important urban roads, the installation of "good" road lighting will result in a reduction of some 30% of the nighttime injury accidents when compared with no or very poor lighting. Accident studies have generally shown that the relative nighttime danger is reduced when the lighting is improved.

The efficiency of road lighting is expressed in terms of supply-and-demand. Both the supply and the demand can be expressed in conspicuity. It is possible to measure the supplied conspicuity of a lighting installation, and the conspicuity required by road users.

The go-no-go limit for road lighting quality, however, cannot be found in this way. Taking part in traffic, as a driver of a car, involves much more than visual activities alone. Driving is not primarily a visual task: in the first instance, it is a decision-making task. Reaching the destination is the first aspect of the driving task. Avoiding accidents represents the second aspect of the task.

For Task I (reaching the destination), route selection and control, speed and position selection and control are relevant. In many cases, disturbances represent conflicts or dangers. Some conflicts or dangers might develop into accidents if no avoiding maneuvers are executed. In all cases, the disturbances are sudden, unpredicted and unwanted, involving situations where information is inadequate.

Collision-avoiding maneuvers include:

- coming to a stop
- avoidance by leaving the traffic lane
- avoidance by swerving within the traffic lane
- adjusting (reducing) speed
- simply going on

The required advance viewing time for coming to a stop is the greatest, for simply going on the smallest.

The specific (or critical) visual object must be known. While it is not necessary to stop for a stone of 20 x 20 cm dimensions, it is necessary to stop for a stationary truck on a two-lane, two-way road when opposing traffic is present. And it is necessary to swerve around the stone, but not around a newspaper or a matchbox. It is difficult to set up an inventory of the critical objects. However, the 20 x 20 cm obstacles are not frequent. In the first place, it seems that the curves in roads and other traffic participants are important. This is in accord with the restricted information that can be deduced from the accident statistics. All this relates to the "demand" side; the picture can be completed only when we know more about the different specific or critical visual objects.

As regards the "supply" side, the picture is nearer to completion. The system built by Blackwell and accepted by CIE provides the possibilities to assess the relation between the photometric and geometric aspects of lighting installations and the degree in which specific objects may be seen.

VISUALLY CRITICAL ELEMENTS IN NIGHT DRIVING, IN RELATION TO PUBLIC LIGHTING

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Purpose of Paper

This presentation focuses upon car driving at night outside built-up areas. In order to apply public lighting selectively and efficiently it is necessary to know which elements in the task environment of a car driver are insufficiently visible for safe and smooth driving, using (dipped) vehicle lighting. The visibility of these "visually critical elements" is amenable to improvement, in particular by public lighting. Until now, the visibility of the so-called "critical object" (something like a brick at 100 m distance on the road surface) has been used as an important criterion for the quality of public lighting. However, the relation between seeing such an object and traffic safety is not very clear.

The results of two exploratory studies on the nature of visually critical elements, done by order of the Netherlands' Roadway Authorities, will be briefly presented. For more information, see Walraven (1980) and Padmos (1981).

Methods

In the first study, nine subjects drove a car along a 112 km trajectory, consisting of various road types in non-built-up areas. Each driver had one nighttime run (with dipped headlights) and one daytime run as a control. Driver's reports of visually critical elements were taken during the runs. Moderate intensities of motorized traffic were present; road surfaces were dry.

In the second study, a representative sample of 1,200 car drivers was interviewed (home-interview) for experiences during driving in non-built-up areas. There were questions about the most important problems encountered during night driving, about character and cause of recently experienced near-accidents and about the appraisal of public lighting.

Results

Visually Critical Elements

The most frequently reported nighttime visually critical elements belonged, in both studies, to the category "course of the road and other geometric road characteristics." The visibility of obstacles on the road surface was never mentioned as a problem. Rarely mentioned was the problem of seeing other cars; somewhat more mentioned was the visibility of bicyclists and pedestrians (interview study only). Glare from oncoming cars' headlights was often mentioned as a problematic circumstance.

From the first study it appeared that most visual problems occurred on unlit local roads, and fewer on unlit main roads. On express highways very few problems were mentioned; here the presence of public lighting did not markedly influence the frequency of problems.

Near-Accidents

Two-hundred twenty-three near-accidents were reported; they were about equally distributed between day and night. Eighty-five percent were with another moving car. However, "not seeing a motor vehicle in time" was mentioned as a cause in only 9% of the cases. In about half of those, this related to the limited scope of the side-mirror. Actually, visual causes as a whole did not constitute more than 27% of the total. Beside

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