Web-Based Training for FHWA Roadway Lighting Workshop
Module 1: Roadway Lighting Design Overview

FHWA Safety Program

U.S. Department of Transportation
Federal Highway Administration

Safe Roads for a Safer Future
Investment in roadway safety saves lives

http://safety.fhwa.dot.gov

Web-Based Training for FHWA Roadway Lighting Workshop

Participant Workbook

Module 1: Roadway Lighting Design Overview

(Other modules include:
Module 2: Lighting Hardware and Light Source Considerations for Roadway Lighting
Module 3: Street and Roadway Lighting Design
Module 4: Other Roadway Lighting Topics)

May 2018

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This document serves as a participant workbook for Web-Based Training for FHWA Roadway Lighting Workshop, Module 1: Roadway Lighting Design Overview. Module 1 covers lighting terminology, the purposes of roadway lighting, warrants for roadway lighting, and lighting guideline documents. Other modules include Module 2: Lighting Hardware and Light Source Considerations for Roadway Lighting, Module 3: Street and Roadway Lighting Design, and Module 4: Other Roadway Lighting Topics.</td></tr>
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Introduction

Training Course Overview

Roadway lighting is presently undergoing a major transition in terms of lighting technologies and recommended practices, after decades of incremental progress. In particular, light-emitting diode (LED) sources offer the potential for decreased lighting energy use, reduced maintenance requirements, improved visibility, and easier control of intensity. Along with these potential advantages, questions have arisen about the possibility of increased glare, light pollution, and impacts on human circadian rhythms.

Many transportation agencies lack "in-house" expertise about lighting due to retirement or reassignment of responsibilities within the agency, and to address this knowledge gap, the Federal Highway Administration (FHWA) has updated its Roadway Lighting Handbook, and offers this web-based training course to help improve understanding about the objectives and benefits of roadway lighting, basic terminology about lighting, practices for determining whether and how lighting should be installed, lighting and control technologies, measurement issues, and additional issues.

Target Audience

The primary intended audience for this training includes traffic safety engineers from transportation agencies whose responsibilities include making design decisions about roadways and roadway safety systems, those who work with the public and communicate about agency decisions regarding roadway lighting, and lighting contractors for the design and specification of roadway lighting systems. The initial module may also be of interest to the general public wishing to learn more about roadway lighting.

Course Outcome

Individuals completing this course will understand:

- The basics of roadway lighting, its potential benefits, and how decisions are made regarding its installation;
- The technology and hardware used in roadway lighting and adaptive control systems;
- The criteria and calculations underlying roadway lighting design and measurement; and
- Additional topics such as lighting for special situations like crosswalks and roundabouts, visual perception issues, light pollution, and possible impacts on circadian rhythms in people.

Course Contents

The course is organized into four modules as follows:

Module 1:	Roadway Lighting Design Overview
Module 2:	Lighting Hardware Design and Light Source Considerations for Roadway Lighting
Module 3:	Street and Roadway Lighting Design
Module 4:	Other Topics (Lighting Equipment Location, Special Locations, Ambient Environments, Spectral Effects)

Navigating the Online Course Modules

Each course module is structured to allow you to review content at your own pace. There is no audio feature in the course modules.

If you wish to leave a course module at any time, simply note the slide that you last viewed, and you will be able to use the slide bar at the bottom of the screen to quickly navigate to that slide when you return to complete the course. Slide numbers can be found at the lower left of each slide.

To navigate through the course, use the “back” and “next” arrow buttons on the bottom right side of each page. These buttons will allow you to advance to the next page, or go the previous page.

If you see a chart or graph of any of the pages, you will be able to place your mouse over the image of the chart to enlarge it.

There are “knowledge check” quizzes throughout the course. You will need to pass each quiz before you can advance to the next page. You are allowed as many attempts as needed to complete each knowledge check. However, if you do not answer correctly on the first attempt, it is a good idea to go back and review the previous section of the course module.

At the end of each course module there are also a series of quiz questions. You have only one try to answer these quiz questions correctly, but you will be able to review the correct answers to each question.

At the end of each course module, there is a list of links to all of the publications mentioned in the module, if you wish to further explore any of the content.

List of Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average daily traffic
ANSI	American National Standards Institute
cd/m²	Candela per square meter
CIE	Commission Internationale de l'Éclairage
CFL	Continuous freeway lighting
CIL	Complete interchange lighting
DG	Design guide
FHWA	Federal Highway Administration
IDA	International Dark-Sky Association
IES	Illuminating Engineering Society
LED	Light emitting diode
MLO	Model Lighting Ordinance
nm	Nanometers (10^{-9} meter)
PIL	Partial interchange lighting
RP	Recommended practice
TAC	Transportation Association of Canada
TM	Technical memorandum
V_λ	Photopic luminous efficiency function

Module 1: Roadway Lighting Design Overview

Roadway Lighting Design Overview
Module 1, Slide 1

This section of the Participant Workbook will help you review the content for Module 1, entitled "Roadway Lighting Design Overview." The top of each workbook page will indicate the module slide title and slide number in order to help you locate content within the workbook that matches content in the online modules.

Navigating This Course
Module 1, Slide 2

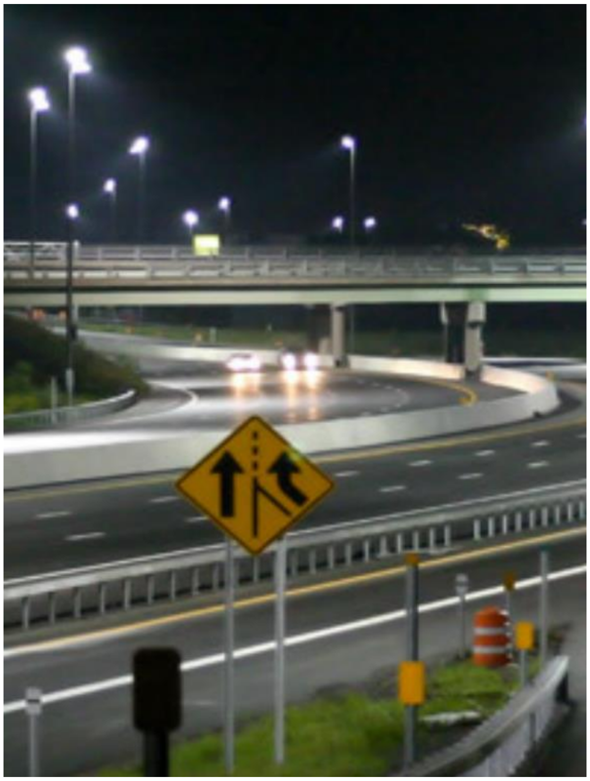
This slide in the online module describes how to navigate through the course module. It is similar to the instructions in this workbook.

Course Objectives
Module 1, Slide 3

Following completion of this module, the user will be able to accomplish the following objectives:

- Recognize the benefits of roadway lighting
- Identify lighting metrics, guidelines, and standards
- Relate lighting factors with visual performance
- Apply warrants for lighting

What are the purposes of roadway lighting?
Module 1, Slide 4



Typical high-mast lighting along a highway at night.

Have you ever asked yourself the question, *why do people install lighting along streets and roadways*? If cars have headlamps to light the roads, why do we need roadway lighting at all?

Lighting is installed along streets and roadways for several reasons. Some reasons are easily quantifiable and supported by many years of research. Others are less easy to quantify. Some common reasons that roadway lighting is installed include:

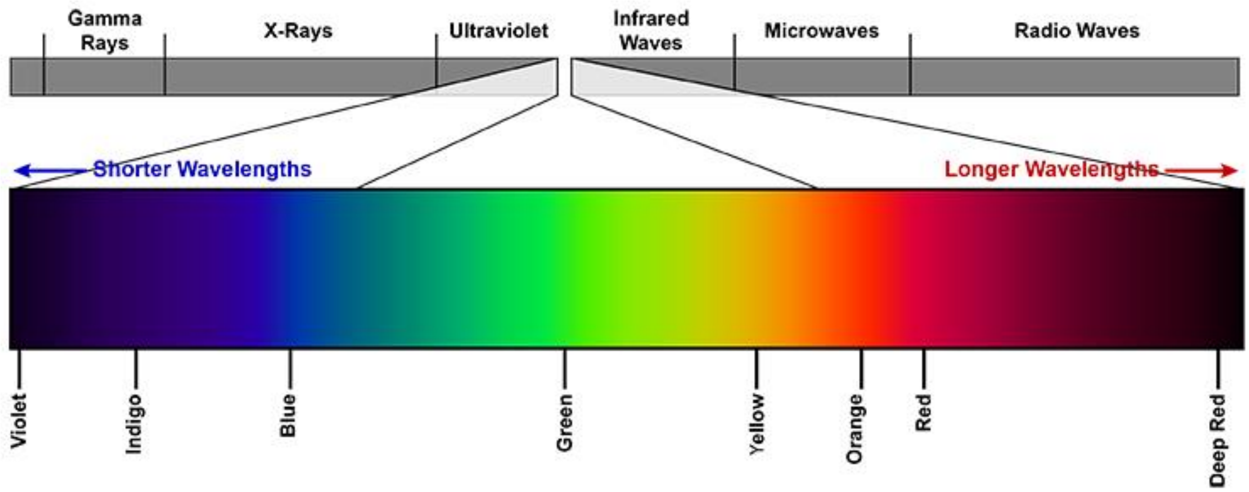
- **Visibility** - lighting supports our ability to see at night.
- **Nighttime crash reduction** - if visibility is improved, it should result in fewer crashes on the roadway.
- **Driver comfort** - roadway lighting improves visual comfort for drivers.
- **Perception of safety** - roadway lighting make us feel safer at night.
- **Crime reduction** - many people feel that roadway lighting will reduce the incidence of crime in an area.

Lighting Terminology
Module 1, Slide 5

Before we begin a more in-depth discussion of the reasons for roadway lighting, we first need to review some lighting terms and concepts. Like any profession, lighting has a unique vocabulary. Understanding these terms will be necessary as you continue to learn more about roadway lighting design. The terms we will review in more detail include:

- **Light**
- **Illuminance**
- **Luminance**
- **Contrast**
- **Visual Performance**
- **Uniformity**
- **Glare**

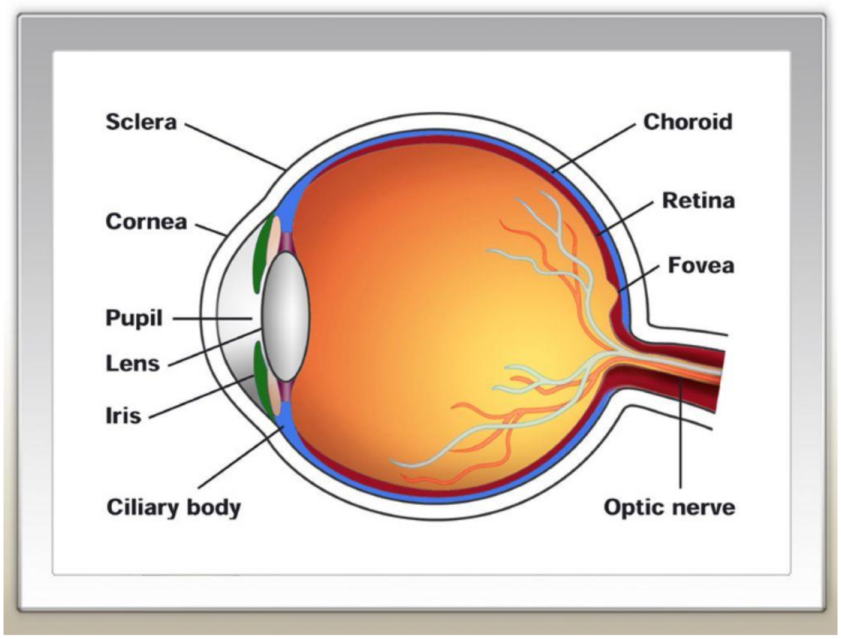
Light Defined
Module 1, Slide 6



Light is optical radiation entering the eye that produces a visual sensation.

Light is one type of energy on the electromagnetic spectrum. It is a small region of energy sandwiched between ultraviolet radiation on the low end, and infrared radiation on the upper end. Light extends from 380 nanometers (nm) to 780 nanometers.

Light and Vision
Module 1, Slide 7



A cross section of the human eye. Light enters through the lens and travels to the retina.

Light is similar to other types of energy, but what makes it unique is that it initiates the process of “seeing.” When we look at an object, what we are seeing is light reflected back from the object. This reflected light travels through our eye’s lens to the retina at the back of the eye where it is converted to neural signals by components called photoreceptors. These photoreceptors transmit visual signals to the brain through the optic nerve.

The brain then interprets these signals to form an image, which is what we see. This entire process happens almost instantaneously, but can only happen when there is light.

Following are definitions for some of the parts of the eye:

Cornea: The cornea is the transparent part of the eye that covers the front portion of the eye. It covers the pupil, iris, and anterior chamber. The cornea's main function is to refract, or bend, light.

Pupil: The opening in the center of the iris through which light enters.

Lens: The lens is a transparent structure in the eye that, along with the cornea, helps to refract light to be focused on the retina.

Light and Vision
Module 1, Slide 7 (continued)

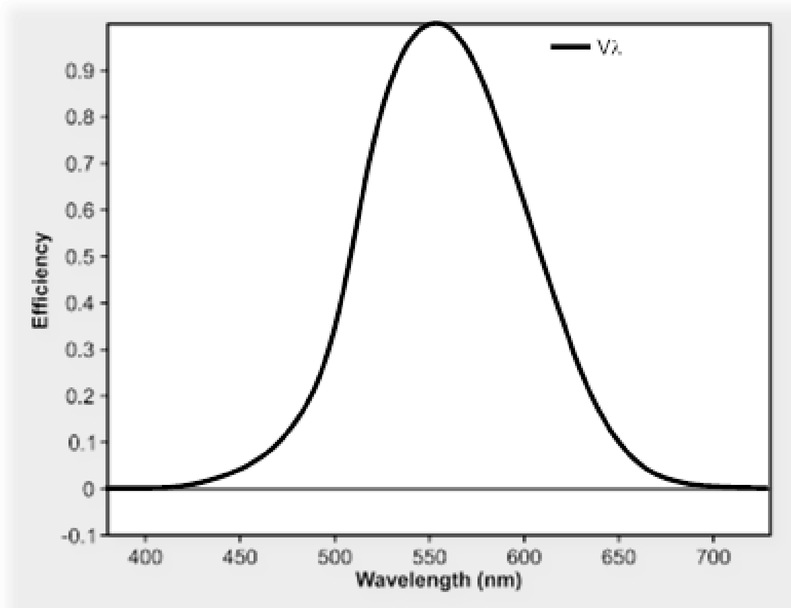
Iris: The iris is a thin, circular structure in the eye, responsible for controlling the diameter and size of the pupil and thus the amount of light reaching the retina. Eye color is defined by that of the iris.

Retina: The retina is the nerve layer that lines the back of the eye, senses light, and creates impulses that travel through the optic nerve to the brain.

Fovea: The fovea is a depression-like area located at the center most part of the retina of the eye. Only cone photoreceptors are located in the fovea. The fovea is the location in which the most acute vision takes place.

Optic nerve: The optic nerve carries the impulses formed by the retina. These impulses are dispatched through the optic nerve to the brain, which interprets them as images.

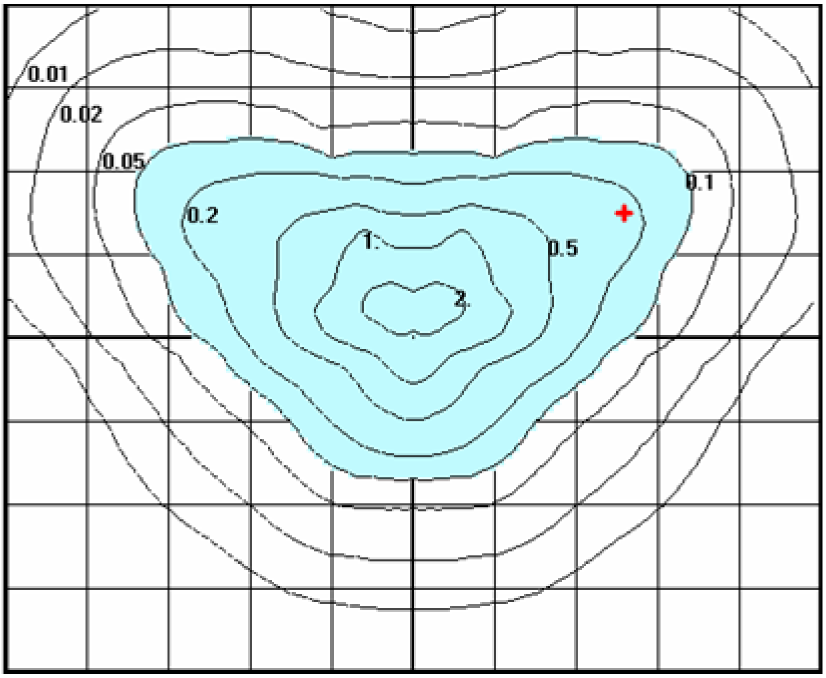
Lumen
Module 1, Slide 8



When we measure light, a weighting function is applied to the wavelengths of light which represents how our eye sees fine detail at daytime light levels. This curve is often referred to with the capital letter "V" followed by the Greek letter lambda (λ).

When we discuss light, we typically think of the lumen, which is the standard measure of light. The lumen does not consider all wavelengths of light equally. It applies a weighting function as shown in the graph above. This weighting function gives more prominence to the wavelengths of light in the middle of the spectrum, around 550 nm and nearly "leaves out" the wavelengths of light at the upper and lower regions of the spectrum (to the left and right on the graph).

Illuminance
Module 1, Slide 9



This diagram illustrates a "pool" of light directly under a pole-mounted, outdoor light fixture. Each contour line represents a different illuminance level (in footcandles) from highest at the center of the diagram to lowest at the edges.

Illuminance is the amount of light (lumens) falling on a surface, per a particular unit area such as square foot or square meter.

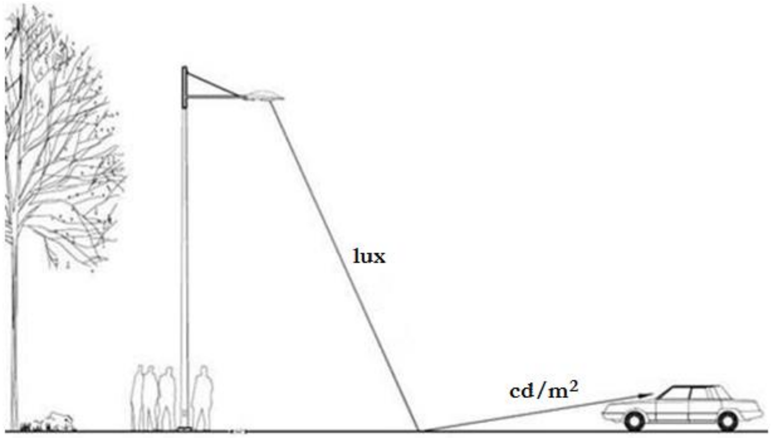
In roadway lighting, we typically will measure horizontal illuminance on the pavement. In places such as crosswalks where there are likely to be pedestrians, we also need to consider vertical illuminance, such as the amount of light falling on people.

In the US we most often measure illuminance in lumens per square foot. This measure is called footcandles.

In other parts of the world they measure illuminance in lumens per square meter. This measure is called lux.

For ease of conversion, we typically apply a 10 to 1 rule to convert lux to footcandles.
10 lux is equal to 1 footcandle.

Luminance
Module 1, Slide 10



In the illustration above, the driver in the car sees the luminance of the roadway surface.

Luminance is easiest to think of as the amount of light reflected or emitted by a surface in a particular direction.

Luminance takes into account the properties of the surface, such as its reflectivity, and the position of the observer. When we see an object, we see luminance. In the illustration at the top, the driver in the car sees the luminance of the roadway surface.

The unit of measure for luminance is candelas (a measure of luminous intensity) per square meter (a unit area of a surface, cd/m^2).

Different sections of roadways will have different luminance measurements depending on the amount of light falling on them, the properties of the roadway surface, and the angle at which they are being viewed.

Knowledge Check
Module 1, Slide 11

Select the correct answer:

24 footcandles is a higher light level (illuminance) than 180 lux.

- ☐ a) True
- ☐ b) False

The correct answer is on the next page.

Knowledge Check Answer
Module 1, Slide 12

The correct answer is a) True. Using the rule of thumb conversion factor of 10 lux is equal to 1 footcandle, 180 lux would be equal to about 18 footcandles, which is less than 24. (*See Module 1, Slide 9.)*

Contrast
Module 1, Slide 13

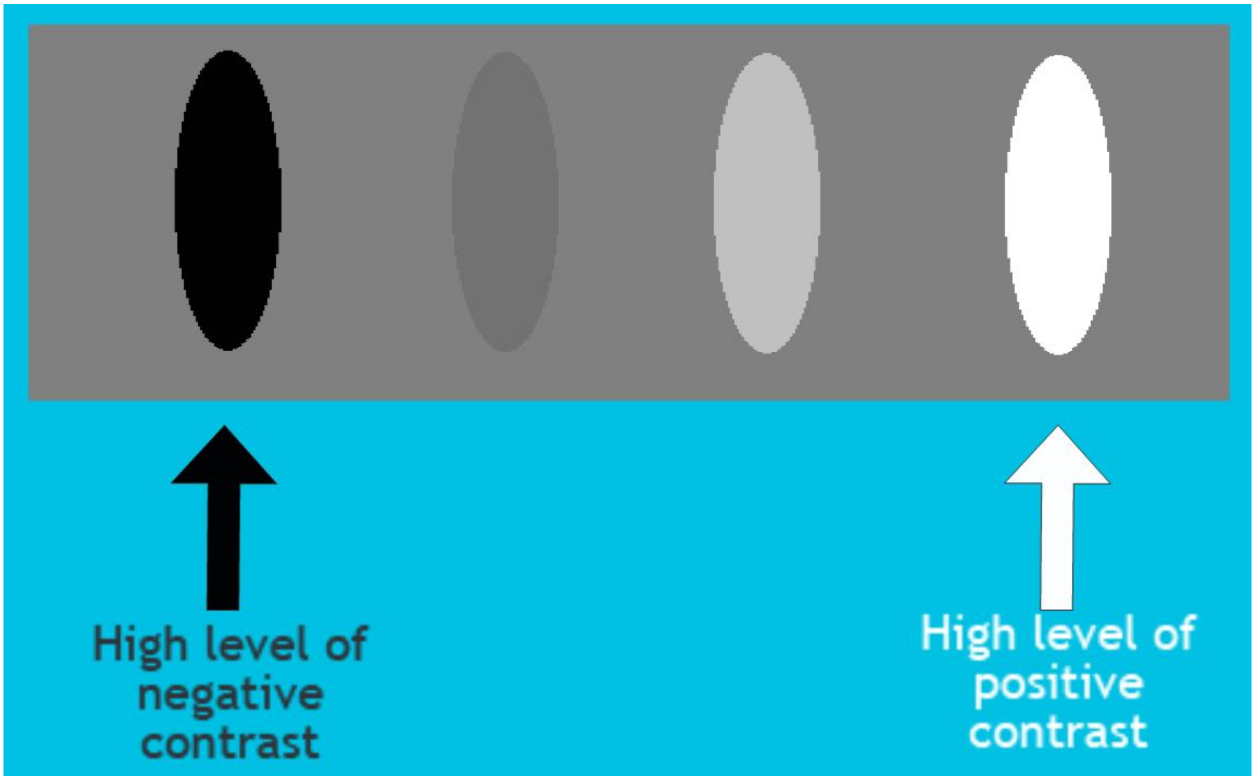
The panel to the left shows newly painted crosswalk pavement markings. Notice the difference in contrast between the markings and the new, dark pavement surface. The panel to the right shows aged crosswalk markings. Notice the reduction in contrast between the markings and the lighter pavement surface.

Contrast is a measure of the luminance difference between a target and its background.

Contrast is one of the factors that affects the visibility of an object or image. Generally, the larger the difference in luminance between the object and its background, the more visible an object will appear. For example, in the image above to the left, it is very easy to see the white pavement markings against the black roadway surface because the difference in luminance between the markings and roadway is very large.

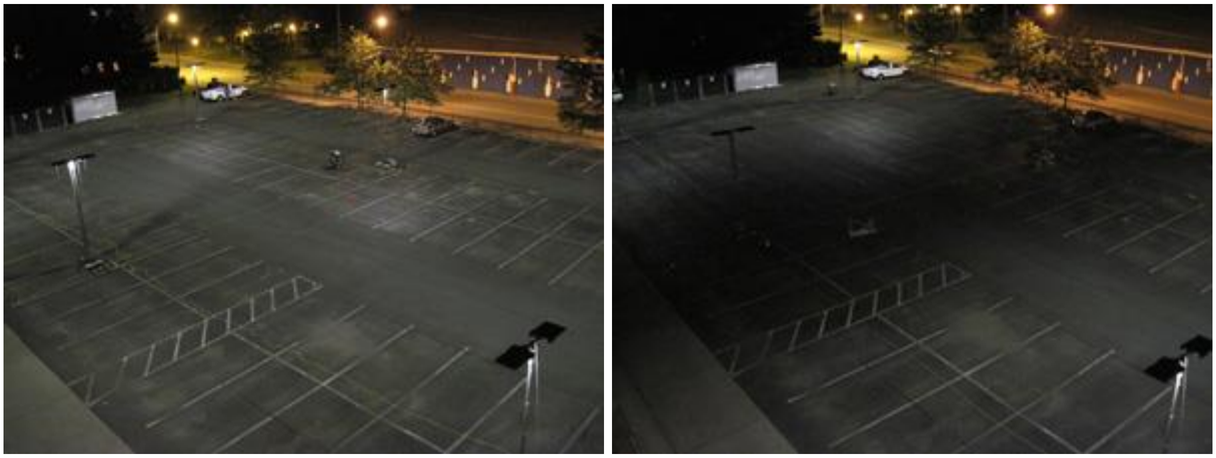
However, as the pavement markings age, and the roadway surface lightens over time, the contrast (luminance difference) between the markings and the roadway surface diminishes, making the markings less visible, as shown in the image above to the right.

Contrast
Module 1, Slide 14



Contrast can be described as being “negative” or “positive.” Negative contrast is when the target is darker (has a significantly lower luminance) than its background. Positive contrast is when the target is brighter (has a significantly higher luminance) than its background. These concepts are illustrated above. Either high negative or high positive contrast will make an object more visible.

Uniformity
Module 1, Slide 15



The illuminance uniformity on the pavement in the left image is 3:1. The illuminance uniformity in the right image is 10:1. You can see how people and objects would be more visible throughout the left parking lot, while there are darker areas in the right parking lot where people and objects may be more difficult to see.

The term uniformity when applied to lighting, has to do with the “evenness” or consistency of the lighting distribution in a particular area, such as on roadway surface. Uniformity can be applied to luminance or illuminance measurements. Lighting guidelines will typically specify a particular illuminance or luminance that should be present on a roadway, and a recommended uniformity of the lighting.

Uniformity is specified in terms of a ratio, such as “ten to one”, typically written as 10:1. This means that the light levels on no area on the roadway should be 10 times higher or lower than any other area.

Uniformity is important because generally, the more uniform the lighting, the easier it is for someone to see objects or people on all areas of the roadway.

Glare
Module 1, Slide 16

The unshielded light fixtures above are an example of discomfort glare.

The vehicle headlamps in this photograph are causing disability glare, significantly reducing visibility for any oncoming drivers.

The Illuminating Engineering Society (IES), the professional body for lighting in North America, defines glare as the sensation produced by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted, which causes annoyance, discomfort, or loss in visual performance and visibility.

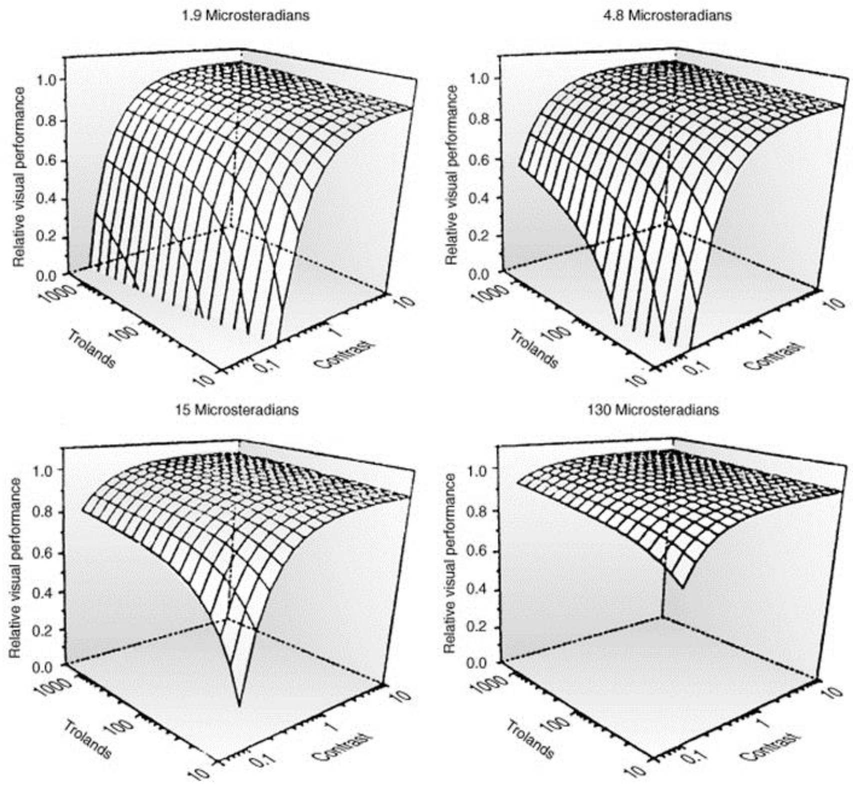
In terms of roadway lighting, as we are driving at night, our eyes become adapted to the relatively dark area on and around the roadway. When we see a bright light source, from fixed roadway lighting or oncoming headlamps for example, this can be uncomfortable to look at, or can cause us not to be able to see anything beyond the bright source.

Discomfort glare is uncomfortable to look at and can reduce visibility, especially at a distance.

Disability glare significantly reduces visual performance by reducing contrast.

Later in this course we will discuss some metrics or measures for glare, and some design techniques to help prevent glare from roadway lighting.

Visual Performance
Module 1, Slide 17



The graphs above show visual performance for viewing targets of different sizes. If a target is very small, as in the graph at the top left, any increase in contrast or luminance will make a big difference in how easy it is to see. However if a target is large, as in the graph at the bottom right, it is easier to see regardless of the amount of light or contrast.

Visual performance describes how quickly and accurately we can process a visual image or visual information. Visual performance depends on several factors, including:

- **Light level** - the luminance of the area or object we are viewing.
- **Contrast** - the difference in luminance between the object and its background.
- **Size** - how large or small the object is.
- **Age** - the age of the observer.

Visual performance can be improved or made worse by varying any of these factors. Some we have no control over, such as the age of the observer (in our case, drivers). The things we can affect are either increasing the light level, or improving the contrast of what a driver needs to see. These functions follow what we call a “plateau” effect, as seen in the graphs above. Once we achieve a sufficient light level and good contrast, for example, adding more light will not improve visual performance any further. However, when lighting conditions are marginal, adding light or improving contrast will have a large effect on improving visibility.

Knowledge Check
Module 1, Slide 18

Select the correct answer:

What issue can be caused by glare on the roadway at night?

- ☐ a) Visual discomfort
- ☐ b) Reduction or loss in visual performance
- ☐ c) Reduction or loss in visibility
- ☐ d) All of the above

The correct answer is on the next page.

Knowledge Check Answer
Module 1, Slide 19

The correct answer is d) All of the above. Glare can cause visual discomfort as well as loss or reduction in visibility or visual performance. (*See Module 1, Slide 16.)*

Purposes of Roadway Lighting
Module 1, Slide 20

The following pages review some of the purposes of roadway lighting in more detail.

Improved Visibility and Visual Performance
Module 1, Slide 21

In the panel to the left, the roadway is lighted only by car headlights. In the panel on the right, the roadway is lighted by car headlights and fixed roadway lighting.

The IES states that the purpose of roadway lighting is to “provide quick, accurate, and comfortable visibility at night.” We know from extensive research into visual performance that lighting is one of the key factors that describes how visible something will be.

Roadway lighting improves visibility by providing the driver with increased visual information as compared to a road lighted only by a car’s headlamps. This increase in visibility has a direct effect on a driver’s ability to see and react to potential hazards in the roadway.

In the illustrations above, the left picture shows a driver’s view of an oncoming car with only headlamps illuminating the roadway. The right picture shows this same oncoming car on a roadway lighted by both car headlamps and roadway lighting. In the right picture the driver has much more visual information including an idea of the speed of the oncoming car, its position on the roadway, its size, and its direction of travel.

Nighttime Crash Reduction
Module 1, Slide 22

Estimated mean effect of road lighting on injury accidents in darkness during different conditions on rural Dutch roads

Conditions		Effect	95 % conf.
All		-54 %	-56 %, -52 %
Weather conditions	Fine weather	-54 %	-56 %, -52 %
	Rainy weather	-45 %	-53 %, -37 %
	Foggy conditions	0 %	-15 %, +18 %
	Snowy weather	-26 %	-40 %, +8 %
Road surface conditions	Dry road surface	-56 %	-59 %, -54 %
	Wet road surface	-46 %	-50 %, -43 %
	Snow / ice covered	-22 %	-31 %, -11 %
Road user	Pedestrian	-70 %	-77 %, -61 %
	Bicycle	-60 %	-65 %, -54 %
	Moped	-61 %	-64 %, -56 %
	MC	-26 %	-42 %, -5 %
	Automobile	-50 %	-52 %, -47 %
Accident type	Hit fixed object	-54 %	-58 %, -49 %
	Frontal collisions	-50 %	-55 %, -43 %
	Flank collisions	-46 %	-51 %, -41 %
	Hit animal	-57 %	-63 %, -50 %
	Rear end collisions	-51 %	-54 %, -46 %

If roadway lighting improves visibility for drivers and pedestrians, then it should reduce nighttime crashes. According to the World Health Organization, 1.24 million road traffic deaths occur every year, worldwide. The International Commission on Lighting (CIE) analyzed 62 lighting and accident studies from 15 countries and concluded that,

“Statistically significant results show reductions in nighttime accidents of between 13 and 75 percent.”

One of these studies is summarized in the chart above. This shows the effect of roadway lighting on crash reduction for different weather conditions, road surface conditions, road users, and crash types. In almost all cases, roadway lighting had a significant effect on reducing crashes.

More recent studies continue to show the beneficial effects of roadway lighting on nighttime crash reduction.

Nighttime Crash Reduction (Continued)
Module 1, Slide 23

CMF	CRF (%)	Quality	Crash Type	Crash Severity	Area Type	Reference
0.72 [B]	28	★★★★☆	Nighttime	A,B,C	All	Elvik, R. and Vaa, T., 2004
0.83 [B]	18	★★★★☆	Nighttime	O	All	Elvik, R. and Vaa, T., 2004
0.31	69	★★★☆☆	All	K	All	Elvik, R. and Vaa, T., 2004

CMF
CRASH MODIFICATION FACTORS CLEARINGHOUSE

Examples of crash modification factors (CMFs) and crash reduction factors (CRFs) associated with roadway lighting, from the CMF Clearinghouse.

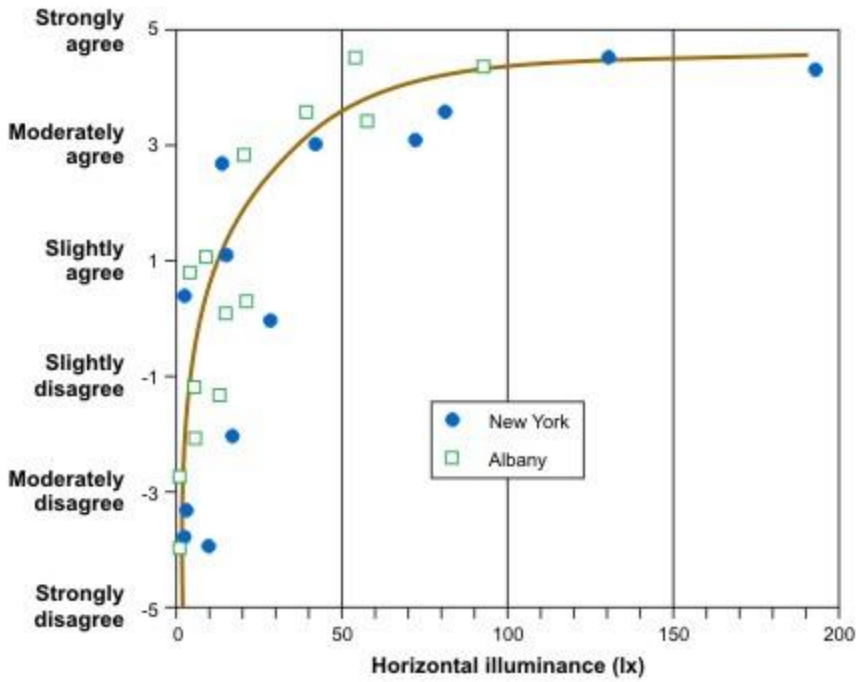
The FHWA established the Crash Modification Factor (CMF) Clearinghouse (www.cmfclearinghouse.org) to gather evidence for the safety impacts of various treatments, including roadway lighting. The CMF is an estimate of the proportion of crashes expected after the safety treatment is installed, compared to before. The Crash Reduction Factor (CRF) is the percent reduction in crashes expected with a safety treatment. The letters indicating crash severity range from crashes involving fatalities (K), severe injuries (A), moderate injuries (B), minor injuries (C), to crashes with property damage only (O).

Improved Visual Comfort for Drivers
Module 1, Slide 24

The roadway lighting along this uniformly lighted street makes it very comfortable for drivers who are not affected by glare from oncoming headlights or any of the other lighting along the street.

The main factor affecting driver comfort on roadways at night is glare from the headlamps of oncoming vehicles and from roadway lighting fixtures. If a roadway is properly lighted at night, glare from headlamps and other light sources along the roadway will be reduced because the roadway lighting will raise the overall ambient light level on the roadway. This will reduce the difference in luminance between any given light sources, such as oncoming car headlamps, and the surrounding environment. This reduces glare and improves visual comfort for drivers.

Improved Sense of Safety and Security
Module 1, Slide 25



People were asked to agree or disagree that the lighting in an area provided good security. The higher the light level (shown on the bottom axis) the more strongly observers agreed with this statement, as shown on the axis to the left side of the graph.

Studies show that nighttime lighting improves peoples' sense of safety and personal security. In other words, if an area is well-lighted at night, people will feel more safe.

The graph above is taken from a study conducted by Dr. Peter Boyce. Dr. Boyce took groups of people to different areas of Albany, NY and New York City at night. Some of these areas were lighted to very low levels, others at much higher levels. He found that there was a direct correlation between light level and people's perceptions of safety and security. The more light, the safer people felt.

This correlation held up to about 30 lux, and then people's safety perception started to level off. This indicated that adding more light did make people feel a little bit safer, but once you reached the level of about 30 lux, you had enough light to make most people feel safe.

Improved Sense of Safety and Security (continued)
Module 1, Slide 26

A street lighted with high pressure sodium (HPS) light sources (left). A street lighted with a "whiter" light source was rated as safer by drivers and pedestrians (right).

Other research, conducted by Dr. Mark Rea and his colleagues, found that there was a direct correlation between the perceived brightness of an outdoor area at night, and people's perception of safety and security.

This was similar to what was found by Dr. Boyce in the study described on the previous slide; however, rather than using light level, Dr. Rea's study used perceived brightness. The brighter an area looked to people at night, the safer they indicated they felt in that area.

This is an important distinction because we can make an area look brighter by using light sources, like light emitting diodes (LEDs) that produce a greater perception of brightness without having to raise light levels and use additional energy.

Crime Reduction
Module 1, Slide 27

Roadway lighting may not reduce the incidence of crime at night.

It would seem reasonable that if a street, roadway, or other area were well-lighted at night, this would have a beneficial effect on reducing crime in that area. We know that people feel more safe in a well-lighted area. One reason for this is that they can see clearly around them, and can see facial details of people that may be approaching from a distance.

However, studies looking at the correlation of roadway lighting and crime reduction have produced conflicting results. In some areas where lighting was added, crime did indeed decrease. However, in other areas where lighting was added, crime increased or stayed the same. In one study, for example, theft from inside cars increased because thieves could more clearly see what was inside the car and were then more likely to try to break in and steal it.

So, we can say that the “jury is still out” on whether or not nighttime lighting reduces crime, until more definitive research results are available.

Knowledge Check
Module 1, Slide 28

Select the correct answer:

According to the Illuminating Engineering Society (IES), the primary purpose of roadway lighting is to:

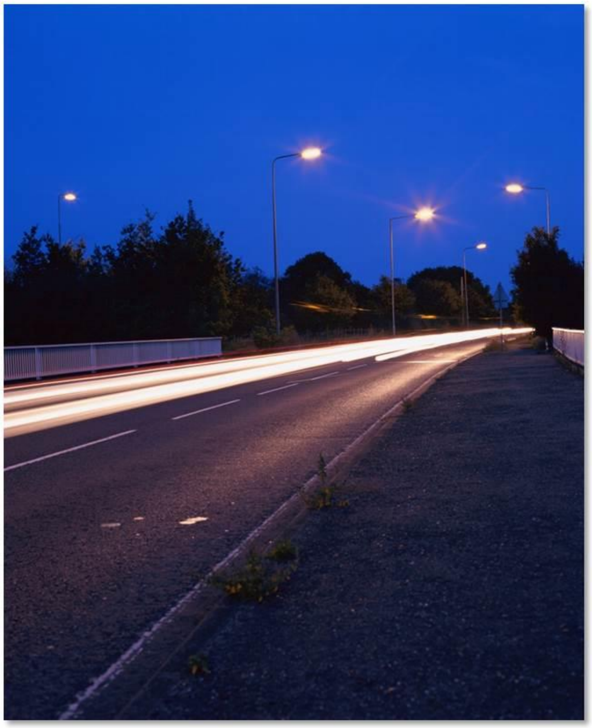
- ☐ a) Prevent crashes at intersections
- ☐ b) Provide quick, accurate and comfortable visibility at night
- ☐ c) Reduce nighttime incidences of crime
- ☐ d) Reduce the number of rear end collisions on highways

The correct answer is on the next page.

Knowledge Check Answer
Module 1, Slide 29

The correct answer is b) Provide quick, accurate and comfortable visibility at night. The IES states that the purpose of roadway lighting is to "provide quick, accurate, and comfortable visibility at night." We know from extensive research into visual performance that lighting is one of the key factors that describes how visible something will be (*See Module 1, Slide 21.)*

Determining if Lighting is Needed in an Area
Module 1, Slide 30



Lighting along a highway interchange at night. Traffic speed is a factor in considering the need for roadway lighting.

The first step in a roadway lighting design process is to determine if lighting is needed in an area. In order to do this, you need to consider the following factors:

Traffic
What is the traffic density in the location?
What is the posted speed limit?
What is the crash history in the location?

Pedestrians
How heavy is the pedestrian traffic throughout the day and night?
How does the pedestrian traffic vary at various times of day and night?

Type of Neighborhood
What is the type of area (commercial, residential)?
What types of buildings are found in the area (homes, businesses, schools, offices)?

Safety
Is the location perceived as safe or unsafe?

Determining if Lighting is Needed in an Area (continued)
Module 1, Slide 31

The grade of a roadway is one factor to consider in determining the need for roadway lighting.

Other factors that should be part of your consideration of whether or not lighting is needed in an area include:

- Geometry
- Number of lanes on a roadway
- Roadway width
- Is there a shoulder on the roadway?
- Are there slopes or curves on the roadway?
- The grade of the roadway
- Does the road have a median?

A study should be conducted looking at all of these factors in order to decide if lighting is likely to make a positive impact on a particular stretch of road or at an intersection or other type of interchange. The answers to the various questions posed here will guide you in your determination of the need for roadway lighting.

Components of “Good” Lighting Design
Module 1, Slide 32

Continuous lighting along a curve on an access road at night provides good illumination along the roadway.

There are several factors that contribute to the quality and effectiveness of a roadway lighting design and installation. These include:

Illuminance or Luminance - Provide the correct amount of light for each type of roadway situation. Some areas, such as busy intersections, will need more light than others, such as low-speed roadways.

Uniformity - How evenly light is applied to roadway surfaces. You want to avoid large contrasts between light and dark areas along the road.

Glare - You want to avoid using light fixtures where the light source is not well-shielded, or that may appear as excessively bright to drivers.

Components of Good Lighting Design (continued)
Module 1, Slide 33

In the picture above, a decorative post-top light fixture is used in an historic area of this city to blend with the aesthetics of the surrounding buildings.

Additional factors contributing to good roadway lighting include:

Aesthetics and Appearance - Light fixtures are seen both during the day and at night. It is important that they fit the character of an area.

Cost - It is important to consider the first cost of a lighting system (purchase and installation) as well as the operating costs (energy and maintenance) of the system.

Light Pollution - You need to consider how the lighting system might contribute to sky glow (light up into the night sky) and/or light trespass (light falling off the roadway onto peoples' property along the road).

Knowledge Check
Module 1, Slide 34

Select the correct answer:

The density of pedestrian traffic throughout the day and night is a factor in determining if roadway lighting is needed in an area.

- ☐ a) True
- ☐ b) False

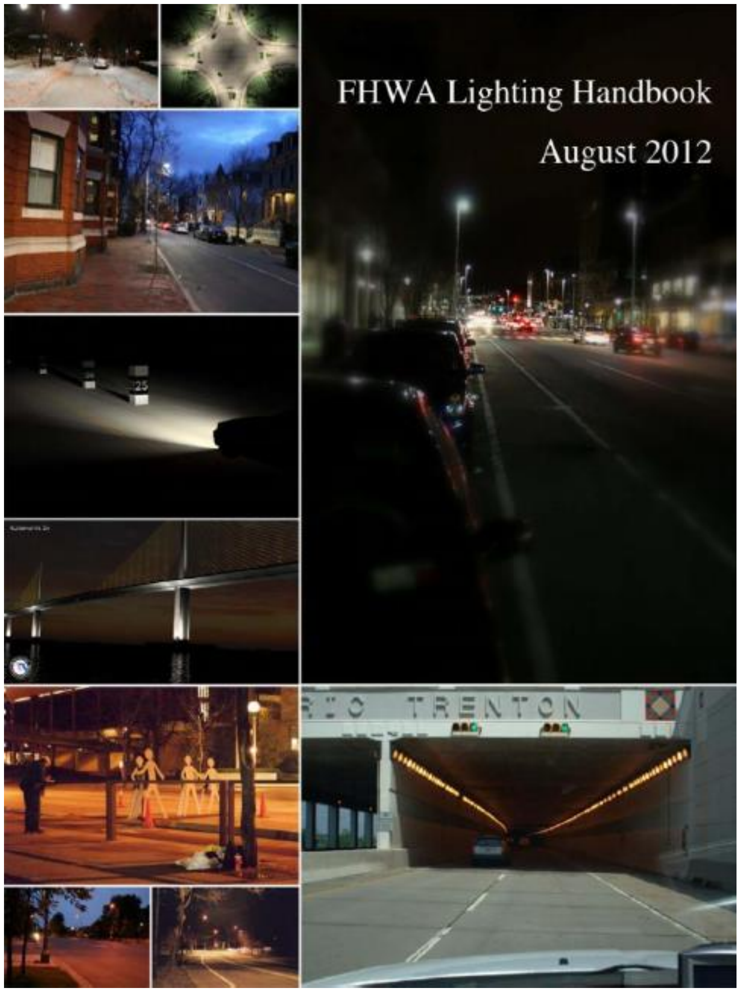
The correct answer is on the next page.

Knowledge Check Answer
Module 1, Slide 35

The correct answer is a) True. Pedestrians are a key consideration when determining if roadway lighting is needed in an area. (*See Module 1, Slide 30.)* Some questions to ask:

- How heavy is the pedestrian traffic throughout the day and night?
- How does the pedestrian traffic fluctuate at various times of day and night?

Federal Highway Administration (FHWA) Lighting Handbook
Module 1, Slide 36



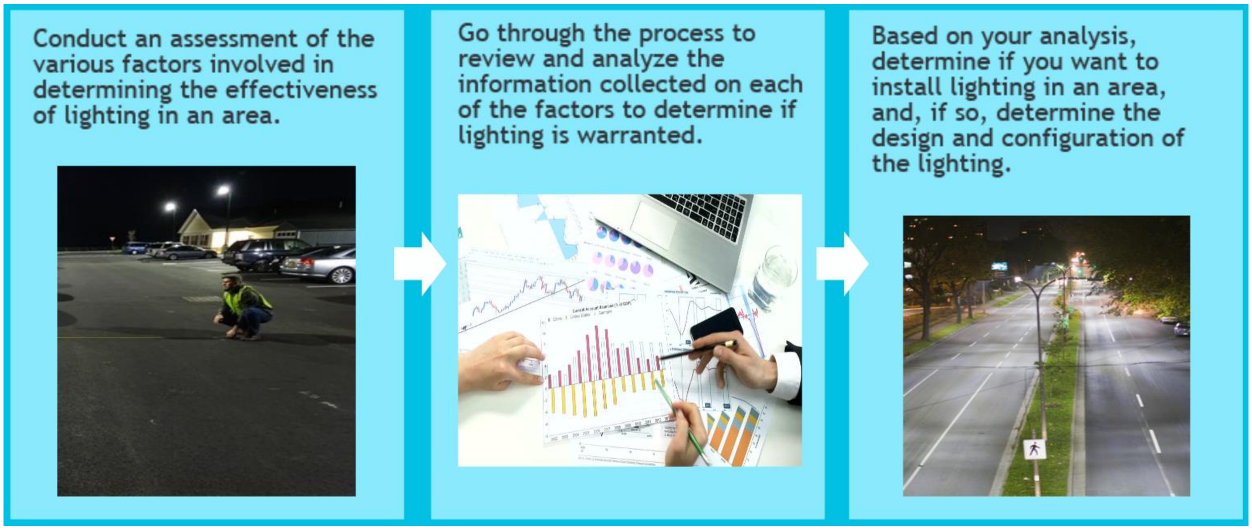
https://safety.fhwa.dot.gov/roadway_dept/night_visib/lighting_handbook

The FHWA Lighting Handbook will guide you in determining if lighting may be needed, or "warranted" in a location.

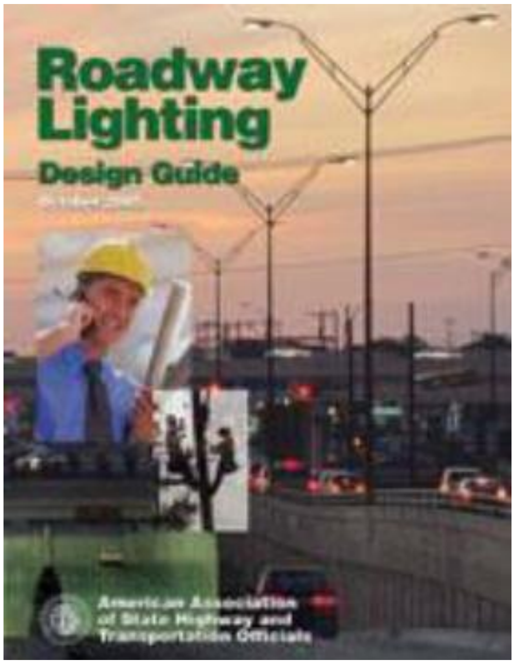
> *"Warrants do not represent requirements to provide lighting. They are a method for evaluating and prioritizing projects in terms of lighting. FHWA uses these warranting methods as a way to evaluate where federal aid could be better spent to increase safety and not to establish lighting requirements."*

The Warranting Process
Module 1, Slide 37

Used to determine if lighting may be effective at improving the safety of a particular roadway, intersection, interchange, or other area.



AASHTO Warranting System
Module 1, Slide 38



https://bookstore.transportation.org/item_details.aspx?ID=1412

AASHTO (American Association of State Highway and Transportation Officials) provides a system to determine if lighting is needed on highways, freeways, interchanges and bridges. AASHTO defines warrants for:

- Continuous Freeway Lighting (CFL)
- Complete Interchange Lighting (CIL)
- Partial Interchange Lighting (PIL)

This warranting system is based on such factors as:

- Traffic volumes
- Spacing of freeway interchanges
- Lighting in adjacent areas
- Night-to-day crash ratio

AASHTO Warrants for Continuous Freeway Lighting
Module 1, Slide 39

The chart below provides information on the cases for where continuous freeway lighting may be warranted.

Case	Warrant Condition
CFL-1	Sections in or near cities where the current ADT (average daily traffic) is 30,000 or more
CFL -2	Sections where three or more interchanges are located with an average spacing of 1 ½ mile or less, and adjacent areas outside the right-of-way are substantially urban in character
CFL-3	Sections with a length of two or more miles that pass through a substantially developed suburban or urban area in which one or more of the following conditions exist: • local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the freeway; • the freeway passes through a series of developments (e.g., residential, commercial, industrial, colleges, parks, terminals) which include roads and/or parking areas that are lighted; • separate cross streets, both with and without connecting ramps, occur with an average spacing of ½ mile or less, some of which are lighted; and • the freeway cross section elements are substantially reduced in width below desirable sections used in relatively open country
CFL-4	Sections where the ratio of Night to Day crash rate is at least 2.0 time the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate. Where crash data is not available, rate comparison may be used as a general guideline for crash severity

AASHTO Warrants for Complete Interchange Lighting
Module 1, Slide 40

Complete interchange lighting (CIL) is defined as the lighting of the freeway through the interchange, including:

- Main Lines
- Direct Connections
- Ramp Terminals
- Frontage Road and Crossroad Intersections

Case	Warrant Condition
CIL-1	Total current ADT ramp traffic entering and leaving the freeway within the interchange area exceeds 10,000 for urban conditions, 8,000 for suburban conditions, and 5,000 for rural conditions.
CIL -2	Current ADT on the crossroads exceeds 10,000 for urban conditions, 8,000 for suburban conditions, and 5,000 for rural conditions.
CIL-3	On unlighted freeways where existing substantial commercial or industrial development is located in the immediate vicinity of the interchange, and which is lighted during hours of darkness; or where the crossroad approach legs are lighted for ½ mile or more on each side of the interchange.
CIL-4	Where the ratio of night to day accident rate within the interchange area is at least 1.5 or higher than the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in night accident rate. Where crash data is not available, rate comparison may be used as a general guideline for crash severity

AASHTO Warrants for Partial Interchange Lighting
Module 1, Slide 41

Partial interchange lighting (PIL) is defined as a lighting system that provides illumination only at the decision making areas of the roadway, including:

- Acceleration and Deceleration Lanes
- Ramp Terminals
- Crossroad at Frontage Road or Ramp Intersections
- Other Areas of Nighttime Hazard

Case	Warrant Condition
PIL-1	Total current ADT ramp traffic entering and leaving the freeway within the interchange area exceeds 5,000 for urban conditions, 3,000 for suburban conditions, and 1,000 for rural conditions.
PIL -2	Current ADT on the crossroads exceeds 25,000 for urban conditions, 20,000 for suburban conditions, and 10,000 for rural conditions.
PIL-3	Where the ratio of night to day accident rate within the interchange area is at least 1.25 or higher than the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in night accident rate. Where crash data is not available, rate comparison may be used as a general guideline for crash severity

AASHTO Warrants for Bridges
Module 1, Slide 42

Lighting would be recommended for this bridge because it also has pathways for pedestrians.

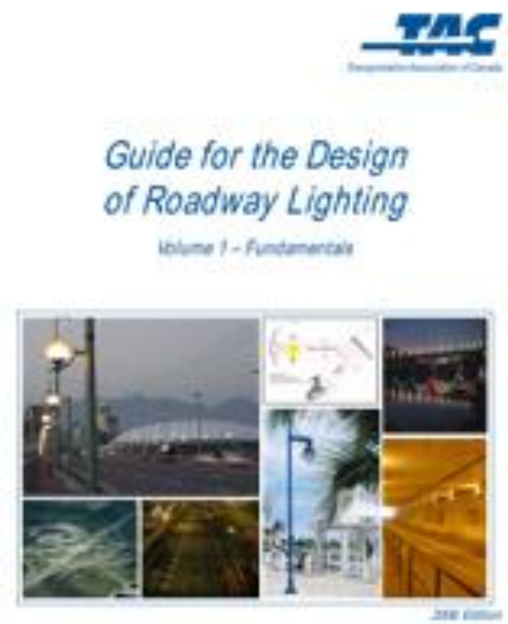
AASHTO recommends that lighting be provided on long bridges in urban and suburban areas even if the approaches are not lighted.

On bridges without full shoulders, lighting can enhance both safety and utility of the bridges, and is therefore recommended.

Where bridges are provided with sidewalks for pedestrian movements, lighting is recommended for pedestrian safety and guidance.

Warrants for Collector, Major and Local Streets
Module 1, Slide 43

Transportation Association of Canada



The roadway lighting warranting process in the U.S. is based on the system published by the Transportation Association of Canada.

The warranting process published by the Transportation Association of Canada (TAC) is used in the United States to help determine if lighting is needed for the following types of streets:

- **Major (Street)** - Serves as the principal network for through traffic
- **Collector (Street)** - Roadways servicing traffic between major and local streets
- **Local (Street)** - Provides direct access to residential, commercial, industrial or other abutting properties.

Warrants for Collector, Major and Local Streets (continued)
Module 1, Slide 44

The TAC warranting system is based on a point scale, taking into account the following factor types:

- Geometric Factors
- Operational Factors
- Environmental Factors
- Crash Rates

Each of these factors is assigned a numeric rating (R) from 1 to 5. It is also assigned a weight (W) based on its relative importance. A score is obtained for each criterion by multiplying (R x W). These scores are then added together. Lighting is warranted if the total score for all criteria is above 60. Lighting is automatically warranted if the night/day crash ratio is greater than 2 to 1 (twice as many crashes at night vs. during the daylight hours).

Warrants for Collector, Major and Local Streets (continued)
Module 1, Slide 44 (continued)

Operational Factors	**Rating Factor *R***					**Weight *W***	**Enter *R***	**Score *R* × *W***
	1	**2**	**3**	**4**	**5**			
Signalized Intersections (%)	80 to 100	70 to 80	60 to 70	50 to 60	0 to 50	0.15		
Left Turn Lane	All Major Intersections or 1-Way	Substantial Number of Major Intersections	Most Major Intersections	Half of Major Intersections	Infrequent Number or Two-Way Turn Lane*	0.70		
Median Width (m)	>10	6 to 10	3 to 6	1.2 to 3	0 to 1.2	0.35		
Operating or Posted Speed Limit (km/h)	≤40	50	60	70	≥80	0.60		
Pedestrian Activity Level			Low	Medium	High	3.15		
Subtotal Operational Factors (*O*):								

*If this condition is met, lighting is warranted.

Environmental Factors	**Rating Factor *R***					**Weight *W***	**Enter *R***	**Score *R* × *W***
	1	**2**	**3**	**4**	**5**			
Percentage of Development Adjacent to Road (%)	nil	nil to 30	30 to 60	60 to 90	>90	0.15		
Area Classification	Rural	Industrial	Residential	Commercial	Downtown	0.15		
Distance from Development to Roadway (m)	>60	45 to 60	30 to 45	15 to 30	<15	0.15		
Ambient (Off Roadway) Lighting	Nil	Sparse	Moderate	Distracting	Intense	1.38		
Raised Curb Median	None	Continuous	At All Intersections (100%)	At Most Intersections (51% to 99%)	At Few Intersections (≤50%)	0.35		
Collision Factors	**Subtotal Operational Factors (*E*):**							
Night-to-Day Collision Ratio	<1.0	1.0 to 1.2	1.2 to 1.5	1.5 to 2.0	>2.0*	5.55		
Collision Factors (*C*):								

*If this condition is met, lighting is warranted.

Warranting Method for Intersections
Module 1, Slide 45

Lighting at this intersection would be automatically warranted because it is signalized.

The warranting method for determining the need for lighting at intersections uses a TAC worksheet point method similar to the method used for streets on the previous pages. It is based on similar types of factors including geometric, operational, environmental, and the crash rate.

Critical factors are:

- Traffic volume
- Nighttime crashes
- Crosswalks
- Raised medians

Full lighting of the intersection is automatically warranted if the intersection is signalized.

Full lighting is also warranted if the score of greater than 240 points in total is achieved when adding up all of the weighted ratings for each individual criterion.

Partial lighting is warranted if a total score of 151 to 239 points is achieved.

Delineation lighting is warranted for a score of 120 to 150 points.

No lighting is warranted for a total score less than 120 points.

Knowledge Check
Module 1, Slide 46

Select the correct answer:

If a municipality goes through the warranting process for a roadway, and the process determines that roadway lighting is warranted, hey are then legally required to install lighting on that roadway.

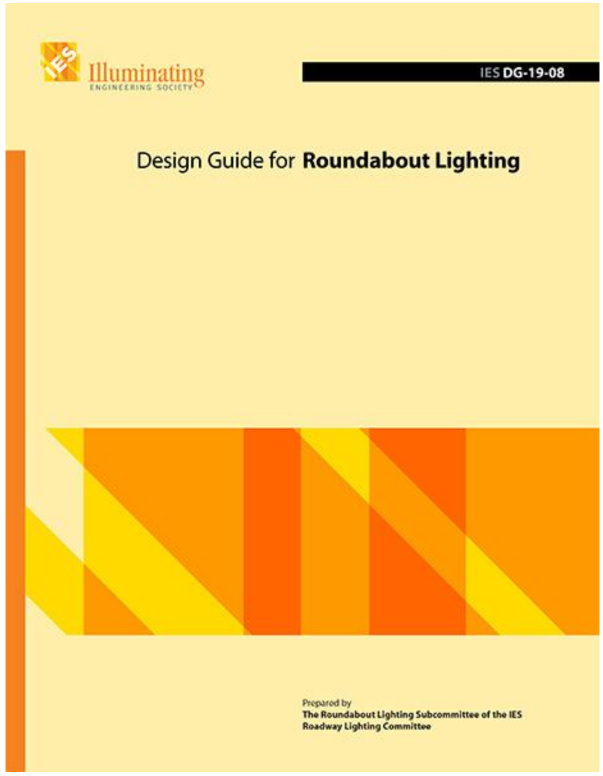
- ☐ a) True
- ☐ b) False

The correct answer is on the next page.

Knowledge Check Answer
Module 1, Slide 47

The correct answer is b) False. Warrants to not represent a requirement to provide lighting. They are a method for evaluating and prioritizing projects in terms of lighting. (*See Module 1, Slide 36.)*

Roadway Lighting Documents
Module 1, Slide 48

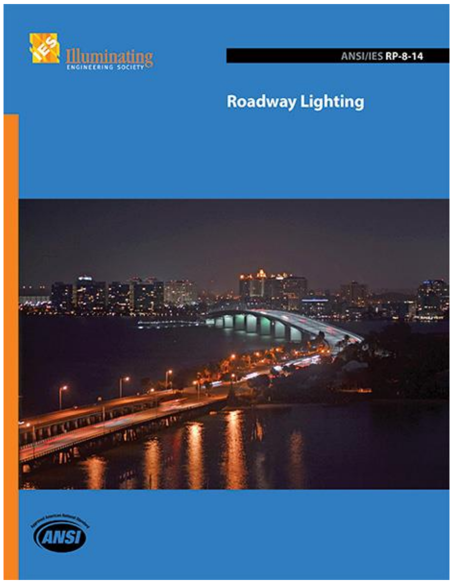


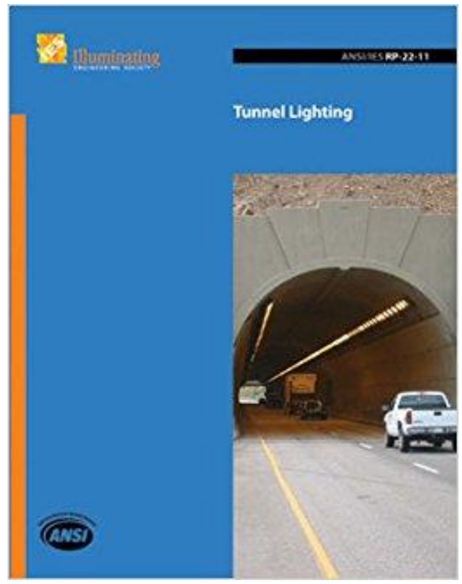
An example of an IES lighting guidance publication.

Once you've used one of the warranting methods to help you to determine if lighting may be needed for a particular roadway, street, or intersection, there are many guideline documents that you can consult to help you to develop a design for the lighting.

These documents will provide you with recommendations about the amount of light (either illuminance or luminance levels), the uniformity of the light distribution, and also provide you with recommendations on how to limit glare from light fixtures.

Roadway Lighting Documents (continued)
Module 1, Slide 49

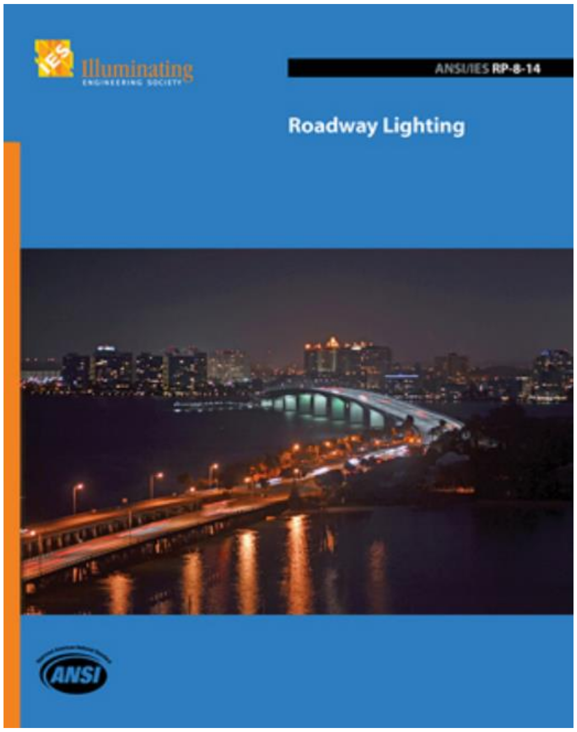




Some commonly used lighting guidelines include:

- **ANSI/IES-RP-8-14** - American National Standards Institute (ANSI) and Illuminating Engineering Society (IES) Recommended Practice (RP) for Roadway Lighting, published in 2014.
- **ANSI/IES-RP-22-11** - Recommended Practice for Tunnel Lighting, published in 2011.
- **IES-RP-19-01** - Recommended Practice for Roadway Sign Lighting, published in 2001.
- **IES-DG-19-08** - Design Guide (DG) for Roundabout Lighting, published in 2008.
- **AASHTO** - Roadway Lighting Design Guide, published in 2005.
- **IES/IDA MLO** - IES/International Dark Sky Association (IDA) Model Lighting Ordinance, published in 2011.

IES RP-8 Roadway Lighting
Module 1, Slide 50



IES Recommended Practice for Roadway Lighting is commonly referred to as "RP-8."

The IES recommended practice document for roadway lighting, provides lighting design criteria for streets/roadways based on luminance and glare ratio. Although the design criteria are based on luminance, illuminance is used for field verification of light levels. A conversion factor is provided to assist you to do this.

Lighting design criteria for intersections is based on illuminance.

The average light level that you select for a particular roadway or intersection will be based on the level of pedestrian conflict (how many pedestrians use the area at night) and the functional classification of the roadway or intersection.

IES RP-8 Roadway Lighting (continued)
Module 1, Slide 51

Pedestrians crossing a city street at night.

The lighting criteria included in IES RP-8 also include recommendations for uniformity (ratios of maximum to minimum light levels) as well as recommendations to limit glare.

An interesting addition to the document that was made when it was last updated in 2014, is that if pedestrian class changes over nighttime hours (for example, if fewer pedestrians are using the roadway area late at night), light level can change accordingly (typically be reduced). This allows for a practice called “adaptive lighting” which we will address in a later course module.

IES RP-8 Roadway Lighting (continued)
Module 1, Slide 52

The lighting along this roadway provides relatively uniform illumination well within the recommendations of IES RP-8.

IES recommendations for roadway lighting are given in luminance, which uses the measure candelas (cd) per square meter (m^2).

IES RP-8 average luminance recommendations:
- Roadways (high speed) [0.6 – 1.0 cd/m^2]
- Streets (low speed) [0.3 – 1.2 cd/m^2]

Horizontal luminance ratio: Maximum-to-minimum
- Roadways (high speed) [5.0 – 6.0:1]
- Streets (low speed) [5.0 – 10.0:1]

IES recommendations for intersection lighting are given in illuminance which uses the measure lumen per square meter or lux.

IES RP-8 illuminance recommendations for intersections:
- [8.0 – 34.0 lux]

Horizontal illuminance ratio (street intersections):
- Average-to-minimum [3.0 – 6.0:1]

Knowledge Check
Module 1, Slide 53

Select the correct answer:

In the IES Recommended Practice for Roadway Lighting, the lighting design criteria for intersections is based on:

- ☐ a) Illuminance
- ☐ b) Luminance

The correct answer is on the next page.

Knowledge Check Answer
Module 1, Slide 54

The correct answer is a) Illuminance. Unlike the recommendations for lighting straight sections of roadway, which are based on luminance, the IES recommendations for intersection lighting are based on illuminance. (*See Module 1, Slide 52.)*

International Roadway Lighting Guidelines
Module 1, Slide 55

International recommendations for lighting are similar to those in the U.S., but tend to more precisely define the various types of roadways.

The Commission Internationale de l´Eclairage (CIE), also known as the International Commission on Illumination publishes a guide - CIE No. 115, Lighting of Roads for Motor and Pedestrian Traffic.

The CIE defines three main lighting classes for roadways:
- M-motorized traffic
- P-pedestrian traffic
- C-vehicle/pedestrian conflicts

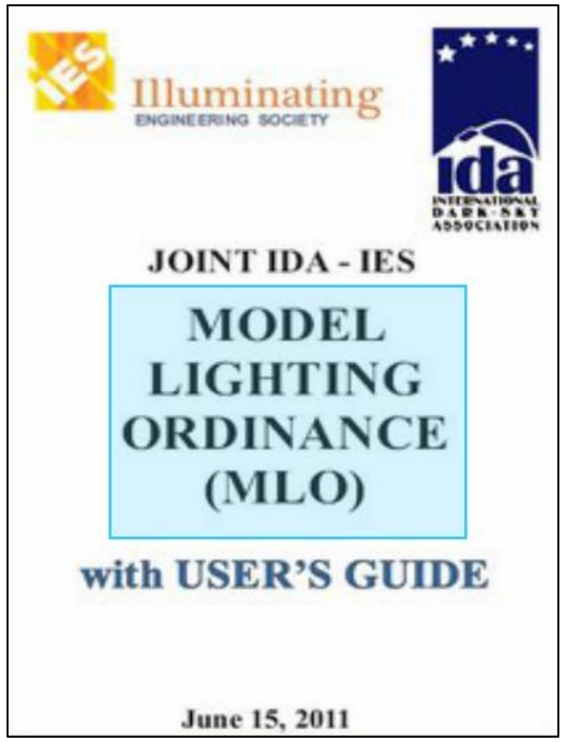
These classes are further refined into subclasses based on factors such as traffic speed and pedestrian conflict, similar to IES-RP-8.

Recommendations for M-class roadways (roadways with primarily motorized traffic and little or no pedestrians are given in luminance. These are:
- M1 (2 cd/m^2) through M6 (0.3 cd/m^2)

Recommendation for P and C class roadways are provided in illuminance.
- P Classes - P1 (15 lux) through P6 (2 lux)
- C Classes - C0 (50 lux) through C5 (7.5 lux)

If functional class changes at different times of night, light levels for a different class may be used during those times (this allows for “adaptive lighting” similar to IES RP-8).

Light Pollution and Light Trespass
Module 1, Slide 56



There has been growing interest in recent years in limiting the amount of light up into the sky, which causes “sky glow” a phenomenon that limits our view of the night sky. Coupled with this is an interest in limiting the amount of light that leaves the roadway area and trespasses onto neighboring properties.

There are two documents that provide recommendations on how to control unwanted light at night and therefore limit light pollution. These are:

IES-TM-11 - IES Technical Memorandum (TM) Light Trespass Research Results and Recommendations. This publication recommends the use of lighting “zones” to use less light in environmentally sensitive areas, for example. It also specifies lighting curfews to dim lighting down or to switch it off after certain hours of night when a roadway or street may be infrequently used.

IES/IDA MLO - Model Lighting Ordinance. This provides recommendations to communities on how they might structure requirements to limit unwanted light at night.

Conclusions
Module 1, Slide 57

This course module has provided information on:

- **The various benefits of roadway lighting.** Reviewing research results that help you better understand why we light roadways at night.
- **The connection between lighting and visibility.** How improvements in lighting can improve visibility and visual performance.
- **Important lighting terms and concepts.** These will help you to better understand discussions and design guidelines about roadway lighting.
- **Warrants for roadway lighting.** Understanding how to determine if lighting is needed on a roadway, intersection, or interchange.
- **Lighting guidelines and recommended practices.** This information assists you to know where to look for more information to assist you with roadway lighting design

Self-Assessment Quiz
Module 1, Pages 58 to 65

Please answer each question.

1. For which potential benefit of roadway lighting is there the least evidence?
   a. ☐ Nighttime crash reduction
   b. ☐ Crime reduction
   c. ☐ Improved visibility
   d. ☐ Increase sense of security
2. What is the standard measure of the amount of light?
   a. ☐ Lumen
   b. ☐ Wavelength
   c. ☐ Retina
   d. ☐ Contrast
3. Which situation would result in the highest visual contrast?
   a. ☐ Old markings on old pavement
   b. ☐ Old markings on new pavement
   c. ☐ New markings on new pavement
   d. ☐ New markings on old pavement
4. True or False? Luminance denotes the amount of light falling on a surface.
   a. ☐ True
   b. ☐ False
5. What illuminance is approximately equal to 30 footcandles?
   a. ☐ 0.3 lux
   b. ☐ 3 lux
   c. ☐ 30 lux
   d. ☐ 300 lux
6. Which factor is least likely to be important in deciding whether or not to install roadway lighting?
   a. ☐ Traffic volume
   b. ☐ Pedestrian volume
   c. ☐ Average temperature
   d. ☐ Night-to-day crash ratio
7. What is the minimum ADT (average daily traffic) at which freeways in or near cities should be illuminated with continuous freeway lighting, according to AASHTO's Roadway Lighting Design Guide?
   ______ vehicles/day

See the following page for the answer key to this self-assessment.

Self-Assessment Quiz Answer Key
Module 1, Slide 66

The correct answers for the self-assessment are provided below.

1. For which potential benefit of roadway lighting is there the least evidence?
   a. ☐ Nighttime crash reduction
   b. ☑ Crime reduction *(see Module 1, Slide 27)*
   c. ☐ Improved visibility
   d. ☐ Increase sense of security
2. What is the standard measure of the amount of light?
   a. ☑ Lumen *(see Module 1, Slide 8)*
   b. ☐ Wavelength
   c. ☐ Retina
   d. ☐ Contrast
3. Which situation would result in the highest visual contrast?
   a. ☐ Old markings on old pavement
   b. ☐ Old markings on new pavement
   c. ☑ New markings on new pavement *(see Module 1, Slide 13)*
   d. ☐ New markings on old pavement
4. True or False? Luminance denotes the amount of light falling on a surface.
   a. ☐ True
   b. ☑ False (*see Module 1, Slide 10*)
5. What illuminance is approximately equal to 30 footcandles?
   a. ☐ 0.3 lux
   b. ☐ 3 lux
   c. ☐ 30 lux
   d. ☑ 300 lux *(see Module 1, Slide 9)*
6. Which factor is least likely to be important in deciding whether or not to install roadway lighting?
   a. ☐ Traffic volume
   b. ☐ Pedestrian volume
   c. ☑ Average temperature *(see Module 1, Slide 30)*
   d. ☐ Night-to-day crash ratio
7. What is the minimum ADT (average daily traffic) at which freeways in or near cities should be illuminated with continuous freeway lighting, according to AASHTO's Roadway Lighting Design Guide?

   __30,000__ vehicles/day *(see Module 1, Slide 39)*

Extended Example Problem

Consider a major roadway with the following geometric, operational, environmental, and collision characteristics. According to the TAC warrants for collector, major and local streets (Module 1, Slide 44), is lighting warranted?

Geometric:

- Four lanes
- 3 m lane width
- 6 median openings per km (average)
- 65 driveways per km (on average)
- Smallest radius curve 250 m
- Largest vertical grade 2%
- 200 m sight distance
- Parking for loading only

Operational:

- 75% signalized intersections
- Most major intersections have left turn lane
- No median
- Posted speed limit 60 km/h
- Medium pedestrian activity

Environmental:

- 50% development adjacent to roadway
- Commercial area
- Development 20 m from roadway
- Moderate ambient lighting
- Raised curb median at 67% of intersections

Collision:

- Night-to-day collision ratio 1.4

See the following page for the answer to this extended example problem.

Extended Example Problem (Answer Key)

For the example roadway, the following items are entered into the warranting tables:

Geometric Factors	Rating Factor *R*					Weight *W*	Enter *R*	Score *R × W*
	1	2	3	4	5			
Number of Lanes	≤4	5	6	7	≥8	0.15	1	0.15
Lane Width (m)	>3.6	3.4 to 3.6	3.2 to 3.4	3.0 to 3.2	<3.0	0.35	4	1.4
Median Openings/km	<2.5 or 1-Way	2.5 to 5.0	5.0 to 7.2	7.2 to 9.0	>9.0 or No Median	1.40	3	4.2
Driveways and Entrances/km	<20	20 to 40	40 to 60	60 to 80	>80	1.40	4	5.6
Horizontal Curve Radius (m)	>600	450 to 600	225 to 450	175 to 225	<175	5.90	3	17.7
Vertical Grades (%)	<3	3 to 4	4 to 5	5 to 7	>7	0.35	1	0.35
Sight Distance (m)	>210	150 to 210	90 to 150	60 to 90	<60	0.15	2	0.30
Parking	Prohibited	Loading	Off Peak	One Side	Both Sides	0.10	2	0.20
Subtotal Geometric Factors (*G*):								29.9

Operational Factors	Rating Factor *R*					Weight *W*	Enter *R*	Score *R × W*
	1	2	3	4	5			
Signalized Intersections (%)	80 to 100	70 to 80	60 to 70	50 to 60	0 to 50	0.15	2	0.30
Left Turn Lane	All Major Intersections or 1-Way	Substantial Number of Major Intersections	Most Major Intersections	Half of Major Intersections	Infrequent Number or Two-Way Turn Lane*	0.70	3	2.1
Median Width (m)	>10	6 to 10	3 to 6	1.2 to 3	0 to 1.2	0.35	5	1.75
Operating or Posted Speed Limit (km/h)	≤40	50	60	70	≥80	0.60	3	1.8
Pedestrian Activity Level			Low	Medium	High	3.15	4	12.6
Subtotal Operational Factors (*O*):								18.55

*If this condition is met, lighting is warranted.

Extended Example Answer Key (continued)

Environmental Factors	Rating Factor *R*					Weight *W*	Enter *R*	Score *R* × *W*
	1	2	3	4	5			
Percentage of Development Adjacent to Road (%)	nil	nil to 30	30 to 60	60 to 90	>90	0.15	3	0.45
Area Classification	Rural	Industrial	Residential	Commercial	Downtown	0.15	4	0.60
Distance from Development to Roadway (m)	>60	45 to 60	30 to 45	15 to 30	<15	0.15	4	0.60
Ambient (Off Roadway) Lighting	Nil	Sparse	Moderate	Distracting	Intense	1.38	3	4.14
Raised Curb Median	None	Continuous	At All Intersections (100%)	At Most Intersections (51% to 99%)	At Few Intersections (≤50%)	0.35	4	1.4
Collision Factors							**Subtotal Environmental Factors (*E*):**	7.19
Night-to-Day Collision Ratio	<1.0	1.0 to 1.2	1.2 to 1.5	1.5 to 2.0	>2.0*	5.55	3	16.65
							Collision Factors (*C*):	16.65

*If this condition is met, lighting is warranted.

In the example above, G + O + E + C = 29.9 + 18.55 + 7.19 + 16.65 = **72.29**. This is greater than 60, so lighting is warranted for this roadway.

Links to Other Resources
Module 1, Slide 67

Illuminating Engineering Society (IES) Lighting Guidelines:
https://www.ies.org/store/

AASHTO Roadway Lighting Design Guide:
https://bookstore.transportation.org/item_details.aspx?ID=1412

FHWA Lighting Handbook:
https://safety.fhwa.dot.gov/roadway_dept/night_visib/lighting_handbook/

IES/IDA Model Lighting Ordinance:
http://darksky.org/our-work/public-policy/mlo/

TAC Guide for the Design of Roadway Lighting:
http://www.tac-atc.ca/en/publications/ptm-lighting06

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