QUALITY INDEXES FOR ROAD LIGHTING: A REVIEW

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ABSTRACT

The scientific literature in public lighting contains a number of theoretical models to assess the quality of lighting installations. Engineers also use normative and state-of-the-art documents in order to achieve a given quality level. Such variety of models and practices may raise some questions. We make an overview of the theoretical models on which road lighting quality indexes are currently based, as well as some normative procedures and recommended practices. We try to point out their theoretical background and their purpose. This rapid overview leads us to separate 4 levels in the engineering process of building a quality index for road lighting applications. The first level is the functional one: the main objective of the lighting installation (e.g. road safety) must be specified. The second level is that of the task: once the objective is set, a corresponding visual task (e.g. target detection) must be identified. The third level is to collect vision science data in order to make a vision model of the task, and of the appropriate thresholds. The fourth level is the operational one: a measurement method must be defined, based on the vision model, for the actual assessment of the quality index of road lighting installations.

Keywords: road lighting, visual performance, quality index, small target visibility, visibility level.

1. INTRODUCTION

There is a need, for public lighting engineers, to have easy-to-use and effective quality indexes. A number of concepts have been proposed in the scientific and technical literature, including the fourth Division of the CIE. The scientific literature in public lighting contains a large number of theoretical models to assess the quality of lighting installations. Engineers also use normative and state-of-the-art documents at a national and international level, in order to achieve a given quality level. Such variety of models and practices may raise some questions. In the following, we make a non-exhaustive overview of the theoretical models on which road lighting quality indexes are currently based, as well as some normative procedures and recommended practices. We try to point out their theoretical background and their purpose.

From a practitioner point of view, road visibility is not an autonomous concept, but a step among others, in order to assess the quality of the lighting installations, and answer the question: "*how well is the public space enlighted?*". Road visibility should then be considered from the functional point of view, that is to say, what is public lighting designed for, and should be compared to other concepts (EN 13 201 in Europe, ANSI/IESNA RP-8-00 in the US).

The main quality indexes are related to the concept of visual performance (Rea, 1982), which comes from psychophysical science. Experimental data are collected on a population of human subjects, for a given visual task, and a mean psychophysical curve is computed from their responses. A performance threshold is usually set at the value corresponding to a 50% probability of success in the task (sometimes 90%). Road visibility is among the main concepts for assessing the public lighting quality in terms of visual performance (CIE, 2002), as opposed to visual appearance indexes (CIE, 1993). Performances depends on the success/failure rate for a specific task, such as detection rate, whereas appearance is a subjective criterion based on judgments, such as brightness). In the following, we consider visual performance criteria used by road lighting practitioners in order to set their practice on a theoretical background.

2. SMALL TARGET VISIBILITY

The idea of target visibility models in road lighting is to characterize a lighting installation considering how well a small target on the road can be detected by a driver, at a distance where the driver uses to pick up information. This can be set in terms of driving safety: the road lighting installations are optimised in terms of a visual task which is critical for a given safety hazard, here a collision with an obstacle. These visibility models use contrast sensibility data from vision science (Blackwell, 1946). Laboratory experiments with thousands of subjects, asked to detect a uniform circular target on a uniform background allowed to model the mean human performance for a standard visual detection task. For a specific visual task, (CIE, 1981) proposes a methodology in order to adapt the detection threshold to the specificity of the task (e.g. to read, or to detect a target on the road while driving), through a detailed analysis of the Relative Task Performance (RTP), which combines several subtasks: ocular fixations, saccadic motions and the “cognitive” part of vision, with weights specific to the task. Gathering the experimental data is among the hard points of this methodology.

The most popular model so far is the “small target visibility” (STV) model, proposed by (Adrian, 1989). He considers the ability to detect a small target standing on the road at a long distance ahead as a quality index of the lighting installation. The model computes the detection threshold for a small target situated on the road, knowing the contrast threshold of the Human Visual System (HVS). The adaptation luminance, which is needed in order to compute this threshold, is taken as the road luminance around the target. Adrian proposes to use the Visibility Level (VL) index, which is the luminance contrast ΔL between the target and the background, over the threshold luminance contrast: $VL = \Delta L/\Delta L_t$. VL=1 means that the target is just detected for the reference visual task (the laboratory task). As this task is far from the driving task, the (CIE, 1981) methodology suggests to set a specific VL threshold for a driving task. (Adrian, 1987) proposes that VL should be greater than 7, in order to consider that the lighting installation allows drivers to avoid small obstacles. This threshold value has been used in other documents since (e.g. (AFE, 2002)). Based on a road visibility study (Gallagher, 1975), a value of VL=15 has also been suggested.

The scenario of the STV model includes a vertical square target of 20 cm. width standing 86 meters ahead of the driver, with a contrast of 0.2, and observation time is 0.2 s. In (CIE, 1995) and in the IESNA procedures, a practical methodology is proposed in order to measure the VL for a given lighting installation, using a specific set of points across the road surface, and taking the mean VL over this set of points as the lighting installation VL.

Lecocq points out a number of weak points in Adrian’s model (Lecocq, 1999). The main point is that the conventional target’s shape does not account for real objects. Thus, he proposes to use a spherical instead of a planar one, which results in a somehow more complex model in terms of computation. Lecocq also proposes to link the observation time to the speed of the vehicles, instead of using a conventional value, and he considers a road surface ahead instead of a single distance. He suggests considering a range of target reflectance values (between 0.05 and 0.6) instead of a conventional one, and taking into account 50 years old drivers. All these proposals tend to define a reference situation closer to a detection task in a driving situation. Other authors have made proposals to improve the model, like using second order quality indexes, such as the uniformity of VL instead of VL (Güler, 2005). The “revealing power” was proposed by Waldram in the thirties (Waldram, 1938). The main idea of this street lighting quality index is to take into account the actual distribution of objects that can be encountered in the streets, in terms of reflectance (Waldram uses statistics about the reflectance distribution of American clothes), avoiding the problem of choosing a conventional reflectance value. This concept was a ghost from the past, until it was discussed by Narisada (see TC 4.36 of the CIE (CIE, 2002)), who proposes to model the detection probability of a small target, as for the VL index, but taking into account a reflectance distribution function.

3. LUMINANCE

Road lighting quality indexes may be considered with an other approach, less related to the visual performance for a specific and conventional visual task. For instance, French recommendations (AFE, 2002), as well as the European norm on road lighting and (IESNA, 2000), give quantitative levels (mainly in terms of illuminance) partly based on visual performance models, but also on the experience of practitioners through a consensus between technical experts. This approach takes into account the objectives that public authorities set on lighting. The European norm makes no obligation to lighten the streets, but a technical report gives reference photometrical levels if one wishes to lighten. These levels depend on non-photometric parameters like vehicles/day, crossing density, road use, lane separation, atmospheric conditions, etc. Some among these parameters are qualitative (estimated on a low/medium/high scale). The public authority must indicate the main destination of public lighting: road safety, traffic, car parking, cycles, navigation, public security, city beautification, etc. All these parameters allow to use a road classification, where photometric minimum values are proposed for luminance (mean and uniformity), glare, and surround ratio. Illuminance (mean and uniformity) is the default parameter when standard conditions are not fulfilled to use luminance data (1° angle of road observation). This approach starts from a classification of the road usage, as it is planned by public authorities. Links between this classification and visual performance thresholds (or even visual task) is not explicit, and is not direct: the thresholds are not the results of psycho-visual experiments, rather an expert agreement taking into account psycho-visual data among other issues (e. g. traffic). Instead of focusing on a single visual task, as STV does, this approach allow to take a number of parameters into account, even though on a much weaker scientific basis. A standard methodology is needed to check luminance level and uniformity. Thus, recommendations propose standard grids, and a simplification method is proposed (CIE, 1984) allowing to use photometric characteristics of the road in order to compute luminance values from illuminance values through the luminance coefficient q=L/E. The CIE model uses two photometric parameters: Q_0 (degree of lightness) and S_1 (degree of specularity). Knowing these parameters allows to use a road surface classification and to compute a luminance distribution from a standard reflection table.

4. RELEVANCE CRITERIA

One may ask why so many criteria are proposed, and why they change over time. In our opinion, it is a symptom of the lack of definitive consensus among experts, about what is the best compromise between two main constraints: an easy (and cheap) criteria to measure, but linked in some way to the illumination quality from a user point of view. Engineers need quantitative criteria when designing or evaluating a lighting installation, but the underlying concepts (visibility, visual task, visual comfort, etc.) are subjective, and far from quantitative. Thus, there is a need to make objective concepts out of subjective ones, ill-defined and strongly varying over individuals and situations. This leads to a pragmatic approach, measuring physical quantities correlated with people ability to perform a relevant visual task. However, this is a modest program, compared to the hypothetical objective of quantifying a "lighting quality" in a general sense. The use of these criteria should be modest as well, because even if they use scientific foundations, they are only partly relevant for the actual driving task. To our sense, this is the main explanation both for the number of concurrent criteria, and for the use of less scientific criteria (as in EN 13 201).

It may be proposed to separate 4 levels in the engineering process of building a quality index for road lighting applications. The first level is the **functional** one: the main objective of the lighting installation (e.g. road safety) must be specified. The second level is that of the **task**: once the objective is set, a corresponding visual task (e.g. target detection) must be identified. The **modelling** level is to collect (or to build) vision science data in order to make a vision model of the task, and if necessary of the appropriate thresholds (e. g. Adrian's STV model). The fourth level is the **operational** one: a measurement method must be defined, based on the vision model, for the actual assessment of the quality index of road lighting installations (e.g. the road surface classification method). Each level depends on the previous one. The lack of experts agreement may be illustrated at any of the four levels.

- At the operational level, not taking in account the whole visual environment by only measuring the road surface may not be correct (especially downtown). The underlying hypothesis that drivers are visually adapted to what they are looking at may also be questioned at this level.
- Lecocq's remarks cited above address the modelling level. (Raynham, 2004) points out a number of missing issues in the STV model: not considering coloured contrasts in the detection task, not considering car lights (in terms of road luminance or in terms of glare). (Güler, 2005) proposes a quality index based on VL uniformity. Dumont points out that the VL definition allows negative values, which makes no physical sense (Dumont, 2006).
- Van Bommel, in TC 4.36, stands on the task level (Stark, 2002). The choice of a detection task far ahead from the car is typical of good old times with few traffic, and should be changed for twenty-first century applications. The use of a static visual task as a reference, without considering visual attention, visual saliency, peripheral vision, etc. also concern this level.
- Even though the European norm lacks psychophysical foundations, it allows to take into account the point of view of road authorities about what the public space (and the public lighting) is designed for. That is to say, it challenges the STV model at the functional level. In this sense, the STV may be considered as a tactical solution for a specific situation, the lighting of roads with low traffic.

In conclusion, road engineers use a number of concepts and definitions about road visibility and road lighting quality. These definitions are compromises between, on one hand, the need for standard procedures and objective criteria (required in socio-technical organisations), and on the other hand, a vanishing goal, the knowledge of the lighting quality in the "customer's" sense (that is, the drivers and pedestrians). They concern four levels of problem setting, referred above as the functional, task, modelling and operational levels. The choices made at any of these four levels have consequences on the resulting quality index, which may explain to some extend the variety of quality indexes found in the literature on public lighting.

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