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Bicycle road lighting – requirements and recommendations

Abstract: Cycling transport in Poland is in the phase of dynamic development. Many cities in Poland realize investments connected with the construction of new and the modernization of existing cycling infrastructure. Road lighting is an element ensuring the safety and comfort of cyclists, particularly during the realization of journeys after dark and in difficult weather conditions. A correctly designed, constructed, and maintained lighting installation contributes to extending the time of use of the infrastructure by cyclists and supports sustainable mobility. To improve traffic safety, infrastructure managers are making investments in spot or linear lighting for bike roads. Cycling traffic may be carried out both together and separately from the carriageway of a road designed for vehicles. Therefore, lighting requirements are formulated in different ways. The article reviews the current lighting requirements, considering the locations of cycling traffic. The lighting classes were used, and their purpose is indicated. The general and specific recommendations of the current guidelines for lighting roads, bicycle roads and pedestrian and bicycle roads are described. The individual stages of the design process of lighting installations are indicated and attention is drawn to the problem of the realization of field measurements.

Keywords: bicycle, lighting, map, requirements, road.

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1. INTRODUCTION

Lighting of roads, including roads for bicycles and roads for pedestrians and bicycles, is one of the basic elements affecting traffic safety. The lighting of road infrastructure performs many functions during nighttime. Well-designed and functioning lighting allows cyclists to travel safely after dark, avoid possible obstacles, and be visible to other road users (pedestrians and drivers). Selection of appropriate lighting levels reduces the risk of accidents and collisions, which are often caused by low levels of visibility on the road [1]. Properly illuminated point objects, bicycle crossings, intersections [2], and linear sections of bicycle routes increase the comfort of riding and make cyclists feel safer, encouraging cycling after dark. The use of modern lighting systems allows the aesthetic qualities of illuminated areas and elements of urban infrastructure to be exposed. Lighting also influences the behavior of traffic participants [3] and changes traffic parameters [4]. The illumination makes reading signs, trail markings, addresses, and general orientation in space easier. As a result of road infrastructure lighting, bicycle and pedestrian and bicycle roads can be used all year round, regardless of the time of day. This increases the number of cyclists active throughout the year and promotes this mode of transportation by extending the bicycle season [5]. Development of cycling infrastructure promotes sustainable urban mobility [6]. This involves the need to create an appropriate infrastructure, which will ensure that users of bicycles can move around efficiently, comfortably and above all safely [7]. Lighted roads, bicycle roads and pedestrian and bicycle roads increase the safety of cyclists and pedestrians, especially women and minorities, who may feel less safe in an unlit urban environment. The European vision for road infrastructure development is to increase the potential of individual and environmentally friendly modes of transport [8]. However, it is also important to remember the adverse effects of road lighting. It contributes to increased levels of light pollution. It generates economic, environmental, and ecological costs, which should be considered before deciding to use lighting in an area [9].

2. FORMAL REQUIREMENTS

The infrastructure manager's duties regarding the road lighting on which bicycles may travel are outlined in art. 20aa ustawy o drogach publicznych published in Dz.U. 2024 poz. 320 (consolidated text, act in force as of June 16, 2025) [10]. It has been indicated that the road manager may plan and carry out lighting for pedestrian crossings or bicycle crossings on public roads in the development area and is to finance this work himself. In addition, the Ministry of Infrastructure's guidelines are in place, which clarify recommendations for areas and spaces designated for bicycle traffic that should be illuminated:

- WR-D-42-1 Design guidelines for bicycle infrastructure. Part 1: Planning for bicycle routes [11],
- WR-D-42-2 Design guidelines for bicycle infrastructure. Part 2: Design of bicycle roads, pedestrian and bicycle roads, and bicycle lanes and contra-lanes [12],
- WR-D-42-3 Design guidelines for bicycle infrastructure. Part 3: Design of bicycle crossings and bicycle infrastructure at intersections and junctions [13].

The formal requirements for lighting bicycle roads in Poland are derived from PN-EN 13201-2 Road lighting provisions. Part 2: Lighting requirements [14]. In addition, there are local required road authorities and cities (e.g., Kraków [15], Warsaw [16, 17]), which detail the design and implementation of road lighting. Bicycle road lighting should be designed based on the criteria contained in industry standards and benchmarks. Neither the former nor the latter is a mandatory document. Still, they allow the design, implementation, and operation of installations based on the latest available technical knowledge and experience of designers. Using the guidelines in preparing, implementing, and accepting investments relieves infrastructure managers of technical expertise in road lighting. Implementing the measurement and acceptance procedures in the guidelines is required.

As of 2022, there are benchmarks and standards in place. The formal provision contained in the Decree of the Minister of Infrastructure of June 24, 2022 on technical and construction regulations for public roads (Dz.U. 2022 r. poz. 1518) [18] determines in § 3, that: If a condition is not specified in the provisions of the Ordinance or is specified in general terms, the road shall be designed, constructed, reconstructed or used by the principles of technical knowledge contained in particular:

- in the benchmarks and standards recommended by the minister in charge of transport under the regulations on public roads,
- in Polish standards.

Polish standards that currently address formal requirements related to road lighting are:

- PN-EN 13201:2016 Road lighting. The standard consists of five parts:
  1. PKN-CEN/TR 13201-1:2016-02 Road lighting. Part 1: Guidelines for the selection of lighting classes [19].
  2. PN-EN 13201-2:2016-03 Road lighting. Part 2: Performance requirements [14].
  3. PN-EN 13201-3:2016-03 Road lighting. Part 3: Calculation of lighting parameters [20].
  4. PN-EN 13201-4:2016-03 Road lighting. Part 4: Methods for measuring lighting efficiency [21].
  5. PN-EN 13201-5:2016-03 Road lighting. Part 5: Energy efficiency indicators [22].
- PN-EN 12464-2:2014-05 Light and illumination. Workplace lighting. Part 2: Outdoor workplaces [23]. The standard specifies the required illumination levels in parking lots, plazas, open and covered transportation platforms, stairs, vehicle repair areas, etc.

Documents WR-D patterns and standards recommended by the Minister of Infrastructure for use in the design of roads and streets (in terms of lighting selection), which is an element of technical knowledge in the field of benchmarks and standards:

- WR-D-72-1: Design guidelines for equipment for the lighting of urban roads and streets. Part 1: Basic and detailed requirements (for basic solutions for all parts of the road and alternative devices for crossing the roadway) [24],
- WR-D-72-2: Design guidelines for equipment for the lighting of urban roads and streets. Part 2: Catalog of typical solutions [25],
- WR-D-41-4: Design guidelines for pedestrian infrastructure. Part 4: Design of lighting for pedestrian crossings (control procedure for pedestrian crossings, pedestrian-bicycle crossings, and bicycle crossings) [26].

3. LIGHTING CLASS REQUIREMENTS

The lighting classes represent the visual requirements of different groups of traffic participants, as each has different requirements, depending on the presence of illumination of parts of the road intended for motor vehicle, bicycle, and pedestrian traffic, as well as in conflict areas. Due to the possibility of conducting bicycle traffic on the roadway, together or separately with pedestrians, and on dedicated bicycle-only roads, there are different lighting situations, classes, and associated quantitative requirements. In addition, the problem is complicated by lighting solutions used to illuminate conflict areas and intersections with permitted bicycle traffic. The guidelines WR-D-72-1 [24] describe in detail the principles of lighting and the criteria for selecting lighting levels for different road parts. The chosen elements were related to the specifics of bicycle traffic, identifying the lighting classes most often installed in these areas (Table 1).

Table 1. Lighting classes are used for lighting design in specific lighting situations with bicycle traffic

Parts of the road	Lighting classes
Roads and streets in sections outside intersection areaswith bicycle traffic allowed	M
Intersection area and conflict areas	C
Separate bike lanes and pedestrian and bicycle roads	P
Bicycle crossings	PC for dedicated solutions, C for classic solutions
Squares with permitted pedestrian or bicycle traffic	P (yards off the roadway), additionally as needed EV, HS, SC
Squares with pedestrian, bicycle, and motorized traffic allowed	C, additionally as required EV, HS, SC
Parking lots and parking bays	C (converted from the M class for road – for bays in the road lane), illuminance classes defined in [14]
Pedestrian way, pedestrian and bicycle way, or bicycle way in a tunnel, on a bridge, or overpass	P
Pedestrian way, pedestrian and bicycle way, or bicycle way under a bridge or overpass	P

In standard [14, 19], and in the guidelines [24, 25] basic lighting requirements for roads and streets are defined by luminance parameters. Classes M apply to all roads and streets with high and medium speeds involving motor vehicles. These are essential thoroughfares, and pedestrian and bicycle traffic may be allowed. In the case of bicycles, traffic can be routed directly on the roadway (Fig. 1) or in a designated bicycle lane located on the roadway.

Fig. 1. Roadway lighting with designated bike lanes

On road sections where there are conflict areas, mixed traffic, pedestrian, bicycle, and motorized traffic, there is a change in roadway geometry or sorting of traffic streams; the requirements defined in class C [14, 19] (based on lighting intensity parameters) apply. Areas also include intersections, bicycle crossings, and pedestrian crossings at which dedicated solutions are not used, and requirements in PC classes are not defined. An example of the implementation of lighting the area of an intersection with a bicycle crossing and a crosswalk illuminated by classic road lighting is presented in Fig. 2.

Fig. 2. Examples of illumination of a bicycle crossing in the intersection area with classic street lighting

On bicycle lanes, pedestrian and bicycle roads, pedestrian paths, and motor vehicle drivers at low speeds on streets and other illuminated areas, located independently or along the roadway, lighting classes P [14, 19]. Implementing P-class lighting is often associated with a separate bicycle, pedestrian, or bicycle-bicycle installation. The advantage of such a solution is the ability to independently control the lighting levels of both areas of the roadway and the pedestrian or bicycle roads. Using separate control algorithms allows individual adjustment of lighting levels to the traffic demand on both roadways. An example of the use of separated lighting of the bicycle road from the lighting of the main carriageway is shown in Fig. 3.

Fig. 3. Examples of lighting bicycle road with separate luminaires

A common situation is to illuminate bicycle or pedestrian roads adjacent to the roadway using the same luminaires as the roadway (Fig. 4) or to use separate luminaires installed on poles set along the lane.

Fig. 4. Examples of lighting pedestrian-bicycle road with the same lighting fixtures

In terms of improving lighting conditions, the most effective way to illuminate a bicycle or pedestrian crossing is to use a dedicated solution based on asymmetrical luminaires that produce positive contrast between the silhouette of the cyclist (or pedestrian) and the observation background. This solution has been recommended in patterns and standards [26]. It involves the installation of separate light fixtures for each direction of vehicle traffic and the introduction of light on the vertical planes of the bicycle crossing (or bicycle crossing and pedestrian crossing). This solution can be used on roads where requirements are defined by luminance or intensity parameters (Table 2).

4. RECOMMENDATIONS FOR BICYCLE ROAD LIGHTING

Under the current regulations [24], specific requirements for bicycle roads have been defined. The road for bicycles is illuminated:

a) in a tunnel,

b) on a bridge or overpass,

c) at the point where bicycle traffic joins traffic on the roadway.

Table 2. Required illuminance parameters for pedestrian crossings using luminaires with asymmetric distribution (dedicated lighting) for roadways illuminated in Classes M (luminance) and in Classes C (illuminance) [26]

Roadway lighting				Lighting a crosswalk or bicycle crossing					
Values before and after a crossing or a bicycle crossing				Level in class PC	Measuring planes				Points A, B, C, D, E, F
					Vertical		Horizontal		
Class level M	L_{avr} [cd · m^{-2}] (min.)	Class level C	E_{avr} [lx] (min.)		E_{vavr} [lx] (exploit. min.)	U_{ov} [–] (min.)	E_{havr} [lx] (exploit. min.)	U_{oh} [–] (min.)	E_{vmin} (A, B, ...) [lx] (exploit. min.)
M1	2.00	C0	50.00	No need for dedicated solutions					
M2	1.50	C1	30.00	PC1	75.00	0.35	75.00	0.40	5.00
M3	1.00	C2	20.00	PC2	50.00	0.35	50.00	0.40	4.00
M4	0.75	C3	15.00	PC3	35.00	0.35	35.00	0.40	4.00
M5	0.50	C4	10.00	PC4	25.00	0.35	25.00	0.40	3.00
M6	0.30	C5	7.50	PC5	15.00	0.35	15.00	0.40	2.00

Explanation of symbols:
L_{avr} – average luminance; E_{avr} – the average value of illuminance; E_{vavr} – the average value of illuminance in the vertical plane; E_{havr} – the average value of illuminance in the horizontal plane; U_{ov} – the overall uniformity of the illuminance in the vertical plane; U_{oh} – the overall uniformity of the illuminance in the horizontal plane; E_{vmin} – the minimum value of illuminance in the vertical plane.

Examples of the implementation of dedicated lighting at bicycle crossings, including pedestrian crossings, are shown in Fig. 5.

Fig. 5. An example of lighting a bicycle crossing including a pedestrian crossing using a dedicated solution (PC class)

Pedestrian and bicycle roads are illuminated:

a) as part of primary routes, routes for pedestrians with disabilities, and school routes,
b) in a tunnel,
c) on a bridge or overpass,
d) at the point where bicycle traffic joins traffic on the roadway,

lighting the bicycle road and the pedestrian and bicycle road is recommended also:

e) forming a velostrade (V) or primary route (P),
f) under a bridge or overpass,
g) at a place of increased risk of collision of traffic participants (e.g., intersecting travel lanes, horizontal curves with radii of less than 20 m, narrowing of the width of the road for bicycles or the route for pedestrians and bicycles, etc.),

h) at a distance of 25 m from a bicycle crossing,

i) where there are objects in the gauge of the bicycle road or pedestrian and bicycle road,

j) on a section with a more than 6% longitudinal gradient.

The WR-D-72-1 [24] guidelines specify detailed requirements for bicycle road lighting:

- A bicycle lane or contra-lane shall be illuminated as part of the roadway lighting.
- Illuminating bicycle service areas is recommended if the area is at least 25 m^2.
- The bicycle road or pedestrian and bicycle road shall be illuminated jointly or separately with roadway lighting. It is recommended to use combined lighting.
- To determine the level of illumination of a bicycle road or a pedestrian and bicycle road located near a roadway illuminated in class M, the parameter of the R_{EI} ambient lighting index is used (Table 2).
- In the case of a bicycle road or a pedestrian and bicycle road lit independently of the roadway, the lighting class shall be determined:
  a) P – in the section between intersection areas (Table 3),
  b) C – in conflict areas (i.e., areas with an increased probability of collision due to the presence of different traffic participants and areas where there is a change in the geometry of the road).
- The recommended minimum levels of lighting class for a bicycle road or pedestrian and bicycle road are specified in Table 3 [24]:
- If the edge of a bicycle or pedestrian and bicycle road runs near the edge of an illuminated roadway and is technically feasible, using the same lighting poles is recommended. Still, separate luminaires are needed to illuminate the roadway and the parts of the road intended for bicycle traffic. Additional lighting poles are used if light distribution may be restricted by vegetation or other objects.
- For bicycle routes that run independently of the roadway, lighting control using detection systems is permitted if it is not technically or economically justified to maintain permanent lighting.
- Bicycle crossings shall be illuminated by the rules for pedestrian crossings specified in WR-D-41-4 [26].
- It is recommended that the bicycle road or pedestrian and bicycle road be illuminated before the bicycle crossing for a distance not less than the L_d value specified in the WR-D-42-3 [13].
- Dedicated lighting is recommended, especially at bicycle crossings located outside intersections.
- It is recommended that a single dedicated solution illuminate a bicycle crossing together with a pedestrian crossing. Separate vertical design planes are then used.
- If it is impossible to cover a bicycle crossing and a crosswalk with a single lighting solution, each lighting area is designed separately.

Table 3. Recommended minimum lighting levels for bicycle and pedestrian roads [24]

Type of road/area	Lighting class P	Horizontal illumination		
		E_{havr} [lx] (kept to a minimum)	E_{min} [lx] (maintained)	U_o [–] (minimum)
Bicycle road for 25 m before and after a bicycle crossing over a single carriageway on a lighted road	P2	10.00	2.00	0.20
Tunnel for bicycles or pedestrians and bicycles	P2	10.00	2.00	0.20
Bicycle road forming a velostrade (V)	P3	7.50	1.50	0.20
Road for pedestrians and bicycles	P3	7.50	1.50	0.20
Bicycle road forming the primary route for bicycles (P)	P4	5.00	1.00	0.20
Bicycle road forming a complementary bicycle route (U)	P5	3.00	0.60	0.20
Bicycle parking stands	P4	5.00	1.00	0.20

Explanation of symbols:
E_{havr} – the average value of illuminance in the horizontal plane [lx]; U_o – the overall uniformity of the illuminance [–].
E_{hmin} – the minimum value of illuminance in the horizontal plane [lx];

5. DESIGN OF BICYCLE ROAD LIGHTING

In carrying out the procedure for the design of road lighting, it is necessary to obtain the information needed to properly select the lighting class in the various areas to be illuminated. The designer, in addition to the required data necessary for the selection of the lighting class resulting from the standards [14, 19]. should have information about:

- traffic participants (vehicle drivers, occurrence of pedestrians, bicycle drivers, people with limited mobility, etc.),
- speed to design and speed allowed,
- traffic volume,
- existing lighting classes and luminaires used,
- plans to expand the road or change its function,
- development of the road's vicinity,
- the local development plan for the road's surroundings,
- traffic forecast in the life cycle horizon of the lighting system,
- the need to cover the road area with video surveillance,
- investor requirements.

The design of the lighting solution with its spatial scope should include all illuminated surfaces and consider the impact of light on the environment. The construction project shall be developed according to the regulations [10], and the formal and legal parts are obligatorily unified in the law [27].

The standard content of the architectural and construction project includes:

- descriptive part with selection of lighting classes and power balance, technical conditions, and agreements,
- drawing part – e.g.: situation plan, sections, profiles, elements of the installation to be marked on the situation plan, among others, locations of poles, locations of cabinets, indication of elements of the surroundings existing in the vicinity of the designed objects, heights of surrounding elements (including buildings, trees).

The standard content of the technical design includes:

- information on the adopted lighting zone in which the designed installation is located,
- a descriptive part with the selection of lighting classes,
- functionality and characteristics of the proposed control system,
- lighting installation diagrams with the designation of existing and designed devices,
- diagrams of lighting cabinets,
- photometric calculations,
- calculated values of energy indicators,
- selection and listing of luminaires,
- selection and listing of cables,
- technical calculations, including voltage drops, electric shock protection, and surge protection.

It is recommended that, in addition to the requirements specified in the regulations, the technical design in the lighting section should include:

- information on the adopted reflectivity class of the road surface,
- a map with the location of lighting poles, cable lines, lighting cabinets, and other installation elements in the geodetic coordinate system (PL-2000),
- results of photometric calculations on all representative illuminated repetitive surfaces, taking into account their geometry,
- results of photometric calculations on planned lighting class reduction scenarios,
- DP and DE energy indices [22] of the entire installation for 100% of the rated capacity of the installation and the planned power reduction scenarios,
- a detailed list of luminaires used, including detailed identification descriptions, polar photometric solid and basic technical parameters, i.e., wattage, luminous flux of the light source, luminous flux of the luminaire, luminous efficacy of the luminaire, color temperature, color rendering index, luminaire maintenance factor,
- installation summary of the luminaires used, including detailed situational data, luminaire installation positions (light sources and reflector positions).

Photometric calculations made for the bicycle roads should include a summary of the basic parameters confirming compliance with the conditions of the adopted lighting class. They can be presented as isolux distribution or values in calculation points. After the design process is completed, the investment implementation process

follows based on the developed documentation. One of its key stages is to confirm, with measurements, the achievement of the assumed lighting effects. The correctness of the implementation of the investment and the compliance of the obtained lighting parameters with the designed lighting classes should be assessed. Lighting measurements should be the basis for acceptance of the investment and commissioning. This data is the basis for conducting an annual assessment of the technical condition of the installation and its degradation in subsequent years of its operation. In addition to classical measurement methods requiring labor-intensive and time-consuming field measurements, it is possible to carry out measurements using specialized measurement vehicles [28, 29], enabling the recording of geodated illuminance measurements (Fig. 6).

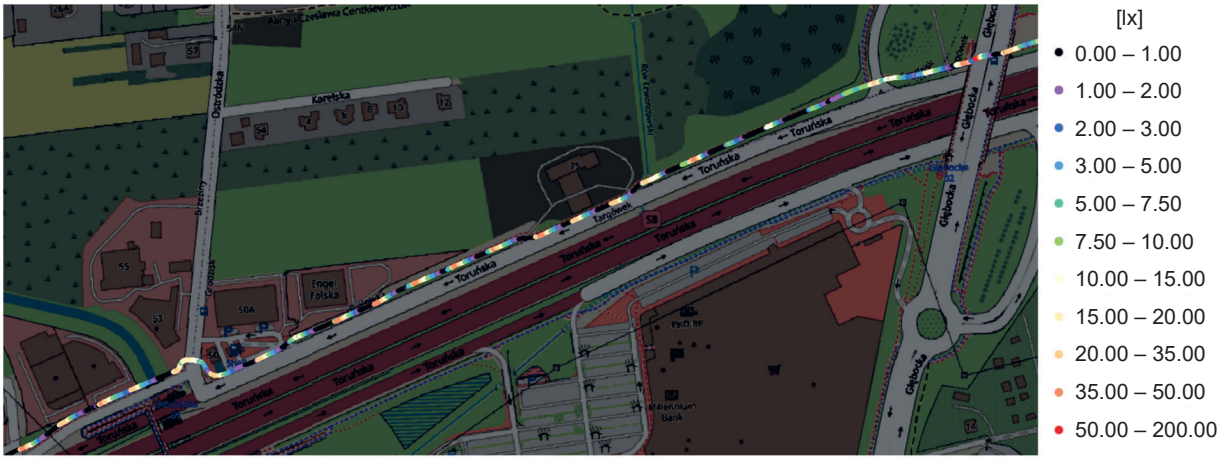

Fig. 6. Map of lighting intensity along the bicycle road

This approach makes it possible to quickly and systematically analyze the status of bicycle road lighting and obtain data on changes in lighting values from selected areas and along the entire bicycle road (Fig. 6). This new measurement tool admittedly has limitations related to the availability of GNSS signal [30, 31], but its use significantly shortens the process of acquiring lighting data.

6. CONCLUSIONS

The main purpose of this article was to review the current requirements for bicycle road lighting in Poland. The following conclusions were formulated:

1. When designing and implementing lighting in urban spaces, it is essential to meet the requirements of industry standards, WR-D guidelines, and sound engineering practices. This article presents only selected aspects of the requirements for the design of bicycle road lighting installations. Comprehensive requirements and a definition of the lighting solution selection are presented in the WR-D-72-1 [24] and WR-D-41-4 [26] guidelines.
2. The use of appropriate design standards allows for a systematized approach to the design, implementation, and maintenance of lighting installations.
3. Bicycle road lighting contributes to improved infrastructure and a reduction in the number of collisions on the road. It also contributes to a reduction in the number of road accidents involving cyclists.
4. The selected lighting situations presented demonstrate the complexity of the problem. Correctly selecting lighting levels within appropriate classes can pose a challenge for infrastructure managers.
5. The selection of classes should be preceded by a daily (preferably annual) traffic volume analysis and correlated with the requirements of the standards [14, 19] and guidelines [24].
6. The selection of lighting levels in a given area should be consistent with the assumptions of local general lighting plans. This is an issue the authors will address in future publications.
7. The results of the analysis provide a basis for continued research on bicycle road lighting using geoinformatics tools [28, 32] to develop bicycle road lighting maps.
8. The traffic safety audit should include surveys of the condition of road lighting, bicycle roads, and pedestrian and bicycle roads. Such surveys should be carried out systematically, in accordance with the WR-D-72-1 [24] and WR-D-41-4 [26] guidelines.

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Oświetlenie dróg rowerowych – wymagania i zalecenia

Streszczenie: Transport rowerowy w Polsce znajduje się w fazie dynamicznego rozwoju. Wiele miast w Polsce realizuje inwestycje związane z budową nowej i modernizacją istniejącej infrastruktury rowerowej. Oświetlenie dróg jest elementem zapewniającym bezpieczeństwo i komfort rowerzystów, szczególnie podczas podróży po zmroku i w trudnych warunkach atmosferycznych. Prawidłowo zaprojektowana, wykonana i utrzymywana instalacja oświetleniowa przyczynia się do wydłużenia czasu użytkowania infrastruktury przez rowerzystów oraz wspiera zrównoważoną mobilność. Aby poprawić bezpieczeństwo ruchu drogowego, zarządcy infrastruktury realizują inwestycje w punktowe lub liniowe oświetlenie tras rowerowych. Ruch rowerowy może odbywać się zarówno łącznie, jak i oddzielnie od jezdni drogi przeznaczonej dla pojazdów. W związku z tym wymagania oświetleniowe są formułowane w różny sposób. W artykule dokonano przeglądu aktualnych wymagań oświetleniowych, uwzględniając miejsca ruchu rowerowego. Posłużono się klasami oświetlenia i wskazano ich przeznaczenie. Opisano ogólne i szczegółowe zalecenia zawarte w aktualnych wytycznych dotyczących oświetlenia dróg rowerowych. Wskazano poszczególne etapy procesu projektowania instalacji oświetleniowych oraz zwrócono uwagę na problem realizacji pomiarów terenowych.

Słowa kluczowe: droga, mapa, oświetlenie, rower, wymagania.