

# Development of photometric criteria for the design of registration plate illumination systems using light simulation methods

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## Abstract

The illumination of registration plates poses challenges for lighting technology. To achieve the wide and steep angles required for homogeneous illumination of the license plate, optics are needed to refract and reflect light. In this work, registration plate lamps with different components are designed. After the construction, the concepts are tested for their limits in terms of position and manufacturability. The entire work is carried out at the company CREAT GmbH in Ingolstadt. All developments in the field of registration plate lighting are subject to the UNECE and country-specific regulations, which must be considered in the development of the lights.[1] Some vehicles currently available on the automotive market are measured to classify and compare the different lamp systems. From the average values, the lamps are designed. Adjustments are repeatedly made to the lighting device to achieve the most homogeneous illumination of the registration plate. As soon as the lights meet the legal requirements, the geometric limits of the lighting device are defined in relation to the plate. As there are different polymers to produce optics, these are simulated with their refractive indices and tested for their effects on the light image.

**Keywords:** Light Simulation, Ray Tracing, Optical Design, Registration/License Plate Illumination, Light Distribution, Luminance, Automotive, UNECE R4

## 1 Introduction

According to statistics[2], the number of fatal road accidents at night are decreasing between 1991 and 2021. In 2021, the number of fatal accidents at night was 575 out of a total of 2600.[2] This corresponds to a percentage of 22.12% of fatal accidents at night. It is noteworthy that only 20 % of all journeys in Germany take place at night.[3] This leads to the assumption that limited visibility in poor lighting conditions significantly increases the

risk of accidents. The risk of accidents at night is still higher than during the day, although the numbers are falling. Optimizing the lighting systems in vehicles therefore not only improves comfort, but also safety.[3] It must also be possible to identify the vehicle at any time. This is usually done via the registration plate, which can be clearly assigned to an owner. In order to ensure that this is also possible at night, an appropriate lighting system must be installed on the vehicle.[4] In most cases, lights are used that are already installed by OEM in other vehicles, so-called carry over parts (COP). With carry

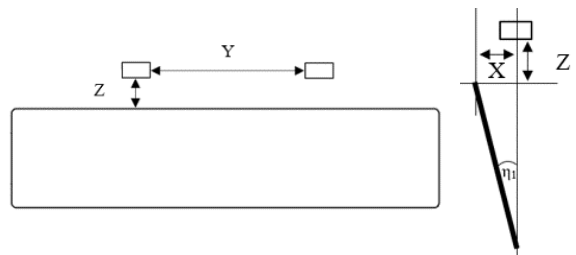
over parts, there is always a risk that certain brightness values required by the UNECE will not be fulfilled.[1] The installation of a registration plate lamps is always associated with the problem of steep lighting and the need for a large aperture angle. For this reason, the beams must be directed to the right places using an optical concept. To gain a better overview of the possibilities of an illumination system for registration plates, various optical concepts are simulated and compared using a light simulation software. The positional shift of the lamps must be considered, for which limits will be defined afterwards. The simulation software can be used to test various optical concepts and verify them in accordance with regulations.[5] For this purpose, a reflector, and a collimator in combination with a diffusing lens are designed and compared. The effect of different polymers with different refraction indices were evaluated. In addition, the installation space for a registration plate lamp is usually very small. This creates challenges in terms of the design of the optics and the positioning of the light source. Due to the limited space, it has many advantages to design the light with the smallest possible elements. However, this should always remain within the production limits.

## 2 Ideal light intensity distribution

The reverse simulation function in the simulation software is used to generate a theoretically ideal luminance distribution for a registration plate lamp. The position for the light is determined for this. Five vehicles are selected for this purpose to obtain an average value for the position of the lamps and its registration plate. A small car, a compact car, a station wagon, a sedan, and an SUV are included in the measurements. The results are shown in Table 1. In Fig. 1 a sketch of the measurement of the cars is illustrated.

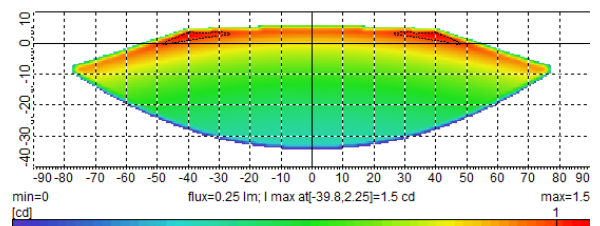
Car	$\eta_1$ [°]	X [mm]	Y [mm]	Z [mm]
Small Car	15,3	-22,0	240	17,0
Compact Car	14,2	-25,0	255	21,0
Sedan	12,8	-31,0	262	31,0
Station Car	12,2	-20,0	281	20,0
SUV	18,0	-33,0	257	43,0
<b>Average</b>	<b>14,5</b>	<b>-26,2</b>	<b>259</b>	<b>26,4</b>

**Table 1:** Measurements of the different cars.



**Fig. 1:** Sketches for measuring the vehicles.

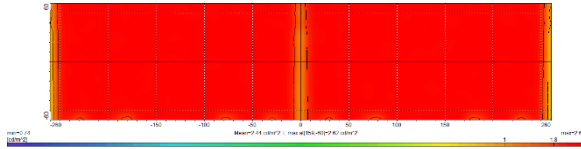
For the reverse calculation of the light distribution, the Calculate Street Light Pattern Reverse[6] function is used. For the lighting characteristic of one lamp, a batwing distribution is expected. It is known for the visually represented shape of wings. The luminous intensity  $I_v$  is increased at an opening angle of  $\pm 40$  to  $\pm 60^\circ$ . In the middle, the luminous intensity  $I_v$  is lower.[7] The result of the reverse luminous intensity distribution can be seen in Fig. 2.



**Fig. 2:** Reverse simulated luminous ideal intensity distribution of one registration plate lamp.

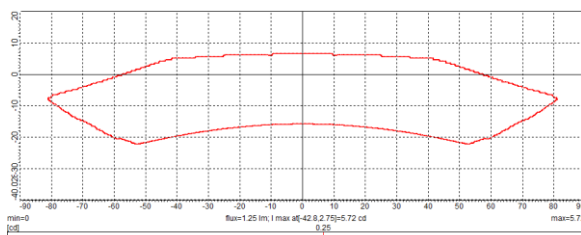
The calculated light distribution is in agreement with the expected batwing distribution. An increased luminous intensity  $I_v$  is observed in the range from  $\pm 27$  -  $\pm 48^\circ$ . In the range

between  $-26^\circ$  and  $26^\circ$ , the luminous intensity  $I_v$  is reduced. The generated LID file is loaded into a point light source and placed at the position simulated from the reverse calculation. The result of the simulated registration plate can be seen in Fig. 3.



**Fig. 3:** The ideal luminance distribution on the registration plate.

The result of the simulation is a homogeneous surface. The average value of the luminance is  $L_{v,average} = 2,44 \frac{cd}{m^2}$  and is therefore slightly below the limit value. A maximum value of  $L_{v,max} = 2,62 \frac{cd}{m^2}$  is measured. The evaluation according to UNECE R4 results in a luminance between  $L_v = 2,54 - 2,58 \frac{cd}{m^2}$ . A statement about the homogeneity can be made from the ratio table. The values are 0.0 in all points, which indicates ideal homogeneity. These values are calculated in accordance with Addendum 147 - UN Regulation No. 148 5.11.3.[8] By creating individual LID files from the measured vehicles, a luminous intensity distribution is generated by superposition. As shown in Fig. 2, the luminous intensity distribution provides a narrow framework for shifts. That means that such a light distribution can only be used theoretically. In most cases a registration plate lamp is used for several vehicles according to the modular principle. For this reason, a greater degree of flexibility is required. The light intensity distribution shown in Fig. 4 represents a more realistic one.



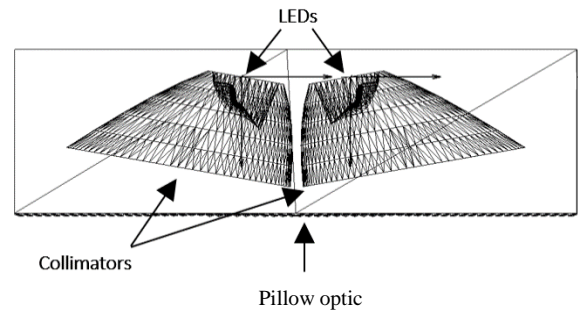
**Fig. 4:** Optimal theoretical Light intensity distribution using overlaid LID files of the measured vehicles.

Compared to Fig. 2, the distribution of luminous intensity is much wider vertically and slightly wider horizontally. This allows more installation positions of the lamps in relation to the registration plate. Based on the LID file in Fig. 4, several vehicles can be covered with one lamp identical in design. Thus, tolerances in production and assembly can also be compensated.

### 3 Simulation results

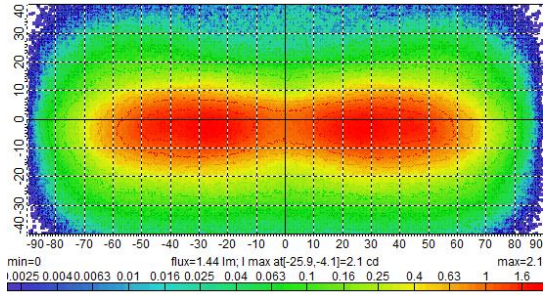
Simulations with four different variants are tested. Two of the variants, the collimator and the reflector, each equipped with a pillow optic as a scattering element, fulfill the ECE standard.[8], [9], [10] The two variants, consisting out of an LED with pillow optics and a Fresnel lens with pillow optics, do not fulfill the ECE standard.

#### Collimator:



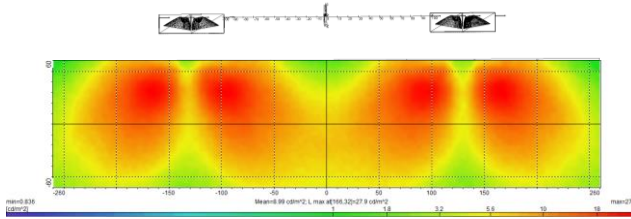
**Fig. 5:** Registration plate lamp with two LED, two collimators and pillow optics as scattering element.

The collimators are tilted outwards by  $10^\circ$ . This is to achieve better illumination of the pillow optic. However, a greater tilt is associated with losses in intensity. In a further step, the scattering of the collimator is set. For this purpose, the inner lens and the TIR are adjusted. One collimator illuminates one side of the pillow optics. The pillow optics are divided into two parts. Thus, they can be adapted to the angle of inclination of the collimator. Since a homogeneous light image is generated by a batwing distribution on the registration plate (see before), the light intensity distribution of the optical system is analyzed.[7] The light intensity distribution is shown in Fig 6.



**Fig. 6:** Luminous intensity distribution of one lamp with collimator and pillow optics. Simulated with a luminous flux of  $\phi_{v,LED} = 1 \text{ lm}$  per LED.

A lower luminous intensity is measured in the center of the distribution than in the outer angular areas. The luminous intensity increases with increasing angles. The optic has a luminous flux of  $\phi_{v,lamp} = 1,44 \text{ lm}$  and a total loss of  $\phi_{v,loss} = 0,56 \text{ lm}$ . A luminous intensity of  $I_{v,lamp} = 2,1 \text{ cd}$  is measured when leaving the optics. The two developed registration plate lamps are mounted at the average of measured positions in Table 1, as shown in Fig. 7.



**Fig. 7:** Two registration plate lamps with collimators and pillow optics as scattering element. The corresponding luminance distribution on the plate is also shown.

The simulation with a set luminous flux of  $\phi_{v,LED} = 1 \text{ lm}$  per LED generates an average luminance value of  $L_{v,average} = 8,99 \frac{\text{cd}}{\text{m}^2}$  and a maximum luminance of  $L_{v,max} = 27,9 \frac{\text{cd}}{\text{m}^2}$ . The evaluation according to UNECE R4 leads to the values shown in the supporting information Fig. 14. The evaluation of Fig. 14 shows the fulfillment with the ECE R4.[8], [9], [10] The minimum percentage value for compliance with the standard is 276 %. This was achieved by doubling the luminous flux per LED to  $\phi_{v,LED} = 2 \text{ lm}$ . With a luminous flux of  $\phi_{v,LED} = 1 \text{ lm}$  per LED, the standard would have been fulfilled. However, the luminance

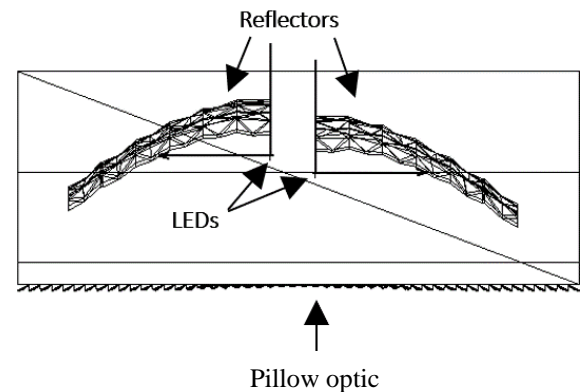
would only be slightly above the limit value. Luminance losses on the registration plate can occur due to material properties, incorrect alignment when mounting the plate lamps or manufacturing tolerances. Therefore, luminance values that are too close to the standards are associated with high risks. The lamp position limits are intended to provide a framework for movement between the registration plate and the lamp. Limit values are determined by gradually changing the single geometric values. As soon as the UNECE standard is not fulfilled, a limit value can be set. The simulated limit values are shown in Table 2.

Kind	Min	Max	Base case
X [mm]	200,0	320	259,0
Y [mm]	0,0	237	26,4
Z [mm]	-8,5	-48	-26,2
$\eta_1$ [°]	0,0	30	14,5

**Table 2:** Geometric limit values for displacements of a lamp with collimators and pillow optics.

Changing the position from the base case leads to a worsening in homogeneity. The limit values specified in Table 2 are simulated with unchanged optics and a luminous flux of  $\phi_{v,LED} = 2 \text{ lm}$ . If a more homogeneous light image is required on the registration plate, adjustments must be made to the optics. The limits for a shift between the two elements can be extended by adjusting.

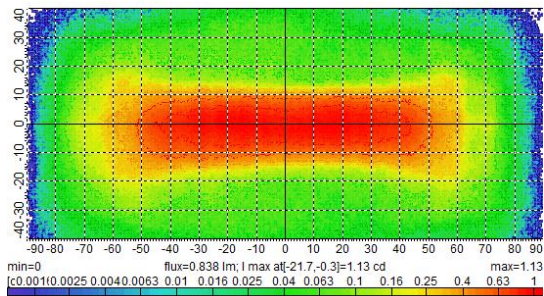
### Reflector:



**Fig. 8:** Registration plate lamp with two reflectors and scattering element in pillow look.

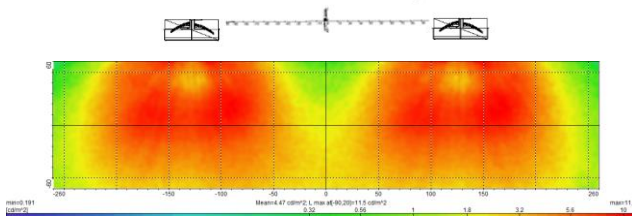


When positioning the reflectors at 90° with respect to the registration plate, the scattered light from the LEDs can be used on the registration plate. For this purpose, the circuit board is fitted with one LED on each side and positioned in the middle of the casing. The opposing LEDs must be offset on the circuit board due to the design. The reflectors are also rotated by +/- 90° in Y-direction. This has the advantage that installation space can be saved. The developed lamp is shown in Fig. 8. The light intensity distribution emanating from this lamp is shown in Fig. 9.



**Fig. 9:** Luminous intensity distribution of the lamp with reflectors and pillow optics. Simulates with a luminous flux of  $\phi_{v,LED} = 1 \text{ lm}$  per LED.

The luminous intensity distribution from one lamp emits a luminous flux of  $\phi_{v,lamp} = 0,84 \text{ lm}$ . This means a loss of the emitted luminous flux of  $\phi_{v,loss} = 1,162 \text{ lm}$ . The losses can be explained by stray light, as the reflectors do not completely enclose the LEDs. In addition, the pillow optics in this concept consist of an entrance and an exit surface. Losses occur on both surfaces due to Fresnel effects.[11] According to the simulation, the emitted luminous intensity  $I_v$  of the lamp with the reflectors is  $I_v = 1,13 \text{ cd}$ .



**Fig. 10:** Two registration plate lamps with reflectors and pillow optics as cover element. The corresponding luminance distribution on the plate is also shown.

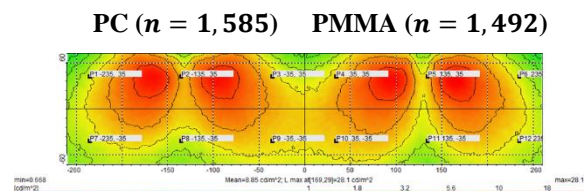
The luminance distribution on the registration plate shows an average luminance value of  $L_v = 4,47 \frac{\text{cd}}{\text{m}^2}$  and a maximum value of  $L_{v,max} = 11,5 \frac{\text{cd}}{\text{m}^2}$ . As the luminous flux of  $\phi_v = 1 \text{ lm}$  per LED was not sufficient in the first simulation, it is increased to  $\phi_v = 3 \text{ lm}$  per LED. The simulation results can be found in the supporting information Fig. 15. The measurement points are all above the required luminous flux of  $L_v = 2,5 \frac{\text{cd}}{\text{m}^2}$ . The lowest measured point P1 has a luminance of  $L_v = 4,15 \frac{\text{cd}}{\text{m}^2}$ , while the brightest point P5 has a luminance of  $L_v = 13,61 \frac{\text{cd}}{\text{m}^2}$ . The ratio table shows good homogeneity due to the values below 1. The limits for an offset between the lamps and the registration plate are determined in this concept by displacement.

Kind	Min	Max	Base case
X [mm]	238	310	259,0
Y [mm]	6	200	26,4
Z [mm]	-14	-52	-26,2
$\eta_1$ [°]	0	30	14,5

**Table 3:** Geometric limit values for displacements of a lamp with reflectors and pillow optics.

#### 4 Influence of refractive index

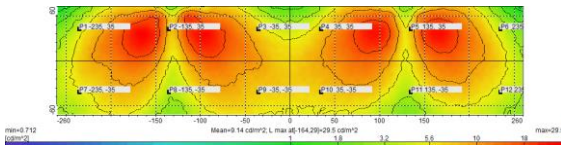
Most of the optics used in registration plate lamps are made of PMMA. The polymer PMMA has a refractive index of  $n_{PMMA} = 1,492$ . [12] PMMA has a large advantage compared to other materials due to its beneficial cost efficiency. Another polymer that is frequently used in the automotive sector is PC with a refractive index of  $n_{PC} = 1,585$ . [12]



**Fig. 11:** Simulation with the materials PC and PMMA. The lamp on the left was simulated with the material PC. The lamp on the right is made of PMMA.

To visualize the difference of the two materials, the ISO lines are shown in Fig. 11. These define the areas with different luminance  $L_v$ . The subdivisions of the ISO lines correspond to the luminance's  $L_v = \{0,56; 1; 1,8; 3,2; 5,6; 10; 18\} \frac{cd}{m^2}$ . The scattering in horizontal direction has barely increased. In the vertical direction, the beams are refracted less strongly. (see supporting information Fig. 16). This effect is explained by the angle of total reflection when entering the optics.[13] In this case, the total reflection has a negative effect with a higher refractive index. A higher refractive index degrades the light image if the optics are not adjusted. A lower refractive index has a positive effect. An optical silicone with a refractive index of  $n_{optical\ silicone} = 1,41$  is available for this purpose.[14] The results of the simulation can be seen in Fig. 12 and in the supporting information Fig. 17.

**Opt. silicon ( $n = 1,41$ ) PMMA ( $n = 1,492$ )**



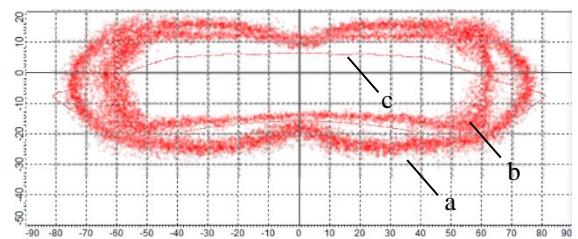
**Fig. 12:** Simulation with the materials of optical silicone and PMMA. The lamp on the left was simulated with the material optical silicone. The lamp on the right is made of PMMA.

The simulation shows that a lower refractive index has an advantage in scattering if the optics remain unchanged. If points P1 and P6 are compared, we observe that the measured values differ slightly, for both a high and low refractive index. However, the situation is different for points P7 and P12. Here the optical silicone with the lower refractive index performs better.

## 5 Conclusion

The geometric relationship between the light and the registration plate varies for different vehicles. The differences between the various vehicle classes are particularly big. For this reason, a registration plate lamp must be flexible in use. This can be achieved by

widening the light cone with the optics. A wider light cone opens many possibilities for positioning the lights on the vehicle to comply with the UNECE R4 standard. However, shifts from the originally planned position are associated with a loss of homogeneity. This can lead to unsightly luminance distributions on the plate, which fulfill the standards but are clearly visible to the end user as a quality feature. It should therefore be considered whether a lamp should produce a homogeneous light pattern on the registration plate or whether compromises can be made in this respect. Changing the polymer for the optics influences the quality of homogeneity. A lower refractive index leads to a better luminous image on the registration plate due to the higher angle of total reflection. A higher refractive index leads to better refractive properties, but the acceptance angle of the optics is decreasing, which leads to a worse result for the scattering on the registration plate. Two different optics fulfill the standard. One is the lamp with collimators, the other with reflectors. The light patterns of both lamps have a batwing-shaped distribution. In Fig. 13 the luminous intensity distribution is shown. The distribution of both lamps fit to the optimal theoretically simulated distribution to a large extent.



**Fig. 13:** Comparison of the emitted luminous intensity distributions of the collimator (a), reflector (b) and the optimal theoretical distribution (c).

The ratio table according to UNECE R4 show better performance of the reflector concept in terms of homogeneity. However, the collimator has a slight advantage due to its extended luminous intensity distribution and effectiveness. The collimator has a clear advantage as it has significantly less loss of luminous intensity. In addition, the collimator is cheaper to manufacture, as both the number of

components and the production tool are less cost intensive. In summary, the collimator with pillow optics can be described as the concept favored in this work.

## Acknowledgement

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## Supporting information

name	value OK [cd/m <sup>2</sup> ]	min/max % / %	min [cd/m <sup>2</sup> ]	max [cd/m <sup>2</sup> ]	test pos./area H,H/V,V [mm]	found pos. [mm]
P1 -235, 35	8.99 OK	360/--	2.50	--	-235.00, 35.00	
P2 -135, 35	15.92 OK	637/--	2.50	--	-135.00, 35.00	
P3 -35, 35	13.79 OK	552/--	2.50	--	-35.00, 35.00	
P4 35, 35	13.69 OK	549/--	2.50	--	35.00, 35.00	
P5 135, 35	15.06 OK	602/--	2.50	--	135.00, 35.00	
P6 235, 35	8.82 OK	353/--	2.50	--	235.00, 35.00	
P7 -235, -35	9.67 OK	397/--	2.50	--	-235.00, -35.00	
P8 -135, -35	7.94 OK	317/--	2.50	--	-135.00, -35.00	
P9 -35, -35	13.78 OK	551/--	2.50	--	-35.00, -35.00	
P10 35, -35	13.90 OK	556/--	2.50	--	35.00, -35.00	
P11 135, -35	6.90 OK	276/--	2.50	--	135.00, -35.00	
P12 235, -35	9.72 OK	389/--	2.50	--	235.00, -35.00	

Ratio table:

Ratio	I P 1	I P 2	I P 3	I P 4	I P 5	I P 6	I P 7	I P 8	I P 9	I P 10	I P 11	I P 12	I												
P 1	I	--	I	0.7	I	0.2	I	0.2	I	0.2	I	0.0	I	0.1	I	0.1	I	0.2	I	0.2	I	0.1	I	0.0	I
P 2	I	0.7	I	--	I	0.2	I	0.1	I	0.0	I	0.2	I	0.5	I	1.1	I	0.2	I	0.1	I	0.3	I	0.2	I
P 3	I	0.2	I	0.2	I	--	I	0.0	I	0.1	I	0.2	I	0.2	I	0.5	I	0.0	I	0.0	I	0.4	I	0.1	I
P 4	I	0.2	I	0.1	I	0.0	I	--	I	0.1	I	0.2	I	0.1	I	0.3	I	0.0	I	0.0	I	0.6	I	0.2	I
P 5	I	0.2	I	0.0	I	0.1	I	0.1	I	--	I	0.6	I	0.1	I	0.3	I	0.1	I	0.1	I	1.2	I	0.4	I
P 6	I	0.0	I	0.2	I	0.2	I	0.2	I	0.6	I	--	I	0.0	I	0.0	I	0.2	I	0.2	I	0.2	I	0.1	I
P 7	I	0.1	I	0.5	I	0.2	I	0.1	I	0.1	I	0.0	I	--	I	0.2	I	0.2	I	0.2	I	0.1	I	0.0	I
P 8	I	0.1	I	1.1	I	0.5	I	0.3	I	0.3	I	0.0	I	0.2	I	--	I	0.6	I	0.4	I	0.0	I	0.0	I
P 9	I	0.2	I	0.2	I	0.0	I	0.0	I	0.1	I	0.2	I	0.2	I	0.6	I	--	I	0.0	I	0.4	I	0.2	I
P 10	I	0.2	I	0.1	I	0.0	I	0.0	I	0.1	I	0.2	I	0.2	I	0.4	I	0.0	I	--	I	0.7	I	0.2	I
P 11	I	0.1	I	0.3	I	0.4	I	0.6	I	1.2	I	0.2	I	0.1	I	0.0	I	0.4	I	0.7	I	--	I	0.3	I
P 12	I	0.0	I	0.2	I	0.1	I	0.2	I	0.4	I	0.1	I	0.0	I	0.0	I	0.2	I	0.2	I	0.3	I	--	I

The light distribution is OK

Fig. 14: Evaluation according to UNECE R4 with a luminous flux of  $\phi_{v,LED} = 2 \text{ lm}$  per LED.

name	value OK [cd/m <sup>2</sup> ]	min/max % / %	min [cd/m <sup>2</sup> ]	max [cd/m <sup>2</sup> ]	test pos./area H,H/V,V [mm]	found pos. [mm]
P1 -235, 35	4.15 OK	166/--	2.50	--	-235.00, 35.00	
P2 -135, 35	12.09 OK	484/--	2.50	--	-135.00, 35.00	
P3 -35, 35	6.75 OK	270/--	2.50	--	-35.00, 35.00	
P4 35, 35	7.35 OK	294/--	2.50	--	35.00, 35.00	
P5 135, 35	13.61 OK	544/--	2.50	--	135.00, 35.00	
P6 235, 35	4.50 OK	180/--	2.50	--	235.00, 35.00	
P7 -235, -35	6.31 OK	252/--	2.50	--	-235.00, -35.00	
P8 -135, -35	12.50 OK	500/--	2.50	--	-135.00, -35.00	
P9 -35, -35	10.63 OK	425/--	2.50	--	-35.00, -35.00	
P10 35, -35	9.69 OK	388/--	2.50	--	35.00, -35.00	
P11 135, -35	12.72 OK	509/--	2.50	--	135.00, -35.00	
P12 235, -35	6.36 OK	254/--	2.50	--	235.00, -35.00	

Ratio table:

Ratio	I P 1	I P 2	I P 3	I P 4	I P 5	I P 6	I P 7	I P 8	I P 9	I P 10	I P 11	I P 12	I												
P 1	I	--	I	0.8	I	0.1	I	0.1	I	0.3	I	0.0	I	0.3	I	0.7	I	0.3	I	0.2	I	0.2	I	0.0	I
P 2	I	0.8	I	--	I	0.5	I	0.3	I	0.1	I	0.2	I	0.5	I	0.1	I	0.1	I	0.1	I	0.0	I	0.2	I
P 3	I	0.1	I	0.5	I	--	I	0.1	I	0.4	I	0.1	I	0.0	I	0.5	I	0.6	I	0.3	I	0.3	I	0.0	I
P 4	I	0.1	I	0.3	I	0.1	I	--	I	0.6	I	0.1	I	0.0	I	0.3	I	0.3	I	0.3	I	0.4	I	0.0	I
P 5	I	0.3	I	0.1	I	0.4	I	0.6	I	--	I	0.9	I	0.2	I	0.0	I	0.2	I	0.3	I	0.1	I	0.6	I
P 6	I	0.0	I	0.2	I	0.1	I	0.1	I	0.9	I	--	I	0.0	I	0.2	I	0.2	I	0.2	I	0.7	I	0.3	I
P 7	I	0.3	I	0.5	I	0.0	I	0.0	I	0.2	I	0.0	I	--	I	0.6	I	0.2	I	0.1	I	0.2	I	0.0	I
P 8	I	0.7	I	0.1	I	0.5	I	0.3	I	0.0	I	0.2	I	0.6	I	--	I	0.2	I	0.2	I	0.0	I	0.2	I
P 9	I	0.3	I	0.1	I	0.6	I	0.3	I	0.2	I	0.2	I	0.2	I	0.2	I	--	I	0.1	I	0.1	I	0.2	I
P 10	I	0.2	I	0.1	I	0.3	I	0.3	I	0.3	I	0.2	I	0.1	I	0.2	I	0.1	I	--	I	0.3	I	0.2	I
P 11	I	0.2	I	0.0	I	0.3	I	0.4	I	0.1	I	0.7	I	0.2	I	0.0	I	0.1	I	0.3	I	--	I	0.6	I
P 12	I	0.0	I	0.2	I	0.0	I	0.0	I	0.6	I	0.3	I	0.0	I	0.2	I	0.2	I	0.2	I	0.2	I	0.6	I

The light distribution is OK

Fig.15: Evaluation according to UNECE R4 with a luminous flux of  $\phi_{v,LED} = 3 \text{ lm}$  per LED.



name	value OK [cd/m <sup>2</sup> ]	min/max % / %	min [cd/m <sup>2</sup> ]	max [cd/m <sup>2</sup> ]	test pos./area H,H/V,V [mm]	found pos. [mm]
P1 -235, 35	4.57 OK	193/--	2.50	--	-235.00, 35.00	
P2 -135, 35	8.65 OK	346/--	2.50	--	-135.00, 35.00	
P3 -35, 35	7.03 OK	281/--	2.50	--	-35.00, 35.00	
P4 35, 35	6.82 OK	273/--	2.50	--	35.00, 35.00	
P5 135, 35	7.57 OK	303/--	2.50	--	135.00, 35.00	
P6 235, 35	4.50 OK	180/--	2.50	--	235.00, 35.00	
P7 -235, -35	4.10 OK	164/--	2.50	--	-235.00, -35.00	
P8 -135, -35	4.14 OK	166/--	2.50	--	-135.00, -35.00	
P9 -35, -35	6.63 OK	265/--	2.50	--	-35.00, -35.00	
P10 35, -35	6.63 OK	265/--	2.50	--	35.00, -35.00	
P11 135, -35	3.42 OK	137/--	2.50	--	135.00, -35.00	
P12 235, -35	4.69 OK	197/--	2.50	--	235.00, -35.00	

**Fig. 16:** Evaluation of UNECE R4 with a lamp on the left side made of PC and on the right side made of PMMA.

name	value OK [cd/m <sup>2</sup> ]	min/max % / %	min [cd/m <sup>2</sup> ]	max [cd/m <sup>2</sup> ]	test pos./area H,H/V,V [mm]	found pos. [mm]
P1 -235, 35	4.51 OK	180/--	2.50	--	-235.00, 35.00	
P2 -135, 35	8.15 OK	326/--	2.50	--	-135.00, 35.00	
P3 -35, 35	7.05 OK	282/--	2.50	--	-35.00, 35.00	
P4 35, 35	7.06 OK	282/--	2.50	--	35.00, 35.00	
P5 135, 35	7.50 OK	300/--	2.50	--	135.00, 35.00	
P6 235, 35	4.65 OK	186/--	2.50	--	235.00, 35.00	
P7 -235, -35	5.33 OK	213/--	2.50	--	-235.00, -35.00	
P8 -135, -35	3.78 OK	151/--	2.50	--	-135.00, -35.00	
P9 -35, -35	7.20 OK	288/--	2.50	--	-35.00, -35.00	
P10 35, -35	7.04 OK	282/--	2.50	--	35.00, -35.00	
P11 135, -35	3.60 OK	144/--	2.50	--	135.00, -35.00	
P12 235, -35	4.64 OK	185/--	2.50	--	235.00, -35.00	

**Fig. 17:** Evaluation of UNECE R4 with a lamp on the left side made of optical silicon and on the right side made of PMMA.