

# ANALYSIS OF THE RESULTS OF THE AUDIT OF LIGHTING PARAMETERS AT PEDESTRIAN CROSSINGS IN WARSAW

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## Abstract:

The night time, based on many world studies, generates an increased risk of serious accidents (with fatalities and serious injuries). This is especially true for accidents with pedestrians. Pedestrian crossings are very sensitive to the influence of the time of day in terms of pedestrian safety, elements of road infrastructure. This is visible on the example of Poland, where numerous accidents at crosswalks are recorded, characterized by high severity at night. Road infrastructure managers take corrective actions to improve this condition. An example of such work is the Road Safety Audit (RSA), initiated in 2016 by the Municipal Roads Management Board in Warsaw. The analyses carried out by the authors, among others, in the years 2016 - 2019, included pedestrian crossings without traffic lights located on roads managed by ZDM (Municipal Roads Authority) in twelve districts: Bemowo, Bielany, Mokotów, Ochota, Praga Południe, Praga Północ, Śródmieście, Targówek, Ursynów, Wawer, Włochy, Żoliborz. The assessment was carried out in terms of the correct lighting of these passages, traffic organization, geometry and environmental impact. The main aim of the article is to present a methodology for evaluating the technical condition of road lighting infrastructure on a large scale (e.g. district, city). The article discusses the general and detailed state of pedestrian safety in Poland against the background of research conducted in Warsaw. The procedure of inspection and assessment of the state of lighting of pedestrian crossings is described and selected results are presented. On the basis of a detailed analysis of the results of individual pedestrian crossings, the general condition of the tested crossings was assessed and recommendations were indicated. An attempt was made to assess the influence of pedestrian crossings lighting on the general state of road safety. A critical evaluation of the obtained effects was made. The utilitarian aim of the article is to apply the described methodology in other cities and to use the results of the conducted analyses to plan and implement road investments in the field of modernization of lighting at pedestrian crossings on a large scale.

**Keywords:** lighting, pedestrian crossings, audit, road, safety

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## 1. Introduction

The illumination of road infrastructure is shown in many research results, as one of the key factors influencing safety levels. Night time has been shown to be associated with an increase in the risk of accidents, especially fatalities and serious injuries. The results of the studies (Gray et al., 2008; Michalaki et al., 2015) indicate an increase in the severity of accidents during the night time by about 30%, with a decrease in the number of accidents with slightly injured victims during the daytime (Gray et al., 2008; Michalaki et al., 2015). The results of studies for Sweden, Norway and the Netherlands indicate that the risk of night-time accidents for pedestrians and cyclists in urban areas has increased nearly two times (Johansson et al., 2009). Studies by (Owens, 2004; Plainis, Murray, 2002; Bassan, Mutani, 2012; Zhang et al., 2020), confirm that a significant proportion of road accidents involving fatalities in developed countries took place at night (Owens, 2004; Plainis, Murray, 2002; Bassani, Mutani, 2012; Zhang et al., 2020) and therefore, as stated by (Horberrry et al., 2006), the improvement of visibility at night may be the main factor reducing the number of accidents.

Studies in Poland (Gaca, Kieć, 2013; Gaca, Pogodzińska, 2017), indicate a significant increase in the risk for pedestrians during the night time, with a slight increase in the risk for other traffic participants, similar results were obtained in the (Kwan, Mapstone, 2009; Ackaah, Adonteng, 2011; Griswold et al., 2011). The increased risk of pedestrian safety at night results from increased vehicle speed and lack of proper visibility of pedestrians, especially when crossing the road (Peden et al., 2004; Duda, Sierpiński, 2019).

The assessment of the impact of lighting on pedestrian safety indicates that pedestrian crossings are a particularly important element of road infrastructure in this respect (Patella et al., 2020). Pedestrian visibility at a pedestrian crossing at night is indicated as a key factor affecting the safety of road users (Bullough et al., 2012). The studies indicate the importance of the way and quality of lighting affecting the distance from which a driver can see a pedestrian approaching, waiting at the crossing or crossing the road (Gibbons et al., 2008, Nambisan et al., 2009). As early as in 1978, Polus and Katz demonstrated a significant reduction in car and pedestrian accidents at night, with the installation of pedestrian crossing

lighting (Polus, Katz, 1978). The increase in the quality of lighting of pedestrian crossings, based on research in Australia, reduced the risk of accidents with pedestrians at night by nearly 60% (Retting et al., 2003).

According to IESNA, there were three times as many fatal accidents at unlit or improperly lit pedestrian crossings as at crossings equipped with proper lighting (ANSI/IESNA, 2000). Numerous studies indicate an improvement in pedestrian safety after the installation of lighting systems dedicated for pedestrian crossings (Markvica et al., 2019; Peña-García et al., 2015; Davidovic et al., 2019). Numerous studies have also focused on the improvement of pedestrian safety by selecting appropriate technical parameters of lighting (Saraiji, 2009; Saraiji, Oommen Ba, 2015; Ackaah, Adonteng, 2011).

The problem of improving pedestrian safety at crossings in Poland has been the subject of research carried out for many years (Budzynski et al., 2019; Budzynski et al., 2017; Jamroz, 2014; RSAR, 2019; Żukowska, 2015). Increasing the safety of unprotected road users can be realized on many levels (i.e.: technical, training, organizational, informational) (Jamroz, 2014; Jamroz et al., 2018).

The assessment of the state of threat to pedestrians can be carried out in general terms on the basis of the analysis of road accident statistics. Every year about 27% of all accidents, 21% of injured people and 33% of fatalities in road accidents are pedestrians (Symon, Komenda Główna Policji - Biuro Ruchu Drogowego, 2020). This group of traffic participants is particularly vulnerable to the tragic consequences of accidents because, unlike drivers, it is not protected in any way, e.g. by the vehicle body, seat belts, airbags or helmets. Figure 1 shows trends in the number of accidents involving pedestrians against all data. The data show a steady decrease in the number of road accidents in recent years, including those with pedestrians (Figure 1). Unfortunately, in the case of fatalities, no significant decreases have been recorded in the last five years. The number of pedestrian deaths has been falling more noticeably during this time, but also these are not significant decreases (about 14% in the last 5 years).

Data for the last six years indicate a significant share of accidents with pedestrians, recorded at pedestrian crossings. In 2018, 3209 accidents were recorded at pedestrian crossings without light-controlled, in which 3126 pedestrians were injured and 241 people

died. The number of accidents with pedestrians recorded at pedestrian crossings without light-controlled was over 44% of all accidents with pedestrians in 2019. Since 2014, a decrease in the number of such accidents by about 5% and the number of fatalities remained at a similar level. At the same time, in the analyzed period, the share of accidents with pedestrians registered at pedestrian crossings increased by 10% and the number of fatalities in these accidents increased by 8% (in 2018, over 46% of all injured victims and 30% of fatalities among pedestrians were registered at pedestrian crossings without traffic signals) (Figure 2).

The Police Headquarters report (Symon, Komenda Główna Policji - Biuro Ruchu Drogowego, 2020) shows that accidents involving pedestrians are more frequent in built-up areas, where the pedestrian traffic intensity is higher. However, outside built-up areas, the effects of accidents are much more serious. Pedestrians died in every second accident in undeveloped areas and in every twelfth in built-up areas. At the same time, the severity of all accidents during

the night time was twice as high as during the day (7 fatalities per 100 accidents during the day and 14 during the night), which is usually due to higher speeds during the night time. Analyzing the data (Symon, Komenda Główna Policji - Biuro Ruchu Drogowego, 2020) in relation to pedestrians and comparing the number of accidents with their share in the monthly system, it results that almost half of all accidents occurred in January, October, November and December, i.e. in months when natural light conditions are worse than in the summer. Apart from lengthening the time without natural lighting, one of the reasons for the increase in the number of accidents involving pedestrians in the autumn-winter period is the occurrence of transport peaks after dusk or before dawn (Jamroz et al., 2018). To increase pedestrian safety, it is important to ensure proper lighting conditions in conflict areas, regardless of the season.

On the picture (Figure 3) have been presented the share of accidents recorded at pedestrian crossings outside the time of daylight (night, dawn, dusk).

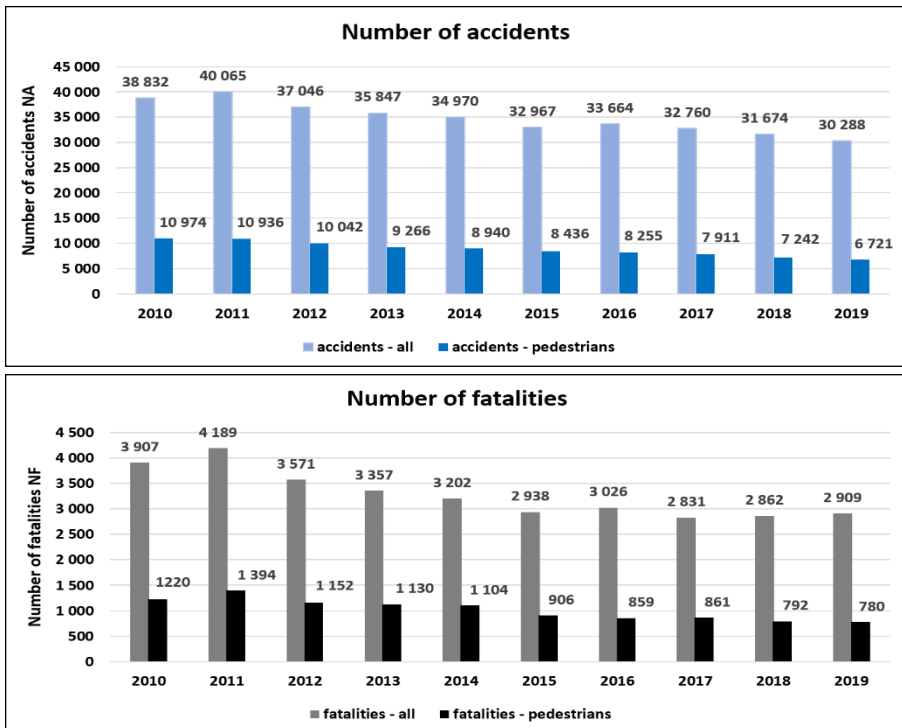


Fig. 1. The number of road accidents and fatalities in Poland - years 2010 – 2019

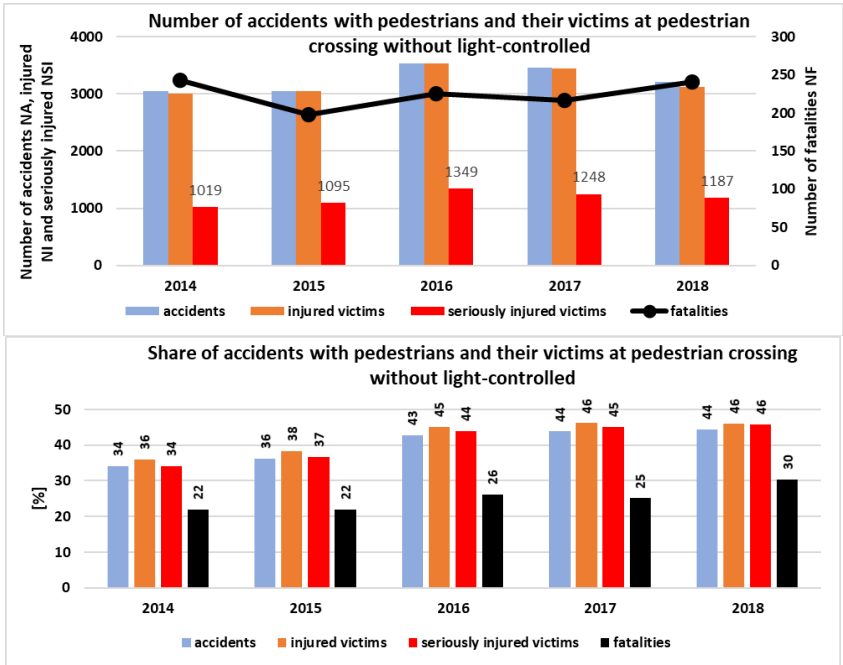


Fig. 2. Share of accidents and their victims with pedestrians, registered at pedestrian crossings (2014 -2019)

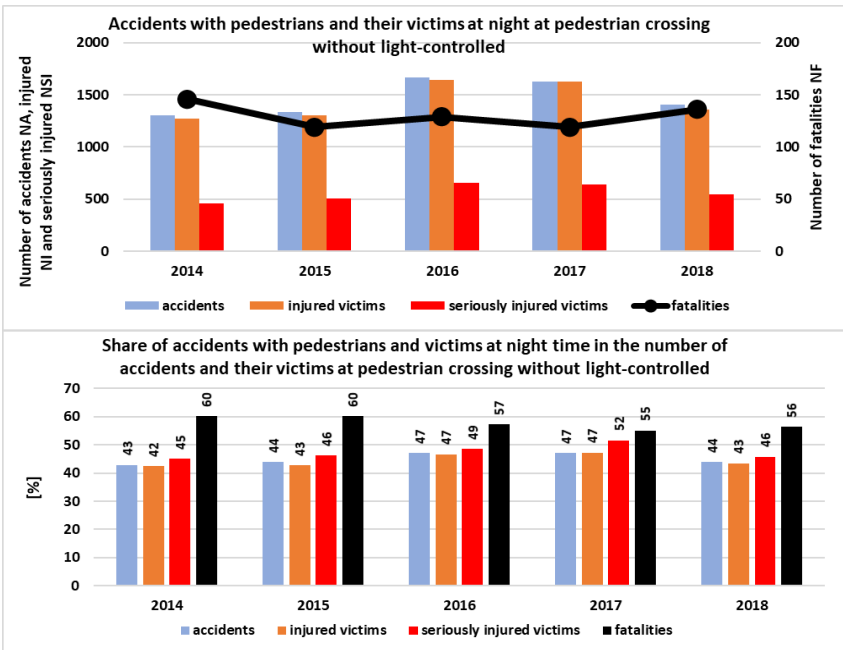


Fig. 3. Accidents with pedestrians at night crossings (2014 – 2018)

In 2018, 1406 such accidents were recorded (43% of accidents at pedestrian crossings without light-controlled), with 1359 injured victims (44%) and 136 fatalities (as many as 56%). The data presented in Figure 3 shows that the improvement of safety in the area of pedestrian crossings at night constitutes a very large potential for the reduction of fatalities among pedestrians. The results of the analysis conducted in Warsaw (ZDM, 2019B) indicate that there is no downward trend in the number of road accidents in the years 2010 - 2018 and a downward trend in the number of fatalities from 2013 (Figure 4). In 2018, the most common type of accidents on Warsaw streets were those involving pedestrians. They accounted for 38% of the total number of accidents. A positive aspect is the fact that in relation to 2016, there was a decrease in this share by nearly 10%, and the number of fatalities itself decreased by 23%.

Accidents at pedestrian crossings constituted by far the largest share in the number of all accidents with pedestrians, in 2018 177 such accidents were recorded (46% of all accidents with pedestrians), in which 182 people were injured, 22 of whom were seriously injured and 6 people died (25% of all pedestrian deaths (Figure 5).

By analysing the number of accidents with pedestrians and their victims recorded at night-time pedestrian crossings, it is important to highlight their significant share. In 2014, 48% of such accidents were recorded in which 50% of all pedestrian deaths were recorded in accidents at pedestrian crossings. Particularly tragic in this respect was the year 2016, when over 80% of such deaths were recorded. This indicates, as in the whole country, a serious problem related to the safety of pedestrians at night crossings (Figure 6).

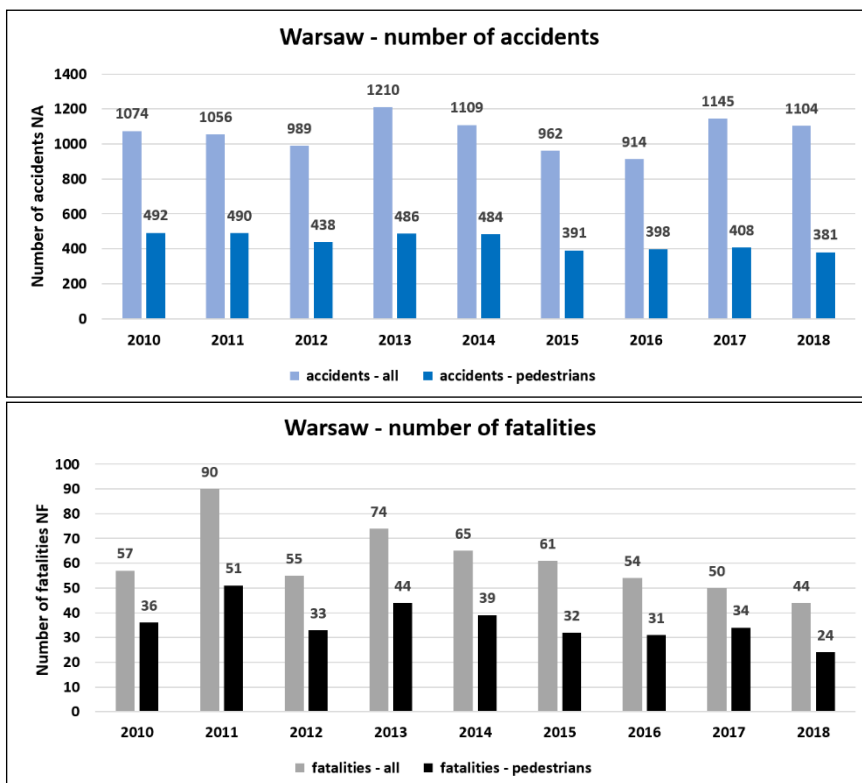


Fig. 4. The number of road accidents and fatalities in Warsaw (2010 – 2018)

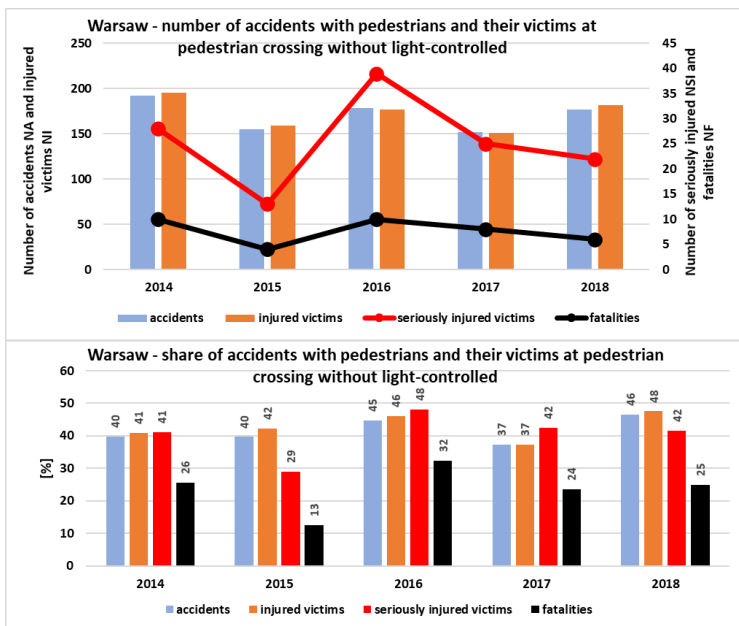


Fig. 5. Share of accidents and their victims with pedestrians registered at pedestrian crossings in Warsaw (2014 -2018)

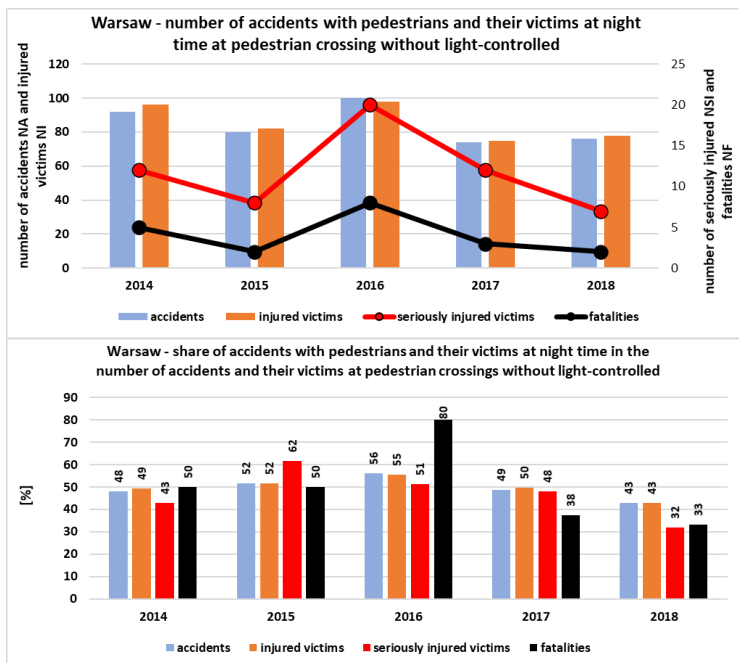


Fig. 6. Accidents with pedestrians at night crossings in Warsaw (2014 – 2018)

The data presented above illustrate the problem of accidents at pedestrian crossings without light-controlled, including at night. However, one should be aware that the locations of accidents with pedestrians, due to their small statistical number, are no longer a map of "black spots". In order to act preventively, a corrective action plan should be drawn up on the basis of maps showing the level of risk at pedestrian crossings, regardless of whether an accident involving pedestrians has occurred here. Hazard maps must relate to existing parameters and the extent to which high safety standards are met. Acting on the hazard map, the Road Administration can act preventively, without waiting for accidents and fatalities, and a constant evaluation of the implemented solutions will allow to assess their effectiveness.

## 2. Objectives

The analyses of pedestrian safety carried out by the ZDM in Warsaw, which indicated such a high degree of their hazard, resulted in taking preventive steps in the form of a decision to carry out comprehensive road safety assessments (NSAs) together with detailed research on the state of lighting of pedestrian crossings (ZDM, 2016). The main objective of the actions taken by the Warsaw Municipal Road Administration was to reduce the number of accidents at pedestrian crossings. In the years 2016 – 2018 (ZDM, 2019A) this goal was achieved in relation to the number of fatalities at night at pedestrian crossings. In the case of all deaths at pedestrian crossings, the number of fatalities has slightly decreased, which indicates the need to intensify actions in this regard.

The main purpose of this article is to present the methodology used to assess the technical condition of road lighting infrastructure implemented on a large scale (e.g. district, city). The article describes the procedure of inspection and assessment of the state of lighting of pedestrian crossings and presents selected results. The test subjects are pedestrian crossings not covered by traffic lights, located on illuminated roads managed by ZDM in Warsaw.

## 3. Methodology for inspection the state of lighting at pedestrian crossings

The authors undertook attempts to systematize the process of evaluating the lighting condition of exist-

ing pedestrian crossings for the needs of modernization activities in the city of Warsaw. It should be noted that the activities undertaken in the field of lighting condition assessment were conducted simultaneously with the work of the team of Road Traffic Safety Auditors, whose task was to assess the remaining elements affecting pedestrian safety.

The tests of lighting condition concerned pedestrian crossings without traffic lights. The night-time field tests and study work of the team of experts made it possible to establish an assessment of the actual lighting condition of pedestrian crossings. The audit was preceded by the development of an original method of conducting measurements in field conditions (ZDM, 2016). The basis for the development of the method for the assessment of the state of lighting of pedestrian crossings are the lighting classes resulting from the normative recommendations used in Poland, which are recorded in the documents of the five-part standard (PN-EN 13201, 2016). It should be noted that until the commencement of works, a uniform and comprehensive security control procedure dedicated to pedestrian crossings, taking into account parametrized lighting factors, was not developed and implemented in Poland. There are countries with formal requirements (DIN, 2010; MD, 2015) and studies (Holec et al., 2009) are being conducted in the area of pedestrian crossings. Worldwide, audits (Mackun et al., 2017; Montella, Mauriello, 2010; Nabors et al., 2007; Pashkevich, Nowak, 2017) assessing the condition of infrastructure designed for pedestrians were also carried out.

In urban agglomerations, the assessment of the state of lighting infrastructure is very important from the point of view of maintaining the existing state or improving lighting conditions (Jamroz, 2014; Jamroz et al., 2018). It should be emphasized that in Poland, until 2016, no similar work was carried out to such an extent, both in terms of numbers and area. Literature studies (Holec et al., 2009; Nabors et al., 2007) preceding the conceptual and field work did not indicate a useful methodology for the assessment of lighting parameters. Authors among the literature encountered one item (Montella, Mauriello, 2010), where an attempt was made to objectively quantify the pedestrian risk, giving weight points and weights to particular pedestrian crossing parameters. However, in this method, the assessment of lighting condition does not include significant qualitative parameters. Literature studies (Montella, Mauriello, 2010;

Nabors et al., 2007) indicate that the lighting assessment factor in the proposed assessment procedures is treated ambiguously, the values of lighting parameters were not taken into account and no recommended and limit values were defined. Weights and weighting points cannot be adopted directly to the Polish conditions due to the local specificity of driving and pedestrian behaviour and other road traffic regulations. Therefore, a completely new, comprehensive assessment method had to be developed, allowing for the identification of risk factors occurring at pedestrian crossings indicated for assessment. One of its elements was the lighting condition of pedestrian crossings. The authors of the Polish method of assessment decided to separate the final assessment in terms of lighting parameters and other road safety parameters (due to difficulties in determining the partial weighting of individual criteria influencing the final result of the comprehensive road safety assessment at pedestrian crossings). This article discusses only the factor of lighting condition assessment.

Measurements of the state of lighting at pedestrian crossings in Warsaw were carried out in 3-4 person measurement teams, consisting of people experienced in conducting specialized tests of road lighting in field conditions. All teams carried out measurements according to the uniform author's procedure (ZDM, 2016; ZDM, 2017; ZDM, 2019A).

At each of the pedestrian crossings, measurements were carried out with the use of the following measurement tools: lux meters, laser distance meters, cameras. In the first stage, the directions of vehicle

traffic were identified and the geometrical parameters of the passageway were taken into account, as well as the location of luminaires in the surroundings of the pedestrian crossing, presented in Figure 7.

There are factors that should be taken into account when evaluating the lighting condition of a pedestrian crossing (Jamroz et al., 2018; Tomczuk et al., 2019) i.e.: providing the driver with appropriate conditions for observing a pedestrian located directly at the crossing and in the waiting zone; providing the pedestrian with appropriate conditions for observing a vehicle approaching a pedestrian crossing; distinguishing the crossing area from the road space observed by the driver; ensuring mutual visibility on the section of access to the pedestrian crossing.

These factors should be considered as a starting point for the analysis and evaluation of lighting in the pedestrian crossing. The applied simplified procedure for the measurement of illumination parameters makes it possible to make an initial classification of the basic lighting parameters in the pedestrian crossing planes related to the lighting levels on the carriageway - horizontal  $E_h$  and on the silhouette of a pedestrian - vertical  $E_v$ .

The grid for measuring the illumination intensity in the horizontal surface named  $E_h$  is shown in Figure 8 (points 1 to 30). The measurement should be made along the edges of  $e_1$  and  $e_2$  and in the axis of the pedestrian crossing. The  $E_h$  surface is related to the illumination of the roadway within the horizontal gangway signs (including the pedestrian crossing signs) and waiting zones (Tomczuk et al., 2017).

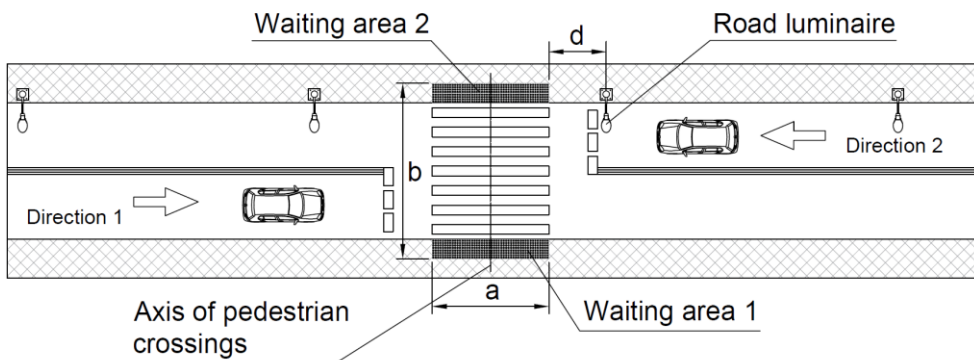


Fig. 7. Geometry of a pedestrian crossing, where: a - width of the pedestrian crossing; b - length of the pedestrian crossing together with the waiting zone; d - distance from the edge of the crossing to the nearest luminaire



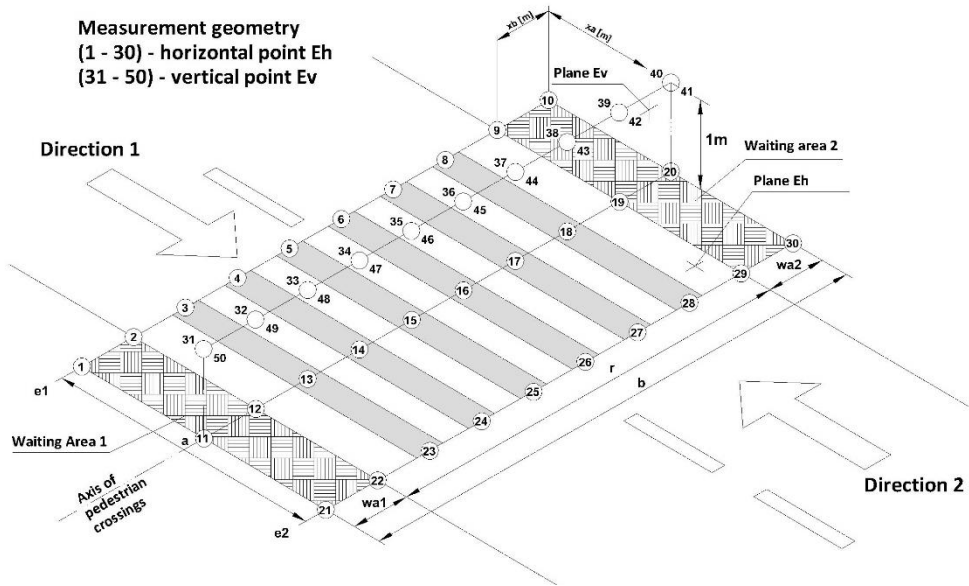


Fig. 8. Grid of measurement points located in planes Eh and Ev (Tomczuk et al., 2017)

On the basis of the values obtained at individual measuring points of the Eh surface, the following parameters related to the illumination intensity in the horizontal plane shall be calculated:  $E_{hmin}$  and  $E_{hmax}$  (minimum and maximum horizontal illumination intensity),  $E_{hav}$  - expressing the average horizontal illumination intensity (being the quotient of the sum of measurement results at successive measuring points of horizontal illumination intensity divided and the number of measurements),  $U_0$  as the uniformity of illumination intensity in the horizontal plane (being the quotient of  $E_{hmin}$  and  $E_{hav}$ ) (Tomczuk et al., 2017).

The measurements in the vertical planes Ev (points from 31 to 50) related to the illumination of a pedestrian silhouette should be made for all directions of vehicle traffic. The height of the measuring head position during the measurement of Ev parameters is 1.0 m from the road surface, in the axis of the passageway, along the entire length of the pedestrian crossing and in the waiting zone (Tomczuk et al., 2017). For each direction of vehicle traffic, the intensity parameters (min, max, average, uniformity) should be determined as for the horizontal plane.

The results obtained by determining the above parameters for both planes are compiled in tables and enable objective evaluation of the lighting condition,

which are allocated on the basis of standardized classes: C - for horizontal illumination and Ev - for vertical illumination (Tomczuk et al., 2017; PN-EN 13201, 2016).

Standard (PN-EN 13201, 2016) does not directly define lighting requirements at pedestrian crossings. However, it defines the intensity requirements for the design and testing of street lighting in traffic areas on horizontal  $E_h$  and vertical  $E_v$  surface. For measurements of horizontal illumination intensity  $E_h$  at pedestrian crossings, lighting classes C related to lighting of conflict zones have been adopted (Table 1).

For the measurements of the vertical intensity of Ev lighting at pedestrian crossings, the EV lighting classes related to the lighting of vertical surfaces were adopted (Table 2).

On the basis of previously conducted measurements and photographic documentation, it is necessary to prepare a report on lighting measurements at the pedestrian crossing, which includes: basic location information, general data, results of measurements and calculations made, description of the state of lighting at the crossing, photos of the lighting situation at the crossing and comments and recommendations for the inspection.

Table 1. C class of lighting and the proposed scale of point marks (PN-EN 13201, 2016)

C Class	Horizontal intensity of illuminance $E_h$		Rating RC Points
	$E_h$ w [lx] (the lowest value, the expected value)	$U_o$ [the lowest value]	
C0	50	0,4	6
C1	30		5
C2	20		4
C3	15		3
C4	10		2
C5	7,5		1
lack of class	<7,5	-	0

Table 2. EV class of lighting and the proposed scale of assessments point (PN-EN 13201, 2016)

EV Class	Vertical intensity of illuminance $E_v$	Rating REVD <sub>1</sub> and REVD <sub>2</sub> Points
	$E_{v,min}$ w [lx] (maintained)	
EV1	50	6
EV2	30	5
EV3	10	4
EV4	7,5	3
EV5	5	2
EV6	0,5	1
lack of class	<0,5	0

The chart of each pedestrian crossing also contains subjective evaluation and the opinion of the evaluation team. The subjective assessment "SE" is issued by the assessment team during the field measurement and is intended to represent the subjective feelings of the assessors related to the lighting of the pedestrian crossing, the waiting zone, the lighting of the pedestrian silhouette located at the pedestrian crossing and the state of street lighting in the vicinity of the pedestrian crossing. The scale of points scores describing subjective 'SE' lighting conditions was adopted: 0 - very bad, 1 - bad lighting conditions, 2 - mediocre, 3 - sufficient, 4 - good, 5 - very good (Tomczuk et al., 2017). The results of the measurements were then aggregated in the database of lighting measurements and allowed to develop a summary report.

Using the procedure of assigning ranking points to each of the classes C (Table 3, RC) and EV (Table 4, REVD1, REVD2), it became possible to determine the objective assessment of the state of pedestrian crossing lighting depending on the lighting class:

$$OE = f_1 RC + f_2 REVD_1 + f_3 REVD_2 \quad (1)$$

where:

OE - objective evaluation,

RC - evaluation associated with lighting the horizontal plane,

REVD1 - evaluation associated with lighting the vertical plane in direction 1,

REVD2 - evaluation associated with lighting the vertical plane in direction 2

$f_1, f_2, f_3$  - the weight factor ( $f_1, f_2, f_3 = 0,33$ ).

The final assessment of the state of lighting of the pedestrian crossing is given on the basis of the sum of the subjective and objective partial assessment:

$$FR = f_4 SE + f_5 OE \quad (2)$$

where:

FR - final ranking,

SE - subjective evaluation,

OE - objective evaluation,

$f_4, f_5$  - the weight factor ( $f_4, f_5 = 0,5$ ).

In the case of finding incorrect levels of light intensity or improper lighting conditions, technical solutions have been proposed to improve the perception of pedestrians at night, both at the passageway itself and in the waiting area (recommendations include a number of treatments ranging from the cheapest and easiest in application to those requiring a comprehensive rebuilding of the lighting system).

As a result of the work carried out, a collective database of lighting parameters was created. On the basis of the summary results of measurements and evalu-

ations, a summary is created together with recommendations and proposals for action to be taken by the infrastructure manager, which have a real chance to improve the lighting situation at the tested pedestrian crossings.

#### 4. Results of the lighting inspection and discussion

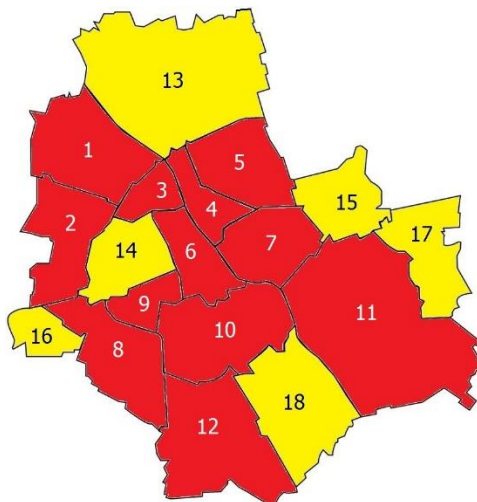
Between 2016 and 2019, the Municipal Roads Authority conducted a safety audit at pedestrian crossings in twelve Warsaw districts (ZDM, 2016; ZDM, 2017; ZDM, 2019A): Bemowo, Bielany, Mokotów, Ochota, Praga Południe, Praga Północ, Śródmieście, Targówek, Ursynów, Wawer, Włochy, Żoliborz, at a total of 3138 pedestrian crossings (Figure 9). Detailed results of the audit were published on the website of the Municipal Roads Administration in the "Surveys and analyses".

The collected results of lighting measurements for 3138 pedestrian crossings allowed to make some generalisations relating to the objective assessment of lighting condition. The mean value of the horizontal illuminance of the tested passages is  $E_{hav} = 20.61$  lx. It was found that this value was not obtained at 1052 (33.5%) pedestrian crossings. However, at 1214 (Figure 10), pedestrian crossings, the mean value of light intensity in the horizontal plane was not obtained, which is higher than 7.5 lx,

which is 38.7% of the total. This means that the requirements of the lowest lighting class C5 were not met on them. Therefore, a group of pedestrian crossings was identified, where corrective actions should be taken first.

The obtained results of measurements of vertical illuminance at pedestrian crossings, measured for two directions of vehicle traffic, were also analysed. The results are presented in Table 5, assigning the obtained values of illuminance to  $E_v$  classes (Tomczuk et al., 2017).

The recorded value vertical illuminance in vertical planes (Table 3) indicates unfavorable conditions for the driver to detect a pedestrian silhouette in the waiting area or roadway. The reason for this situation is the use of highly suspended street lighting fixtures (negative contrast) for lighting the pedestrian crossing area, which introduce light mainly in the horizontal plane. Only few pedestrian walkways were equipped with dedicated solutions (approx. 1%). Improvement can be achieved by using specialized lighting fixtures dedicated to the illumination of pedestrian crossings (luminaires with double asymmetry), where light is introduced to the silhouette of the pedestrian from the direction of vehicle movement (positive contrast, reinforcing the effect of pedestrian lighting with car projectors).



Bielany	– 246 (2017)
Bemowo	– 162 (2019)
Żoliborz	– 181 (2019)
Praga – Północ	– 164 (2019)
Targówek	– 220 (2017)
Śródmieście	– 373 (2016)
Praga – Południe	– 356 (2016)
Włochy	– 240 (2019)
Ochota	– 208 (2016)
Mokotów	– 355 (2017)
Wawer	– 399 (2019)
Ursynów	– 234 (2017)
Białołęka	– realized in 2020
Wola	– realized in 2020
Rembertów	– realized in 2020
Ursus	– realized in 2020
Wesoła	– realized in 2020
Wilanów	– realized in 2020

Fig. 9. Number of audits of pedestrian crossings carried out in individual districts of Warsaw in 2016 - 2019 (ZDM, 2016; ZDM, 2017; ZDM, 2019A) (red marked with the districts audited, yellow with the districts to be audited in future years)

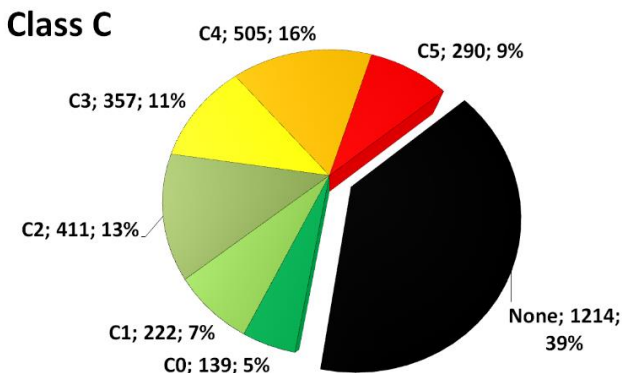


Fig. 10. Percentage of Class C horizontal lighting intensity at pedestrian crossings  $E_h$

Table 3.  $E_v$  classes - Summary of results for the pedestrian crossings analysed

Class $E_v$	$E_{vmin}$ [lx] (minimum maintained)	Direction 1		Direction 2	
		Number of pedestrian crossings	%	Number of pedestrian crossings	%
EV1	50	13	0,4	0	0,0
EV2	30	35	1,1	26	0,8
EV3	10	561	17,9	577	18,4
EV4	7,5	320	10,2	366	11,7
EV5	5	611	19,5	618	19,7
EV6	0,5	1495	47,6	1440	45,9
None	< 0,5	103	3,3	111	3,5

Using the methodology described in Chapter 2 to obtain the final ranking evaluation, the state of lighting of pedestrian crossings was classified based on the subjective and objective evaluation (ZDM, 2016; ZDM, 2017; ZDM, 2019A). The graph presents the final grades obtained on the basis of subjective and objective grades for the surveyed pedestrian crossings in 12 districts (Figure 11). The results of the objective evaluation take into account the achievement of the illuminance class C, so they include the parameter of uniformity of illuminance in the horizontal plane. Sometimes a slight unevenness may significantly affect the objective assessment, while experts found a very good level of lighting. This criterion is difficult to express in field conditions in a subjective assessment by lighting auditors. It is therefore reasonable to combine the assessments resulting from the lighting parameters and the expert assessments. The obtained final marks give a complete picture of the analyzed lighting situation. They allow to clearly state what number of pedestrian crossings should be modernized in the first and further order.

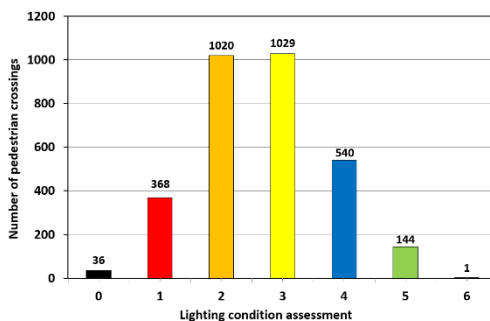


Fig. 11. Summary of assessments of the state of lighting of pedestrian crossings in the final perspective

The above-described measuring activities carried out in twelve Warsaw districts were aimed at determining the state of lighting at the existing pedestrian crossings, as well as at identifying problems and formulating recommendations. On the basis of local inspections carried out at night and on the basis of measurements of lighting parameters, it was estab-

lished that the condition of street lighting raises concerns in the context of the implementation of lighting tasks at pedestrian crossings selected for testing. From the point of view of the road infrastructure administration, the most important element of the audit are clearly defined recommendations to be implemented after its implementation. It should be emphasized that each of the audited pedestrian crossings was individually and in detail described, as well as compiled in a database allowing for searching and compiling information. This work focuses on general conclusions. Table 4 compiles all comments and recommendations for the improvement of lighting conditions at 3138 pedestrian crossings.

In order to improve the lighting condition of pedestrian crossings it is possible to apply several repair variants, e.g.: installation of additional road lighting on new poles, installation of additional luminaires on existing poles, replacement of booms. It is also possible to replace the existing luminaires with new ones or to install additional installation in the vicinity of pedestrian crossings equipped with luminaires with strictly directed light distribution.

Special attention must be paid to the problem of systematic maintenance of street lighting installations in the context of improving existing lighting in the vicinity of pedestrian crossings and maintaining the assumed effects for new installations. As can be seen from the recommendations in Table 4, maintenance

of luminaires, cleaning of luminaires and replacement of light sources are the main causes affecting the state of lighting in pedestrian crossings. A low-cost solution to improve lighting conditions in pedestrian crossings is to replace the existing light source with another one with higher power parameters, or a combination of power and light colour (usually LED type luminaire).

Attention was drawn to the problem of removing the existing obstacles to light, these are mainly crowns of tall trees obscuring street lighting fixtures. In Warsaw, many worn out street lighting installations should be replaced by modern systems in the future. When designing them, special attention should be paid to the aspect of proper lighting of pedestrian crossings and the proper selection of emission parameters of the luminaires used.

By analysing in detail the level of safety at pedestrian crossings without traffic lights in Warsaw, by district, a comparison was made of the incidence of accidents during daytime and night time in the years 2014 and 2018. In addition, the average level of lighting in individual districts was assessed. Table 5 presents the results of this analysis. At this level, it is not possible to directly determine the impact of light levels on the occurrence of accidents at night crossings, due to too many variables. The safety level is related to, among other things, the geometry of the crossing area, the technical condition of the infrastructure, traffic organization and also lighting.

Table 4. Combined overview - notes and recommendations (ZDM, 2016; ZDM, 2017; ZDM, 2019A)

no.	Comments and recommendations	Number of actions	Activities [%]
1	Complete street lighting system maintenance	2035	27,0
2	Cleaning of luminaires in the pedestrian area	1034	13,7
3	Replacing a light source with a more powerful one in a pedestrian area	713	9,4
4	Replacing a light source with another one with a different light colour in the vicinity of a pedestrian crossing	597	7,9
5	Installation of additional passageway lighting with dedicated asymmetrical beam luminaires	540	7,2
6	Installation of a street lighting fixture in the vicinity of a pedestrian crossing	515	6,8
7	Installation of additional luminaires on existing street lighting poles	466	6,2
8	Removal of light obstructions	408	5,4
9	Performing alignment checks and adjusting luminaires and light sources	359	4,8
10	Replacement of street lighting fixtures in the vicinity of a pedestrian crossing	308	4,1
11	No comments	228	3,0
12	Replacing faulty light sources with new ones in the pedestrian area	182	2,4
13	Replacing all street lighting fixtures	82	1,1
14	Changing the way (or height) of fixing street luminaires around a passageway	65	0,9
15	Elimination of sources of glare	14	0,2
	THE SUM	7546	100,0

Table 5. Characteristics of individual districts of Warsaw

The district	Accidents all over the day			Percentage of accidents at night				
	Number of accidents	Number of seriously injured and fatal victims	% accidents	% of seriously injured and fatal victims	Number of accidents / number of pedestrian crossings	Number of seriously injured and fatal victims / number of pedestrian crossings	Number of pedestrian crossings	Average level of illuminance [lx]
Bemowo	35	11	57,1	36,4	0,12	0,02	162	26,2
Białołęka	61	3	63,9	66,7	-	-	-	-
Bielany	50	5	44,0	40,0	0,09	0,01	246	18,7
Mokotów	66	10	54,5	50,0	0,10	0,01	355	17,1
Ochota	50	19	52,0	42,1	0,13	0,04	208	16,9
Praga-Południe	61	13	59,0	46,2	0,10	0,02	356	16,1
Praga-Północ	38	2	42,1	0,0	0,10	0,00	164	23,6
Rembertów	19	3	31,6	66,7	-	-	-	-
Śródmieście	86	11	47,7	63,6	0,11	0,02	373	19,9
Targówek	78	8	51,3	62,5	0,18	0,02	220	27,8
Ursus	31	8	64,5	87,5	-	-	-	-
Ursynów	38	10	57,9	70,0	0,09	0,03	234	20,7
Wawer	58	9	31,0	44,4	0,05	0,01	399	21,6
Wesoła	14	3	64,3	100,0	-	-	-	-
Wilanów	12	3	41,7	33,3	-	-	-	-
Włochy	39	12	38,5	25,0	0,06	0,01	240	22,1
Wola	85	27	41,2	29,6	-	-	-	-
Żoliborz	32	8	46,9	62,5	0,08	0,03	181	31,9
THE SUM	853	165	49,4	-	-	-	-	-

The Table 5 presents data on road accidents and their victims at pedestrian crossings without signalling for all districts of Warsaw and data on the number of crossings, the number of accidents and their victims per crossing and the level of lighting in the districts that were assessed during the audit so far. Noteworthy is the high share of accidents at night crossings in the districts of Wesoła, Ursus, Białołęka, Praga-Południe, Ursynów, Mokotów, Ochota and Targówek and the share of fatalities and serious injuries in the districts of Wesoła, Ursus, Ursynów, Białołęka, Rembertów, Śródmieście, Targówek and Żoliborz. Taking into account the number of night-time accidents, the districts of Targówek, Ochota and Bemowo pay attention to the number of passages, and in the case of the number of fatalities and severely wounded, the districts of Ochota, Żoliborz and Ursynów stand out. At the same time, the lowest level of lighting was recorded in the districts of

Praga-Południe, Ochota, Mokotów, Bielany and Śródmieście.

The above analysis shows that the problem of accidents at night-time crossings varies between districts of the city and confirms the need for an individual approach to each of the assessed crossings. Each pedestrian crossing should be assessed individually and independently in terms of lighting and road safety. The assessment of the impact of lighting levels on pedestrian safety at crosswalks requires further research over a longer period of time and the use of indirect methods to assess pedestrian safety (Gaca, Kieć, 2015; Gaca, Kieć, 2016; Szagała et al., 2016).

## 5. Conclusions

As a result take necessary corrective actions, given the high share of pedestrians in the total number of road accident victims in Poland. It should be taken into account that the assessment of lighting condi-

tion carried out using the basic parameter, i.e. illuminance, does not provide full and often sufficient information about the lighting condition at a given pedestrian crossing. It is possible to perform additional tests of the luminance parameters (to deepen the analysis of lighting conditions in the environment), taking into account the silhouette of the pedestrian and allowing to determine the contrast of the pedestrian with the background (Baleja et al., 2015; Baleja et al., 2017; Tomczuk et al., 2019), however, it should be borne in mind that this test is significantly more expensive. Indirect support for the reference level of lighting at the pedestrian crossing would be to establish and maintain the given street lighting classes.

An additional element which requires further testing is the values of weights used in the final assessment of the pedestrian crossing. The weights have been established empirically, but further research should be carried out in order to determine them objectively, which is the authors' future goal. This applies in particular to scales f4 and f5. Until the weights are developed mathematically, auditors and inspectors should be trained so that their subjective evaluation is based on similar criteria.

In selected countries, regulations on lighting pedestrian crossings have been in place for many years (DIN, 2010; MD, 2015). Also in Poland, in 2017, on the basis of experiences related to audits carried out in Warsaw, guidelines for proper lighting of pedestrian crossings were developed (Jamroz et al., 2018). They were created at the request of the Ministry of Infrastructure represented by the secretariat of the National Road Safety Council and since 2018 they have been recommended by the Minister of Infrastructure for use on public roads in Poland.

The introduction of lighting requirements in the area of pedestrian crossings, in particular for dedicated solutions, requires the validation of the results of the designed installation at the stage of investment acceptance. On the other hand, at the stage of operation it is possible to carry out systematic supervision over the condition of the lighting system and, on this basis, to carry out the necessary maintenance measures necessary to maintain the lighting parameters at the pedestrian crossing.

All measurement procedures described in the document should be carried out systematically, at least every 5 years (Jamroz et al., 2018), at the stage of

operation of the lighting system and relate to the assumptions made at the stage of designing the lighting of the pedestrian crossing. The application and enforcement of the provisions of developed guidelines for proper lighting of pedestrian crossings at the stage of operation may contribute to the improvement of safety of unprotected road traffic participants in Poland.

Despite the existing standards (PN-EN 13201, 2016) and guidelines (Jamroz et al., 2018), the state of lighting at pedestrian crossings in Poland is not subject to systematic control on a large scale (town, province, country). The developed method of lighting condition assessment will allow for the continuation of control works in the future and verification of the applied solutions improving lighting conditions at pedestrian crossings and will contribute to the improvement of road infrastructure. Adoption and application of a uniform and repeatable procedure on a national scale will enable comparison of results and comprehensive control of lighting condition.

The analysis needs to be complemented by more districts that are in the process of being evaluated by the auditors. It should also be noted the need for effective selection and implementation of proactive actions, improving pedestrian safety. It is also necessary to verify the measures implemented in terms of their effectiveness. In further research work, the authors will perform detailed analyses at selected crossings to determine the impact on the safety level of selected lighting parameters, geometry, traffic organization and behavior of road users.

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