Quality and planning of road lighting

Prof. Grega Bizjak, PhD
Laboratory of Lighting and Photometry
Faculty of Electrical Engineering
University of Ljubljana
In today’s world feeling of safety in more and more important. Light and lighting contribute to better safety on roads and streets.
There is less traffic during the night (25%) but there are more accidents resulting in death or severe injury (45% of traffic fatalities occurs during the night).
Good road lighting means better safety and less accidents (some research show that lighting can reduce number of accidents during the night for up to 30%).
Increased illuminance means better visibility and less crime.

The ratio between the number of crimes at night and during the day at a certain illumination at night.
Fact

Needed electrical energy per capita:

- Germany: 50 kWh
- Slovenia: 80 kWh
- Finland: 148 kWh yearly.
Fact

Yearly costs for electrical energy for road lighting

Germany: 12.5 €
Slovenia: 8 €
Finland 7.5 € per capita.
The quality of road lighting has many aspects:

- quality of life,
- technical quality,
- financial quality and
- ecological quality.
Quality of life

During the night traffic accidents are more frequent and have more serious consequences than during the day.

Number of injured in total
Number of injured during the day
Number of injured during the night

Moderate injuries, Severe injuries, Fatal injuries
Quality of life

More light on a road surface means less accidents and better safety.

The ratio between the number of accidents with injuries at night and during the day vs luminance of road surface in cd/m².
Quality of life

Light protects against crime.

With the increased illuminance of residential areas the crime rate drops.
The basic motto of road lighting: good visibility and be easily visible for all traffic participants.
Visual ability of people depends on luminances in their field of vision.

Needed contrast sensitivity ($\Delta L/L$) vs luminance of the environment.
Technical quality

Visual ability of people depends on luminances in their field of vision.

Visual acuity vs adaptation luminance
Technical quality

Visual ability of people depends on luminances in their field of vision.

Relative sensitivity vs adaptation time (min)
Technical quality

Recognition of shapes (objects) depends on luminance or colour contrast (or both).

in daylight  with road lighting  in moonlight
The basis for adequate vision is therefore appropriate luminance in our environment (field of vision). It can be defined by:

- **luminance** (cd/m\(^2\))
- **illuminance** (v lx)
Financial quality

The cost of road lighting:
- investments costs;
- maintenance costs;
- operating costs (costs of electrical energy).
Financial quality

The chipest possibility: no lighting at all?! Not allways true!
Financial quality

Road lighting is relatively inexpensive: 20 € per capita yearly:

- 10 € for operating costs;
- 10 € for electrical energy.
Financial quality

With new and more effective lighting sources and lamps, up to 30% of electric energy can be saved.

Investment return period: 2 to 6 years.
Ecological quality

Electrical energy consumption: production of electrical energy contributes to the CO₂ emissions.

Consumption: primary energy, electrical energy, el. en. for lighting
Ecological quality

**Lighting pollution:** light which doesn’t reach road surface but goes to nearby property or sky is not useful for road lighting.

“**The Good”**

“**The Bad”**

“**The Ugly”**
Ecological quality

Recycling of lamps and luminaires: lamps and luminaires contain various (including toxic and harmful) substances, and represent a potential source of raw materials, so they should be recycled.
Ecological quality

Effects on insects and animals: artificial light at night can disrupt the rhythm of life of different types of insects and animals.
Street lighting is an indispensable part of our lives.

Quality street lighting improves safety, saves energy and is environmentally friendly.

Unfortunately, this very much depend on good lighting planning.
What is important at road lighting?

Minimum required level of luminance or illuminance:

On roads for motorized traffic, lighting is planned according to required luminance.

On streets and traffic area for mixed traffic lighting is planned according to required illuminance.
Luminance and illuminance

Illuminance (lx) depends only on light source and distance to the illuminated area, luminance (cd/m²) depends also on reflectance of the illuminated area.
What is important at road lighting?

Not just luminance or illuminance but also their uniformity!

If one lamp is switched off or broken, the resulting dark area might be dangerous for the road users (especially pedestrians and cyclists).
What is important at road lighting?

Limitation of glare!
What is important at road lighting?

Also:

• direction of light
• shadows
• colour of light
• colour rendering
What is important at road lighting?

On pedestrian areas (semi-cylindrical) vertical illuminance on the head level is also very important (for face recognition).
What is important at road lighting?

Optical guidance:
• Luminaires should be placed so that they show the course of the road;
• Different colour of light can be used to warn on dangerous areas (pedestrian crossings, crossroads ...
Planning criteria

The criteria for road lighting depend on potential risk:

• density of traffic,
• participants in traffic,
• speed of traffic,
• road construction parameters.
Planning criteria

Road lighting must provide participants in traffic good visibility of:

- area, course and borders of traffic surfaces,
- driveways and intersections,
- obstacles on the road,
- other road users.
Planning criteria

Needed luminance and illuminance values for different roads can be found in:

• National standards,
• CIE documents,
• EN standards (13201).
Tasks and evaluation criteria for road lighting:

- direction of view is defined so we use luminance concept;
- density of traffic;
- tasks: to see course and borders of traffic areas, obstacles on road and other participants in traffic.
Luminance or illuminance

On traffic areas with defined viewing direction (roads) the lighting should be planned according to concept of luminance.
For the road user, only the part of the road in a field of vision is important.
Field of observation

• Eye of the driver is located at a height of 1.5 m above the road on the right half side of the road (point B).
• The view is directed forwards and downwards at an angle of 1°.
• Field of view includes additional 0.5° to each side, covering the area between 0.5° and 1.5°.
• Field observation starts so at 60 m distance from the driver and extends up to 160 m distance.
• There is an international agreement that field of observation always starts at luminaire.
Field of calculation

- When the driver moves forward also the field of observation moves forward and is therefore variable.
- As the field of observation starts at luminaire it chances only until next luminaire and then repeats.
- Driver’s field of observation so repeats after every luminaire.
- That is the reason why the field of calculation only includes the longitudinal part of the road between two luminaires.
- In traverse direction field of calculation includes the entire width of the carriageway or the width of the one-direction carriageway if they are separated.
As the situation repeat, it is enough if the calculations are made on field of calculation (between two luminaires) and not on the entire field of observation.
Calculation points

\[ D = \frac{S}{N} \]

\[ d = \frac{W_L}{3} \]

60 m

\[ \frac{W_L}{2} \]
What is the right luminance?

Selection procedure (EN 13201):
- define traffic area and select set of lighting situations;
- define the relevant area in detail;
- select the range of lighting classes;
- select one lighting class from the range;
- find the lighting performance requirements for the selected lighting class(es).
What is the right luminance?

Possible users are: motorized traffic, slow moving vehicles, cyclists, pedestrians;
And speed might be:
>60 km/h
>30 km/h in <60 km/h
>5 km/h in <30 km/h
walking speed
### Technical quality - Roads

Standards and recommendations state minimum luminance (cd/m²) based on traffic and road parameters.

<table>
<thead>
<tr>
<th>Separation of carriage changes</th>
<th>Inter-</th>
<th>Traffic flow (vehicles per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ways</td>
<td>changes</td>
<td>&lt;15.000</td>
</tr>
<tr>
<td></td>
<td>spacing</td>
<td></td>
</tr>
</tbody>
</table>

| Yes | > 3 km | 0,75 | 1,00 | 1,00 |
|     | < 3 km  | 1,00 | 1,00 | 1,50 |
|     | < 3     | 0,75 | 0,75 | 1,00 |
|     | > 3     | 0,75 | 1,00 | 1,50 |
| No  | > 3 km  | 1,00 | 1,50 | 1,50 |
|     | < 3 km  | 1,50 | 1,50 | 1,50 |
|     | < 3     | 0,75 | 1,00 | 1,50 |
|     | > 3     | 1,00 | 1,50 | 1,50 |
What is the right luminance?

Streets with low traffic rate, low number of intersections.

0.5 cd/m²
What is the right luminance?

Roads with medium traffic rate, medium density of intersection.

1,0 cd/m²
What is the right luminance?

Roads with high traffic rate and/or high number of intersections ...

2,0 cd/m$^2$
Uniformity of the luminance

- Objects (obstacles on the road) are only noticeable if there is a contrast between them and the surroundings.

- Proper luminance is not enough. We also need good uniformity to model a background for objects to be noticed.
Uniformity of the luminance

Needed overall uniformity of the luminance $U_0$ as well as longitudinal one $U_l$ can be found in standards. Sometimes also transverse uniformity $U_t$ is important also.
Uniformity of the luminance

How different longitudinal uniformities look like?

$U_l = 0,5$
Uniformity of the luminance

How different longitudinal uniformities look like?

\[ U_l = 0.625 \]
Uniformity of the luminance

How different longitudinal uniformities look like?

$U_l = 0.77$
Limiting glare

Each luminaire is seen under different angle with respect to view direction. Smaller angle means more glare.
As luminance of the traffic area depends on properties of its surface (reflectance), it is necessary to include this into planning process. There are two main characteristics of a surface:

- **roughness** $\chi_p$ (rough, smooth)
- **reflectance** $q_0$ (light, dark)
Planning road lighting - Streets

Tasks and evaluation criteria for street lighting:
- less numbered but more diverse traffic participants;
- direction of view is not defined so we use concept of illuminance;
- tasks: to reduce threats to the weakest street users (pedestrian, cyclists),
- appearance of the street.
Luminance and illuminance

On traffic areas where viewing direction can not be clearly defined and/or are intended for mixed traffic the illuminance concept should be used.
### Technical quality - Streets

Standards and recommendations state minimum illuminance (lux) based on conditions.

<table>
<thead>
<tr>
<th>Parked vehicles</th>
<th>Difficulty of navigational task</th>
<th>Traffic flow pedestrians and cyclists</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Normal</td>
<td>3,0</td>
</tr>
<tr>
<td></td>
<td>Higher</td>
<td>5,0</td>
</tr>
<tr>
<td>Yes</td>
<td>Normal</td>
<td>5,0</td>
</tr>
<tr>
<td></td>
<td>Higher</td>
<td>7,5</td>
</tr>
</tbody>
</table>
Selection of luminaires

The most important criterion for the selection of luminaires are good technical characteristics which assure proper luminance and/or illuminance levels. But other characteristics should not be neglected.
Selection of luminaires

Design

As the luminaires are installed practically on every 30 m of traffic areas the design (form) is also very important.
Selection of luminaires

Construction details

Appropriate design and construction of the luminaire makes the installation and maintenance easier which means savings in time and money.
Selection of luminaires

Materials

Housing and other mechanical parts of the luminaire must be resistant to corrosion. The materials should be lightweight and should have the appropriate mechanical properties and durability.
Selection of luminaires

Safety

is also an important issue. Both mechanical and electrical safety (reducing risk of touching live parts) are important.
Selection of light source

Selection of light source influences:

• Needed luminous flux of the luminaire;
• Luminous intensity distribution;
• Number of poles and distance between them;
• Wanted colour of light;
• Wanted colour rendering index;
• Efficiency of installation;
• Installed electrical power;
• Maintenance interval.
High pressure sodium lamp

Working pressure 0.25 bar, working temperature 1000 K.

Yellowish white light.

Colour temperature: 2200 K.

Efficiency: 95 to 150 lm/W.

Live span: up to 24,000 h.

Colour rendering index: 20 - 65.

Electrical power up to: 1000 W.
High pressure mercury lamp

Mercury vapor gives mostly UV light so fluorescent powder costing is used to transfer UV to visible light.

Efficiency: up to 60 lm/W.
Life span: >15,000 h.
Colour rendering index: 23 - 55.
Colour temperature: 2000 - 4000 K.
Electrical power up to: 400 W
Metal halide lamp

Based on high pressure mercury lamp but with added metal halide compounds in the arc tube, which improve the efficiency and CRI of the light.

Efficiency: 67 to 95 lm/W.
Life span: 15,000 ur.
Colour temperature: 3000 - 6000 K.
Colour rendering index: up to 95.
Electrical power up to: 2000 W.
Compact fluorescent lamp

The same as fluorescent lamp but in compact design.
Not for use in cold environments.
Efficiency: up to 70 lm/W.
Life span: 12,000 h.
Colour temperature: 2700 - 6500 K.
Colour rendering index: up to 85.
Light emitting diodes (LED)

Very small lighting source.
Used mostly in special luminaires.

Efficiency: up to 100 lm/W.
Life span: 50,000 h.

Colour temperature: 2700 - 6500 K.
Colour rendering index: up to 90.
Low pressure sodium lamp

Mostly for road lighting, not suitable for pedestrian areas.

Best efficiency: up to 200 lm/W.

Monochromatic light: yellow at 589 nm.

Colour temperature: 1750 K.

Life span: 16,000 h.

Electrical power up to: 180 W
Geometry of lighting installation is characterized by following parameters:

• mounting height (H);
• distance between luminaires (D);
• carriageway width (S);
• luminaire overhang (S1);
• luminaire outreach (S2);
• upcast (tilt) angle (\(\delta\)).
Geometry of lighting installation
Pole placement

The placement of the poles for luminaires could be:

• one sided placement;
• axial placement;
• two sided opposite placement;
• median placement and
• two sided staggered placement.

Pole placement should always be chosen according to road parameters and circumstances.
• One sided placement is suitable for roads with small carriageway width (up to 10 m).
  • Luminaire mounting height (H) must be equal or greater as carriageway width (S): \((S/H) \leq 1\)
• Luminaires are usually mounted on poles.
• Luminance on lane closer to poles is larger as on the other lane.
Axial placement

• Axial placement is usually used on roads where the buildings are located on both sides of the road (easier installation).

• Also here luminaire mounting height (H) must be equal or greater as carriageway width (S): \((S/H)\leq 1\)
Two sided placement

- Two sided placement is used in case of wider carriageways (over 10 m), with no or only narrow (less than 2m) median.
- Two sided opposite or two sided staggered placement can be used: \((S/H)<1.5\).
- At two sided staggered placement the height of the luminaire can be lower than width of carriageway: \((S/H)>1\).
- If median is wider, we can additionally use also median placement.
Median placement

- It is used in the case of two carriageways with a width of less than 10 m and with width of median between 2 m and 6 m.

- Luminaires are mounted on a two-arm poles positioned in the middle of median.

- Luminance distribution is about the same as at one-side placement, although it should be taken into account that all luminaires illuminate both carriageways.
Special cases - guidance

- In curves luminaires should be placed on outer side - better optical guidance.
End of the road (crossroad with priority road) can be „marked“ by increased luminance and a pole on the other side.
Calculation of luminance

luminance of road surface can be calculated with different methods:

• using r coefficients;
• using efficacy coefficients;
• using iso-cd/m² diagram;
• using iso-r and iso-cd diagrams;
• using iso-q and iso-lux diagrams;
• using computer simulation tools.
Calculation of illuminance

Like luminance also illuminance can be calculated with different methods:

• using efficiency coefficients;
• using z iso-lux diagram;
• using grafo-analytical method;
• using computer simulation.
Conclusions …

• Planning of road lighting starts with selection of needed parameters from standards and recommendations.
  • Follows selection of lighting sources, luminaires, poles, their placement … .
  • At the end the lighting installation should be checked if it fulfills the needed requirements.
Questions?