions/discontinuities) in the roadway, adopting an expression of target visibility consistent with visual performance parameters detailed in CIE Publication No. 19/2 as the criterion measure of effectiveness for comparisons between vehicle headlamps and fixed lighting installations.

Initially, a revised, effective-contrast term (C_{eff}*) was defined to denote the dimensionless quantity derived by: 1) obtaining the difference between the luminance of a detection target and the luminance of its background, 2) dividing this figure by the level of background luminance alone, and, 3) adjusting the quotient to take an observer's relative contrast sensitivity (RCS) and the existing level of veiling luminance, or disability glare factor (DGF), into account. Values entered into calculations of C_{eff}* were determined according to current U.S. low-beam headlight performance specifications, a computer simulation of illuminance and luminance levels produced by a representative fixed lighting system, and the recommended (1983) IES Standard Practice for Roadway Lighting.

Key parameters describing the (simulated) hazard detection task included, first, the assumption of a 650-foot longitudinal separation distance between an observer and a to-be-detected hazard, both located in the center (northbound) lane of a six-lane divided highway. This detection distance was chosen as an intermediate, "compromise" figure with respect to the overall range of possible values defined by stopping sight distance (SSD) and decision sight distance (DSD) formulations for vehicles traveling at freeway speeds. Next, target characteristics were specified, describing a three-dimensional object consistent with current ASSHTO standards: A 7-inch sphere with a cylindrical base of the same diameter, colored a uniform 18% gray. For calculations of target luminance, this (simulated) hazard was modeled as a two-dimensional, flat vertical plane with a task detail size of 2.5 arc-minutes and a uniform reflectance of 12.7 percent. In all cases, the observer was presumed to be a 64-year old, alert driver performing under normal (dry) nighttime operating conditions.

The fixed lighting system included in the analysis consisted of a 68-foot staggered arrangement of 200-watt high-pressure sodium lamps (22,000 lumens/lamp), housed in medium cutoff, type-III distribution luminaires with a 30-foot mounting height, a 2-foot overhang, and a light loss (depreciation) factor of 0.81. Roadway width was 104 feet from edgeline to edgeline (including 12-foot median), and pavement type was designated as worn Portland cement with CIE R1 surface characteristics. Vehicle headlight systems considered in the analysis were #4,000, round 5 3/4-inch type 2 sealed-beam incandescent lamps and #H4656 type 2A1 halogen lamps.

The effectiveness of fixed versus vehicle-based lighting in providing the visual inputs needed to perform the defined detection task was determined for the driving situations involving: 1) an observer's vehicle alone, 2) an observer's vehicle plus an opposing (i.e., southbound) vehicle located downstream of the target position, and 3) an observer's vehicle plus an opposing vehicle located upstream of the target position. C_{eff}* values for the fixed lighting system in isolation -- ranging from maximum to minimum contrast levels depending upon a target's longitudinal position within a single luminaire cycle -- served as the common basis for comparison across all three driving situations.

For the 650-foot observer target separation distance, results of the analysis indicated that fixed roadway lighting reaches a level of effectiveness of roughly 150 to well over 300 times greater than that of vehicle headlights, both for situations involving an observer's vehicle alone and for situations involving an observer's vehicle plus an opposing vehicle located upstream of a (simulated) roadway hazard. In situations involving an observer's vehicle plus an opposing vehicle downstream of the detection target, fixed lighting systems are approximately ten times (i.e., 7x to 14x) more effective than vehicle headlights. The relative importance of each identified driving situation in the context of this research, as well as the issue of potential "conflicts" between fixed and vehicle-based lighting systems, were addressed in a summary and discussion of the findings.

USE OF THE PHILIPS OPEN-AIR LABORATORY FOR VISIBILITY RESEARCH

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The open-air road lighting laboratory in Eindhoven is used for three different activities:

- road lighting research
- the testing of new road lighting systems
- demonstrating different realistic road lighting situations, especially for educational purposes

The facilities consist of an asphalted road surface, 250 m long and 17 m wide, flanked by masts mounted on rails. By moving the masts along the rails, the longitudinal spacing between the luminaires can be varied between 24 m and 48 m. Encircling each mast is a drum-like housing with eight separate compartments, in each of which a different type of luminaire complete with lamp and control gear can be installed. A selected luminaire, with the lamp already burning, can be moved to a gate in the drum and extended out over the road to give the desired amount of overhang. The height of the drums, and thus the height of the luminaires above the road, can be varied between 2 m and 16 m.

All sorts of arrangements (from single-sided to opposite and staggered) can be made by remote control from a control room at the end of the road, as can changes in spacing, mounting height, overhang, and luminaire and lamp type. Some installations employ lamps whose light output can be varied between 10 and 100 percent. From an observation room adjacent to the control room, observers can view the road with the perspective of a road user. In this room various instruments are available for instantaneously measuring the lighting quality parameters. A view of the road ahead as seen from the driver's position, together with measure lighting and geometric data of the installation, can be stored on videotape using a closed-circuit television system.

Many tests involving observers -- static tests especially -- have been conducted at the open-air laboratory. For example, the first tests on glare restriction measures for road lighting, which led to the CIE Glare Control Mark System for Road Lighting, were carried out here. Studies on the visibility of obstacles on the road under different lighting and weather conditions have been