ASSESSMENT OF VISIBILITY
ON PEDESTRIAN CROSSING – COMPUTATIONAL MODEL

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Abstract

As statistical analyses conducted by The National Police Headquarters indicate, pedestrian crossing which is supposed to be a safe place for unprotected participants of road traffic is an area where about 10% of road accidents occur in which at least 3500 persons are injured, and over 200 die annually. Despite constant development of road infrastructure in Poland, this situation fails to improve in the expected way. Several reasons of this state of affairs can be detected. Undoubtedly a decisive factor in pedestrian safety at night-time is ensuring the drivers proper observation conditions of pedestrian crossings.

The article will present assessment of lighting of pedestrian crossings making use of Small Target Visibility model. Due to the use of luminance and contrast criterion, it is possible to assess visibility level – a key parameter responsible for perception of a pedestrian by a driver on pedestrian crossings. Graphic chart showing accidents with pedestrian participation in the European Union, target for visibility research by means of STV method on pedestrian crossing, visibility level VL by means of STV method, Location of objects on pedestrian crossing by means of STV method, pedestrian crossing illuminated by lighting frames, visibility level on pedestrian crossing obtained as a result of lighting frames illumination from the first and second observation direction are presented in the paper.

Keywords: transport, pedestrian lighting, road lighting, luminance, STV

1. Introduction

Pedestrian crossing is an area of increased risk of sustaining injuries or losing life as a result of collision of a pedestrian with fast moving vehicles. As researches conducted in Great Britain [1] in 2003 indicate, 22% of all fatal accidents took place on pedestrian crossings. This is the reason for special treatment of these fragments of the road. A pedestrian has priority over other vehicles and crossing the road at a designated place lowers the risk of accident occurrence. As it was established, about 30% of pedestrians fail to observe the designated places of pedestrian traffic and cross the road at a forbidden place [1]. Despite increased efforts put into road infrastructure, still almost 25% of all accidents take place on pedestrian crossing or in its area [2]. As it follows from the presented research results [2], a decisive factor in the possibility of noticing a pedestrian are directional reflection coefficients of materials used for clothing worn by pedestrians.

Statistical analysis of accidents conducted by The National Police Headquarters [3] indicates a retained and very disadvantageous ratio of fatal road accidents. On Polish roads on average 5.5 thousand people die annually. Researches show that the highest number of accidents occur in built-up areas (about 70%) and the most frequent kind of accident is running over a pedestrian (about 30%). According to the data from annual reports, pedestrians constitute the second, as for the number, group of road accident casualties (that is 1852 fatalities in 2008). About 37% of all road accident casualties in Poland constitute the "unprotected" participants of road traffic. Special attention should be paid to this group because in contrast with road traffic participants travelling in cars, these people are not protected by the car body, they cannot count on the protection of air bags or safety belts. In 2009, 12834 accidents with the participation of pedestrians were reported (29% of the total), in which 1477 persons died (32.3% of the total), and 12328 were injured (22% of the

total). The majority of casualties were pedestrians whose behavior is often posing a great threat. In 2009 pedestrians caused 11.3% of incidents. In places accessible to pedestrian traffic (Tab. 1) 8211 accidents were reported, which constitutes 64% of all accidents with the participation of pedestrians. 530 persons died (36.1% of the total number of killed pedestrians), 8320 persons were injured (69.2% of the total number of injured pedestrians).

Tab. 1. Road accidents and their consequences in places dedicated to pedestrian traffic in 2009 [10]

Selected places of pedestrian traffic	Accidents	Fatalities	Injuries
Pedestrian crossing	3775	230	3809
Junction	3711	246	3741
Pavement, pedestrian way	420	21	450
Hard shoulder	159	22	165
Public transport stop	146	11	155
Total number	8211	530	8320

Statistical research conducted by European Commission on Transport [4] proves disadvantageous situation of pedestrians in Poland in comparison with other European Union countries. The number of fatalities with the participation of pedestrians over the years 2008-2009 (Fig. 1) presented in 2010 unambiguously points to this problem.
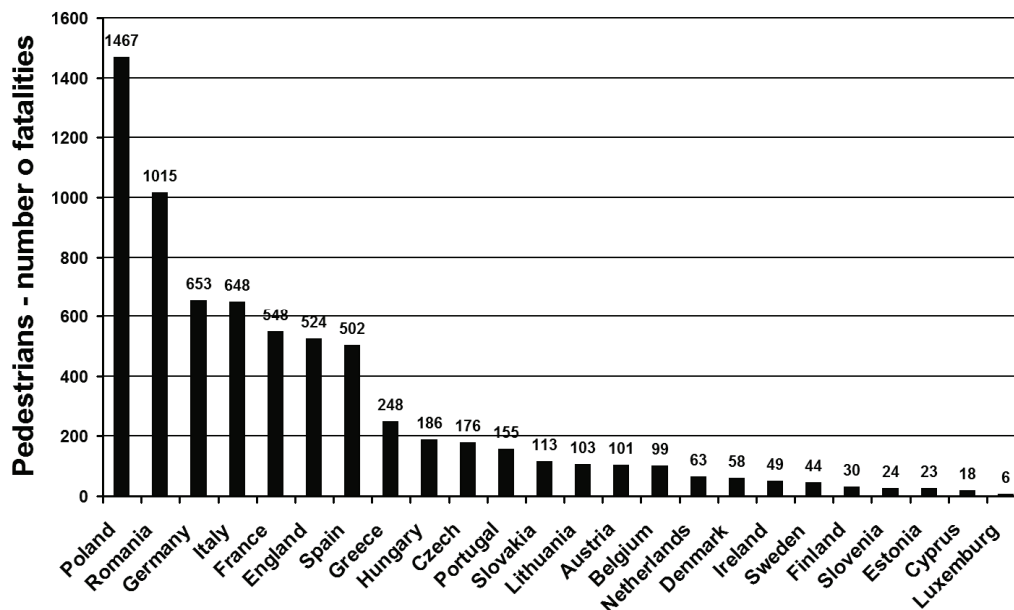

Fig 1. Graphic chart showing accidents with pedestrian participation in the European Union [4]

2. Visibility assessment model on pedestrian crossing

Recommendations concerning design of road lighting drawn up by International Commission on Illumination CIE [5] are reflected in European lighting standards. However, European lighting standards fail to include the notion of visibility, focusing on the guidelines defined by means of luminous flux density and luminance. Visibility model was recommended for use in the USA by IESNA [6] in the year 2000.

The formal notion of STV (Small Target Visibility) was defined for the first time in the norm ANSI / IES RP-8-1990 (IESNA, 1990) proposed for the use of designing of road lighting. Visibility Level (VL) was adopted by CIE as a complement of luminance parameters. Introduction

of visibility parameter resulted from the assumption that luminance parameters of the roadway are insufficient for determining whether an object on the roadway is visible or not. The defined value of STV is a measurement of visibility of any two-dimensional object. The norm introduces the notion of standard small object of the measurements 18x18cm reflection coefficient equaling ρ=0.2. The notion "visibility level" VL is connected with observation conditions of a standard object placed on a roadway at a distance of 83.07m in front of the observer. The distance results from keeping the observation angle of the object equaling 1º, approximate to road observation conditions by the driver whose eyes are at the height of 1.45m over the roadway. The value of visibility STV is calculated on the basis of object location and its reflection parameters. In effect, target and background luminance contrast is obtained and the value of fog luminance is calculated. The norm adopts requirements concerning road lighting expressed by VL parameter.

Calculations of visibility level from STV model are conducted for specified parameters of luminance measurement. Calculation methodology was presented in ANSI / IESNA RP-8-1990 (IESNA, 1990). This methodology constitutes the basis for such current calculation programs as AGI32 or Dialux 4.9. The model adopted for simulation uses the assumption of ideal observation conditions connected with roadway surface and atmospheric transparency.

New recommendations were introduced in the year 2000 [6] concerning visibility assessment by means of STV method. The main change in relation with the previous requirements was determination of the value of reflection coefficient of the object used for measurements on the level of ρ=0.5. What was also standardized was the time of object perception (0.2s). It was established that the age of the observer should equal 60 years. For calculation of visibility, an average value of obtained single measurements should be taken. The measurements of the object were left unchanged and equal 0.18x0.18m. The distance from which the object is perceived was left unchanged (83.07m) as well as angular size of the object (7.45′). The height at which the observer perceives the object was also left unchanged (1.45m).

The method of visibility assessment presented in ANSI/IESNA RP-8-00:2000 [6] requires the following assumptions:
- the observer is located on a parallel line in relation to the centre of roadway, which goes through calculated points,
- the observer is located at a distance of 83 m from the target observed,
- the observer is located at the height of 1.5m over the roadway level and observes the roadway at the angle of 1º,
- the surface of the road is even, solid, homogenous, dry and has defined features of directional reflection coefficient which are expressed in the conditions of reduced luminance coefficient,
- the surface of the observation object (target) must be vertical and indicate the features of material of Lambertian reflection,
- the calculations are conducted only taking into account lighting frames installed within the road lane and pedestrian way without the participation of scattered light,
- luminous flux distribution of installed lighting frames is known and determined by means of directional luminance curves.

On the basis of the norm IESNA RP-8-00 [6] design recommendation were created [7]. As it results from the quoted document, different criteria can be used for designing and measurement of lighting on pedestrian crossing, including those concerning visibility criteria VL (STV). Recommended minimum value of visibility level is 3.8. These requirements refer to all pedestrian crossings regardless of traffic lights existence. One of the requirements is locating a lamp post in front of pedestrian crossing in such a way that a pedestrian is illuminated from the direction of incoming vehicles.

In accordance with recommendations of the norm RP-8-00 [6] from the year 2000, for visibility assessment on pedestrian crossing by means of STV method [6,8,10], the material of dispersed characteristics of reflection and the coefficient ρ = 0.5 was assumed. Fig. 2 below presents basic measurements and the view of the real object used in the present paper.

Fig. 2. Target for visibility research by means of STV method on pedestrian crossing

Target visibility depends on several factors [8,9], among others, age of the observer and their individual perception features, length of observation period, color, size and shape of observation target, target luminance, contrast value, adaptation luminance, visual complexity of background, motion dynamics, glare parameters.

Visibility level for the critical target on the road surface is assumed as [8, 9]:

$$VL = \frac{\Delta L_{actual}}{\Delta L_{threshold}} \ , \tag{1}$$

where:

ΔL_{actual} - is the difference of luminance between a tested target and its background in real conditions,

$\Delta L_{threshold}$ - is the difference of luminance necessary for obtaining minimum visibility between the target of given angular measurements and its background.

The difference of luminance between a tested object and its background in real conditions can be calculated from the following pattern:

$$\Delta L_{actual} = L_t - L_b \ [cd/m2], \tag{2}$$

where:

L_T - target luminance,
L_B - background luminance

If target luminance is higher than background luminance, there is positive contrast. However, if target luminance is lower than background luminance, then we deal with negative contrast. For both cases, minimum luminance difference must be determined for perceiving the object against the background with the assumed probability level. Threshold luminance difference can be calculated in the following way:

$$\Delta L_{threshold} = k \cdot \left(\frac{\Phi^{1/2}}{\alpha} + L^{1/2} \right)^2 \cdot F_{CP} \cdot \frac{a(\alpha, L_b) + t}{t} \cdot AF \ . \tag{3}$$

If it was assumed that observation period equaled t=2s, then threshold luminance difference can be expressed in the following way:

$$\Delta L_{threshold} = k \cdot \left(\frac{\Phi^{1/2}}{\alpha} + L^{1/2} \right)^2 , \tag{4}$$

where:

k   - target perception probability coefficient (k=2.6 for the probability equaling 99.9%) [8, 10],
Φ, L - background luminance functions,
α - angular size of the object,
F_{CP} - contrast polarization factor,
$a(\alpha, L_b)$ - parameter dependent on the angular size of the object and background luminance,
t   - target observation time,
AF   - Age Factor.

In the above equation $\Phi^{1/2}$ and $L^{1/2}$ are assumed in the following way, depending on the value of background luminance:

If background luminance $L_b \geq 0.6\,[\text{cd/m}^2]$ then:

$$\Phi^{1/2} = \log\left(4.1925 L_b^{0.1556}\right) + 0.1684 L_b^{0.5867} \text{ and } L^{1/2} = 0.05946 L_b^{0.466}.$$

If background luminance $0.00418 < L_b < 0.6\,[\text{cd/m}^2]$ then:

$$\log\Phi^{1/2} = -0.072 + 0.3372\log L_b + 0.0866\left(L_b\right)^2 \text{ and } \log L^{1/2} = -1.256 + 0.319\log L_b.$$

If background luminance $0.00418 < L_b\,[\text{cd/m}^2]$ then:

$$\log\Phi^{1/2} = 0.028 + 0.173\log L_b \text{ and } \log L^{1/2} = -0.891 + 0.5275\log L_b + 0.0227\left(\log L_b\right)^2.$$

For shorter observation periods (for STV model [6] assumed as 0.2s) for proper object recognition, a higher luminance value ΔL is indispensable, thus the following coefficient should be taken into account in the calculations:

$$\frac{a(\alpha, L_b) + t}{t}, \tag{5}$$

where a - parameter dependent on the angular size of the target and background luminance L_b (according to Blondel-Rey, data for calculations $a(\alpha, L_b)$ come from experimental research conducted by Schmidt - Claussen and Blackwell [6]).

$$a(\alpha) = 0.36 - 0.0972 \cdot \frac{\left(\log\alpha + 0.523\right)^2}{\left(\log\alpha + 0.523\right)^2 - 2.513\left(\log\alpha + 0.523\right) + 2.7895}, \tag{6}$$

$$a(L_b) = 0.355 - 0.1217 \cdot \frac{\left(\log L_b + 6\right)^2}{\left(\log L_b + 6\right)^2 - 10.4\left(\log L_B + 6\right) + 52.28}. \tag{7}$$

The angle α is the angular size of the object. The target of the radius r seen from the distance d has the measurement of observation angle described by the equation:

$$\alpha = 2\tan^{-1}\left(\frac{r}{d}\right) \cdot 60, \text{ [minutes].} \tag{8}$$

For objects observed whose angular measurement $\alpha < 60'$ the value $a(\alpha, L_b)$ can be approximated by the equation determining the influence of perception time:

$$a(\alpha, L_b) = \frac{\left[a(\alpha)^2 + a(L_b)^2\right]^{1/2}}{2.1}. \tag{9}$$

For shorter target observation periods:

$$\Delta L_t = \Delta L_{t=2\sec} \frac{a(\alpha, L_b) + t}{t}. \tag{10}$$

To obtain the difference between ΔL for positive and negative contrasts, contrast polarization factor can be determined F_{CP}. The value ΔL_{neg} can be calculated from the condition:

$$\Delta L_{neg} = \Delta L_{pos} \cdot F_{CP}, \tag{11}$$

where ΔL_{pos} is the value for perception time for t = 2sec.

Contrast polarization factor F_{CP} is calculated according to the following equation:

$$F_{CP}(\alpha, L_b) = 1 - \frac{m\alpha^{-\beta}}{2.4\Delta L_{pos, t=2sek}}, \tag{12}$$

where:

$$\Delta L_{pos,t=2sek} = k \cdot \left(\frac{\Phi^{1/2}}{\alpha} + L^{1/2} \right)^2 . \tag{13}$$

It obtains the value equaling 1 for positive contrast, however, for negative contrasts – the value lower than 1. The value of 'm' parameter in this equation can be calculated from the following dependency:

$$m = 10^{-10^{-\left[K (\log L_b + 1)^2 + 0.0245 \right]}} , \tag{14}$$

where :
K = 0.125 for $L_b \geq 0.1 \, [\text{cd/m}^2]$,
K = 0.075 for $L_b \geq 0.004 \, [\text{cd/m}^2]$

For all L_b the value $\beta = 0{,}6 L_b^{-0.1488}$

Value ΔL for observers older than 23 years, can be calculated by means of the following equation:

$$\Delta L_{age} = \Delta L_{23} \cdot AF , \tag{15}$$

where: AF (Age Factor) depending on the age of the observer equals:

1. 23 [years] < age < 64 [years] ; $AF = \dfrac{(age - 19)^2}{2160} + 0.99$,

2. 64 [years] < age < 75 [years]; $AF = \dfrac{(age - 56.6)^2}{116.3} + 1.43$.

For assessment it is indispensable to give the classification of visibility level. Visibility scale is presented in Fig. 3.

Fig.3. Visibility level VL by means of STV method

3. Simulation research

Fig. 4 presents the arrangement of objects on pedestrian crossing. Target and background luminance measurement is conducted for each traffic direction observing the object situated in front of the observer from the distance of 83.07 m.

Conducting a measurement on the opposite traffic lane in relation to the assumed driving direction is indispensable in the case of measurements on pedestrian crossing. Information about obtained contrast is essential for the whole roadway width and it is a reflection of a real traffic situation.

A pedestrian can be located at any traffic lane, and the driver of a vehicle approaching the pedestrian crossing must be ensured with observation conditions of the whole area of pedestrian crossing including the waiting and safety zone. The objects must be placed on the roadway within the axis of pedestrian crossing below the stretch E-F (Fig. 4) with the distance between the next measurement points $\Delta L \leq 1$m.
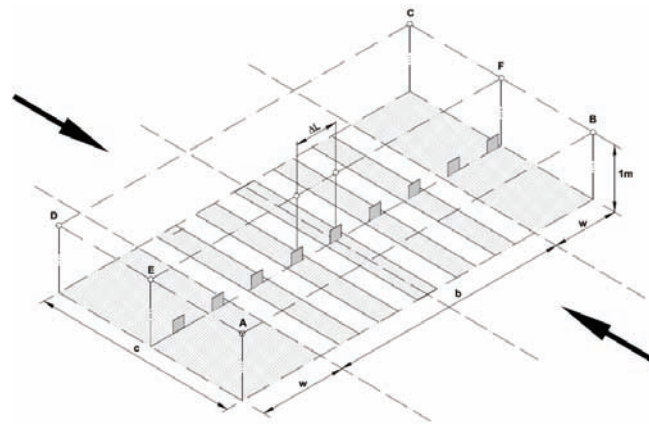
Fig.4. Location of objects on pedestrian crossing by means of STV method

The article presents sample simulation research results conducted by means of Dialux 4.9 program [11] for the case of pedestrian crossing lighting by lighting frames situated in a one-sided manner, so that one of them is placed next to the crossing – Fig. 5.

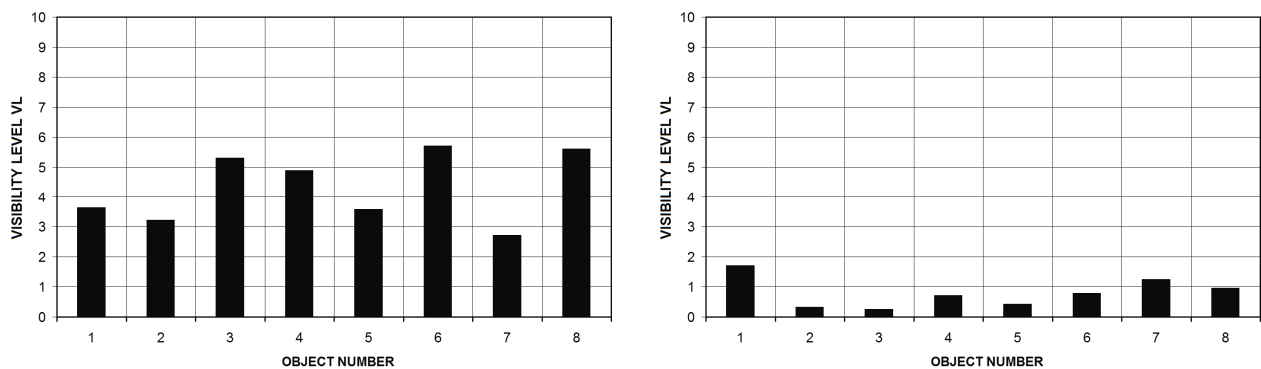*Fig. 5. Pedestrian crossing illuminated by lighting frames*

Fig. 6. Visibility level on pedestrian crossing obtained as a result of lighting frames illumination from the first and second observation direction

4. Conclusions

The proposed method of visibility assessment on pedestrian crossing on the basis of STV model [6, 8, 10] allows for unambiguous verification of the applied lighting concept. It should be

mentioned that the visibility obtained also depends on background luminance, which should be accounted for in the analysis of real traffic situations.

When analyzing the above case of pedestrian crossing lighting by means of street lighting frames, it can be stated that the solution applied fails to ensure satisfactory visibility level for both observation directions. For the first observation direction (Fig. 7), in which a lighting frame is situated at a distance of 3 m before the crossing, visibility values obtained are between fair and very good level. However, for the other observation direction, visibility values practically do not exceed a very poor level. In this case high background luminance causes visibility reduction to the values that do not ensure proper observation conditions from the driver's seat and might be the reason of not noticing the pedestrian.

The conducted simulation researches confirmed the possibility of using STV method for verification of the state of pedestrian crossing lighting.

The obtained simulation researches results should not be treated unambiguously without conducting practical verification. The simulation presented in the paper can serve as a basis for conducting fieldwork and performing validation of results for these pedestrian crossings for which lighting projects had been carried out.

The issue presented above does not exhaust the whole spectrum of problems connected with lighting installed on pedestrian crossing. It is a mere introduction to conducting further research work. Researches that are being conducted at present are aimed at determining recommendations concerning visibility values obtained on pedestrian crossing.

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