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Lighting Techniques and Methods for Some Essential Components of Road Infrastructure in Romania

[1] Gheorghe Neamțu, [2] Marinela Ință, [3] Ioan Țincu

[1] Ph. D. Engineer, Associate Professor at "Lucian Blaga" University of Sibiu, 10 Victoriei Street, Sibiu, Romania
[2] University Lecturer, Ph. D. Engineer, Professor at "Lucian Blaga" University of Sibiu, 10 Victoriei Street, Sibiu, Romania
[3] University Lecturer, Ph. D. Mathematician, Professor at "Lucian Blaga" University of Sibiu, 10 Victoriei Street, Sibiu, Romania

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Corresponding Author: **Gheorghe Neamțu**

Abstract

Good quality lighting of streets, National Roads (DN) or highways is essential for road safety, personal safety and the urban or suburban environment. It also supports commercial and recreational activities at night, which can have a major impact on the economic growth of the area. The purpose of street lighting is not to direct light directly in front of cars, this is done by using their headlights. Instead, the adjacent areas are illuminated, hiding potential hazards from the side (street intersections or roadside). The scientific paper presents an original study and a personal opinion of the authors on the techno-economic and scientific acceptance of techniques and methods of lighting some essential components of road infrastructure in Romania. In this way interested readers can learn about the need for lighting of road infrastructure components, some theoretical considerations on the lighting of road infrastructure components, siting solutions for lighting systems of road infrastructure elements, risk areas involving street lighting, illumination of intersections of National Roads as well as between national roads and other intersecting public roads, illumination of railway level crossings, illumination of pedestrian crossings on National Roads, illumination of parking areas, illumination of road junctions, illumination of public transport stations, illumination of art elements (bridges, footbridges and overpasses) and illumination of toll stations. At the end of the paper, conclusions are drawn and presented on the research carried out by the authors.

Keywords: Lighting System, Risk Area, Intersection, Pedestrian Crossing, Railway Level Crossing, Road Junction, Bus Stop, Parking, Toll Station

1. Introduction

Public road lighting in Romania stems from the need for orientation, comfort, confidence and safety. It is done when necessary to prevent and reduce potential road accidents, to save time and money on travel, to reduce community costs and, last but not least, to reduce greenhouse gas pollution. The reduction of NOx emissions from internal combustion engines of motor vehicles is greatly influenced by street lighting, as perfect observation of road elements by drivers in road traffic contributes to a high flow of road traffic at night and, of course, to the correct use of vehicles and the correct operating regime of internal combustion engines. This creates smaller stationary times and hence lower chemical and noise emissions from vehicles and their engines in areas of properly lit streets or roads. The lighting of road arteries is achieved by means of a functional technological system, including specific constructions, installations and equipment. The architecture and operation of this system is directly dependent on and influenced by the supply of electricity or the existence of natural sunlight (for luminaires whose energy is obtained from photovoltaic panels and stored in individual electrical storage for power supply - those renewable energy sources) and connection to the national energy system. If the street lighting network is fed from the national power grid, the required electricity shall be distributed from the transformer substations via power lines (underground or aerial) to the luminaire location. The connection of the poles supporting the luminaires to the electricity grid shall be made via underground networks and switch and distribution boxes. If the luminaires are powered by renewable energy (solar or wind), their electrical accumulators shall be placed in the luminaires or in well sealed and insulated underground boxes. The electric

batteries will have the capacity to provide the necessary energy to run the luminaires throughout the night, with multiple recharging cycles and possibilities. From the point of view of the human psychic, the perception of street lighting systems and the human eye's reaction to light are defined by a series of factors relating to age, gender, state of health, occupation, level of information or culture and, last but not least, rhythm of life. The electric batteries will have the capacity to provide the necessary energy to run the luminaires throughout the night, with multiple recharging cycles and possibilities. From the point of view of the human psyche, the perception of street lighting systems and the human eye's reaction to light are defined by a series of factors relating to age, gender, state of health, occupation, level of information or culture and, last but not least, rhythm of life.

1.1 Lighting needs of road infrastructure components

The need for lighting of road infrastructure components stems from the following considerations:

- the visual impact of these systems on the street landscape;
- reducing the economic and financial costs of energy investment and maintenance;
- Romanian government policy to reduce greenhouse gas and noise pollution from road vehicles;
- problems related to how living organisms adapt to light or darkness;
- protecting biodiversity, animal behavior, birds and life cycles;
- occupational health, safety and user comfort issues, as well as the proper maintenance of these systems.

2. Literature Review

The regulation at European level of the lighting of road infrastructure elements is in accordance with the provisions of EN 13201/2016 (2,3,4) [1], which defines how to calculate energy performance indicators for road lighting installations using the calculated power density indicator (PDI) DP and the calculated annual energy consumption indicator (AECI) DE. Standard SR CEN-TR 13201 - street lighting part 1: covers the selection of lighting classes; standard SR EN 13201-2, street lighting part 2 covers the performance requirements; standard SR EN 13201-3 street lighting part 3 covers the calculation of performance and standard SR EN 13201-4 street lighting part 4 covers the methods for measuring photometric performance.

Most European countries have their own rules inspired, adapted or corrected according to this quality standard.

Romanian authorities through the National Standardization Organization - ASRO [2], which is the national platform for the development and adoption of European and international standards (ASRO is a full member of CEN - European Committee for Standardization (2006) CENELEC - European Committee for Standardization in Electrotechnics (01.02.2006)), through the Romanian standard SR 13433:1999 [3], in connection with the development and modernization of the national road network, in 2012 published the *Guide on the conditions under which the lighting of national roads and highways will be carried out*. According to this guide, national roads (DN) and highways, in populated areas, will be illuminated according to the technical regulations in force. In rural areas, only those stretches of road which become dangerous for road traffic and which present a high risk or have a high number of road accidents due to darkness will be illuminated, namely: intersections or roundabouts; railway level crossings; pedestrian crossings; highway junctions; parking lots; tunnels; underpasses; bridges and viaducts longer than 100 m; bus and maxi-taxi stations; areas for premises and services, parking lots or other areas with pedestrian facilities.

The guide also recommends lighting up national roads and highways:

- in all areas or sections of road where there is a risk or where there has been a high number of road accidents;
- on sections of roads with difficult geometics and/or special conditions (forests, rivers or lakes);
- at intersections where traffic lanes are separated for cornering or turning;
- on national roads passing through populated areas.

In order to take all these considerations into account, when deciding whether or not to illuminate certain parts of a road or street, specialists have to take into account certain criteria, such as [4, pp. 12-13]:

- average travel speed, traffic volume, road configuration and the presence of risk areas impose how to evaluate the need for road lighting;
- there is the possibility to estimate savings in the use of road lanes as a benefit of street lighting. Significant savings are achieved when the rate of serious road accidents is low;
- the basis for calculating the benefits resulting from the installation of street lighting can be justified by the volume of traffic, taking into account the average number of road traffic injuries and fatality rates for each type of road. On national roads and highways, savings from reduced travel time should also be taken into account;
- the cost-effectiveness of street lighting in the overall economics of road traffic is analyzed by comparing the average annual savings in total roadway costs with the total annual costs of the lighting system and the costs resulting from collisions with the poles installed for road lighting;
- when traffic volumes are low, which would not imply that road lighting can be justified by simply reducing the number of road events, street lighting can be justified on the basis of:
  - the inhomogeneity of the traffic environment;
  - inadequate road alignment for proper orientation;
  - reduced distance between intersections;
  - more pedestrian crossings and public transport stations;
  - lack of sidewalks for pedestrian traffic, even in cases where, from a cost-effectiveness calculation, street lighting would not be one-sidedly cost-effective from a traffic perspective.

The rehabilitation or reconditioning of physically and morally aged lighting installations is extremely important. It is possible to achieve better lighting with lower energy consumption using new design or new technologies. Improved lighting and lighting control systems usually give good cost-benefit ratios and relatively short amortization periods [4, p. 13].

Other international reference documents, which regulate street lighting or road infrastructure elements at European level, are [4, pp. 25-26]:

- CIE S 017 ILV International Lighting Vocabulary;
- CIE 23 International Recommmandations for Motorway Lighting;
- CIE 88 Guide for the road tunnels and underpasses;
- CIE 93 Road Lighting an Accident Countermeasure;
- CIE 115 Lighting of Roads for Motor and Pedestrian Traffic;
- CIE 132 Design Methods for Lighting of Roads;
- CIE 140 Road Lighting Calculations;
- CIE 144 Road Surface and Road marking Reflection Characteristics;
- CIE 180 Road transport lighting for developing countries;
- CIE 189 Calculation Tunel Lighting Quality Criteria;
- CIE 194 On Site Measurement of the Photometric Properties of Road and Tunel Lighting;
- CIE TC 5.14 Maintenance of outdoor lighting system.

3. Theoretical considerations on road infrastructure component lighting

In order to better understand the field, it is necessary to define certain terms and at the same time to present the conditions, principles and recommendations for the lighting of road infrastructure components.

- ***Luminance, L.*** Luminance is a measure of how bright a surface that emits or reflects light feels to the human eye, causing blinding.

Examples of luminance values in the environment are given below:

- midday sun - until 150,000 cd/cm^2 ;
- matt incandescent lamp – 2 ... 5 cd/cm^2 ;
- compact fluorescent lamp – 0,9 ... 2,5 cd/cm^2 ;
- moon – 0,25 cd/cm^2.

Aspects quality and comfort of lighting systems and light sources are assessed with photometric units derived from the light flux are shown in Table 1. Artificial lighting sources and systems are assessed by the following basic quantities:

Table 1: Fundamental measures

Fundamental sizes	Notation [unit of measurement]	Name of the unit of measurement
Luminous flux	F, [lm]	Lumen
Luminous intensity	I, [cd]	Candle
	Derived sizes	
Lighting	E, [lx]	Lux
Luminance	L, [cd/m^2]	Nit
Bright excitement	M, [M/m^2]	-
Color rendering	Ra	
Degree of blindness	Ti, [%]	
Luminance distribution		
Average horizontal illuminance	E_h	Lux
Minimum vertical illuminance	E_v	Lux
Medium cylindrical illumination	E_c	Lux

Among the fundamental measurements there is one very important parameter from the point of view of energy efficiency - *"luminous efficiency"* - a measurement that characterizes the efficiency of the process of converting electrical energy into optical radiation energy. It is measured by the ratio *lm/W* - how many lumens are produced at a power consumption of one watt.

- ***Average road surface luminance*** L_{av} is influenced by the contrast acuity of the driver's eye and the contrast of obstacles on the road or street against the background field of view, directly influencing the visual performance of the human eye. Fig 1 shows the relationship between the mean luminance of the road surface and the revealing power *(RP)* factor for a suitable uniformity *(U0 = 0.4%)* and a physiological glare index *TI = 7%.* The value for Lav is the minimum value that must be maintained over the lifetime of the lighting installation for each element of road infrastructure. The average surface luminance of a road or road infrastructure element depends on the light distribution from the lighting body, the luminous flux of the light source, the geometry of the installation and the reflectance properties of the road surface. The calculation of the average road luminance for the road surface shall be carried out according to CIE 140-2000.

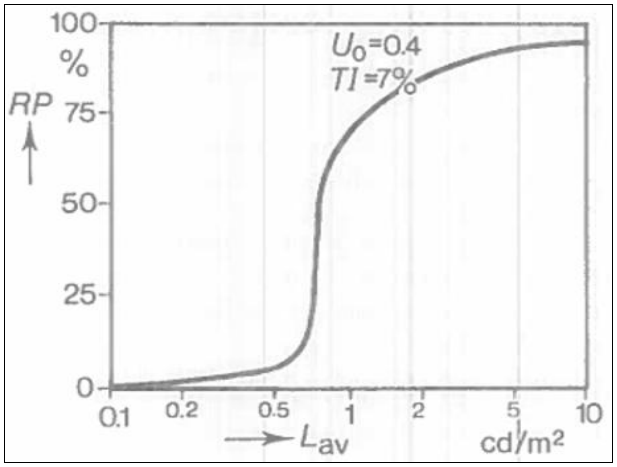

Fig 1: The relationship between average surface luminance and the revealing power, RP factor [4, p. 14]

- ***The light of the voile*** is defined by that value which indicates the brightness of the voil, superimposed on the clear image of the scene in front of the drivers driving on that lighted street or road. It is manifested by the diffusion of light directly onto the users' retina, increasing the sensation of a bright wave (hence the name light wave).
- ***Overall road luminance uniformity, U0*** is the ratio between the minimum luminance measured at a point on the surface and the average luminance of the L_{av} road surface. The importance of this principle defines the control of visibility on arterial roads.
- ***Longitudinal uniformity of road surface luminance, UI*** is the ratio of the minimum and maximum luminance along the entire length of the roadway in a specified direction.
- ***Growth threshold or disability blindness, TI*** is the result of light scattering in the driver's eye which reduces the contrast of the image formed on the retina. *TI* is the measure of the loss of visibility due to incapacitating glare from lighting. The relationship for calculating this parameter is based on the percentage by which the luminance must be increased to make obstacles in the roadway visible in the presence of glare

if they are only visible in the absence of glare when the lamps are screened from the view of the observer.

- ***Side by side area report*** is the ratio of the average illuminance on lanes or areas outside the edges of the roadway to the average illuminance on lanes inside the edges of the roadway (sidewalks, bicycle lanes, emergency lane - if not marked in the study area and is a nearby or adjacent area).
- ***Visual orientation.*** Visual guidance is a concept that includes complex measures to be taken so that road or street users can easily recognize the configuration of the road or street in accordance with the maximum permissible speed for that section of road or street. Specific to unlit roads or streets this guidance (orientation) is restricted exclusively to the area illuminated by the headlights of motor vehicles. The improvement of visual guidance, which contributes significantly to the safety and comfort of road users, can be achieved by appropriate street lighting at bends and intersections. The elements to be considered in this respect are the following:
  - for the lighting of highways with lanes separated by a median zone, adequate visual guidance can be achieved by placing the luminaires on poles arranged in the central zone. The advantage of this mode of lighting is that the poles supporting the luminaires are placed opposite each other, but also that the investment cost or maintenance costs are reduced;
  - a one-sided lighting system on the outside of the curves also ensures adequate illumination (Figure 2a);
- for curves with small radii (less than 300 m), their configuration has to be taken into account. In this respect, Figure 3 shows a case where the lighting was only one-sided and the lighting in the area of the curve was on the outside of the curve, not on the inside. In order to prevent these shortcomings it is important to avoid placing elements of the street lighting system like those shown in Figure 3a (the confusion that can arise due to the wrong arrangement of the poles supporting the luminaires). This creates the impression of a straight road, which can lead to serious road accidents. It is recommended that the pillars should be placed as shown in Figure 2b to ensure proper guidance.

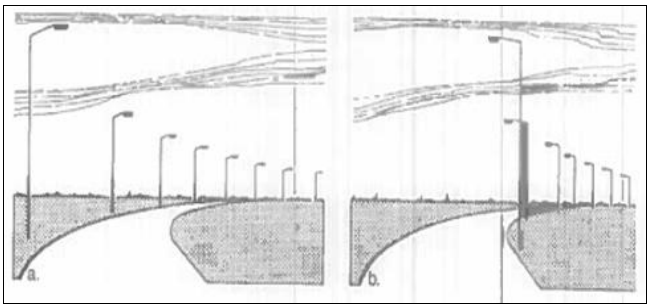

Fig 2: Location of lighting on the outside of the curve (a) and on the inside of the curve (b) [4, p. 18]

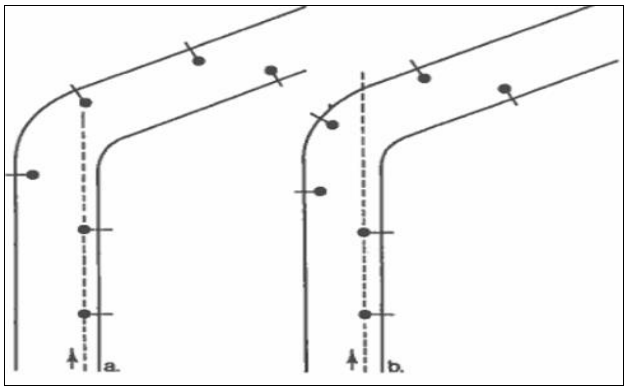

Fig 3: Types of one-sided lighting for curves with radius less than 300 m [4, p. 19]

- ***Visual field complexity*** is a collection of lighting, or other visual elements that appear in the field of vision of road users that may confuse, distract, disturb or indispose. Even though certain visual guidance elements provided by the street, road or environment may be close, they are likely to mislead, disturb the perception of essential elements or events such as traffic lights, or change the direction of travel of other road users (e.g. advertising billboards, poles, buildings, illuminated or illuminated sports facilities, etc).
- ***Ambient light level*** is the estimated luminance level for the environment. Illuminated roadside illuminated billboards should also be considered here. The placement of illuminated billboards on the side of roads or streets shall be avoided as far as possible. If, however, this possibility does not exist, their light level shall not exceed by more than one lighting class the level of street lighting for that roadway.
- ***One-sided lighting*** is defined by the arrangement of poles supporting the luminaires on one side of the road or street.
- ***Bilateral lighting opposite*** is defined by the arrangement of the poles supporting the lighting columns on opposite sides of the road or street, facing each other.
- ***Lighting class M (or ME).*** It is the class of lighting intended for motorized vehicular traffic.
- ***Lighting class C (or CE).*** It is the class of lighting intended for conflict zones.
- ***Light*** is the visual assessment of the energy radiated by a body in the electromagnetic wavelength band $\lambda = 380 - 740$ nm perceived by an eye as a visual sensation. Any body whose temperature is above "absolute zero" (0^{o} K) emits energy. The propagation of this energy in the surrounding environment is achieved by electromagnetic waves. The basic parameters of electromagnetic radiation are: frequency or wavelength (spectral component) and amplitude (energy characteristic), which depend on the structure of the radiating body and the energy state of the atoms. The wavelength band of electromagnetic radiation (Figure 4) is enormous and extends from 1015 nm (alternating

current) to 10-3 nm (cosmic radiation), while radiation that causes the eye to feel light (optical) is only the segment between 380 nm and 740 nm. For information: 1 nm = 10 - 9 m.

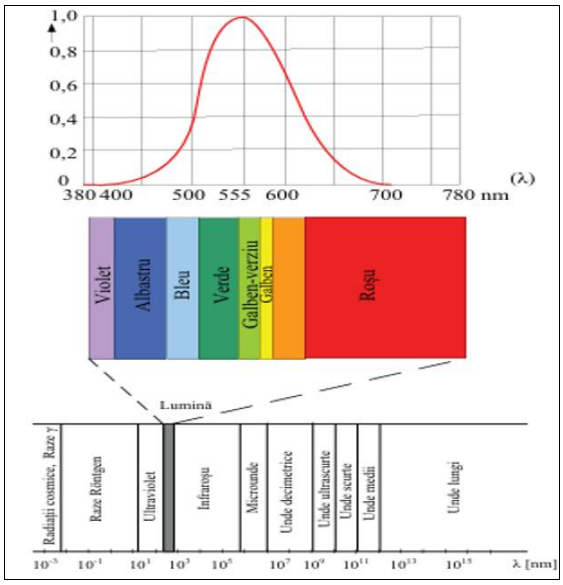

Fig 4: Wavelength band of electromagnetic radiation [nm]

The visible spectrum covers wavelengths between 380 - 740 nm and is categorized between ultraviolet (50 , 380 nm) UV and infrared (300 - 5000 nm) IR radiation. Radiation of different wavelengths in the visible spectrum produces different sensations, defined by the term color. The visible spectrum can be divided into six zones corresponding to the fundamental colors (Table 2).

Table 2: Fundamental colors

Wave length [nm]	Color
380xxx430	Violet
430xxx485	Blue
485xxx570	Green
570xxx600	Yelow
600xxx610	Orange
610xxx740	Reed

Radiation in the optical (visible) spectrum emitted at a single wavelength is called monochromatic radiation and gives the eye the sensation of a particular color. The superposition of several monochromatic radiations creates complex (polychromatic) radiation. The sensation of the color white is the result of the mixing, in certain proportions, of all the monochromatic radiations of the visible spectrum. Conventionally, white light corresponds to the radiation of the absolute blackbody at a temperature of 5,000 K. The white light emitted by the Sun is a mixture of radiation of all wavelengths of the visible spectrum (it also contains IR and UV radiation). The radiation spectrum emitted by incandescence is continuous (contains all wavelengths of optical radiation, full spectrum). The light emitted by electric discharges in gases or metal vapors has a discontinuous spectrum, composed of lines, corresponding to the atomic composition of the substance in the discharge zone - inert gases, mercury vapors, sodium, metal halogens, etc. From a technical point of view, according to the normative acts of the International Commission on Illumination (CIE - Commission Internationale de l'Eclairage) artificial light sources are classified according to their color. The colour of an artificial light source is characterized by its colour temperature. The color temperature of a light source is defined as the temperature (in K) of the blackbody whose radiation is the same color as that of the light source under analysis. Table 3 shows the CIE classification of artificial light sources.

Table 3: CIE classification of artificial light sources

Definition of CIE	Color temperature range, K
Group 1 (warm)	< 3,300 K
Group 2 (medium)	3,300 – 5,000 K
Group 3 (cold)	> 5,000 K

The Sun's thermal radiation comprises a continuous spectrum with wavelengths extending from about 300 – 4,500 nm, with an average color temperature of 5,000 K.

- ***Photometric unit*** is the unit by which artificial light sources are photometrically rated. These sources are nothing more than energy converters:
  - in electric lamps, electrical energy is converted into electromagnetic radiation energy (optical energy);
  - in combustion lamps (stearin, kerosene, kerosene gas, natural gas) the thermal energy resulting from the oxidation reaction (combustion) is converted into electromagnetic radiation energy (optical energy).
- ***Luminous flow,*** is the fundamental size of the optical field is the luminous flux, evaluated by the luminous sensation it produces and measured in lumen (lm). According to the *"C. I. E. International Lighting Vocabulary"*, luminous flux is defined as follows: a quantity derived from the energy flux by evaluating the radiation after its action on a selective receiver, whose spectral sensitivity is defined by a normalized function of the spectral relative luminous efficiency. Lumen corresponds to the luminous flux emitted by a monochromatic light source with a wavelength of 555.5 nm and using 1/683 W. Luminous flux defines the energy characteristics of light sources and is used to determine the luminous efficiency and luminous efficacy of light sources and lighting installations. All other photometric quantities used in lighting science and practice are related to luminous flux.
- ***Light intensity, I.*** Since light sources do not distribute the light flux uniformly in the surrounding space, the notion of luminous intensity was introduced to characterize the luminous action (illumination effect) of the source in a given direction. The unit of measurement of luminous intensity is the candela [cd]. In 1979, the 16th General Conference on Weights and Measures (CGPM) adopted the unit of measurement candela with the following definition: definition The spatial distribution of the luminous intensity of a light source is a very important characteristic. The candela is the luminous intensity, in a given direction, of a source emitting monochromatic radiation at a frequency of 54 x 1,013 Hz and having a radiant intensity in that direction of 1/683 of a watt per steradian.
- ***Lighting, E*** appreciate the density of luminous flux received by a surface and by definition, the illuminance E of a surface is the ratio of finite values of luminous flux to the size of the surface. The unit of measurement of illuminance is the lux [lx].

- ***LED spotlight.*** A constant concern, internationally, is to increase the performance of artificial light sources, which requires both studies on increasing the parameters of current sources and studies on new solutions for obtaining artificial light. One of the solutions that has opened new directions and perspectives in the development of lighting has become LEDs (Light Emitting Diode). LED lamps correspond to the 3rd generation of artificial light sources, after incandescent and gaseous discharge sources. The light source in this case is an assembly (Fig. 5) of semiconductor elements with strictly determined properties, which determine the radiation spectrum and form the luminous flux. The spectrum of the emitted radiation (the color of the emitted light) is determined by the composition of the semiconductor elements used to make LEDs. In this respect, the use of LED lighting sources is of particular interest in cases where a certain spectrum of light radiation (a certain color or spectrum of light) is required. Achieving a certain color, in the case of conventional light sources, requires the presence of filters that allow the desired radiation to pass through. This results in a particularly low efficiency of the source, with about 80% of the radiation emitted by the source being blocked by color filters. The use of LED sources allows choosing the desired color, achieving a much higher energy efficiency than the classical solution. An essential advantage of this type of light sources is that the f lux value of the light practically does not depend on the value of the supply voltage at voltage deviations within ± 10%. The luminescent diode structure is shown in Figure 5. It is an arrangement of LEDs connected in series and parallel, on which the supply voltage of the modules and the lamp power depend. In the lamp scheme 5 modules with 6 of 6 LEDs are used in the lamp matrix, which produces a light flux of approx. 6,000 lm. From the schematic it can be seen that the number of modules (lamp wattage) can be much higher and the regulation of the light flux can be ensured by partially connecting/disconnecting the number of modules in a lamp.

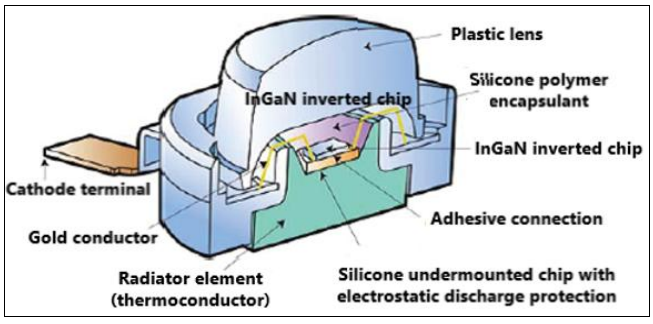

Fig 5: Luminescent diode structure

LEDs have no filament or electrodes (elements that wear out during operation), which makes them long-lasting and extremely impact resistant. The lifetime of an LED luminaire is very long (about 50,000 hours), which is an essential advantage in general, and in particular in cases where the replacement of light sources is accompanied by high costs (high rise halls, market and street lighting in crowded cities, hazardous areas in enterprises, etc.). 6 shows a luminaire with LEDs for outdoor lighting systems. The simplicity of the controls for changing the emitted luminous flux, depending on the desired program or depending on the level of natural lighting, makes it possible to use LED lamps efficiently for creating a comfortable and economical lighting environment.

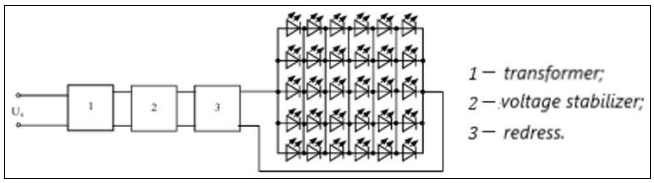

Fig 6: Principle diagram of an LED lamp

The advantages of lighting road infrastructure elements with LED luminaires are the following:

- *Luminous efficacy*. The most important criteria for electrical light sources. At the moment it has reached 120-160 lm/W and in 2-3-1 years it will reach 200 lm/W;
- *Spectral composition.* A very important parameter for indoor lighting systems, architectural lighting, exhibition halls, sports grounds, central urban markets. In the case of LEDs, the desired spectral package is obtained by the respective mounting of the optical cell;
- *Dimensions.* The light sources, depending on the need (luminaire purpose), can be very compact, and by grouping several LEDs together, the characteristic dimensions of fluorescent lamps can be obtained;
- *High ability to resist numerous "on-off" cycles.* Incandescent and gas discharge lamps contain elements, which are sensitive (wear out) depending on the number of "on/off" cycles, the nature of the wear phenomena being different. Since LEDs do not contain elements that would wear out, the operating temperature does not reach values that would increase the "ageing" of the semiconductor assembly. This feature favors the use of LEDs for applications with presence sensors or beacons;
- *Instant on.* No time is required to reach operating mode. High-pressure discharge lamps need up to three minutes to reach full light output. The duration of the re-ignition process reaches 10-20 min. from the moment of switching off. LEDs reach their maximum light output virtually instantaneously and can re-ignite immediately after being switched off;
- *Vibration resistance.* In street lighting conditions (and in the case of elevators, airplanes, trains, cars, etc.) lighting fixtures, being mounted at great heights (8-25 m) for several reasons are subject to vibrations which cause or accelerate the failure of the elements of the classical light sources (discharge lamps). In the case of LEDs the vibrations can not cause the failure of the component parts, as they are all a consolidated body;
- *Low temperature operation*. Fluorescent lamps perform poorly at low temperatures, requiring high voltages to turn on and having lower luminous flux. LED performance improves at low temperatures. For this reason they are useful for applications in refrigerated spaces, freezers, cold rooms, outdoor applications;
- *Compatibility.* As LEDs are compatible with various electronic dimming devices, they allow for the

adjustment of illuminance levels and color cues. As technology evaluates, the area of dimming and color control become areas of innovation in lighting. They have no infrared or ultraviolet emissions. Incandescent lamps convert about 80% of their energy into infrared radiation, with only 20% converted to light. Because the share of ultraviolet radiation from discharge lamps at high pressures is considerable, their use is conditional. LEDs do not emit infrared or ultraviolet radiation;

- *Integration.* The LED modules were initially realized as part of a grid-powered lighting system, but with the development of photovoltaic cells and having compatible initial electrical parameters, they will be easily integrated into a stand-alone lighting system with photovoltaic cells as power supply, which offers enormous potential for increased energy efficiency.

The parameters characterizing the lamps are:

- *Efficiencyl ηc*, defined as the ratio between the luminous flux *Φc* emitted by the lamp and the luminous flux *Φl* emitted by the lamp;
- *How to distribute Fc in space,* defines the distribution of light flux between the lower and upper hemispheres. In order to increase energy efficiency and reduce light pollution, it is recommended that 95% of the luminaire's f lux value should be directed to the lower hemisphere;
- *Photometric curve (CFM) of the luminaire.* Let us compare two luminaires with equal light fluxes and different CFM (Figure 7A - concentrated light flux distribution; B - broad light flux distribution). Let us analyze the horizontal surface illuminance distribution for three situations:

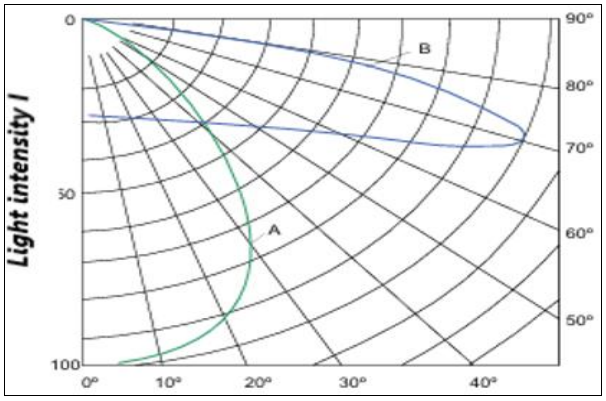

Fig 7: Standardized photometric curves, A - concentrated distribution, B - large distribution

- D1. Direction 0º: According to the mathematical relationship:

$$E = \frac{Ia\ cos\theta}{r^2},\ \text{lx} \qquad (1)$$

and the value of luminous intensity *I* in the case of photometric curve A will be much higher compared to curve B. As a result, the luminaire with photometric curve B provides the normative value of the illuminance level, whereas, the luminaire with curve A will cause excess illuminance in the area;

- D2. Direction 40º: Since the I values in both cases are practically equal, the illuminance values of the respective areas will be equal;
- D3. Direction 60º: The luminous intensity values I have an aqueous ratio of 1:5. As a result, the luminaire with photometric curve B will provide the normative level in that area. In the case of curve type A the illuminance level of the respective area will be 5 times lower and far away from the normative value. It is obvious that the illuminance level provided by the luminaire with photometric curve A in the zone 0º will be much higher than the normative one, and in the zone of the directions 60º and beyond it will be much lower than the required one. In this case there will be a high level of non-uniformity of illuminance, which will not occur in the case of the luminaire with photometric curve B. This is a case of inefficient use of electricity. ***Reflectance coefficient,*** is the coefficient that road designers need to keep in mind when profiling the construction of a street, road or highway.These coefficients directly influence the lighting results. In figure 8 a, b, c, d and e we show the light reflectance coefficients in different situations:

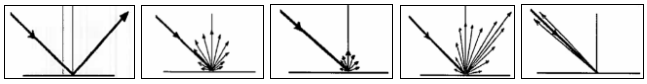

Fig 8: Reflection coefficient: a) ideal; b) diffuse (ideal case); c) of absorbent materials; d) real; e) in the same direction as the incident light ray [4, pp. 38-39]

Analysis of the data presented in Figure 8 shows that:

- in the case of ideal reflection (Fig. 8 a), the incident light ray is reflected entirely at an angle equal to the angle of incidence;
- in the case of diffuse reflection (Figure 8b), we are dealing with an ideal case;
- in the case of reflection from absorbing materials (Figure 8c), most of the light is absorbed;
- in the case of true reflection (Figure 8d), no problems are created;
- the case of reflection in the same direction as the incident light beam (Figure 8e), no problems are created.

4. Placement solutions for road infrastructure lighting systems

Positioning of the columns supporting the luminaires and their position in relation to the surface or objective to be illuminated (infrastructure components or elements) is important, as failure to comply with certain rules defining these aspects would reduce the visibility of users and therefore road safety.

The luminaires in relation to their position in relation to the road infrastructure elements to be illuminated may be located as followsl:

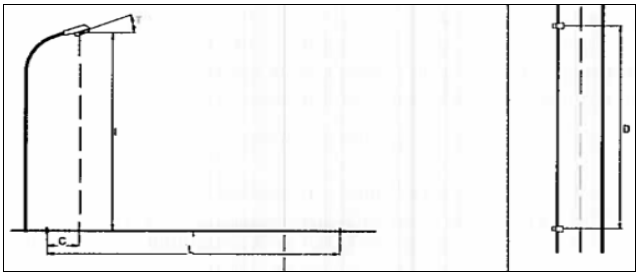

Fig 9: Placement of one-sided lighting [4, p. 30]

- ***One-sided*** (on one side of the street or public road) (Figure 9). It is one of the most economically advantageous street lighting solutions. In this case, the following aspects should be taken into account:
  - visual orientation in the arrangement (ordering) of poles;
  - the calculations for the dimensioning of the lighting system shall be carried out in both directions separately (the conditions required by the standard must be met in both directions);

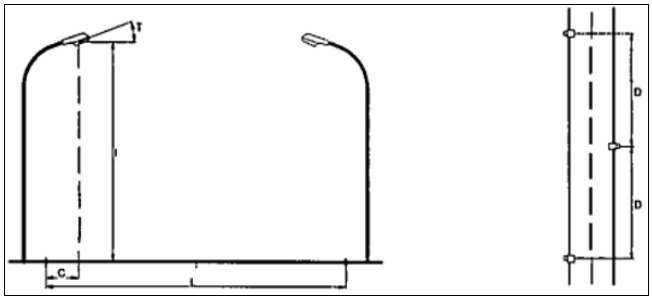

Fig 10: Placement of alternating bilateral lighting [4, p. 31]

- ***Bilateral alternate,*** (Figure 10). In this case the poles supporting the luminaires are arranged on the two sides of the street or public road in the form of a broken line which appears to be made up of several letters Z zig-zagged together.Here it is necessary to pay particular attention to the constancy of the luminance. In this way, the alternation between illuminated and unilluminated (dark, not visible) areas or elements will be avoided;

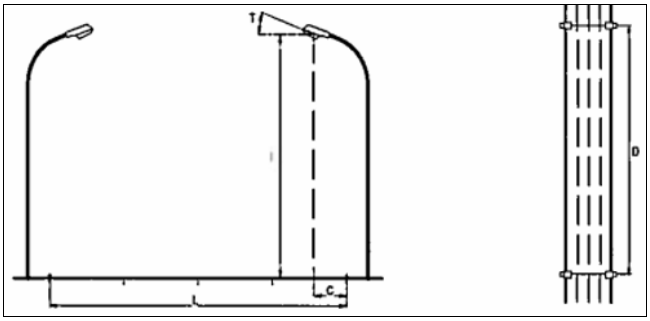

Fig 11: Placement bilateral lighting face to face [4, p. 31]

- ***Bilateral opposite (face to face),*** (Figure 11). În in this case the poles supporting the luminaires are placed on both sides of the street or public road, facing each other. This method of lighting is recommended when the width of the road or street allows it (it is large enough);
- ***Suspended.*** It is a method of street lighting used in particular when the width of the street or public road does not allow it (it is small, insufficient) and the presence of abundant vegetation or buildings does not allow the placement of poles or lighting fixtures on poles;

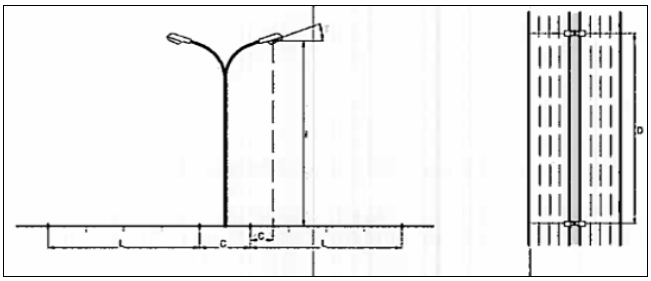

Fig 12: Placement of central lighting (double-braced or double-centered) [4, p. 32]

- ***Central (double-braced or double-centered),*** (Figure 12). It is a method of street lighting in which luminaires are mounted by means of poles in the median zone between the traffic lanes. This method can be considered as a unilateral lighting system for each direction of travel;
- ***Combined (double-braced center and forward facing).*** This method of street lighting can be considered as alternating bilateral lighting for each direction. It is a frequently used solution in the lighting zone of highways with excessively wide freeways (more than three lanes in each direction);
- ***Catenary.*** (Figure 13). In this case, the luminaires are supported by steel cables, which are stretched between the poles located in the median zone between the traffic lanes. This method of street lighting is ideal for narrower highways (two lanes in each direction). The choice of this method is the choice of road and highway designers, taking into account the restrictive requirements in certain areas.

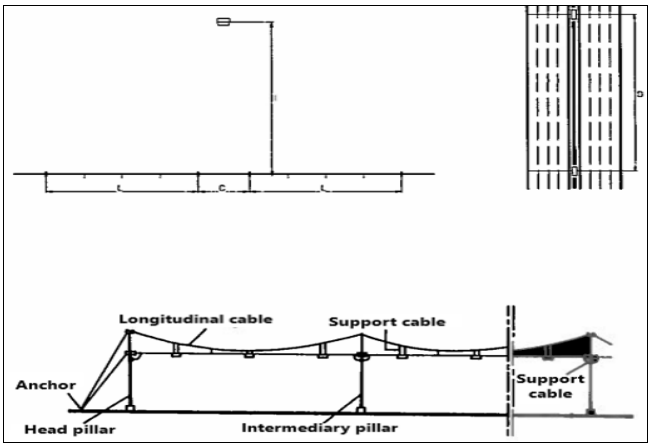

Fig 13: Placement of catenary lighting [4, p. 33]

5. Risk areas involving street lighting

Risk areas are those areas that, in terms of street lighting, belong to arterial roads, where the visual load is high and can cause road events.

The particularities of risk areas derive from the following considerations:

- it is obligatory to illuminate the traffic lanes of road vehicles between two risk areas when these areas are less than one kilometer apart;
- it is recommended to limit the speed of road vehicles in the vicinity of risk areas (at least for one of the conflict participants);
- when there are differences between two adjacent areas with more than one lighting class (e.g. M1 and M4). A transit zone of 150 m may be established within which road users can adapt vehicle speed;
- it is necessary to mutually link (correlate) the street lighting system for risk areas with the other existing areas on the road/street sector (architectural, road, advertising, etc).

Where road vehicle traffic is low, in order to save energy and protect the lighting system, remote street lighting management systems can be introduced in areas at risk of road accidents, whereby variations in luminous flux can be created at hourly intervals. The value of lighting parameters can be set on the basis of traffic studies according to those luminance classes. The imposition of such intelligent street lighting systems is an economic intransigence based on a cost-benefit calculation. In reality, this remote management of street lighting is frequently used in major road junctions which are characterized by high levels of road vehicle traffic, with significant differences in the number of vehicles at known times of day (annual, or at toll stations or border crossings).

In the following, we will present the lighting of the most important road infrastructure elements in Romania.

6. Illumination of intersections of national roads (DN) as well as between national roads and other intersecting public roads

Intersections of national public roads are particularly important stretches of public lighting. The attention of road vehicle drivers when approaching a national road intersection is achieved by [4, pp. 54-55]:

- to increase the lighting level by 50% relative to the highest level of the arterials entering the intersection;
- ifferent colors of light sources can be used for orientation;
- the street lighting targets to be achieved must be in accordance with the Romanian quality standard SR -EN 13201 part II, page 9 in the form of CE classes between CE0 and CE5, with requirements between 50 lx and 7.5 lx average maintained illuminance. The choice of the class will be made one step higher than the step of the artery with the most restrictive conditions (e.g. an intersection with class ME2 and an artery with class ME4 - the intersection will be calculated with class CE1);
- he location of the poles will be as close as possible to the corners of the intersection and in the case of unilateral solutions, the preferred location is on the right side of the road, towards the entrance of the intersection;
- all arterials entering or exiting the intersection must be illuminated for a distance of 150 meters from the entrance/exit to/from the intersection.

Way for the choice of lighting classes for the risk areas on this category of road infrastructure is realized as follows:

- the evaluation index is calculated according to specific parameters (the evaluation index is stipulated in the table in Annex 1 of the Technical Road Bulletin No 2-3/ year VIII/ 2012);
- by determining the lighting class C, the evaluation index score obtained using the data presented in Table 4 is taken;

Table 4: Conditions required to fulfill the criteria of class C [4, p. 55]

Lighting class	Average illuminance for the total area used E in lx	Illuminance uniformity U0 (E)	TI blinding factor	
			High and moderate speed [Km/h]	Low and very low speed [Km/h]
C0	50	0.40	10	15
C1	30	0.40	10	15
C2	20	0.40	10	15
C3	15	0.40	15	20
C4	10	0.40	15	20
C5	7.5	0.40	15	20

Number of lighting class:

$$C = 6 - Vws \quad (2)$$

Careful selection of the appropriate values will generate class numbers between 0 and 5. If the result is not an integer, the lowest whole number will be used. For areas at risk, luminance is the recommended protection criterion. However, where short distances are targeted and other factors prevent the use of luminance criteria, illuminance may be used for part of the risk area or for the whole area. The correspondence between luminance and the mean horizontal illuminance depends on the reflectance of the road surface, a criterion represented by the q0 value. Table 5 shows the relationship between M-classes and C-classes for three values of q0.

Table 5: Comparable classes M and C for three values of q0 [4, p. 56]

Road lighting class M			M1	M2	M3	M4	M4	M6
Average luminance L in cd/m^2			2.0	1.5	1.0	0.75	0.50	0.30
Lighting shading C if q0 = 0.05 cd/m^2/lx			C0	C1	C2	C3	C4	C5
Average illuminance E in lx			50	30	20	15	10	7.5
Lighting shading C if q0 = 0.07 cd/m^2/lx		C0	C1	C2	C3	C4	C5	
Average illuminance E in lx		50	30	20	15	10	7.5	
Lighting shading C if q0 = 0.09 cd/m^2/lx	C0	C1	C2	C3	C4	C5		
Average illuminance E in lx	50	30	20	15	10	7.5		

To correctly interpret the data presented in Table 5, the following example is given: if the most important road leading to the risk area is M4 and q0 = 0.07 cd/m^2/lx, the class is equivalent to C4 and the risk area is recommended to be designed to class C3.

If luminance is used as a criterion to illuminate the risk area, it is important to calculate the glare index *TI*, for the relevant observer positions observing the risk area.

A particular case of intersections is roundabouts. In this case, the lighting system will have to comply with all the requirements presented above, plus the particularities:

- it is forbidden to place lighting poles only inside the central island - lighting will also be provided with poles placed outside the roundabout;

- the posts shall be placed in such a way that the shape of the roundabout can be seen through the guide created. The placement of the poles in line shall be avoided so that the drivers of road vehicles understand the round shape of the roundabout intersection. This is shown in Figure 14.

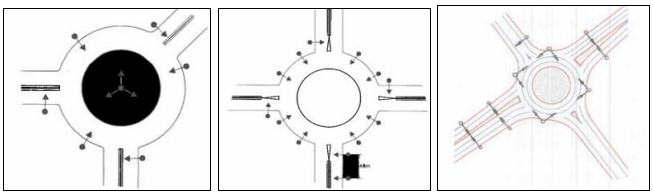

Fig 14: Placement of street lighting poles at roundabout intersections [4, pp. 58-59]

7. Lighting railway level crossings

Railway level crossings are intersections between road and rail arteries. This type of junctions may be equipped with barriers, or only signalized by traffic lights or road signs. Such a lighting system in these areas must ensure special conditions such as [4, p. 53]:

- national roads which is crossed by a railway track shall comply with the requirements for public street lighting according to the Romanian standard SR EN 13201 for a distance of at least 200 m before and after the railway level crossing;
- in this area should be 50% higher than the illuminance level of the traffic artery;
- the guiding of the luminous flux should be done in such a way that the intersection area can be easily observed by users;
- it is recommended to change the light color in this area;
- it is recommended to place markers (flashing lights) with blinking flashing light (red - which means prohibition) to warn users;
- the location of the luminaires shall be as shown in Figure 15.

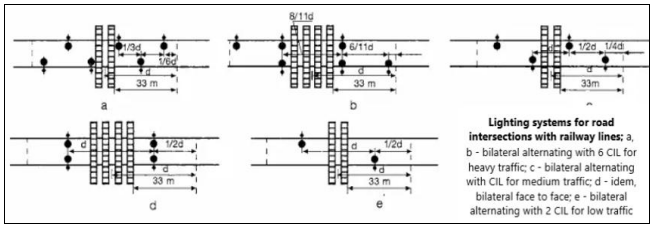

Fig 15: Placement of lights at railway level crossings [5, p. 107], [4, p. 54]

8. Lighting of pedestrian crossings on national roads (DN)

Pedestrian crossings can be found on national roads, in princes, in urban areas (in localities where it is a necessity), or in exceptional cases in parking lots. In these areas it is compulsory, from the point of view of street lighting, that the speed of road vehicles in these areas must be limited to a maximum of 50 km/h according to the road code regulated in Romania by the Emergency Government Ordinance No. 195/2002 on traffic on public roads, with subsequent additions and updates [5].

Regarding pedestrian crossings, an appropriate lighting system should ensure the following specific requirements [4, p. 50]:

- the DN that is crossed by the pedestrian crossing must be illuminated according to the Romanian standard SR EN 13201 for a minimum distance of 200 meters before and after the pedestrian crossing place;
- în the area of the pedestrian crossing shall be at least 50% higher than the illuminance level of the road on which the pedestrian crossing is installed;
- the light flow should be directed in such a way that pedestrians can be observed by drivers;
- is recommended to change the light color;

it is recommended to place flashing light markers (or flashing lights on road signs) to warn drivers.

Positioning luminaires in the pedestrian area shall be realized according to the data shown in Figure 16. When the luminance level is high, the luminaires in this area should be positioned in such a way that a good negative contrast is provided, with pedestrians visible as dark silhouettes against a bright background. The type, location and orientation of the additional luminaires used in relation to the pedestrian crossing should be such that a positive contrast is achieved and that there is no glare that is distracting to drivers. One solution in this respect is to install luminaires at a short distance from the pedestrian crossing point in the direction of the flow of vehicles and direct the light towards the crossing. For two-way public roads, one luminaire should be installed before the pedestrian crossing in each direction of vehicle flow.

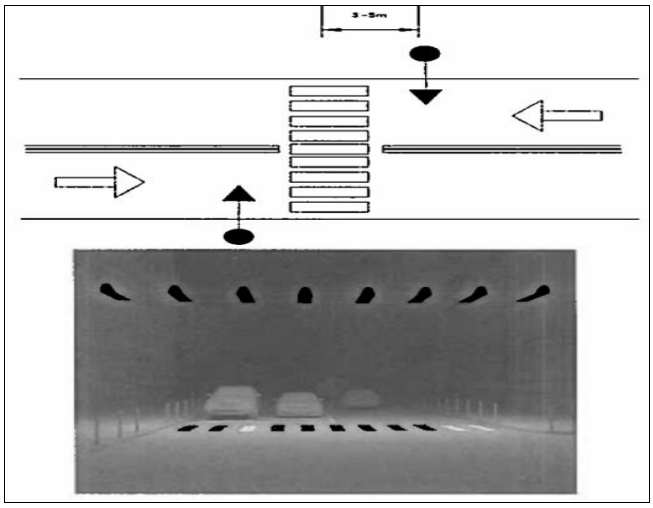

Fig 16: Placement of lighting at pedestrian crossings [4, p. 54]

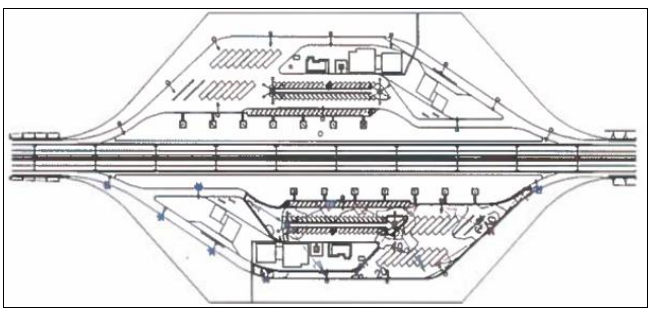

Fig 17: Lighting model of a parking lot [4, p. 61]

9. Lighting of parking spaces

The parking areas for road vehicles on Romania's highways must be equipped with lighting systems that comply with the standards in force. The reason for the lighting of such spaces derives from the need to increase safety and security, but

also from the need to increase visibility when turning around or moving vehicles within them. In the present case, adequate lighting can be provided only by placing the poles supporting the luminaires in the green areas delineated by the curbs so as not to obstruct the drivers of road vehicles when turning, reversing or parking.

The lighting systems can be realized by means of poles with heights of 14-20 m and floodlight batteries, or by means of road lighting poles with heights of 8-10 m and road lighting fixtures. In truck and/or bus/coach parking areas, consideration shall be given to their height and the height of the poles supporting the luminaires shall not be less than 14 m (14-18 m). The color of the light and the light rendering index shall be identical to that of the road arteries. The lighting parameters to be achieved and at the same time respected in motorway parking areas for road vehicles shall be in class *S1:* $E_m > 15$ *lx* and $E_{min} > 5$ *lx*, where E_m is the average illuminance maintained over the surface of the parking area, including its traffic arteries, and E_{min} is the minimum illuminance maintained over the same surface. Similar lighting systems shall be designed and implemented for parking areas in the highway area, as they are also considered at-risk areas.

10. Lighting of road junctions

According to the specific literature, road junctions are also called *Interchanges* and are those intersections of freeways or intersections between highways and DN, which are realized with grade differentials and on-ramps for each direction of the highway or roads.

The risk at these road junctions is due to drivers and is related to orientation and lane changes, slowing down or speeding up, exiting or entering highway traffic flows.

The risk zones of road junctions are determined according to [4, p. 62]:

- an area of 150 m before the point of formation of the special deceleration lane on the traffic artery;
- a 150 m zone after lane closures on arterial roads;
- both arterial roads intersecting the entrance and exit ramps;
- the transfer ramps for motor vehicle traffic from one artery to another, in full.

Areas of risk related to road junctions should be treated as a whole, without differentiation of lighting classes between one area or another.

In this case there are the following solutions concerning public street lighting: placement of high poles equipped with floodlight batteries - a solution mainly adopted when the dimensions of the road junction are relatively small. The height of the poles supporting the luminaires will be between 14-35 m. Poles higher than 20 m should be equipped with access for maintenance and servicing (fire ladder, mobile platform, etc.). The technical and lighting calculations must take account of the differences in level between the traffic arteries, which makes it necessary to install road lighting columns 8-12 m high, equipped with road lighting equipment. The location of these poles should provide a favorable visual guidance for drivers, and it is recommended that they be placed on the outside of bends. The technical and luminance parameters in these areas can be determined in accordance with the Romanian standards SR-EN 13201 - part 2, performance criteria, based on luminance - classes ME (W) 1-5 [4, pp. 62-63].

The way the poles are placed in road junctions is shown in Figure 18.

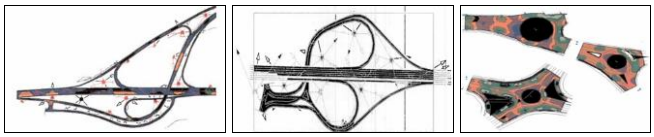

Fig 18: Examples of lighting at road junctions [4, pp. 63-65]

From the analysis of the data presented in Figure 18, it can be seen that the floodlights and their orientation on the high pillars are represented by black arrows, while the colors appearing on the roadways represent isocandela curves (surfaces with the same luminance). As can be seen, apart from the quantitative aspects, qualitative aspects can also be assessed by evaluating the level of glare with factor $TI < 10$, and the lighting fixtures for the lower elevation arteries must be taken into account in terms of glare occurring to users on the higher elevation arteries.

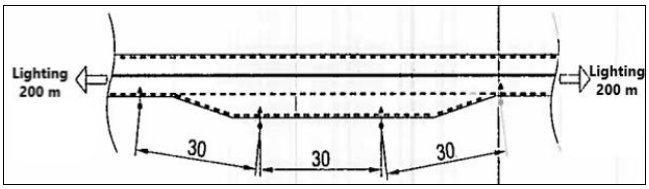

Fig 19: Example of bus station lighting [4, p. 68]

11. Lighting of public transport stations

On extra-urban roads or urban streets, passengers are transported by public transport for certain activities in a centralized mode. They board or alight from or to their destination on means of transport in specially designated areas at the side of the road or street. These spaces are called public transport stations. At the side of the road or street, where they are located, they may or may not be set back from the traffic side of the arterial road on which the means of public transport enters, stops, alights and/or embarks passengers and then merges into the flow of vehicles in that flow, re-entering the first lane to follow its established route. In Romania, the road traffic regulations provide that these means of transportation (buses) have priority at the exit (departure) of a station, in relation to other road vehicles traveling on that road. For this reason, the station intended for buses or other means of public transport (trolleybuses, minibuses, trams, etc.) constitutes a risk area requiring a street lighting system. The lighting system in this case can be realized by means of poles equipped with road lighting equipment placed in an area of at least 200 m before the start of the lane for the bus stop, along its entire length and in an area of 200 m after the end of that lane.

The parameters to be fulfilled are expressed in lighting classes CE0 - CE5 depending on the importance of the traffic artery [4, p. 67].

An example of how to illuminate public transport stations is shown in Figure 19.

12. Lighting of art elements (overpasses, bridges and footbridges)

Overpasses are parts of suspended traffic arteries on which pedestrians or road vehicles cross other roads, streets, railways or other objects suspended.

Bridges are parts of roads or streets that cross waterways, valleys or other natural obstacles.
Footbridges are parts of roads or streets that cross over small natural obstacles.
These are all considered risk areas due to [4, pp. 68-69]:

- narrowing of the entrance roadway - either by eliminating the entrance lane, eliminating the shoulder or reducing the number of lanes;
- increase the effects of a possible accident in the area - the consequences are generally higher compared to a normal area, the possibilities of a chain reaction accident are higher, as there is no possibility of leaving the roadway;
- requent wet and icy conditions when crossing valleys or streams;

the presence of ramps at the entrance or exit of the overpass or from the bridge.

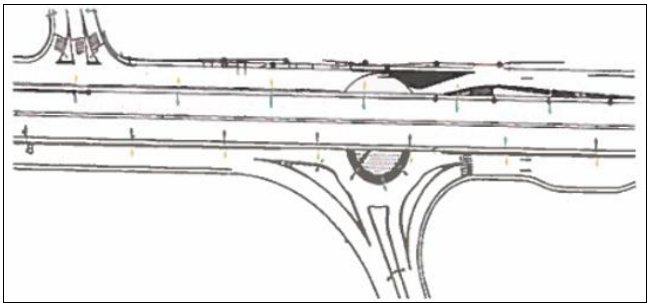

Fig 20: Example of overpass lighting [4, p. 69]

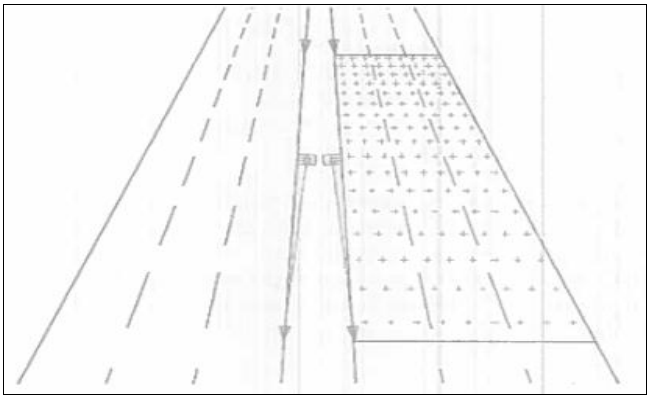

Fig 21: Graphical representation of the risk area for an overpass or bridge [4, p. 69]

According to the international literature, the risk zone in this case is determined and defined by the existence of an overpass or bridge for a length of 100 m. On small bridges or overpasses with ecomplex geometries that may generate accidents, street lighting systems shall be established and implemented in accordance with the provisions of current legislation Figure 20 shows an example of lighting for an overpass and Figure 21 graphically shows a risk zone within an overpass or bridge. Analysis of the data presented in Figure 21 shows that the risk zone is demarcated as the entire overpass or bridge, including any bifurcations, related parking lots, or access ramps, and may also include a 150 m zone before and a 150 m zone after the overpass or bridge. The technical and lighting parameters specific to these areas are laid down in the Romanian quality standard SR EN 13201, part 2 - performance criteria. It is recommended to comply with luminance-dependent criteria (classes ME(W) 1 - ME(W) 5, after which illuminance criteria CE0-CE5 will be applied).

13. Lighting of toll stations

The toll stations in Romania are located on the road infrastructure where payment is required to cross certain objectives (e.g. crossing the bridge over the Danube between Fetești - Cernavodă, on the A2 highway), at river crossings by ferry (e.g. crossing of the Danube by ferry between Călărași Chiciu - Ostrov Silistra Bulgaria; at Galați between Galați and I.C. Brătianu in Tulcea county; between Isaccea and Tulcea, etc), or by ferry (e.g. crossing of the Danube between Turnu Măgurele – Nikopole, Bulgaria), but also at other crossing points. Of all these toll stations, the most modern one, illuminated according to current standards, is the toll station on the A2 highway, at the Fetești - Cernavodă bridge crossing (Figure 22).

Fig 22: Pictures of the Fetești – Cernavodă for crossing on the bridge tool station, A2 -Highway, Roamania

This category of infrastructure objectives that must be provided with road lighting systems also includes land border crossing points (customs points) in Romania, but as of January 1, 2025, our country entered the Schengen area with land borders, and for this reason they have become simple free crossing points of state borders. Customs checks on travelers, goods or motor vehicles are no longer carried out here, the crossing is free. Therefore, the lighting at these border crossing points is only important for guiding the drivers of vehicles transiting through the customs locations to the exits/entrances from/into neighboring countries or Romania.
Delimitation of the area for which lighting is provided [4, p. 71]:

- 150 m before entering the risk area on all traffic arteries - entering the risk area is considered to be the place where the profile of a traffic artery is first changed (e.g. the place where an additional lane is formed in addition to the highway profile, except for pedestrian crossings and railway level crossings for which a distance of 200 m is recommended);
- the entire risk area with possible access roads, crash lanes, or ramps;
- 150 m after the end of the risk zone (the place where the traffic artery returns to the standard profile), (e.g. the place where the last acceleration lane closes and the highway returns to the standardized profile except for pedestrian crossings and railway level crossings for which a distance of 200 m is recommended);
- the whole area under the awnings of the toll stations.

The main characteristics of these toll stations is the gradual deceleration from cruising speed until the road vehicle stops at the toll station. This is regulated by the road traffic regulations in Romania and is done gradually from an appropriate distance to the toll station by limiting the speed of road vehicles. They generate problems for road vehicle drivers to adapt to specific conditions and particular visual loads. Another element of major importance is the need to

orient and choose the direction towards the narrow location through which each vehicle will pass to the toll station, according to the size and gauge and the payment method (for prepayment at a fuel station, or prepayment or later payment by SMS on a GSM device, etc.).

The performance criteria for lighting systems are stipulated in the Romanian quality standard SR EN 13201, part 2 and will take into account luminance and illuminance level.

The complexity of the lighting systems in these areas will allow the following approaches [4, pp. 72-73]:

- will be used poles between 14-35 m high placed on the edge of the area, on which will be placed projector type lighting equipment;
- will be used poles with a height of 8-12 m equipped with road lighting - for small areas or in addition to those with high or very high heights, used for areas of minimum 150 m located at the beginning and end of the risk areas - the area where the roadway has the standard profile;
- under canopy lighting fixtures - floodlights or dedicated recessed floodlight type fixtures providing local lighting in the toll station area;
- traffic guidance/directing lighting on the ground or on structural elements separating toll stations equipped with LED bulbs, other light sources and/or reflective devices with white LED indicators, flashing or continuous on/off.

Lighting under the canopies of the toll stations must be powered by uninterruptible power supply. If traffic studies for these areas show that queues are forming after dark, the lighting system shall be extended to an area correlated to the length of the queue of road vehicles. The extension of the lighting system will be operated (switched) individually by the toll station system by manual or automatic action, as required.

14. Conclusions

During the lifetime of a public lighting system, new requirements may arise, important changes in the parameters initially taken into account may occur, which determines the classification of an area of the illuminated road infrastructure into a different lighting class. That is why specialists in the field, governmental or local authorities must analyze and propose the modification of these street lighting installations through rehabilitation, reconstruction or extension. In this case, the same steps, the same steps, the same steps should be taken in order to find optimal, viable practical solutions for those lighting systems in accordance with the reality of the area or infrastructure element for which the lighting system was designed. Any extensions will strictly comply with the requirements of the legislation and quality standards presented.

In order to prevent certain problems with lighting in at-risk areas, the lighting of intersections, road-rail intersections, pedestrian crossings, it is recommended to install an electronic system for detecting faults and to notify them via GSM communication to a dispatcher. This would facilitate prompt resolution of problems within 24 hours.

At pedestrian crossings, local lighting with additional luminaires should be analyzed by specialists, so that the objective of direct illumination of pedestrians crossing the road on or near the crossing should immediately draw the attention of drivers to the presence of the pedestrian crossing in the immediate vicinity (immediate understanding on the part of the driver that there is a danger of a collision between his vehicle and a potential pedestrian).

At pedestrian crossings the most appropriate luminaires are those with asymmetric light distribution.

In order to avoid confusion and driver error in traffic, it is not recommended to use different light sources at the same road junction.

Given the size of the road junctions, it has been found that they end up requiring large installed powers (due to the floodlight batteries), which generate high electricity consumption. For this reason, it is advisable to install remote management systems to manage electricity consumption. This system should be based on studies carried out by specialists on road traffic at certain times of the night or seasonally, with variations in the luminous flux of the luminaires according to need, and thus lowering the energy consumption.

It is recommended that when authorizing a new station for public transport, it should also be made compulsory to install appropriate lighting in accordance with the Romanian quality standard SR EN 13201.

A system for remote management of electricity consumption will also be integrated into the toll stations in order to save energy. This system will ensure appropriate lighting, in accordance with the standards in force, depending on the volume of traffic of vehicles passing through the toll station.

15. References

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