Increasing of visibility on the pedestrian crossing by the additional lighting systems

Richard Baleja¹, Petr Bos¹, Tomas Novák¹, Karel Sokansky¹ and Tomas Hanusek¹

¹Faculty of Electrical Engineering and Computer Science, VSB - Technical University of Ostrava, 17. listopadu, 70833 Ostrava, Czech Republic

E-mail: richard.baleja.st@vsb.cz

Abstract. Pedestrian crossings are critical places for road accidents between pedestrians and motor vehicles. For this reason, it is very important to increase attention when the pedestrian crossings are designed and it is necessary to take into account all factors that may contribute to higher safety. Additional lighting systems for pedestrian crossings are one of them and the lighting systems must fulfil the requirements for higher visibility from the point of view of car drivers from both directions. This paper describes the criteria for the suitable additional lighting system on pedestrian crossings. Generally, it means vertical illuminance on the pedestrian crossing from the driver’s view, horizontal illuminance on the crossing and horizontal illuminance both in front of and behind the crossing placed on the road and their acceptable ratios. The article also describes the choice of the colours of the light (correlated colour temperature) and its influence on visibility. As a part of the article, there are case designs of additional lighting systems for pedestrian crossings and measurements from realized additional lighting systems by luxmeters and luminance cameras and their evaluation.

1. Introduction
The pedestrian crossings are one of the most dangerous places in the field of transport. The largest number of traffic accidents happens there. To limit the number of accidents, it is necessary to illuminate the crossing enough for pedestrian to be seen on the crossing.

The aim of this article is to get readers acquainted with the criteria which need to be followed when dealing with a design of lighting system for a pedestrian crossing, which would make the pedestrians more visible. In most cases, pedestrian crossings are illuminated insufficiently and they are in conflict with the applicable regulations. At the present time, the lighting systems of pedestrian crossings should meet the requirements of the Ministry of Transport of the Czech Republic - “Technické kvalitativní podmínky staveb a pozemních komunikací, Chapter 15 - Appendix 1 Přisvětlování přechodu”. However, a new standard ČSN 36 045 is being prepared. It will deal with the illumination of infrastructure there will be also a detailed description of issues and requirements for the illumination of pedestrian crossing.

The majority of newly implemented pedestrian crossings disregard this regulation. In most of the cases, it is caused by ignorance of the issue and disregarding calculation of the vertical illuminance; in the projects, it is only the horizontal illuminance, which is evaluated in the place of pedestrian crossing. The crossing is obviously highlighted on the road, pedestrians can see which way to go but
they may no longer be seen by the approaching driver because proportion of the vertical part of the crossing area can be insufficient for securing the necessary contrast between the pedestrians and the background. The shortage is mainly caused by misplacement of lights or by using lights with inappropriate luminous intensity curve. The lights are placed too close to the crossing transition and therefore it is often impossible to achieve the necessary vertical illuminance.

2. Division of the analysed areas at pedestrian crossings
The pedestrian crossing is divided into several sections; each of these sections has different requirements for additional lighting. Basic space of the pedestrian crossing determines a section which is situated directly on the place where the road is crossed. Unextended complementary space defines a section which is the entrance of the pedestrian crossing on the pavement. Extended complementary space is defined in cases when each driving direction is divided into the left and the right traffic lane by the traffic island.

In the Figure 1, the above-mentioned spaces of the pedestrian crossing are analogously illustrated. Marked areas apply for the left driving direction. For the opposite driving direction (view), the situation is analogous.

A = basic space
B = unextended complementary space
B’ = extended complementary space

Figure 1. Typical pedestrian crossing (left) and the pedestrian crossing with a median strip (right). [3]

In the regulation “Technické kvalitativní podmínky (TKP15)“, these spaces are defined in detail and lighting requirements for additional lighting of these spaces are described there. Logically, the requirements for the basic space illumination are slightly higher than the requirements for the complementary space illumination. It requires higher level of vertical illuminance there which must meet the given requirement for evenness whereas the evenness of illumination in the complementary space does not have to be evaluated. The evenness of illumination needs to be evaluated only in case of the extended complementary space. The choice of the appropriate type of light for the given pedestrian crossing is chosen on the basis of an evaluation of maintained average luminance or illumination of a particular roadway, on which the crossing will be set up. Table 1 depicts the required parameters for the pedestrian crossing illumination. Vertical illumination evaluates them at the height of 1 meter over the roadway from both driving directions. The requirement for the evenness of illumination for the basic and the extended complementary space is 0.4.
Table 1. Average maintained vertical illumination. [3]

| Maintained value of the existing lighting | Average maintained vertical illuminance(lx) | The lowest | The highest |
|------------------------------------------|--------------------------------------------|------------|------------|
| Luminance of roadway (cd.m⁻²)            | Horizontal illuminance of roadway (lx)      | Basic      | Complementary | All spaces |
| 1.5 ≤ L                                 | 50 ≤ E                                      | No additional lighting system is set up |
| 1.0 ≤ L < 1.5                          | 30 ≤ E < 50                                 | 75          | 50          | 200        |
| 0.75 ≤ L < 1.0                         | 20 ≤ E < 30                                 | 50          | 30          | 150        |
| 0.5 ≤ L < 0.75                         | 10 ≤ E < 20                                 | 30          | 20          | 100        |
| L < 0.5                                 | E < 10                                     | 15          | 10          | 50         |

It is important to stress the function of extended complementary space. It corresponds with the part of a crossing which is located directly on the roadway but in the opposite direction from the view of approaching driver. Extended complementary space is used as a protection for pedestrians in the middle of the roadway.

3. Making pedestrians more visible on the crossing

There are two ways to make pedestrian more visible while using lights. The first possibility is to achieve the so called negative contrast (Figure 2) when the pedestrian is seen as a dark-coloured figure on the light-coloured background. This effect can be achieved by doing nothing. It means that there is no lighting added on the pedestrian crossing even in the case when constellation of the crossing and illumination of the roadway is suitable. Luminaire which is placed far enough behind the crossing increases luminance of the road and thus the picture of a pedestrian is projected as a dark-coloured silhouette on the light-coloured background.

![Figure 2. Negative contrast and a way to achieve negative contrast. [4]](image)

The second possibility is the use of positive contrast (Figure 3) when a pedestrian is seen as light-coloured figure on the dark-coloured background. To achieve necessary contrast, it is necessary to add more lighting to the pedestrian crossing. Additional lighting is realized by luminaires which are placed in front of the pedestrian crossing from the view of the approaching vehicles. The luminaires are usually placed 1 to 2 metres from the crossing to achieve the required vertical illumination. This distance may vary depending on the type of luminaires used, that is why it is always necessary to calculate the pedestrian crossing lighting by a program and then, based on the calculation, position of the luminaires needs to be drawn into the plan. For a design of the pedestrian crossing illumination, special luminaires with asymmetrical luminous intensity curve are used. A suitable public lighting placed both in front of and behind the pedestrian crossing must be a part of the quality illuminated
crossing. The regulation “TKP15” defines directly these distances from the crossing in both directions which depends on the speed limit for the given roadway.

![Figure 3. Positive contrast and a way to achieve the positive contrast. [4]](image)

4. Lighting systems on the pedestrian crossings

As already mentioned, it is not easy to project an adequate lighting for a pedestrian crossing. At the beginning of the project, it is important to choose an appropriate place for its implementation. The pedestrian crossing should be placed $A=\pi r^2$ on the well-arranged part of the road, where a pedestrian will not be hidden by parked vehicles or trees and plants. It is necessary to take into consideration the fact that the additional lighting of the crossing can be disturbing for the surrounding residential buildings. For the appropriate project of illumination, it is possible to use nowadays a lot of specialized programs which enable to model the given lighting situation and then determine the type and position of luminaires.

![Figure 4. Example of a pedestrian crossing model made in Relux program.](image)

The figure 4 shows a model situation of the pedestrian crossing lighting. On the right side, there are components of illuminance vector of the crossing ($E_\theta$), vertical ($E_v$) and horizontal illumination ($E_h$).

To demonstrate the lighting design of a pedestrian crossing. The article presents two situations of the crossing illuminance. The first situation, which is represented in the Figure 5, illustrates a luminance analysis of the pedestrian crossing in Petřvald.

Illuminating system of the model pedestrian crossing is realized by two luminaires of Philips LUMA type, with an asymmetric light distribution. The luminaires are placed in front of the crossing (from the view of an approaching driver). By an appropriate combination of the luminaires placement and their light intensity curves, a balanced ratio between vertical and horizontal illuminance was
achieved. Thus, not only the pedestrian but also the crossing itself is visible. It is also the public lighting placed both in front of and behind a crossing which forms a quality illuminated pedestrian crossing. As a result of simultaneous light coming from the public lighting there are no significant contrasts and the driver is able to recognize obstacles apart from the crossing in time. LED lamps illuminating the crossing have high correlated colour temperature and the public lighting in front of and behind the crossing is realized by high-pressure sodium lamps. As a result of that lighting colour difference, the pedestrian crossing is recognized from its surroundings not only by the luminance contrasts but also by the colour contrast.

Figure 5. Luminance analysis of the crossing from both directions.

Table 2. Measured values of the picture luminance analysis.

| Area     | Minimum luminance (cd/m²) | Maximum luminance (cd/m²) | Average luminance (cd/m²) |
|----------|---------------------------|----------------------------|---------------------------|
| Crossing | 0.38                      | 13.92                      | 4.06                      |
| Background| 0.06                      | 2.94                       | 0.22                      |
| Pedestrian| 0.10                      | 17.64                      | 2.7                       |

| Area     | Minimum luminance (cd/m²) | Maximum luminance (cd/m²) | Average luminance (cd/m²) |
|----------|---------------------------|----------------------------|---------------------------|
| Crossing | 0.22                      | 10.63                      | 2.31                      |
| Background| 0.05                      | 11.68                      | 0.13                      |
| Pedestrian| 0.07                      | 16.03                      | 2.35                      |

On the other hand, there are many crossings which are not laminated in accordance with the regulations. Figure 6 illustrates a crossing with unsuitable lighting system. There are columnar luminaires of height about 1.2 m used but they fail to illuminate pedestrians to the desired extent and direction and in certain cases the can dazzle the approaching driver. From the luminance analysis, it is apparent that the pedestrian on the crossing is illuminated insufficiently and thus there is no contrast which is necessary for the approaching driver to distinguish the pedestrian.
Figure 6. A photograph of a crossing and its luminance analysis. [5]

Table 3. Measured values of the picture luminance analysis

| Area      | Minimum luminance $(\text{cd/m}^2)$ | Maximum luminance $(\text{cd/m}^2)$ | Average luminance $(\text{cd/m}^2)$ |
|-----------|-------------------------------------|-------------------------------------|-------------------------------------|
| crossing  | 1.13                                | 19.31                               | 5.05                                |
| background| 0.62                                | 13.93                               | 3.03                                |
| pedestrian| 1.17                                | 16.37                               | 3.59                                |

In this case the calculated contrast between the pedestrian and background of the crossing is only 0.67, this value is too low for the pedestrian to be distinguished on the crossing. The table 3 also shows that the maximum luminance value can cause that a driver may be dazzled and thus will not be able to distinguish the situation happening on the crossing.

Figure 7. In Example of incorrect placement of pedestrian crossing – parked vehicles overshadow the complementary space on the right side. [5]
Nevertheless, neither the most quality pedestrian crossing lighting is not capable to compensate the appropriate clothing of the pedestrian in terms of its reflectivity. Calculated value of the contrast between a pedestrian and a background depends considerably on the reflectivity of the pedestrian’s clothing. Dark-coloured clothes show far lower luminance measurements than the clothes made of light-coloured materials.

5. Conclusion
While designing a pedestrian crossing, and dealing with its lighting systems, this issue has to be solved from several points of view. It is necessary to respect not only the legal requirements for the pedestrian crossing itself, but also the requirements for its illuminance. While designing lighting for a pedestrian crossing, it is important to analyse properly the public lighting of the roadway and draw up the project with regard to that lighting. Public lighting (lighting of a roadway) is, in the most cases, a source of background luminance and that is what the contrast value between a pedestrian and a background depends on. Public lighting must ensure the corresponding value of background luminance both in front of and behind the pedestrian crossing and the ratio between a pedestrian luminance and luminance of the background should be in the range of 1 to 10.

Currently, gas-charged lamps are being replaced by LED lamps. In comparison with the gas-charged lamps, the LED lamps provide several advantages. Benefits of LED lamps installation lie especially in significant prolongation of a lighting life expectancy from about 8 000h to 50 000 or even 100 000h. Another significant advantage is the possibility of setting the luminous flux from the luminaire directly in the process of installation (a dimmable ballast) so the balanced luminance contrast between a pedestrian and a background can be set.

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