THE REPUBLIC OF SLOVENIA
MINISTRY OF INFRASTRUCTURE

TECHNICAL SPECIFICATION TSG-211 -XXX: 2025

Pursuant to Article 13 of the Roads Act (Official Gazette of the Republic of Slovenia, Nos 132/2022, 140/22 – ZSDH-1A, 29/23, and 78/23 – ZUNPEOVE) and Article 50(6) of the Railway Safety Act (Official Gazette of the Republic of Slovenia, Nos 30/18 and 54/21), the Minister of Infrastructure issues the following technical specification:

ROAD DESIGN AND TRAFFIC SAFETY

ROAD LIGHTING

TSPI - P.03.410: 2025

Minister of Infrastructure
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Number:

In Ljubljana,

This technical specification P.03.410: 2025 is issued having regard to the information procedure in accordance with Directive (EU) 2015/1535 of the European Parliament and of the Council of 9 September 2015 laying down a procedure for the provision of information in the field of technical regulations and of rules on Information Society services (OJ L 241, 17. 9. 2015, p. 1).

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1 Subject of the technical specification

The technical specification provides professional bases for the design and execution of road lighting on public traffic areas.

2 Definition of terms

The individual terms used in this Technical Specification mean:

Illuminance (in a point of the surface) is the ratio of the luminous flux dΦ_v that falls on an element of the surface on which the point is located and the surface dA of that element. Symbol: E. Unit: lx = lm • m^{-2}.

Luminance (in a given direction, in a given point of actual or imaginary surface) is a quantity defined by the equation:

$$L = \frac{d^2 \Phi_v}{d A \cdot \cos\theta \cdot d\Omega}$$

where d$^2\Phi_v$ is a luminous flux transmitted by an elementary beam when passing through a given point and propagated in the solid angle dΩ in a given direction; dA is the area of the section of that beam in which the point is given; θ is the angle between the perpendicular to that section and the direction of the beam. Symbol: L. Unit: cd • m^{-2} = lm • m^{-2} • sr^{-1}

Average luminance is the arithmetic mean of the luminance at grid points in the computation field.

Overall uniformity of luminance is the quotient of the minimum value of luminance at any point of the computation field and the average luminance.

Longitudinal uniformity of luminance is the quotient of the minimum and maximum luminance value at points in a longitudinal direction along each centre axis of each lane of the grid points.

Edge illuminance ratio is the minimum value obtained from the ratio of the average horizontal illuminance on a longitudinal strip along the edge of the carriageway outside the carriageway to the average horizontal illuminance of the corresponding longitudinal strip on the carriageway.

The threshold increment is the ratio of the average initial luminance of the carriageway and the equivalent initial luminance of the cut-off (see procedure and equations in the SIST EN 13201-3 standard).

Lamp is a device intended to emit, filter or convert light from one or more light sources, including all parts necessary to support, attach and protect the lights and with auxiliary equipment for connection to the power source.

Orientation lighting is the lighting of a public area carried out with one or more lamps which is intended only for basic orientation in the room and is therefore not subject to the requirements of the SIST EN 13201 standard. According to this standard, orientation lighting can be classified in class P7.

3 Symbols and Acronyms

	Unit	Meaning of the marking
E	lx	illuminance
L	cd m^{-2}	luminance

4 Traffic area lighting

Appropriately illuminated traffic areas contribute to traffic safety, visual guidance, reduction of traffic accidents, personal safety, sense of safety, aesthetic enhancement of the space, etc.

The main tasks of road lighting are:

- to ensure the appropriate luminance of the specified parts of traffic areas and the surrounding area during night time,
- to provide easy orientation for motor vehicle drivers,
- to provide visual guidance for all road users,
- to increase the perception and concentration of road users on the accompanying effects from the surrounding area,
- to enable the perception of objects and obstacles on the road,
- to enable the identification of persons in areas with multiple criminal events.

The visual tasks may be different for a user of road surfaces and vary depending on their field of observation. The visual field of observation depends on the speed of users. For pedestrians and (slow) cyclists, the visual field is broad, while for the drivers of speed motor vehicles it is narrow and mostly concentrated on the road and the narrower surroundings. Consequently, depending on the intended users of the traffic areas, the traffic areas can be roughly divided into areas intended for pedestrians and cyclists, as well as into areas intended for motor vehicle drivers.

4.1 Lighting of traffic areas for motor traffic

Good visual perception capability and visual comfort are important for a motor vehicle driver. The driver must see the direction and edge of the carriageway, conflict areas, pedestrian crossings, traffic signs, possible obstacles on the road, etc. in a timely and clear manner, in the case of small angles between the direction of viewing and the traffic surface. The visibility of obstacles is influenced by the contrast between the observed and background, visual acuity, depth of vision or assessment of distance, perception rate, reflectance of the surface, etc.

The criterion used in describing the lighting requirements of surfaces for motor vehicles is luminance. The luminance of the traffic area takes into account the fact that the driver’s visibility depends both on the level of illuminance of the roadway and on the reflection properties of the carriageway surface. As a result, requirements for surfaces for motor vehicles are also indicated based on luminance.

Road lighting therefore allows the driver to see further than the surface illuminated by the car headlights in the dark part of the day, thus improving the driver's visual perception while driving. This reduces night-time driving stress, as the complexity of the observation field is reduced and the driver can have more time to react safely where necessary. In addition to the luminance values of the illuminated road surface, the driver’s visual perception is also affected by the horizontal uniformity of the road surface luminance, the glare of road lamps and also the ambient luminance. Sufficient ambient luminance reduces the contrast between the non-lighted surroundings and the road surface, and the driver is able to detect other road users or obstacles along the road faster (e.g. animals along the road).

The concept of luminance can be used to light traffic areas where there are sufficient distances and higher speeds. The choice of lighting levels of traffic areas for motor traffic defined by lighting classes M is described in the technical report SIST-TP CEN/TR 13201-1.

We cannot use the concept of luminance in conflict areas and in traffic areas for pedestrians and cyclists. In conflict areas, distances are too short, while in traffic areas for pedestrians and cyclists, the traffic speeds are low. The basic criterion used in such situations is horizontal illuminance.

4.2 Lighting of traffic areas for pedestrians, cyclists and slow traffic areas

The lighting of traffic areas for pedestrians and cyclists provides users not only with the safe use of the traffic area, but also creates a pleasant ambient environment in the dark part of the day. Horizontal illuminance is used as a lighting metric quantity to describe the requirements for pedestrian and cyclist traffic areas (and vertical, semi-cylindrical or hemispherical illuminance in certain cases where face recognition is required), as pedestrians' and cyclists' field of vision is wide, their speeds are low and the angle between the direction of vision and the traffic area is large.

Since both the appropriate level of illuminance and the uniformity of illuminance are important for the feeling of personal safety of a pedestrian or cyclist, the visual perception of pedestrians and cyclists is expressed by the average horizontal illuminance $\bar{E}$ and by the minimum horizontal illuminance E_{min}. The choice of lighting levels of traffic areas for pedestrians, cyclists and slow traffic areas defined by lighting classes P is described in the technical report SIST-TP CEN/TR 13201-1.

4.3 Lighting of conflict areas

A conflict area is an area where motor traffic flows cross or where there are overlaps between areas commonly used by other road users (SIST TP CEN TR 13201-1: 2015). Drivers can be warned of an approaching conflict area, if it is illuminated, by increasing the illuminance of the area itself in relation to the illuminance of the surrounding area or the illuminance of the traffic areas leading to the conflict area. Visual tasks for drivers in conflict areas are very specific, as they must react appropriately to the situation at shorter distances and at lower speed, as well as pay attention to several factors at the same time (presence of other vehicles, pedestrians, cyclists, traffic calming devices, etc.). The choice of lighting levels of conflict areas defined by lighting classes C is described in the technical report SIST-TP CEN/TR 13201-1.

5 Principle of determining the lighting class and calculating the necessary lighting parameters

A lighting class is defined as a group of lighting requirements that allow adequate visual perception to individual groups of users of the traffic area, depending on the type of traffic area and the surrounding area. The needs in relation to visual perception may change during the night and also at different seasons of the year, so recommendations for the required lighting properties may also vary at different times.

Depending on the main users and the type of use of the traffic area, three types of lighting classes are distinguished.

M classes are intended for traffic areas for motor vehicles, such as main roads as well as roads in settlements where the average and higher driving speed (>40 km/h) is permitted. The use of M classes on low-driving-speed surfaces is not appropriate. The lighting criteria are based on luminance, general and longitudinal uniformity of luminance. Only pavements or other areas for pedestrians and/or cyclists shall be illuminated on roads in settlements with low to moderate traffic density. These shall be illuminated in accordance with P classes.

C classes are also intended for traffic areas for motor vehicles, but for use in conflict areas, such as roads and streets in shopping centres, more demanding road intersections, roundabouts, and areas where it is not possible or not practicable to calculate the luminance of the carriageway. These classes may also be used for the lighting of pedestrian and cycling areas. The lighting criteria are based on horizontal illuminance as well as uniformity of illuminance.

P classes are intended for pedestrian and cyclist areas for use on pavements and on cycle paths and other traffic areas, which run separately or along the carriageway of the traffic road, in the streets of residential areas, pedestrian areas, car parks, school yards, etc. Lighting criteria are based on horizontal illuminance of the traffic area. The minimum conditions are determined by the average and minimum value of horizontal illuminance. For P classes, **orientation lighting**, used in areas with low number of users and low lighting requirements, is also considered as P7 class.

Three more classes have been added to the three basic lighting classes, with specific requirements for vertical, semi-cylindrical or hemispherical illuminance added.

Due to the requirement for face recognition, the lighting classes of the HS group are based on hemispherical illuminance. The minimum conditions are determined by the average hemispherical illuminance and uniformity of the hemispherical illuminance

SC classes are intended as additional classes in areas where public lighting must ensure the identification of persons and objects, as well as in areas with a higher crime risk, and are based on semi-cylindrical illuminance.

EV classes are intended as additional classes for areas where visual perception of vertical surfaces is required, such as toll stations. The criterion is vertical illuminance.

The design process begins by collecting data on the traffic and construction parameters of the traffic area (road) and other conditions that influence the determination of the lighting class and thus the required luminance or illuminance. **The information necessary to determine the lighting class shall be provided by the responsible project manager in cooperation with the road manager**. Data must be obtained on:

- the speed limit on the road, i.e. on the speed of users of the traffic area;
- the volume of traffic;
- the composition of traffic or road users (motor vehicles, cyclists, pedestrians, etc.);
- the separation of traffic lanes;
- the density of intersections or distance between branches;
- parked vehicles on the side of the road;
- ambient luminance;
- the difficulty of orientation or navigation in the space,
- requirement for face recognition

If increased lighting needs persist for very short periods or are very rare, consideration should be given to the reasonableness of taking into account this situation and if this is not reasonable due to the negligible risk or the negligible contribution of lighting, the situation in the rest of the night shall be taken into account.

5.1 Selection of M class

The lighting classes of group M are intended for traffic areas for motor vehicles on main roads, including, under certain exceptions, on roads in settlements where moderate to high driving speeds (>40 km/h) are permitted. The use of M classes on low-driving-speed surfaces (>40 km/h) is not appropriate. The use of these classes depends on the geometry of the area in question, traffic and time-dependent circumstances. Only pavements or other areas for pedestrians and/or cyclists shall be illuminated on roads in settlements with low to moderate traffic density. These shall be illuminated in accordance with P classes.

Based on the above parameters, according to the procedure described in the technical report SIST-TP CEN/TR 13201-1, Road lighting – Part 1: Guidelines on selection of lighting classes, we select the appropriate lighting class M. This can be done with the help of the data below.

Based on the traffic area data obtained, weighting values are determined. For lighting class M, eight weighting values are obtained, describing the conditions of the traffic area:

Speed

- very high ($v \geq 100$ km/h): the weighting value is 2,
- high (70 km/h < v < 100 km/h): the weighting value is 1,
- moderate (40 km/h < $v \leq 70$ km/h): the weighting value is -1,
- low ($v \leq 40$ km/h): weighting value is -2, (class P shall be used for pedestrian area)

Traffic density

- high (motorway and multi-lane roads in one direction: > 65 % of maximum capacity, other roads: > 45 % of maximum capacity) corresponding to LOS C classes or more: the weighting value is 1,
- medium (motorway and multi-lane roads in one direction: from 35 % to 65 % of maximum capacity, other roads: from 15 % to 45 % of maximum capacity), corresponding to LOS B class: the weighting value is 0,
- low (motorway and multi-lane roads in one direction < 35 % of maximum capacity, other roads: < 15 % of maximum capacity), corresponding to LOS A class: the weighting value is -1,

  NOTE: When determining the capacity of the road and the traffic density, the HCM methodology described in Annex A shall be used. Low traffic density corresponds to LOS A, medium to LOS B and high to LOS C or more.

Traffic composition

- Mixed with a high proportion of motor vehicles: the weighting value is 2
- Mixed: the weighting value is 1
- Motor vehicles only: the weighting value is 0

  NOTE: If there is a separate pavement or a separate bicycle path, pedestrians or cyclists on the road are not taken into account!

Separation of directional carriageways

- no: the weighting value is 1
- yes: the weighting value is 0

  NOTE: In roundabouts, traffic takes place in only one direction, so even in multi-lane roundabouts, we consider that the directional carriageways are separated (weighting value is 0).

Density of intersections/branches

- high (> 3 intersections/km or < 3 km between branches): weighting value is 1
- low (≤ 3 intersections/km or ≥ 3 km between branches): the weighting value is 0

Parked vehicles

- yes: the weighting value is 1
- no: the weighting value is 0

  NOTE: The presence of parked vehicles can cause shadows on the carriageway and otherwise limit the visibility of events and the monitoring of the surrounding environment, thereby reducing traffic safety especially for pedestrians between parked vehicles.

Ambient luminance

- high: the weighting value is 1
- moderate: the weighting value is 0
- low: the weighting value is -1

  NOTE: The ambient luminance affects the design and adjustment of lighting in relation to environmental conditions. This parameter is used to assess the impact of direct or indirect ambient light on the lighting of road infrastructure. Environmental light reduces the contrast between objects and background. High ambient luminance occurs in city centres or densely illuminated areas (e.g. commercial centres, areas with large advertising facilities, advertising panels, LCD screens, areas in city centres where illuminated displays are located). Moderate ambient luminance usually occurs in urban residential areas or peripheral urban parts. Low ambient luminance occurs in rural areas or less illuminated areas, such as roads between settlements or in the natural environment.

Navigational task

- very difficult: the weighting value is 2
- difficult: the weighting value is 1
- easy: the weighting value is 0

  NOTE: Difficult navigation means that the driver needs more visual information to drive safely and reliably. This is usually related to factors such as: complexity of the road (intersections, roundabouts, steep curves, changes in the direction of the carriageway), environmental factors (limited visibility or pedestrian crossings), high density of traffic signs, and a lack of natural reference points (for example, trees or buildings along the road). However, easy navigation describes situations where the driver needs less visual information because driving is easy and predictable. This includes straight, long sections of roads with no significant changes in direction or complex elements, roads with a limited number of signs and markings, areas with natural reference points to assist the driver in orientation.

Using the above criteria, we select for each parameter the appropriate option and read the appropriate weighting value. All eight weighting values are added up and the appropriate lighting class M is calculated from the equation:

$$Appropriate\,lighting\,class\,M = 6 - \sum_{i=1}^{8} weighting\,value_i$$

If the sum of the weighting values is < 0, lighting class M6 shall be used. If the sum of the weighting values is ≥ 6, lighting class M1 shall be used.

If the sum of the weighting values is < -1 during the maximum traffic density time (morning and afternoon peak in winter), consider switching off road lighting in late night hours (22:00 to 5:00 in the morning)

Selection of M class according to the hour of the day

The needs in relation to visual perception may change during the night and also at different seasons of the year, so recommendations for the required lighting properties may also vary at different times. Since the traffic density changes during the course of the day, and on certain roads also the traffic composition (no cyclists are expected during night time between 22:00 and 5:00) and the ambient luminance, lighting classes also change. The table below shows an example of a selection of class M for such a road where the time zones are:

Δt_1 time from lighting activation to the end of the afternoon traffic peak (only in winter time)

Δt_2 time from the end of the afternoon traffic peak to 22:00

Δt_3 time from 22:00 to 5:00 in the morning

Δt_4 time from 5:00 until the end of the morning peak traffic (only during winter time)

In the case of a road, parameters have been identified which do not change:

- speed: 50 km/h (weighting value: -1)
- traffic composition: motor vehicles only (weighting value: 0)
- separation of directional carriageways: no (weighting value: 1)
- density of intersections: high (weighting value: 1)
- presence of parked vehicles: yes (weighting value: 1)
- navigational task: easy (weighting value: 0)

And the parameters that change:

- traffic density: high in the afternoon and morning peak (weighting value: 1), medium from the afternoon peak to 22:00 (weighting value: 0), and low during night time, (weighting value: -1)
- ambient luminance: during night time (from 22:00 to 5:00, advertising signs in the surrounding area are switched off and the luminance is moderate (weighting value: 0), and high during the rest of the time (weighting values: 1).

Based on the data obtained, the sum of the weighting values for each time period can be used to determine the lighting class.

Table 1: Time intervals and selected lighting classes

Time interval	Time	Sum of weighting values	ST class
Δt_1	up to 18:00	3	M3
Δt_2	18:00 to 22:00	2	M4
Δt_3	22:00 to 5:00	0	M6
Δt_4	after 5:00	3	M3

5.2 Selection of C class

The lighting classes of group C are intended to be used in conflict areas in roads where most of the traffic consists of motor traffic. Conflict areas are those where motor vehicle traffic flows cross or flow into areas intended for pedestrians, cyclists or other road users. Areas where the geometry of the road changes, e.g. reduction of the number of traffic lanes, narrowing of the lane or width of the carriageway, shall also be considered as conflict areas. In conflict areas, there is an increased chance of collisions between vehicles, between vehicles and pedestrians, cyclists and other road users and/or between vehicles and fixed obstacles.

Based on the above parameters, according to the procedure described in the technical report SIST-TP CEN/TR 13201-1, Road lighting – Part 1: Guidelines on selection of lighting classes, we select the appropriate lighting class C. This can be done with the help of the data below.

Based on the traffic area data obtained, weighting values are determined. For lighting class C there are seven weighting values, describing the conditions of the traffic area:
Speed

- very high ($v \geq 100$ km/h): the weighting value is 3,
- high (70 km/h < v < 100 km/h): the weighting value is 2,
- moderate (40 km/h < $v \leq$ 70 km/h): the weighting value is 0,
- low ($v \leq$ 40 km/h): the weighting value is -1,

Traffic density

- high: the weighting value is 1,
- medium: the weighting value is 0,
- low: the weighting value is -1,

Traffic composition

- Mixed with a high proportion of motor vehicles: the weighting value is 2
- Mixed: the weighting value is 1
- Motor vehicles only: the weighting value is 0

Separation of directional carriageways

- no: the weighting value is 1
- yes: the weighting value is 0

Parked vehicles

- yes: the weighting value is 1
- no: the weighting value is 0

NOTE: The presence of parked vehicles can cause shadows on the carriageway and otherwise limit the visibility of events and the monitoring of the surrounding environment, thereby reducing traffic safety especially for pedestrians between parked vehicles.

Ambient luminance

- high: the weighting value is 1
- moderate: the weighting value is 0
- low: the weighting value is -1

NOTE: The ambient luminance affects the design and adjustment of lighting in relation to environmental conditions. This parameter is used to assess the impact of direct or indirect ambient light on the illuminance of road infrastructure. Environmental light reduces the contrast between objects and background. High ambient luminance occurs in city centres or densely illuminated areas (e.g. commercial centres, areas with large advertising facilities, advertising panels, LCD screens, areas in city centres where illuminated displays are located). Moderate ambient luminance usually occurs in urban residential areas or peripheral urban parts. Low ambient luminance occurs in rural areas or less illuminated areas, such as roads between settlements or in the natural environment.

Navigational task

- very difficult: the weighting value is 2
- difficult: the weighting value is 1
- easy: the weighting value is 0

NOTE: Difficult navigation means that the driver needs more visual information to drive safely and reliably. This is usually related to factors such as: complexity of the road (intersections, roundabouts, steep curves, changes in the direction of the carriageway), environmental factors (limited visibility or pedestrian crossings), high density of traffic signs, and a lack of natural reference points (for example, trees or buildings along the road). However, easy navigation describes situations where the driver needs less visual information because driving is easy and predictable. This includes straight, long sections of roads with no significant changes in direction or complex elements, roads with a limited number of signs and markings, areas with natural reference points to assist the driver in orientation.

Using the above criteria, we select for each parameter the appropriate option and read the appropriate weighting value. All seven weighting values are added up and the appropriate lighting class C is calculated from the equation:

$$\text{Appropriate lighting class } C = 6 - \sum_{i=1}^{7} \text{weighting value}_i$$

If the sum of the weighting values is ≤ 0, lighting class C5 shall be used. If the sum of the weighting values is ≥ 6, lighting class C1 shall be used.

In many cases, before and after the conflict area, the road is illuminated in class M. The illuminance of the conflict area must be aligned with the illuminance of the road before and after the conflict area. The illuminance level in the conflict area shall not be lower than the lighting class before and after the conflict area and on connecting roads. In any case, it is recommended that the lighting class in the conflict area is one class higher than the highest lighting class of roads flowing into it.

Since roads of class M are designed according to the required luminance and conflict areas according to the required illuminance, the luminous intensity of the carriageway must be taken into account when selecting a comparable class.

Based on Table 2 and consideration of luminous intensity (represented by the factor Q_0), we determine the appropriate lighting class C equivalent to the M class used. For example, if the road (Q_0 = 0.06 cd·m^{-2}·lx^{-1}) is illuminated according to class M3, the corresponding C class is C3.

Table 2: Comparable lighting classes M and C

Lighting class M			M1	M2	M3	M4	M5	M6
Lighting class C, if Q_0 ≤ 0.05 cd·m^{-2}·lx^{-1}			C0	C1	C2	C3	C4	C5
Lighting class C, if 0.05 cd·m^{-2}·lx^{-1}< Q_0 ≤ 0.08 cd·m^{-2}·lx^{-1}		C0	C1	C2	C3	C4	C5	C5
Lighting class C, if Q_0 > 0.08 cd·m^{-2}·lx^{-1}	C0	C1	C2	C3	C4	C5	C5	C5

The factor Q_0 or luminous intensity used in Table 2 indicates the gloss of the road surface, i.e. whether the surface reflects more or less light. The higher value of luminous intensity means that the surface reflects more light and, as a result, appears brighter. The size of the factor Q_0 depends on the reflecting properties of the road surface, both in terms of diffuse reflectance and in terms of directional reflectance. Taking into account the classification of the road surface according to its reflectance in four R classes (CIE publications 66:1984 and 144:2001), the size Q_0 for surfaces in class R1 is about 0.10 cd·m^{-2}·lx^{-1}, in classes R2 and R3 the value Q_0 is about 0.07 cd·m^{-2}·lx^{-1} and in class R4 the value Q_0 is about 0.08 cd·m^{-2}·lx^{-1}. In doing so, road surfaces in different classes can be described as:

- R1: the road surface reflects the light in a diffuse way;
- R2: the road surface reflects the light in a poorly diffused way;
- R3: the road surface reflects the light in a poorly directional way;
- R4: the road surface reflects the light in a directional way.

Some indicative luminous intensity values are given in the table below.

Table 3: Table of luminous intensity for the most common carriageway materials [5]

R table	Q_0 [cd·m^{-2}·lx^{-1}]	Carriageway material
C1	0.10	CIE C1 – concrete
C2	0.07	CIE C2 – asphalt
N1	0.10	CIE class = 1, very diffuse
N2	0.07	CIE class = 2, concrete
N3	0.07	CIE class = 3, asphalt
N4	0.10	CIE class = 4, smooth asphalt
R1	0.10	IES RP-8 Properties of mostly diffuse reflectance, characteristic of Portland cement or asphalt surface with at least 15 % aggregates composed of artificial bleaching aggregates.
R2	0.07	IES RP-8 Combination of diffuse and mirror reflectance, characteristic of asphalt surfaces with aggregate consisting of at least 60 % gravel size greater than 10 mm. Also asphalt surfaces consisting of 10 % - 15 % artificial bleach in the aggregate mixture.
R3	0.07	IES RP-8 Slightly mirror reflection, characteristic of asphalt surfaces with dark aggregates, coarse texture and a few months of use. This surface is common in the USA.
R4	0.08	IES RP-8 Mostly mirror surface, characteristic of a very smooth texture of asphalt.
W1	0.11	CIE W1 – wet road surface
W2	0.15	CIE W2 – wet road surface
W3	0.21	CIE W3 – wet road surface
W4	0.25	CIE W4 – wet road surface

5.3 Selection of P class

Lighting classes P are intended for pedestrian and cyclist areas running separately or along the carriageway of the thoroughfare or road (pavements) in the settlement, and for areas for motor vehicle drivers at low speeds on roads in settlements or parking areas.

NOTE: If lamps of lighting class P, which have a much wider angle of light emission, are used for pedestrian areas along the carriageway of a thoroughfare or a road, special care must be taken in the choice of lamp (optics) to ensure that they do not cause glare to motor vehicle drivers.

Based on the above parameters, according to the procedure described in the technical report SIST-TP CEN/TR 13201-1, Road lighting – Part 1: Guidelines for the selection of lighting classes, we select the appropriate lighting class P.

Based on the traffic area data obtained, weighting values are determined. For lighting class P there are five weighting values, describing the conditions of the traffic area:

Speed

- low ($v \leq 40$ km/h): the weighting value is 1,
- very low (walking): the weighting value is 0,

Area traffic

- very occupied: the weighing value is 1,
- normal: the weighting value is 0,
- calm: the weighting value is -1,

NOTE: In the case of pavement lighting, the number of pedestrians on the pavement shall be taken into account, not the number of motor vehicles on the road!

Traffic composition

- Pedestrians, cyclists and motor traffic: the weighting value is 2
- Pedestrians and motor traffic: the weighing value is 1
- Pedestrians and cyclists only: the weighting value is 1
- Only pedestrians: the weighting value is 0
- Only cyclists: weighting value is 0

NOTE: On local roads and areas on which there are no motor vehicles, a weighting value of 0 or 1 shall be used!

Parked vehicles

- yes: the weighting value is 1
- no: the weighting value is 0

NOTE: The presence of parked vehicles can cause shadows on the carriageway and otherwise limit the visibility of events and the monitoring of the surrounding environment, thereby reducing traffic safety especially for pedestrians between parked vehicles.

Ambient luminance

- high: the weighting value is 1
- moderate: the weighting value is 0
- low: the weighting value is -1

NOTE: The ambient luminance affects the design and adjustment of lighting in relation to environmental conditions. This parameter is used to assess the impact of direct or indirect ambient light on the illuminance of road infrastructure. Environmental light reduces the contrast between objects and background. High ambient luminance occurs in city centres or densely illuminated areas (e.g. commercial centres, areas with large advertising facilities, advertising panels, LCD screens, areas in city centres where illuminated displays are located). Moderate ambient luminance usually occurs in urban residential areas or peripheral urban parts. Low ambient luminance occurs in rural areas or less illuminated areas, such as roads between settlements or in the natural environment.

Facial recognition

- required: additional requirements for hemispherical illuminance
- not required: no additional requirements

Using the above criteria, we select for each parameter the appropriate option and read the appropriate weighting value. All five weighting values are added up and the appropriate lighting class P is calculated from the equation:

$$Appropriate\,lighting\,class\;P = 6 - \sum_{i=1}^{5} weighting\,value_i$$

If the sum of the weighted values is < 0, lighting class P7 (orientation lighting) shall be used. If the sum of the weighting values is ≥ 6, lighting class P1 shall be used.

If the sum of the weighting values is < -1, the reasonableness of installing road lighting should be considered.

Technical report SIST-TP CEN/TR 13201-1, Road lighting – Part 1: Guidelines on selection of lighting classes [2] also provides an alternative way to determine the lighting class P, which can be used instead of the one described above.

5.4 Examples of the selection of lighting class

To help understand the process of selecting the appropriate lighting class and the appropriate horizontal illuminance, some examples are given below. When determining the lighting class, the traffic density is taken into account in a simplified manner, where the structure of the vehicles is not taken into account, but only the number. The traffic density with all details may be taken into account according to Appendix A.

5.4.1 Examples of determining lighting class M

5.4.1.1 Example 1

Regional road R2 in the settlement. This is one of the busiest sections of the road and the road surface also needs to be illuminated. Along the road there is a pedestrian walkway (pavement), but since the road is in the settlement, it can be expected that during the morning and afternoon peaks and in the evening, traffic consists of motor vehicles, mopeds and bicycles. The road also has several intersections or turn-offs to houses. The remaining parameters can be seen in the figure below. A graph of the average daily loads is produced from the data of the automatic traffic counter on this road. On the basis of the loads, the sum of the weighting values for each time period is calculated.

Figure 1: Traffic density overview for the road section under consideration

Figure 2: The congested part of the road within the settlement that needs to be illuminated.

The selection of lighting class begins by determining the weighting values of:

- speed: moderate (50 km/h), weighting value = -1;
- traffic density: low, weighting value = -1,
- traffic composition: mixed, weighting value = 1;
- separate directional carriageways: no, weighting value = 1;
- density of intersections: high, weighting value = 1;
- parked vehicles: none, weighting value = 0;
- ambient luminance: low: weighting value = -1;
- navigational task: easy, weighting value = 0.

Then add up all weighting values:

$$\sum_{i=1}^{8} weighting\, value_i = -1-1+1+1+1+0-1+0=0$$

and determine the appropriate lighting class by subtracting the sum of the weighting values from 6:

$$\text{lighting class M} = 6 - \sum_{i=1}^{8} weighting\, value_i$$

$$\text{M class} = 6 - \sum_{i=1}^{8} weighting\, value_i = 6 - 0 = 6$$

For the lighting of the road in this case, the lighting class shall be M6. As there is less traffic in the evening than in the morning and afternoon peak hours, a 30 % reduction in luminance according to class M6 is allowed. At night there is even less traffic and a 50 % reduction in luminance according to class M6 is allowed.

5.4.1.2 Example 2

In this case, it is a category G1 urban approach road, with two lanes in each direction.

This is one of the busiest sections of the road and the road surface also needs to be illuminated. There is a green lane along the road, with a pedestrian walkway and a separate cycle track. Only motor vehicles are present on the road. The speed limit is 70 km/h. A graph of the average daily loads is produced from the data of the automatic traffic counter on this road. On the basis of the loads, the sum of the weighting values for each time period is calculated.

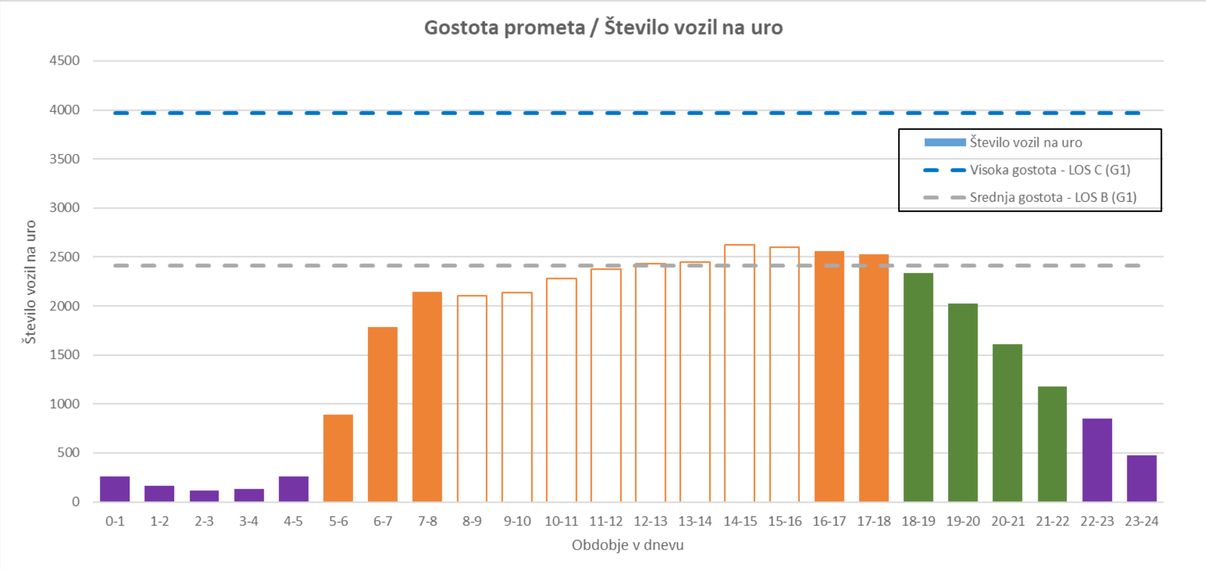


Figure 3: Traffic density overview for the road section under consideration

Figure 4. Example of the urban approach road

The selection of lighting class begins by determining the weighting values of:

- speed: moderate (70 km/h), weighting value = -1;
- traffic density:
  - afternoon peak: medium, weighting value = 0,
  - morning peak, evening and night time: low, weighting value = -1,
- traffic composition: motor traffic only, weighting value = 0;
- separate directional carriageways: yes, weighting value = 0;
- density of intersections: high, weighting value = 1;
- parked vehicles: none, weighting value = 0;
- ambient luminance: low: weighting value = -1;
- navigational task: easy, weighting value = 0.

Then add up all weighting values:

- afternoon peak:

$$\sum_{i=1}^{8} weighting\,value_i = -1+0+0+0+1+0-1+0=-1$$

- morning peak, evening, night time:

$$\sum_{i=1}^{8} weighting\,value_i = -1-1+0+0+1+0-1+0=-2$$

and determine the appropriate lighting class by subtracting the sum of the weighting values from 6:

$$\text{lighting class M} = 6 - \sum_{i=1}^{8} weighting\,value_i$$

- afternoon peak:

$$\text{M class} = 6 - \sum_{i=1}^{8} weighting\,value_i = 6+1 = ¿\,M6$$

- morning peak, evening, night time:

$$\text{M class} = 6 - \sum_{i=1}^{8} weighting\,value_i = 6+2 = ¿\,M6$$

For the lighting of the road during peak load in this case, the lighting class shall be M6. As there is less traffic in the morning peak and in the evening than in the afternoon peak, a 30 % reduction in luminance according to class M6 is allowed. At night there is even less traffic and a 50 % reduction in luminance according to class M6 is allowed.

5.4.2 Examples of determining lighting class C

5.4.2.1 Example 1:

In this case, a pedestrian crossing is on a category G2 road in a settlement where the speed is limited to 50 km/h. The road has a pavement in front of and behind the crossing. There is no cycle path, so motor vehicles and cyclists can be expected on the road. Road lighting is in front of and behind the crossing. A graph of the average daily loads is produced from the data of the automatic traffic counter on this road. On the basis of the loads, the sum of the weighting values for each time period is calculated.

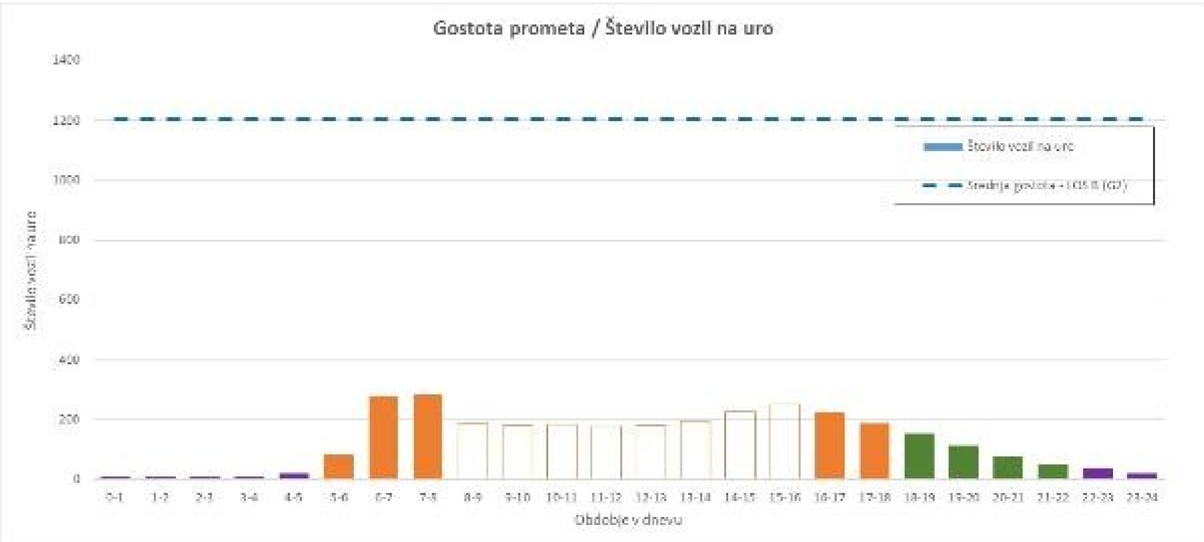


Figure 4: Traffic density overview for the road section under consideration

Figure 5. Pedestrian crossing on the road through the settlement

The selection of lighting class begins by determining the weighting values of:

- speed: moderate (50 km/h), weighting value = 0;
- traffic density: low, weighting value = -1
- traffic composition: mixed, weighting value = 1;
- separate directional carriageways: yes, weighting value = 0;
- parked vehicles: none, weighting value = 0;
- ambient luminance: moderate: weighting value = 0;
- navigational task: easy, weighting value = 0.

Then add up all weighting values:

$$\sum_{i=1}^{7} weighting\ value_i = 0-1+1+0+0+0+0=0$$

and determine the appropriate lighting class by subtracting the sum of the weighting values from 6:

$$\text{lighting class C} = 6 - \sum_{i=1}^{7} weighting\ value_i$$

$$\text{C class} = 6 - \sum_{i=1}^{7} weighting\,value_i = 6 - 0 = 5$$ (if sum is ≤0, class C5 shall be selected)

For the lighting of the road during peak load in this case, the lighting class shall be C5. As there is less traffic in the afternoon peak and in the evening than in the morning peak, a 30 % reduction in luminance according to class C5 is allowed. At night there is even less traffic and a 50 % reduction in luminance according to class C5 is allowed.

5.4.2.2 Example 2

In this case, it is a roundabout on a category G2 road outside the settlement. The speed is limited to 50 km/h. The cycle path is separate so that only motor vehicles can be expected on the road. There is no road lighting in front of and behind the roundabout. A graph of the average daily loads is produced from the data of the automatic traffic counter on this road. On the basis of the loads, the sum of the weighting values for each time period is calculated.

Figure 5: Traffic density overview for the road section under consideration

Figure 5. Roundabout outside the settlement

The selection of lighting class begins by determining the weighting values of:

- speed: moderate (50 km/h), weighting value = 0;
- traffic density: low, weighting value = -1,
- traffic composition: motor traffic only, weighting value = 0;
- separate directional carriageways: yes (traffic in the roundabout takes place only in one direction, so even in roundabouts with several lanes it is considered that directional carriageways are separated), weighting value = 0;
- parked vehicles: none, weighting value = 0;
- ambient luminance: moderate: weighting value = 0;
- navigational task: easy, weighting value = 0.

Then add up all weighting values:

$$\sum_{i=1}^{7} weighting\, value_i = 0-1+0+0+0+0+0=-1$$

and determine the appropriate lighting class by subtracting the sum of the weighting values from 6:

$$\text{lighting class C} = 6 - \sum_{i=1}^{7} weighting\, value_i$$

C class = 6 – $\sum_{i=1}^{7} weighting\, value_i = 6-(-1)=5$ (if sum is ≤0, class C5 shall be selected)

In this case, the road lighting corresponds to lighting class C5 during the morning and afternoon peak hours. As there is less traffic in the evening than in the morning and afternoon peak hours, a 30 % reduction in luminance according to class C5 is allowed. At night there is even less traffic and a 50 % reduction in luminance according to class C5 is allowed.

5.4.3 Examples of determining lighting class P

5.4.3.1 Example 1

In this case, it is the lighting of a pedestrian lane on the carriageway of an uncongested road in a settlement where the speed limit is 50 km/h.

Figure 5. Pedestrian lane on the carriageway of an uncongested road in a settlement

The selection of lighting class begins by determining the weighting values of:

- speed: low (walking), weighting value = 0;
- area traffic: calm, weighting value = -1,
- traffic composition: mixed traffic, weighting value = 2; (because the pedestrian lane is not denivelated)
- parked vehicles: none, weighting value = 0;
- ambient luminance: low, weighting value = -1;
- Facial recognition: not necessary, no additional requirements.

Then add up all weighting values:

$$\sum_{i=1}^{5} weighting\,value_i = 0-1+2+0-1=0$$

and determine the appropriate lighting class by subtracting the sum of the weighting values from 6:

$$\text{lighting class P} = 6 - \sum_{i=1}^{5} weighting\,value_i$$

$$\text{P class} = 6 - \sum_{i=1}^{5} weighting\,value_i = 6 - (0) = 6$$

In accordance with the procedure described in the standard SIST EN 13201-1, a lighting class P6 would be appropriate for pedestrian lane lighting in this case. If the pedestrian lane was denivelated, only pedestrians would be taken into account in the traffic composition and the sum of the weighted value would be -2. Where the sum of the weighted values is less than 0, the surface may be illuminated in class P7, that is, by means of orientation lighting.

5.4.3.2 Example 2

In this case, it is the illumination of the main square in the old town centre, which is blocked by submersible bollards, but motor traffic is not banned. The area is marked with a sign for the shared traffic space area.

Figure 5. Example of the main square in the town

The selection of lighting class begins by determining the weighting values of:

- speed: low (<40 km/h), weighting value = 1;
- area traffic: normal, weighting value = 0,
- traffic composition: pedestrians, cyclists and motorised traffic (mopeds, e-bikes, e-scooters), weighting value = 2;
- parked vehicles: none, weighting value = 0;
- ambient luminance: normal, weighting value = 0;
- facial recognition: desirable, see additional requirements.

Then add up all weighting values:

$$\sum_{i=1}^{5} weighting\,value_i = 1+0+2+0+0=3$$

and determine the appropriate lighting class by subtracting the sum of the weighting values from 6:

$$\text{lighting class P} = 6 - \sum_{i=1}^{5} weighting\,value_i$$

$$\text{P class} = 6 - \sum_{i=1}^{5} weighting\,value_i = 6-3=3$$

In accordance with the procedure described in the SIST EN 13201-1 standard, we would choose a lighting class P3 for the illumination of the square in the old town centre. Since in the night-time the occupancy decreases as well as ambient luminance, P5 class may be selected from 22:00 to 5:00.

6 Luminous flux reductions and switching off lighting

Conditions on traffic areas change over the course of a night (or a week or a year), which also affects lighting needs. The values of the weighting parameters on the basis of which lighting classes are determined are also being changed. The lighting shall be adapted to the actual conditions of the traffic area in such a way that, in conditions where the areas have a negligible number of road users and there are no specific hazards, the lighting can be switched off and where the lighting still makes sense, the luminous flux shall be reduced

6.1 Reductions of luminous flux and operating regime

The quality parameters of road lighting depend on the selected lighting class. The selection of the lighting class is also influenced by parameters that change during the day or week. Thus, on the selected section of the road during the day, we can have three different lighting classes.

Given that luminance and illuminance are the most important parameters of road lighting quality and that the level of luminance and illuminance is dependent on the selected lighting class, it is necessary to adjust the luminous flux of the lamps during the day.

The SIST-TP CEN/TR 13201-1: 2015 states that the choice of lighting class depends on the following parameters:

- traffic speed
- traffic density
- traffic composition
- separation of directional carriageways
- density of intersections
- parked vehicles
- ambient luminance
- navigational tasks

As the density and composition of traffic and, in certain locations, the ambient luminance change during the course of the day, these are key parameters that influence the reduction of the luminous flux of lamps.

Depending on the vehicle density and taking into account that during the longest night in winter the road lighting is switched on around 16:00 and switched off at 8:00, the dark part of the day when the road lighting lamps are lit can be divided into 4 intervals, namely:

- 16:00 to 18:00
- 18:00 to 22:00
- 22:00 to 5:00
- 5:00 to 8:00

Figure 6: Example of distribution of the number of vehicles per day

Data on the density of vehicles may be obtained from automatic traffic meters for the individual time period of the day.

As can be seen from the graph above, the vehicle density varies greatly during the day and the luminance or illuminance of the road must also be adjusted to this traffic density.

According to SIST-TP CEN/TR 13201-1: 2015, the traffic density also influences the selection of lighting classes M and C. For lighting classes M, high traffic density is defined when 65 % of the maximum capacity of a motorway or multi-lane road in one direction is exceeded and 45 % of the maximum capacity of single-lane roads in one direction is exceeded. The mean traffic density is when the load is between 35 % and 65 % of the maximum capacity of a motorway or multi-lane road or between 15 % and 45 % of the maximum capacity for single-lane roads. Low traffic density can be assumed when a motorway or multi-lane road is loaded with less than 35 % of the maximum capacity, and a single-lane road is loaded with less than 15 % of the maximum capacity. For lighting classes C, the traffic density is not specifically defined. Since roads or road sections in lighting class C are mostly “surrounded” with roads in lighting class M, it is sufficient to select an appropriate lighting class M for the (priority) road before the conflict area and then according to SIST-TP CEN/TR 13201-1: 2015 select the appropriate class C according to the luminous intensity of the carriageway.

Table 4: Extract from the table for the determination of lighting class M (SIST-TP CEN/TR 13201-1: 2015)

		Motorways, multi-lane roads	Roads with one lane	Weighting value
Traffic density	High	> 65 % of maximum capacity	> 45 % of maximum capacity	1
	Medium	from 35 % to 65 % of maximum capacity	from 15 % to 45 % of maximum capacity	0
	Low	< 35 % of maximum capacity	< 15 % of maximum capacity	-1

Table 5: Extract from the table for the determination of lighting class C (SIST-TP CEN/TR 13201-1: 2015)

		Weighting value
Traffic density	High	1
	Medium	0
	Low	-1

Technical report SIST-TP CEN/TR 13201-1: 2015 does not indicate the method for calculating the capacity of the road, nor does it justify the stated limits for the different loads of the road. Based on the analysis prepared by the Faculty of Maritime Studies and Transport (see Annex A), the maximum capacity as well as the traffic density can be determined using the level of service according to the HCM (Highway Capacity Manual [A2]) methodology. The HCM distinguishes 7 levels of service. Levels of service LOS) are divided into classes from A to F, where A represents free traffic flow, B reasonably free traffic flow or steady traffic, C stable flow, at or near free flow, D steady traffic at high density, which is already approaching unstable flow, E unstable traffic flow and F forced or breakdown traffic flow with congestion. Based on the descriptions given in Annex A, it can be concluded that the road is already over capacity at levels of service D and above. According to this methodology, the limit between the levels of service C and D can therefore be determined as the maximum capacity of the road. According to this methodology, level of service A represents low traffic density and level of service B represents moderate traffic density. However, when the number of vehicles exceeds the limit between the levels of service B and C, the road has a high vehicle density. Furthermore, the levels of service C and D can be considered to be high density, and E and F to be extremely high density.

Since the methodology for calculating road capacity and traffic density according to the HCM is well founded and frequently verified in practice, levels of service are used to determine traffic density, and not percentage limits according to the road capacity as given in the technical report. All cases in this document are also made by determining the traffic density on the basis of levels of service from the HCM. The Table 6 summarises the input data for calculating the free-flow speeds and the limits between the low and medium and the medium and high traffic densities for standard road categories.

Table 6: Input data and the limits between the low and medium and the medium and high traffic densities for standard road categories (the unit for traffic density is "vehicles per traffic lane")

	typical lane width	No. of lanes/ direction	min. radius (m)	maximum curvature (rad/m)	average curvature (rad/m)	edge strip (m)	shoulder (m)	shoulder + kerb (m)	*FFS* (km/h)	Low traffic density to flow (LOS A)	Medium traffic density to flow (LOS B)	Road capacity (LOS C)
AC	3.75	2				2.5	1	3.5	129	905	1420	2064
HC	3.5	2				2.5	1	3.5	95	665	1045	1520
G1	3.5	1	60	0.017	0.0017	0.5	1	1.5	90	630	990	1442
G2	3	1	25	0.040	0.0040	0.25	1	1.25	86	600	945	1378
R1	3	1	20	0.050	0.0050	0.25	1	1.25	85	590	930	1354
R2	3	1	20	0.050	0.0050	0.25	1	1.25	83	580	915	1331
R3	3	1	17	0.059	0.0059	0.25	1	1.25	80	565	885	1286
RT	2.75	1	10	0.100	0.0200	0	0.75	0.75	58	410	640	934

Based on the specified maximum capacity and limit values for medium and high traffic density, hourly values for the number of vehicles per lane for the standard road categories are determined. Because certain roads of category G1 and G2 appear as roads with one or two lanes (in the same direction), these options are separated in Table 7.

Table 7: Limit values for the number of vehicles per hour in one direction for moderate and high traffic density and maximum road capacity

Road category	No. of lanes / direction	Maximum capacity (vehicles/hour/direction)	Limit value for high density (vehicles/hour/direction)	Limit value for moderate density (vehicles/hour/direction)
Motorways	2	4128	2840	1810
Expressways	2	3040	2095	1330
G1	2	2884	1980	1260
G1	1	1442	990	630
G2	2	2756	1890	1200
G2	1	1378	945	600
R1	1	1354	930	590
R2	1	1331	915	580
R3	1	1286	885	565
RT	1	934	640	410

The traffic data for individual sections is obtained from the data of automatic traffic meters. This information is obtained from the Roads and Road Transport Directorate of the Republic of Slovenia (e.g. e-publication Traffic Count). From the publication, data can be obtained for each meter point on the density of traffic for each hour of the day for the year under consideration. In this way, the traffic density weights for the lighting class are determined. For the example of the section under consideration, which is on a category G2 road for which basic data are given in Table 8 and the traffic density shown in Figure 6, it can be concluded that during the morning and afternoon peaks (from 5:00 to 8:00 and from 16:00 to 18:00) there is high traffic density, while in evening (from 18:00 to 20:00) the traffic density is medium, and during night time (from 20:00 to 6:00) the traffic density is low, which means that due to the impact of the traffic density we have three different lighting classes. However, if we take into account that during night time there are no cyclists on the road or the number of cyclists is extremely small, the weight for the traffic structure is also changed during night time in the case of a road where traffic is mixed during the day.

Example of determining lighting class for section on road G2 104, section 1139 LOKA – TRZIN.

Table 8: Table with determination of lighting class

	Morning and afternoon peak (5:00 – 8:00 and 16:00 – 18:00)		Evening time (18:00 – 22:00)		Night time (22:00 – 06:00)	
Parameter	**Value**	**Points**	**Value**	**Points**	**Value**	**Points**
Traffic speed	60 km/h	-1	60 km/h	-1	60 km/h	-1
Traffic density	High	1	Medium	0	Low	-1
Traffic composition	Motor traffic only	0	Motor traffic only	0	Motor traffic only	0
Separation of directional carriageways	No	1	No	1	No	1
Density of intersections	High	1	High	1	High	1
Parked vehicles	Not present	0	Not present	0	Not present	0
Ambient luminance	Low	-1	Low	-1	Low	-1
Navigational tasks	Easy	0	Easy	0	Easy	0
Sum of points		**1**		**0**		**-1**
Lighting class		**M5**		**M6**		**M6**

According to the calculated lighting classes, the carriageway would be illuminated with a luminance of 0.50 cd/m^2 during the morning and afternoon peaks (in winter time) and with a luminance of 0.30 cd/m^2 during the evening time. Despite the same class in evening and night time, due to the decrease in traffic density, we reduce the luminance of the carriageway during night time by 30 % to a value of 0.20 cd/m^2.

If, when calculating the lighting class, lighting class M6 would be obtained for all three time periods in a day, then during the most dense traffic, the road should be illuminated with 0.30 cd/m^2, during the evening time with 30 % lower luminous flux and luminance of 0.20 cd/m^2 and during night time with 50 % lower luminous flux than for class M6, i.e. with luminance of 0.15 cd/m^2. The general and longitudinal uniformity shall remain the same as for class M6.

The same is true for lighting classes C. If Class C5 is calculated for all periods in a day, then, during peak traffic, the area is illuminated by an average maintained illuminance of 7.50 lx, reduced by 30 % to 5.00 lx during moderate traffic and reduced to 50 % of the class C5 value during minimum traffic, i.e. 3.75 lx. The overall uniformity shall remain the same as for class C5.

6.2 Switching off lighting

On roads with an extremely low night-time traffic density (between 24:00 and 5:00) illuminated in accordance with class M, the lighting may be switched off during the late night hours. Exceptionally, a reduction of luminous flux shall be applied to sections that are also subject to increased traffic loads at night. If the corresponding pedestrian and cycling surfaces are also illuminated within the lighting of a road with class M, orientation lighting may be used for the needs of pedestrians and cyclists.

On road facilities illuminated in accordance with class C, as a rule, the lighting is not switched off, but the luminous flux is reduced during late night hours. In the case of very low traffic and unproblematic situations, switching off is also recommended for facilities illuminated in accordance with this class.

In areas for pedestrians and cyclists illuminated in accordance with classes P, the lighting in the late night hours is usually switched off if it is class P7 or P6. In the case of class P6, if the location is urban or if the pavement is along a road of category higher than R3, a reduction of the luminous flux shall be carried out instead of switching off. In the case of class P6, if there are special needs (e.g. a location in a highly tourist area), a changeover to orientation lighting in accordance with class P7 shall be made instead of switching off.

In accordance with the above recommendations, the lighting of the pavements shall also be adjusted. In late night hours, it is recommended that the lighting be switched off for pavements along R3 or lower category roads illuminated in accordance with class P7. For pavements illuminated according to class P6, if it is not an urban location, it is recommended to reduce the lighting to an orientation according to class P7, and in the case of an urban location, the reduction of the luminous flux to 50 % is usually carried out. If the pavement is along a road with a class lower than R3, it is also recommended that for pavements illuminated according to class P6 be switched off during late night hours.

7 Recommended methods of lighting traffic areas

The following are examples of lighting installation on traffic areas for which lighting is required in accordance with the legislation and the technical specifications. When illuminating traffic areas, the reasonableness and method of road lighting must be examined separately for each location from the point of view of ensuring traffic and general safety as well as the reduction of light pollution, visual degradation of the space and electricity consumption. The recommendations made are adapted to the specific situation, as appropriate.

The design of road lighting must take into account the situation of the road, lighting requirements, peculiarities in the traffic flow, light effects of the surroundings, as well as environmental and landscape context.

The placement of the lamps is possible in several ways. Some of the most common positioning of the lamps in relation to the carriageway are shown in the following figures.

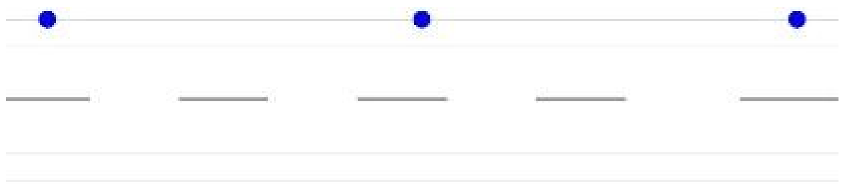


Figure 7: Single-sided installation of lamps

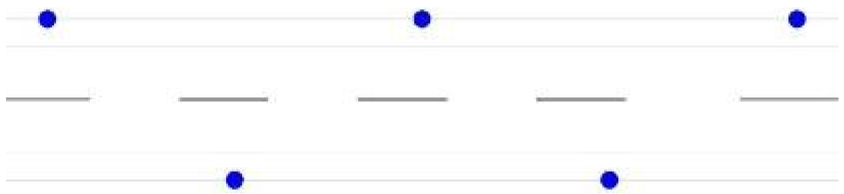


Figure 8: Two-sided offset installation of lamps

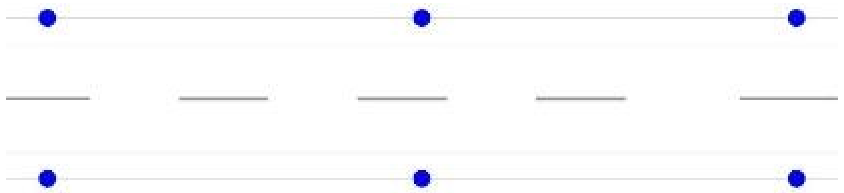


Figure 9: Two-sided opposing installation of lamps

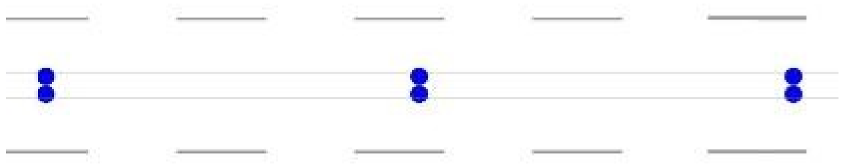


Figure 10: Two-sided central installation of lamps

When selecting lamps, great attention should be paid to the appropriate choice of optics and thus the spatial distribution of the luminous intensity. For the illumination of traffic areas falling within lighting classes M and P, lamps shall be selected with optics such that the ratio between the height of the pole (installation of the lamp) and the distance between the poles is at least 1:5. The height of the pole is determined according to the width of the carriageway and the position of the lamp.

7.1 Roads in the settlement

It is generally recommended to position the lamps in such a way as to cause as little hindrance as possible to pedestrian visibility. From this point of view, the execution with lamps on pillars placed in the area of the pavement or between the lane and the pavement is poor, as the pillars can block a person walking on the pavement. It is much more suitable placed along the pavement on the side away from the road.

Road lighting in the most congested parts of roads in settlements is prescribed by Article 75 of the Rules on traffic signs and equipment on roads.

Only the most congested parts of the roads in the settlement are illuminated. The most congested parts of the road are those parts which have a high traffic density according to SIST-TP CEN/TR 13201-1 during at least one part of the dark part of the day.

On the parts of roads in settlements that are not the most congested, we only illuminate pedestrian areas, cycling areas (cycle crossings, roads in settlements with shared traffic lanes, places where motor traffic and cycling traffic are intertwined, areas of physical traffic calming devices for cyclists in settlements (in accordance with Article 49 of the Rules on cycling areas), traffic calming devices (in accordance with the Technical Specification for Public Roads TSC 03.800: 2009 Traffic calming devices and measures) and service traffic areas (on or along a public road).

7.1.1 Pavement along an uncongested part of a road in a settlement

The lighting of these roads is important from the perspective of the pedestrians and cyclists appearing on this road section. Lighting of these areas allows drivers to see pedestrians and cyclists more quickly and more easily. The placement of lamps on one side of the road is more appropriate for less congested roads or roads with a limited area of placement of lamps. The disadvantage of such placement of lamps may be that pedestrians and cyclists on the other side of the road have less adequate lighting, which may lead to a risk of accident. The position of the lamps on both sides of the road allows equal lighting of the road on both sides, which can improve the visibility of all road users, including pedestrians and cyclists on both sides of the road. There may be a problem with the placement of such lamps on certain roads, such as narrow and low-traffic roads, where there may not be enough space to position the lamps on both sides of the road. A disadvantage may also be the increased costs of setting up and maintaining lighting. When deciding between a one-sided and two-sided placement of the lamps, it is crucial to take into account the specific circumstances of each case (spatial constraints), including the density of traffic and road users (density of presence of pedestrians and cyclists on the section).

The example of road shown below (Figure 11) is a carriageway with a pedestrian area on each side. As it is an uncongested part of the road in the settlement, only pedestrian areas are illuminated. In the same way, we would consider the case if there were bicycle areas next to the carriageway or, in addition to pedestrian areas, also bicycle areas.

The following figures show various examples of the placement of lamps according to the corresponding lighting class. Individual lighting class P is defined by the average maintained illuminance $\bar{E}$ and minimum maintained illuminance E_{min}. It is also recommended that appropriate uniformity be ensured so that the average maintained illuminance value does not exceed 7.5 times the minimum illuminance value

Figure 11: Example of a road in a settlement (carriageway and pedestrian areas)

The present case relates to the lighting class P6. In order to qualify for a higher class, the output luminous flux of the lamps must be increased accordingly, and the locations of the lamps remain the same.

Requirements for lighting class P6

Average maintained illuminance $\bar{E}$:	2.00 lx
Minimum maintained illuminance E_{min}:	0.40 lx

7.1.1.1 Lamps located on one side of the road

If pedestrian and/or cyclist areas are illuminated by lamps placed on one side of the road, they shall be placed on poles of such height as to provide adequate lighting for the pedestrian and/or cycling area also on the opposite side.

The area for pedestrians and/or cyclists closer to the lamps shall be illuminated in the appropriate lighting class. Any area for pedestrians and/or cyclists on the other side of the road will be less illuminated. The task of the lighting is to ensure a safe path for the user of areas for pedestrians and/or cyclists, for which one illuminated area in the appropriate lighting class is sufficient.

Details of selected lamps and mounting

Luminous flux:	1,100 lm
Installation height:	7 m
Distance between poles:	35 m
Carriageway width	6 m
Pavement width	1.5 m
Maintenance factor:	0.9

Results

Table 9: Results of an example of lighting an uncongested part of a road with lamps on one side of the road

	Pedestrian area 1*	Pedestrian area 2
Average maintained illuminance $\bar{E}$	2.12 lx	1.35 lx
Minimum maintained illuminance E_{min}	0.42 lx	0.84 lx

* Pedestrian area 1 shall be on the side of the road where the lamps are placed.

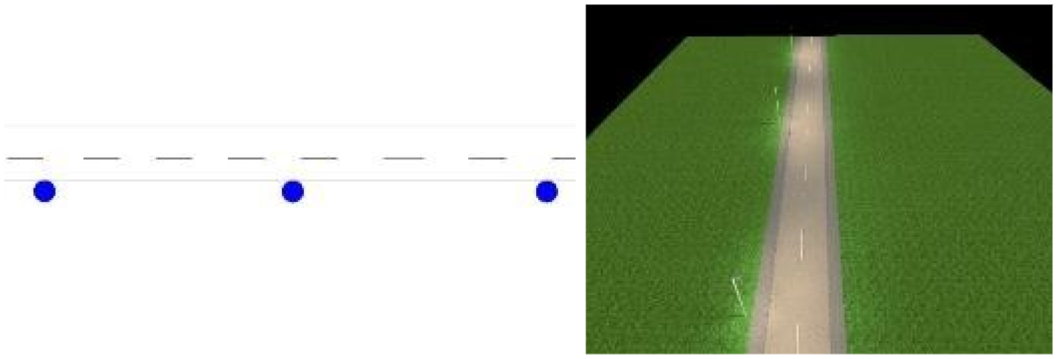


Figure 12: Example of placing lamps on one side of the road to illuminate pedestrian areas on the uncongested part of the road in a settlement

In this way, we can also illuminate uncongested parts of the road, where there is lane sharing or a mix of motorised and cycling traffic.

7.1.1.2 Lamps placed offset on both sides of the road

In practice, this type of lamp installation is avoided, but some settlements have a structure that requires this type of lighting.

Details of selected lamps and mounting

Luminous flux:	500 lm
Installation height:	4 m
Carriageway width	6 m
Pavement width	1.5 m
Distance between poles:	27 m (between lamps on the same side)
Maintenance factor:	0.9

Results

Table 10: Results of an example of lighting an uncongested part of a road with lamps on both sides of the road

	Pedestrian area 1	Pedestrian area 2
Average maintained illuminance $\bar{E}$:	2.63 lx	2.63 lx
Minimum maintained illuminance E_{min}	0.42 lx	0.42 lx

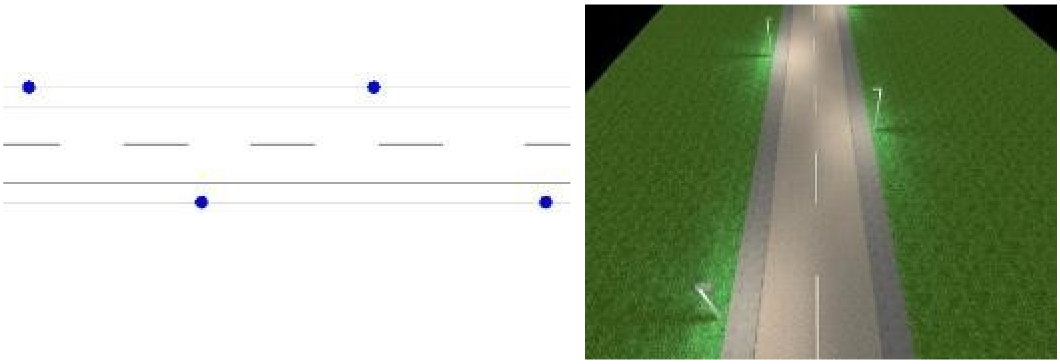


Figure 13: Example of placing offset lamps on both sides of the road to illuminate pedestrian areas on the uncongested part of the road in a settlement

7.1.2 The congested part of the road in a settlement

Congested parts of roads in the settlement are often exposed to increased traffic in motor vehicles, pedestrians and cyclists. An appropriate level of lighting in these areas allows drivers to have better visibility of the road, traffic signs and other road users, thus contributing to reducing the risk of accidents. The impact of lighting on traffic safety on the congested parts of roads in settlements has some specific aspects. Due to the high density of pedestrians, cyclists and motor traffic and the dense traffic network, the driver's perception of the traffic situation is particularly important. Proper lighting of these areas allows pedestrians and cyclists to be clearly visible and to feel safer when moving along the carriageway. Poorly lit road sections can make it difficult to properly assess the traffic situation and increase the risk of accidents. Therefore, the installation of efficient public lighting on road sections, which illuminates all important elements, including pedestrian crossings and cycle paths, is crucial. Better perception of the traffic situation may also allow traffic to flow more smoothly. It is also important to optimally install public lighting to avoid glare and ensure clear visibility, which reduces the possibility of accidents due to better perception of the surroundings. Properly designed, implemented and maintained lighting can make a significant contribution to reducing the risk of traffic accidents.

Lamps may be placed on one or both sides of the road. Outside towns, as a general rule, one-sided positioning shall be used, except in the case of congested roads with a traffic surface profile wider than normal.

The lighting of the congested part of the road in the settlement can be shown on the same road example as before (Figure 11). As this is the congested part of the road in a settlement, we illuminate the carriageway and pedestrian areas. Examples of the layout of lamps for lighting class M4 are shown. We also follow the recommendations of the standard that the difference between adjacent lighting classes should be less than two classes (i.e. pedestrian areas may be illuminated with classes P6–P2 in our case).

Requirements for the case of lighting class M4

Average maintained luminance of carriageway $\bar{L}$:	0.75 cd/m^2
Minimum luminance uniformity U_0:	0.40
Minimum longitudinal luminance uniformity U_l:	0.60
Maximum relative threshold increment f_{TI}:	15 %
Minimum edge illuminance ratio R_{EI}:	0.30

7.1.2.1 Lamps located on one side of the road

Details of selected lamps and mounting

Luminous flux:	5,250 lm
Installation height:	7 m
Distance between poles:	28 m
Maintenance factor:	0.9

Results

Table 11: Results of an example of lighting *of the carriageway on the* congested part of the road with lamps on one side of the road

Carriageway	
Average maintained luminance of carriageway $\bar{L}$	0.75 cd/m^2
Luminance uniformity U_0	0.47
Longitudinal uniformity U_l	0.80
Relative threshold increment f_{TI}	15 %
Edge illuminance ratio R_{EI}	0.38

Table 12: Results of an example of lighting of the pedestrian area on the congested part of the road with lamps on one side of the road

Pedestrian areas	Pedestrian area 1*	Pedestrian area 2
Average maintained illuminance $\bar{E}$	14.87 lx	5.15 lx
Minimum maintained illuminance E_{min}	6.61 lx	3.69 lx

* Pedestrian area 1 shall be on the side of the road where the lamps are arranged.

Pedestrian area 1 is illuminated for lighting class P2 and pedestrian area 2 for lighting class P4.

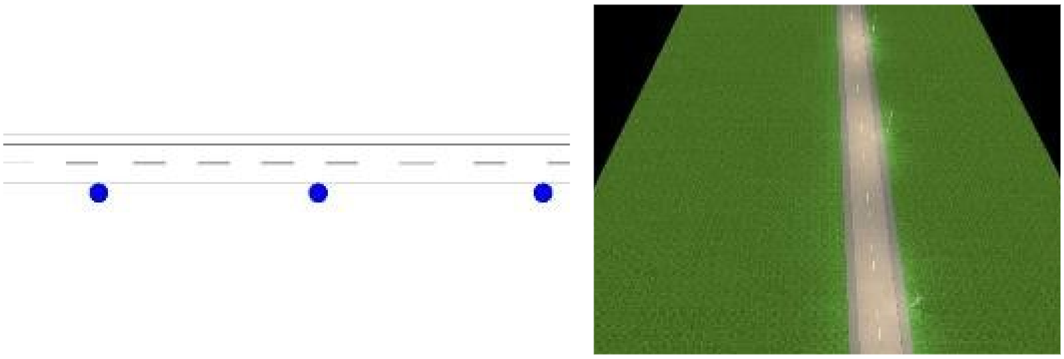


Figure 14: Example of placing lamps on one side of the road to illuminate carriageway and pedestrian areas on the congested part of the road in a settlement

7.1.2.2 Lamps located on both sides of the road

Details of selected lamps and mounting

Luminous flux:	2,500 lm
Installation height:	5 m
Distance between poles:	29 m
Carriageway width	6 m
Pavement width	1.5 m
Maintenance factor:	0.9

Results

Table 13: Results of an example of lighting of the carriageway on the congested part of the road with lamps on both sides of the road

Carriageway	
Average maintained luminance of carriageway $\bar{L}$	0.75 cd/m^2
Luminance uniformity U_0	0.62
Longitudinal uniformity U_l	0.61
Relative threshold increment f_{TI}	13 %
Edge illuminance ratio R_{EI}	0.91

Table 14: Results of an example of lighting of the pedestrian areas on the congested part of the road with lamps on both sides of the road

Pedestrian areas	Pedestrian area 1	Pedestrian area 2
Average maintained illuminance $\bar{E}$	13.37 lx	13.37 lx
Minimum maintained illuminance E_{min}	3.32 lx	3.32 lx

Both pedestrian areas are illuminated for lighting class P2.

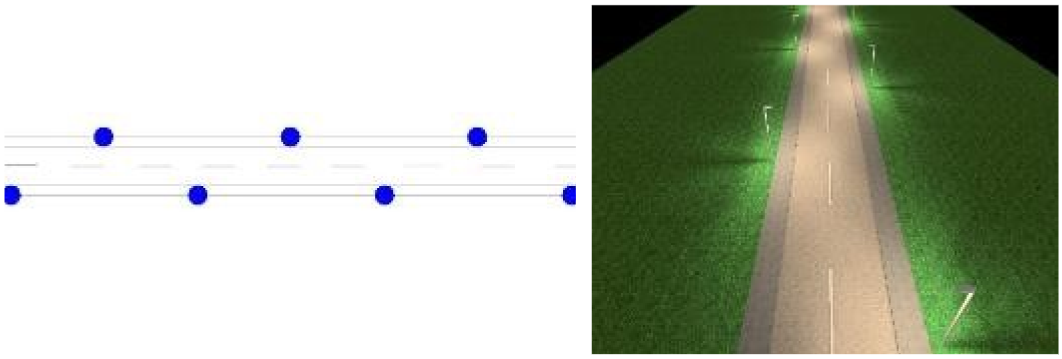


Figure 15: Example of placing lamps on both sides of the road to illuminate carriageway and pedestrian areas on the congested part of the road in a settlement

7.2 Pedestrian crossings and underpasses

The lighting of pedestrian crossings is prescribed in Article 75 of the Rules on traffic signs and equipment on roads and Article 24 of the Roads Act. The lighting of pedestrian underpasses is prescribed by Article 75 of the Rules on traffic signs and equipment on roads.

7.2.1 Pedestrian crossings

Pedestrian crossings shall be illuminated in accordance with the guidelines in the Manual for road lighting in the area of crossings for pedestrians and/or cyclists. This manual also displays and describes individual cases.

7.2.2 Pedestrian underpasses

Adequate illuminance, visibility and a sense of personal security must be ensured in underpasses. The luminous flux of the lamps shall be very high during the day in order to achieve sufficient illuminance, so users don't feel like they're entering a black tunnel. This makes the transition from the surroundings to the underpass and vice versa easier for the user, as there is no visual disturbance due to the need for a large and time-consuming adaptation.

The underpass entrances must be naturally illuminated, and the underpass including entrances must be adequately lit by artificial lighting 24 hours a day (see Pedestrian Infrastructure – General Directions).

Requirements for the illuminance of underpasses are specified in standard EN 12464-1. During daylight hours, the underpass shall be illuminated by artificial lighting whenever the natural light illuminance in the darkest part of the underpass does not reach 50 lx. However, in the dark part of the day, it shall be illuminated with 10 lx or more if the entrance and/or exit from the underpass are illuminated. In this case, the underpass must be illuminated in the same way as the pavement in front of and behind the underpass. Lighting with presence sensors should be used. When there are no users in the underpass, it should be illuminated with minimum illuminance (e.g. 10 %) and not entirely in the dark.

Requirements for lighting of pedestrian underpasses for low user density during daylight hours

Average maintained illuminance $\bar{E}$: 50 lx
Minimum illuminance uniformity U_0: 0.30
Minimum colour appearance index R_a: 80

Requirements for lighting of pedestrian underpasses for low user density during the dark part of the day

Average maintained illuminance $\bar{E}$: 10 lx
Minimum illuminance uniformity U_0: 0.30
Minimum colour appearance index R_a: 80

Details of selected lamps and mounting

Luminous flux: 600 lm
Maintenance factor: 0.9

Results

Table 15: Results of an example of lighting of pedestrian underpass in the dark part of the day

Average maintained illuminance $\bar{E}$	10.8 lx
Illuminance uniformity U_0	0.54
Colour appearance index R_a	83

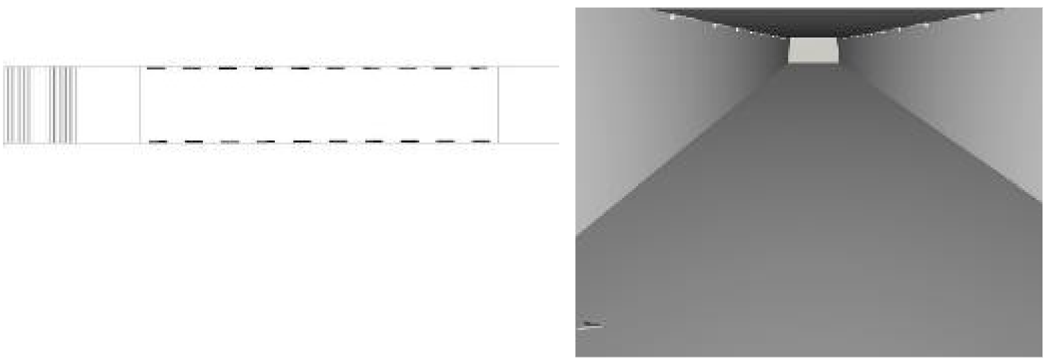


Figure 16: Example of the placement of lamps to illuminate underpasses under e.g. railway tracks

7.2.3 Pedestrian corridors in the area of marked crossings or underpasses

Pedestrian corridors or pavements outside the settlement are not illuminated, and examples of such corridors within the settlement are already covered by the lighting of the uncongested or congested part of the road in the settlement.

7.3 Motorway and expressway junctions

At high-density junctions, lighting shall be installed primarily for the purpose of visual guidance of drivers. The correct positioning of the lamps in relation to traffic conditions and the optimal choice of lighting classes contribute to better safety and the efficient and safer management of traffic flows at these critical points of the road network.

If the road is not illuminated before and after the junction, the selection of lighting class M6 is recommended. The two examples of junctions below are shown for lighting class M6.

Requirements for lighting class M6

Minimum maintained luminance of carriageway $\bar{L}$:	0.30 cd/m^2
Minimum luminance uniformity U_0:	0.35
Minimum longitudinal uniformity U_l:	0.40
Maximum threshold increment f_{TI}:	20 %
Minimum edge illuminance ratio R_{EI}:	0.30

7.3.1 Motorway junctions

The lamps shall be placed on one side of the motorway, usually on the right side in the direction of travel (to facilitate the maintenance of the lamps). For maintenance purposes, the height of the poles may be no more than 12 m.

The motorway junction shall be illuminated by placing two lamps before and after the junction. The lamp in the junction itself is already considered to be one of two lamps. The layout of the poles or the distance between them is influenced by the width of the directional carriageway of the motorway and the height of the installation of the lamps. The height of the poles is determined according to the width of the wider part of the directional carriageway of the motorway (i.e. before the junction) and is maintained until the end of the junction. We shall select lamps with such optics as to minimise the mounting height in relation to the width of the directional carriageway of the motorway.

The lighting in the motorway junction is intended for the visual guidance of traffic participants, so it is sufficient to illuminate the junction with lighting class M6 (if the road is not illuminated before and after the junction).

Details of selected lamps and mounting

Luminous flux:	8,500 lm
Installation height:	12 m
Distance between poles:	60 m
Maintenance factor:	0.9

Results

Table 16: Results of an example of motorway junction lighting

Maintained luminance of carriageway $\bar{L}$	0.30 cd/m^2
Luminance uniformity U_0	0.40
Longitudinal uniformity U_l	0.50
Relative threshold increment f_{TI}	9 %
Edge illuminance ratio R_{EI}	0.34

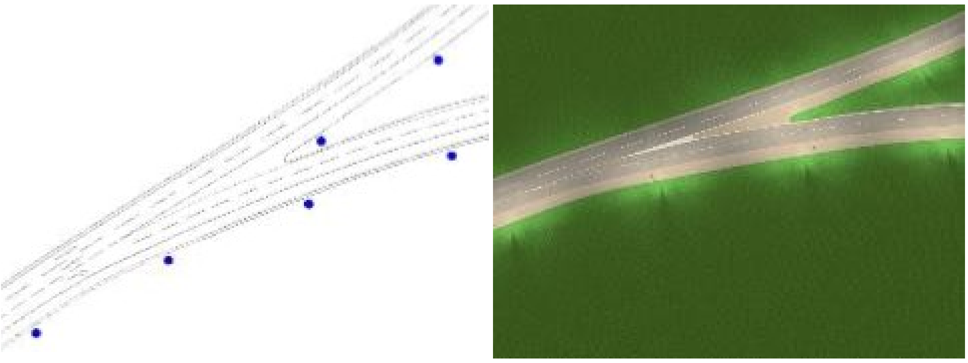


Figure 17: Example of the placement of lamps for the lighting of the motorway junction

7.3.2 Expressway junctions

The lamps shall be placed on one side of the expressway, usually on the right side in the direction of travel (to facilitate the maintenance).

The expressway junction shall be illuminated by placing two lamps before and after the junction. The lamp in the junction itself is already considered to be one of two lamps. The layout of the poles or the distance between them is influenced by the width of the directional carriageway of the expressway and the height of the installation of the lamps. The height of the poles is determined according to the width of the wider part of the directional carriageway of the expressway (i.e. before the junction) and is maintained until the end of the junction. We shall select lamps with such optics as to minimise the mounting height in relation to the width of the directional carriageway of the expressway.

In the case at hand, we take into account that the road is not illuminated before the junction, so the lighting is designed for lighting class M6.

Details of selected lamps and mounting

Luminous flux:	6,000 lm
Installation height:	9 m
Distance between poles:	49 m
Maintenance factor:	0.9

Results

Table 17: Results of an example of expressway junction lighting

Maintained luminance of carriageway $\bar{L}$	0.30 cd/m^2
Luminance uniformity U_0	0.35
Longitudinal uniformity U_l	0.41
Relative threshold increment f_{TI}	12 %
Edge illuminance ratio R_{EI}	0.49

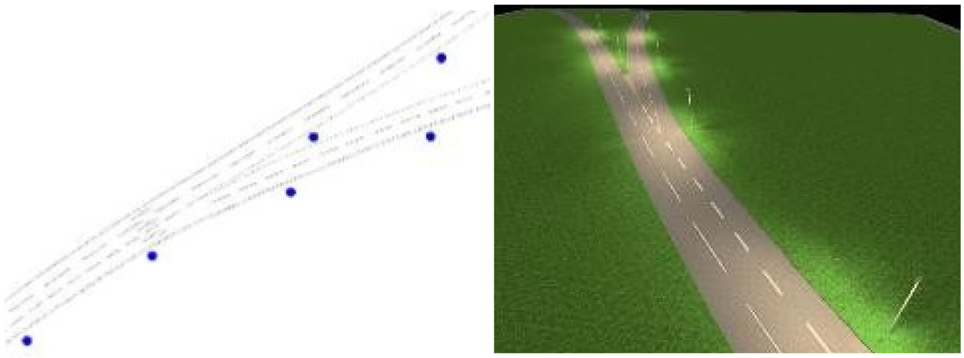


Figure 18: Example of the placement of lamps for the lighting of the expressway junction

7.3.3 Junctions on long-distance roads

According to the Rules on traffic signs and equipment on roads, junctions on long-distance roads are not illuminated. If there is a need for greater traffic safety in the area of the junction on a long-distance road, it shall be illuminated as shown in the example below.

Before the junction, one lamp shall be placed on the opposite side of the road, looking in the direction of travel towards the junction, and two after the junction on the same side of the road. An additional lamp is placed at the site of the junction, illuminating the junction. The layout of the poles or the distance between them is influenced by the width of the carriageway of the long-distance road and the height of the installation of the lamps. The height of the poles is determined according to the width of the wider part of the carriageway (i.e. before the junction) and is maintained until the end of the junction. We shall select lamps with such optics as to minimise the mounting height in relation to the width of the carriageway.

Also for the case of a junction on a long-distance road, we will take into account that the road is not illuminated before and after the junction, so the lighting is designed for lighting class M6.

Details of selected lamps and mounting

Luminous flux:	2,000 lm
Installation height:	5 m
Distance between poles:	27 m
Maintenance factor:	0.9

Results

Table 18: Results of an example of the lighting on the long-distance road junction

Maintained luminance of road surface $\bar{L}$	0.32 cd/m^2
Luminance uniformity U_0	0.43
Longitudinal uniformity U_l	0.43
Relative threshold increment f_{TI}	15 %
Edge illuminance ratio R_{EI}	0.36

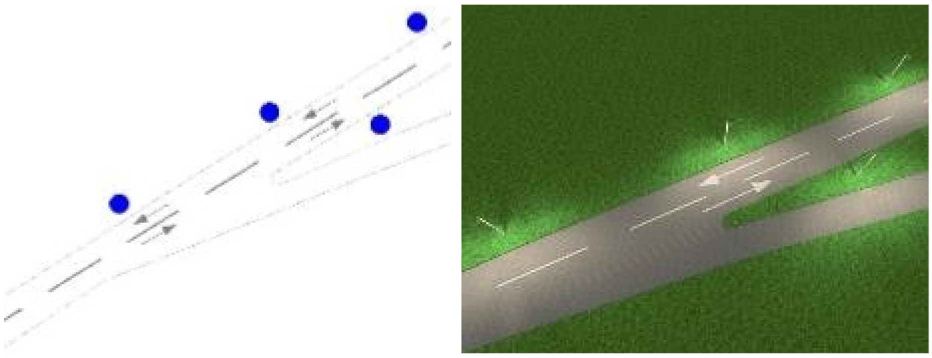


Figure 19: Example of the placement of lamps for the lighting of the long-distance road junction

7.4 Entries and exits on motorways and expressways

Lighting at entries and exits shall assist drivers in visual guidance (direction) and safe navigation when entering and exiting a motorway or expressway, especially under conditions of reduced visibility and at night.

The lighting of junctions to motorways and expressways is prescribed in Article 75 of the Rules on traffic signs and equipment on roads.

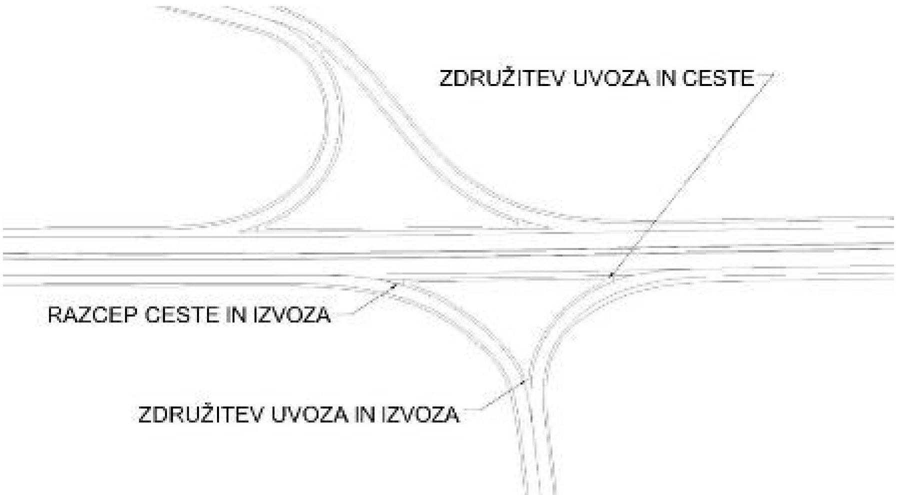


Figure 20: Example of entry and exit on a motorway or expressway

Entries and exits on unlit motorways and expressways shall be illuminated with 5 lx and with an illuminance uniformity of at least 0.35. This lighting is intended for the visual guidance of traffic participants. If motorways or expressways are illuminated before entries and exits, they shall be illuminated in appropriate lighting class C according to the lighting before or after exit. Select the appropriate C class according to the lighting class before or after the covered area. If the motorway or expressway is previously lit in class M, we take the table of comparable classes C and M, and if (afterwards) the intersection is lit in class C, we choose the same class C or one class lower than the class C of the intersection

At the exit, a maximum of two lamps are placed before the junction point of the exit. The exit road is illuminated up to the point where the entry and exit merge. Before the merging point of an entry and exit, a maximum of two lamps shall be placed on the side of the entry road before the merging point itself. After the merging point of the entry and the road, no more than two lamps shall be placed to illuminate the entry.

An example of the illumination of the entry and exit on a motorway and expressway can be seen in the example in the Figure 20. It is an entry and exit on an unlit motorway, so we illuminate them with 5 lx.

The layout of the poles or the distance between them is influenced by the width of the directional carriageway of the motorway or expressway and the height of the installation of the lamps. In the present case, in order to ensure proper conditions, lamps can be used on poles of height 7 m and distance between poles 35 m. The height of the poles is determined according to the width of the carriageway of the entry road onto the motorway or expressway. We shall select lamps with such optics as to minimise the mounting height in relation to the width of the carriageway.

Details of selected lamps and mounting

Luminous flux:	2,750 lm
Installation height:	7 m
Distance between poles:	35 m
Maintenance factor:	0.9

Results

Table 19: Results of an example of a motorway and expressway entry and exit

Average maintained illuminance $\bar{E}$	5.01 lx
Illuminance uniformity U_0	0.40

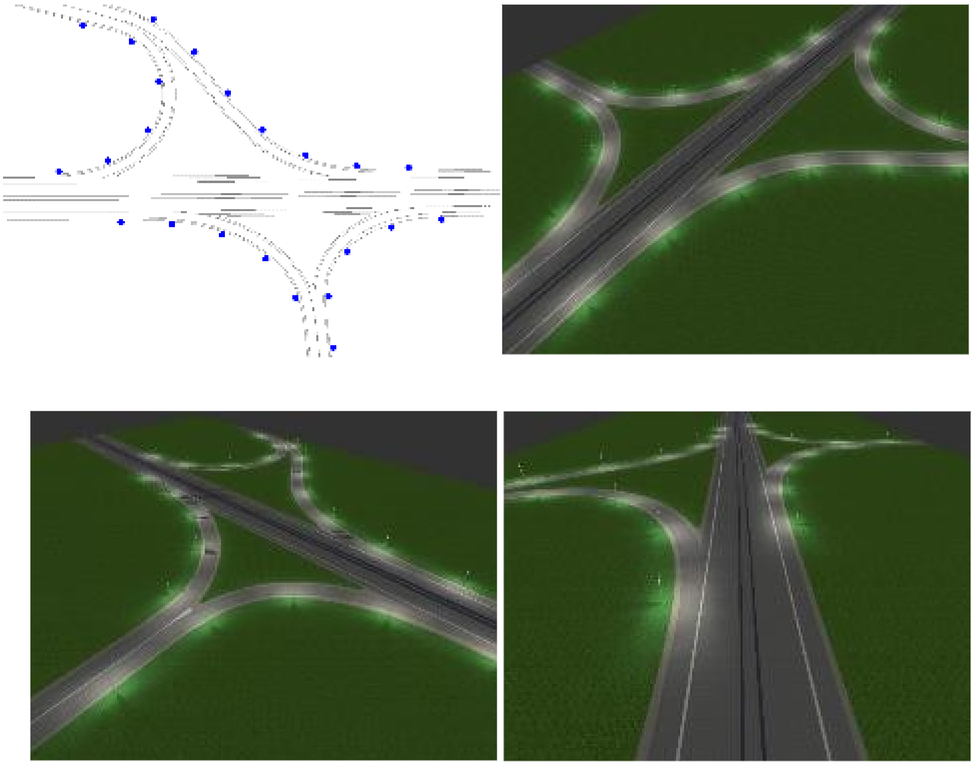


Figure 21: Example of the placement of lamps to illuminate the entry and exit on a motorway or expressway

7.5 Service traffic areas along public roads

The lighting of service traffic areas on public roads is prescribed by Article 75 of the Rules on traffic signs and equipment on roads. Service traffic areas include bus stops, parking areas, rest areas, service stations, traffic control areas, turning areas and control station areas.

7.5.1 Bus stops

Lighting at bus stops helps to ensure the safety and comfort of passengers and other road users. Light at bus stops allows drivers to see better and passengers waiting for the bus and other road users to be more visible, reducing the risk of accidents, especially in low visibility conditions. In addition, the presence of light at bus stops gives passengers greater comfort and also a feeling of greater safety in terms of other potential dangers or criminal acts (robbery, assault). Properly illuminated pedestrian and cyclist crossings at bus stops increase their safety when crossing the road, as they enable drivers to detect pedestrians faster.

Only bus stops for buses in public regular road transport during timetable period are illuminated! School bus stops are not illuminated!

For bus stops in settlements located outside the traffic lane and illuminated with the lighting of pedestrian or carriageway areas, no additional lighting is required. Orientation lighting shall be used to illuminate bus stops outside settlements (lamp with an exit luminous flux of 500 lm mounted on a pole of 4 m height and equipped with an optics to illuminate the entire width of the bus stop (pavement + carriageway)). Since it is orientation lighting, there are no special lighting requirements, no lighting class is selected either. Solar lamps may also be used for orientation lighting.

A pedestrian and/or cyclist crossing may also be arranged within the bus stop, which must be adequately illuminated according to the Manual for road lighting in the area of crossings for pedestrians and/or cyclists. The lamp, which is intended for the horizontal and vertical lighting of the crossing, cannot also be used as the lamp for the lighting of the bus stop. The bus stop must be illuminated separately from the lighting of the pedestrian and/or cyclist crossing. The height of the pole shall remain 4 m, even if the height of the lamp pole for lighting of the crossing is greater.

The lamp shall be placed in front of the bus stop in the direction of travel. The lights in the shelter (if one exists) are not subject to street lighting and are also not suitable as the sole lighting of the bus stop. To illuminate the bus stop, we should select a lamp with optics to illuminate the entire width of the bus stop (pavement + carriageway).

Lighting at bus stops is switched off after the last arrival or departure of the bus. Only lamps at bus stops with a denivelated island are lit at all times, where the axis of the main flow of traffic changes. For lamps that are not switched off, the luminous flux shall be reduced to 10 % during the time outside the timetable.

There are several options for bus stops, which are laid down in the Rules on bus stops. The lighting of a bus stop for some examples of bus stops is illustrated in the following examples.

Details of selected lamps and mounting

Luminous flux:	500 lm
Installation height:	4 m
Maintenance factor:	0.9
Maximum illuminance under the lamp	< 10 lx

7.5.1.1 Bus stops outside a settlement with a denivelated island

In this case, these are bus stops located outside the settlement where one of them has a denivelated island along the road, but the direction of the axis of the main traffic flow does not change. Both lamps are switched off half an hour after the last arrival or departure of the bus according to the timetable.

In Figure 22, we can see that the bus stop shelter creates a dark area in front of the shelter. This problem can be solved with an additional lamp in the bus stop shelter, which is not the subject of street lighting. The lighting of the shelter should be executed by means of an presence sensor!

The denivelated island falls within the area of the bus stop, so it is sufficient to only illuminate the beginning of the denivelated island in the direction of travel.

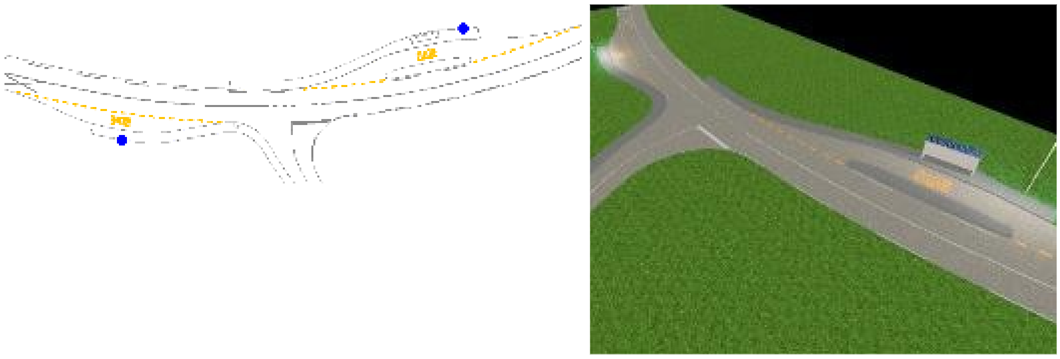
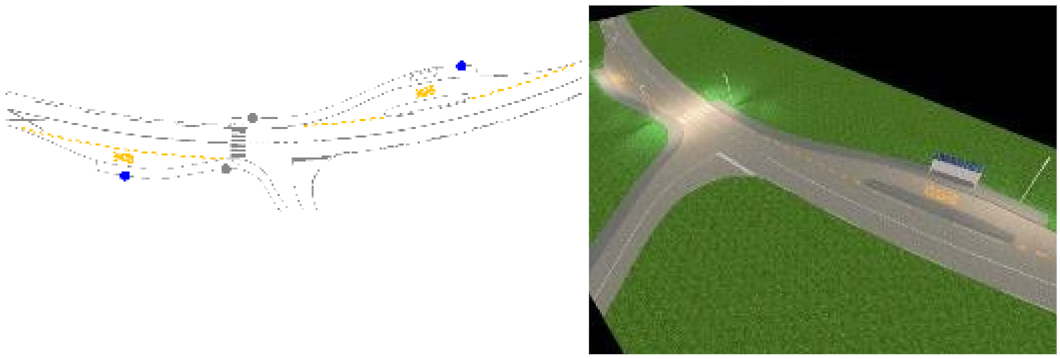


Figure 22: Example of a lamp installation for lighting bus stops outside settlements with a denivelated island

7.5.1.2 Bus stops outside settlements with a denivelated island and a pedestrian crossing between them

This is the same situation as in the first case, except that there is a pedestrian crossing between the two stops. Bus stops are illuminated with orientation lighting as separate areas in relation to the pedestrian crossing. Pedestrian crossing lighting shall be reduced independently during reduced traffic density or in accordance with the road lighting before and after the crossing, if one exists.



*The grey colour indicates lamps that are not the subject of the example, but are nevertheless shown for the sake of completeness of the example.

Figure 23: Example of a lamp installation for lighting bus stops outside settlements with a denivelated island and a pedestrian crossing between them

7.5.1.3 Bus stops on the uncongested part of the road in the settlement or on the carriageway outside the settlement

In this case, these are bus stops on the uncongested part of the road in the settlement. The bus stop shall be illuminated for one P class higher than the pavement, the uniformity of the illuminance shall be at least 0.40.

In our case, the pedestrian areas are illuminated in accordance with the requirements for lighting class P6, which means that the bus stop must be illuminated in accordance with the requirements for lighting class P5. The data of lamps illuminating pedestrian areas are the same as in the case of lighting on the uncongested part of the road in the settlement (see subchapter). To adequately illuminate the bus stop on an uncongested part of the road, another lamp is added (due to the uniformity of illuminance) and the luminous flux of the lamps is increased accordingly (to achieve illuminance by one P class higher than on pedestrian areas leading to the bus stop).

a) *Lighting of a bus stop on an uncongested part of a road in a settlement with two lamps mounted at the same height as the pedestrian lighting lamps*

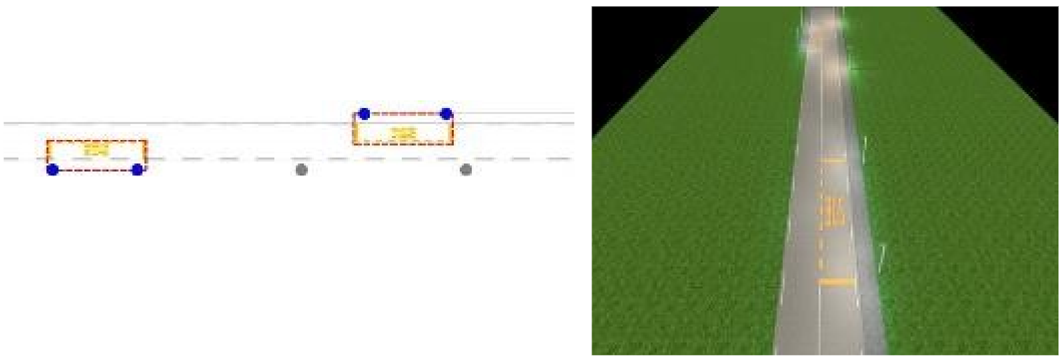
Data on selected lamps and mounting to illuminate <u>pedestrian areas</u>

Luminous flux:	500 lm
Installation height:	4 m
Distance between poles:	27 m
Maintenance factor:	0.9
Maximum illuminance under the lamp	< 10 lx

Results

Table 20: Results for an example of lighting of a bus stop on an uncongested part of a road in a settlement with two lamps that are mounted at the same height as the pedestrian lighting lamps

	Bus stop 1	Bus stop 2	Pedestrian areas
Average maintained illuminance $\bar{E}$	3.56 lx	3.02 lx	2.63 lx
Minimum maintained illuminance E_{min}	1.79 lx	1.68 lx	0.42 lx
Illuminance uniformity U_0	0.50	0.56	/



* The grey colour indicates lamps that are not the subject of the example, but are nevertheless shown for the sake of completeness of the example. If necessary, existing pavement lamps shall be removed or repositioned.

Figure 24: Example of setting up lamps for the lighting of bus stops on the uncongested part of the road in a settlement with two lamps

b) *Lighting of a bus stop on an uncongested part of the road in the settlement with a single lamp mounted higher than the installed lamps for pedestrian area lighting*

Data on selected lamps and mounting to illuminate <u>bus stops</u>

Luminous flux:	800 lm
Installation height:	6 m
Maintenance factor:	0.9

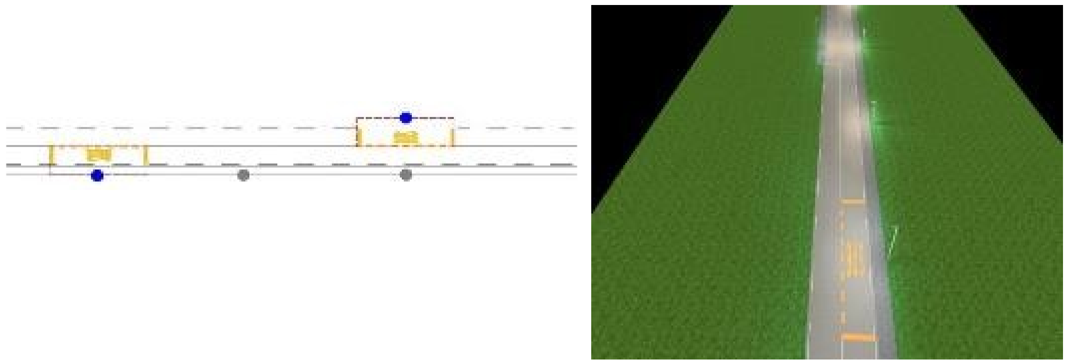
Data on selected lamps and mounting to illuminate <u>pedestrian areas</u>

Luminous flux:	500 lm
Installation height:	4 m
Distance between poles:	27 m
Maintenance factor:	0.9
Maximum illuminance under the lamp	< 10 lx

Results

Table 21: Results of an example of lighting bus stops on an uncongested part of the road with a single lamp

	Bus stop 1	Bus stop 2	Pedestrian areas
Average maintained illuminance $\bar{E}$	3.64 lx	3.12 lx	2.63 lx
Minimum maintained illuminance E_{min}	1.66 lx	1.44 lx	0.42 lx
Illuminance uniformity U_0	0.46	0.46	/



* The grey colour indicates lamps that are not the subject of the example, but are nevertheless shown for the sake of completeness of the example.

Figure 25: Example of setting up lamps for the lighting of bus stops on the uncongested part of the road with one lamp

In the same way, with two lamps on the lower poles or with one lamp on the higher pole, bus stops in the carriageway outside the settlement can also be illuminated.

7.5.1.4 Opposite bus stops on the carriageway outside a settlement

In this case, we have opposite bus stops on the carriageway outside a settlement. The carriageway in front of and behind bus stops is not illuminated, so bus stops are illuminated with orientation lamps.

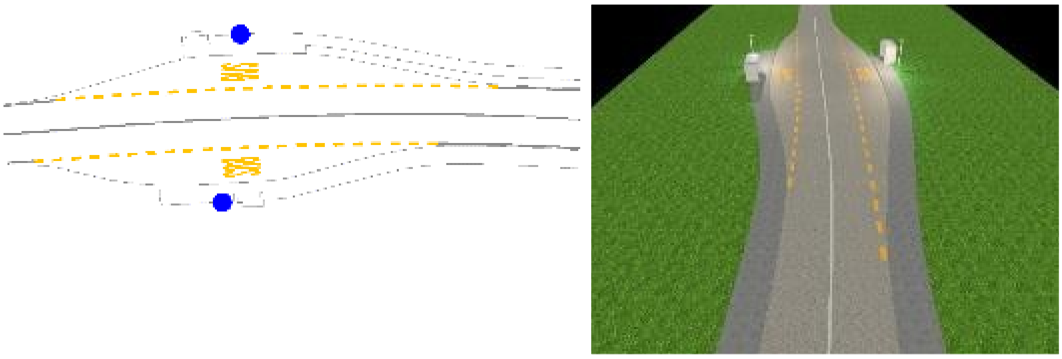


Figure 26: Example of lamps to illuminate opposite bus stops outside the carriageway on a road outside a settlement

7.5.2 Car parks

Lighting in car parks contributes to the traffic safety and comfort of users, as well as to safety when parking and moving within the car park. Adequate lighting allows drivers to have better visibility of parking spaces, obstacles, footpaths and other car park elements. This reduces the possibility of collisions between vehicles and vehicle injuries and prevents unnecessary accidents. Similarly, properly illuminated footpaths and pedestrian crossings at the car park allow pedestrians to move and cross the car park safely. For these reasons, adequate lighting in car parks contributes to ensuring traffic safety and the safety of all the occupants of the car park.

A car park is a traffic area intended for stopping and parking vehicles (ZCes-2). Requirements for the illuminance of car parks are specified in standard SIST EN 12464-2. The required horizontal illuminance is measured on the ground. If we also provide adequate vertical illuminance, this also increases the feeling of security and the recognition of human faces. When designing the car park lighting, we take care primarily of the appropriate horizontal illuminance. It is recommended to switch the lamps on/off with the help of a presence sensor or motion sensor.

When lighting car parks, it is very important to rationally assess the actual needs at each location.

Requirements for the lighting of car parks (referred to in standard SIST EN 12464-2: 2014)

Average maintained illuminance $\bar{E}$:	5 lx
Minimum illuminance uniformity U_0:	0.25
Minimum colour appearance index R_a:	20

Details of selected lamps and mounting

Luminous flux:	1,100 lm
Installation height:	5 m
Maintenance factor:	0.9

Results

Table 22: Results of an example of car park lighting

Average maintained illuminance $\bar{E}$	5.25 lx
Illuminance uniformity U_0	0.47

Colour appearance index R_a	70

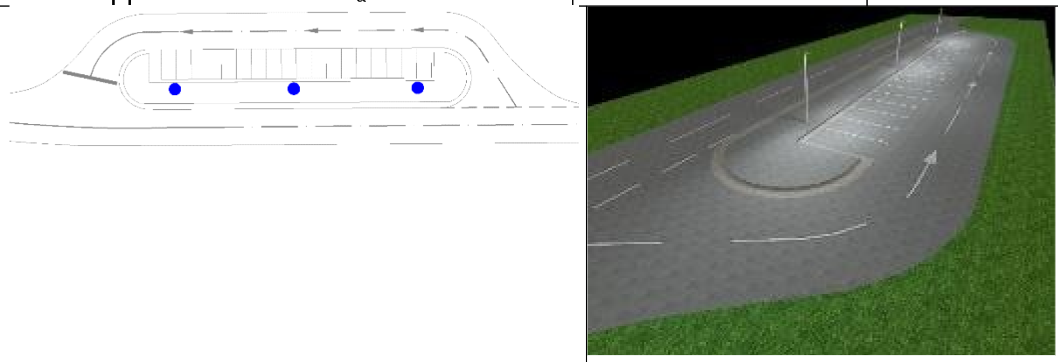


Figure 27: Example of the placement of car park lamps

7.5.3 Rest areas

Correct lighting at rest areas allows drivers to have better visibility and orientation, which reduces the risk of accidents or unexpected events during manoeuvring at the rest area. Proper lighting of entries and exits to rest areas allows vehicles to enter and exit traffic safely and contributes to better visibility and safety at these locations. Light at rest areas also makes it safer for pedestrians in these areas, as it allows them to see and detect vehicles and other road users better. The presence of light at a rest area can deter potential offenders by reducing the possibility of vandalism, burglary or other criminal activities. In addition to safety, lighting at rest areas also makes it possible for road users to have a comfortable and pleasant stay during their stops. For these reasons, adequate lighting at the rest area is essential to ensure traffic safety and the safety of all participants in the rest area.

Rest area is a service traffic area marked with traffic signalisation, intended for short stops of road users (Zces-2). The requirements for the lighting of rest areas are not mentioned directly in any document, so that the requirements for car parks in standard EN 12464-1 are taken into account (see example for car park). If the rest area is located on a motorway or expressway, the entry and exit to the motorway or expressway shall be illuminated in accordance with the instructions in this specification. Entries and exits to rest areas outside motorways and expressways shall not be illuminated.

A rest area is an entire part where it is possible to stop and/or park the vehicle, as well as any pedestrian areas.

The example shown below is a rest area along a motorway. In addition to the lighting of the rest area, the lighting of entry and exit is shown. The results are shown only for the rest area. The entry and exit to the rest area are illuminated in accordance with the instructions in this specification.

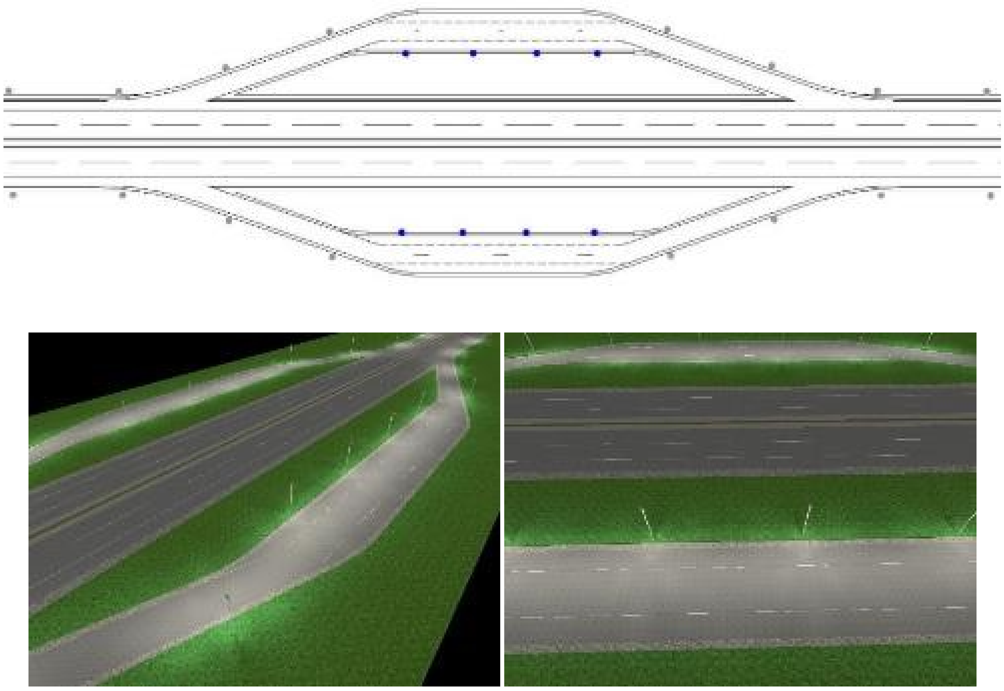
Details of selected lamps and mounting

Luminous flux:	2,000 lm
Installation height:	7 m
Maintenance factor:	0.9

Results

Table 23: Results of an example of rest area lighting

Average maintained illuminance $\bar{E}$	5.17 lx
Illuminance uniformity U_0	0.24
Colour appearance index R_a	70



* The grey colour indicates lamps that are not the subject of the example, but are nevertheless shown for the sake of completeness of the example.

Figure 28: Example of the placement of rest area lamps

7.5.4 Service stations

Correct lighting in entries, exits and stationary traffic areas in service stations enables drivers to have better visibility and orientation. This reduces the risk of accidents when entering and leaving the station and when manoeuvring vehicles on the station area. Also, the illumination of these areas makes them safer for pedestrians. This reduces the possibility of accidents during the crossing of stationary traffic areas. In addition to safety, lighting at service stations also makes it possible for road users to have a comfortable and pleasant stay during their stops.

Entries and exits to service stations outside motorways and expressways shall be illuminated in the appropriate lighting class C. If the carriageway is not illuminated, the service stations shall be illuminated in lighting class C5. On motorways and expressways, entries and exits shall be illuminated in accordance with the instructions in this specification. Parking areas and rest areas in service stations shall be illuminated in accordance with the instructions for the lighting of parking areas in this specification. The lighting of the covered part of the service station building is not subject to road lighting.

Requirements for lighting class C5

Average maintained illuminance $\bar{E}$:	7.50 lx
Minimum illuminance uniformity U_0:	0.40

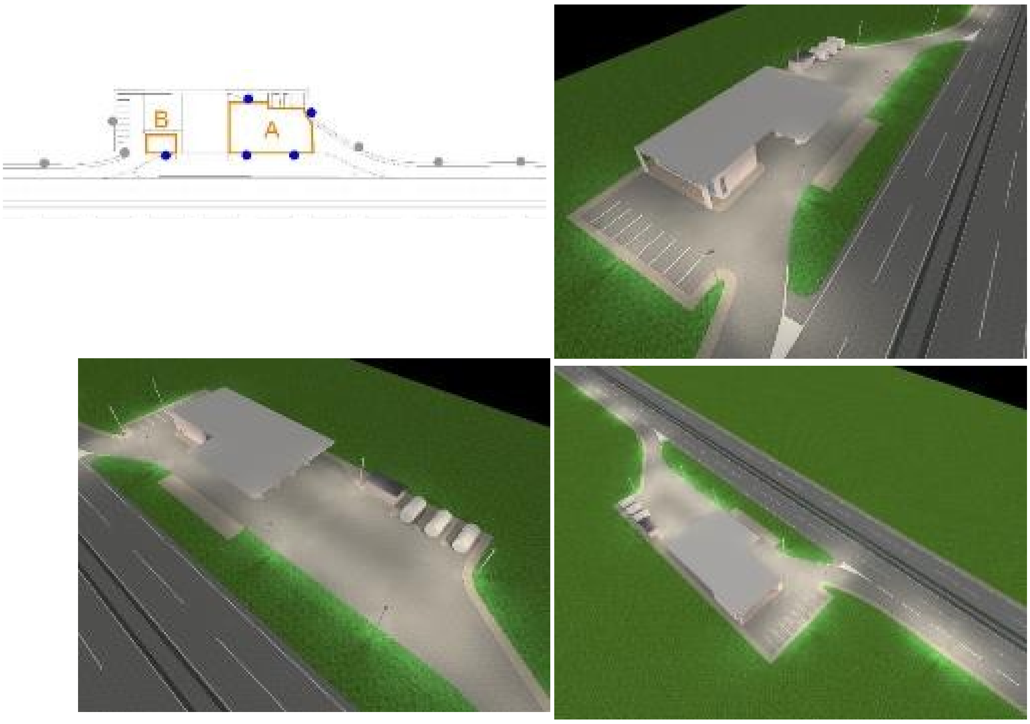
Details of selected lamps and mounting

Luminous flux:	2,750 lm
Installation height:	7 m
Maintenance factor:	0.9

Results

Table 24: Results of an example of service station lighting

	Uncovered area of service station A	Uncovered area of service station B
Average maintained illuminance $\bar{E}$	7.70 lx	8.88 lx
Illuminance uniformity U_0	0.45	0.61



* The grey colour indicates lamps that are not the subject of the example, but are nevertheless shown for the sake of completeness of the example.

Figure 29: Example of the placement of lamps for the lighting of the service station

7.5.5 Traffic control areas

Lighting of these areas is necessary at night and in conditions of poor visibility to ensure effective traffic control and safety. Correct lighting enables clear visibility of traffic equipment, enabling drivers to quickly detect and understand traffic information. Light can also improve the operation of control cameras and other traffic monitoring devices, which increases the efficiency of traffic control and management in these areas.

Work surfaces in traffic control areas are to be illuminated according to the instructions of the users (DARS, police) with the following:

- 150 lx for covered work areas (not subject to road lighting), and
- 50 lx for uncovered work areas.

The recommended minimum illuminance uniformity for work areas on traffic control areas is U_0 = 0.25. For other requirements (e.g. direct ambient illuminance, glare, colour appearance) follow the recommendations of SIST EN 12464-2 Light and lighting – Lighting of work places – Part 2: Outdoor work places.

The lighting system in the entire area of traffic control areas, along with entries to and exits from traffic control areas, should be operated only during actual use, otherwise it should be switched off. The lighting of the covered parts of buildings in traffic control areas is not subject to road lighting and is therefore not included in the example below.

Requirements

Average maintained illuminance $\bar{E}$ of uncovered areas:	50.0 lx
Minimum illuminance uniformity U_0:	0.25

Details of selected lamps and mounting on uncovered parts of traffic control areas A and B

Luminous flux:	24,250 lm
Installation height:	9 m
Maintenance factor:	0.9

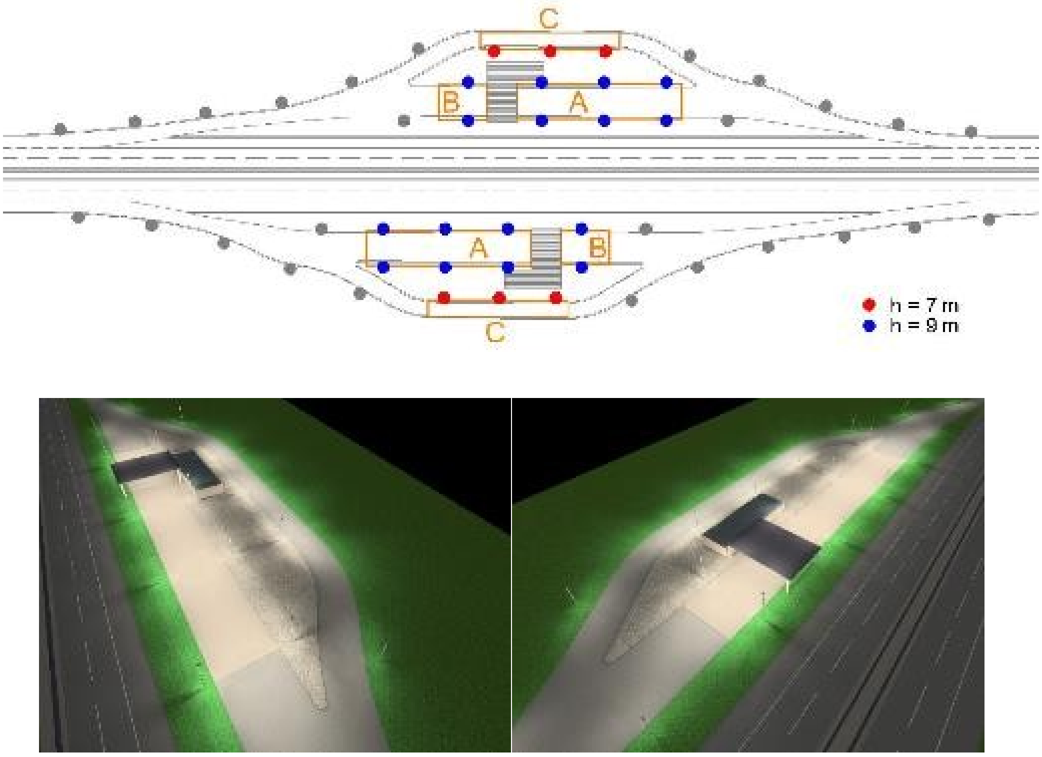
Details of selected lamps and mounting on uncovered part of traffic control area C

Luminous flux:	24,250 lm
Installation height:	7 m
Maintenance factor:	0.9

Results

Table 25: Results of an example of lighting of traffic control areas

	Zone A	Zone B	Zone C
Average maintained illuminance $\bar{E}$	55.8 lx	50.7 lx	55.0 lx
Illuminance uniformity U_0	0.47	0.34	0.42



* The grey colour indicates lamps that are not the subject of the example, but are nevertheless shown for the sake of completeness of the example.

Figure 30: Example of the placement of lamps for the lighting of traffic control areas

7.5.6 Turning areas

In the Public Roads Act, turning areas are defined as specially constructed and marked traffic areas along the carriageway of a road intended exclusively for public passenger transport.

Within a turning area, bus stop shall be illuminated by means of orientation lighting and the remaining areas shall not be illuminated.

Details of selected lamps and mounting

Luminous flux:	500 lm
Installation height:	4 m
Maintenance factor:	0.9
Maximum illuminance under the lamp	< 10 lx

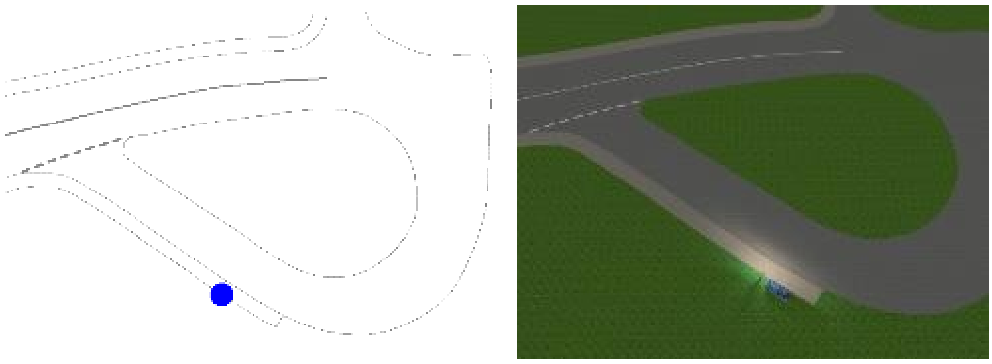


Figure 31: Example of the placement of turning area lamps

7.5.7 Control station areas

Control station areas include, for example, toll stations and border crossing points.

Correct lighting of control stations allows better visibility for drivers around the station, which facilitates navigation and stopping of vehicles. This is particularly important at toll stations where the vehicle is to be stopped for the payment of tolls or for crossing the border. Light at control stations allows for better visibility of traffic equipment, such as traffic signs, signalisation and toll devices. This enables drivers to understand traffic information more quickly and easily, and improves safety in these areas. The presence of lights at control stations can help reduce accidents and collisions by giving drivers better visibility and thus more time to adjust their speed and make the necessary manoeuvres.

Control stations shall be illuminated in accordance with the appropriate lighting class C. Parking areas and rest areas at control stations shall be illuminated in accordance with the instructions for lighting parking spaces in this specification (see subchapter Error: Reference source not found). The conflict area begins with the end of the central safety barrier on the road. The lighting of the covered part of the control station building is not subject to road lighting.

Requirements for lighting class C5

Average maintained illuminance $\bar{E}$: 7.50 lx
Minimum illuminance uniformity U_0: 0.40

Details of selected lamps and mounting

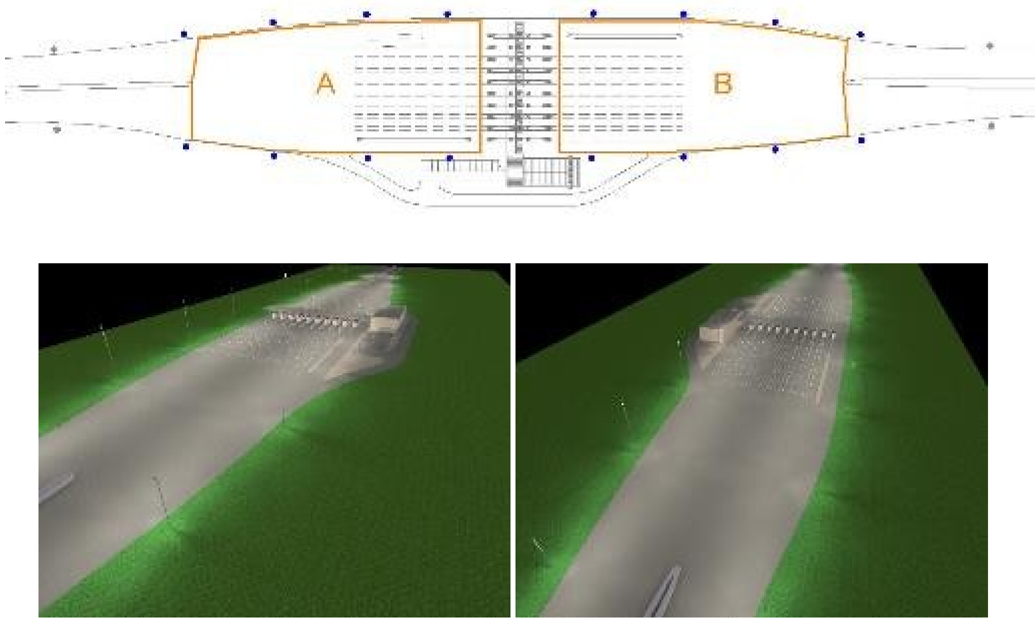
Luminous flux: 17,500 lm
Installation height: 20 m
Maintenance factor: 0.9

Results

Table 26: Results of an example of control station lighting

	Zone A	Zone B
Average maintained illuminance $\bar{E}$	7.74 lx	7.80 lx
Illuminance uniformity U_0	0.41	0.45

* *View from the side of the control station building (figure below).*



* The grey colour indicates lamps that are not the subject of the example, but are nevertheless shown for the sake of completeness of the example.

Figure 32: Example of the placement of lamps for the lighting of the control station

7.6 Channelised intersections

Channelized intersection is an intersection (also a roundabout) where traffic management is regulated with the help of horizontal signalisation and traffic islands. Traffic islands can be directional, splitter islands, pedestrian and cyclist islands. The traffic islands can be denivelated or marked with horizontal traffic signalisation, which means that the pavement markings for central reservations (hatched area) and fields for traffic channelization, which are determined by the regulation in the field of traffic signalisation, are also considered as splitter traffic islands (TSPI-PGV.03.244). As intersections are where traffic flows cross, they are a conflict area. For conflict areas, we use lighting classes C according to the instructions in the Technical Report SIST-TP CEN/TR 13201 (see Chapter Error: Reference source not found).

7.6.1 Intersections with three or more classified lanes

The lighting of larger intersections helps to reduce the risk of accidents and congestion caused by sudden braking by making it quicker and easier for drivers to understand the traffic situation, especially in high traffic density situations. It gives drivers better visibility of the traffic lane arrangement, allowing them to adjust their speed and get into the correct lane in time. The presence of lights at intersections also improves pedestrian safety by making it easier for drivers to detect pedestrians crossing the road at crossings.

The first lamp in front of the intersection shall be positioned in such a way that the denivelated island forming part of the intersection is also illuminated. If there is no denivelated island on the arm before the intersection, then a maximum of two lamps shall be installed in the direction of exit from the intersection from the end of the conflict area.

NOTE: Arms that do not have three or more classified lanes shall not be illuminated.

The case under consideration is made for lighting class C4.

Requirements for lighting class C4

Average maintained illuminance $\bar{E}$:	10.0 lx
Minimum illuminance uniformity U_0:	0.40

Details of selected lamps and mounting at the intersection

Luminous flux:	6,000 lm
Installation height:	11 m
Maintenance factor:	0.9

Details of selected lamps and mounting on the arms of the intersection

Luminous flux:	5,000 lm
Installation height:	8 m
Maintenance factor:	0.9

Results

Table 27: Results of lighting of the conflict area in a channelised intersection with more than three classified lanes

Average maintained illuminance $\bar{E}$	11.3 lx
Illuminance uniformity U_0	0.44

Table 28: Results of lighting of arms in an intersection with more than three classified lanes

	Area A	Area B
Average maintained illuminance $\bar{E}$	10.2 lx	13.5 lx
Illuminance uniformity U_0	0.49	0.44

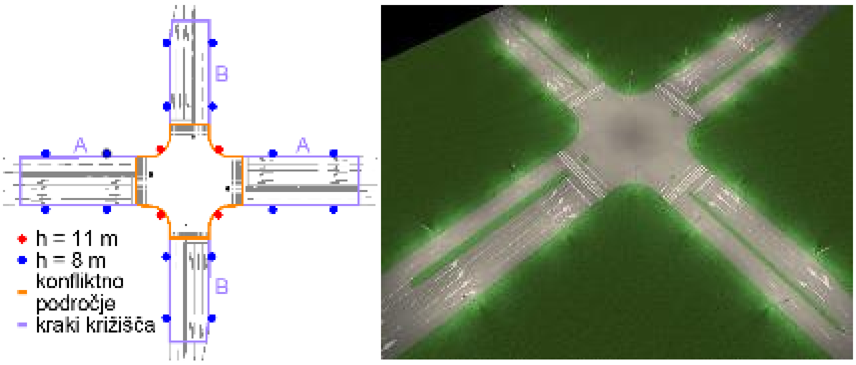


Figure 33: Example of the placement of lamps for the lighting of intersection with more than three classified lanes

7.6.2 Roundabouts

With correctly positioned lamps around the outer perimeter of the roundabout, conflict spots, such as entries and exits from the roundabout, are adequately illuminated. This makes it easier for drivers to detect other vehicles, pedestrians and cyclists. Better visibility of conflict points and pedestrian crossings contributes to safer crossing of crossings and also to smoother traffic at the roundabout. Driving through a roundabout becomes more predictable and safer, thereby reducing the risk of congestion and road accidents. The light on the arms in front of a roundabout also acts as a warning to drivers that they are approaching a roundabout. This is particularly important in the case of multi-lane roundabouts, which helps drivers to adjust speed and select the right traffic lane in time, which in turn reduces the possibility of incorrect vehicle manoeuvres.

In the cases shown below, the lamps are placed around the outer perimeter of the roundabout in such a way that conflict spots are adequately illuminated. Conflict spots at a roundabout are entries into and exits from the roundabout. Pedestrian crossings shall be illuminated in accordance with the guidelines in the Manual for road lighting in the area of crossings for pedestrians and/or cyclists.

The lamp poles for pedestrian crossing lighting should not be higher than the lamp poles for the lighting of a roundabout.

Before a multi-lane roundabout, no more than two lamps shall be installed on each arm at the appropriate distance from the roundabout. Before single-lane roundabouts, the arms are not illuminated.

The following examples are made for lighting class C4.

Requirements for lighting class C4

Average maintained illuminance $\bar{E}$:	10.0 lx
Minimum illuminance uniformity U_0:	0.40

a) Roundabout without pedestrian crossings

At a roundabout without pedestrian crossings, only the entry part to the intersection where the denivelated islands are located shall be illuminated.

Since this roundabout is symmetrical, the results are the same for all four conflict areas.

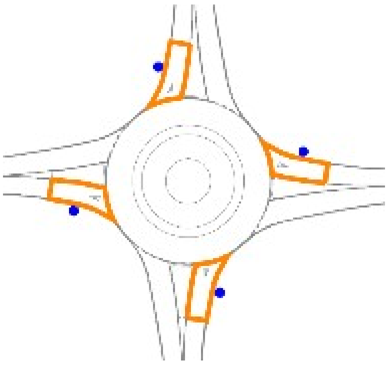
Details of selected lamps and mounting

Luminous flux:	2,500 lm
Installation height:	6 m
Maintenance factor:	0.9

Results

Table 29: Results of an example of a roundabout without pedestrian crossings

Average maintained illuminance $\bar{E}$	9.63 lx
Illuminance uniformity U_0	0.45



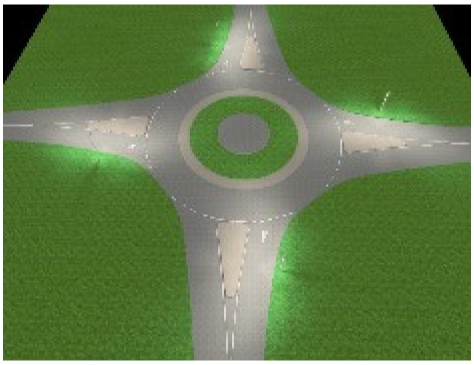


Figure 34: Example of the placement of lamps for lighting a roundabout without pedestrian crossings

b) Roundabout with independent pedestrian crossings

The results are only shown for the conflict area of the roundabout, as pedestrian crossings are already so far away from the conflict areas of the roundabout that it is more sensible to illuminate them separately from the roundabout with asymmetric lamps. Lighting of pedestrian crossings is not the subject of this case.

The lamp for lighting the pedestrian crossing on the side of the direction of travel towards the roundabout shall be considered to be the first of two lamps on the roundabout arm.

Since this roundabout is symmetrical, the results are the same for all four conflict areas.

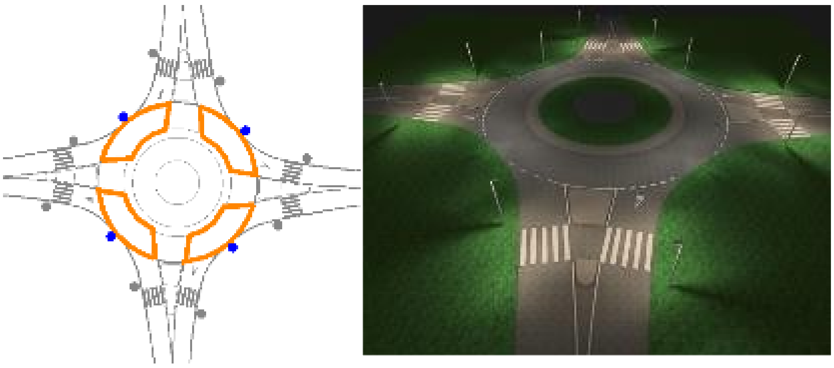
Details of selected lamps and mounting

Luminous flux:	2,500 lm
Installation height:	6 m
Maintenance factor:	0.9

Results

Table 30: Results of an example of a roundabout with independent pedestrian crossings

Average maintained illuminance $\bar{E}$	10.6 lx
Illuminance uniformity U_0	0.58



* The grey colour indicates lamps that are not the subject of the example, but are nevertheless shown for the sake of completeness of the example.

Figure 35: Example of the placement of lamps for lighting a roundabout with independent pedestrian crossings

c) Roundabout with included pedestrian crossings

In this case, pedestrian crossings are also part of the roundabout and are therefore illuminated as part of the lighting of the roundabout.

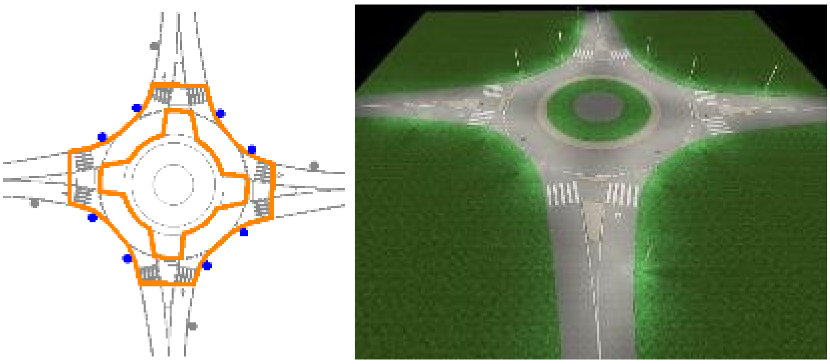
Details of selected lamps and mounting

Luminous flux:	2,200 lm
Installation height:	6 m
Maintenance factor:	0.9

Results

Table 31: Results of an example of a roundabout with included pedestrian crossings

Average maintained illuminance $\bar{E}$	11.3 lx
Illuminance uniformity U_0	0.48



* The grey colour indicates lamps that are not the subject of the example, but are nevertheless shown for the sake of completeness of the example.

Figure 36: Example of the placement of lamps for lighting a roundabout with included pedestrian crossings

7.6.3 Turbo roundabouts

The lighting of entries and exits in the turbo roundabout enables drivers to have better visibility and understanding of areas where different traffic lanes intersect. This allows faster decisions and appropriate speed adjustments, reducing the chance of incorrect manoeuvres or carelessness and, consequently, the chance of an accident. Properly illuminated areas of entry and exit can contribute to better traffic flow and reduce congestion. Better visibility for drivers also means greater safety for pedestrians and cyclists, since it is easier for drivers to notice their presence and allow them to cross the road safely.

The lighting of turbo roundabouts is subject to the same rules as for the lighting of ordinary roundabouts. Also in a turbo roundabout, only the conflict areas (the areas of entry and exit to and from the turbo roundabout) are illuminated.

The example is made for lighting class C4. The results are only shown for conflict areas in a turbo roundabout. Lighting of pedestrian and cyclist crossings is not the subject of this case.

The lamp poles for pedestrian crossing lighting should not be higher than the lamp poles for the lighting of a roundabout.

Before a turbo roundabout, no more than two lamps shall be installed on each arm at the appropriate distance from the turbo roundabout.

The lamp for lighting the pedestrian crossing on the side of the direction of travel towards the turbo roundabout shall be considered to be the first of two lamps on the turbo roundabout arm.

Requirements for lighting class C4

Average maintained illuminance $\bar{E}$: 10.0 lx
Minimum illuminance uniformity U_0: 0.40

Details of selected lamps and mounting

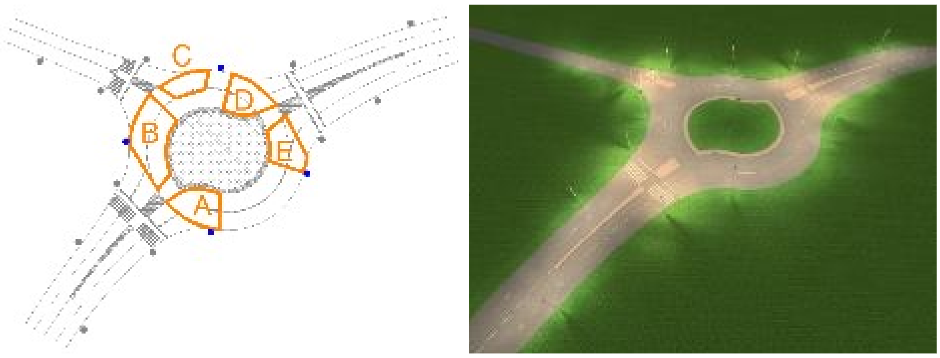
Luminous flux: 8,500 lm

Installation height:	12 m
Maintenance factor:	0.9

Results

Table 32: Results of an example of lighting of a turbo roundabout

Conflict areas	A	B	C	D	E
Average maintained illuminance $\bar{E}$	12.0 lx	11.6 lx	10.1 lx	10.2 lx	11.0 lx
Illuminance uniformity U_0	0.61	0.53	0.90	0.60	0.55



* The grey colour indicates lamps that are not the subject of the example, but are nevertheless shown for the sake of completeness of the example.

Figure 37: Example of the position of lamps to illuminate the turbo roundabout

7.7 Traffic calming devices

Illuminated traffic calming devices enable drivers and other road users to gain better visibility of these elements of the road, which increases obstacle perception on the road. Drivers notice these devices faster and react in a timely manner to changes in traffic conditions, such as humps, ramps, carriageway narrowings, etc.

Traffic calming devices within the settlement shall be illuminated as part of the lighting of the carriageway or pedestrian and/or cycling areas. Traffic calming devices outside the settlement shall be illuminated with a single lamp (traffic calming device orientation lighting). The lamp shall be placed close to the beginning of the traffic calming device. If the traffic calming device is illuminated with a sign with internal illuminance, the installation of road lamps is not required.

7.7.1 Lighting of trapezoidal ramp without pedestrian crossing

The example below is a ramp on the uncongested part of the road in the settlement. Only the two ramp entrances are illuminated. Lamps with optics for pedestrian crossings may be used to illuminate the ramp.

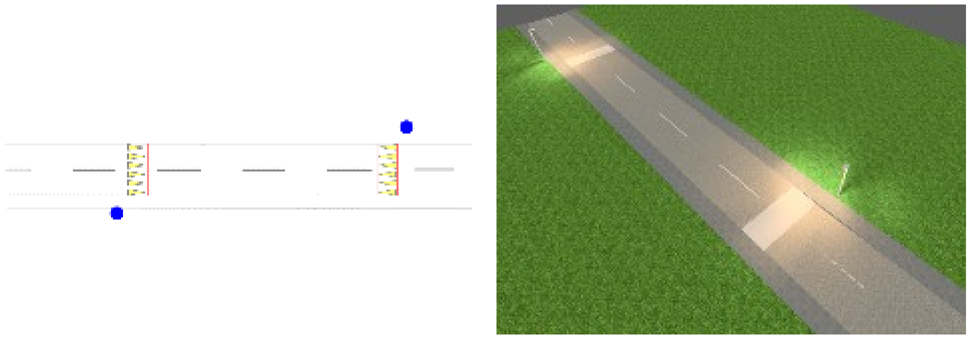


Figure 38: Example of the placement of lamps to illuminate the ramp of trapezoidal shape without pedestrian crossing on the uncongested part of the road within the settlement

7.7.2 Lighting of trapezoidal ramp with pedestrian crossing on the uncongested part of the road

The example below is a ramp on the uncongested part of the road in the settlement. The ramp is illuminated as part of the pedestrian crossing lighting. Additional lighting of the traffic calming device is not required.

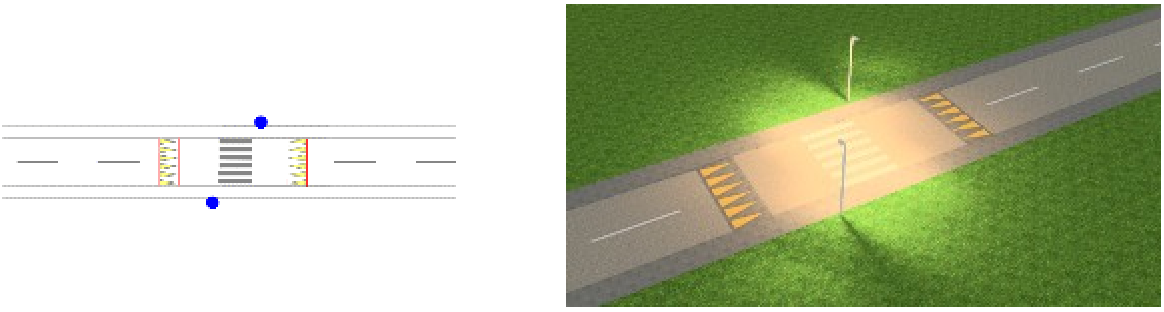


Figure 39: Example of the placement of lamps to illuminate the ramp of trapezoidal shape with a pedestrian crossing on the uncongested part of the road within the settlement

7.7.3 Lighting of trapezoidal ramp with pedestrian crossing on the congested part of the road

The example below is a ramp on the congested part of the road within the settlement. In this case, the ramp is illuminated as part of the lighting of pedestrian areas by lamps on both sides of the road and as part of the pedestrian crossing lighting (see the example of the lighting of the uncongested part of the road by lamps on both sides of the road and follow the guidelines in the Manual for road lighting in the area of crossings for pedestrians and/or cyclists).

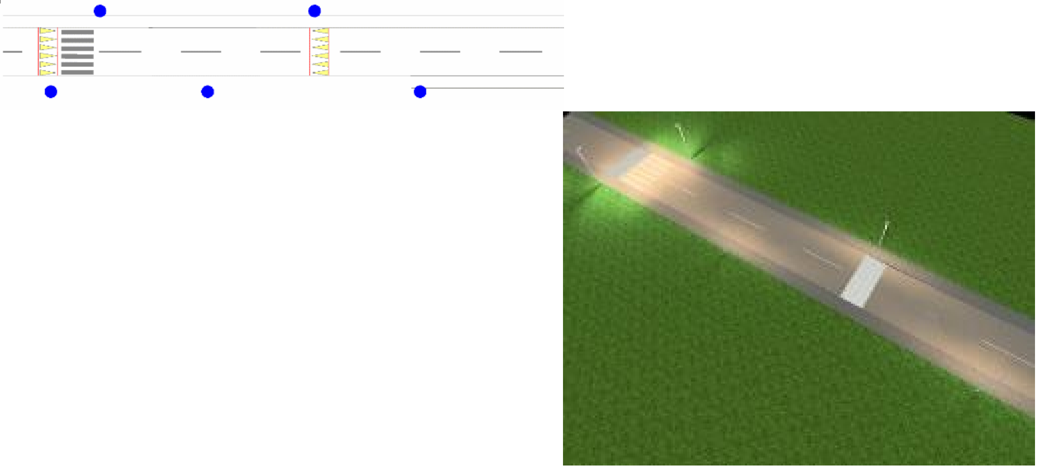


Figure 40: Example of the placement of lamps to illuminate the ramp of trapezoidal shape with a pedestrian crossing on the congested part of the road within the settlement

7.7.4 Lighting of denivelated islands in an intersection

The lamps shall be placed in such a way that all denivelated islands are illuminated. The classified lanes before the intersection shall not be illuminated in this case.

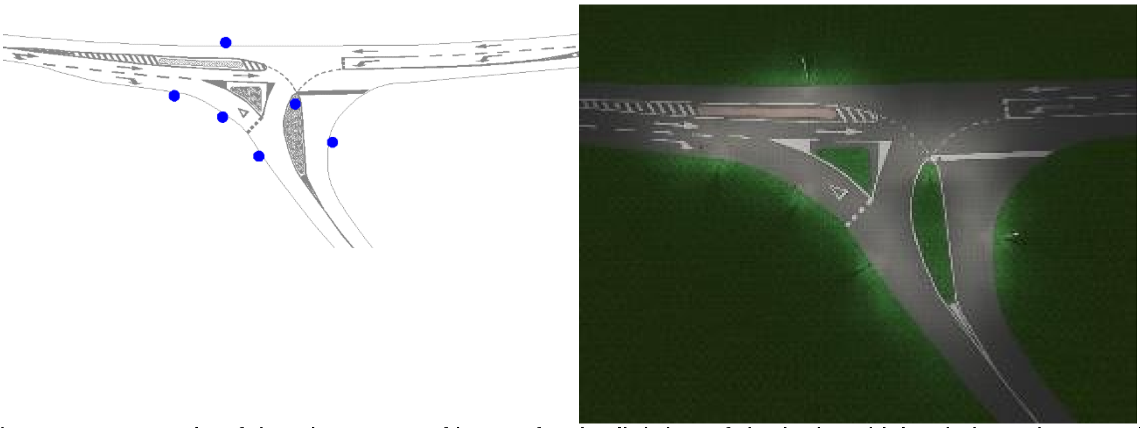


Figure 41: Example of the placement of lamps for the lighting of denivelated islands in an intersection

7.7.5 Lighting of the denivelated island at the bus stop

An example of the lighting of a denivelated island on a bus stop outside the settlement is visible in the first example of bus stop lighting (see subchapter Error: Reference source not found).

7.7.6 Lighting of a denivelated island to offset the axis of the directional carriageway on a road outside a settlement

The lamp shall be placed on the side of the road with an offset of the axis of the directional carriageway on the pole of the corresponding height in relation to the width of the road.

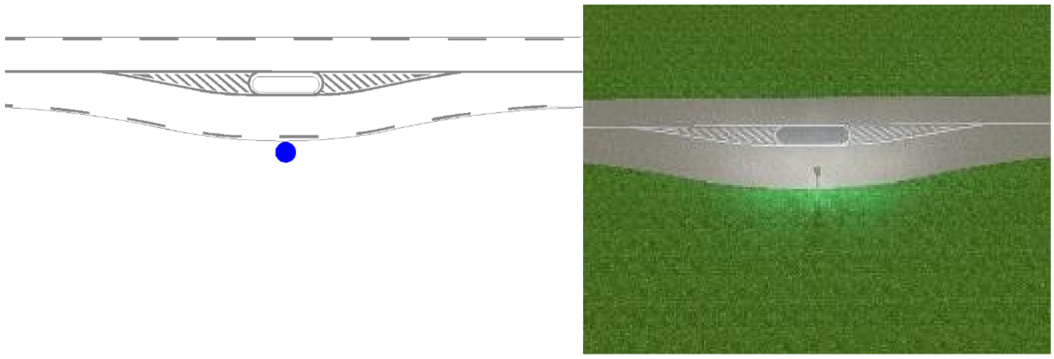


Figure 42: Example of placement of lights for the lighting of a denivelated island to offset the axis of the directional carriageway from one side of the road

7.8 Cycling areas

In urban areas where motor and cycling traffic intersects, adequate lighting is essential to prevent accidents. Cycling crossings that are adequately illuminated are more recognisable to motor vehicle drivers, allowing for a better adjustment of speed and stopping of vehicles when approaching an intersection or crossing for cyclists. This increases the safety of cyclists by giving them better visibility and thus reducing the chance of accidents.

The lighting of cycling areas is prescribed in Article 49 of the Rules on cycling areas. Cycling areas outside settlements are not illuminated.

7.8.1 Cycling crossings in the settlement

Cycling crossings shall be illuminated in accordance with the guidelines in the Manual for road lighting in the area of crossings for pedestrians and/or cyclists. The individual cases are shown and described in the manual. As a general rule, cycling crossings within settlements should be adequately lit.

An example of the lighting of a cycling crossing is also shown in an example of lighting of a turbo roundabout.

7.8.2 Roads in settlements with shared traffic lanes

Roads in settlements with shared traffic lanes shall be illuminated in the same way as the congested parts of roads in the settlement (see the examples of lighting of the congested part of the road in subchapter Error: Reference source not found).

7.8.3 Areas within the settlement where motor and cycle traffic intersect

For areas within a settlement where motorised and cycling traffic intersect, all cycle lane connections to the carriageway for motor vehicles shall apply. For the illumination of areas where motor traffic and cycle traffic intersect and which are not already illuminated by another lighting system (e.g. a congested part of the road), orientation lighting shall be used (a lamp with a luminous flux output of 500 lm mounted on a pole 4 m high and with appropriate optics illuminating only the area of traffic mixing).

Details of selected lamps and mounting

Luminous flux:	500 lm
Installation height:	4 m
Maintenance factor:	0.9

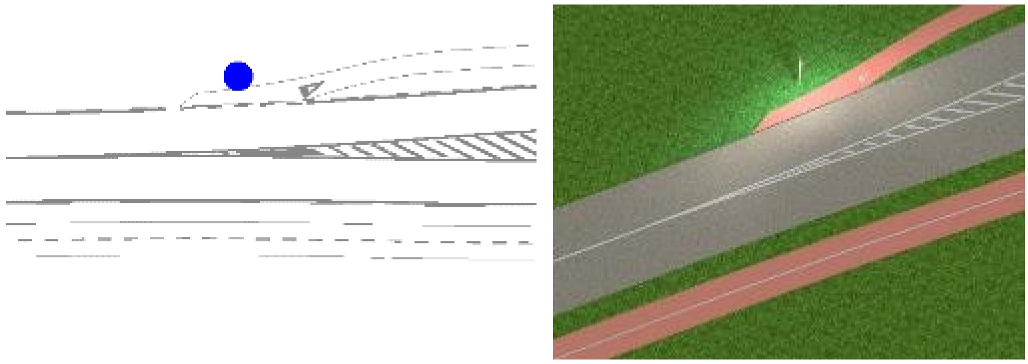


Figure 43: Example of the location of lights to illuminate the area where motor and cycle traffic intersect

Since the cycling areas outside settlements are not illuminated, the connections of the cycle path to the carriageway outside settlements are not being illuminated.

7.8.4 Areas of physical traffic calming devices for cyclists in settlements

The areas of physical traffic calming devices for cyclists in the settlements are illuminated in the same way as traffic calming devices (see examples of lighting of traffic calming devices in subchapter Error: Reference source not found).

8 Carrying out lighting measurements

Measurements of quality indicators of lighting parameters shall be carried out in accordance with standard SIST EN 13201-4.

Depending on the requirements of the lighting classes, the following lighting parameters shall be measured.

For lighting class M, lighting measurements shall be carried out for the assessment of:

- luminance,
- general luminance uniformity,
- longitudinal luminance uniformity,
- edge illuminance ratio.

Measurement of the relative threshold increment cannot be carried out without an imaging luminance meter (ILMD) and corresponding software and is therefore omitted in this document.

For lighting class M, lighting measurements shall be carried out for the assessment of:

- horizontal illuminance,
- illuminance uniformity.

When measuring lighting parameters at pedestrian and/or cyclist crossings, lighting measurements to assess vertical illuminance shall also be carried out.

For lighting class P, lighting measurements shall be carried out for the assessment of:

- horizontal illuminance (medium and minimum),

If facial recognition is also required, lighting measurements for lighting class P shall also be carried out for the assessment of:

- vertical illuminance, and
- semi-cylindrical illuminance.

8.1 Measuring instruments

Depending on the measurement objective pursued, the maximum expanded measurement uncertainty of the results given must be determined in accordance with the CIE 198:2011 and SIST EN 13201-4 documents. When making decisions based on measurements of the electricity consumption of road lighting or any other parameter of SIST EN 13201-5, the impact of measurement uncertainty must also be taken into account.

Instruments for measuring lighting properties must be evaluated in accordance with SIST EN 13032-1 regarding all relevant properties. The influence of these properties on the measurement result must be evaluated in the measurement uncertainty model.

In order to ensure measurement traceability, all instruments used must be calibrated in the measuring ranges used.

The measuring properties of the instruments used must be consistent with the purpose of the measurement. Luminance must be measured with a luminance meter whose properties are appropriate for the purpose of the measurement. Illuminance must be measured with an illuminance meter whose properties are appropriate for the purpose of the measurement.

8.1.1 Requirements for the luminance meter

Luminance measurements can be made with a spot luminance meter or with an imaging luminance meter (Imaging Luminance Measurement Devices – ILMD).

For both types of luminance meters, the influence of light sources located outside the measurement field must be taken into account and/or evaluated.

The meter must provide at least three significant digits or figures. This means that the resolution of the meter shall be at least 0.01 cd/m^2 in the measuring range up to 9.99 cd/m^2 and at least 0.1 cd/m^2 in the measuring range up to 99.9 cd/m^2.

The meter must meet accuracy class A (according to DIN 5032-7).

Regardless of the type of luminance meter, when measuring the luminance at the grid points, the size of the measured surface shall not be more than 2 arc minutes in the vertical plane and not more than 20 arc minutes in the horizontal plane. The measuring field angle of the instrument must not be less than 1 arc minute.

The field of observation according to SIST EN 13201-3 starts 60 m from the observer (location of the luminance meter). The maximum values of the measuring cone angles from the luminance meter are set so as to avoid overlapping of the observed surfaces at this distance.

With the given requirements for the luminance meter, the observed distance of 60 m between the meter and the beginning of the observation field and the height of the meter installation of 1.5 m, the measured area of each measuring point on the ground is 0.36 m wide at the beginning of the observation field and 0.51 m at the end of the 30 m long observation field and 1.47 m long at the beginning of the observation field and 3.04 m at the end of the 30 m long observation field (Figure 42).

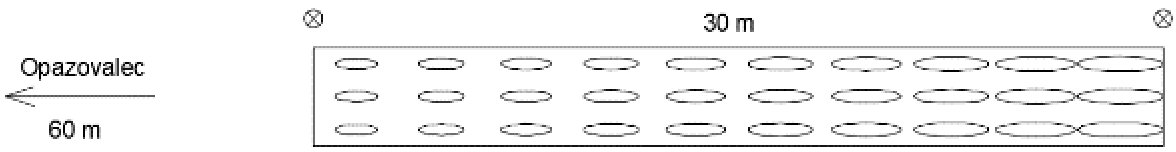


Figure 44: Size of the measurement point surface when measuring luminance with a suitable instrument

If luminance measurements are made at a distance of less than 60 m, it is recommended that the luminance meter's measuring cone does not exceed 30 arc minutes. The size of the measured surface of each point on the carriageway may not be greater than 0.5 m transversely and not more than 2.5 m longitudinally. Also in this case, the surfaces of the measuring points shall not overlap.

8.1.2 Requirements for the illuminance meter

Both horizontal and vertical illuminance must be measured with an illuminance meter (lx-meter). The meter must meet accuracy class A (according to DIN 5032-7). To measure the horizontal illuminance, the measuring head must be fitted with a gimbal or spirit level allowing for its horizontal installation.

In order to measure vertical illuminance, the measuring head must be placed in a suitable tripod that ensures its vertical position. Here as well, the use of a gimbal or spirit level is recommended.

The meter must provide at least three significant digits or figures. This means that the resolution of the meter shall be at least 0.01 lx in the measuring range up to 9.99 lx and at least 0.1 lx in the measuring range up to 99.9 lx.

The meter, together with the measuring head (or heads, if different heads for horizontal, vertical and semi-cylindrical illuminance are used), must be properly calibrated with the indicated traceability to the International System of Units (SI).

8.2 Measured sections

The measurements must address the entire surface of the road lighting installation at all operating regimes (lighting classes).

If the lighting properties are designed in the same way for the entire length of the road lighting installation, a certain number of sections can be selected and measurements (measured sections) are taken on them. In this case, the reasons and explanation for such measurement and the consequences of such measurement must be recorded in the measurement report. One of the most common criteria for selecting a particular section is the voltage drop in the supply line or the distance between lamps. The section with the maximum voltage drop or the section with the maximum distance between the lamps shall be selected.

8.3 Measured parameters

On the measured section, it is also necessary to measure geometrical data (distance between poles, width of the carriageway and lane). These data must be measured or known in order to establish the origin of the coordinate system and to determine the measurement points.

The location, inclination and orientation of the illuminance meter sensor (in the case of illuminance measurements) or the location of the measured surface (in the case of luminance measurements) with respect to the measurement points shall be recorded in the measurement report.

For illuminance measurements, the z-coordinate (the height of the sensor surface above the road surface) must also be recorded in the measurement report.

Measurements to verify compliance with the requirements of the standard shall examine all lighting quality parameters for the selected lighting class.

A reduced number of parameters may be used if the client or operator also agrees and this choice is also taken into account in the design of the installation of road lighting.

Measurements to verify compliance with the requirements of the project brief shall examine the parameters as determined and taken into account in the design of the road lighting installation.

The weather and environmental conditions (temperature, moisture, light imposed) must also be recorded in the measurement report. If the supply voltage may affect the operation of the lighting, voltage measurements must also be carried out and reported. Most modern LEDs are not sensitive to supply voltage changes within the U_n±10% range.

The report shall include a diagram or sketch of the location with the lamps, measuring field and measuring points drawn. The diagram/sketch must uniquely indicate the measurement location.

8.4 Conditions for measurements – stabilisation after activation

The lamps need a certain amount of time to stabilise their luminous flux. All measurements shall be carried out once the stabilisation period has been completed.

If there are concerns about the luminous flux stability of the road lighting installation during the measurement, control measurements should also be carried out. This is done by measuring illuminance at the same place or points at regular intervals to ensure that stability is achieved and maintained before and during the period of measurement of the lighting parameters of the road lighting installation.

Such measurements shall also be carried out when there is a possibility that the luminous flux of the lamps may decrease during the measurement due to the automatic activation of the reduction.

For this purpose, a “Data logger” can be used, allowing the storage of illuminance values along with time. It is proposed to store illuminance values within a 1-minute interval. For possible correction of measured results on full luminous flux from measurement at time of reduction, the time of measurement must also be recorded in the evaluation field at the individual measurement. It is recommended to use an alarm on the “data logger” to immediately alert the measurer that the lamps have entered the reduced luminous flux mode. If, in this case, measurements continue, it is necessary to wait for the lamps to stabilise again when the power is reduced.

8.5 Weather conditions

The weather conditions must be such that they do not significantly affect the measurements. Under certain weather conditions, atmospheric absorption significantly reduces the illuminance level or changes the measured luminance.

If the weather conditions at the time of measurement do not constitute normal conditions, the measurements must be postponed.

8.5.1 Measuring instruments

High or low temperatures and condensation or moisture on the surfaces of the measuring instruments may affect calibration and accuracy of the measuring instruments. Due to high wind speeds, measuring instruments may vibrate or oscillate.

The impact of weather conditions on the operation of the instrument shall be taken into account by applying correction factors. These effects shall be taken into account in the assessment of the measurement uncertainty.

If the weather conditions are outside the range of known correction factors, the measurements should be postponed.

8.5.2 Installation of road lighting

High or low temperatures or high wind speeds may affect the output luminous flux of thermally sensitive light sources or lamps.

High wind speeds may cause the lamps to oscillate/swivel.

The transmittance of the atmosphere will have a significant effect on the light that will reach the surface under consideration and, in the case of luminance measurements, will also affect the light reflected from the measured surface to the luminance meter.

Luminance measurements shall only be performed when the road is completely dry. Slight moisture on the carriageway can significantly affect the luminance of the road surface.

If the weather conditions at the time of measurement do not constitute conditions used in the design phase of road lighting, the measurements must be postponed.

8.5.3 Carriageway conditions

The photometric characteristics of the road surface may change significantly over time, especially during the first three years.

In the case of luminance measurements on a new road surface, the measured values may differ from the expected values, because the actual luminous intensity is different from that used in the design phase (measured or obtained from standard road surface tables).

In this case, the lighting conditions on the carriageway can be assessed by comparing the illuminance measurements and the luminance calculation (the procedure is explained in the informative Appendix E of SIST EN 13201-4:2014).

8.5.4 Imposed light and obstacles / Ambient light

When measurements are intended to evaluate only road lighting, direct or reflective ambient light must be prevented or evaluated. The measures taken for this must be recorded in the measurement report.

When taking measurements, areas that do not contain obstacles that cause shadows must be selected. These may include trees, parked cars or urban furniture. The presence of any obstacles should be recorded in the measurement report.

Any shadow from the measurer should be minimised. Care must be taken that the personnel performing the measurements or the equipment used do not obscure the light that would otherwise reach the photometric head (illuminance measurement) or the measured road surface (luminance measurement) or reflect light that would otherwise not reach the photometric head or measured road surface.

8.6 Photometric measurements – Location of the measuring points

The position of the grid points at which measurements are taken shall be the same as that determined by SIST EN 13201-3:2014.

If permitted by the tender or agreed with the client, measurements may be made at a smaller number of points, using at least 50 % of the standard grid points, or using an alternative grid of measurement points. The simplified grid or alternative grid must have an even distribution of points in the considered area, which is used to define the entire grid (see SIST EN 13201-3:2014).

The accuracy of the location of the metering points must be included in the assessment of the measurement uncertainty.

8.7 Luminance measurements

8.7.1 Observer location (luminance meter) and location of metering points

For luminance measurements, the observer position must be the same as defined by SIST EN 13201-3:2014, i.e. 60 m before the start of the evaluation field. The observer's position is in the middle of the lane. The height of the sensor shall be exactly 1.5 m at a measuring distance of 60 m, which is the average eye height when driving a car.

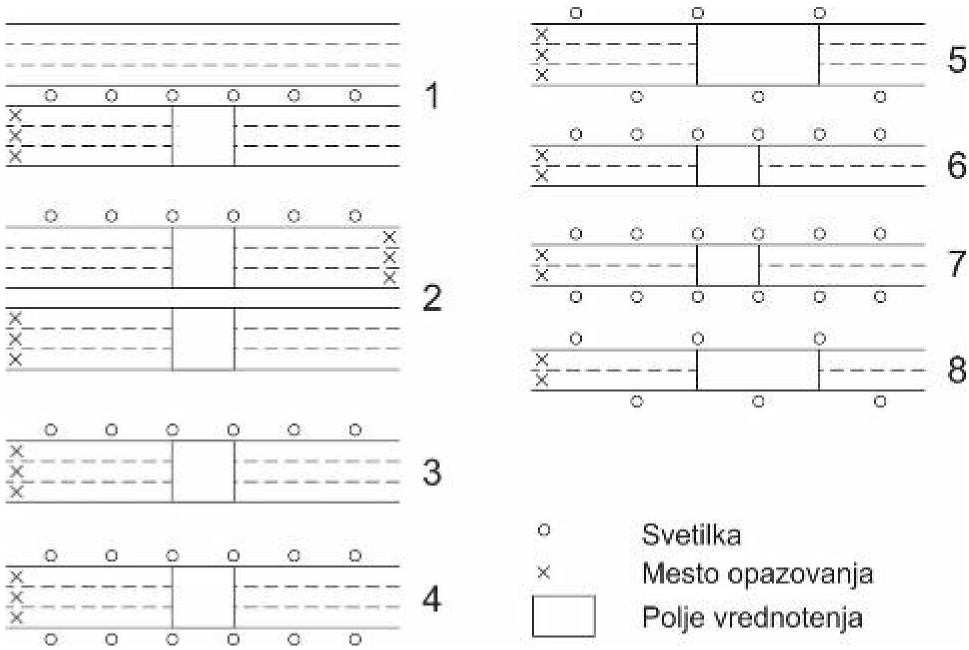
The measurement can be carried out at a smaller distance and at a proportionately lower height. However, the visual angle of the meter must be (89 ± 0,5)° with respect to the normal to the road surface. Thus, at a measuring distance of 40 m, the meter is installed at a height of 1 m and at a measuring distance of 20 m it is installed at a height of 0.5 m.

The accuracy of the observer's location must be included in the assessment of the measurement uncertainty.

The luminance meter shall be placed on the centreline of each lane!

In the transverse direction, the observer position (meter) must be in the middle of each lane. The average luminance value, the general luminance uniformity and the relative threshold increment shall be calculated for the entire carriageway (the evaluation field) for each observer position. The longitudinal luminance uniformity is calculated at the centre line of each lane. If there are several lanes on the carriageway, the lowest of the measured/calculated values shall be taken as the result of the average luminance, the general luminance uniformity and the longitudinal luminance uniformity. As a result of the relative threshold increment, the maximum of the measured values must be taken into account.

The figure below shows some of the most common examples of how the observer is positioned in relation to the field of evaluation.



1 Six-lane road with a central green lane and a double central distribution of lamps
2 Six-lane road with a central green lane and a single-sided distribution of lamps
3 Three-lane road with a one-sided distribution of lamps
4 Three-lane road with a double-sided distribution of lamps
5 Three-lane road with a double-sided offset distribution of lamps
6 Two-lane road with one-sided distribution of lamps
7 Two-lane road with a double-sided distribution of lamps
8 Two-lane road with a double-sided offset distribution of lamps

Figure 45: Observer locations according to the evaluation field

The measurement points within the evaluation area are determined for each traffic lane separately. Within the lane, the points are arranged in a rectangular grid where the longitudinal distance between the individual points is equal to:

$$D=\frac{S}{N}$$

where:

- *D* is the longitudinal distance between two measuring points (m);
- *S* is the distance between two lamps (m).
- *N* is the selected number of longitudinal measurement points in the field of evaluation, whereby the following must apply:
  if $S \leq 30$ m, N=10,
  if $S > 30$ m, N is the minimum integer used to obtain $D \leq 3$ m.

The transverse distance between the individual points is equal to:

$$d=\frac{W_L}{3}$$

where:

- *d* is the transverse distance between two measuring points (m);
- W_L is the width of the evaluation area – lane width (m);

The points are positioned so that the distance between the edge of the evaluation area and the first longitudinal row of measuring points is equal to *d*/2.

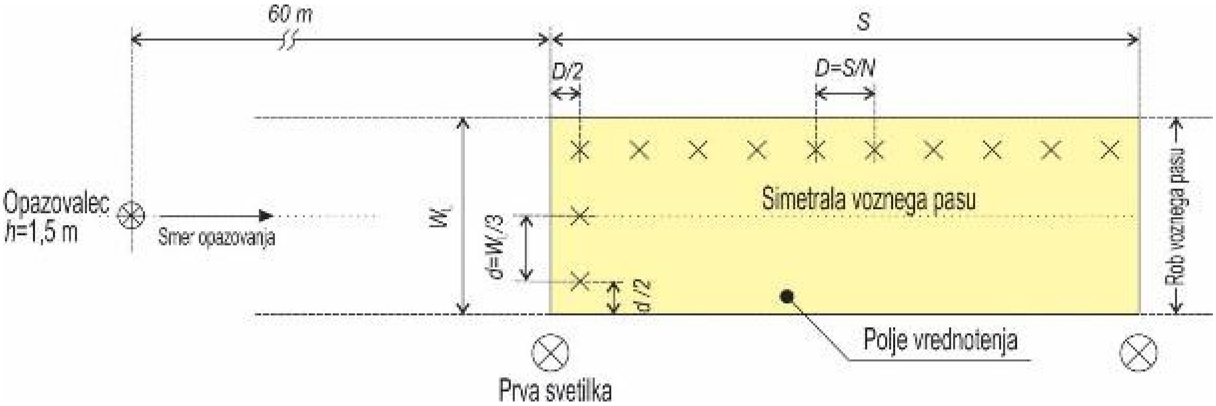


Figure 46: Placement of measuring points in each lane for luminance measurement

8.7.2 Selection of metering points

If some points of the measuring grid are located on the horizontal road markings (arrow, line, zebra, crossing over the road), they are not taken into account when determining the average value of luminance and uniformity. However, these points shall be recorded in the measurement report.

Some points of the grid may be located in the shade of the facility (tree) or in the oil stain, etc. In such cases, it is recommended to exclude these points when determining the average value of luminance and uniformity, but they should nevertheless be recorded in the measurement report. Alternatively, the measured values may be assessed using algorithms in Informative Annex B of SIST EN 13201-4:2014.

The minimum and maximum measured luminance values on the surface under consideration shall be indicated in the measurement report.

8.7.3 Measurement of the average luminance value

The average luminance value shall be calculated as the average luminance value measured at the entire evaluation field or with one reading of the relevant road surface area when using an imaging luminance meter.

Note: For the calculation of the average luminance value, the measured values on all lanes at one observer position shall be taken into account. For example, in situations 6, 7, 8 in Figure 45, the luminance of both traffic lanes is measured twice, and in situations 1-4, the luminance of all three lanes is measured three times.

8.8 Illuminance measurement

8.8.1 General

Each of the four different types of illuminance may be measured, depending on the lighting class or classes of road lighting. These are:

- horizontal illuminance,
- hemispherical illuminance,
- semi-cylindrical illuminance,
- vertical illuminance.

8.8.2 Measurement points grid

The position of the grid points at which measurements are taken shall be the same as that determined by SIST EN 13201-3:2014. The location of the points is shown in the figure below.

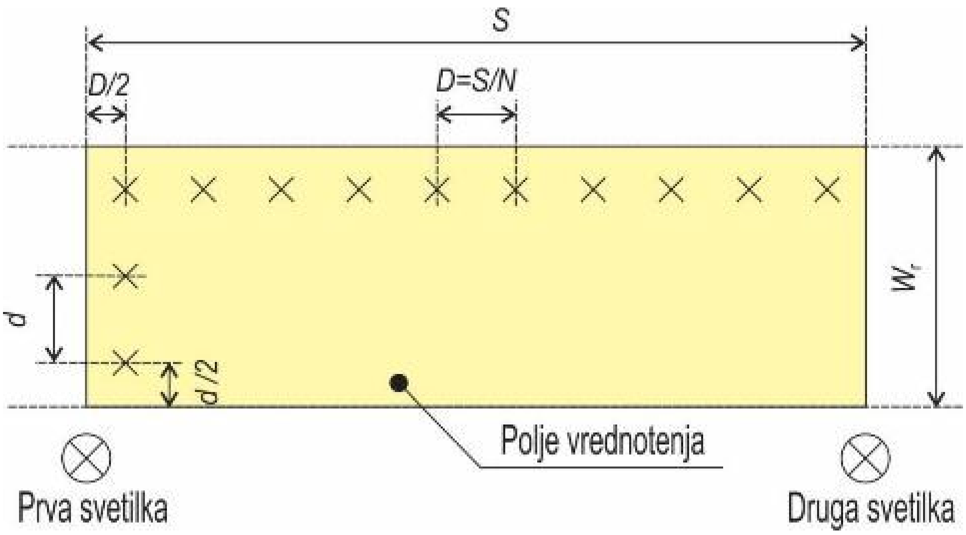


Figure 47: Measuring grid when measuring illuminance

The measuring points must be evenly distributed over the evaluation field. The number of points is determined according to the rule below. The longitudinal distance between the individual points is equal to:

$$D = \frac{S}{N}$$

where:

- *D* is the longitudinal distance between two measuring points (m);
- *S* is the distance between two lamps (m).
- *N* is the selected number of longitudinal measurement points in the field of evaluation, whereby the following must apply:
  - if $S \leq 30$ m, N=10,
  - if $S > 30$ m, N is the minimum integer used to obtain $D \leq 3$ m.

The transverse distance between the individual points is equal to:

$$d = \frac{W_r}{n}$$

where:

- *d* is the transverse distance between two measuring points (m);
- W_r is the width of the lane or the width of the evaluation field (m);
- n is the number of points in the transverse direction, which may be 3 or more, or the minimum integer, greater than 2, used to obtain $d \leq 1.5$ m

8.8.3 Measuring grid on surfaces of irregular shape

For surfaces of irregular shape and if the spacing between the lamps is not uniform, it is difficult to connect the spacing of the grid points to the spacing of the lamps. In this case, a measuring grid shall be made where the distance between the measuring points in any direction shall not exceed 1.5 m. The main directions of traffic flow when calculating vertical and semi-cylindrical illuminance shall be determined according to the use or probable use of the measured area.

Example of determination of measurement points for illuminance measurement

Roundabout with one lane.

Inner diameter: 7.5 m

Outer diameter: 15 m

We calculate the width of the lane, which is 7.5 m. As there is only one lane, there are 3 points in the grid of measurement points in the transverse direction. We take into account that the first point is separated from the inner circle by half the distance between the points. Depending on the width of the lane, which is 7.5 m, the distance between the points is 2.5 m. The distance between the points in the longitudinal direction must not be more than 3 m. Therefore, on the outer concentric circle of the measuring points, which has a calculated diameter of 13.75 m and a circumference of 86.4 m, we determine 30 points. Thus, the distance between the measuring points on this circle will be approximately 2.9 m. Also on the inner two circles, we choose 30 points so that the measuring grid is correct. On each arm, we add 9 more measurement points on each lane.

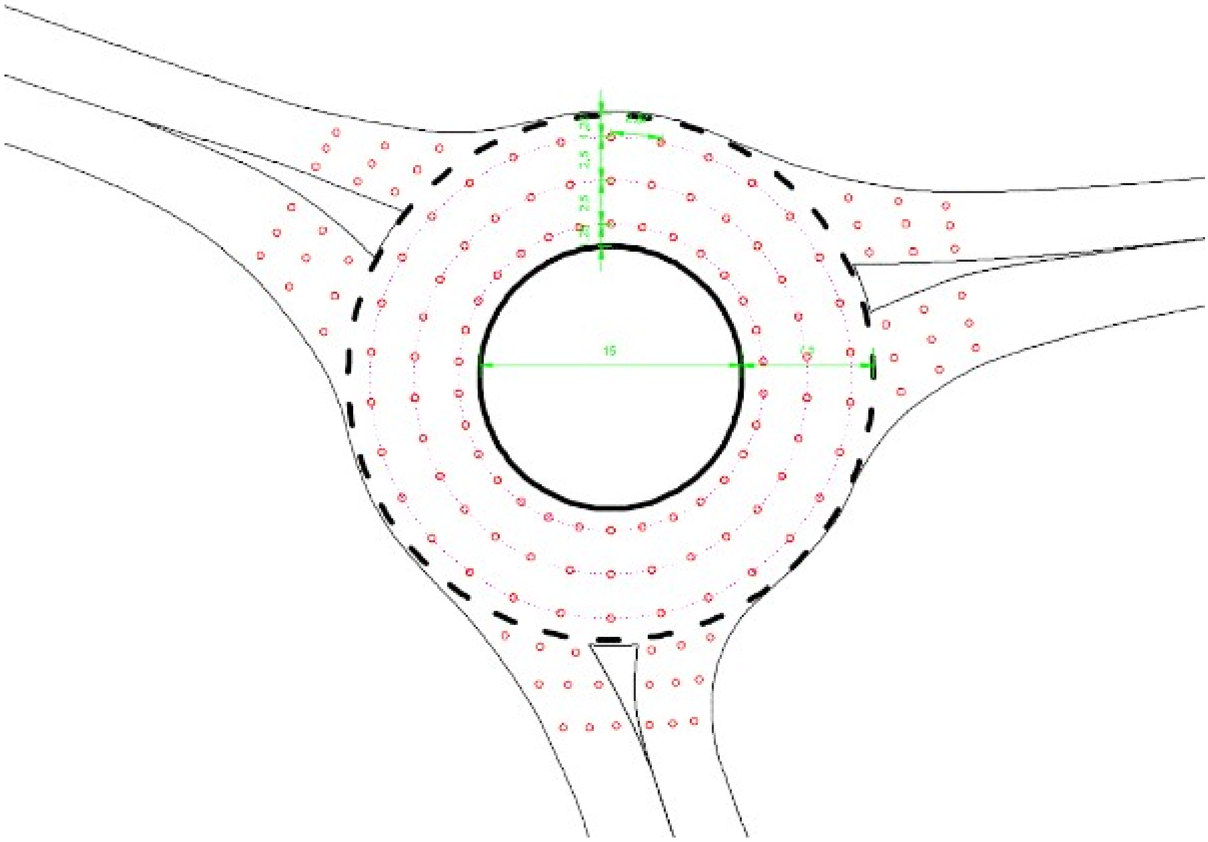


Figure 48: Example of a measuring grid when measuring illuminance at a roundabout

8.8.4 Selection of metering points

Some points in the grid can be located in the shade of structures (i.e. Trees). In such cases, it is recommended that these points be excluded when calculating the average and/or minimum illuminance and uniformity values. Nevertheless, the illuminance values at these points shall be recorded in the measurement report. Alternatively, the measured values may be assessed using algorithms in Informative Annex B of SIST EN 13201-4:2014.

8.8.5 Measurement of horizontal illuminance

When measuring horizontal illuminance, the photosensitive surface of the photometric head must be horizontal or parallel to the normal road surface plane.

The height of the photosensitive surface of the photometric head (measurement height) shall be indicated in the measurement report.

Theoretically, the photosensitive surface of the photometer head must be placed on the ground, but this is generally not possible due to the detector's thickness and any supports, e.g. gimbal/cardan/stabiliser.

The measurement must be carried out no more than 10 cm above the road surface.

The influence of measurement height must be taken into account in the measurement uncertainty. If possible, a correction factor for the measurement height shall be determined. In this case, the measurement uncertainty shall take into account the corrected value of the illuminance and the influence of the uncertainty of the correction factor.

8.8.6 Measurement of hemispherical illuminance

The hemispherical illuminance at a point can be measured with an illuminance meter for measuring illuminance in the plane by the following procedure. Horizontal illuminance $E_{h,m}$, which is the contribution of all lamps, shall be measured at the point. The component $E_{l,m}$ shall be measured as the contribution of an individual l-th lamp. The photosensitive surface of the photometric head shall be turned in such a way that the light hits it at a right angle from the lamp under consideration and all other light is excluded. The measured hemispherical illuminance $E_{hs\,m}$ is given:

$$E_{hs,m}=\left(\frac{1}{4}E_{h,m}+\sum_{y=1}^{n_{lu}}E_{l,m}\right)$$

where:

$E_{h,m}$ is the measured horizontal illuminance, which is the contribution of all road lighting lamps.

$E_{l,m}$ measured rectangular illuminance due to the l-th lamp

n_{lu} number of road lighting lamps

The other conditions for measuring hemispherical illuminance are the same as those for horizontal illuminance.

8.8.7 Measurement of semi-cylindrical illuminance

Semi-cylindrical illuminance at a point can be measured with a meter for measuring semi-cylindrical illuminance (Figure 49).

Figure 49: Meter for measuring semi-cylindrical illuminance

The centre of the photosensitive surface of the photometric head must be located at a height of 1.5 m above ground level. The photosensitive surface of the photometric head must be vertical and correctly oriented, usually facing longitudinally to the principal direction of pedestrian movement.

The semi-cylindrical illuminance at a point can be measured with an illuminance meter for measuring illuminance in the plane by the following procedure. At the point, the vertical illuminance is measured in the three main directions where the sensor semi-cylinder would be pointing. The semi-cylindrical illuminance is the average of these three vertical illuminance values.

8.8.8 Measurements of vertical illuminance

The centre of the photosensitive surface of the photometric head must be located at a height of 1.5 m above ground level according to the grid points defined in SIST EN 13201-3. The photosensitive surface of the photometric head must be placed vertically and correctly oriented, usually at right angle to the main directions of pedestrian movement.

8.8.9 Additional requirements for static measuring systems

When measuring illuminance, in order to reduce the effects of measuring systems or meters, an illuminance meter with a photometric head attached to the meter with a cable or an illuminance meter with a cable for freezing the measured value shall be used. The cables must be long enough so that the meters can be positioned in such a way that they do not obscure the light that would otherwise reach the photometric head.

The use of stabilisers (gimbals) facilitates the task of maintaining the photometer head at the correct inclination with respect to the normal plane of the road.

When measuring horizontal illuminance, the measurement height must be within 100 mm of the ground. If road lighting lamps are located at a height of less than 2 m, the photometer head may be located no more than 50 mm from the ground, unless the illuminance values are also calculated at the actual measurement height.

8.8.10 Measurement of the edge illuminance ratio (REI)

The edge illuminance ratio shall be measured in accordance with the requirements for the measurement of horizontal illuminance and the measurement grids specified in the preceding chapters.

When the measured illuminance values in the grid points are known, the edge illuminance ratio shall be calculated using the following equations, summarised according to SIST EN 13201-3: 2015:

$$R_{EI\,12,m} = \frac{\overline{E}_{h,\,pas\,1,m}}{\overline{E}_{h,\,pas\,2,m}}$$

$$R_{EI\,43,m} = \frac{\overline{E}_{h,\,pas4,m}}{\overline{E}_{h,\,pas3,m}}$$

$$R_{EI,m} = min\left(R_{EI\,12,m}, R_{EI\,43m}\right)$$

In some cases, measurements of illuminance in areas outside the carriageway are difficult or impossible to perform. In these cases, the edge illuminance ratio cannot be calculated, but the measurement report shall nevertheless give the ratios between the measured average horizontal illuminance and the calculated average horizontal illuminance of the same lanes of the carriageway.

NOTE For example, if these areas are not accessible, are not level or there are barriers or objects that cause shadows.

8.8.11 Measurement of the threshold increment (f_{TI})

If necessary, the threshold increment may be measured using the procedure described in SIST EN 13201-4: 2015.

8.8.12 Measurements of illuminance on pedestrian crossings

Measurements of lighting parameters at pedestrian and cyclist crossings shall be carried out in accordance with the Manual for road lighting in the area of crossings for pedestrians and/or cyclists.

8.9 Measurements of non-lighting parameters

8.9.1 General

The selection of non-lighting measurements must be coordinated for the purpose of the measurements. If measurements are carried out for comparison with requirements, it is recommended that precise measurements of non-lighting parameters be carried out.

When measurements are taken to monitor the state of road lighting, it is possible that less detailed measurements of non-lighting parameters will be sufficient

8.9.2 Power voltage

If necessary, a continuous measurement of the power voltage or at least the voltage values at the beginning and end of the measurement shall also be carried out during the measurement of lighting parameters. The measurement shall be carried out at a significant point of the electrical installation in such a way that any changes can be observed. To carry out these measurements, it is proposed to use a V-meter with a recording function. If the luminous flux of the lamps in the road lighting is considered to be independent of the changes in the power voltage, no continuous measurement of the power voltage is required.

8.9.3 Temperature and humidity

If necessary, temperature and humidity shall be measured at a height of 1 m above the ground. They shall be recorded at least at the beginning of the measurements, but may also be recorded several times during the course of the measurement.

8.9.4 Geometrical data / Situation

If necessary, measurements of the geometry of the road lighting installation shall be taken (see Informative annex E of SIST EN 13201-4).

These measurements may include measurements of installation situation, poles height and overhang length. In addition, the inclination of the installation of the lamps, the orientation of the lamps and the rotation of the lamps shall be assessed, if this information is important for achieving the measurement objectives.

8.9.5 Instruments for non-lighting measurements

The measurement of non-lighting parameters relevant to the measurement objectives/purposes shall be carried out with calibrated instruments.

The decision to use non-calibrated instruments for certain non-lighting parameters shall be indicated in the measurement report. For these parameters, the measurement uncertainty is not estimated.

8.9.6 Measurement report

The measurement report must contain at least:

- measurement subject/facility;
- the place and time of measurement. In the case of a road, the location shall contain the code of the road, section and mileage;
- ambient temperature and humidity;
- a drawing or aerial image of the valuation field with the surrounding area. The position of the observer and the position of the measuring points must be unambiguously determined on the drawing and in the results table;
- all information collected during the measurement, if relevant for the purpose of the measurement;
- details of the instruments used, their identification/serial number for unambiguous identification and their calibration conditions (date, validity and metrological traceability);
- details of weather and environmental conditions and the electrical properties of the power supply;
- a brief description of the procedures used in the measurement and data processing, including an assessment of the measurement uncertainty. (If the Contractor has a method of work described in a separate document, it is sufficient to refer to the method.)
- the measurement results with their measurement uncertainty for the full luminous flux and for all luminous flux reduction stages;
- the reason, justification and consequences of the selection of road lighting installation areas, if measurements are not taken over its entire length;
- measures taken to avoid or take account of direct or reflected light from the surroundings;
- all other information referred to in the preceding chapters;
- the reduction rate or programmed reduction rates, if present;
- a description of the measuring equipment used;
- a description of the lighting device;
- identification of the observed deficiencies of the lighting device;
- meter calibration certificate;

The person responsible for taking the measurements must sign the measurement report.

8.9.7 Assessment of measurement results

When carrying out a measurement to assess conformity with the required project conditions, it is necessary to compare the measurement results with the calculations. In the conformity assessment, it should be taken into account that the calculations have been carried out with the maintenance factor taken into account, and measurements are usually carried out when the lighting is completely new and there has not yet been a reduction in the luminous flux of the light sources. The measurements thus carried out are not directly comparable with the calculations. In order to make a correct comparison, we have two procedures:

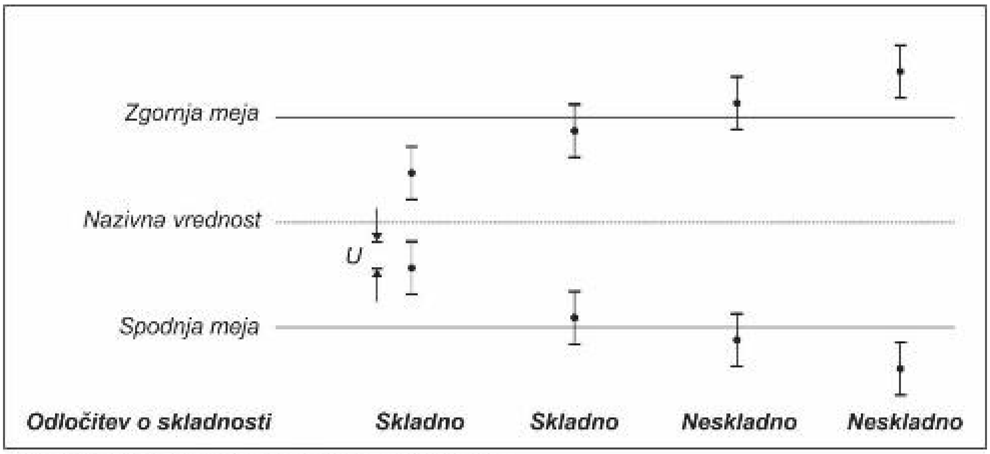
1. Calculations shall be repeated taking a maintenance factor of 1.0 into account. These calculations are directly comparable to measurements of the new road lighting installation.
2. If it is not possible to repeat the calculations with a maintenance factor of 1.0, the values of luminance and illuminance are divided by the maintenance factor in the results of the calculations. These values are comparable with measurements of the new road lighting installation.

If lamps are installed with ballasts that allow the “Constant Lumen Output” function and this function is enabled, then the results of the measurements and calculations can be directly compared.

When the results of the measurements carried out are compared with the requirements of the project conditions or the requirements of lighting classes, the measurement results must be multiplied by the maintenance factor. These corrected results are compared with the requirements.

Similarly, the measured results shall be corrected if the measurements were taken when the lamps were in the reduction of the luminous flux. The corrected result is compared with the requirements.

When making a decision on compliance with the requirements, the decision-making rule must be clearly specified (Figure 50 and Figure 51)



U = 95% razširjene merilne negotovosti meritve

Figure 50: Decision-making rule without taking into account the measurement uncertainty

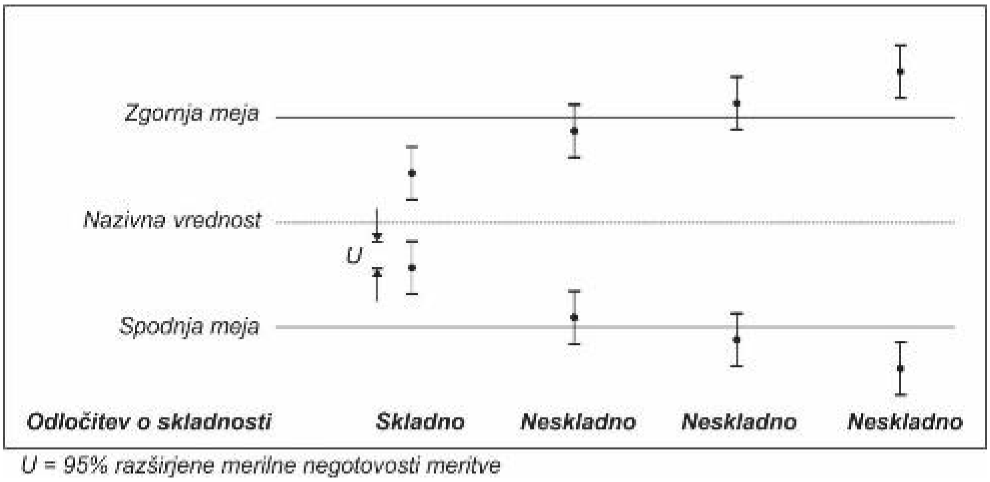


Figure 51: Decision-making rule taking into account the measurement uncertainty

9 Other technical requirements for the design and execution of road lighting

9.1 Technical requirements for installed equipment

When preparing the tender documentation or the request for quotation, the technical requirements to be met by the lamps should be described as precisely as possible. The technical requirements should include all important lighting, electrical, mechanical and design data of the lamps, but should not restrict competition too much. The requirements are set out below, which may, however, be extended or reduced for the needs of the individual tender documentation.

The Client should reserve the right to request samples of the lamps offered for the purpose of technical evaluation of the offers, i.e. verification of the required technical characteristics.

9.1.1 Evidence to demonstrate compliance with technical requirements

As evidence that the lamps offered meet the required technical characteristics, tenderers are requested to provide the following for the lamps offered:

- a technical data sheet with all the required data,
- ENEC or ENEC+ certificate, if deemed necessary,
- EU Declaration of Conformity, certified by the lamp manufacturer,
- calculation of illumination in case the requirements of SIST EN 13201-2 or other requirements are specified in the tender specifications,
- the photometric data of the offered lamps in digital form in LDT or another comparable format.

If any of the technical characteristics of the offered lamps are not evident from the available technical data sheets or technical catalogues, as proof of the technical characteristics of the offered lamps, the tenderer may provide a certified declaration from the producer of the lamps.

All documentation submitted must be in Slovenian. If any of the documents submitted by the tenderer as evidence is written in a foreign language, the tenderer must submit it together with a certified translation into Slovene by a certified court interpreter.

9.1.2 Lighting requirements

The Client ordering the lighting for the section under consideration shall provide all relevant information to the designer, who shall determine the lighting class of the section. **The information necessary to determine the lighting class shall be provided by the responsible project manager in cooperation with the road manager**. When the lighting class is known, the minimum requirements for parameters (SIST EN 13201-2) describing the quality of road lighting are also known.

The tenderer himself determines the power, luminous flux and optics of the lamp to meet the required conditions.

We propose to require that the calculations are made in the free software packages DIALux or Relux, so that the client can check them himself. This also makes it easier to compare the calculations of the different tenderers and to prevent or find possible manipulations in the calculations.

The results of the calculations must be in Slovenian.

The following data must be clearly visible in the results:

- total power of the lamp (including losses in the ballast),
- the output luminous flux of the lamp, which must take into account any losses on the lens, reflectors and/or protective glass,
- similar colour temperature of light,
- colour appearance index,
- light efficiency of the lamp (lm/W),
- ULOR.

In the luminance calculations, basic data on the surface being processed must also be entered. If these data cannot be obtained, it is proposed to select a typical carriageway material R3 with a luminous intensity Q_0=0.07 cd·m^{-2}·lx^{-1}.

The maintenance factor used also depends on the lamps and the maintenance of the luminous flux of these lamps. In modern light sources, a maintenance factor of 0.9 is usually used, but if a permanent luminous flux function (CLO, or comparable) is enabled in the ballast, a maintenance factor of 0.95 may be used.

The optical system of the lamp shall comply with the Regulation on the limit values for light pollution of the environment (ULOR=0) and shall ensure a limitation of glare class G*3 to G*6 according to the requirements given in SIST EN 13201-2.

Similar colour temperature of light should be 2700 K and 2200 K in nature protection areas. The colour appearance index (Ra, CRI) shall be greater than 70. Lamp service life: at least 60,000 hours (the methods by which the service life is determined may be: L80B20, L80B10, L70B10, L80 – Ta 25°C). There is no need for MacAdam ellipse requirements for street lighting lamps.

9.1.3 Electrical characteristics

The lamps shall have a supply carried out in such a way that when the lamp cover or the electrical part is opened, the supply is interrupted and all essential parts of the lamp (power supply, communication module, LED module) are without power supply.

The lamps must operate smoothly in the voltage range from 207 to 253 V (230 V (1±10%)).

Adequate overvoltage protection must be installed. Lamps must be resistant to overvoltages of at least up to 10 kV or more.

The lamp must have thermal protection installed that reduces the luminous flux or even shuts off the lamp when critical values are exceeded.

Each lamp must have a suitable connection electrical cable (power supply and communication). The minimum cross-section of each conductor is 1.5 mm^2, the conductor must be copper and fine-wired. Individual conductors must be uniquely marked (L, N, PE, D+, D-). The lamp must already be wired with a suitable long cable (length to the connection panel in the pole).

9.1.4 Design requirements

The lamps should be of the same family on the entire road section under consideration. “The same family” of lamps means that the lamps have:

- the same manufacturer,
- the manufacturer has named the lamps as a family of lamps,
- the lamps are similar in appearance or shape,
- lamps of the same family may have differently large housings.

This ensures that a section of road or, for example, an entire settlement has a uniform visual appearance of the lamps. At the same time, the number of different types of lamps is reduced due to the easier subsequent maintenance of the lamps.

9.1.5 Environmental requirements

When defining environmental requirements, the requirements for each individual location must be checked separately. The correct minimum ambient temperature needs to be defined, as there are large differences in minimum temperatures within Slovenia. If the lamps are located in the vicinity of the sea, they must be properly galvanically protected against salt spray and have the appropriate UV resistance. The lamp must operate smoothly at least in the ambient temperature range from -20°C to +35°C.

9.1.6 Other requirements

The lamps must be designed in modular fashion and allow for the replacement or repair of individual parts of the lamp.

The requirement to easily change individual parts of the lamps on location without tools is not sensible, because the lamps are almost never serviced on the field. In most cases, all non-functioning lamps are dismantled and the service is carried out in workshops.

The requirement for a die-cast housing restricts competition too much, as even lamps that are gravity die-cast and then suitably mechanically treated or made of extruded material may be suitable for certain applications.

The translucent part of the lamp may be made of safety tempered glass or a suitable UV-resistant plastic. Lamps that do not have a translucent part of the lamp, because the lenses also represent the protection of light emitting diodes against atmospheric effects, must use UV-resistant artificial lenses. The mechanical resistance of the translucent part or lenses must in any case be at least IK 08.

All lamps should be ready to be included in the advanced city management system (“Smart city”). A smart city is a system that combines information and communication technology (ICT) and various physical devices connected to the Internet of Things (IoT) network in order to optimise the efficiency of the operation and services of the advanced management of the city and the connection to the citizens. For inclusion in the advanced control system, the lamps must be equipped with an appropriate programmable ballast.

In order for the lamps offered to meet the stated condition of being ready to join an advanced city management system, they must be equipped with:

- a programmable ballast with communication protocol DALI 2.0,
- Zhaga socket (or equivalent) with all necessary fittings and with a cover that prevents water and dirt entering the socket or the lamp and that maintains the IP level of protection of the lamp.

9.2 Justification for the installation of poles with passive safety characteristics

According to the literature, approximately half of the deaths in road accidents occur in accidents where the vehicle has run off the road. Among these, approximately 12 % to 15 % are those where the vehicle has run into a tree or a road lighting pole. [6] In fatal road traffic accidents in the USA, road lighting pole impact caused slightly more than 2 % of deaths. This figure is 4 % for deaths in accidents where the vehicle has run off the road. If we look in more detail at the number of deaths due to impact of the vehicle on the public lighting pole, the statistics show the following: 13 % of the deaths were motorcyclists; in 37 % of cases, the collision occurred on the curve; 58 % of cases occurred on roads where the speed is limited to 50 km/h to 70 km/h; 65 % of such accidents occurred in urban environment. [7] 220,578 accidents occurred in Slovenia between 2005 and 2009, with a total of 72,518 injuries, of which 1198 were fatal. In 5610 injuries, the cause was a collision with a fixed object, and 183 of these injuries were fatal. [8] So, a collision with a fixed object (it is not possible to tell from the study how many of these objects were road lighting poles) is responsible for just over 15 % of fatalities in road accidents, similar to the situation elsewhere in the world.

Experimental vehicle crashes into a rigid road lighting pole [9] were carried out in Romania. The vehicle used was a Fiat Punto 55, year 1995-1998, i.e. a small passenger car weighing between 850 and 900 kg. During a collision with a speed of 39.4 km/h, the pole was driven into approximately half of the engine space or half of the distance between the start of the vehicle and the first axle. The maximum deceleration during collision was 350 m/s^2. At a higher speed (60 km/h), the pole ended up approximately 10 cm before the windscreen or at the first axle. Maximum deceleration was 305 m/s^2. At a speed of 85.9 km/h, the consequences are more severe, the pole ended up approximately at half of the windscreen. The maximum measured deceleration was 300 m/s^2. On the fourth attempt, the vehicle's speed was 102.8 km/h and the pole ended up at the beginning of the roof of the vehicle. The maximum deceleration during collision was 285 m/s^2. The results indicate that, at higher speed, the deceleration is slightly lower, but at e.g. 100 km/h, the entire engine part of the car ends up in the car cabin and thus causes severe, most likely fatal, injuries to the driver and passengers. The measured decelerations were large, but short-lived. The Encyclopaedia Britannica on damage caused by deceleration states the following: “Exposures to deceleration forces lasting longer than 0.2 second can cause fluid displacement or tissue deformation. If the duration of deceleration in a position facing forward is less than 0.2 second, the maximum endurable deceleration force is 30 g (approximately 300 m/s^2). This causes a drop in blood pressure, rise in pulse rate, weakness, and pallor of the skin. In the backward-seated position, forces up to 35 g (approximately 350 m/s^2) can be tolerated with few apparent difficulties." On this basis, it can be concluded that the decelerations in the event of a collision with a speed of 40 km/h in a rigid public lighting pole are not so high as to cause death, but the death of the driver and/or passengers may be due to the deformation of the vehicle in the event of a collision. The experimental collisions described above therefore suggest that collisions at speeds of up to 40 km/h with a certain probability do not cause death nor cause serious injuries.

Definitions, specifications and requirements for road lighting poles are specified in the SIST EN 40 standard. The requirements for road lighting poles with passive safety characteristics and their testing are laid down in standard SIST EN 12767. The Standard divides poles with passive safety characteristics into three categories according to the amount of energy they can absorb upon impact:

- HE Category poles (High Energy absorbing) may absorb a large amount of energy, which means that they also cause the maximum damage to the vehicle that crashes into such a road lighting pole. The pole slows down the vehicle by 50 km/h to 100 km/h upon impact, meaning that the vehicle may not come to a complete stop at speeds above 50 km/h. For example, in a collision with a speed of 100 km/h, the "exit speed" can still be 50 km/h. This does, however, significantly reduce injuries in the event of a secondary collision with the barrier behind the pole. Certain poles of this category may stop the vehicle on impact even at speeds of more than 50 km/h, but in this case the damage to the vehicle and passengers is correspondingly larger, but must still remain within the permissible body load values specified in the standard SIST EN 12767.
- LE Category (Low Energy absorbing) are low energy absorbing poles. These normally bend under the vehicle upon impact before breaking off or collapsing. Upon impact, the vehicle is slowed down by 30 km/h to 50 km/h.
- The third category is NE (Non Energy absorbing) poles where the vehicle speed is slowed down by less than 30 km/h in the event of a collision. This significantly reduces damage to the vehicle and passengers in the event of a pole collision, but increases the likelihood of a secondary collision with a speed of more than 70 km/h and injuries (including other road users) in this secondary collision, if there are other obstacles or other road users behind the pole.

The standard prescribes the marking of passive safe by means of, for example: 100-HE-C-S-NS-MD-0, where the meaning of the individual parts of the marking is:

- 100: the number at the beginning of the marking indicates with what impact speed the pole was tested. Possible speeds are 100 km/h, 70 km/h or 50 km/h. In addition, each passive safe pole must also be tested at a speed of 35 km/h.
- HE: is the category sign for impact energy absorption and can also be LE or NE in addition to HE.
- C: is an indication of the level of safety of passengers. The markings are from A (most safe) to E (least safe). Markings means a different deceleration upon impact, expressed in the ASI index and different theoretical speed of head impact in a hypothetical point in the passenger cabin (TIHIV). Not all safety level markings are possible for all markings for the energy absorption category due to technical limitations. Thus, for HE poles, passenger safety markings B or A are not possible. Safety marking A is only possible when the speed difference before and after the impact is no more than 3 km/h.

- S, X or R: The pole and the foundation are the whole unit to be tested, so the pole must always be installed in accordance with the manufacturer's instructions. Standard SIST EN 12767 defines in Annex B the individual foundation type where S is the mark for the standard foundation composition, the mark X has a special composition and the mark R means that the pole is fixed to a flat continuous rigid surface (asphalt or concrete) which, with its thickness, ensures adequate anchoring of the pole and the displacement of the fastening after the test impact must not be greater than 1 cm.
- NS: the marking indicates the mode of collapse of the pole. The two possible markings are SE (separation), which means that the pole separates from the base (breaks off or splits) on impact, and NS (no separation), which means that the pole does not separate from the base and therefore remains in one piece. The pole may behave differently at different impact speeds, and NS is a desirable feature because if the pole breaks, parts of the pole may cause additional impacts or injuries to other road users.
- MD: the penultimate part of the mark defines the directional class of the pole. The SD (Single Directional) mark means that the pole is only passive safe in the event of an impact from one direction (20°). In the BD (Bi Directional) mark, the pole is passive safe in the event of an impact from two directions (20° and 160°). The third possible sign is the MD (Multi Directional) and means that the pole is passive safe in a collision from any direction. Such a pole constitutes the greatest safety.
- 0: the last part of the marking indicates the risk of roof intrusion. After a collision, the pole may fall on the roof of the vehicle and enter it due to its weight, creating an additional hazard for the driver and passengers. There are two options: 0 (not sensitive to dent) for poles which, when dropped to the roof, do not cause intrusion of more than 102 mm (4 inches) and 1 (sensitive to dent) which, when dropped to the roof, may cause a larger groove.

The European standard EN 12767 (or SIST EN 12767) does not make any recommendations for the use of poles in certain situations, but such recommendations can be found in the English appendix to this standard and in some national recommendations on the use of passive safe road equipment (Norway, Sweden, Finland, Slovakia, Poland). The recommendations vary from country to country, but can be summarised as follows:

- Alongside roads with a speed limit above 65 km/h or 70 km/h, it is recommended to use poles with a test speed mark of 100. If the speed limit is lower than this, then with test speed mark 70. The use of poles marked with a test speed 50 is discouraged in most countries because crash speeds, even on roads with a 50 km/h speed limit, are usually higher than this speed.
- Alongside roads in rural areas where we have only motor traffic and there are no other structures or traffic users (pedestrians, cyclists) along the road and the roadside surface ensures the possibility of safe stopping of the vehicle, it is recommended to use poles with energy absorption marking NE, which cause minor damage to the vehicle and passengers and do not stop the vehicle.
- Alongside roads in the rural areas where there are other obstacles (trees, buildings, etc.) or parallel traffic areas for other road users (pedestrians, cyclists, etc.) and along urban roads (settlement, etc.), it is recommended to use poles with the energy absorption marking LE or HE.
- The other characteristics are selected according to the specific situation.

Passive safe road lighting poles are recommended in places where there is a certain probability of a motor vehicle crashing into the pole and the permissible speed of the vehicle is such that serious injuries to the occupants of the vehicle can occur.

In general, the recommendations for placing passive safe poles in the literature can be summarised as follows:

- On roads where speed is limited to a sufficiently low value (30 km/h or maximum 40 km/h in settlements), passive safe poles are not required.
- The use of passive safe poles is not required if they are behind the guard rail and outside the working area of the railing.
- Passive safe poles are also not required if vehicles are parked alongside the road.
- Similarly, passive safe poles are not required where the driving speed due to the geometry of the road or other obstacles is not greater than 30 km/h.
- In all the above cases, however, it is recommended to use passive safe poles in places where accidents are common and where there is a higher likelihood of collision, e.g. on the outside of sharp curves.
- In a rural environment and in urban non-populated areas, where there are no other traffic participants or other obstacles behind road lighting poles and there is therefore no risk of secondary collision, passive safe poles with the energy absorption marking NE may be used.
- In the urban environment and in places in the rural environment where there is a risk of secondary collision, the use of passive safe poles with the energy absorption marking LE or HE is recommended.
- In places where there is a cycle path or pedestrian pavement or other road users behind the road lighting poles, poles with the energy absorption marking HE are generally recommended. The use of poles with marking LE is also possible if the speed limit is less than 50 km/h. However, it is usually recommended to use poles with HE marking also in these cases.
- For road lighting poles placed in the centre lane between carriageways or traffic lanes, it is recommended to use passive safe poles with energy absorption marking HE.
- If the speed limit is less than 70 km/h, passive safe poles with a speed mark of 70 may be used. At a higher speed limit, passive safe poles with a speed mark of 100 must be used.

As a general rule, select a passive safe pole with the best possible indication of the passenger safety level (A, B, C, D, E) available according to the energy absorption marking required and the speed marking.

9.3 Consideration of development trends and environmental impact

The design of road lighting must, of course, take into account the development trends and the environmental impact of road lighting. Both can be grouped in a slogan: “Light only where needed, only when needed and only as much as needed.” In doing so, it is also necessary to take into account the new knowledge on the impact of the light spectrum on organisms in the environment as well as the current state of the art in road lighting. The landscape context must also be taken into account, as inadequately placed lighting, including lighting equipment itself, represents one of the most pronounced contributions to excessive urbanisation of rural areas.

Light only where needed: road lighting has proven to have a significant negative impact on the environment, which is why its use is increasingly being limited. While it used to be the custom to light all roads and paths, today the trend is to light only where light is really needed at night. The main reason for the installation of road lighting is to ensure adequate traffic safety. In doing so, we want to protect especially the more vulnerable road users, i.e. pedestrians and cyclists. For this reason, e.g., the lighting of roads for motor vehicles outside settlements is not required. In settlements where there is a pavement along the road, lighting of the road is not required, and in the case of a larger number of pedestrians in the dark part of the day, it is possible to adequately illuminate the pavement in a reasonably appropriate manner. Some guidance on what is and is not required to illuminate is found in the Rules on traffic signs and equipment on roads: "Road lighting is used to illuminate the most congested parts of roads in settlements, pedestrian crossings and underpasses, intersections with three or more classified lanes, motorway and expressway junctions and their connections, traffic service areas, bus stops on regular public passenger transport routes, roads at border crossings, and roads in medium- and long-distance tunnels. Short tunnels must be illuminated if pedestrian or cyclist traffic is allowed through the tunnel. (Article 75, paragraph 3)". For all other traffic areas, however, careful consideration is needed as to why an area should be illuminated and whether the benefits of illumination outweigh the negative impacts on the environment and surrounding residents. The impacts of electricity consumption and investment funds are, of course, also taken into account.

Under "light only where needed", it is also understood that only the traffic area is illuminated, but not the areas adjacent to the traffic area (grassy area, courtyard, house next to the pavement, etc.). When choosing a lamp or optics, we therefore need to take care not to cause intrusive light, i.e. light that ends up outside the surface to be illuminated.

Light only when needed: certain traffic areas are in use only for a certain part of the day. There are virtually no cyclists on cycling routes outside settlements during night time. After 20:00 or 21:00, there are also no pupils on school routes. Also, the overall density of traffic, especially of pedestrians and cyclists, decreases considerably after 23:00 or 24:00. Therefore, in the absence of road users, road lighting is not required either. Switching off road lighting, whether in groups or individually, can be arranged with today's technology without too much difficulty. Operating schedules may be set using modern power supplies in the lamps. It is possible to use intelligent lighting with sensors that respond to the presence of pedestrians or cyclists on the traffic surface. The use of a button or sensor for switching on the pedestrian crossing lighting and a timer to switch it off can also be a very useful solution to reduce the environmental impact of lighting.

Light only as much as needed: human vision is very flexible, so we can still orient ourselves in the environment even with only the light of stars. In an urban environment, some more light is required for safe movement and orientation due to other light sources that affect the adaptation of the eye. Indicative numbers can be found in the standard SIST EN 13201-2. However, it should be taken into account that the standard's recommended level of illuminance or luminance of the traffic area depends on various factors, including traffic density. It is selected by means of the selection of a lighting class, the framework instructions are provided by the technical report SIST-TP CEN/TR 13201-1. The technical report also assumes that traffic conditions are changing during the night, which means that the appropriate lighting class is also being changed. If the traffic density is reduced, if the number of different road users changes… the lighting class is also changed accordingly. This can be taken into account with modern technology by setting appropriate dimming schedules for the lamps in the ballast or driver in the lamp. In addition, the illuminance and luminance values in the standard should be seen as recommended optimal values and not as values to be exceeded as far as possible. Pedestrian lighting surveys carried out in recent years show that these values are too high rather than too low. Even at lower values than given in the standard, adequate visibility of the traffic surface is easily achieved and thus the safety of its users is adequate. There is therefore no need to overlight traffic areas. This may have a negative impact on the adaptation of the eye and increase glare, as well as increase electricity consumption and light pollution of the environment.

Colour of light: Before the widespread use of light-emitting diodes (LEDs), sodium lamps (low- or high-pressure) with a bright yellow colour were considered the best light source for road lighting. Because of their emphasis on the yellow part of the spectrum, they had a higher light efficacy than the older high-pressure mercury lamps, because the human eye is most sensitive to the yellow-green part of the light spectrum. With the arrival of LEDs, the colour of light in road lighting has shifted to a more blueish range (colour temperature 4000 K) as such LEDs had the highest light efficacy at the time. With the development of LEDs, the differences in light efficacy at different colour temperatures have been reduced so that today there is no reason to no longer use LEDs with a lower colour temperature (2700 K or even 2200 K). LEDs with a lower colour temperature have a smaller proportion of blue light in the light spectrum, thereby affecting less the melatonin level in the human organism, on insects and on the scattering of light in the atmosphere. As a result, certain countries have already limited the colour temperature of the light of road lights to 3000 K or less.

In addition to the above, in recent years there has also been a strong trend of digitalisation of road lighting or so-called smart road lighting, sometimes referred to as dynamic lighting. Road lighting lamps can be connected to the network and operated remotely. It is also possible to connect different sensors to the same network (e.g. presence of traffic participants, traffic density, etc.), weather stations, cameras… and all of these can be used for smart control of road lighting. Such a system allows lighting control in relation to current conditions, which can reduce both electricity consumption and light pollution of the environment. When there are no road users, road lighting may be switched off or operate at minimum power. However, in the event of pedestrian or vehicle arrival, the lighting is switched on or its power increased so as to achieve the appropriate lighting conditions. However, after a pedestrian or vehicle moves on, the previous situation shall be restored. In addition, the system can provide data on the performance of individual lamps and other components, making maintenance of street lighting easier and cheaper.

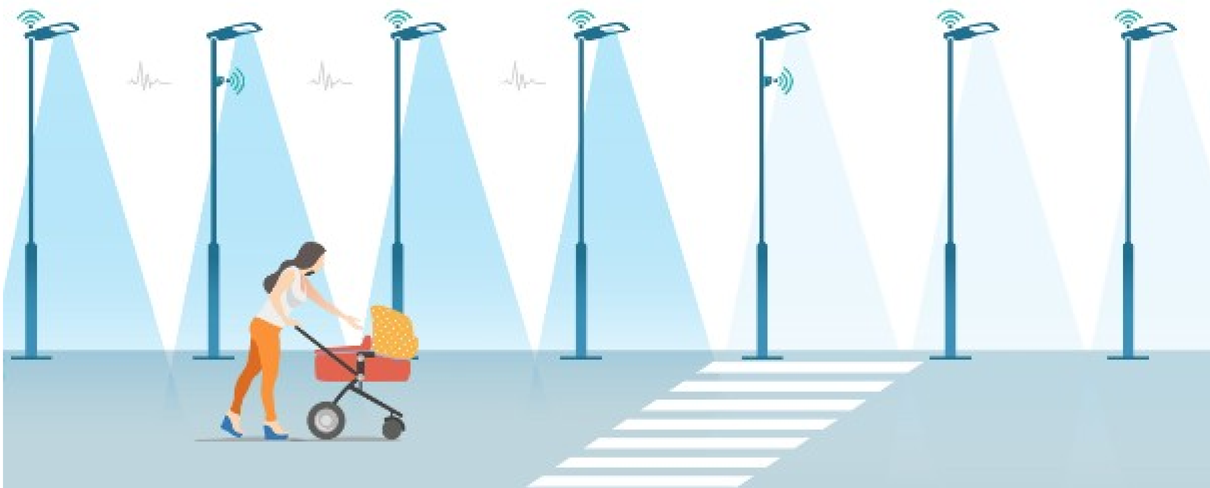


Figure 52: Demonstration of the operation of smart (dynamic) lighting, where appropriate conditions are ensured with regard to the presence of road users by means of sensors and communication between the lamps and the control station

In summary: development trends in road lighting today point to the following:

- consideration of the environmental and spatial impact;
- a thorough consideration of whether road lighting is really necessary in a particular area;
- the correct selection of lighting classes, taking into account the actual conditions after e.g. individual intervals of the dark part of the day;
- use of energy-saving lamps with appropriate optics so as to achieve adequate illuminance of the traffic area, adequate energy efficiency and minimal environmental impact;
- selection of appropriate light colour (2700 K for general use and 2200 K in nature conservation areas);
- selection of the ballast or driver that enables dimming of the lamp at least at adjustable intervals;
- the use of smart (dynamic) road lighting (sensors, controls, remote control, etc.).

10 Development trends in road lighting

The main trends in the development of road lighting in recent years have been the reduction of electricity consumption, which was again shown as a very important parameter during the energy crisis in 2022, and the reduction of light pollution of the environment. Within this, we can detect the following trends:

- Transition to LED technology: Light-emitting diodes (LEDs) have been shown to be an energy-efficient light source with a long service life. Today, their luminous efficacy (lm/W) exceeded the luminous efficacy of all other light sources used in both road and internal lighting. The same applies to their service life. In addition, LEDs are of very small dimensions, which allows the use of lenses to direct light, which in turn results in additional savings in energy consumption compared with the use of reflectors in other light sources. Currently, LEDs account for between 40 % and 60 % of the light source market and are expected to exceed 80 % in the next decade.
- Smart lighting systems: It is also possible to reduce the electricity consumption for road lighting by switching off the lighting in certain parts of the night and by adjusting the levels of luminance or illuminance in accordance with the current conditions on the traffic area. Therefore, in addition to adaptive lighting (lamps that control the luminous flux), smart road lighting systems integrate sensors, cameras and control systems that monitor traffic density, road users (pedestrians, cyclists, motor vehicles) and the weather, and control the lighting parameters depending on the time of day. In addition to further energy savings, smart lighting systems also provide increased traffic safety. Manufacturers are offering an increasing number of (different) smart lighting systems operating with different communication channels (energy network, wireless by radio signals, wireless in mobile network, etc.).
- Related infrastructure: It is possible to connect smart lighting systems to other infrastructure systems within a city or municipality. Such connections enable central control, maintenance and collection and storage of data. This in turn further increases savings (e.g. less maintenance costs) and user safety (faster elimination of defects) of traffic areas.
- Integrative lighting: insights into the benefits that integrative lighting (human centric lighting) can have on people have also influenced the development of street lighting, especially in urban environments. By taking into account the biological and

psychological effects of light on people, it is possible to make lighting more friendly to people, as well as to other living beings (animals and plants).

- Lamps with solar panels: The integration of solar panels and batteries into the lamp makes it possible to install road lighting even where there is no electricity grid in the vicinity. In certain cases, especially where there are many sunny days and the average annual temperatures are sufficiently high, the use of lamps with solar panels can provide a suitably sustainable and economical solution. Unfortunately, lamps with solar panels are not a reliable solution for road lighting. During prolonged periods of bad weather (winter, prolonged rainfall, etc.), the energy generated by the solar panels during the day may not be enough to keep the lighting running all night. As a result, such lighting is especially suitable where orientation lighting is sufficient, but not in traffic areas where road lighting is necessary to ensure traffic safety. Solar panel lamps are therefore not suitable for road lighting, which is a mandatory requirement according to the Rules on traffic signs and equipment on roads.
- Use of new materials: the use of new materials for the production of road lighting lamps is also a trend, such as aluminium alloys or composite materials for the housing, polycarbonates and acrylics and glass for the optical elements of the lamps, special ceramics for cooling systems, different surface treatment techniques... The use of new materials can reduce the electricity consumption for the production of lamps, extend their service life, and allow recycling and reuse of the material. All of this results in further reductions in energy consumption and environmental impact throughout the life cycle of the lamp.
- Data analysis: smart lighting systems can collect, with the help of various sensors and cameras, a larger amount of data that the owner (city, municipality) can use to improve other infrastructure if properly analysed. With the help of these data, it is possible to optimise traffic flows, improve safety as well as the planning of transport and other infrastructure.
- Aesthetics: More and more attention is also paid to aesthetics in the design of road lighting – the appearance of lamps, poles and overall layout, as well as compatibility with the context of the landscape or settlement. Road lighting with good aesthetic appearance not only performs its basic functions but also improves the appearance and attractiveness of urban areas. This, however, may attract more visitors to such areas, which in turn may also result in some positive impact on the economies of this area.

In addition to better energy efficiency of road lighting, much attention is also being paid to making it more environmentally friendly or reducing light pollution. Light pollution is most commonly understood as excessive, misdirected or disturbing artificial light produced by road and other (outdoor) lighting due to human activities, which interferes with the natural or living environment. Light pollution has harmful effects on the environment, i.e. on people, animals and plants. Here are some more trends related to reducing light pollution:

- Obstructing and directing light: the use of well-designed optics in lamps allows light to be directed only on the surfaces where it is needed to ensure adequate visibility. This reduces the amount of light being dispersed into the environment (light pollution) and, consequently, the energy consumption. This way, better visibility of road users can be achieved, while reducing light pollution and electricity consumption.
- Smart lighting: luminous flux control in smart lighting and its adaptation to traffic conditions on the illuminated surface, e.g. switching off the lighting in certain parts of the night or reducing the luminous flux in reduced traffic or the number of different road users. In doing so, we reduce energy consumption for road lighting, as well as the light pollution that lighting causes, while not reducing traffic safety.

- Colour temperature of light: various studies have confirmed that light of different wavelengths has different effects on humans as well as on nature. In most cases, the impact decreases with the increase in the wavelength of light. Warm white (low colour temperature) or even orange (amber) light is therefore more suitable than more bluish (cold white) light. As a result, more and more countries limit the colour temperature of light that can be used for road lighting to 3000 K or even less.
- Dark Sky Parks: more and more dark sky parks are being set up around the world to minimise or even eliminate light pollution. The purpose of these areas is to protect and preserve the natural theme for the observation of stars, wild animals and human well-being.

The two main trends in road lighting: the reduction of electricity consumption and the reduction of light pollution are mutually supportive and complementary. The use of LED technology, better lamps and more intelligent use with the integration of luminous flux control reduces both electricity consumption and light pollution. However, it is still possible to maintain or even improve safety on illuminated surfaces.

11 Reference documentation

- SIST-TP CEN/TR 13201-1 Road lighting – Part 1: Guidelines on selection of lighting classes
- SIST EN 13201-2 Road lighting – Part 2: Performance requirements
- SIST EN 13201-3 Road lighting – Part 3: Calculation of performance
- SIST EN 13201-4 Road lighting – Part 4: Methods of measuring lighting performance
- SIST EN 13201-5 Road lighting – Part 5: Energy performance indicators
- BS 5489-1: 2020 – TC Design of road lighting – Lighting of roads and public amenity areas – Code of practice
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- Pedestrian infrastructure – General orientations, ver. 1.01, August 2017
- Rules on bus stops (Official Gazette of the Republic of Slovenia, Nos 106/11, 36/18 and 132/22 – ZCes-2)
- Rules on road connections to public roads (Official Gazette of the Republic of Slovenia, Nos 86/09, 109/10 – ZCes-1 and 132/22 – ZCes-2)
- Rules on cycling areas (Official Gazette of the Republic of Slovenia, Nos 36/18 and 132/22 – ZCes-2)
- Rules on the method of marking public roads and on records of public roads and structures on them (Official Gazette of the Republic of Slovenia, Nos 49/97, 2/04, 109/10 – ZCes-1 and 132/22 – ZCes-2)
- Rules on road design (Official Gazette of the Republic of Slovenia, Nos 91/05, 26/06, 109/10 - ZCes-1, 36/18 and 132/22 – ZCes-2)
- Rules on traffic signs and equipment on roads (Official Gazette of the Republic of Slovenia, Nos 99/15, 46/17, 59/18, 63/19, 150/21, 132/22 – ZCes-2 and 26/24)
- Rules on the regular maintenance of public roads (Official Gazette of the Republic of Slovenia, Nos. 38/16 and 132/22 – Zces-2)
- Rules on roadblocks (Official Gazette of the Republic of Slovenia, Nos 4/16 and 132/22 – Zces-2)
- Rules for carrying out investment maintenance and maintenance works in the public interest on public roads (Official Gazette of the Republic of Slovenia, Nos 7/12 and 132/22 – Zces-2)
- Manual for road lighting in the area of crossings for pedestrians and/or cyclists, Ljubljana, March 2019 (available at: https://www.gov.si/assets/organi-v-sestavi/DRSI/Dokumenti-DRSI/Navodila-gradiva/Prometna-signalizacija/Prirocnik-za-cestno-razsvetljavo-v-obmocju-prehodov-za-pesce-in-ali-kolesarje.pdf)
- TSC 02.203: 2009 Traffic calming devices and measures at level intersections without traffic lights

- TSPI-PGV.03.320: 2023 Road design and traffic safety – Pedestrian areas
- TSPI-PGV.03.244: 2023 Road design and traffic safety – Intersections
- TSPI-PGV.03.245: 2023 Road design and traffic safety – Intersections with spiral flow
- TSC 03.800: 2009 Traffic-calming devices and measures
- TSPI – PGV.03.244: 2023 Road design and traffic safety – Roundabouts
- TSPI – PGV.03.245: 2023 Road design and traffic safety – Roundabouts with spiral flow
- TSPI - PGV.03.320:2023 Road design and traffic safety – Pedestrian areas
- TSG-V-006: 2018 Classification of facilities
- Regulation on the limit values for light pollution of the environment (Official Gazette of the Republic of Slovenia, Nos 81/07, 109/07, 62/10, 46/13 and 44/22 – ZVO-2)
- Decree on Green Public Procurement (Official Gazette of the Republic of Slovenia, Nos 51/17, 64/19 and 121/21)
- Roads Act – ZCes-2 (Official Gazette of the Republic of Slovenia Nos 132/22, 140/22 – ZSDH-1A, 29/23 and 78/23 – ZUNPEOVE)

12 Literature

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ANNEX A: Assessment of road congestion in relation to capacity

1 Introduction

The methodology of the road congestion assessment consists of two parts, namely the determination of limit capacities according to standard road categories and the determination of peak loads on the basis of AADT. It is based on statistics that take into account daily traffic fluctuations and on the basis of typical road geometries. However, derogations are always possible, as many roads of a certain category do not meet the standards that would be considered if the roads were built today (e.g. mountain roads), while some roads deviate from typical profiles in terms of dimensions (e.g. A5 motorway, Maribor - Pince). The method is suitable for estimating road congestion outside settlements, on sections where traffic is not regulated by traffic lights, because in this case the capacity of the road drops according to the priority of the direction of traffic in the traffic light programme, often to as low as 40 % of the capacity estimated for an unregulated priority road.

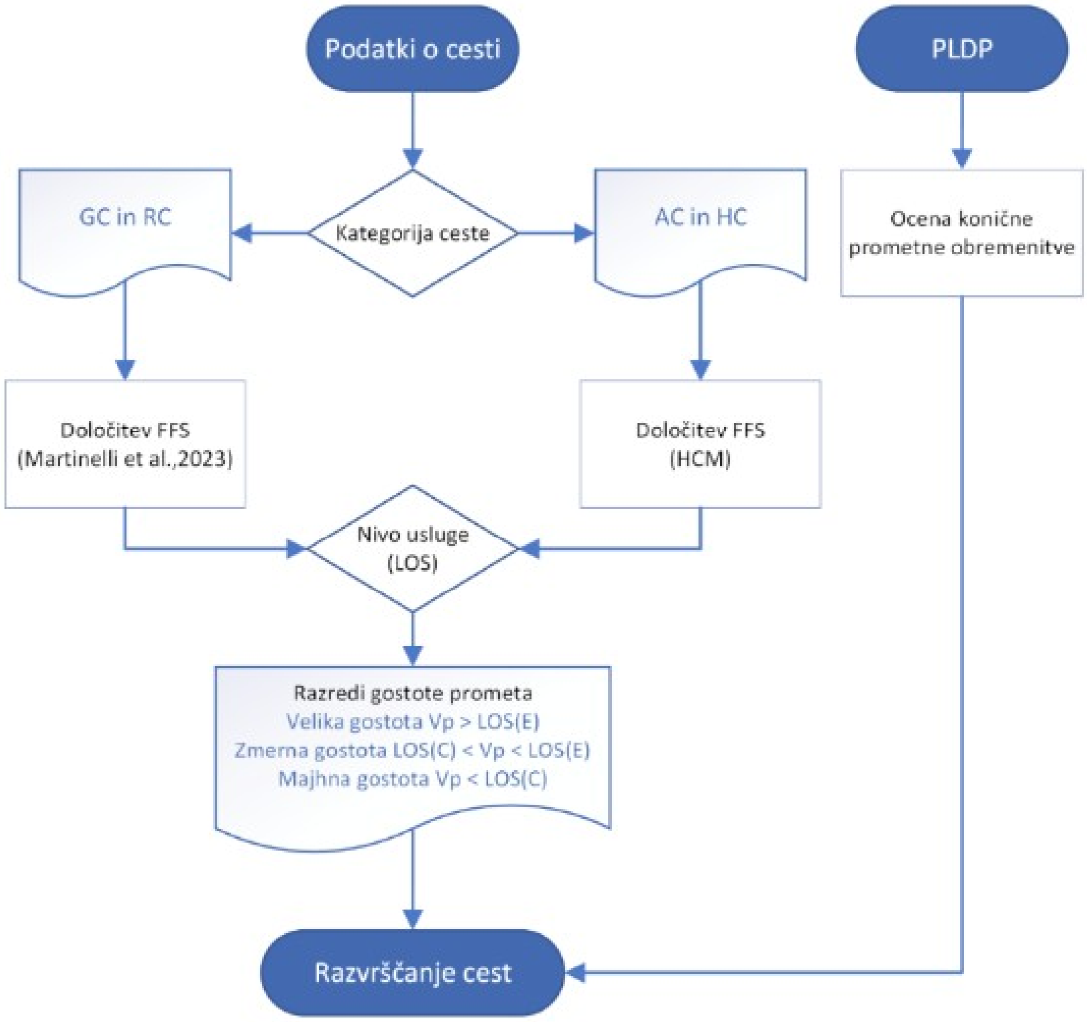

Figure A.1: Summary of the methodology.

The methodology for road capacity assessment, which is taken from the “Highway Capacity Manual” [A2], is shown in Figure A.1. First, we calculate the speed of free traffic flow. Based on this speed and traffic density, the road can be placed in the appropriate level of service (LOS). Classification in the level of service gives us information about the congestion of the road.

2 Determination of limit loads through levels of service

2.1 Calculation of free flow speed for AC and HC

The calculation of free flow speed (FFS) for motorways (AC) and expressways (HC) requires the use of several different parameters and data. The steps and data needed to calculate the FFS are outlined below, together with examples of how to use the equations and tables. The calculation is detailed in the HCM (Highway Capacity Manual) [A2]

Table A 1: Parameters for determining AC and HC capacity.

Geometric data for the basic section of the motorway and the expressway		
Required data and units	**Potential data sources**	**Proposed default value**
Free flow speed, i.e. FFS (km/h)	Direct speed measurements, assessment from planned speed or speed limits	Basic speed of free traffic flow: speed limit +8 km/h For roads in the speed range 90-130 km/h
Number of traffic lanes in one direction on a motorway (No)	Road census, aerial recording	Minimum 2 lanes
Lane width (m)	Road census, aerial recording	In the range from 3.0 m to 3.75 m
Width of right edge strip (m)	Road census, aerial recording	In the range from 0 m to 3.0 m
Total ramp density (entries/exits) at a given distance (ramp/km)	Road census, aerial recording	In the range of 0-6 ramps/km
Type and course of the terrain (flat, hilly, defined slope, i.e. length and size of slope)	Road design, analytical assessment	The data must be provided

Data needed to analyse AC and HC sections (and motorways without emergency lane):

- the speed of free traffic flow (FFS), in the range from 90 km/h to 130 km/h,
- number of traffic lanes in each direction (min. 2),
- width of traffic lanes (in the range from 3 m to 3.75 m),
- width of the right edge strip (in the range from 0 to 3 m and above),
- ramp density at a given distance (in the range of 0-6 ramps/mile or 0-6 ramps/1.6 km)
- type and course of the terrain (flat, hilly terrain),

The free flow speed for the basic section of the motorway (if not measured) can be assessed according to the following equation:

$$FFS = BFFS - f_{LW} - f_{RLC} - \left(19.44 \cdot TRD^{0.84}\right) \quad \text{(km/h)}$$

Where:

FFS free flow speed [km/h]

BFFS speed for the base section of the motorway section [km/h]

f_{LW} traffic lane width impact factor [km/h]

f_{RLC} lateral obstacles impact factor [km/h]

TRD average ramp density over three miles left and right of the cross-section analysed [no. Of ramps/km]

Table A 2 shows how lane width affects the reduction of free flow speed (FFS). Therefore, if the average lane width is ≥ 3.6 m, there is no decrease in FFS. If the average lane width is between 3.3 m and 3.6 m, the FFS is reduced by 1.9 km/h. If the average lane width is between 3.0 m and 3.3 m, the FFS is reduced by 6.6 km/h.

Table A 2: Traffic lane width impact factor.

Average lane width (m)	FFS reduction (f_{LW}) (km/h)
≥ 3.6	0.0
≥ 3.3 – 3.6	1.9
≥ 3.0 – 3.3	6.6

Figure 3 shows how lateral obstacles (e.g. proximity to structures or other road elements) influence the reduction of free flow speed (FFS), according to the number of traffic lanes.

Table A 3: Lateral obstacles impact factor.

Lateral distance – influence of lateral obstacles (m)	Number of lanes in one direction FFS reduction (km/h) (f_{RLC})			
	2	**3**	**4**	**5**
≥ 1.8	0.0	0.0	0.0	0.0
1.5	0.6	0.4	0.2	0.1
1.2	1.2	0.8	0.4	0.2
0.9	1.8	1.2	0.6	0.3
0.6	2.4	1.6	0.8	0.4
0.3	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

The tables and equation presented allow the calculation of free flow speed (FFS) for motorways and expressways, taking into account different geometric and traffic factors. The use of these data and factors enables an accurate estimation of FFS, which is essential for the design and analysis of road infrastructure and associated road lighting.

2.2 Calculation of free flow for G, R and RT roads

Main, regional and tourist roads have fairly diverse outline dimensions, carriageway widths and curves, which means that it is difficult to estimate the free flow speed according to the formulas in the HCM, as these are primarily adapted to motorways. Therefore, we have decided to use model 2 from the article Martinelli et al. [A3], which was developed on the basis of an analysis of the free flow speed on regional and local roads in Italy, which have characteristics quite similar to those of Slovenian roads.

According to this model, the free flow speed can be assessed using the equation:

$$FFS = 69.06 - 1491.22 * CCR_m + 1.54 * RSW + 2.25 * PRS + 11.6 * NL - 1.45 * NA - 1.45 * FO + ¿$$
$$+ 5.06 * MMv - 8.17 * EMv + \frac{0.23 * CAR}{PF} + \frac{5.05 * PF}{MC} + 5.34 * MT$$

Table A 4 describes the variables and their units needed to calculate the free flow speed. The Martinelli model [A3] offers a modified method for estimating the free flow speed on main, regional and tourist roads. This method takes into account the specific characteristics of these roads, such as the curvature, the width of the shoulder, the number of traffic lanes and other relevant factors. Using this method, more accurate FFS estimates can be obtained for roads that differ in geometric characteristics from AC and HC.

Table A 4: Martinelli et al. model parameters.

Symbol	Parameter	Units	Description
CCR_m	average curvature	rad/m	The curvature is calculated from the ratio of the length of the path to the change in the angle of the carriageway. For example, a curve with length of 157 m and an angle of 90° represents a radius of 100 m. The curvature is 0.01. The simplified curvature can also be calculated using reciprocal values of curve radius. If such curves cover 10 % of the total road, the average curvature is then 0.001. A more detailed explanation is given in [A3]
RSW	shoulder width	m	Shoulder width
PRS	lane width	m	Width of the asphalted side lane
NL	number of lanes / direction	-	
NA	number of access routes	km^{-1}	Number of entries / access routes per km
FO	prohibition of overtaking	%	Percentages of the section with prohibited overtaking
MMv	visible centre line	-	1 – visible, 0 – not visible
EMv	visible side line	-	1 – visible, 0 – not visible
CAR/PF	percentage of passenger cars	%	We used the average value on all roads excluding AC and HC – 86%.
PF/MC	load	-	the ratio of the flow and capacity of the road. A default value of 0.34 is proposed for estimating FFS.
MT	terrain type	-	1 – hilly, 0 – flat

2.3 Determination of the limit traffic loads from the free flow speed

The determination of the limit traffic loads is based on the HCM methodology of levels of service. Levels of service (LOS) are divided into classes between A and F, where each class can be described as follows:

- LOS A: free traffic flow. The presence of other vehicles on the road section has practically no impact on users. The choice of speed and manoeuvrability is free. Traffic can move at speeds close to or even above the limit and drivers have full mobility between lanes. The average distance between vehicles is about 167 m or 27 car lengths. The consequences of accidents or malfunctions are easily absorbed. The level of comfort of road users is excellent, as drivers need minimal attention. LOS A usually occurs late in the evening in urban areas and often in rural areas.
- LOS B: relatively free traffic flow or uniform traffic. The presence of other vehicles starts to influence the behaviour of individual drivers. The choice of speed is free, but the manoeuvrability is slightly reduced. The shortest average distance between vehicles is around 100 m or 16 car lengths. The comfort of road users remains excellent as drivers only need to look after nearby vehicles.
- LOS C: stable flow, at or near free flow. Traffic is uniform but limited. The presence of other vehicles affects drivers. This affects the choice of speed and manoeuvring, which requires caution. The ability to change the lane is noticeably limited and requires greater attention from the driver. The minimum distance between vehicles is about 67 m or 11 car lengths. The comfort level at this level falls quickly because drivers have an increasing impression that they are caught between other vehicles. Most experienced drivers feel comfortable, the load on the road is still below but close to its capacity, and the speed of traffic is maintained. Minor incidents may still not cause congestion, but accidents or vehicle failures may already have noticeable effects and may cause traffic delays. This is the target LOS for some urban and most rural motorways.
- LOS D: constant traffic at high density, but approaching a unstable flow. The speed and manoeuvrability is reduced by the increased traffic density. The vehicles are relatively close to each other (50 m or 8 car lengths). The comfort level for road users is low, as collisions with other vehicles must be constantly avoided. A slight increase in traffic can cause some operation problems and saturate the network. Even minor incidents will result in traffic delays. An example is the load on roads in the shopping centre in the middle of the working day or a functional urban motorway between the traffic peak (commuting time to and from work). This is usually the planned level of service for city streets in peaks, because achieving LOS C would require excessive costs and, for example, the need to add lanes on bypass roads.
- LOS E: unstable traffic flow, we can talk about traffic saturation, the road can already be beyond the capacity limit. At the lower limit of the traffic density of this class, the speed is still uniform but low. Later, the traffic flow becomes uneven and the speed decreases rapidly because there are practically no usable gaps to manoeuvre in the traffic flow. Manoeuvring is only possible when restricting another vehicle. Speeds rarely reach the published limit. The distance between vehicles is approximately 37 m or 6 car lengths. Any disruption to the traffic flow, such as merging of traffic on the entries or reducing the number of traffic lanes, will cause a shock wave that will affect traffic beyond the point of disruption. Any incident will cause serious delays. The level of comfort of road users becomes low, and the road users are in a frustration state.
- LOS F: forced or interrupted traffic flow, congestion. Unstable speed with queuing at several points. Cycles of stopping and driving with no obvious pattern because they are generated by the behaviour of other drivers. Each vehicle moves in step with the vehicle in front, slowing down frequently. A high level of attention is required for the user, with

practically no comfort. The traffic density is above the design capacity. A road in permanent congestion would be classified as LOS F, given that the road is classified as LOS according to the average traffic condition and not the current traffic condition.

Figure A.2 represents the levels of service determined according to the limit density of traffic flow per traffic lane. The maximum capacity of a road can be considered as the traffic density at which traffic is still flowing steadily in a free flow of traffic. The maximum capacity is therefore exceeded when the level of service (LOS) reaches D and higher. On this basis, the traffic density can be described as low in LOS A, moderate in LOS B and high in LOS C and above. The division is shown in Table A5.

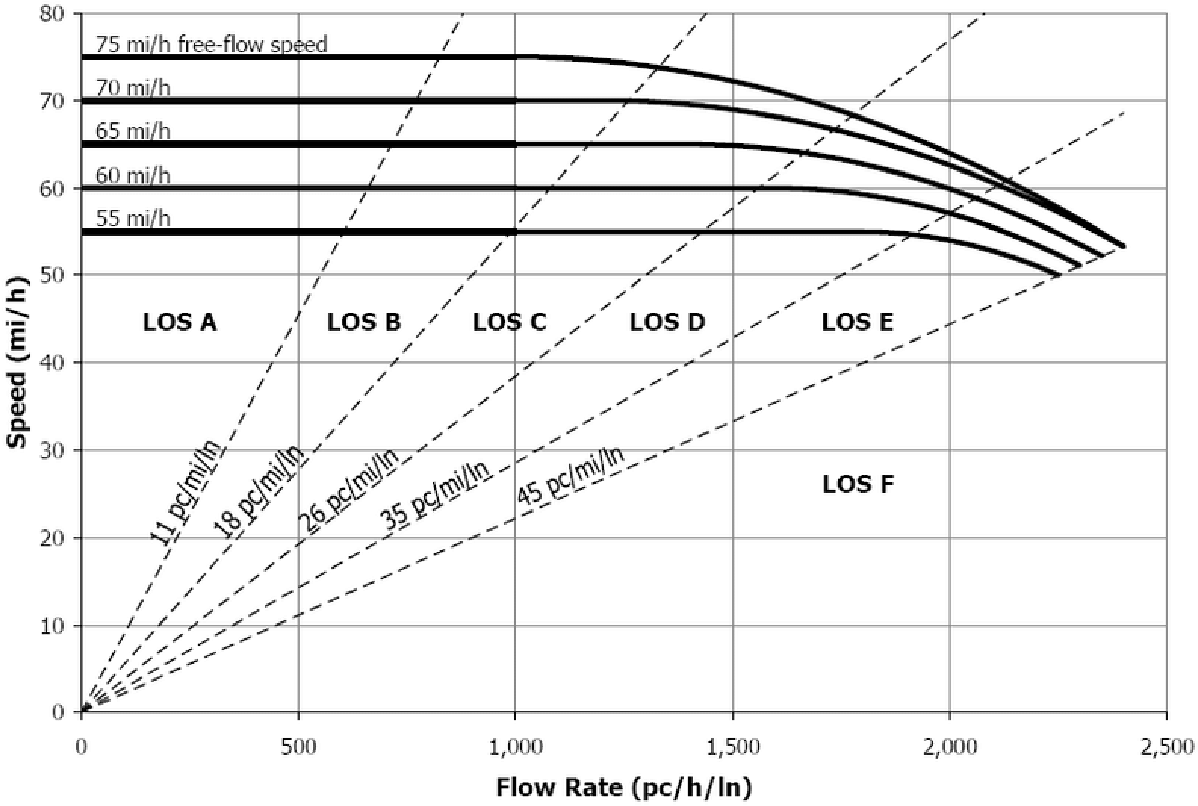

Figure A.3: The dependence of the limit flow on the free flow speed.

Table A.5 shows the traffic flow density limits used to determine the level of service (LOS). In the table, the load is expressed as PCE/km, where PCE stands for Passenger Car Equivalent. The PCE is used to convert different types of vehicles into equivalent passenger cars. This is intended to facilitate the analysis and modelling of traffic flows, as different vehicles (e.g. trucks, buses, motorcycles) have different impacts on traffic flow. According to the HCM methodology, the PCE is expressed according to the terrain type (Table A.).

Table A.5: Traffic flow density limits.

Traffic density	LOS	from		to	
Low	**A**			11 PCE/mi/ln	7 PCE/km/ln
Medium	**B**	11 PCE/mi/ln	7 PCE/km/ln	18 PCE/mi/ln	11 PCE/km/ln
High	**C**	18 PCE/mi/ln	11 PCE/km/ln	29 PCE/mi/ln	16 PCE/km/ln
	D	26 PCE/mi/ln	16 PCE/km/ln	35 PCE/mi/ln	22 PCE/km/ln
	E	35 PCE/mi/ln	22 PCE/km/ln	45 PCE/mi/ln	28 PCE/km/ln
	F	45 PCE/mi/ln	28 PCE/km/ln		

Typical values for the main road categories are shown in Table A.6. The limit traffic flow (vehicles/h/lane – rounded to 5) is determined by the levels of service (LOS), namely LOS C, LOS D, LOS E and LOS F indicate high traffic density; LOS B indicates moderate traffic density; and low traffic density is indicated by LOS A. It is important to note that if the road, in dimensions and curves, deviates significantly from the typical road for a certain category, a specific calculation by HCM or Martinelli is required. Typical values of *FFS* for AC and HC have thus been determined using the HCM equation and for the other road categories using the Martinelli model.

Table A.6: Limit traffic flows for standard road categories (applies to one lane in one direction).

	typical lane width	no. of lanes / direction	min. radius (m)	maximum curvature (rad/m)	average curvature (rad/m)	edge strip (m)	shoulder (m)	shoulder + kerb (m)	*FFS* (km/h)	*FFS* (mph)	Low traffic density to flow (LOS A)	Medium traffic density to flow (LOS B)	share of daily traffic during peak hours
AC	3.75	2				2.5	1	3.5	129	80	905	1420	0.08
HC	3.5	2				2.5	1	3.5	95	59	665	1045	0.08
G1	3.5	1	60	0.017	0.0017	0.5	1	1.5	90	56	630	990	0.1
G2	3	1	25	0.040	0.0040	0.25	1	1.25	86	54	600	945	0.1
R1	3	1	20	0.050	0.0050	0.25	1	1.25	85	53	590	930	0.1
R2	3	1	20	0.050	0.0050	0.25	1	1.25	83	52	580	915	0.1
R3	3	1	17	0.059	0.0059	0.25	1	1.25	80	50	565	885	0.1
RT	2.75	1	10	0.100	0.0200	0	0.75	0.75	58	36	410	640	0.1

3 Assessment of adjusted traffic load

3.1 Adjusted traffic load

Adjusted traffic load is a key parameter enabling accurate assessment of traffic load based on the actual number and type of vehicles using the road. This parameter is calculated using several factors that take into account the time patterns of traffic, the number of traffic lanes and the proportion of freight vehicles. The adjusted traffic load estimates the traffic flow density, which is classified into three limit values, as shown in Table A.5. The adjusted traffic load can be calculated using the equation:

$$V_p = \frac{V}{PHF \cdot N_p \cdot f_{HV}}$$

Where:

V_p adjusted traffic load [PCE/h/lane],

V relevant traffic load [vehicle/h],*

PHF peak hour factor,

N_p number of traffic lanes in one direction,

f_{HV} is the adjustment factor for the share of freight vehicles,

* A traffic load is taken from the AADT table for the AADT traffic meter vehicle/day (direction 1 and direction 2 combined), and this value is divided by 2 (because the meter measures data in both directions). The AADT value obtained is then multiplied by the factor *k*, which represents the factor for the hourly distribution of traffic loads. This factor is determined using the traffic peak criterion, which is usually between 0.10 and 0.13 on AC and HC. It is recommended to take a value of *k*=0.1 in the calculation, which means about 10 % of the AADT. The value *V* is calculated as:

$$V = \frac{AADT}{2} * k$$

When calculating the adjusted traffic load (V_p), the proportion of freight vehicles on a given road and their corresponding conversion into passenger vehicle equivalents according to the type of terrain must be taken into account. In the equation for calculating the adjusted traffic load, this is taken into account by the adjustment factor for the proportion of freight vehicles (f_{HV}), which is calculated using the equation:

$$f_{HV} = \frac{1}{1 + P_t(E_t - 1)}$$

Where:

f_{HV} is the adjustment factor for the share of freight vehicles,

P_t share of freight vehicles (coefficient),

E_t is the conversion factor to passenger car equivalent.

The value of conversion factors to the passenger car equivalent E_t is obtained from Table A 7. On flat terrain, the conversion factor for freight vehicles and buses into passenger car equivalents is 2.5. This means that one truck or bus in a flat terrain affects traffic flow in the same way as 2.5 passenger cars. The flat terrain has a lower impact on speed reduction and traffic flow, so the value of the factor is lower. On hilly terrain, the conversion factor for freight vehicles and buses into passenger car equivalents is 3. This means that one truck or bus in a hilly terrain affects traffic flow in the same way as 3 passenger cars. Hilly terrain increases the impact of heavy vehicles on the traffic flow by increasing the need for stronger braking and acceleration and greater speed reduction.

Table A 7: Value of the factor for conversion into the equivalent of a passenger car

Factor for conversion to passenger car equivalent	Terrain type	
	Flat	Hilly
E_t	2.5	3

3.2 Estimation of the value of the factor *k* for different types of roads

The AADT value is derived from the year-round counting of traffic in specific locations and does not contain data on seasonal, weekly and daily fluctuations of traffic. However, we can estimate peak hour traffic from the data, taking into account daily fluctuations, where peak hours are clearly visible.
As an example, we list a few counter points and their daily fluctuations, with an indication of traffic by hours, for the counter points shown in Table A.8.

Table A.8: Considered counter points and share of AADT in peak hour.

Section	Counter point	Road category	Period	Share of AADT in peak hour (*k* factor)
03283 Laško – Šmarjeta	580 Strmca	G1	1.1.2014 – 31.12.2019	0.089
03282 Celje - Laško	90 Kočnica	G1	1.1.2014 – 31.12.2019	0.092
12621 Črnova – Arja vas	133 Velika Pirešica	G1	1.1.2014 – 31.12.2019	0.086
Celovška cesta LJ	1028-180 Celovška	-	April 2016	0.074
A1	893 Ravne	AC	7.4.2022 – 7.4.2023	0.074
A1	0836 Jasovnik	AC	7.4.2022 – 7.4.2023	0.070

In Figures A.4-A.7, we see hourly traffic distributions and the share of daily traffic at a specific hour. The samples are similar both on urban sections, on motorways and on main roads outside settlements. There are, however, slight differences in the proportion of AADT in peak hours, calculated values were between 0.070 and 0.092. Roads where there is more traffic also during night hours have a lower proportion, while roads with greater fluctuations (main roads) have a higher proportion of traffic during peak hours. Based on the results for the rapid assessment of the load of individual sections, it is recommended to conservatively apply the factor k = 0.1, which means that 10 % of daily traffic is performed in peak hours.

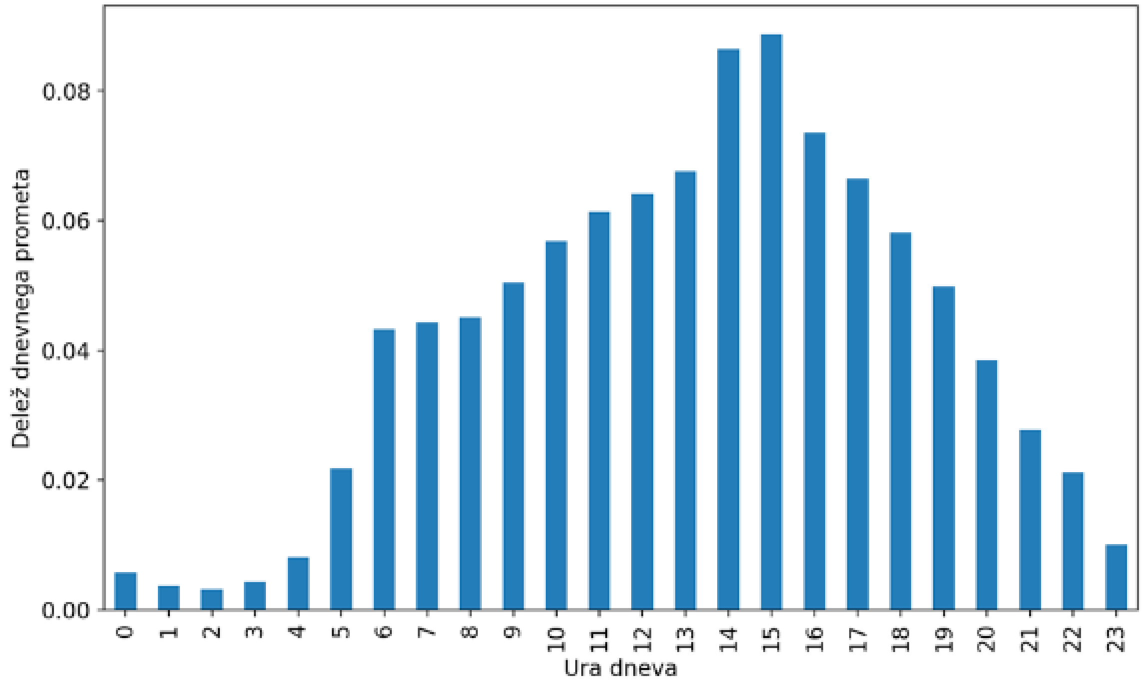

Figure A.4: Share of hourly traffic - Kočnica.

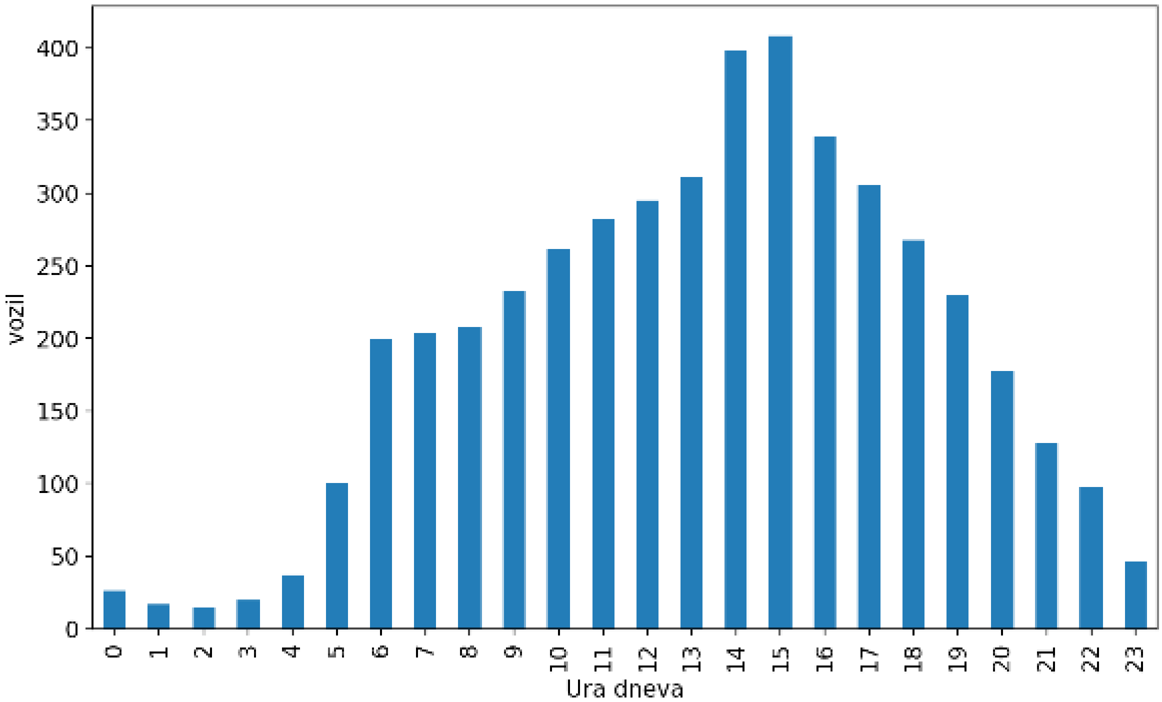

Figure A.5: Average hourly traffic – Kočnica.

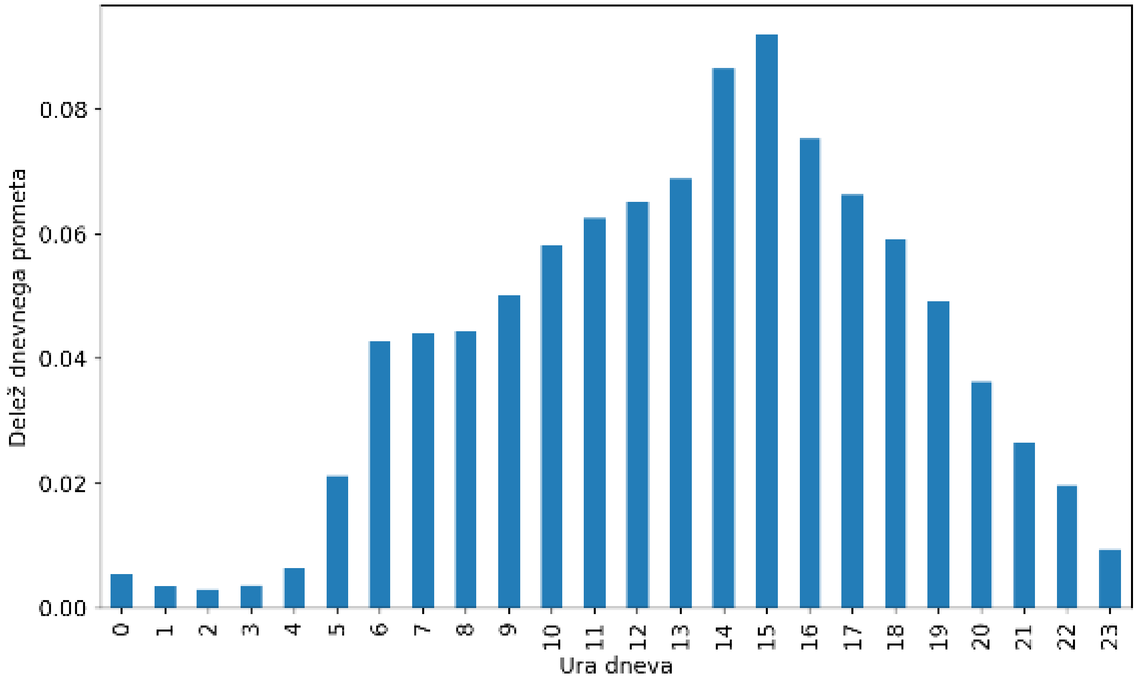

Figure A.6: Share of hourly traffic in AADT – Strmca.

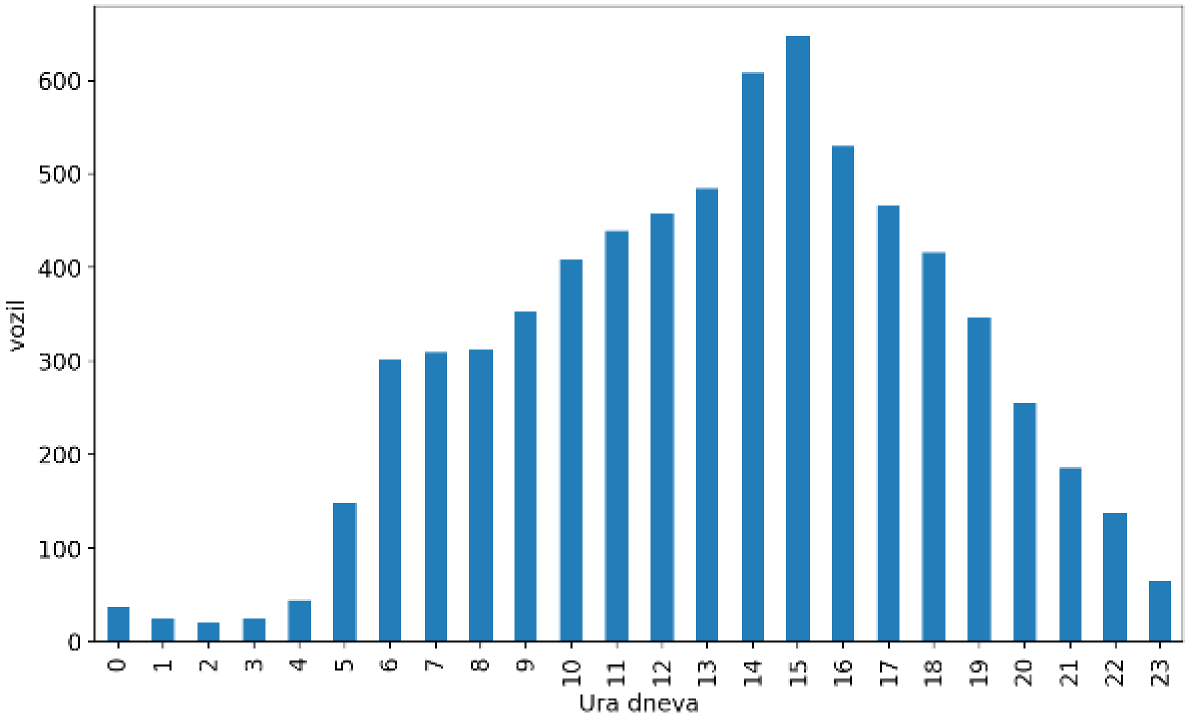

Figure A.7: Average annual number of vehicles per hour – Strmca.

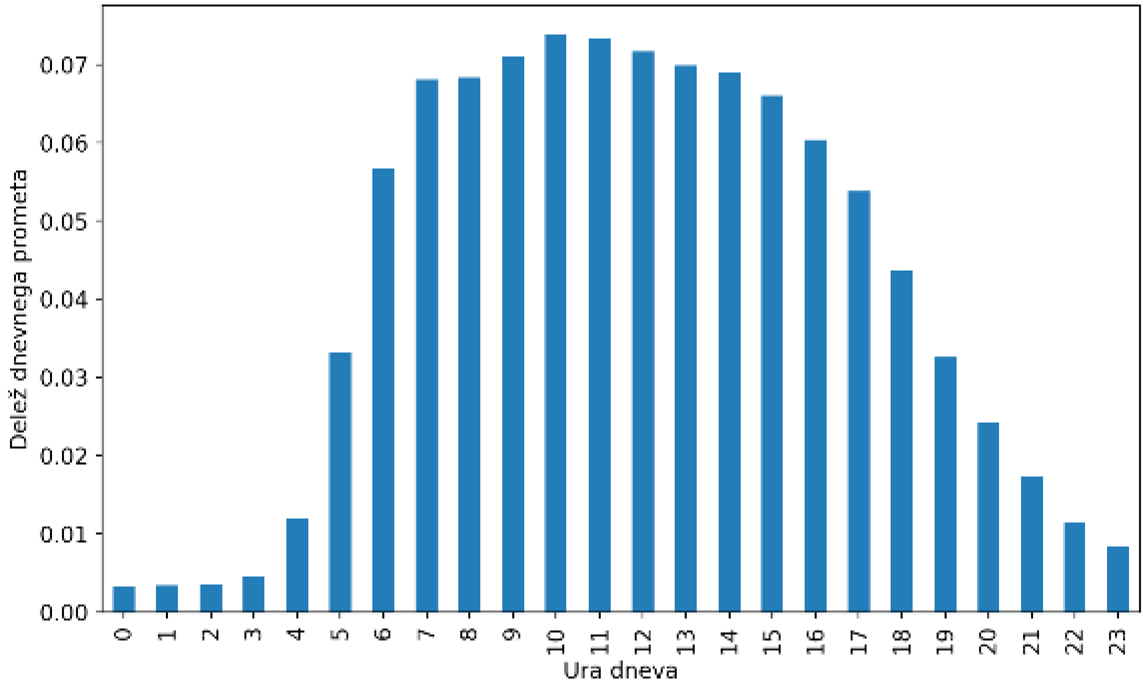

Figure A.8: Share of hourly traffic in AADT – Ravne AC.

4 Examples of calculations

4.1 Example of calculation AC1:

Calculation example on the road A1 Slovenske Konjice – Dramlje – Celje Vzhod (traffic counters: Pletovarje AC (896), Zima AC (1029)) two lanes in each direction forming the basic section of the motorway.

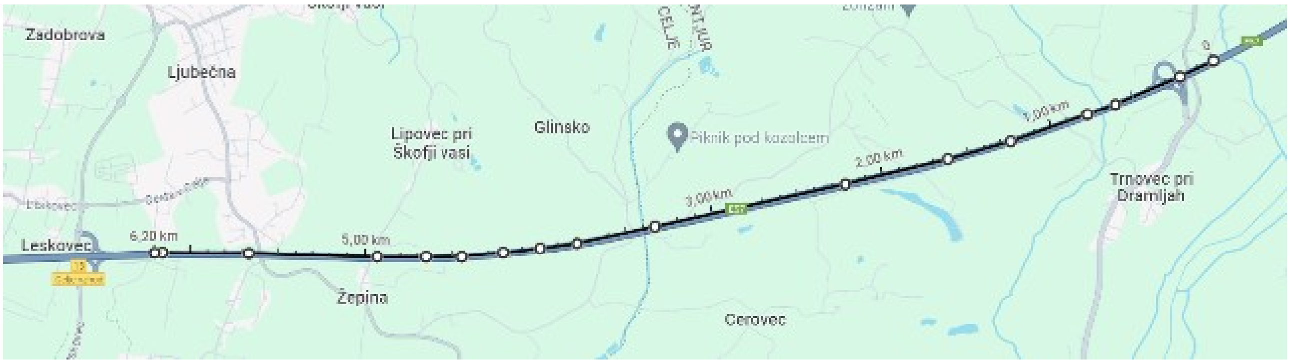

Figure A.9: Section Dramlje – Celje Vzhod.

The estimated speed of free traffic flow is calculated according to the following equation:

$$FFS = BFFS - f_{LW} - f_{RLC} - \left(19.44 \cdot TRD^{0.84}\right)$$

Where:

FFS free flow speed at section [km/h];

BFFS speed for the base section of the motorway section is 130 km/h + 8 km/h =138 km/h;

f_{LW} the impact factor of the width of traffic lanes [mi/h] deduced from Table A 2 and is 0, because the width of the lane is 3.75 m (Article 28 of the Rules on road design);
f_{RLC} lateral obstacles impact factor [km/h] deduced from Table A 3 and is 0, since the width of the emergency lane is 2.5 m, i.e. wider than the maximum width of 1.8 m (Article 34 of the Rules on road design) and the number of traffic lanes is 2;
TRD average ramp density within three miles to the left and to the right of the cross-section analysed (No. of ramps/3 miles). We take into account that 3 miles = 4828 m, i.e. about 4.8 km. We get 2 ramps/3 miles or 2/3= 0.66 ramps/mile. From this we obtain 0.66/1.609 = 0.414 ramps/km

The estimated free flow speed according to the equation is as follows:

$$FFS = BFFS - f_{LW} - f_{RLC} - \left(19.44 \cdot TRD^{0.84}\right)$$

$$FFS = 138 - 0 - 0 - \left(19.44 \cdot 0.414^{0.84}\right) = ¿$$

$$FFS = 128.73 \frac{km}{h} \approx 129 \frac{km}{h}$$

The calculated *FFS* corresponds to the standard AC road category, as presented in Table A.6.

We calculate the percentage factor of freight vehicles for the section Slovenske Konjice – Dramlje according to the equation:

$$f_{HV} = \frac{1}{1 + P_t\left(E_t - 1\right)}$$

Where:
f_{HV} is the adjustment factor for the share of freight vehicles,
P_t share of freight vehicles (coefficient),
E_t is the conversion factor to passenger car equivalent (2.5 for flat terrain),

The share of freight vehicles P_t is the ratio between the number of freight vehicles + buses and other traffic, it is calculated according to the following equation:

$$P_t = \frac{N_t}{N} \cdot 100\,(\%)$$

Where:
N_t number of freight vehicle and buses
N the number of all vehicles on the section.

The calculation tells us what the share of freight vehicles is on the section under consideration. The number of freight vehicles and buses is obtained by adding up everything except PC (passenger cars) and motorcycles in Table A.9.

Table A.9: AADT Pletovarje AC (896) A1 (section Slovenske Konjice – Dramlje)

YEAR	All AADT vehicles	Motorcycles	PC	BUS	Light trucks <3.5 t	Medium trucks 3.5–7 t	Heavy trucks over 7 t	Trucks with trailers	Tugs
2022	39200	96	26849	205	4900	615	330	815	5390
Share (%)	100	0.24	68.49	0.52	12.50	1.57	0.84	2.08	13.75

The calculated share of freight vehicles is:

$$P_t = \frac{N_t}{N} \cdot 100\,\% = \frac{12255}{39200} \cdot 100\,\% = 31.26\,\%$$

The adjustment factor for the share of freight vehicles is therefore:

$$f_{HV} = \frac{1}{1 + P_t \left(E_t - 1\right)} = \frac{1}{1 + 0.3126 \cdot \left(2.5 - 1\right)} = 0.6808$$

It is now possible to calculate the adjustment of traffic loads for the selected section of Slovenske Konjice – Dramlje (counter point: Pletovarje AC - 896). The relevant traffic load is calculated using the formula from Chapter 3.1 of this Annex, taking into account k=0.1.

$$V_p = \frac{V}{PHF \cdot N_p \cdot f_{HV}}$$

$$\frac{V_p = \frac{1960}{0.85 \cdot 2 \cdot 0.6808} = 1693 \frac{PCE}{h}}{lane}$$

Where:

- V_p adjusted traffic load [PCE/h/lane],
- V relevant traffic load [vehicle/h/direction]
- N_p number of traffic lanes in one direction,

The relevant traffic load is obtained by dividing the AADT value from the traffic counter 39200 vehicles/day by 2 (because it is measured in two directions) and obtaining 19600 vehicles/day. This is multiplied by the factor *k* (the hourly distribution factor of traffic loads obtained using the peak criterion, which is usually on AC and HC between 0.10 and 0.13), taking *k* = 0.1, i.e. about 10 %, and obtaining *V* = 1960 vehicles/h/direction.

From the calculated value of the adjusted traffic load (1693 PCE/h/lane), the number of vehicles per kilometre can also be calculated (adjusted vehicle density):

$$G_p = \frac{V_p}{FFS}$$

$$\frac{G_p = \frac{1693}{129} = 13.1 \frac{PCE}{km}}{lane}$$

Where:

- G_p the adjusted vehicle density [PCE/km/lane]
- V_p adjusted traffic load [PCE/h/lane],

According to the calculated values of the adjusted traffic load V_p and the adjusted vehicle density G_p, the section Slovenske Konjice – Dramlje can be included in LOS C, with the help of Figure A.2 and Table A.5 respectively, so the traffic density on this section is high.

We also calculate the situation on the Dramlje – Celje Vzhod section

Table A.10: AADT Zima AC (1029) A1 (section Dramlje – Celje Vzhod)

YEAR	All AADT vehicles	Motorcycles	PC	BUS	Light trucks <3.5 t	Medium trucks 3.5–7 t	Heavy trucks over 7 t	Trucks with trailers	Tugs
2022	42333	103	29424	213	5315	685	347	826	5420
Share (%)	100	0.24	69.51	0.50	12.56	1.62	0.82	1.95	12.80

Share of freight vehicles:

$$P_t = \frac{N_t}{N} \cdot 100\,\% = \frac{12806}{42333} \cdot 100\,\% = 30.25\,\%$$

The adjustment factor for the proportion of freight vehicles in section Zima (1029) is:

$$f_{HV} = \frac{1}{1 + P_t\left(E_t - 1\right)} = \frac{1}{1 + 0.3025 \cdot \left(2.5 - 1\right)} = 0.6878$$

Adjustment of traffic loads for the selected section Dramlje – Celje Vzhod (counter point: Zima AC - 1029):

$$V_p = \frac{V}{PHF \cdot N_p \cdot f_{HV}}$$

$$\frac{V_p = \frac{2116}{0.85 \cdot 2 \cdot 0.6878} = 1810 \frac{PCE}{h}}{lane}$$

We also calculate the number of vehicles per kilometre (adjusted vehicle density):

$$G_p = \frac{V_p}{FFS}$$

$$\frac{G_p = \frac{1810}{129} = 14.0 \frac{PCE}{km}}{lane}$$

Depending on the traffic flow density classes according to V_p and G_p, this AC section also has high traffic density, i.e. LOS C.

4.2 Example of calculation HC3:

Example of calculation on HC3: Ljubljana Northern Bypass: Savlje – Šiška industrial zone (counter point: N Bypass (174)) – Celovška – Vodnikova – Podutik (counter point: Dravlje HC (199)) two traffic lanes, the basic section of the expressway is 3.2 km.

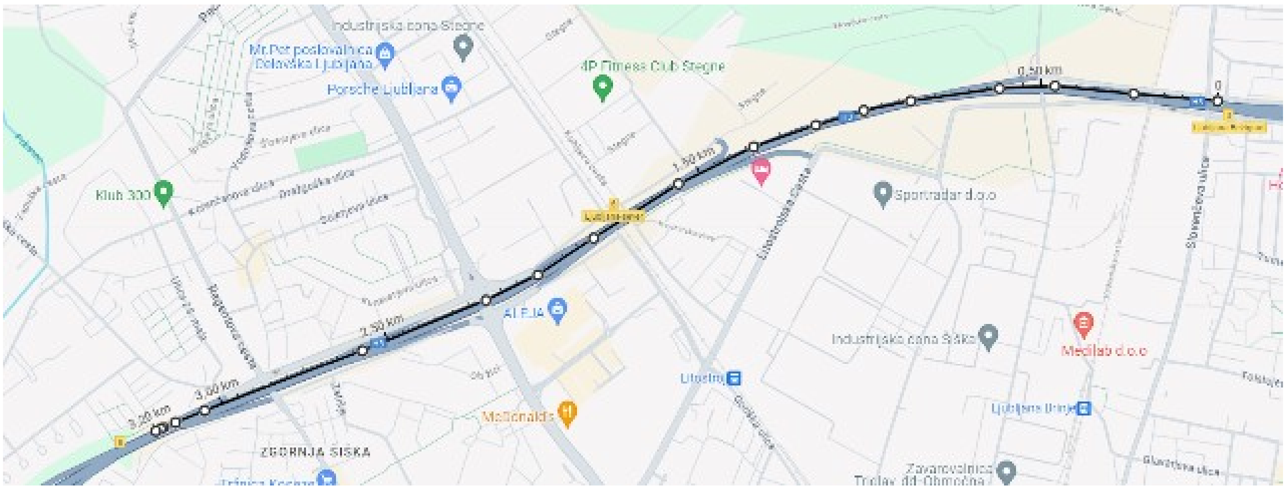

Figure A.10: Section LJ Northern Bypass.

The estimated speed of free traffic flow is calculated according to the following equation:

$$FFS = BFFS - f_{LW} - f_{RLC} - \left(19.44 \cdot TRD^{0.84}\right)$$

Where:

FFS	free flow speed at section [km/h];
BFFS	speed for the base section of the motorway section is 110 km/h + 8 km/h =118 km/h;
f_{LW}	the impact factor of the width of traffic lanes [mi/h] deduced from Table A 2 and is 0, because the width of the lane is 3.5 m (Article 28 of the Rules on road design);
f_{RLC}	lateral obstacles impact factor [km/h] deduced from Table A 3and is 0, since the width of the emergency lane is 2.5 m, i.e. wider than the maximum width of 1.8 m (Article 34 of the Rules on road design) and the number of traffic lanes is 2;
TRD	average ramp density within three miles to the left and to the right of the cross-section analysed (No. of ramps/3 miles). We take into account that 3 miles = 4828 m, i.e. about 4.8 km. We get that 6 ramps/3 miles or 6/3 = 2 ramps/mile. From this we obtain 2/1.609 = 1.243 ramps/km

The estimated speed of free traffic flow is according to the following equation:

$$FFS = BFFS - f_{LW} - f_{RLC} - \left(19.44 \cdot TRD^{0.84}\right)$$

$$FFS = 118 - 0 - 0 - \left(19.44 \cdot 1.243^{0.84}\right) = \frac{94.66\,km}{h} \approx 95\frac{km}{h}$$

The calculated *FFS* corresponds to the standard HC road category, as presented in Table A.6.

We calculate the conditions on the section LJ (Savlje – Šiška industrial zone) where the counter point N Bypass (174) is located. The freight vehicle share factor is calculated using the following equation:

$$f_{HV} = \frac{1}{1 + P_t\left(E_t - 1\right)}$$

Where:

f_{HV}	is the adjustment factor for the share of freight vehicles,
P_t	share of freight vehicles (coefficient),
E_t	is the conversion factor to passenger car equivalent (2.5 for flat terrain),

The share of freight vehicles P_t is the ratio between the number of freight vehicles + buses and other traffic, it is calculated according to the following equation with the data from Table A.11:

$$P_t = \frac{N_t}{N} \cdot 100\,(\%)$$

Table A.11: AADT on section LJ (Savlje – Šiška industrial zone)

YEAR	All AADT vehicles	Motorcycles	PC	BUS	Light trucks <3.5 t	Medium trucks 3.5–7 t	Heavy trucks over 7 t	Trucks with trailers	Tugs
2022	67656	176	57004	132	6454	592	436	472	2390
Share (%)	100	0.26	84.26	0.20	9.54	0.88	0.64	0.70	3.53

Share of freight vehicles:

$$P_t = \frac{N_t}{N} \cdot 100\,\% = \frac{10476}{67656} \cdot 100\,\% = 15.48\,\%$$

Adjustment factor for the share of freight vehicles:

$$f_{HV} = \frac{1}{1 + P_t(E_t - 1)} = \frac{1}{1 + 0.1548 \cdot (2.5 - 1)} = 0.8115$$

We calculate the adjustment of traffic loads for the selected section LJ (Savlje – Šiška industrial zone):

$$V_p = \frac{V}{PHF \cdot N \cdot f_{HV}}$$

Where:

- Vp adjusted traffic load [PCE/h/lane],
- V relevant traffic loads [vehicle/h]
- PHF peak hour factor (between 0.85 and 0.98 for motorways and for multi-lane roads between 0.75 and 0.95) – 0.85 was taken in the calculation
- N number of traffic lanes in one direction (2 lanes = driving + overtaking),
- f_{HV} is the adjustment factor for the share of freight vehicles (calculated)

The current traffic load from the traffic counter 67656 vehicles/day is divided by 2 (because it is measured in two directions) and we obtain 33828 vehicles/day, which is multiplied by the factor *k* (the hourly distribution factor of traffic loads obtained by means of the peak traffic criterion, which is usually between 0.10 and 0.13 on AC and HC), taking k = 0.1 and obtaining V = 3383 vehicles/h/direction.

$$\frac{V_p = \dfrac{3383}{0.85 \cdot 2 \cdot 0.8115} = 2452 \dfrac{PCE}{h}}{lane}$$

We also calculate the number of vehicles per kilometre (adjusted vehicle density):

$$G_p = \frac{\frac{V_p}{FFS} = \frac{2452}{95} = 25.8 \frac{PCE}{km}}{lane}$$

Depending on the traffic flow density classes according to V_p or G_p, this HC section has high traffic density (LOS E).

For the situation on the section LJ (Vodnikova - Podutik), the relevant data are from the Dravlje HC (199), which are given in Table A.12

Table A.12: Dravlje HC (199) LJ (Vodnikova – Podutik)

YEAR	All AADT vehicles	Motorcycles	PC	BUS	Light trucks <3.5 t	Medium trucks 3.5–7 t	Heavy trucks over 7 t	Trucks with trailers	Tugs
2022	61654	180	51716	108	5904	612	466	384	2284
Share (%)	100	0.29	83.88	0.18	9.58	0.99	0.76	0.62	3.70

The share of freight vehicles and buses as shown in the table is:

$$P_t = \frac{N_t}{N} \cdot 100\,\% = \frac{9758}{61654} \cdot 100\,\% = 15.82\,\%$$

The adjustment factor for the share of freight vehicles is as follows:

$$f_{HV} = \frac{1}{1 + P_t (E_t - 1)} = \frac{1}{1 + 0.1582 \cdot (2.5 - 1)} = 0.8082$$

The adjustment of traffic loads for the selected section LJ (Vodnikova – Podutik) is:

$$V_p = \frac{V}{PHF \cdot N \cdot f_{HV}}$$

$$\frac{V_p = \frac{3083}{0.85 \cdot 2 \cdot 0.8082} = 2244 \frac{PCE}{h}}{lane}$$

And number of vehicles per kilometre (adjusted vehicle density):

$$G_p = \frac{\frac{V_p}{FFS} = \frac{2244}{95} = 23.6 \frac{PCE}{km}}{lane}$$

According to the calculated parameters, this HC section is also subject to high traffic density (LOS E).

4.3 Example of calculation HC (A5):

An example of calculation on the Pomurje Motorway A5 which, according to its construction, is closer to HC (expressway): section Turnišče – Dolga vas (counter point Mostje AC (1048)) – Lendava (counter point Lendava AC(884)) has two lanes, without an emergency lane, there is only a shoulder on the side (1 m). The base section of the motorway is 4 km long.

Figure A.11: A5 motorway.

Estimated speed of free traffic flow according to the equation:

$$FFS = BFFS - f_{LW} - f_{RLC} - \left(19.44 \cdot TRD^{0.84}\right)$$

Where:

FFS	free flow speed at section [km/h];
BFFS	speed for the base section of the motorway section is 110 km/h + 8 km/h =118 km/h;
f_{LW}	the impact factor of the width of traffic lanes [mi/h] deduced from Table A 2 and is 0, because the width of the lane is 3.5 m (Article 28 of the Rules on road design);
f_{RLC}	lateral obstacles impact factor [km/h] is read from Table A 3 and is 2.4 because there is no emergency lane, but only a shoulder of approx. 1 m and the number of traffic lanes is 2;
TRD	average ramp density within three miles to the left and to the right of the cross-section analysed (No. of ramps/3 miles). We take into account that 3 miles = 4828 m, i.e. about 4.8 km. We get 4 ramps/3 miles or 4/3 = 1.33 ramp/mile. This results in 1.33/1.609 = 0.8287 ramp/km.

$$FFS = 118 - 0 - 2.4 - \left(19.44 \cdot 0.8287^{0.84}\right) = 99\,\frac{km}{h} \approx 100\,\frac{km}{h}$$

The calculated *FFS* slightly deviates from the standard road categories presented in Table A.6. The AC is also not a typical AC, but something between AC and HC, based on geometric characteristics.
We calculate the situation on the first part, i.e. the Turnišče - Dolga vas section, for which data are obtained from the counter point Mostje AC (1048) and presented in Table A.13

The adjustment factor of the share of freight vehicles is calculated using the equation:

$$f_{HV}=\frac{1}{1+P_t(E_t-1)}$$

Where:

- f_{HV} is the adjustment factor for the share of freight vehicles,
- P_t share of freight vehicles (coefficient),
- E_t is the conversion factor to passenger car equivalent (2.5 for flat terrain),

The share of freight vehicles P_t is the ratio between the number of freight vehicles + buses and other traffic. It is calculated according to the following equation:

$$P_t=\frac{N_t}{N}\cdot 100(\%)$$

The calculation tells us the share of freight vehicles on the section in question compared to all vehicles. We consider everything except PC and motorcycles as freight vehicles.

Table A.13: AADT Pomurje Motorway (1048 Mostje)

YEAR	All AADT vehicles	Motorcycles	PC	BUS	Light trucks <3.5 t	Medium trucks 3.5–7 t	Heavy trucks over 7 t	Trucks with trailers	Tugs
2022	13548	30	7293	99	1617	141	63	437	3868
Share (%)	100	0.22	53.83	0.73	11.94	1.04	0.47	3.23	28.55

Share of freight vehicles:

$$P_t=\frac{N_t}{N}\cdot 100\,\%=\frac{6225}{13548}\cdot 100\,\%=45.95\,\%$$

Adjustment factor for the share of freight vehicles:

$$f_{HV}=\frac{1}{1+P_t(E_t-1)}=\frac{1}{1+0.4595\cdot(2.5-1)}=0.5919$$

We calculate the adjustment of traffic loads for the selected section Turnišče – Dolga vas:

$$V_p=\frac{V}{PHF\cdot N_p\cdot f_{HV}}$$

$$\frac{V_p=\frac{677}{0.85\cdot 2\cdot 0.5919}=673\frac{PCE}{h}}{lane}$$

Where:

- V_p adjusted traffic load [PCE/h/lane],
- V relevant traffic loads [vehicle/h]
- PHF peak hour factor (between 0.85 and 0.98 for motorways and for multi-lane roads between 0.75 and 0.95) – 0.85 was taken in the calculation
- N_p number of traffic lanes in one direction (2 lanes = driving + overtaking),

f_{HV} is the adjustment factor for the share of freight vehicles (calculated)

The current traffic load from the traffic counter of 13548 vehicles/day is divided by 2 (because it is measured in two directions) to obtain 6774 vehicles/day. This is multiplied by the factor *k* (the hourly distribution factor of traffic loads obtained using the peak criterion, which is usually on AC and HC between 0.10 and 0.13), taking k = 0.1, and obtaining V = 677 vehicles/h/direction.

And number of vehicles per kilometre (adjusted vehicle density):

$$\frac{G_p = \frac{V_p}{FFS} = \frac{673}{100} = 6.7\,\frac{PCE}{km}}{lane}$$

Depending on the traffic flow density classes according to V_p or G_p, this AC section has low traffic density (LOS A:).

We also calculate the conditions on the Dolga vas – Lendava section according to the data in Table A.14 relating to the counter point Lendava AC (884).

Table A.14: AADT Pomurje Motorway (884 Lendava AC)

YEAR	All AADT vehicles	Motorcycles	PC	BUS	Light trucks <3.5 t	Medium trucks 3.5–7 t	Heavy trucks over 7 t	Trucks with trailers	Tugs
2022	11660	25	6581	100	1570	153	70	271	2890
Share (%)	100	0.21	56.44	0.86	13.46	1.31	0.60	2.32	24.79

Share of freight vehicles:

$$P_t = \frac{N_t}{N} \cdot 100\,\% = \frac{5054}{11660} \cdot 100\,\% = 43.34\,\%$$

Adjustment factor for the share of freight vehicles:

$$f_{HV} = \frac{1}{1 + P_t\left(E_t - 1\right)} = \frac{1}{1 + 0.4334 \cdot \left(2.5 - 1\right)} = 0.6062$$

Adjustment of traffic loads for the selected section (884 Lendava AC):

$$V_p = \frac{V}{PHF \cdot N_p \cdot f_{HV}}$$

$$\frac{V_p = \frac{583}{0.85 \cdot 2 \cdot 0.6062} = 586\,\frac{PCE}{h}}{lane}$$

And number of vehicles per kilometre (adjusted vehicle density):

$$\frac{G_p = \frac{V_p}{FFS} = \frac{586}{100} = 5.9\,\frac{PCE}{km}}{lane}$$

Depending on the traffic flow density classes according to V_p or G_p, this AC section also has low traffic density (LOS A:).

4.4 Example of calculation RC (409):

The fourth example concerns the Republic Road RC 409: Divača – Kozina. The section under consideration is shown in the figure below. Data at the counter point Divača (77) have been taken into account

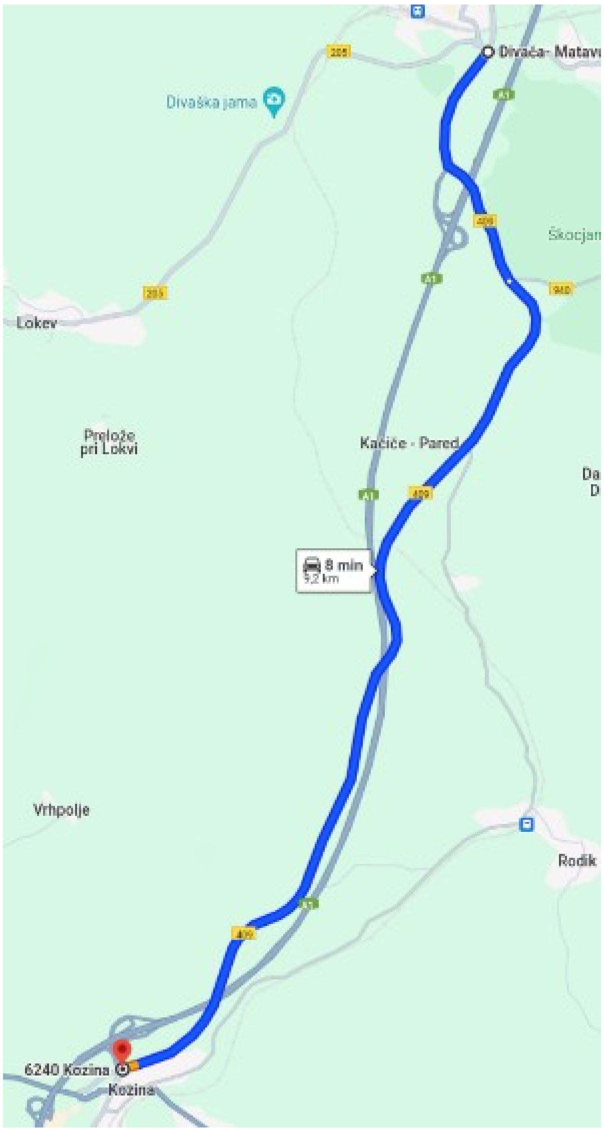

Figure A.12: Section Divača – Kozina.

We take into account the procedure on Figure Error: Reference source not found and find that the regional road (R2) requires the determination of the free flow speed by the Martinelli et. al method described in Chapter 2.2, using the equation:

$$FFS = 69.06 - 1491.22 * CCR_m + 1.54 * RSW + 2.25 * PRS + 11.6 * NL - 1.45 * NA - 1.45 * RO + ¿$$
$$+5.06 * MMv - 8.17 * EMv + \frac{0.23 * CAR}{PF} + \frac{5.05 * PF}{MC} + 5.34 * MT$$

Table A 4 defines the data specific to the given road and taken into account in the calculation – if available. Otherwise, default values may be used as an indicative approximation if the road geometry does not deviate too much from the characteristic road of the given category (curves, width, etc.).
The estimated parameters are shown in the following table.

Table A.15: Parameters of the RC Divača – Kozina section.

Symbol	Parameter	Units	Estimation
CCR_m	average curvature	rad/m	From the satellite image of the road, the average curve is estimated to be 0.002: the curves at about 50 % of the road have a radius of about 300 m, thus the average curvature is 1/300 * 0.5 = 0.002
RSW	shoulder width	m	1
PRS	lane width	m	0.3
NL	number of lanes/direction	-	1
NA	number of access routes	km^{-1}	10 access routes / 9.2 km = 1.1 km^{-1}
FO	prohibition of overtaking	%	50
MMv	visible centre line	-	1 – visible
EMv	visible side line	-	1 – visible
CAR/PF	percentage of passenger cars	%	86 (default value)
PF/MC	load	-	0.34 (default value)
MT	terrain type	-	1 – hilly

After inserting the data, we get:

$$FFS = 90.61 \frac{km}{h}$$

which is the expected result according to the geometry of the road.

We proceed by calculating the adjustment factor for freight vehicles, which depends on the share of freight vehicles in total traffic:

$$f_{HV} = \frac{1}{1 + P_t \left(E_t - 1 \right)}$$

Where:

P_t – share of freight vehicles (coefficient),

E_T — weight factor for freight vehicles (use 3 for hilly terrain according to the table);

The share of freight vehicles P_T is the ratio between the number of freight vehicles + buses and other traffic, obtained from the AADT data for the counter point Divača (77) on the road under consideration. The input data of the AADT at counter point is shown in Table A.16.

Table A.16: AADT in the counter point Divača (77) on the road RC 409: Divača – Kozina.

YEAR	All AADT vehicles	Motorcycles	PC	BUS	Light trucks <3.5 t	Medium trucks 3.5–7 t	Heavy trucks over 7 t	Trucks with trailers	Tugs
2022	2,307	201	1,542	17	151	30	175	12	179
Share (%)	100 %	8.7 %	66.8 %	0.7 %	6.5 %	1.3 %	7.6 %	0.5 %	7.8 %

The share of freight vehicles represents vehicles other than PC or motorcycles compared to all vehicles and amounts to 24.5 %.

Adjustment factor for the share of freight vehicles:

$$f_{HV}=\frac{1}{1+P_t\left(E_t-1\right)}=\frac{1}{1+0.245\cdot\left(3.0-1\right)}=0.671$$

It is now possible to calculate the relevant traffic load for the selected section:

$$V=\frac{\dfrac{AADT\cdot k}{N_s}=\dfrac{2307\cdot 0.1}{2}=115.35\,\dfrac{vehicles}{h}}{direction}$$

Where:

- V relevant traffic load [vehicle/h/direction]
- $AADT$ average annual daily traffic (meter reading)
- k is the peak hour factor as described in Chapter 3.2,
- N_s No of directions measured by the meter

The adjusted traffic load can then be calculated for the selected section:

$$V_p=\frac{V}{PHF\cdot N_p\cdot f_{HV}}=\frac{115.35}{0.95\cdot 1\cdot 0.671}=181\,PCE/h/lane$$

Where:

- V_p adjusted traffic load [PCE/h/lane],
- V_{daily} hourly traffic load [vehicle/h],
- k is the peak hour factor as described in Chapter 3.2,
- N No of traffic lanes in one direction

We also calculate the number of vehicles per kilometre (adjusted vehicle density):

$$G_p=\frac{V_p}{FFS}$$

$$\frac{G_p=\dfrac{181}{90.61}=2.0\,\dfrac{PCE}{km}}{lane}$$

Where:

- G_p the adjusted vehicle density [PCE/km/lane]
- V_p adjusted traffic load [PCE/h/lane],

The result shows that the road load is equal to LOS A, which means a low traffic density according to the condition in Table A.5.

5 Literature

[A1] Rules on road design. (Official Gazette of the Republic of Slovenia, Nos 91/05, 26/06, 109/10 – ZCes-1, 36/18 and 132/22 – Zces-2), Available at: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV5811

[A2] TRB, Highway Capacity Manual, Sixth Edition: A Guide for Multimodal Mobility Analysis, Washington, USA, 2016, Vol.7

[A3] Martinelli, V.; Ventura, R.; Bonera, M.; Barabino, B., Maternini, G.; Estimating operating speed for county road segments – Evidence from Italy, 2023, Available at: https://doi.org/10.1016/j.ijtst.2022.05.007

[A4] Traffic loads, Open Data of Slovenia, 2022, Available at: https://podatki.gov.si/dataset/pldp-karte-prometnih-obremenitev

Annex B: Standardisation of road lighting

Recommendations for correct road lighting are given in the standard SIST EN 13201. The standard gives the most important influencing parameters, such as driving speed, traffic density and composition, function and general road alignment and environmental conditions, for various lighting situations – areas for motor traffic, conflict areas, areas for pedestrians and cyclists and areas for slow traffic. The standard applies to permanently installed lighting, which provides good visibility for users during night time on public traffic areas and increases traffic safety, traffic flow and public safety.

Standard EN 13201 consists of five parts under the general heading Road lighting:

- Part 1: Guidelines on selection of lighting classes (technical report)
- Part 2: Performance requirements
- Part 3: Calculation of performance
- Part 4: Methods of measuring lighting performance
- Part 5: Energy performance indicators

All parts, except the first, are the same in all EU countries. The first part is not a standard, but a technical report, so its content may vary from one country to another. The content of all documents is based on the Technical Report CIE 115:2010, “Lighting of Roads for Motor and Pedestrian Traffic” of the CIE (Commission Internationale de l'Eclairage).

In Slovenia, we currently use the technical report SIST-TP CEN/TR 13201-1:2015, which is a translation of the technical report CEN/TR 13201-1:2015. The technical report differs from the standard in that it **is not a normative document** and does not lay down requirements or experimental methods, but rather provides guidelines, recommendations and interpretations for the implementation of the normative standard.

Below is a summary of the relevant content of all parts of standard EN 13201.

1 SIST-TP CEN/TR 13201-1: 2015

The document provides recommendations for the determination of lighting classes. The document presents methods that constitute the starting points of the comprehensive approach to road lighting design. These methods introduce general parameters and their impact on lighting requirements, but in real situations, the unique characteristics of the lighting need to be taken into account before a final definition of the lighting class can be made.

This Technical Report indicates the parameters and weighting values for different lighting situations (motor traffic areas, conflict areas, pedestrian areas and slow traffic areas) for the selection of the appropriate lighting class. The use of an appropriate lighting class may not be justified due to temporary changing conditions, such as traffic density, weather conditions, ambient luminance, road surface condition, etc., and therefore it is permitted or required to adjust the appropriate level of average luminance or illuminance using adaptive lighting. When using adaptive lighting, it is important that changes in average luminance or illuminance do not affect the other external limit quality criteria given for the lighting class system M (motor traffic), C (conflict areas) and P (pedestrian and slow traffic areas).

The document provides tables that allow the calculation of the lighting class for each lighting situation (M, C and P) according to the influencing parameters and their weighting values. Parameter weighting values are time-dependent, which can be taken into account when determining the lighting class for each time interval. Data on changing values can be obtained, for example, from data from traffic control stations, weather stations on main roads or from a control system that operates based on time dependency or comprises real time data. Thus, the use of a lighting class may be subject to specific requirements (bad weather, road works, poor visibility, serious accidents).

1.1 Lighting classes for motor traffic (M)

The lighting classes for motor traffic (M) are intended for drivers of motor vehicles for the lighting of roads and traffic routes that allow moderate to high driving speeds. In the standard we find parameters that influence the choice of lighting class for different options and situations. These parameters are: intended speed or speed limit, traffic density, traffic composition, directional carriageway separation, hub and intersection frequency, parked vehicles, ambient luminance and navigational task complexity. Each parameter has several options to choose from. The limits between the quantities may be set out in the description or apply without conditions. Depending on the appropriate choice of options and description, the weighting value of each parameter is determined. Weighting values are added up and then the lighting class M is determined according to the procedure in the standard. Possible classes are between one and six.

1.2 Lighting classes for conflict areas (C)

Conflict areas include intersections of traffic flows, convergence of traffic flows into areas for pedestrians, cyclists or other road users, and areas that are frequently used by several different road users. Group C lighting classes are mainly intended for use on main roads where most of the traffic consists of motor traffic.

The main design criterion is luminance, and on certain parts where it is not possible to apply luminance criteria, the illuminance criterion may be used. The ratio of luminance to the average horizontal illuminance depends on the luminous intensity or reflectance of the road surface, and is represented by the value Q_0. Based on the value Q_0, we can determine a comparable lighting class C in relation to class M. Lighting class C, according to the table in the standard, can be larger than class M for up to two classes. Possible classes C are between zero and five. We first select from the table the highest lighting class for the road or roads leading into the conflict area, and then in the same column we determine the equivalent lighting class C, taking into account the reflective properties of the carriageway. It is recommended that the actual Class C used for the conflict area in question is one level higher than the class that would be selected following the procedure described above. The level of lighting in the conflict area shall not be lower than the highest class of lighting on the connecting roads.

This determination process of class C is primarily intended to be used in a given conflict area and is generally applicable, but for certain conflict areas (for urban centres, for areas subject to specific national requirements and for conflict areas where roads leading to it are free of lighting), the same principle of determining the lighting class can be applied as for lighting class M (selection of the weighting values in individual parameters and use of an equation to determine the number of the lighting class by using a sum of the weighting values). The parameters affecting the selection of lighting class C are: intended speed or speed limit, traffic density, traffic composition, directional carriageway separation, parked vehicles, ambient luminance and navigational task complexity.

1.3 Lighting classes for pedestrian areas and slow traffic areas (P)

Lighting classes P are intended for pedestrians and cyclists using pedestrian and cycle paths and for motor vehicle drivers driving at a lower speed in the emergency lane or parking spaces. Visual tasks and needs of pedestrians are different from visual tasks of drivers, as their speed is significantly lower and the relevant objects that must be observed are much closer than those that are important to motor vehicle drivers. Thus, the parameters and situation descriptions are different from the parameters for classes M and C. These parameters are: intended speed or speed limit, surface traffic, traffic composition, parked vehicles, ambient luminance and facial recognition. Possible P classes are between one and six. The second volume of the standard also mentions class P7, which at low levels of need leaves the lighting judgement to the designer, and is used in this document in the context of orientation lighting

The lighting criteria of classes P are based on the horizontal illuminance of the traffic area and are given by the average and minimum illuminance of the road. The average hemispherical illuminance of the carriageway and the overall uniformity of this illuminance, which are covered by the HS classes, could also be used. The standard describes two further groups of classes, namely SC, which are used as an additional class for cases where public lighting must ensure the identification of persons and objects in areas where the risk of crime is higher than normal, and EV, which are used as additional classes for cases where the visibility of vertical surfaces is required. The guidelines for the determination of HS, SC and EV classes are not covered by this technical report, since decisions on the use of these classes are defined in national road lighting policy and the rules of the handling for road lighting. Also, additional requirements for the parameter “facial recognition” may be defined at national level for each country.

The document also presents in Annex B an alternative method of selecting lighting classes when using adaptive lighting. This method provides a refined evaluation of the levels of luminance or illuminance within a specified lighting class. It is based on the functional or administrative classification of roads determined by the road manager and the choice of five different coefficients determining the overall weighting coefficient.

At national level, the road descriptions in Table B.1 of the standard may be maintained or supplemented, and the rules for the handling of road lighting may be supplemented at national level.

2 SIST EN 13201-2: 2016

This standard is a Slovenian standard and is equivalent to European standard EN 13201-2: 2015. It is the second volume of the SIST EN 13201 series of standards and describes the required characteristics for road lighting. The technical report (Part One of SIST EN 13201) presents the procedure for determining the appropriate lighting class for road lighting and this part determines the requirements for the characteristics of road lighting of a given class in terms of the visual needs of road users and environmental parameters. The requirements are given in tables for each lighting class separately.

Lighting classes M are intended for motor vehicle drivers on main roads and roads in residential areas, where medium to higher driving speeds are permitted. The standard gives a table with the requirements and interpretations of the Class M lighting criteria, which are:

- the road surface luminance of the carriageway for dry and wet road surface conditions (average maintained luminance of the carriageway ($\bar{L}$), minimum luminance uniformity (U_0), minimum longitudinal luminance uniformity (U_l) and minimum luminance uniformity U_{0w} for wet conditions),
- maximum relative threshold increment (f_{TI}) (disturbing glare),
- minimum edge illuminance ratio (R_{EI}) (ambient lighting where there are no traffic surfaces adjacent to the carriageway).

The given luminance of the road surface apply to driving along a road section with a recognition distance between 60 m and 160 m.

Lighting class C are intended for motor vehicle drivers and are used when calculations of the luminance of the road surface are not used or are not feasible, when visible distances are less than 60 m, when several observer positions are inadequate, and when classes P and HS are not appropriate. They are therefore used in conflict areas (roads and streets in shopping centres, more demanding intersections, roundabouts and areas with greater congestion). The table in the standard gives the requirements for each lighting class, which are:

- average maintained illuminance ($\bar{E}$) and
- minimum illuminance uniformity (U_0).

Lighting classes P and HS are intended for pedestrians and cyclists on pedestrian and cycle paths, hard shoulders, road sections running separately or along the carriageway of a traffic route, streets in residential areas, pedestrian areas, car parks, school yards, etc. The table in the standard sets out the requirements for each lighting class, which are

a) for P classes:

- average maintained illuminance ($\bar{E}$),
- minimum maintained illuminance (E_{min}),
- minimum maintained vertical ($E_{v,min}$) and minimum maintained semi-cylindrical ($E_{sc,min}$) illuminance for the case of need for facial recognition,

b) for HS classes:

- average maintained hemispherical illuminance ($\bar{E}_{hs}$),
- minimum uniformity of hemispherical illuminance (U_0).

Lighting classes SC are additional classes for situations in which road lighting must ensure the identification of persons and objects and for parts of road surfaces where the risk of crime is greater than normal. The values of the minimum maintained semi-cylindrical illuminance ($E_{sc,min}$) are given in the table, which are evaluated in a plane 1.5 m above the road surface.

Lighting class EV are additional classes for cases where the visibility of vertical surfaces on carriageways is required (certain toll stations, intersections, passenger transfer areas, etc.). Lighting requirements are based on minimum maintained vertical illuminance ($E_{v,min}$).

Various other aspects of road lighting must also be taken into account, namely:

- maintenance factor,
- a correction factor that takes into account the temperature dependence of certain light sources,
- the appearance of road lighting (day and night) and environmental considerations,
- luminance classes G* to limit disturbing glare and control disruptive light (when it is not possible to calculate the threshold increment (f_{TI})),
- D glare index classes to limit adverse glare,
- a suitable lighting level (in terms of energy efficiency),
- sky glow (the proportion of light emitted by lamps into the upper hemisphere or reflected from illuminated surfaces towards the sky and then partly back towards the ground),
- pedestrian crossing lighting (adequate horizontal and vertical illuminance, positive contrast and adequate limited glare),
- evaluation of disturbing glare for classes C and P (Appendix C in the standard gives the maximum f_{TI} values).

3 SIST EN 13201-3: 2016

This standard is a Slovenian standard and is equivalent to European standard EN 13201-3: 2015. It is the third of the SIST EN 13201 series of standards and defines the agreements and mathematical procedures used to calculate the photometric properties of road lighting installations, which are presented in the second part of the standard.

The calculation of the lighting quality characteristics of this standard requires photometric data in the form of a spatial luminance distribution table (*I*-table), giving the distribution of luminance values of the lamp in all relevant directions, and road surface reflectance data in the form of an *r*-table. The tables give the values of *I* and *r* for the angles specified, the values at intermediate angles are determined by linear interpolation. For road lamps, the C-plane coordinate system is used, as specified in the standard (luminous intensities must be given at the angular spacings specified in the standard, linear interpolation is used to estimate the luminous intensities between the given angles, using the instructions and equations in the standard.). Data on the reflectance of the road surface is given by a reduced luminance coefficient at angular intervals and in directions and angles given in the standard (tan(ε), β). The values are presented in *r*-tables. If we need a value from the *r*-table, which is between two values, we use linear interpolation again. Annex B shows the extended format of *r*-table used for low lamp mounting heights (H < 2 m), as there are some points that are too far away from the lamp where we cannot calculate the luminance as presented below.

In order to determine the luminous intensity from the lamp to a point, the vertical photometric angle (γ) is determined first and then the photometric azimuth (C) is determined, taking into account the inclination of the installed lamp in relation to its inclination for measurement, orientation and rotation. With their values, the luminous intensity $I_k(C,\gamma)$ of the k-th lamp is determined. The luminance L at a point is then calculated according to the equation in the standard. The luminance value is affected by the luminous intensity $I_k(C,\gamma)$ k-th lamp, the complete maintenance factor f_M, the reduced luminance coefficient r_k(tan(ε), β) and the installation height H_k of the k-th lamp above the road surface, where tan(ε) and β are determined according to the procedure in the standard.

In the longitudinal direction of the area under consideration, the field of calculation must cover two lamps in the same row. Where there is more than one row of lamps and the spacing of the lamps between the rows is different, the calculation field is placed between the two lamps in the row with the greater or greatest spacing.

Since such a procedure does not necessarily give the right luminance for the entire lighting installation, as these are different if the distances between two successive lamps are different, the field where the results are worst shall be selected in accordance with the requirements of SIST EN 13201-2.

The calculation points are then defined in the selected field and must be evenly distributed in the calculation field according to the instructions in the standard. For the purpose of luminance calculation, the eye of the observer should be 1.5 m above road level and 60 m before the calculation field of the relevant area, and in the transverse direction the observer should always be placed in the centre of each lane (examples of the observer position for different road types are presented in the standard). It also describes the limit of the area for the installation of the lamps to be taken into account when calculating the luminance at the calculation point.

In the next step, we calculate the luminance or one of the required four types of illuminance according to the design criteria set out in SIST EN 13201-2 (horizontal, hemispherical, semi-cylindrical or vertical illuminance). For each of the four illuminances, the standard gives the equation in which the previously specified variables are inserted.

From the calculated luminance or illuminance values, it is possible to determine the quality characteristics relating to them, namely average luminance, general uniformity, longitudinal uniformity, threshold increment f_{TI} and edge illuminance ratio R_{EI}.

Annex A of the standard describes the mathematical and information technology arrangements that can be used for R_{EI} and f_{TI} calculations, in addition to the aforementioned procedures. A table is provided giving the proposed symbols for the variables, parameters and fields in the source code, together with descriptions, as well as a flow diagram for the calculation of all the variables and parameters we have already listed.

4 SIST EN 13201-4: 2016

This standard is a Slovenian standard and is equivalent to European standard EN 13201-4:2015. It is the fourth volume of the SIST EN 13201 series of standards and determines:

- procedures for measuring photometric quality parameters of road lighting installations (referred to in SIST EN 13201-2),
- arrangements and measurement procedures for the characterisation of road lighting installations,
- selection and correct use of luminance and illuminance meters,
- measurement requirements in accordance with the measurement objectives and the expected accuracy,
- the arrangements for evaluating the measurement uncertainty of the parameters included,
- the use of tolerance analysis in the design of road lighting installations, and
- conditions that may lead to significant inaccuracies in measurements and precautions to reduce them.

- the objectives requiring measurements of photometric quality parameters of the road lighting system, which are:
  1. **measurements at the end of the test period** (verification of compliance of road lighting installations with the requirements of the standard during final testing/handover),
  2. **measurements during the life span of road lighting** (measurements to control the luminous flux of lights of adaptive road lighting at given intervals during the life span of road lighting, in order to verify compliance with the requirements of the standard on the basis of maintained values),
  3. **measurements of adaptive road lighting** (measuring the luminous flux of adaptive road lighting lamps continuously or with a certain interval for installation efficiency at a given value within a given tolerance),
  4. **deviation measurement** (carried out as necessary to check compliance with the design requirements or the environmental impact).

The measurements must be carried out using an accurate measurement procedure specified in the standard. They can be performed using static or dynamic measuring systems (these allow measurements to be performed faster than static measuring systems). The standard first describes both the general and specific requirements for measurement procedures and measuring devices (luminance meters and illuminance meters). Procedures are also laid down for the evaluation of measurement uncertainty and the allocation of different sources of measurement uncertainty to different classes. Measurements are taken for the entire length of the road lighting installation or on measured sections (when the installation characteristics of the road lighting are designed the same for the entire length of the road lighting installation). The first step in the measurement process is to determine the parameters affecting the measurement (road geometric parameters, position, inclination and orientation of the light-sensitive surface of the illuminance meter, position of the surface to be measured relative to the nominal grid points for the luminance measurement, height of the light-sensitive surface of the detector relative to the road surface, and the photometric quality parameters for the relevant lighting class). The measurement results can be compared with the requirements of the standard or design requirements, but we must take into account the expanded measurement uncertainty of measurement according to instructions in the standard and apply the requirements regarding the parameters of road lighting installations according to SIST EN 13201-2.

The standard indicates and describes the different measurement conditions that must be taken into account for the suitability of measurements. Measurement conditions that affect measurement values are e.g. ageing of light sources and lamps before measurements, stabilisation after being switched on, weather conditions, carriageway conditions, foreign light sources and light obstructing.

During the photometric measurements care shall be taken to ensure that the locations of the measuring points are the same as the grid points given in SIST EN 13201-3, unless otherwise specified. For points located e.g. in the shade of a tree or on an oil stain (in the case of a luminance measurement), it is recommended that no measurement is made, which shall be indicated accordingly in the report. Similarly, when measuring luminance, the observer's location shall be the same as that indicated in SIST EN 13201-3. When evaluating the measurement uncertainty of a measurement, the accuracy of the grid point and observer locations with respect to the third part of the standard shall also be included. The average luminance is calculated as the average value of the measured luminance at the grid points or using an imaging luminance meter (ILMD) where the average luminance value is determined by one reading of the corresponding road surface area. For the measurement of all four types of illuminance (according to the needs of the lighting class), the standard provides instructions for the measurement of each type of illuminance separately, as well as the procedures for measuring the edge illuminance ratio R_{EI} and measuring the threshold increment f_{TI}. However, for photometric measurements, attention must also be paid to the non-photometric parameters measured for the connection for the purpose of measurement in cases where this is required. These parameters are supply voltage, temperature and humidity, geometric data and calibration of the instruments.

All measurements performed are stated and described in the measurement/test report (an example of the report is given in Annex H of this standard).

In Annex A, the table compiles the evaluated tolerances of the main parameters. The table is used in the analysis of tolerances, which is a mathematical tool for evaluating the expected technical characteristics of a given road lighting installation. It can indicate the likelihood that the installation will meet the required performance characteristics and also evaluate the reasons for discrepancies between the measurement results and the design requirements. Annex B presents important specific parameters, where normative photometric parameters are concerned, which may be evaluated for investigative purposes on a longitudinal part of the lane instead of on the entire lane, under the conditions and procedures presented in this Annex. Annex C gives agreements for symbols of photometric quality parameters and Annex D gives guidelines for measuring systems for adaptive road lighting, which are taken into account in measuring systems where the luminous flux of lamps is controlled. Annex E gives recommendations on measurements that are intended to determine deviations between photometric measurements and design requirements. Annex F contains a detailed measurement uncertainty evaluation procedure, together with descriptions of the parameters that influence the measurement uncertainty of the luminance/illuminance measurement and which are related to the measuring instrument, process or dynamic measurement system used. Annex G provides some practical information useful for the preparation of measurement procedures.

5 SIST EN 13201-5: 2016

This standard is a Slovenian standard and is equivalent to European standard EN 13201-5: 2015. It is the fifth volume of the SIST EN 13201 series of standards and determines the energy efficiency indicators of road lighting installations in order to identify the potential savings that can be achieved through improved energy efficiency. The standard introduces two indicators, namely the Power Density Indicator (PDI) D_p with unit W*lx^{-1}*m^{-2} and the Annual Energy Consumption Indicator (AECI) D_E with unit Wh*m^{-2}. The power density indicator D_p shows the power required for road lighting installation, and the annual energy consumption indicator D_E determines the electricity consumption during the year. Both can be used for all traffic areas covered by the group of lighting classes M, C and P.

In order to compare the energy efficiency of alternative road lighting installations, the luminous efficacy of an installation η_{inst}, with the unit lm*W^{-1}, can also be used.

Before calculating the expected amount of energy used in accordance with this standard, it is necessary to ensure that an appropriate lighting class is selected according to the visual needs of the road users (see SIST EN 13201-1), that all design criteria in SIST EN 13201-2 are met and that excessive lighting is reduced to the lowest level that is technically possible.

First, the standard shows how the power density indicator D_p and the variables that influence the calculation are calculated. The equation contains variables such as the system power of the lighting installation to illuminate the area under consideration P, the average horizontal illuminance maintained of the sub-areas "i" $\bar{E}_i$ and the areas of the sub-areas "i" A_i (illuminated by the lighting installation). The system power P is the sum of all operating power of the light sources, control devices and all other electrical devices directly connected to the lighting of the area. The average horizontal illuminance $\bar{E}$ and surface A are determined on the basis of the selected lighting class and in accordance with SIST EN 13201-3.

The calculation of the annual energy consumption indicator of a road lighting installation is affected by the operating power P_j (related to the operating period), the duration diagram of operating periods t_j (when the power P_j is consumed) and the size of surface area A illuminated by the same lighting installation.

Annex A shows the different operating modes and examples of calculations of energy efficiency indicators, together with typical values of energy efficiency indicators of modern technical solutions of lamps and installations. Thus, for example, diagrams of full power operation (the lamps operate constant at full power), operation with several power levels (different lighting levels in time intervals – classical type of reduction) and operation with several power levels and control according to traffic density (different lighting levels through the time interval, within levels are sub-levels controlled according to the presence of traffic) are displayed. Annex B presents the luminous efficacy of the installation and its factors. Annex C presents the light factor of the lighting that can be used for energy efficiency labelling of road lighting installations, independently of the lighting components used. Finally, Annex D provides recommendations on the presentation of energy performance indicators.

Annex C Regulation of road lighting abroad

Under the EU acquis, national standardisation bodies are required to transpose EU standards as identical national standards and to withdraw conflicting national standards. As a result, the EN 13201 series of EU standards is valid both in Slovenia and in neighbouring European countries.

Since, however, the first volume of this series identified by the code SIST-TP CEN/TR 13201-1: 2015, due to insufficient consensus of EU Member States, has not been adopted as a standard but as a technical report, some countries have adopted national versions of this document. A brief overview of the situation in neighbouring countries is given below, and an overview of some national documents used instead of CEN/TR 13201-1 is given in the following chapter. The data was collected through a survey of professionals working professionally in the field of road lighting.

Austria: Only roads and streets in urban areas are illuminated, but not outside urban areas. Parts from 2 to 4 of EN 13201 are in use, and instead of the first part, the national ÖNORM O 1055 document is in use. In addition, two more national documents related to road lighting are in use: ÖNORM O 1051 "Straßenbeleuchtung - Beleuchtung von Konfliktzonen" and ÖNORM O 1052 "Lichtimmissionen - Messung und Beurteilung". The use of the EN 13201 group of standards is not mandatory, but most designers (strictly) follow the recommendations in the standards, both for luminance and illuminance values as well as for uniformity. Road lighting renovations where only lamps are changed are an exception, but in general, values below the recommended values are not acceptable. A reduction of the luminance of lighting class M6 is possible by 50 % if the system includes real-time traffic counts, but not based on traffic statistics. Road lighting is be switched off during night time unless the municipality so decides in agreement with the residents and the emergency services. Pedestrian and cycling lighting in settlements is also not switched off at night, nor the lighting of bus stops.

In addition to the lighting parameters, the appearance of the lighting installation during the day is also considered. In relation to light pollution, there are certain limitations with regard to the luminance of buildings, light beams and colour temperature, given in ÖNORM O 1052, which are strictly considered by the authorities as the state of the art, but are not mandatory. New knowledge in the field of light pollution are taken into account in the design of road lighting. Nevertheless, some environmental experts have certain concerns, e.g. on the reasonableness to illuminate the roundabouts outside settlements and on the values in EN 13201-2.

Italy: The lighting of roads outside settlements is decided at local level (municipalities). Parts from 2 to 4 of EN 13201 are in use, and instead of the first part, the national standard UNI 11248 “Road lighting - Selection of lighting classes” is applied. In addition, the following are also used: UNI 11431 "Use of luminous flux controllers in road lighting", UNI/TS 11690 "Road lighting - Definition and evaluation of the object Visibility Factor (FVO) in street lighting installations according to UNI 11248", UNI/TS 11726 "Lighting design of pedestrian crossings in roads with motorized traffic" and UNI 10819 "Light and lighting - outdoor lighting application - lighting quantities and calculation procedures for the evaluation of the upward scattered luminous flux". In principle, standards are not mandatory, but a few acts refer to them. EN 13201 series standards are (strictly) followed in the design process and all parameters for road lighting. Values lower than those for class M6 do not apply. Road lighting is not switched off at night, but the parameters can be reduced (by class). Lighting in pedestrian areas and bus stops is also not switched off.

The urban planning expertise is partly taken into account in the context of the lighting plans (master plan). The problem of light pollution is addressed by provincial legislation and standard UNI 10819. Designers in many cases take into account new insights in this area, and environmental experts are mostly satisfied with the new installations.

Hungary: Roads outside settlements are generally not illuminated except in certain cases (according to valid consideration), such as: heavily congested sections of motorways, motorway service areas and associated entries and exits, bridges, roundabouts, critical intersections, cyclist crossings and roads between settlements that are very close together and that also include pavements and/or cycle lanes. All 5 parts of EN 13201 with original content are in use. Although the standard is not mandatory, it is used as a reference. Local legislation may also prescribe lower values, e.g. the lighting plan (master plan) for Budapest allows for 5 % lower uniformity for M classes 1 to 4 and 10 % lower uniformity for classes M5 and M6. Within settlements, M classes are used for asphalted roads and P classes are generally used for gravel roads. Lowering the luminance below the value for M6 is permitted and used. Some municipalities want to switch off road lighting at night time, which is often not possible because the power supply is connected to the traffic lights supply. In principle, pedestrian and cycling lighting is not switched off during night time, except in a few cases. However, the lighting of bus stops is switched off if it is not connected to other road lighting.

The urban planning experts are not taken into account in the design of lighting. However, certain measures are applied to reduce light pollution, such as the use of flat glass lamps, the inclination of the lamps 0°, if appropriate lighting parameters can be achieved, and the limitation of colour temperature to 3000 K. Designers are aware of new light pollution insights, but are “forced” to adhere to the standard, which sometimes excludes their use. There is also a national light pollution document, which prescribes that no new installation should increase the artificial luminance of the sky (artificial airglow), but it is not considered and required. There are not many complaints from environmentalists, except in really extreme cases (coloured-lit facades, heavily lit shopping centre car parks outside working hours, heavily lit advertising boards, poorly directed agricultural lighting, entertainment centre lighting, etc.).

Croatia: Standard EN 13201 is also adopted as the Croatian standard HRN EN 13201 including the first part, which has the designation HRN CEN/TR 13201-1 and is, like the other parts, adopted in English. In the field of nature conservation, Croatia has “Zakon o zaštiti od svjetlosnog onečišćenja” and “Pravilnik o zonama rasvijetljenosti, dopuštenim vrijednostima rasvjetljavanja i načinima upravljanja rasvjetnim sustavima”. No suitable interlocutor could be found for more information.

Germany: The view of road lighting in Germany varies slightly from one federal state to another. Roads outside settlements are generally not illuminated. When designing lighting in settlements, deviations from the illuminance (luminance) and uniformity standard are also tolerated, especially when the lighting is renovated, when only the lamps are replaced and not also the poles. Germany has adopted EN 13201 into its standardisation system, but only parts 2 to 4. Instead of the first part, they have their own national standard with the designation DIN 13021-1. The standard is described in more detail below. While the use of the standard is not mandatory, it is considered as a recommendation. The use of reduction of luminous flux and switching off lighting at night depends on local decisions. In some places, lowering levels below M6 or P6 is also practised. In principle, road lighting is not switched off, but in some cases the lighting of cycling and pedestrian areas is switched off. The same applies to the lighting of bus stops.

In relation to light pollution, there are no general regulations, but there is, for example, a regulation on this subject in relation to railway lighting. Nevertheless, designers are aware of the problem and this is also highlighted by conservationists.

Czech Republic: Municipalities are responsible for road lighting in the Czech Republic. Standard EN 13201 is implemented in use, covering all five parts including the first. It is mandatory for busier (transit) roads. For new installations, the standard is strictly applied, but for renovations (replacement of lamps only) it is not. Lower parameter values than in the standard are generally tolerated for existing installations, not for new installations. The reduction of the parameters is possible within the classes. The municipality's lighting plan (master plan), which is a mandatory document for the municipality, must be taken into account in the design. The reduction of parameters below the values for class M6 does not apply. However, in smaller settlements (villages), switching off street lighting during night time is used, but not on transit roads. Switching off pedestrian and cyclist lighting is also partly practised, depending on the area (industrial, tourist), as is lighting at bus stops.

In the field of light pollution, the Czech Republic has a technical standard, ČSN 360 459, which must be taken into account for new installations. Using this standard, new knowledge in the field of light pollution has also been incorporated into the design by default. The opinion of conservationists on road lighting is similar to that in Slovenia.

Slovakia: Roads outside settlements are no longer being illuminated today, but have been lit in the past, so some older installations are still in use. In Slovakia, all 5 parts of EN 13201 are also in use, with even the first part having the status of a standard with the designation STN 36 0410. Although the use of the standard is not mandatory, it is used in most cases. Even in the case of lighting in less traffic and rural areas, the lighting shall be designed in accordance with the standard. The urban planning profession is not involved in lighting design, (too) high poles are not a problem, but recently, for reasons of saving money, installations with relatively low poles (3 m) have been appearing in the urban environment. The reduction of luminous flux is sometimes applied, but there are no related instructions or recommendations. Certain municipalities also shut off road lighting completely during night time, primarily for savings reasons. Pedestrian and cycling lighting is not normally switched off, except in cases where presence sensors are used. Likewise, the lighting of bus stops is not switched off, but it is usually only illuminated in cities where bus traffic takes place all night.

There are practically no restrictions in the area of light pollution for road lighting. In some places, the ULOR=0 criterion is used, but otherwise Slovakia's legislation restricts the use of forced light only for lighting workplaces, sports facilities and private land. In this area, however, they want to implement changes at least for new installations. In most cases, lighting designers are not aware of light pollution issues.

Netherlands: In the Netherlands, roads outside settlements are also being illuminated, especially in dense or mixed traffic (pedestrians, cyclists). Exceptions are protected natural areas. The EN 13201 standard is adopted in the national standardisation system with Parts 2 to 5, and there are national recommendations (guidelines) instead of the first part. Lighting design mostly follows the recommendations in the standard, especially in urban environments. The urban planning expertise is also taken into account, which may influence the positioning of the poles... Lowering the lighting parameters below M6 class values is allowed and applied. It is not common practice to switch off road lighting during night time, but more commonly used is the regulation of luminous flux. However, during night time, the lighting of less congested pedestrian and cycling paths in protected natural areas is switched off. Bus stops are lit all night, especially for fear of vandalism.

Light pollution affects the design of road lighting, especially at the boundaries of protected natural areas and when there is a risk of forced light entering dwellings. The designers also take into account good advice from conservationists. In the field of light pollution, there are also national recommendations, which mainly summarise the CIE documents in this field. Discussions on light pollution tend to revolve around the question of whether a given road should be illuminated or the regulation of luminous flux should be applied, and the levels of luminance/illuminance are usually not questioned.

Poland: In Poland, roads outside settlements are also being illuminated, but since municipalities are responsible for this, it also depends on the financial situation of the municipality. All 5 parts of EN 13201 are used, in English language. While the use of the standard is not mandatory, designers tend to adhere to it. Many times the standard is also required by procurement investors. It is also required by the Directorate-General for Roads and Motorways. However, for older installations and in cases where no measurements are required after implementation, the projects may also deviate from the requirements of the standard. However, some national road lighting documents are also in use: WR-D-41-4 "Guidelines for designing pedestrian Infrastructure. Part 4: Design of pedestrian crossing lighting", WR-D-72-1 "Guidelines for designing devices for lighting rural roads. Part 1: Basic and specific requirements" and WR-D-72-2 "Guidelines for designing devices for lighting rural roads. Part 2: Catalog of typical solutions". The EN 12464-2 standard (for car parks) and the CIE 150 document (on light pollution) are also applied. In principle, the urban planning profession is not involved in lighting design. The values of the lighting parameters below the required for M6 are not usually used, but at least in the rural areas, road lighting is completely switched off during night time. This is usually decided by municipalities or road managers. There is no national recommendation on this topic. The lighting of pedestrian and cycling areas is not, in principle, switched off, but during night time the luminous flux decreases according to the amount of traffic. Bus stops remain illuminated during night time as well.

Designers are largely unaware of, or do not take into account, new developments in the field of light pollution. The more informed ones try to take this into account, but still stick to the requirements in the standard. However, there are also some measures to reduce light pollution, e.g. some investors require ULOR=0. There are national recommendations on this subject (WR-D-72-1, 2022), which should apply to national roads, but not all of them are followed. Conservationists and informed citizens believe that there is too much road lighting and that the levels are too high.

Denmark: In Denmark, only roads in settlements are lit. The standard EN 13201 is fully adopted in Denmark, including the first part, use is not mandatory and is not directly applied, but rather a manual for road lighting has been developed on the basis of it. The switching off of road lighting at night is not practised, but a reduction of the luminous flux by one or more classes is (obligatory) applied. The same applies to the lighting of pedestrian and cycling areas.

Denmark has a national light pollution regulation. Road lighting designers are aware of this problem and also take into account new insights in this area.

Sweden: As a rule, in Sweden, roads are illuminated in settlements where there is mixed traffic and which are also used by more vulnerable road users. Roads outside settlements are not illuminated unless traffic is very dense and the orientation is very difficult. Roads outside settlements near schools and bus stops with many passengers, tunnels and roundabouts are also illuminated. There are all five parts of EN 13201 among Swedish Standards, but only the second and third parts are strictly applied. In particular, the second part is referred to in the document “Swedish Transport Agency's regulations and general advice on property requirements for roads, streets, tramways and subways (building regulations)”, which also describes the design of road lighting. There are also certain national requirements for SS-EN 13201-2. In addition to the requirements of the aforementioned standard, planning advice from urban expertise is often taken into account, so that, in addition to suitable lighting parameters, appropriate appearance of road lighting as well as cost-effectiveness are sought. Designers also work with conservationists to minimise the impact of lighting on nature. Class M6 is not widely used, and WE5 (for wet pavement) is much more in use, and the reduction of luminous flux according to schedule (referred to in the following paragraph) is also applied. Lighting is not switched off at night, but luminous flux reduction is used. The same applies to bus stops. For pedestrian and cyclist lighting, switching off the lighting at night is used in combination with presence sensors.

Newer projects are also affected by awareness of light pollution problems. They also have national guidelines in this area, which will be implemented in 2024 and which mainly give the following requirements: no lighting outside urban areas (with a few exceptions), use of appropriate design tools (GIS), where sensitive areas are indicated, use of flat glass and ULOR=0, as little blue light as possible and colour temperature must be less than 3000 K, restrictions on the light efficiency of lamps, reduction of luminous flux during night time by 40 % (between 20:00 and 22:00 and between 5:00 and 6:00) and 60 % (between 22:00 and 5:00), lighting parameters should not exceed the minimum values by more than 20 %, use of presence sensors on pedestrian and cycling areas (if applicable), remote control of road lighting, special requirements where road lighting could affect the animals (e.g. prevent the passage of certain areas, etc.).

Finland: The decision to illuminate certain roads (inside or outside the settlement) is based on traffic volume and cost analysis. However, some roads, e.g. tunnels, motorways in urban areas, etc., are always illuminated. When designing road lighting, the second and third parts of standard EN 13201 are mainly used, and the content of the first part is included in the national design guidelines for road lighting. In principle, the use of standards is not mandatory, but calls for tenders for road lighting often require it. Even in less populated areas, designers stick to M classes if the road is asphalted, otherwise they use C classes. Designers also take into account the urban profession, if the appearance of the installation is also important. Also, at least in the larger cities, care is taken when drawing up plans to avoid obtrusive light. For the most part, only classes M3 to M5 and scheduled luminous flux reduction are used in the design of road lighting. Where luminous flux regulation is possible, it is reduced by 40 % between 20:00 and 22:00 and between 5:00 and 6:00, and by 60 % between 22:00 and 5:00. Where regulation is not possible (approximately 17 % of installations are affected), the road lighting is switched off between 0:00 and 5:00. The lighting of pedestrian and cycling areas is usually not switched off during night time, but the reduction of luminous flux is applied if the technology allows it. The same applies to bus stops.

There is considerable interest in the views of environmentalists, especially at higher levels of decision-making, and less so at lower levels - depending on the project and location. There is no specific national document on the subject, and the principles of CIE 150 apply in particular.

1 German national standard DIN 13201-1:2021-09

The standard first presents the categorisation of roads, parameters and weighting values. The parameters for determining individual lighting classes are given for each type of traffic surface separately. Roads are categorised as motorways (Autobahnen), rural roads (Landstraßen - außerorts), main thoroughfares (Hauptverkehrsstraßen), access roads (Erschließungsstraßen), collector roads (Sammelstraße) and residential streets (Anliegerstraße)), cycle lanes (Radwege), pedestrian lanes (Gehwege) and other traffic areas (sonstige Verkehrsflächen) such as conflict areas, parks and rest areas. All categories also have certain subcategories of roads with the restrictions described.

The parameters taken into account in determining the lighting class for a particular type of road are: maximum permitted speed, width of traffic lanes, number of nodes, separation of the directional lane, number of lanes in each direction, one-/two-way traffic regime, walking direction, structural demarcation or spatial separation from adjacent traffic areas, traffic volume, traffic flow of cyclists, pedestrian traffic flow, composition of traffic, cyclists, pedestrians, ambient luminance, parked vehicles, facial recognition, resident function and the need for additional requirements. For a given type of traffic surface, not all of the parameters listed are relevant, but the weighting values are determined only for the specified parameters.

Lighting classes M are determined separately for motorways, rural roads, main thoroughfares and collector roads where the speed limit is > 30 km/h, and for each designated time interval separately. Lighting classes used at different time intervals must not differ by more than three lighting classes.

The lighting classes for conflict areas C are determined from the table showing the selection of lighting classes C and P according to M classes and according to the light-intensity value of the road surface. The table also shows the reference average luminance values for individual lighting classes. They are given because of the requirement that the ratio of the average luminance values of adjacent areas should be no more than 2.5. From the same table, lighting classes P are also determined for cases where the road is considered a separate area and the adjacent traffic areas must be illuminated in relation to the specific lighting class of the road. The determination of lighting class C by taking into account the weighting values for individual parameters is not covered by this standard.

Lighting classes P are determined by a similar procedure as classes M for a different type of traffic area, such as collector roads with a speed limit ≤ 30 km/h, residential streets, cycle tracks, pedestrian walkways and other traffic areas with a speed limit ≤ 30 km/h (parking areas, rest areas, bus stops). Lighting classes used at different time intervals must not differ by more than three lighting classes.

Once the weighting values for the individual parameters have been determined, the procedure for determining the lighting class for the type of traffic area under consideration is the same as in the technical report SIST-TP CEN/TR 13201-1. The lighting class is obtained from the given equation by using the sum of the weighting values.

2 Swiss national standard SNR 13201-1:2016

The Swiss first part adheres to the procedure of the first part of the European standard, differences are only in the size of the weighting values and in the descriptions of the individual quantities of the parameter “traffic density”.

The traffic density parameter is divided into two parts, thus contributing two values to the sum of the weighting values. First, the weighting values are determined on the basis of the average daily number of vehicles in both directions, and then the weighting value is determined as a percentage of the maximum traffic density capacity. Traffic density thus has a greater weight in contributing to the weighting values of SUV, which also makes sense as traffic density is one of the key parameters in determining the lighting class.

The lighting classes M and P are determined in the same way as in the first part of the European standard. Two options are given for determining the lighting class C. As in the first part of the EU standard, the lighting classes C can be determined from the table showing the choice of classes C in relation to classes M. Alternatively, the classes can be determined in the same way as classes M and P, i.e. by using parameters and weighting values. Another difference with respect to the EU standard is that different luminous intensity limit values Q_0 are given in the table for the selection of the appropriate C class according to the M class.

3 Austrian national standard ÖNORM O 1055:2017-09

The Austrian Part I, like the Swiss Part I, uses data on the average daily number of vehicles in both directions, for both motor vehicles and pedestrians, to calculate traffic density. For the other parameters, the descriptions also provide more defined situations on the basis of which the weighting value is chosen.

The lighting classes M and P are determined in the same way as in the first part of the European standard. For the determination of C classes, the same table is also given for the selection of the C class in relation to the M class, but the determination of the C class by taking into account the weighting values of the individual parameters is not included in this standard.

The parameters taken into account in determining the lighting class for a particular road type are the same as in the first part of the European standard (intended speed or speed limit, traffic density, traffic composition, directional carriageway separation, frequency of nodes and intersections, parked vehicles, ambient luminance and navigational task complexity). The weighting values are also the same, differences are only in the description of certain parameters, e.g. in the “traffic density” parameter in the determination of lighting classes M, concrete numbers of vehicles are indicated instead of percentages of the maximum capacity of road surfaces, the parameter “travel speed” in the determination of lighting classes P is also more precisely defined, etc.

A table has also been added to the standard showing the choice of C and P classes in relation to M classes and the luminance value. The table is intended for use in areas where the road is considered a separate traffic area and adjacent areas must also be classified in the appropriate lighting classes. For cases where there are insufficient parameters for the appropriate classification of adjacent areas in the appropriate lighting class, e.g. on emergency lanes, cycle tracks or pavements, the selected lighting class may be no more than two levels lower than the adjacent class.

The table also gives, according to the lighting classes M and according to the road surface luminance values, the lighting classes SC, EV and HS, which are not found in the first part of the European standard (although the footnotes state that the HS classes are practically irrelevant in Austria).

When describing the transition from the illuminated area to the less illuminated or non-illuminated area and vice versa, it is stated that without the use of an adaptive lighting system, there can be a difference in the lighting classes of the two areas of up to two classes.

The standard also provides an extension of the weighting values for the parameter “traffic density” for the time frame between 22:00 and 06:00, in order to reduce the lighting class during this time. The expanded weighting values are determined in two ways, based on the average daily traffic value in one table and the maximum hourly traffic density at that time in the other table. If we use another method, the time period from 22:00 to 06:00 can be divided into several smaller time intervals and the weighting value for the traffic density can be determined on the basis of the maximum hourly traffic density during this time interval.

In areas where traffic is regulated or controlled by traffic sensors (Ger. “Verkehrssensoren”), even in periods without traffic, a minimum illuminance level must be maintained of not less than 50 % of the luminance/illuminance of the lowest lighting class M, C or P (i.e. 50 % M6, C5 or P6). When the sensor detects the presence of a road user, the adaptive lighting level is set to match the current time period.

4 British national standard BS 5489-1:2020

The first part of the British Standard BS 5489 gives detailed recommendations for road lighting designers in the main part. It first describes the reasons for the need for road lighting, touching on environmental impact, sustainability, economics and the impact of lighting on people. On the subject of road lighting design, it lists and justifies the appropriate places for the installation of lamps, lamp technology, light sources, lighting control methods, it also describes the photometric characteristics in relation to the second and third parts of BE EN 13201 and describes the lighting of special areas, such as conflict areas, bridges, airports, ports, etc. In Annexes B – G, the standard also describes more precisely concepts such as durability, typical maintenance factors and their calculation and a description of the procedure for road lighting design for different types of traffic areas. The lighting classes are discussed in Annex A.

The lighting classes M are set out in two tables. In both, classes are set for conditions such as moderate ambient lighting, good visibility and non-presence of parked vehicles. The first table lists lighting classes for motorways where the speed of vehicles is $v \geq 60$ mph and for traffic areas used by both drivers of motor vehicles as well as cyclists and pedestrians, where the speed of vehicles is $40 < v < 60$ mph. In addition to speed, the selection of the lighting class also takes into account the parameters of traffic flow, carriageway type (single carriageway, dual carriageway) and, for dual carriageways, the frequency of nodes/intersections, where high frequency is defined as nodes/intersections less than 3 km apart. In cases where we have a high frequency of intersections, a risk assessment shall determine whether any of the intersections constitute a conflict area. Traffic density can be determined either by reference to average daily traffic and specified values in this standard or according to the percentage limits given in EN 13201-1.

The second table lists lighting classes for traffic areas used by drivers of motor vehicles, cyclists and pedestrians and where the speed of vehicles is $v \leq 40$ mph. The parameters and parameter descriptions are the same as in the first table, as well as the provisions regarding the determination of traffic density.

In addition to the parameters set out in EN 13201-1, a risk assessment may be taken into account in the selection of the lighting class in traffic areas with specific characteristics. The risk assessment shall be applied when taking into account parameters such as:

- traffic composition (where low-speed motor vehicles, pedestrians and cyclists share the road),
- the presence of parked vehicles, bus stops or pedestrian crossings,
- ambient luminance (if this is low, it is also reasonable to reduce the lighting class); and
- visual guidance (if visual guidance is poor due to different factors, it is reasonable to increase the lighting class).

Taking into account all parameters, the lighting class can be adapted accordingly by the designer, usually no more than one class up or down.

For conflict areas, lighting classes C are defined on the basis of the lighting class of the road before the conflict area, i.e. one class higher than the M class for all illuminance levels. Where traffic routes with different M-classes meet, the highest of these shall be taken into account in determining the class for the conflict area. For complex or large single-level intersections representing conflict areas, it is generally recommended to install fewer lamps on poles higher than 12 m.

The selection of the lighting class P shall take into account parameters such as traffic density, the environmental zone (zones taken from the document "Guidance notes for the reduction of obtrusive light", Institution of Lighting Professionals, 2004) and the types of users of the route (cyclist and pedestrian only routes and routes for slow vehicles at v ≤ 30 mph). The additional requirements are taken into account for areas with a higher crime level or where the safety of the user of the traffic area is conditional. The lighting classes represent the minimum level of illuminance in the area under consideration, a more appropriate illuminance of the area requires a risk assessment.

The risk assessment shall take into account parameters such as:

- traffic composition (where low-speed motor vehicles, pedestrians and cyclists share the road),
- the complexity of the visible task (presence of parked vehicles, traffic calming devices, etc.), and
- the level of crime or the need to facial recognition (if necessary, an appropriate lighting class EV may be selected).

The risk assessment shall also take into account the S/P ratio and the colour appearance index value of the selected lamp. Taking into account all parameters, the lighting class can be adapted accordingly by the designer, usually no more than one class up or down.

The standard adheres to the principles set out in the first part of the European standard, that for lighting in the areas of cyclists, pedestrians and slow vehicles, the general uniformity of lighting illuminance is also of great importance, and that the average illuminance value must be less than 1.5 times the minimum illuminance value specified for a given lighting class.

The standard also provides a table comparing the lighting classes C and P for urban areas and city centres according to the types of road users (pedestrians only, vehicles and pedestrians on a separate surface, vehicles and pedestrians on the same surface), traffic density and the environmental zones already mentioned. The table is intended for certain areas in city centres, separated into environmental zones, where the selected area may be better illuminated using a lighting class P rather than C.

5 Italian national standard UNI 11248 EN

The lighting classes in this standard are determined according to the category of road and the speed limit of the road.

First, the designer divides the considered case of road into several study zones. The zones are determined in such a way that the conditions of the parameters affecting the selection of the lighting class of each zone are homogeneous. The road category is then determined for each zone, and based on this, by means of the table in the standard, the corresponding lighting design entry class.

Lighting classes are divided into: lighting design entry class, lighting design class, and operating lighting design class.

The lighting design entry class depends exclusively on the road category and the speed limit on the road. The risk assessment analysis then determines a lighting design class that covers parameters with constant influence in lighting operation and an operating lighting design class that, in addition to parameters with constant influence in lighting operation, also covers current and possible operating conditions.

When analysing the risk assessment, the lighting design class is determined by tables in the standard where the influencing parameters are given (complexity of the normal field of vision, low density of conflict areas (determined by the designer), visible markings in conflict areas, active traffic signalling, crime hazard, percentage of maximum hourly traffic, lower complexity of the type of traffic participants), and the designer may take into account, in the risk assessment, other parameters that are permanently present (constant lower traffic flow according to maximum, FAI – Federated Artificial Intelligence adaptive systems).

With the parameters taken into account (e.g. if, according to statistical data, the traffic density is shown to be constantly lower than 50 % of the maximum capacity), the lighting design entry class may be reduced by one class according to the lighting design class chosen. If it is less than 25 % of the maximum capacity, then by two classes).

For cases of roads with other traffic areas in addition to the carriageway, we use a table comparing the lighting classes M, C and P. In the first table, general comparisons of the classes are given. This differs from the table in the first part of the European standard in the classification of classes C and P according to classes M (e.g. the comparison of class C0 can be compared with class M1 for road surfaces with luminous intensity $Q_0 \leq 0.05\ cd \cdot m^{-2} \cdot lx^{-1}$, and for larger luminous intensity values, class M1 is compared with classes C1 or C2). Classes P are comparable to classes M3 – M6, regardless of the luminous intensity of the road surface.

The second table shows the additional lighting classes C and P for luminous intensity values $0.05\ cd \cdot m^{-2} \cdot lx^{-} < Q_0 \leq 0.08\ cd \cdot m^{-2} \cdot lx^{-}$ and, independently of luminous intensity, the EV classes.

When considering a road made up of several types of traffic surface with class differences of more than two classes, the highest class of the specific traffic surface is selected as the entry class.

In addition to guidance on the selection of the lighting class, the standard also provides recommendations and examples in annexes on the lighting of intersections (Annex A), describing the characteristics relating to the luminosity of road surfaces (Annex B), provides information on the assessment of the correlation between lighting requirements and road types to assist in design (Annex C), gives norms illustrating the design and management characteristics for certain types of adaptive lighting systems (Annex D), and information for the illumination of cycle paths and pavements (Annex E).

Attachment D: Regulations on road lighting

Road lighting is dealt with in several acts, rules and regulations and is difficult to manage because of this. The following is a description of the content of the various documents involved in the field of road lighting. In addition to the latest regulations and draft regulations in force, regulations that have expired but are still in force due to the non-implementation of new regulations are also taken into account. Finally, for a quick overview of the content, a summary of all the requirements and provisions of the regulations under discussion is added.

1 Roads Act – ZCes-2 (Official Gazette of the Republic of Slovenia Nos 132/22, 140/22 – ZSDH-1A, 29/23 and 78/23 – ZUNPEOVE)

In the Roads Act, road lighting is described as traffic equipment to provide illuminance for individual parts of the road. Traffic equipment is defined as a means and device for protecting road users due to built barriers and factors of the natural environment, traffic regulation, ensuring traffic safety and the forced stopping of vehicles. Traffic equipment must correctly identify pedestrian lanes and traffic layout determined by the road manager for the road or part thereof or for the settlement or part thereof (Article 2). All traffic calming devices shall also be marked with appropriate traffic equipment (Article 25). This is further specified in the Rules on traffic signs and equipment. Public roads and non-categorised roads used for public road transport must be equipped with the prescribed traffic signalisation and traffic equipment to warn road users of the danger on the road or part of the road, to indicate to them the restrictions, prohibitions and obligations, to give them the necessary information for safe and unhindered traffic and to guide them in traffic. The traffic equipment must comply with the prescribed traffic regime and traffic technical and safety conditions on the road or part of the road. Traffic equipment is used to indicate hazards, temporary obligations, restrictions or prohibitions in traffic. The Act also states that pedestrian and cyclist crossings must be illuminated at night in accordance with this Act and the Environmental Protection Act, and there is no more detailed provisions and direction in the document.

Traffic equipment is an integral part of the road (Article 11). Article 49 sets out the division and categorisation of public roads. Public roads are traffic areas that are of general interest to traffic and can be freely used by anyone in the manner and under the conditions laid down bythis Act and the Act governing road traffic rules (Article 3).These are divided into national and municipal roads. National roads are owned by the Republic of Slovenia and municipal roads are owned by municipalities. Given the importance for traffic and the connection function in the space, national roads are categorised into motorways, expressways, main roads of the 1st and 2nd class, regional roads of the 1st, 2nd and 3rd class, as well as national cycling routes, and municipal roads into local roads, public routes and municipal cycling routes. Article 50 of the Act states that for the purposes of planning, condition monitoring, management, maintenance and statistical purposes, a public road register shall be kept as a bank of road data (BRD), which shall comprise descriptive, numerical, graphical and other data on public roads and the structures on them and shall constitute a single database. For national roads, it is managed by the Directorate, and for municipal roads by the municipality (Article 50, Article 115).

Traffic equipment is installed and removed by the provider of regular road maintenance as part of the regular maintenance work (Article 24). The installation, replacement, addition or removal of traffic signalization and traffic equipment on national roads is ordered by the national road operator (Article 87). The manager of municipal roads and the way in which the management tasks are carried out are determined by the competent municipal authority by means of a general act (Article 108). Article 18 states that traffic equipment on public roads must be installed and marked in accordance with this Act and in such a way that it is clearly visible. It must be regularly maintained and replaced, substituted or re-marked whenever it is destroyed, damaged or removed. Owners or holders of the right to use land adjacent to a public road must allow such interventions as are strictly necessary for the smooth use of the public road, including the installation of traffic equipment (Article 22). In this case, the right of ownership of the property may be temporarily or permanently encumbered by a public utility easement, and the owner is entitled to compensation if a public utility easement is created. If the owner refuses to allow the intervention, they will be fined. The tasks and powers of the operator of national roads are set out in Article 66. These tasks include, inter alia, keeping records of national roads and summary records of public roads, drawing up expert bases for the maintenance and development plans of national roads and drafting these plans, and tasks relating to the preparation of expert bases for the technical regulations governing the design, construction and maintenance of public roads. The operator of national roads shall regularly maintain the national roads (Article 68), with the exception of traffic areas, structures and devices on the road land of the national road, which are in the function of the public areas of the settlement and are maintained by the municipality (Article 72). Traffic areas, structures and installations on the road land of a national road that are in the function of public areas of the settlement but are maintained by the municipality include parking bays, parking areas, bus stops and other traffic areas outside the carriageway, cycle paths, pavements and road structures in these areas, road lighting, traffic lights, except traffic light control devices, and traffic signalization with external or internal illumination with associated power supply network, including electricity supply, and green areas and urban amenities in the area of the road land. Connections of municipal roads to the national road are a special case. The connections are regularly maintained by the municipality, and the traffic equipment and signalling intended for traffic on the national road is maintained by the national road maintenance company. The Directorate also maintains the traffic signalization and traffic equipment of national cycle routes that run on municipal roads and are intended for cyclists (Article 74). The municipal road manager regularly maintains and supervises municipal roads (Article 110), including road connections up to the boundary of the road land of the municipal road, with associated traffic signalization and traffic equipment (Article 111).

The implementation of this Act is subject to inspection by the inspectorate responsible for national roads and, for municipal and non-categorised roads, by the municipal inspection body (Article 129). Inspections also check, among other things, that traffic signalization and traffic equipment on public roads are installed and maintained in accordance with the conditions laid down in the rules governing roads (Article 131).

2 Rules on traffic signs and equipment on roads (Official Gazette of the Republic of Slovenia, Nos 99/15, 46/17, 59/18, 63/19, 150/21, 132/22 – ZCes-2 and 26/24)

The Rules specify the purpose, types, meaning, form, colour, size, characteristics and installation of traffic signs and traffic equipment on public and non-categorised roads used for public road transport (Article 1). In Article 2, paragraph 6, road lighting is defined as part of traffic equipment. Traffic equipment, together with traffic signs, are the means and devices which warn road users of hazards, indicate restrictions, prohibitions and obligations, and give the necessary notices to ensure safe and unhindered traffic and guide them in traffic. Article 5 stipulates that traffic equipment must meet technical standards (in terms of shape, colour, size, materials). The areas for the installation of traffic equipment are set out in Article 7. The area for the installation of traffic signs and traffic equipment is a strip along the carriageway of the road, 8.00 m on motorways and expressways and 5.00 m on other roads, measured from the outer edge of the carriageway. If the carriageway also includes cycling, pedestrian or other traffic areas, the width of this lane shall be 2.00 m measured from the outer edge of these areas. Article 9, paragraph 17, provides that road lighting poles may also be used for the load-bearing structure of traffic signs. General provisions regarding road lighting are set out in Article 75. In these Rules, road lighting is lighting that provides adequate visibility on the road at night and in reduced visibility in order to increase road safety for all road users. The lighting shall, in relation to the design speed of the road, provide an adequate level of illumination and illuminance of the traffic surfaces and shall optically guide traffic in accordance with the regulations governing permissible light pollution of the environment. The areas to be illuminated by road lighting are defined in paragraph three of this Article. Road lighting is used to illuminate the most congested parts of roads in settlements, pedestrian crossings and underpasses, intersections with three or more classified lanes, motorway and expressway junctions and their connections, traffic service areas, bus stops on regular public passenger transport routes, roads at border crossings, and roads in medium- and long-distance tunnels. Short tunnels must be illuminated only if pedestrian or cyclist traffic is allowed through the tunnel.

3 Rules on road design (Official Gazette of the Republic of Slovenia, Nos 91/05, 26/06, 109/10 - ZCes-1, 36/18 and 132/22 – ZCes-2)

The Rules on road design refer to road lighting in Article 59 in three paragraphs. It is determined that road lighting ensures illuminance of the carriageway and surfaces adjacent to the road so that road users can easily notice unexpected obstacles during night time or when daylight is inadequate. The quality of road lighting is determined by visibility criteria depending on the design speed, the level and uniformity of illumination and illuminance, the limitation of glare and the optical guidance mode.

It also specifies the locations where road lighting must be installed, namely on roads in settlements, at channelized intersections, at junctions on long-distance roads, at intersections of main and regional roads outside settlements, at bus stops, on pedestrian walkways in the area of marked crossings or underpasses, in the areas of control stations, petrol stations, rest areas and service stops, and in car parks.

Provisions concerning the locations where road lighting must be installed have been amended in the Rules on road design with provisions from the Rules on traffic signs and equipment on roads, which significantly reduce the traffic areas with mandatory lighting. The Rules on traffic signs and equipment on roads is a more recent regulation and is therefore relevant.

4 Rules on road connections to public roads (Official Gazette of the Republic of Slovenia, Nos 86/09, 109/10 – ZCes-1 and 132/22 – ZCes-2)

Road lighting is referred to in Article 26 of the Rules on road connections to public roads. The road lighting of the connection shall ensure the prescribed level of lighting and illuminance of all traffic surfaces and adequate optical guidance in reduced visibility. In the connection area, road lighting in the main traffic direction is specified by the applicable regulations. However, road lighting requirements do not apply to individual connections on roads outside settlements. These requirements do not mean that all connections to public roads must be illuminated, except individual connections outside settlements, but rather provide a requirement that connections which are illuminated, on the basis of other regulations and recommendations, shall be illuminated in accordance with these regulations and the other requirements of Article 26 of the Rules.

5 Rules on the method of marking public roads and on records of public roads and structures on them (Official Gazette of the Republic of Slovenia, Nos 49/97, 2/04, 109/10 – ZCes-1 and 132/22 – ZCes-2)

Article 18 of the Rules provides that, for defence needs and for action in the event of diversion of traffic due to its smooth and safe conduct, the Directorate of the Republic of

Slovenia for Roads keeps a consolidated record of technical data on all public roads. Each year, the municipal administration must send the data on municipal roads to the Directorate of the Republic of Slovenia for Roads for the register of technical condition data, as provided for in Article 17.e.

This data includes not only general road data, but also information on traffic signs and traffic equipment. More on transport equipment and traffic signs can be found in the Rules on traffic signs and equipment on roads.

6 Rules on cycling areas (Official Gazette of the Republic of Slovenia, Nos 36/18 and 132/22 – ZCes-2)

Article 2 of this document provides in the second paragraph that an integral part of the cycling areas are also parking areas and resting places for bicycles and their equipment, as well as traffic signs and traffic equipment for cyclists. First paragraph of Article 43 stipulates that bicycle parking area must also meet the conditions for safe parking in terms of illuminance. The design of traffic equipment in parking areas must comply with the regulations in the field of traffic signs and equipment on roads (first paragraph of Article 46). Article 49 requires road lighting to be provided at cycle crossings, on roads in settlements with shared traffic lanes, at places where motorised and cycling traffic intersect, and in areas with physical traffic calming devices for cyclists in settlements. Lighting on cycling surfaces is not required outside settlements. The third paragraph also provides that the intensity of the road lighting of cycling areas should be adjusted if the density of cycling traffic and the luminance of the surrounding area changes during night time.

7 Rules on bus stops (Official Gazette of the Republic of Slovenia, Nos 106/11, 36/18 and 132/22 – ZCes-2)

Article 22 of this document stipulates that adequate lighting of the pedestrian crossing point must be provided in the area of the bus stop.

8 Rules for carrying out investment maintenance and maintenance works in the public interest on public roads (Official Gazette of the Republic of Slovenia, Nos 7/12 and 132/22 – Zces-2)

Article 8 of the document stipulates that the review of the road design documentation shall also cover road lighting. A review is compulsory if the execution of investment maintenance works, maintenance works in the public interest or construction works requires the preparation of project documentation (Article 7). Article 16 also lays down the requirements for the inspection of maintenance work in the public interest. However, in the case of the installation of equipment or installations, including road lighting, an internal inspection must be carried out by the persons responsible for carrying out the maintenance work in the public interest and by the future maintainer of the equipment or installations before the commission inspection itself. A record of the inspection shall be drawn up, clearly indicating that the equipment or installations inspected are in perfect working order, and shall be presented by the contractor at the commission inspection of the maintenance work carried out.

9 TSPI – PGV.03.244: 2023 Road design and traffic safety – Roundabouts

The document provides guidelines for the technical design of roundabouts on public and non-categorised roads used for public road transport in the Republic of Slovenia, including in the area of road lighting, as this is a prerequisite for traffic safety at night. The road lighting of the roundabout is described in subchapter 4.7.5. It is specified that the roundabout must be adequately illuminated at night, both at the entries and at the exits of the roundabout, as well as the areas of conflict points and the central island. Particular attention should be paid to adequate lighting of pedestrian/cyclist crossings.

It is recommended that road light poles be placed around the perimeter of the roundabout. If the roundabout is of larger dimensions, it is possible to install road light poles also on its central island. The distribution should be even with respect to the distance between the individual lamps and the distance to the centre of the island. It is recommended that each approaching leg (entry or exit) be illuminated at a distance of at least 60 m from the roundabout (if there is no road lighting already arranged on the approaching leg). The colour of the light and the height of the lamps should be uniform over the entire area of the roundabout, but not lower than on the approaching legs.

The document also deals with mini roundabouts, which are usually built as part of an existing intersection. Regarding the requirements for road lighting of such roundabouts, subchapter 5.3.2 states that mini roundabouts shall be adequately illuminated and chapter 5.5 that adequate road lighting shall be used to make mini roundabouts detectable (night-time visibility), among other things.

10 TSPI – PGV.03.245: 2023 Road design and traffic safety – Roundabouts with spiral flow

The technical specification provides guidelines for the planning, design and construction or traffic-technical and design-technical dimensioning of roundabouts with spiral carriageway (turbo roundabouts) on public roads in the Republic of Slovenia. Chapter Seven of the document states that the turbo roundabout must be adequately illuminated at night to meet traffic safety conditions.

11 TSC 03.800: 2009 Traffic-calming devices and measures

The document deals with traffic calming devices and measures. Traffic calming devices and measures are physical, light or other devices and obstacles that physically prevent road users from driving at inappropriate speed or warn them of a speed limit on a dangerous section of the road. Devices and measures are determined on the basis of the traffic and accommodation functions of the road, and these are ensured by appropriate urban planning and/or by traffic calming devices and measures. The traffic conditions for the use of traffic calming devices and measures are defined by the peak hourly volume (PCE/h) and the vehicle structure.

Road lighting is covered in this document under public lighting, which is most prominent in architectural design, according to subchapter 4.4.7.2. It is stipulated that public lighting must enable drivers to clearly see the lanes and the road space and at the same time adapt to the function of the road. Particularly important is the lighting of critical points (intersections, pedestrian crossings, traffic calming devices, etc.). Thus, on roads with a significant traffic function, lamps on high poles (10 m) are used, while on roads with a significant residential function, lamps on low poles (3-5 m) are used. In addition to the height of the poles, the type of light plays an important role in creating the ambience of the street. Other traffic calming measures and devices should be specially illuminated where necessary to improve visibility. Chapter 5 presents traffic calming measures and devices using concrete examples. These include, for example, humps and platforms (Subchapter 5.4), carriageway narrowings and directional carriageway delineations (Subchapter 5.5) and carriageway axis - directional carriageway offsets (Subchapter 5.6). Lighting is required for all of these cases.

12 Manual for road lighting in the area of crossings for pedestrians and/or cyclists

The lighting of a pedestrian and/or cyclist crossing usually has two purposes. On the one hand, it warns the driver that they are approaching a crossing or the so-called conflict area. If the crossing is on a lit road, this can be achieved by increasing the luminance or illumination of the carriageway (crossing area) or by changing the colour (colour temperature) of the light. On an unlit road, the lighting of a pedestrian and/or cyclist crossing also draws the driver's attention to the crossing and alerts them to the crossing. On the other hand, the lighting of the pedestrian and/or cyclist crossing allows the driver to detect (in a timely manner) a pedestrian or cyclist at or near the crossing during the dark part of the day. The Manual recommends using positive contrast at crossings where the pedestrian or cyclist is brighter than the background. This is achieved by adequate vertical illuminance. Normal road lighting provides mostly horizontal illuminance, which helps the driver to identify objects on the carriageway, but not objects located above the carriageway. Therefore, additional lighting is almost always required to illuminate pedestrian and/or cyclist crossings. This additional lighting must provide adequate vertical illuminance in the pedestrian crossing zone of a height between 1.0 m and 1.5 m. The document presents the complete procedure for determining the horizontal and vertical illuminance of a crossing using the procedures in the technical report SIST-TP CEN/TR 13201-1, Road Lighting – Part 1: Guidelines on selection of lighting classes and SIST EN 13201-2, Road lighting – Part 2: Performance requirements according to the data on the traffic and construction parameters of the road and other conditions affecting the determination of the lighting class. Technical solutions for the lighting of pedestrian and/or cyclist crossings are also presented.

13 Rules on the regular maintenance of public roads (Official Gazette of the Republic of Slovenia, Nos. 38/16 and 132/22 – Zces-2)

Article 10 of the Rules states in its second paragraph, points 7 and 8, that the work of regular road maintenance also includes the regular maintenance of traffic signs and equipment and regular maintenance of road lighting, installations and arrangements. The second paragraph of Article 11 sets out the work of the inspection service, which includes the repair and cleaning of vertical traffic signs and the cleaning and minor repair of traffic equipment, which, according to the Rules on traffic signs and equipment on roads, also includes road lighting. Article 17 provides further details on the regular maintenance of road lighting. It states that road lighting, installations and arrangements shall be maintained in such a way as to ensure their proper functioning. The reasons preventing this must be rectified without delay and, if this is not possible, appropriate temporary solutions and insurance measures must be implemented.

14 TSC 02.203: 2009 Traffic calming devices and measures at level intersections without traffic lights

The document sets out the technical conditions for traffic-technical design of traffic calming devices and measures at level intersections without traffic lights on public roads and on non-categorised roads used for public road transport. The document does not include roundabouts and mini roundabouts (these are dealt with in the TSPI – PGV.3.244: 2023). Chapter 7 lists the types of devices and measures used to calm traffic at intersections. In all of these cases, the implementation states that transparency can also be provided by public lighting.

15 TSPI PCPV PGV.03.480 Devices and measures to improve safety of motorcyclists

The document relates more indirectly to road lighting in Chapter 4.3.1, which describes safe roadside. A safe roadside is defined as a strip immediately adjacent to the carriageway, free of rigid point or linear physical obstacles (retaining walls, bollards, road lighting poles or power lines, etc.), the collision with which could increase the consequences of traffic accidents. If dangerous elements in the roadside cannot be removed, either by moving them away or by protecting them, they must at least be additionally marked. Chapter 7.1.2 also mentions that a motorcycle crash cushion (MCC) may exceptionally be installed on the poles of traffic signs or public lighting.

16 TSPI – PGV.03.320: 2023 Road design and traffic safety – Pedestrian areas

The document states in subchapter 8.2 that the lighting of the pedestrian crossing and the additional lighting of the pedestrian crossing shall be carried out in accordance with the Manual for road lighting in the area of crossings for pedestrians and/or cyclists. Subchapter 7.1 also stipulates that the marking of independent pedestrian crossings shall include, inter alia, the provision of lighting at the pedestrian crossing point.

17 Regulation on the limit values for light pollution of the environment (Official Gazette of the Republic of Slovenia, Nos 81/07, 109/07, 62/10, 46/13 and 44/22 – ZVO-2)

Article 1 of the Regulation on the limit values for light pollution of the environment describes its purpose. In the field of road lighting, this lays down requirements for targets for the annual electricity consumption of lamps that are installed in the lighting of roads and other uncovered public areas. These values are stated in Article 5. The electricity consumption of all lamps in the territory of a municipality for the lighting of municipal roads and public areas, calculated per inhabitant (with permanent and temporary residence) in that municipality, may thus not exceed 44.5 kWh. In municipalities where there are fewer than 1,000 inhabitants, the maximum electricity consumption of all lamps may nevertheless be 44.5 MWh. For national roads, the target value for electricity consumption is 5.5 kWh (calculated per inhabitant of Slovenia). With regard to the management of road lighting, Article 16 states that lighting, with the exception of adverse weather conditions, must be switched off during the day, which is the task of the lighting manager. Article 21 requires that a lighting system (and therefore also road lighting), where the sum of the electrical outputs of the lamps exceeds 10 kW, must be accompanied by a lighting plan showing basic information on the light source. This shall be reviewed and supplemented or amended accordingly every 5 years. It is also stipulated that a new plan must be drawn up in the event of an increase in power of more than 15 % or in the event of replacement of more than 30 % of the lighting system lamps. The plan for road lighting must contain information on the operator, the light source, the location of the lighting, the annual electricity consumption, the total electric power and the number of lamps installed, the proportion of the luminous flux that the lamps emit upwards and the total length and surface of the illuminated roads and other public areas.

The regulation also lays down requirements relating to road lighting from a nature conservation perspective. Article 1 also states that the document prohibits the use of light emitted in the form of light beams towards the sky and surfaces reflecting light towards the sky, as well as measures to reduce the emission of light into the environment. The Regulation also aims to protect nature from the harmful effects of light pollution, to protect living spaces from the disturbing illumination caused by the lighting of uncovered surfaces, to protect people from glare, to protect astronomical observations from sky glow, and to reduce the electricity consumption of light sources that cause light pollution. Article 4 thus stipulates that lamps used for lighting must have a percentage of upward luminous flux equal to 0 %. With regard to illuminance on windows of protected spaces, Article 17 states: the illuminance on windows of protected spaces shall not exceed the limit values set out in the table in the annex to the document. The limit value is determined for the window that is most exposed due to lighting.

Article 22 states that only data provided by a person who is qualified to carry out luminance and illuminance control may be used for determining illuminance and luminance data, and Article 26 further states that infringements of the requirements of this Regulation are subject to fines.

18 Decree on Green Public Procurement (Official Gazette of the Republic of Slovenia, Nos 51/17, 64/19 and 121/21)

The decree governs green public procurement. Green public procurement is a procurement in which the Contracting Authority orders, under the Public Procurement Act (Official Gazette of the Republic of Slovenia, Nos 91/15 and 14/18), goods, services or works which have a lower environmental impact compared to conventional goods, services and works over their entire lifetime and provide savings in natural resources, materials and energy, and which have the same or better functionalities (Article 1). Article 4 of the document states that the subject of public procurement, for which consideration of environmental aspects is mandatory, shall also be road lighting and road signalling. The object “road lighting” is described in more detail in Annex 1 under point 66: “Road lighting” means the lighting of the public surface or the network and devices for providing illumination of particular parts of the road, road structures such as a bridge, viaduct, underpass, overpass, culvert, tunnel, gallery, support and retaining structure and underpass and overpass, and other uncovered public areas, excluding lighting for security purposes, for military, defence or protective activities in areas for the purposes of defence and protection against natural or other disasters, if arising from the performance of tasks in the defence of the State or the protection, rescue and relief in the event of natural or other disasters, occasional outdoor lighting at public or private events (e.g. festivals, concerts, etc.), decorative lighting of buildings, civil engineering structures and public areas during the period from 1 December to 15 January.

Article 6 of the Decree presents environmental aspects and objectives of green public procurement. Points 19, 20, 22 and 23 are relevant for the subject of road lighting, stipulating that the proportion of electrical lamps classified in the highest energy class made available on the market must be at least 90 %, that the proportion of lamps that permit the use of electrical lamps classified in the highest energy class made available on the market must be at least 90 %, that when road lighting is renovated at least 30 % of the electricity consumption saving must be ensured and that at least 30 % of the road lighting allows the reduction of unnecessary light emissions.

19 Road lighting and traffic signalling – Examples of environmental requirements and criteria, version 1.1, January 2020 (refers to ZeJN)

The document gives examples of environmental requirements where the subject of the procurement is road lighting lamps, road lighting design, lamps and road lighting systems, the execution or installation of road lighting, road lighting maintenance and traffic signalling, but does not cover poles, consoles and other supporting elements of road lighting lamps (point 1). The key environmental impacts addressed are energy consumption at all stages, in particular at the stage of use of road lighting and traffic signalling, the high energy consumption in the use of bulbs in traffic signalling, the use of natural resources and materials and the production of waste (hazardous and non-hazardous), air, soil and water pollution due to the use of hazardous substances and light pollution due to road lighting (point 2.). For an effective approach to the ZeJN, suggestions are made in point 3 of the document, such as purchasing high-efficiency lamps and efficient ballasts, encouraging the purchase of lighting systems with low energy consumption for the light provided, the use of LED lamps in traffic signalling, the use of ballasts with dimming capability, the use of lamps with lower mercury content and the use of lamps that limit the emission of light above the horizontal line. Point 5 sets out the same objectives as the ZeJN in points 22 and 23, with the clarification that the objective of reducing unnecessary light emissions by at least 30 % in road lighting implies the possibility of regulating the luminous flux in the case of new installations.

Under point 6, the environmental requirements and criteria for existing road lighting, the environmental requirements and criteria for the design of new/refurbishment road lighting, examples of environmental requirements for the installation of road lighting and the criteria for the design of road lighting are presented.

For road lighting lamps that are intended as replacement lamps for already existing road lighting or for first installation in commissioned lamps or lighting systems, 3 procurement criteria are given, namely the criterion “higher energy efficiency class”, the criterion “lower mercury content” and the criterion “lamp luminance maintenance”. In the first, the energy efficiency class is observed. Classes A+ or A++ ***(Note: these classes are no longer valid as of 2021, when the revised energy efficiency scale is applied, using energy classes A (energy-saving) to G (energy-wasting))*** are scored with extra points when ranking the bids. The criterion “lower mercury content” refers to high pressure sodium (VT Na) lamps and high pressure metal halide (VT MH) lamps and mercury content. If the latter is lower than the value in the document, this is scored with extra points. Under the “lamp luminance maintenance” criterion, the values of the LLMF factors (lamp lumen maintenance factor – the ratio of the luminous flux emitted by the lamp at a given time in its life to the initial luminous flux) and LSF (lamp survival factor, defined as fraction of the total number of lamps that continue to operate at a given time under defined conditions and switching frequency) are compared to the values contained in the document. If the values are higher, this is scored with extra points.

In the field of road lighting design, the document stipulates that the project must be prepared by staff who have at least three years of experience in lighting design or appropriate professional competence in the field of lighting technology. The calculation of the maintenance factor, the power of the lighting system (average power in the case of luminous flux control over time), including the control, is required, and the energy performance indicator must also be determined (according to lighting classes: M – traffic areas for motor vehicles, C – conflict areas, P – areas for pedestrians and cyclists). For class M, we are interested in luminance; for class P and C, we are interested in illuminance. These examples of environmental requirements are only applicable when the contracting authority is procuring a project for new road lighting or for the renovation of existing road lighting.

For the case where the contracting authority procures new lamps without a transitional road lighting project and for the case where replacement lamps are procured for a road lighting system for which a project has already been drawn up, the tenderer shall ensure that the project will be designed in accordance with the field of road lighting design and the contracting authority shall rank the bids on the basis of two criteria, namely “energy efficiency” and “luminous flux control”. The first looks at energy efficiency indicators, the second at the way the luminous flux is controlled.

With regard to the execution and installation of road lighting, it is stated that installation or refurbishment (maintenance) must be carried out by personnel who have at least three years of experience in the installation of lighting systems or who have the appropriate professional competence in electrical service technique.

Regarding the maintenance of road lighting, it states that maintenance must be carried out by suitably qualified personnel and that the electrical parts of the lamp, whether installed or replaced, must not impair the luminous efficacy of the lamp.

20 Summary of the content of road lighting regulations

Road lighting is equipment to ensure the illuminance of individual parts of the road (Article 2 of the Roads Act) during night time or at inadequate daylight (e.g. fog) (Article 75 of the Rules on traffic signs and equipment on roads, Article 4 of the Decree on Green Public Procurement) and falls under traffic equipment (Article 2 of the Roads Act, Article 2 of the Rules on traffic signs and equipment on roads).

The following are all the types of traffic areas for which the relevant lighting is foreseen in legislative documents and technical guidelines and specifications. Other instructions and recommendations relating to road lighting are also collected.

Traffic areas intended to be illuminated with road lighting

- **the most congested parts of roads in settlements** (Article 75 of the Rules on traffic signs and equipment on roads),
- **roads in settlements with shared traffic lanes** (Article 49 of the Rules on cycling areas),
- **pedestrian crossings** (Article 75 of the Rules on traffic signs and equipment on roads, Article 24 of the Roads Act (subchapter 4.4.7.2 in TSC Traffic calming devices and measures), Manual for road lighting in the area of crossings for pedestrians and/or cyclists, TSPI – PGV.03.329: 2023 Road design and traffic safety – Pedestrian areas),
- **cycling crossings** (Article 24 of the Roads Act, Article 49 of the Rules on cycling areas)
- **places where motorised and cycling traffic intermingle in settlements** (Article 49 of the Rules on cycling areas),
- **intersections with three or more classified lanes** (Article 75 of the Rules on traffic signs and equipment on roads),
- **motorway and expressway junctions and their connections** (Article 75 of the Rules on traffic signs and equipment on roads),
- **roundabouts, together with entries and exits (recommended at least 60 m from the roundabout), conflict point areas and the central island** (subchapter 4.7.5 in TSPI – PGV.03.244: 2023 Road design and traffic safety – Roundabouts),
- **mini roundabouts** (subchapter 5.3.2 in TSPI – PGV.03.244: 2023 Road design and traffic safety – Roundabouts),
- **turbo roundabouts** (chapter 7 in TSPI – PGV.03.245: 2023 Road design and traffic safety – Roundabouts with spiral flow),
- **bus stops** (Rules on bus stops),
- **pedestrian crossing points in the area of a bus stop** (Article 22 of the Rules on bus stops),
- **on the surfaces of control stations, such as border crossing points and toll stations** (Article 75 of the Rules on traffic signs and equipment on roads),

- **service traffic areas along public roads, such as** e.g. rest areas, parking areas, bus stops, turning areas, traffic control areas, service stations (Article 75 of the Rules on traffic signs and equipment on roads),
- **medium and long tunnels, in short tunnels only if pedestrian and cyclist traffic is allowed through them** (Article 75 of the Rules on traffic signs and equipment on roads),
- **traffic calming devices, such as humps, ramps, carriageway narrowings, delineations of directional carriageways, deflections of the axis of the carriageway – directional carriageways** (Article 25 of the Roads Act, Chapter 5 in TSC 03.800: 2009 Traffic calming devices and measures, Chapter 7 in TSC 02.203: 2009 Traffic calming devices and measures at level intersections without traffic lights).

Requirements, recommendations and nature protection conditions for road lighting

- The electricity consumption of all lamps calculated per inhabitant in the municipality (or in the country for national roads) is, with regard to Article 5 of the Regulation on the limit values for light pollution of the environment:
  - in the area of the municipality, for lighting municipal roads and public areas, maximum of 44.5 kWh,
  - in municipalities with less than 1,000 inhabitants, 44.5 MWh,
  - for national roads, 5.5 kWh.
- The installation of traffic equipment (including road lighting) and traffic signs is possible on the hardened longitudinal part of the carriageway (Article 2 of the Roads Act). The area is thus the strip along the road, measured from the outer edge of the carriageway:
  - 8.00 m for motorways and expressways,
  - 5.00 m for other roads and
  - 2.00 m, if cycling, pedestrian or other traffic areas are also an integral part of the carriageway (Article 7 of the Rules on traffic signs and equipment on roads).
- For lighting, lamps should be used with an upward flux of light equal to 0 % (Article 4 of the Regulation on the limit values for light pollution of the environment).
- It is recommended that road light poles be placed around the perimeter of the roundabout. If the roundabout is of larger dimensions, it is possible to install road light poles also on its central island. The distribution should be even with respect to the distance between the individual lamps and the distance to the centre of the island. It is recommended that each approaching leg (entry or exit) be illuminated at a distance of at least 60 m from the roundabout (if there is no road lighting already arranged on the approaching leg). The colour of the light and the height of the lamps should be uniform over the entire area of the roundabout, but not lower than on the approaching legs (subchapter 4.7.5 v TSPI – PGV.03.244: 2023 Road design and traffic safety – Roundabouts).
- On roads with a distinctly residential function, lamps on low poles (3-5 m) shall be used (subchapter 4.4.7.2 in TSC 03.800: 2009 Traffic calming devices and measures).
- The Manual for road lighting in the area of crossings for pedestrians and/or cyclists recommends the use of a positive contrast at crossings (the pedestrian or cyclist is brighter than the background). This is achieved by proper vertical lighting. The document presents the complete procedure for determining the horizontal and vertical illuminance of a crossing using the procedures in the technical report SIST-TP CEN/TR 13201-1, Road Lighting – Part 1: Guidelines on selection of lighting classes and SIST EN 13201-2,

Road lighting – Part 2: Performance requirements according to the data on the traffic and construction parameters of the road and other conditions affecting the determination of the lighting class.

- If the density of cycling traffic and the ambient luminance at night changes, the intensity of the road lighting of the cycling areas shall be adjusted (Article 49 of the Rules on cycling areas).
- Article 6 of the Decree on Green Public Procurement presents the objectives of road lighting from the environmental point of view:
  - the proportion of electrical lamps classified in the highest energy class available on the market must be at least 90 %,
  - the proportion of lamps that allow the use of electrical lamps classified in the highest energy class made available on the market must be at least 90 %,
  - in the case of road lighting renovation, at least 30 % of the electricity consumption saving must be ensured,
  - at least 30 % of road lighting must allow reduction of unnecessary light emissions (in point 5 of the Road lighting and traffic signalling – Examples of environmental requirements and criteria related to ZeJN, this is described as a possibility of regulating luminous flux in the case of new installations).

Instructions and recommendations for maintenance, design documentation and plans, reviews and records of public roads

- Within the boundary of the settlement, traffic equipment (and thus also road lighting) is maintained by the manager of the municipal roads designated by the municipality (Article 108 of the Roads Act) and traffic equipment of the national roads is maintained by the operator of the national road (Article 87 of the Roads Act).
- The operator of national road shall regularly maintain the national roads (Article 68 of Roads Act), with the exception of traffic areas, structures and devices on the road land of the national road, which are in the function of the public areas of the settlement and are maintained by the municipality (Article 72 of Roads Act). Traffic areas, facilities and installations on the road land of the national road, which serve as public areas of the settlement but are maintained by the municipality, also include road lighting, including electricity supply and green areas and urban equipment in the area of road land. Connections of municipal roads to the national road are a special case. The connections are regularly maintained by the municipality, and the traffic equipment and signalling intended for traffic on the national road is maintained by the national road maintenance company. The Directorate also maintains the traffic signalization and traffic equipment of national cycle routes that run on municipal roads and are intended for cyclists (Article 74). The municipal road manager regularly maintains and supervises municipal roads (Article 110), including road connections up to the boundary of the road land of the municipal road, with associated traffic signalization and traffic equipment (Article 111).
- Maintenance must be carried out by suitably qualified personnel with at least three years' experience in installing lighting systems or with appropriate qualifications in electrical services engineering, and the electrical parts of the lamp installed or replaced must not impair the luminous efficacy of the lamp (document Road lighting and traffic signalling - Examples of environmental requirements and criteria).
- A review is compulsory if the execution of investment maintenance works, maintenance works in the public interest or construction works requires the preparation of project documentation. However, in the case of the installation of equipment or installations,

including road lighting, an internal inspection must be carried out by the persons responsible for carrying out the maintenance work in the public interest and by the future maintainer of the equipment or installations before the commission inspection itself. A record of the inspection must be drawn up, clearly showing the perfect functioning of the equipment or installations inspected, and then presented by the contractor at the commission inspection of the maintenance work carried out (Articles 7 and 16 of the Rules for carrying out investment maintenance and maintenance works in the public interest on public roads).

- For a lighting system (and therefore also for road lighting) where the sum of the electrical outputs of the lamps exceeds 10 kW, a lighting plan showing the basic data on the light source must be drawn up, checked and updated or amended as appropriate every 5 years (Article 21 of the Regulation on the limit values for light pollution of the environment). It is also stipulated that a new plan must be drawn up in the event of an increase in power of more than 15 % or in the event of replacement of more than 30 % of the lighting system lamps.
- For the area of road lighting design, the document Road lighting and traffic signalling – Examples of environmental requirements and criteria states that the project must be prepared by staff who have at least three years of experience in lighting design or appropriate professional competence in lighting technology and that the project must be designed in accordance with the area of road lighting design and guidance in this document.