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A road tunnel model for the systematic study of lighting situations

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ABSTRACT

In this study we employ a road tunnel model to simulate the crossing in a car at variable speeds using running LED-lights. Different lighting situations were created, namely symmetric-, counterbeam- and probeam lighting and were measured using a luminance camera. The results show that probeam lighting yields a much better object illumination than counter-beam- and symmetric-lighting while consuming the same amount of power as symmetric- and counterbeam lighting due to use of LED-technology. Based on this we argue that probeam lighting is a viable alternative to the commonly used counterbeam lighting in the interior zone of road tunnels.

1. Introduction

The illumination of a road tunnel is of uttermost importance for driver safety in order to reduce the risk of accidents. It has to aid the driver in detecting moving objects and also obstacles (such as knocked-out animals or car pieces) in front of them. From a technical point of view the challenge is to accomplish perfect lighting conditions already at the tunnel entrance, keep glare at a minimum and enable good contrast sensitivity. However, the illumination of road tunnels is also an enormous cost factor as it consumes the biggest part of energy (Peña-García et al., 2015). Additionally, high levels of luminance consequently lead to higher costs of installation, as the required number of luminaries, electronics and wiring grows. Thus, there are attempts to lower the costs for light installations using different approaches, such as climbing plants at portal gates as proposed by Peña-García et al. (2015) or the use of sunlight, where Peña-García et al. (2016) improved the efficacy of light pipes through heliostats.

In principle there are three possibilities to illuminate a tunnel, namely: symmetric lighting, counterbeam lighting and probeam lighting. Although probeam lighting has superior properties as will be discussed in more detail in the following section, the main disadvantage with this technique is a low pavement luminance yield compared to symmetric- and counterbeam lighting at the same amount of consumed power. Because of this, probeam lighting is not used in Austrian road tunnels or in those of other European countries. As of now Japan is the only country that employs probeam lighting in its road tunnels (Sato and Hagio, 2014). However, tests in Austria have already been performed, namely a field study financed by the Austrian motorways and highways-financing PLC (ASFINAG) and in the context of a research project by Bartenbach GmbH, which was funded by the Austrian Research Promotion Agency (FFG). These studies resulted in several publications concerning different lighting situations in road tunnels and their effects on visual perception and safety (Pohl, 2010), cognitive and visual performance parameters (Canazei et al., 2011), the psychology of perception (Pohl, 2015) and the properties of probeam lighting compared to other techniques (Quinger, 2011).

In order to be able to compare different lighting situations of the interior zones of road tunnels systematically in a laboratory environment, we developed a custom-build model, where different lighting situations can be generated. It employs running lights, where each luminary can be controlled individually, i.e. switched on/off consecutively, in order to simulate different car speeds. Due to the emergence of light emitting diodes (LED) and their energy efficiency compared to conventional luminaries, the interior zones of road tunnels are nowadays often equipped with LEDs (van Bommel, 2014) which is also why LEDs have been employed in our model.

Looking into the model, the dynamic light installation creates the illusion of driving through a tunnel. Thus we are able to simulate a crossing by car at variable speeds and luminance. Using a luminance camera quantitative data about the illumination can be gained for tunnel crossings employing different lighting situations.

Road tunnel models have been also used by other groups in order to study a variety of topics, such as optimizing the use of solar light for energy saving, as demonstrated by Peña-García et al. (2011) or the study of light-pipes for the use of sunlight (Gil-Martín et al., 2014).

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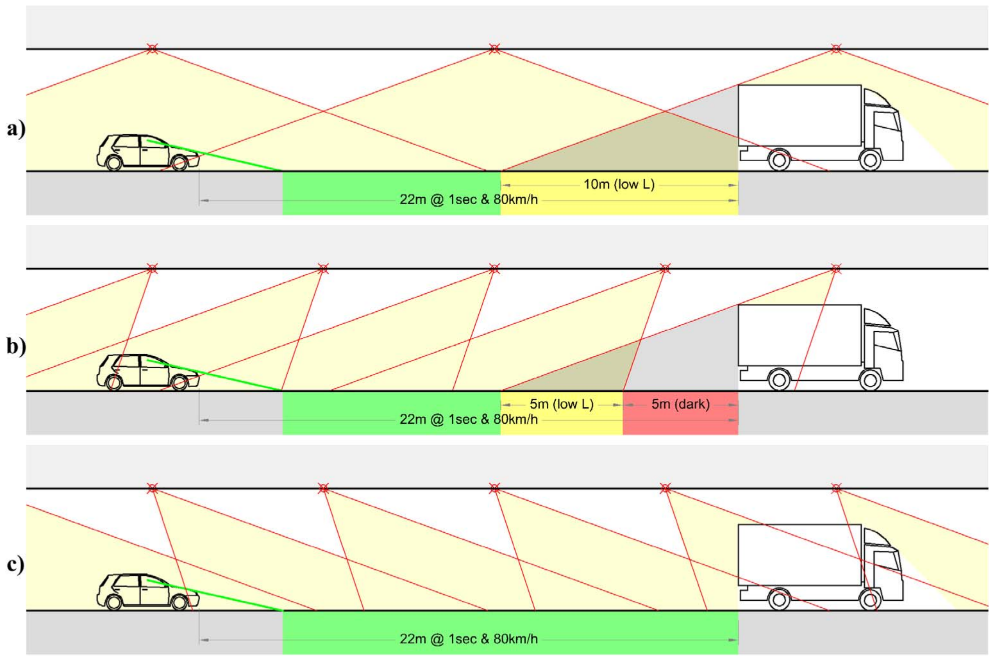

Fig. 1. Comparison of different lighting situations: (a) symmetric lighting, (b) counter-beam lighting, (c) probeam lighting.

2. Lighting situations and light sources

In this section the properties of three different lighting situations will be discussed and compared. Fig. 1 illustrates the luminance achieved by symmetric-, counter-beam and probeam lighting, with green, yellow and red indicating areas of high luminance, low luminance and darkness.

In the case of symmetric lighting the luminaries radiate light symmetrically in two directions, i.e. with and against the traffic. The main advantage of this technique is the high luminary distance, leading to the lowest energy consumption of all three concepts. However, as can be seen in Fig. 1a bright and dark vertical faces are alternating and there is a high glare for the driver. Symmetric lighting is the standard lighting situation used in the interior zone of European road tunnels.

Counterbeam lighting directs the light only towards the direction of the driver, leading to a bright pavement surface but also to a high glare and a low object luminance, creating a big negative contrast. Additionally there are dark vertical faces as can be seen in Fig. 1b. Thus it has the best effect with no other cars in the tunnel. This type of illumination is currently used in the entrance zone of tunnels.

The high pavement luminance is the reason that these two lightning situations are used in road tunnels, as this is the main evaluation criterion for tunnel lighting.

Last but not least we want to discuss probeam lighting. This technique directs the light away from the driver, leading to a lighting situation with a darker pavement surface compared to counterbeam lighting. In principle the pavement surface should appear as bright as with counterbeam lighting, however, due to reflection from the coating, the pavement appears brighter for counterbeam lighting. There could be also glare due to reflections from vehicle windows ahead. On the upside probeam lighting leads to bright vertical faces, resulting in a positive contrast. Continuous line probeam lighting eliminates any distance between the luminaries, which leads to an overall very steady lighting, bright vertical faces and no glare, but an obviously higher energy demand as much more luminaries have to be installed. Overall, probeam lighting shows the best effect with many cars in the tunnel.

Besides the lighting situations themselves, also the light sources have to be considered. Conventional lighting techniques used in road tunnels are fluorescent, high pressure sodium, low pressure sodium and high pressure mercury lamps (Buraczynski et al., 2010).

Compared to the aforementioned light sources LEDs have a lot of advantages, as their brightness can be quickly adjusted to the maximum level and overall they are more energy-efficient, as discussed by Moretti et al. (2016), although their acquisition costs are still higher than those of conventional luminaries. Given this, road tunnel illumination with LED light can reduce energy costs (Moretti et al., 2016) and additionally could render probeam lighting as a viable alternative, as the higher energy consumption of this lighting situation to achieve a high pavement luminance compared to the other techniques would be balanced by this light source.

When it comes to high traffic volume though, a bright pavement surface is not as important as good object recognition, because little pavement surface can be actually seen, as depicted in Fig. 2. This means that, regardless of a lower pavement luminance (at the same level of power consumption) probeam lightning is the superior lightning situation compared to counterbeam- and symmetric lighting, as good object illumination is paramount to ensure driver safety.

3. Materials and methods

Fig. 3 depicts a sketch of the model as seen from the front. All dimensions are given in decimetre, the scale of the model is 1:16 and it has a total length of 40 dm. Different car speeds can be simulated by

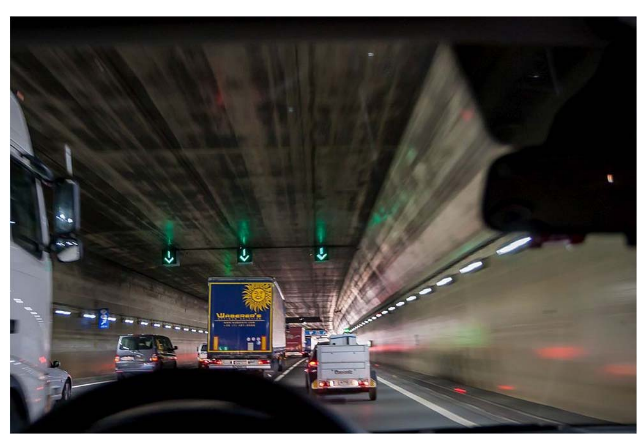

Fig. 2. Picture taken from a car at high traffic volume.