



International Commission on Illumination  
Commission Internationale de l'Eclairage  
Internationale Beleuchtungskommission

# **NEW CONCEPT FOR ROAD LIGHTING TO IMPROVE THE VISIBILITY OF CYCLISTS IN SHARED ROAD SPACE**

Hansen, F., et al.

DOI 10.25039/x051.2025/9be6ag

This article is also published as part of:

Proceedings of the CIE 2025 Midterm Meeting Vienna, Austria, July 4-11, 2025:  
Scientific Conference (July 7-9, 2025)

DOI 10.25039/x051.2025

in

Proceedings of the CIE (International Commission on Illumination)

ISSN no. 3061-015X (print), 3061-0168 (online)

The paper has undergone double-blind peer review and its final version has been presented at the CIE 2025 Midterm Meeting, Vienna, Austria, July 4–11, 2025.

© CIE 2025

All rights reserved. This work is licensed under the Creative Commons Attribution-NonCommercial 4.0 International License (<https://creativecommons.org/licenses/by-nc/4.0/>). Any mention of organizations or products does not imply endorsement by the CIE.

CIE Central Bureau  
Babenbergerstrasse 9/9A  
A-1010 Vienna, Austria  
Tel.: +43 1 714 31 87  
e-mail: [ciecb@cie.co.at](mailto:ciecb@cie.co.at) — [www.cie.co.at](http://www.cie.co.at)

# NEW CONCEPT FOR ROAD LIGHTING TO IMPROVE THE VISIBILITY OF CYCLISTS IN SHARED ROAD SPACE

Hansen, F.<sup>1</sup>, Schumacher, S.<sup>1</sup>, Walkling, A.<sup>2</sup>, Völker, S.<sup>1</sup>

<sup>1</sup> Technische Universität Berlin, Berlin, GERMANY <sup>2</sup> Bundesanstalt für Straßenwesen, Bergisch-Gladbach, GERMANY

frithjof.hansen@li.tu-berlin.de

## Abstract

Since the number of accidents involving cyclists is significant, partly due to poor visibility, our research aimed to develop and test a new lighting concept for urban road lighting systems to improve the visibility of cyclists.

The previous requirements of CIE 115 and subsequently EN 13201 aim to ensure a negative contrast with the help of certain illumination levels. The approach we subsequently investigated was to create a positive contrast in conflict situations with a low lighting level. For this purpose, the parameter vertical illuminance was selected, quantified and implemented by optimised light distributions. The effectiveness of the parameter was then validated by practical measurements in which the effect on the visibility of cyclists was assessed.

On the basis of the investigations, recommendations were developed, along with a proposal for revising EN 13201, the application of which would lead to a lighting concept that enables a higher visibility of cyclist.

*Keywords:* Cyclists, Visibility, Road lighting, Contrast

## 1 Introduction

Cycling is trendy. In this context, municipalities, federal states and the federal government in Germany are pursuing the goal of further increasing the share of bicycle traffic as an ecological form of mobility. Bicycle traffic can make a major contribution to achieving transport policy goals such as reducing CO<sub>2</sub>-emissions and alleviating inner-city traffic problems (KOSSMANN et al. 2022).

But cycling at night is challenging due to low light conditions and contributes to a higher mortality rate in accidents involving pedestrians and cyclists (WOOD, 2019). During the night, the number of accidents involving cyclists is 26 % higher than during the day, which highlights the need for improved visibility and safety measures (BENEA et al., 2019). An accident analysis in four German cities showed that 19 % of turning-related accidents involving motor vehicles and cyclists occurred at dusk or in the dark (KOLREP-ROMETSCH et al., 2013). Furthermore, studies show that darkness significantly reduces the use of bicycles, but that road lighting can mitigate this effect (FOTIOS et al., 2019; UTTLEY et al., 2020; UTTLEY & FOTIOS, 2023). These results suggest that minor improvements to lighting could help to make bicycles a year-round mode of transport.

However, the standard EN 13201 (DIN, 2016; DIN, 2021), which is decisive for the design of road lighting, has limitations in its applicability to cycle paths. The parameters and limit values of the P-classes specified here are based on CIE 115 (CIE, 2010), which was primarily developed for motorised traffic and pedestrians and is not fully transferable due to different requirements.

At the same time, technical developments offer great potential for improving road safety. Innovative technologies are increasingly being used in both bicycle and traffic engineering and enable the development of lighting concepts to protect special road users.

## 2 Development and validation of a lighting concept and its parameter

The context and steps for developing the lighting concept based on a new parameter model to increase the visibility of cyclists are described in more detail below.

### 2.1 Definition of Visibility Level (VL)

The concept presented here assumes that a visibility level (VL) of 10 ensures sufficient visibility of cyclists. The VL is defined as the ratio between the luminance difference of the visual target and its background ( $L_b$ ) and the threshold luminance difference ( $\Delta L_{\text{threshold}}$ ), as follows:

$$VL = \frac{\Delta L}{\Delta L_{\text{threshold}}} \tag{1}$$

Here, the luminance difference ( $\Delta L$ ) between the target luminance ( $L_T$ ) and the background luminance ( $L_b$ ) is given by:

$$\Delta L = L_T - L_b \tag{2}$$

The threshold luminance difference ( $\Delta L_{\text{threshold}}$ ), defined according to Adrian's visibility model (ADRIAN 1989), is calculated by the following equation:

$$\Delta L_{\text{threshold}} = 2.6 \cdot \left( \frac{\phi_{1/2}}{\alpha} + L_{1/2} \right)^2 \cdot F_{cp} \cdot \frac{\alpha(L_b, \alpha) + t}{t} \cdot AF \tag{3}$$

The auxiliary functions  $\phi_{1/2}$  and  $L_{1/2}$  reflect a composite of Ricco's and Weber's law (ADRIAN, 1989), while the factor  $F_{cp}$  describes the influence of the contrast polarity. The observer age is accounted for by the age factor  $AF$ . The target size, denoted by  $\alpha$ , is measured in arcminutes and the term  $\frac{\alpha(L_b, \alpha) + t}{t}$  considers the influence of the exposure time.

### 2.2 Relationship between vertical illuminance and target luminance

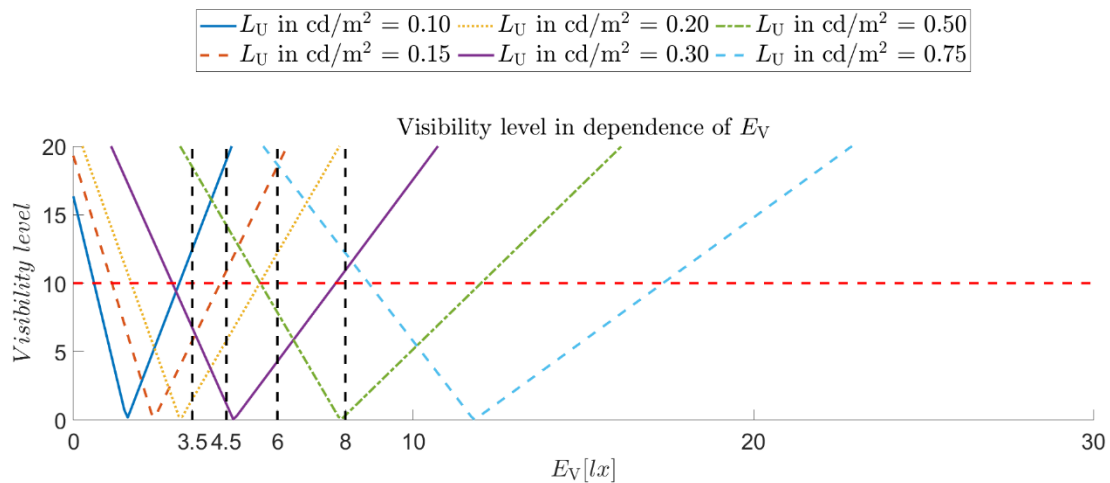
At night-time, the luminance on visual targets, such as cyclists, is primarily determined by the vertical illuminance ( $E_V$ ) from road lighting installations. For surfaces approximated as Lambertian reflectors, target luminance ( $L_T$ ) and vertical illuminance ( $E_V$ ) are related through surface reflectance ( $\rho$ ):

$$L_T = \rho \cdot E_V \tag{4}$$

In this parameter model, the vertical illuminance is therefore used to increase the target luminance. To facilitate modelling cyclists are simplified as uniform Lambertian surfaces. This assumption allows for the analysis of vertical illuminance ( $E_V$ ) across various background luminances ( $L_b$ ). These luminance values correspond to typical pavement luminances specified for P-class lighting conditions according to Table 12 of DIN EN 13201-1 (DIN, 2021), assuming a pavement reflectance of  $\rho = 0.15$  and are furthermore referenced to as  $L_U$ . These values are founded on the assumption that at least part of the visibility target is seen against the background of the parameterized road surface.

Assumptions for other influencing factors on the visibility level (VL) are based on typical cyclist characteristics, including an object height of 1.5 m (approximately 100') and an average surface reflectance of 0.2. The age factor ( $AF$ ) is set to represent an older observer aged 60, reflecting both the demographic shift towards an ageing population and a conservative worst-case scenario. For comparison, calculations were also conducted using the standard observer age of 23 years (Table 1), which is typically applied in existing norms. Factors such as the observer's state of adaptation and the influence of veiling luminance were excluded from the model, as they are highly dependent on local road lighting configurations and cannot be generalised.

As such, the derived parameter model can be seen in Figure 1:



**Figure 1 – Visibility level in 60 m distance (vertical axis) in dependence of vertical illuminances  $E_V$  in the measuring field (horizontal axis) for different background luminance's  $L_U$  (coloured lines). The horizontal red line demarcates the visibility level of 10. The calculation of the visibility level was conducted in accordance with the method outlined by Adrian (ADRIAN, 1989) employing an object size  $\alpha$  of 1.5 m (100'), a surface reflectance  $\rho$  of 0.2, and an observer age of 60 years.**

### 2.3 Derived parameter values

In visual perception, contrast polarity is categorized as:

- **Negative contrast:** the visual object is darker than its brighter background.
- **Positive contrast:** the visual object is lighter than its darker background.

Current lighting standards for P-class lighting predominantly employ horizontal illuminance to achieve negative contrast. This method works effectively under high background luminance conditions. However, for low background luminance levels ( $L_U \leq 0.30 \frac{\text{cd}}{\text{m}^2}$ ), object and background luminances tend to converge. As a consequence, visual objects can become indistinguishable from the background, significantly reducing their visibility.

Figure 1 illustrates clearly how insufficient vertical illuminance ( $E_V$ ), leading to low target luminances, especially at low background luminances, causes the visibility level ( $VL$ ) to fall below the critical threshold of 10, resulting in the objects becoming effectively invisible.

It is critical that in the P3–6 and M6 classes, which are usually applied for cycle paths, only low background luminance  $L_U \leq 0.30 \frac{\text{cd}}{\text{m}^2}$  are achieved, and cyclists can easily become invisible due to the luminances becoming similar. Targeted brightening with the help of vertical illuminances to create a positive contrast is one possibility to ensure here that cyclists remain visible above the  $VL = 10$  threshold.

To determine the corresponding vertical illuminance values at a height of 1.5 m as presented in Table 1, the second intersection point of each luminance curve with the  $VL = 10$  threshold (represented by the dashed horizontal red line) was selected. At this point, additional illumination of the target further increases the positive contrast significantly, making it unlikely for the luminances of the target and the background to converge.

**Table 1 – Derived values for two observer ages for vertical illuminances as suggestion for an addition to the horizontal illuminance values in EN 13201-2**

class	Horizontal illuminance		Vertical illuminance in conflict zones (observer age: 60 years)	Vertical illuminance in conflict zones (observer age: 23 years)
	$E_{avg}$ [maintenance value]	$E_{min}$ [maintenance value]	$E_{v,min}$ [maintenance value]	$E_{v,min}$ [maintenance value]
	lx	lx	lx	lx
P1	15	3	-	-
P2	10	2	-	-
P3	7.5	1.5	8	7
P4	5	1	6	5
P5	3	0.6	4.5	3.5
P6	2	0.4	3.5	2.5
P7	-	-		

The application of this parameter is recommended for conflict zones, where cycle path or lanes merge or cross with other traffic flows. Corresponding assessment areas for both typical conflict situations were defined and also considered separately in the validation described below.

**2.4 Feasibility and validation of increasing the visibility level**

For the validation, it was first necessary to check whether a higher vertical illuminance at a height of 1.5 m can be achieved compared to the horizontal illuminance at the same point. To this end, a Python tool was used to analyse theoretical light distributions for a variety of different road geometries with regard to the fulfilment of predefined exclusion and quality criteria.

Following the successful theoretical validation of the proposed lighting model through computational optimisation, its practical feasibility and effect on cyclist visibility were tested on a road lighting research track. The test site is equipped with six luminaires mounted on adjustable-height poles, spaced at 20-metre intervals. Each luminaire includes four independently controllable LED modules with differing light distribution curves (LDCs), enabling a wide range of lighting scenarios to be simulated. While the available LDCs were not specifically optimised for the proposed model, their flexibility allowed for a meaningful experimental evaluation.

Eight lighting scenarios were implemented on the test track: four representing compliance with the existing EN 13201-2 (DIN, 2016) standard for P3 to P6 classes (“Current”), and four additional scenarios that incorporated the proposed vertical illuminance values at a height of 1.5 metres as suggested in the new model (“New”). Based on the previous optimisation analysis, a mounting height of 6 metres was selected, combined with a 20-metre pole spacing. This configuration, yielding a height-to-spacing ratio of 1:3.3, was previously shown to be well-suited for meeting both horizontal and vertical illuminance requirements across all classes and profiles.

Scenario-specific dimming values were determined using lighting design software (DIALux and LightTools), and the resulting scenes were validated through measurements of horizontal and vertical illuminance. Measurements were taken at six designated points on the test track based on the standard grid defined in EN 13201-4 (DIN, 2016) to validate the simulation.

To quantify visibility levels (*VL*), a grey card was positioned at 1.5 m height at a point where the desired parameters were achieved. This height corresponds to standards for semi-cylindrical illuminance used in face recognition tasks (EN 13201-2, Section 4.1). The grey card was aligned laterally and recorded using a luminance camera (LMK 6 with a 50 mm lens) from two observation positions:

1. **Longitudinal traffic scenario:** The camera was placed 30 m from the nearest luminaire, aligned centrally with the grey card.
2. **Junction scenario:** The camera was placed 9.1 m longitudinally and 7 m laterally from the card, to simulate a peripheral glance.

Eight lighting scenarios were evaluated from both positions. Using a MATLAB script, the visibility level of the grey card was calculated from the luminance images (Table 2).

**Table 2 – VL of the grey card for the different scenarios**

		VL longitudinal	VL junction
P3	Current	74,73	168,00
	New	106,54	207,70
		+43 %	+24 %
P4	Current	50,60	130,20
	New	65,92	158,39
		+30 %	+22 %
P5	Current	25,93	85,80
	New	33,01	107,00
		+27 %	+25 %
P6	Current	19,17	64,90
	New	27,10	86,91
		+41 %	+34 %

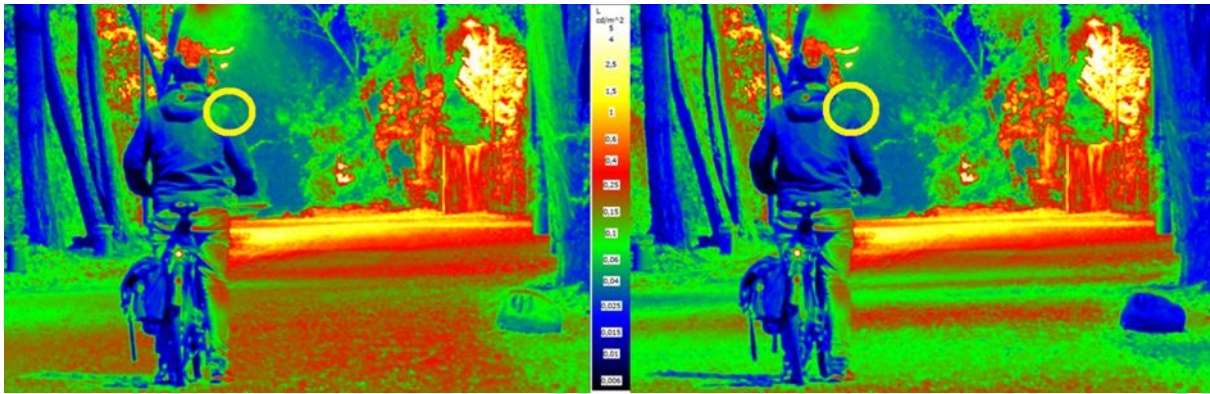
Improvements in VL ranged from 27 % to 43 % in the longitudinal view, and from 22 % to 34 % in the junction view. Higher gains in the longitudinal scenario were attributed to darker, unlit backgrounds, whereas in the junction case, vegetation near the road was partially illuminated by the luminaires.

All measured VL values exceeded the critical threshold of 10, due to favourable test field conditions with minimal background luminance. In real-world urban environments, where background luminance from adjacent traffic or building facades is often higher, the margin of safety provided by the new parameter model becomes even more valuable.

## 2.5 Cyclist Visibility Validation

In a follow-up measurement series, the grey card was replaced with a real cyclist positioned at the position of the grey card. The same observation positions were used. Given the complex geometry and material properties of the cyclist, the evaluation focused on qualitative visual improvement. Nonetheless, a simplified Weber contrast calculation at the cyclist's right shoulder (highlighted in Figure 3) offered a quantifiable result: the new model – using a higher vertical illuminance – yielded a Weber contrast of 0.6, compared to just 0.23 under the current model.

This confirms the findings from the grey card measurements and supports the claim that the proposed lighting concept substantially enhances the visibility of actual cyclists.



**Figure 3 – Luminance images of a cyclist. Left: new parameter model weber contrast 0.6, right: current parameter model weber contrast 0.23**

### 3 Recommendations for urban lighting and for a revision of the EN 13201

In order to implement the developed lighting concept, it was necessary to formulate guidelines for adapting the EN 13201. Furthermore, a guideline for municipalities was drawn up that summarises recommendations for the design of lighting for cycle paths.

There are two main scenarios in which cycle paths interact with other traffic flows in urban environments. On the one hand, there are isolated paths that are physically separated from other traffic flows. In these scenarios, the standard approach of P-class lighting is sufficient and does not require any visibility-based adjustments. On the other hand, there are cycle paths or lanes that cross or merge with other traffic flows. These scenarios represent conflict zones with high visibility requirements. The theoretical model proposes two approaches for such conflict zones to enable the detection of cyclists at any point within the zone:

- Employing vertical illuminance as an additional parameter to realize a positive contrast
- Adhering to C-class lighting standards.

In addition, it is proposed to take the homogeneity of the luminance of the surrounding into account when selecting the P class and to ensure that no M6 can be selected for mixed traffic by adjusting the selection tables for M classes, since the specified luminance level of 0.30 cd/m<sup>2</sup> is too low here to allow sufficient negative contrast.

### 4 Summary

To summarise, cycling at night presents unique challenges and an increased risk of accidents due to limited visibility. Road lighting plays an important role in this regard.

The study presented here examined the visibility of cyclists under real road lighting conditions and proposes a novel model for creating positive contrast that improves the visibility and safety of cyclists at night. The focus of this model is the application of vertical illuminance as an additional parameter when planning road lighting for conflict-prone traffic zones. Furthermore, adjustments to the selection tables of EN 13201 are proposed.

### References

- ADRIAN, W. 1989. Visibility of Targets: Model for Calculation. *Lighting Research & Technology*, 21, 181-188. <https://doi.org/10.1177/096032718902100404>
- BENEA, B., TRUSCĂ, D., TOGĂNEL, G. et al. 2019. The Influence of the Color of the Reflective Vest on the Visibility of the Cyclist at Night. *The 30th SIAR International Congress of Automotive and Transport Engineering*; DOI:10.1007/978-3-030-32564-0 42.
- CIE 2010. CIE 115:2010. Lighting of roads for motor and pedestrian traffic. Technical report, 2nd ed. ed. Vienna: CIE. ISBN 978-3-901906-86-2

- DIN EN 13201 2016. Straßenbeleuchtung. Teil 2: Gütemerkmale, Teil 3: Berechnung der Gütemerkmale, Teil 4: Methoden zur Messung der Gütemerkmale von Straßenbeleuchtung, Teil 5: Energieeffizienzindikatoren.
- DIN 13201 2021. Straßenbeleuchtung – Teil 1: Auswahl der Beleuchtungsklassen.
- FOTIOS S., UTTLEY, J. and FOX, S. 2019. A whole-year approach showing that ambient light level influences walking and cycling. *Lighting Research & Technology* 51(1): 55–64.
- KOKOSCHKA, S. 1988. Zur Berechnung von Schwellenkontrasten für die Detektion einfacher Sehobjekte. *LICHT* 1988 (4), 305–308.
- KOLREP-ROMETSCH, H. et al. 2013. Abbiegeunfälle Pkw/Lkw und Fahrrad. Gesamtverband der Deutschen Versicherungswirtschaft e. V., Unfallforschung der Versicherer, Berlin.
- KOSSMANN, I. et al. 2021. Sicheres Radfahren in einem gemeinsam genutzten Straßenraum. Berichte der Bundesanstalt für Straßenwesen.
- SCHIERZ, C. 2016. Grundlagen der Beleuchtungstechnik. Baer, Barfuß, Seifert (Hrsg.). ISBN 978-3-341-016343. Huss-Medien Berlin. S.77-83
- IIVANOVICI, M. and RICHARD, N. 2016.
- UTTLEY, J., FOTIOS, S. and LOVELACE, R. 2020. Road lighting density and brightness linked with increased cycling rates after-dark. *Public Library of Science one*; 15(5): e0233105.
- UTTLEY, J. and FOTIOS, S. 2023. The effect of changes in light level on the numbers of cyclists. *Lighting Research & Technology* 55(4): 399–413.  
DOI:10.1177/14771535221147849.
- WOOD, J. M. 2019. Nighttime driving: visual, lighting and visibility challenges. *Ophthalmic & physiological optics*, 40(2), 187–201. DOI:10.1111/opo.12659