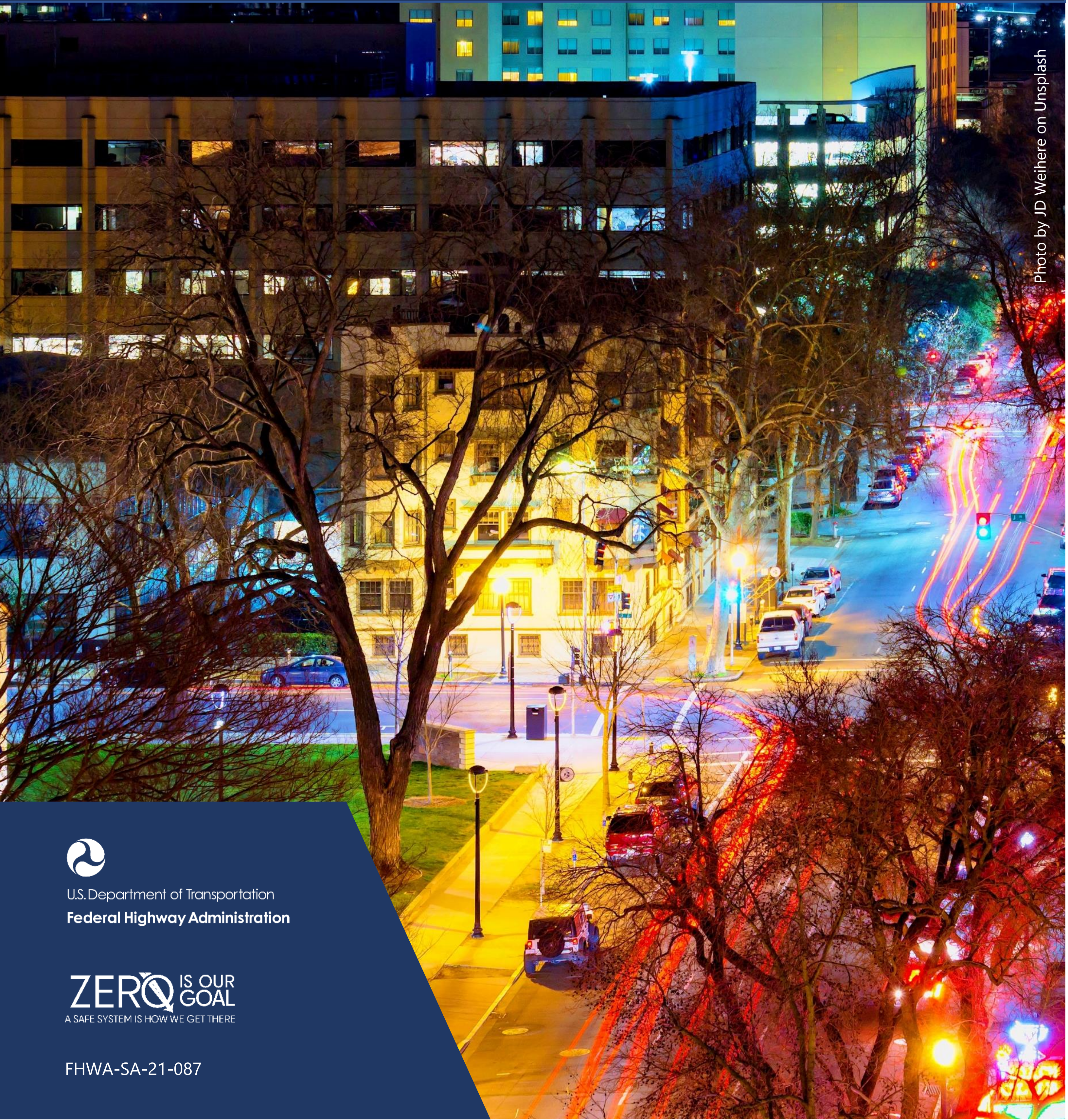
PEDESTRIAN LIGHTING PRIMER

APRIL 2022



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U.S. Department of Transportation
Federal Highway Administration

ZERO IS OUR GOAL
A SAFE SYSTEM IS HOW WE GET THERE

FHWA-SA-21-087

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Lighting of pedestrian facilities plays a key role in increasing the safety performance of the road network for all users. Effective pedestrian lighting installations are a means of addressing the vulnerability of pedestrians during dark conditions and improving safety and security of all road users spanning different ages and abilities, including wheelchair and other mobility device users. Lighting not only makes it easier for drivers to see pedestrians, but also improves pedestrians' abilities to see their surroundings and detect trip hazards. It increases pedestrians' perceived levels of safety and security associated with the use of pedestrian facilities. Lighting may also increase pedestrians' confidence in performing certain tasks, such as assessing and selecting appropriate gaps at uncontrolled crossings and monitoring vehicles approaching and making different movements through signalized intersections. The Federal Highway Administration (FHWA) published this primer to be a resource for transportation practitioners interested in the safety and security benefits of pedestrian lighting as well as lighting design considerations at locations with existing or future pedestrian activity.</td></tr>
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1. Introduction

Lighting of pedestrian facilities plays a key role in increasing the safety performance of the road network for all users. Effective pedestrian lighting installations are a means of addressing the vulnerability of pedestrians during dark conditions and improving the safety and security of all road users spanning different ages and abilities, including wheelchair and other mobility device users. Lighting not only makes it easier for drivers to see pedestrians, but also improves pedestrians' abilities to see their surroundings and detect trip hazards. It increases pedestrians' perceived levels of safety and security associated with the use of pedestrian facilities. Lighting may also increase pedestrians' confidence in performing certain tasks, such as assessing and selecting appropriate gaps at uncontrolled crossings and monitoring vehicles approaching and making different movements through signalized intersections. The Federal Highway Administration (FHWA) research report Street Lighting for Pedestrian Safety *documents these benefits of lighting (Terry et al., 2020). FHWA published this primer to be a resource for transportation practitioners interested in the safety and security benefits of pedestrian lighting as well as lighting design considerations at locations with existing or future pedestrian activity.*

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The primer has five sections:

Section 1 provides background information that illustrates the need and motivation of the primer, along with the primer purpose and scope.

Section 2 details the lighting design process, including assessments of potential lighting needs, design criteria, equipment selection, control strategy determination, and design and verification.

Section 3 presents a design example for a given set of conditions, including pedestrian volume, area type, and context.

Section 4 contains a discussion of the conclusions and findings of this document.

Section 5 is a list of the reports, journal articles, and other resources referenced herein.

1.1. Purpose and Scope of Primer

The purpose of this primer is to be a resource for transportation practitioners interested in lighting design considerations for locations with pedestrian activity. This primer is a user-friendly companion document to the FHWA research report *Street Lighting for Pedestrian Safety* (Terry et al., 2020). More specifically, the primer highlights how the results from the FHWA research report *Street Lighting for Pedestrian Safety* can complement commonly used lighting design guides such as those listed in Section 1.3. The primer also provides basic information that practitioners can consider when providing lighting to improve pedestrian safety. The primer is written in a manner that assumes the reader may have only basic knowledge of lighting terminology. However, it is important that a qualified lighting designer perform the actual steps of lighting design and finalize any design plans.

The objective of the research documented in the FHWA research report *Street Lighting for Pedestrian Safety* (Terry et al., 2020) was to provide lighting recommendations for pedestrian safety, including any specific needs for and examples of lighting associated with Safe Routes to School (SRTS) for children. In developing the lighting recommendations, the companion FHWA research report considered the ability of pedestrians to see and detect hazards on walkways and crosswalks, the visibility of pedestrians to motorists, and impacts of lighting on pedestrian decisions related to whether to cross a roadway.

1.2. Pedestrian Safety and Security

Pedestrian traffic fatalities in the U.S. have been steadily increasing over the past 10 years, both in frequency and as a proportion of total traffic fatalities. Figure 1 presents annual pedestrian fatality numbers from 2009 to 2019 and clearly displays this trend. During this same period, the estimated number of pedestrians injured in crashes fluctuated from year-to-year as shown by the bars in figure 2, but with the five-year rolling average trendline (the solid line in figure 2) showing a steady increase from approximately 64,000 in 2009 to approximately 75,000 in 2019.

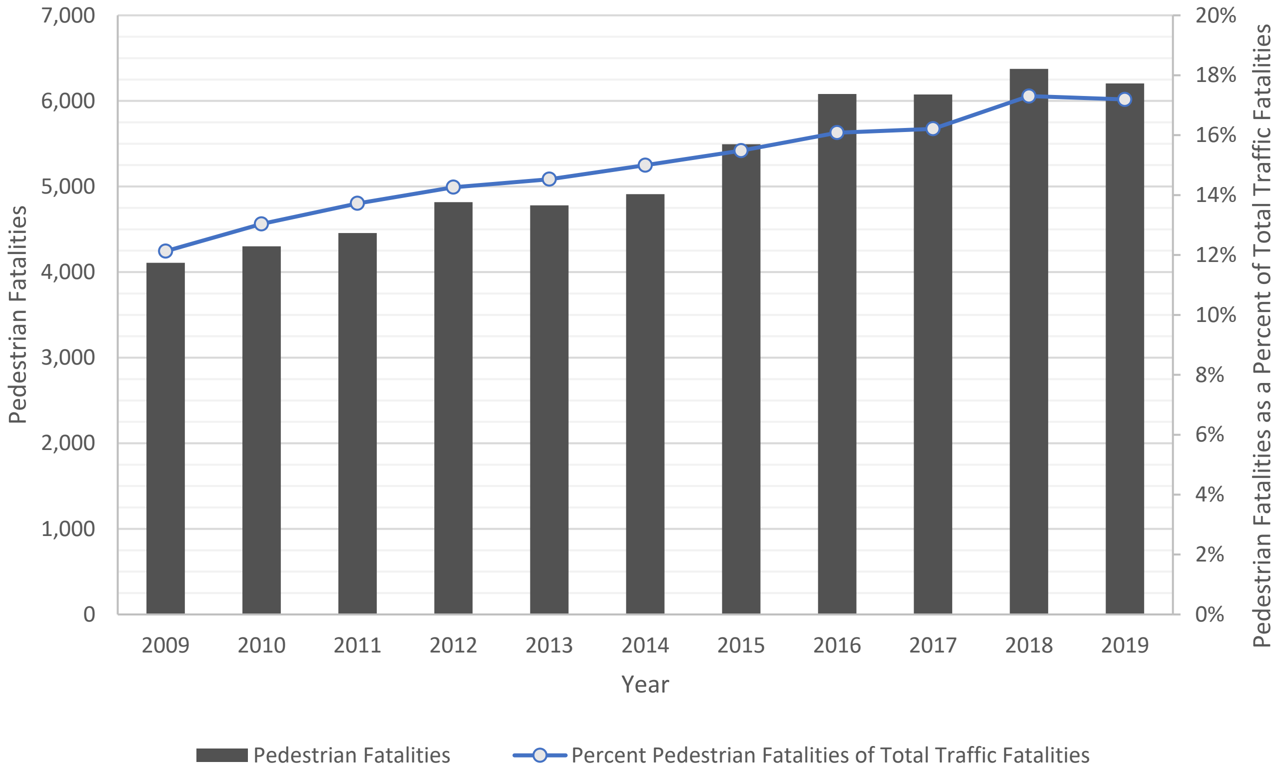


Figure 1. Graphic. Pedestrian fatalities per year and pedestrian fatalities per year as a percent of total traffic fatalities. Source: NHTSA.

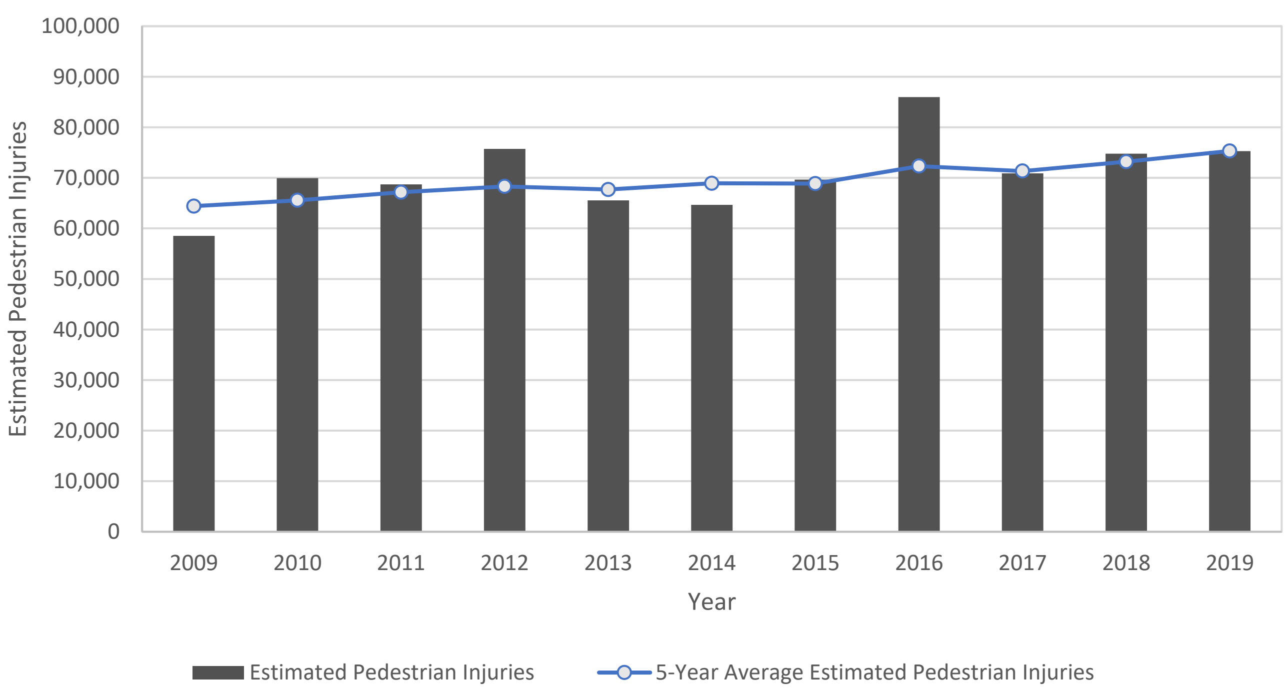


Figure 2. Graphic. Estimated pedestrian injuries per year and five-year average estimated pedestrian injuries per year. Source: NHTSA

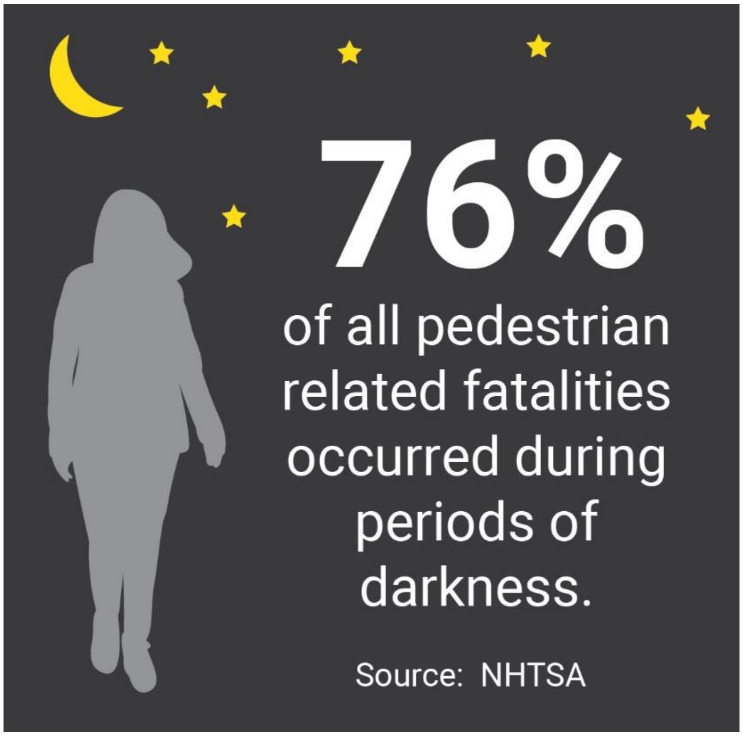


Figure 3. Graphic. Infographic for nighttime pedestrian fatalities. Source: FHWA.

The National Highway Traffic Safety Administration (NHTSA) reported that **76 percent of pedestrian fatalities in 2019 occurred in dark conditions** (including "Dark – Not Lighted," "Dark – Lighted," and "Dark – Unknown Lighting") as shown in figure 3 (NHTSA, 2021). This percentage increased from 69 percent of pedestrian fatalities occurring in dark conditions in 2009. Figure 4 **shows that minority communities experience a disproportionate burden of pedestrian fatalities in dark conditions. These statistics are compelling but become even more so when considering that only about 25 percent of all traffic volume occurs after dark** (Griffith, 1994; CIE, 2010). **This means that the majority of pedestrian traffic fatalities occur during the time of day when fewer vehicles are on the road**. Figure 5 shows that the frequency of pedestrian fatalities during dark conditions has experienced an increasing trend over the past 10 years.

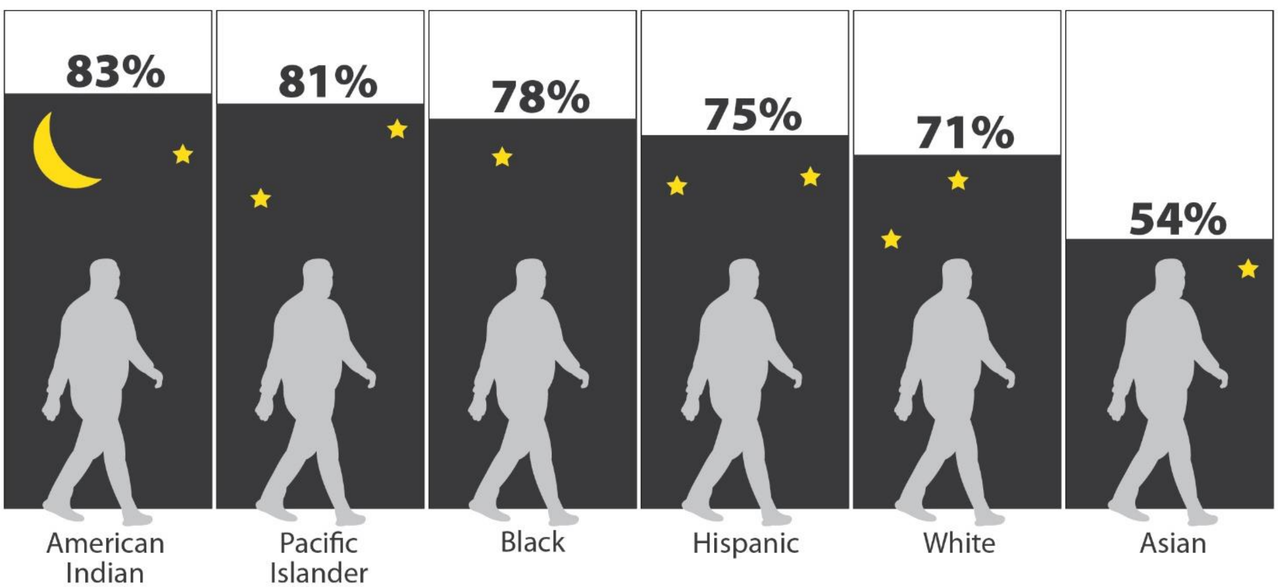


Figure 4. Graphic. Percentage of pedestrian fatalities in dark conditions (i.e., "Dark – Not Lighted," "Dark – Lighted," or "Dark – Unknown Lighting") by race (2008–2018). Source: NHTSA.

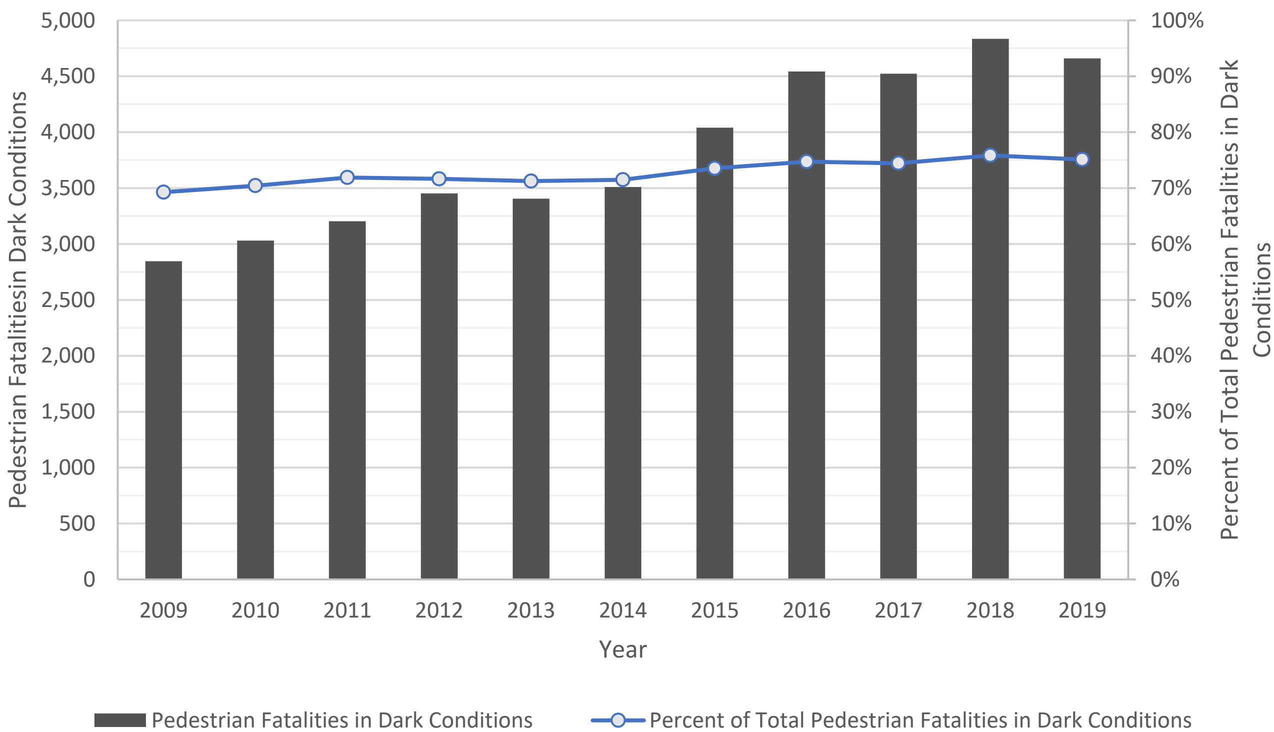


Figure 5. Graphic. Dark condition (i.e., "Dark – Not Lighted," "Dark – Lighted," or "Dark – Unknown Lighting") pedestrian fatalities per year and dark condition pedestrian fatalities per year as a percent of total pedestrian fatalities. Source: NHTSA.

Pedestrians are the most vulnerable road user population at night and are **between three and almost seven times more vulnerable in the dark than during daylight hours** (Sullivan & Flannigan, 1999). Given these statistics, **pedestrians have the potential to gain significant safety performance benefits from new or improved lighting.**

In addition to increasing traffic crash risk, dark conditions can also have negative effects on pedestrian security. People may avoid walking at night as a precaution against potential crime (Painter, 1996). Darkness is one of the primary factors that influences potential personal risk and heightened fear, as darkness reduces visibility and recognition and creates additional blind spots. Women, in particular, report experiencing fear, real or perceived, at night that significantly constrains their travel behavior. Studies have documented that women suffer disproportionately high rates of victimization, especially from gender violence and theft, at night (Smith, 2008). Good lighting plays a role in reducing women's fear of walking or accessing transit at night (Loukaitou-Sideris, 2010). Lighting for pedestrian security is particularly important at locations where the walking space is restricted, ambient light may be blocked, and pedestrian traffic is more separated from the surrounding context. New or improved lighting can increase security and encourage pedestrian activity at night, specifically at and near transit stops. This can improve the safety and security of transit riders while boarding, alighting from, or waiting for transit. The American Public Transportation Association (APTA) developed the document *Security Lighting for Transit Passenger Facilities* as a resource for these situations (APTA, 2009).

The **Crash Modification Factors (CMF) Clearinghouse** contains several CMFs that quantify **reductions in the number of vehicle/pedestrian crashes** due to the addition of lighting: CMF IDs 435, 436, 440, 441, and 2379.

1.3. Benefits of Lighting for Pedestrian Safety and Security

Several studies of the effects of lighting on road safety concluded that proper lighting has the potential to reduce the number of nighttime pedestrian fatalities and injuries (Elvik & Vaa, 2004; Ye et al., 2008). These studies have resulted in CMFs that quantify reductions in the number of vehicle/pedestrian crashes due to lighting ranging from 0.58 (42 percent reduction) to 0.19 (81 percent reduction), depending on the crash severity of interest. These include CMF IDs 435, 436, 440, 441, and 2379 in the CMF Clearinghouse.

Zhou & Hsu (2012) collected illuminance data over 3 years along a 32-mile U.S. 19 corridor in Florida. The corridor had the highest pedestrian crash frequency in the county. More than 82 percent of the pedestrian crashes along the corridor occurred on segments with some type of lighting already present. The researchers paired the illuminance data with nighttime pedestrian crash data and found that road segments with lower levels of lighting were associated with a higher frequency of nighttime pedestrian crashes than segments with higher light levels. Nearly half of all the crashes occurred on segments where the illuminance was less than 10 lumens per square meter (lux). This study's findings highlighted that pedestrian safety depends not only on lighting presence, but also on the quality of lighting that is provided.

One pedestrian population that may especially benefit from improved lighting is school-age children. These children may travel to or from school, often by walking or biking, during the early morning or evening hours. Even if school hours are limited to the daytime, there are often before or after school activities that may cause students to travel earlier or later. Depending on the time of year, these trips could occur during twilight or total darkness. Furthermore, children are particularly vulnerable to vehicular traffic. They are often smaller in stature, and thus more difficult for motorists to see. Children are also not as experienced at judging the direction of sounds, estimating the speed and distance of oncoming vehicles, or anticipating other road users' behavior. Jonah & Engel (1983) found that the likelihood of child pedestrians being injured more than doubles during dark conditions. The Safe Routes to School (SRTS) Online Guide identifies pedestrian-scale street lighting as an important measure for improving safety and security for children walking to school (Safe Routes to School, 2015). This is especially true at intersections and other crossings.

In addition to improving pedestrian safety, lighting can also improve the personal security of pedestrians. Several studies show that new or improved lighting increases pedestrians' perception of security. Peña-García, Hurtado, & Aguilar-Luzón (2015) surveyed 275 pedestrians in Granada, Spain and found that higher illuminance levels tend to increase perceptions of security. Several other studies have shown lighting to have a substantial effect on perception of security (Loewen, Steel, & Suedfeld, 1993; Nasar, Fisher, & Grannis, 1993; Nasar & Jones, 1997). In addition to the presence of lighting, the type, quality, and distribution of lighting also affect perceived security (Boyce et al., 2000; Haans & de Kort, 2012; Markvica, Richter, & Lenz, 2019; Portnov et al., 2020). Painter (1996) studied both the occurrence of crime and pedestrian fear of crime on three streets in the United Kingdom that were identified as being "poorly lit, fear inducing, and potentially hazardous." After lighting improvements were implemented, incidents of crime and disorder decreased significantly at two of the three sites (the third had low occurrence of crime in both the before and after cases). The results also suggested that the improved lighting had a positive affect outside the immediate study area, reducing crime on several adjacent unlit streets. It also led to a marked increase in perception of personal security, with over 90 percent of respondents reporting their fear of crime had decreased, and significant increases in pedestrian activity. Chalfin et al. conducted a randomized experiment to study the effectiveness of street lighting in reducing crime. The study took place in New York City using temporary lighting installations and found that the addition of street lighting reduced outdoor nighttime crime by 36 percent (Chalfin et al., 2019) Painter & Farrington (1997) performed a survey-based experiment in the United Kingdom that showed crime prevalence decreased by 23 percent after improved lighting was installed, compared to a decrease of 3 percent at the control location. Crime incidence (average number of victimizations per household) decreased by 41 percent, compared to no change at the control location.

1.4. Existing Guidance and Gaps

There are several documents that provide general information on lighting warrants and design criteria. These include:

- American Association of State Highway and Transportation Officials (AASHTO) *Roadway Lighting Design Guide*, 7th Edition (AASHTO, 2018).
- Transportation Association of Canada (TAC) *Guide for the Design of Roadway Lighting* (TAC, 2006).
- National Cooperative Highway Research Program (NCHRP) Report 152 *Warrants for Highway Lighting* (also known as the FHWA Method) (Walton & Rowan, 1974).
- Illuminating Engineering Society (IES) RP-8-18 *Recommended Practice for Design and Maintenance of Roadway and Parking Facility Lighting* (IES, 2018).
- FHWA *Informational Report on Lighting Design for Midblock Crosswalks* (Gibbons et al., 2008).

Subsequent sections of this primer will cover selected content from these non-binding reference documents in more detail, focusing on the material within each of them that applies to lighting for pedestrian safety. In general, a majority of existing lighting references emphasize motorist needs.

A companion FHWA research report to this primer, *Street Lighting for Pedestrian Safety*, identified several gaps in existing lighting resources (Terry et al., 2020). These include:

- Understanding the visibility of children by motorists in low-light conditions.
- Understanding differences in light level requirements that may exist between adult and child pedestrians to maintain visual performance.
- Identifying recommended light levels resulting in optimal visibility for both pedestrians and drivers based on:
    - Empirical research to support the specification of light levels for both pedestrians and drivers.
    - Research and information on recommended lighting for sidewalks, roadway segments without crosswalks, and separated pedestrian facilities (to supplement current recommendations for crosswalk lighting).
- Establishing a universal metric for designing pedestrian lighting (e.g., vertical illuminance, semi-cylindrical illuminance, etc.).
- Understanding the effects of different lighting sources and luminaire types on pedestrian visibility.

2. Lighting Design Process

Lighting system design should consider a variety of factors, including safety and comfort for all road users, impacts to the environment, and energy consumption. Lighting design generally involves the steps in figure 6, each of which are discussed in this section of the primer.

Figure 6. Graphic. The major steps in lighting design. Source: FHWA.

The flowchart in figure 7 illustrates how the general lighting design process flows through each of these steps and depicts how background information, policies, and design reference materials inform the process, beginning with lighting analysis and ultimately resulting in a completed design. The final, iterative steps of the process include selecting pole locations, with initial arrangements often being revised multiple times to meet primary and secondary design criteria. These steps as shown in figure 7 are recommended by IES and AASHTO but are not required under FHWA regulations. The flowchart is included to illustrate a typical lighting design process.

For each step of the lighting design process, the following sections provide: 1) an overview of selected terminology and general lighting design considerations with references to other documents for additional information and 2) specific lighting design considerations for pedestrians.

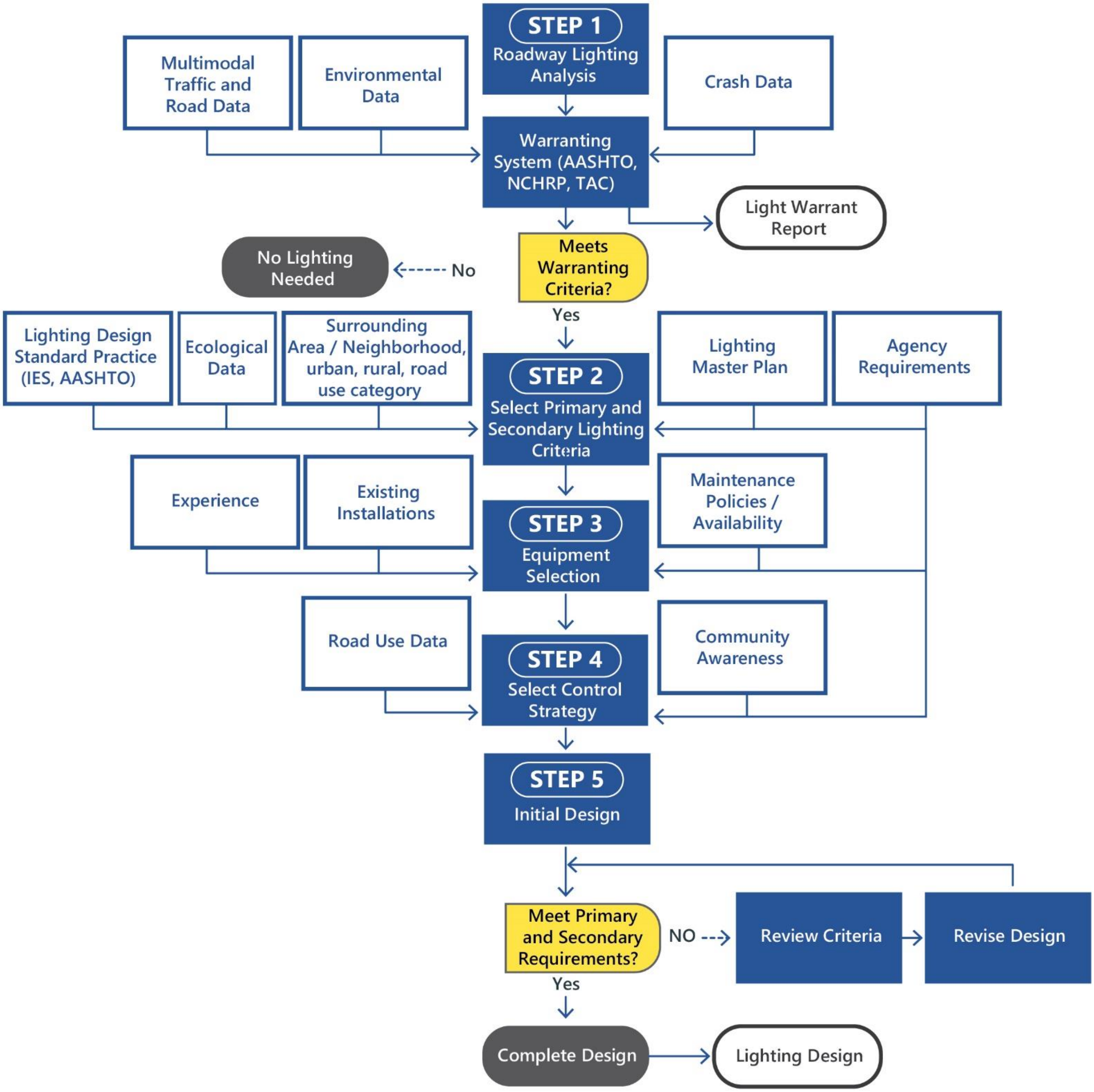


Figure 7. Graphic. Typical lighting design process flowchart (not required under FHWA regulations). Source: FHWA.

2.1. Assessment of Potential Lighting Needs

2.1.1. General Principles of Lighting Needs Assessment

A lighting warrant is a condition or set of conditions that are evaluated for a study area to inform the installation of lighting. Lighting warrants commonly include assessments of the amount of traffic (motorized and nonmotorized), roadway geometry, the surrounding environment, and crash statistics. Lighting practitioners in the United States generally reference three sources of lighting warrant procedures, though FHWA regulations do not require the use of these sources or the procedures they contain:

- AASHTO *Roadway Lighting Design Guide, 7th Edition* (AASHTO, 2018).
- TAC *Guide for the Design of Roadway Lighting* (TAC, 2006).
- NCHRP Report 152 *Warrants for Highway Lighting* (Walton & Rowan, 1974).

Each resource provides a framework for evaluating different warrant criteria and considering the benefits and cost effectiveness of installing lighting. The resources focus primarily on the installation of lighting to improve the general visibility and conditions for motorists. Resources for warranting lighting installations for pedestrians are more limited.

2.1.2. Pedestrian Considerations for Lighting Needs Assessment

The practice of evaluating the need for pedestrian lighting varies widely among different regions, State Departments of Transportation (DOTs), and local agencies, and decisions are often made on a case-by-case basis. The information provided in this primer represents a sample of factors that can be part of a needs assessment for pedestrian lighting. It is based on a recent literature review and targeted scan tour conducted by the FHWA Safe Transportation for Every Pedestrian (STEP) program.

As part of its STEP program, FHWA collaborated with State and local stakeholders to increase implementation of countermeasures that reduce pedestrian fatalities, particularly at uncontrolled crossing locations. In February 2021, participants from the FHWA STEP team and six State DOTs gathered virtually for an FHWA STEP Pedestrian Lighting Scan Tour to discuss approaches to site selection and prioritization for potential lighting improvements.

A key outcome of this scan tour involved FHWA documenting noteworthy State agency practices related to lighting for pedestrian safety. The factors most often used by the State DOTs in attendance to determine warranting conditions for pedestrian lighting include pedestrian crash history, especially during hours of darkness, pedestrian volumes, and the perceived level of risk and vulnerability of pedestrians (see table 1).

FHWA grouped the factors based on their prevalence in the reviewed literature and sampled agency policies and practices. While the factor groupings in table 1 are in part listed based on input from the participating States for the Scan Tour and are not always research based, lighting designers can consider how to incorporate these factors into their own local and regional noteworthy practices and to inform their decision-making process.

State and local agencies responsible for lighting decisions, or other governing bodies (e.g., city councils) may grant exemptions from providing pedestrian lighting when warranting criteria are met due to historical or environmental reasons. In locations without pedestrian lighting, other measures to enhance user visibility of roadway edges, pedestrian crossings, and the roadside can guide drivers and pedestrians navigating darker sections of roadway and increase driver awareness of pedestrian presence. Examples include high visibility markings, parking restrictions, and signing (FHWA, 2017; FHWA, 2018).

Additionally, agencies can equitably engage with underserved communities to determine where and how new and improved lighting can most benefit the community by considering their priorities, including eliminating crash disparities, connecting to essential neighborhood services, improving active transportation routes, and promoting personal safety. In 2019, Portland Bureau of Transportation (PBOT) conducted a citywide "Walking Priorities Survey" to understand the barriers Portlanders face while walking. When evaluating the demographics of survey respondents, it became clear that Black Portlanders were underrepresented. So, PBOT created a "Walking While Black" focus group to better understand if Black Portlanders experience unique barriers or identify unique priorities to improve walking (PBOT, 2019). As shown in figure 8, the focus group revealed that Black Portlanders identified poor street lighting as the biggest barrier to walking, compared to the citywide population which rated it much lower. As a result, Portland introduced new lighting-level guidelines to increase lighting on public streets.

WHAT MAKES WALKING DIFFICULT IN PORTLAND?	BLACK PARTICIPANTS	CITYWIDE PARTICIPANTS
Poor Lighting	5.00	3.62
Sidewalks/walking paths missing on BUSY streets	4.94	4.66
People driving too fast on BUSY streets	4.82	4.29
Not enough safe places to cross BUSY streets	4.78	4.46
People driving too fast on RESIDENTIAL streets	4.74	4.44
Sidewalks/paths missing on RESIDENTIAL streets	4.71	4.29
Drivers not stopping for pedestrians crossing the street	4.47	4.29
Buckled/cracked sidewalks, or other tripping hazards	4.47	3.46
Missing curb ramps at Intersections	4.00	3.22
Not enough time to cross the streets	3.91	3.08

SURVEY SCALE FROM 1 (NOT IMPORTANT) TO 6 (REALLY IMPORTANT)

Figure 8. Focus group results for places that are most important to improve for walking in Portland. Source: PBOT.

Table 1. Factors identified by a STEP Pedestrian Lighting Scan Tour for assessing pedestrian lighting needs. Source: FHWA.

Group 1 Most common Factors	Group 2 Less Common Factors	Group 3 Other Factors
Average daily traffic (ADT) volumes	Available sight distance	Ambient lighting levels
Functional classification	Benefit-cost analysis	Frequency of inclement weather
Nearby development, land use, or density	Channelization devices (curb, guardrail, etc.)	Presence of parking
Night-to-day crash ratio*	Intersection layout complexity	Retroreflective pavement markings (reduced need for lighting)
Night or pedestrian crash history	Presence of multiple turn lanes	Anticipated crossing locations for children (e.g., schools , parks, recreation centers)
Ped/bike presence and crossing maneuvers (any – with or without marked crossings)	Speed limit (often 35+ or 45+ mph)	Speeding history (10+ mph over posted)
Ped/bike volume during hours of darkness (often 100+/hr)	Vertical and horizontal curvature	Turning movement volumes
-	-	Wide or depressed medians

Note: * Night-to-day crash ratio = number of crashes at night / number of crashes during day.

- = not applicable.

2.2. Selection of Design Criteria

Once a need for lighting in the study area is established, design criteria are then identified. The selected criteria for general roadway lighting applications typically make up two categories: primary criteria and secondary criteria.

- Primary criteria are the desired lighting levels in the project area that the lighting system is designed to provide. Lighting levels are often defined using measures of luminance or illuminance.
- Secondary criteria guide the characteristics of a lighting system, including aesthetics, comfort of the light source, and the ability to limit excess light output.

In addition to these factors, there are additional design criteria to consider for pedestrian lighting applications, discussed in section 2.2.3.

2.2.1. Primary Design Criteria

Design criteria and recommended practices are guided by basic measures of lighting levels such as average and average-to-minimum ratios. IES *RP-8-18,* a recommended practice for the design and maintenance of roadway lighting, identifies criteria for average luminance and uniformity ratios for various road classifications (IES, 2018). The AASHTO *Roadway Lighting Design Guide* provides recommended lighting levels using illuminance criteria rather than luminance (AASHTO, 2018). FHWA regulations do not require the use of these sources or the procedures they contain. The next two sections provide additional background on illuminance and luminance.

Illuminance

Illuminance is a measure of how much light is falling on a surface per unit area. Illuminance is measured in International System (SI) units of lux (lx) or non-SI units of foot-candles (fc) common to the US, where one foot-candle is equal to 10.764 lux. There are three methods of measuring illuminance when considering lighting designs: horizontal, vertical, and semi-cylindrical.

Horizontal illuminance is measured on a road surface in a horizontal orientation (see figure 9), defining the amount of light falling on a horizontal plane. Increasing horizontal illuminance at night with lighting improves the accuracy and speed at which information can be ascertained by the user from the roadway environment (Boyce, 1973; Eloholma et al., 2006; Rea, 2000; Terry et al., 2016). Previous studies have indicated that nighttime crashes at intersections can be mitigated by an increase in the horizontal illuminance level (Bhagavathula et al., 2015; Minoshima et al., 2006; Oya, Ando, & Kanoshima, 2002).

Vertical illuminance defines the amount of lighting falling on a vertical plane (see figure 9). For lighting design, measurements of vertical illuminance are typically recorded at the eye level of observers oriented to their path of travel—whether drivers or pedestrians. Vertical illuminance helps road users see objects, but also influences the amount of glare experienced by those users. The vertical-to-horizontal illuminance ratio is a measure of potential glare, with higher ratios representing more glare. Generally, a vertical illuminance measurement height of 1.5 m from the ground represents the eye height of a standing pedestrian.

Semi-cylindrical illuminance is a measure that considers the light falling on a semi-cylinder rather than on a flat surface by measuring the light falling on a surface from a wider angle than a vertical illuminance measurement (see figure 9). This metric may more accurately represent the ability of a driver to see a pedestrian in some scenarios since it helps account for the three-dimensional nature of pedestrians. It may also be an effective metric for pedestrian lighting requirements when considering pedestrian-to-pedestrian interactions on a pedestrian facility given that facial recognition can be important for a pedestrian's perception of safety.

Luminance

Luminance is the amount of light emitted from a surface in a specific direction per unit area of the surface. Luminance is measured in either SI units of candela per square meter (cd/m^2) or non-SI units of footlambert (fL), where one fL is equal to 3.426 cd/m^2. In terms of visual perception, an observer perceives luminance. It is an approximate description of how "bright" an object appears when viewed from a given direction. Research has shown that increasing the luminance of the roadway surface makes objects on the roadway easier to detect (Economopoulos, 1978). At night, drivers can detect objects sooner as the average luminance of the roadway increases (Cuvalci & Ertas, 2000; Gibbons et al., 2015; He et al., 1997; Lewis, 1999). A luminance measure describes perceived brightness of an object when viewed from a given direction.

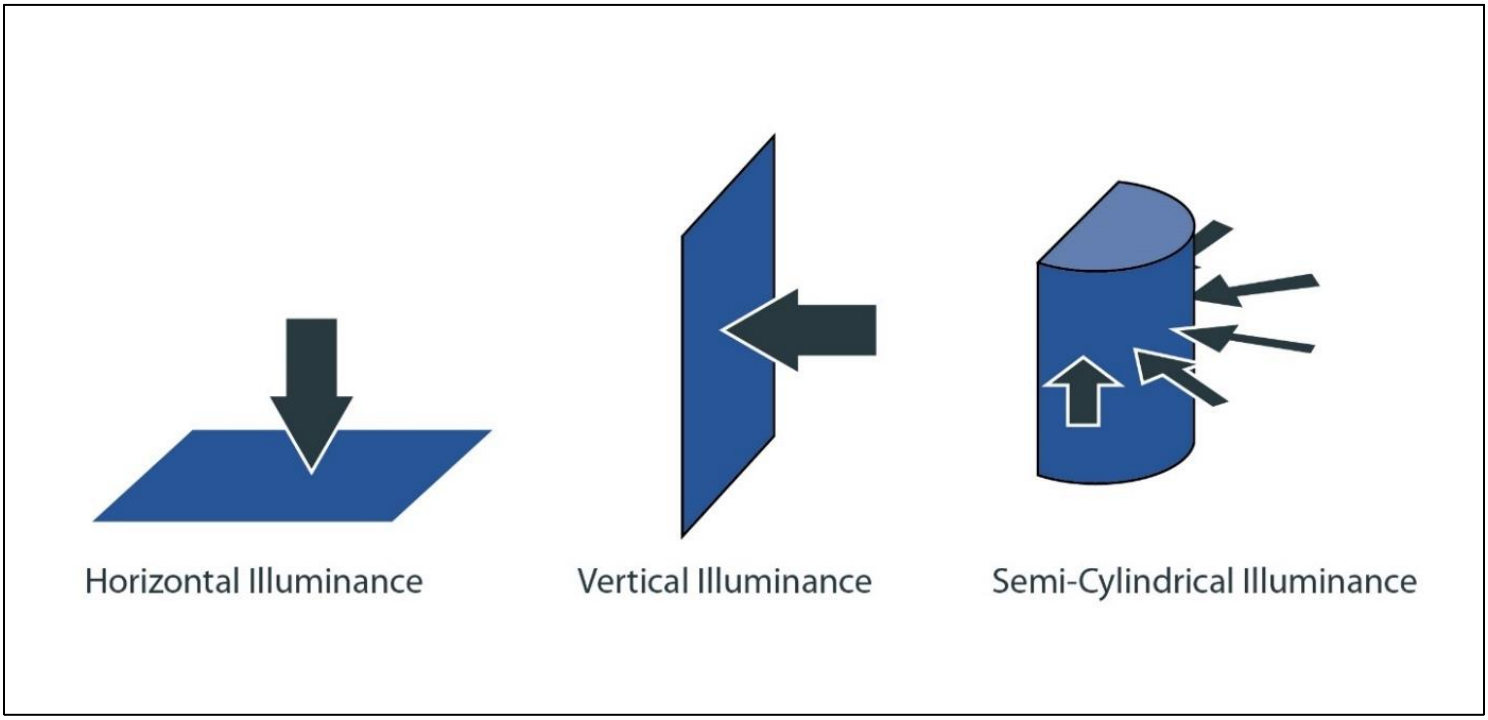
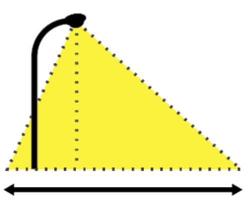


Figure 9. Graphic. Methods of calculating illuminance. Source: FHWA.

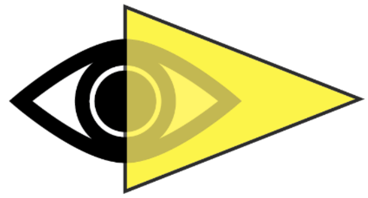
2.2.2. Secondary Design Criteria

Secondary design criteria are selected to guide characteristics, selection, and placement of the light sources. Local agencies or municipalities often provide policies or master plans that influence the selection of secondary design criteria using the following metrics.

Correlated color temperature (CCT) of the light source - A measure of the apparent color output of a light source, measured in degrees Kelvin (K) (IES, 2018). Luminaires manufactured for use in roadway and pedestrian applications are tested for color temperature. CCT represents the relative warmth of the emitted light. Lower values (e.g., 2700K) indicate a warm, yellow tone of light; higher values (e.g., 5000K or more) indicate a cool, blue tone of light; a neutral white is around 4000K.



Surround ratio – A ratio of the illuminance spilling over the edge of a path or roadway relative to the illuminance on the path or roadway (CIE, 2000). A surround ratio is calculated by comparing the average illuminance in the area adjacent to a roadway equal in width to one travel lane, to the average illuminance in the roadway. Recent research has shown that a surround ratio of at least 80 percent provides significant benefits for the detection of objects and pedestrians both in and beside the roadway.



Glare – Difficulty or discomfort associated with a light source in direct view of the observer (IES, 2018). Veiling luminance is a common measure of glare used to guide the lighting design process. There are two types of glare that may occur due to the presence of a light source.

- Disability glare is intensity from a light source that limits a road user's ability to see.
- Discomfort glare occurs when light from a light source causes discomfort to a road user.

It is important for both types of glare to be minimized. IES RP-8-18 provides recommended maximum allowable levels for glare (IES, 2018). Glare can become more of a potential issue for pedestrian scale lighting (6.5m in height or lower). Figure 10 shows an example of glare from a light source. Section 2.2.3 of this primer recommends an approach to mitigating glare from lower mounting heights by increasing the vertical illuminance and luminance.

Figure 10. Photograph. Example of glare from a light source. Source: FHWA.

Light trespass – Excess light that falls on areas or surfaces that are not intended to be illuminated, such as private properties, residential areas, or the night sky (IES, 2018). A common method of quantifying light trespass is by calculating the vertical illuminance on a vertical plane at the public ROW. Light trespass is minimized with careful selection, placement, and orientation of luminaires so that light is directed toward the area intended to be illuminated. Alternatively, shielding of a light source may be an effective means of blocking unwanted light output from a luminaire. Figure 11 presents an illustration of light trespass from a luminaire.

Recommended limitations on light trespass often become more stringent in areas of environmental sensitivity. IES RP-8-18 provides recommended maximum allowable levels for light trespass based on environmental zone ratings (IES, 2018). Environmental zones are determined by surrounding land use and development.

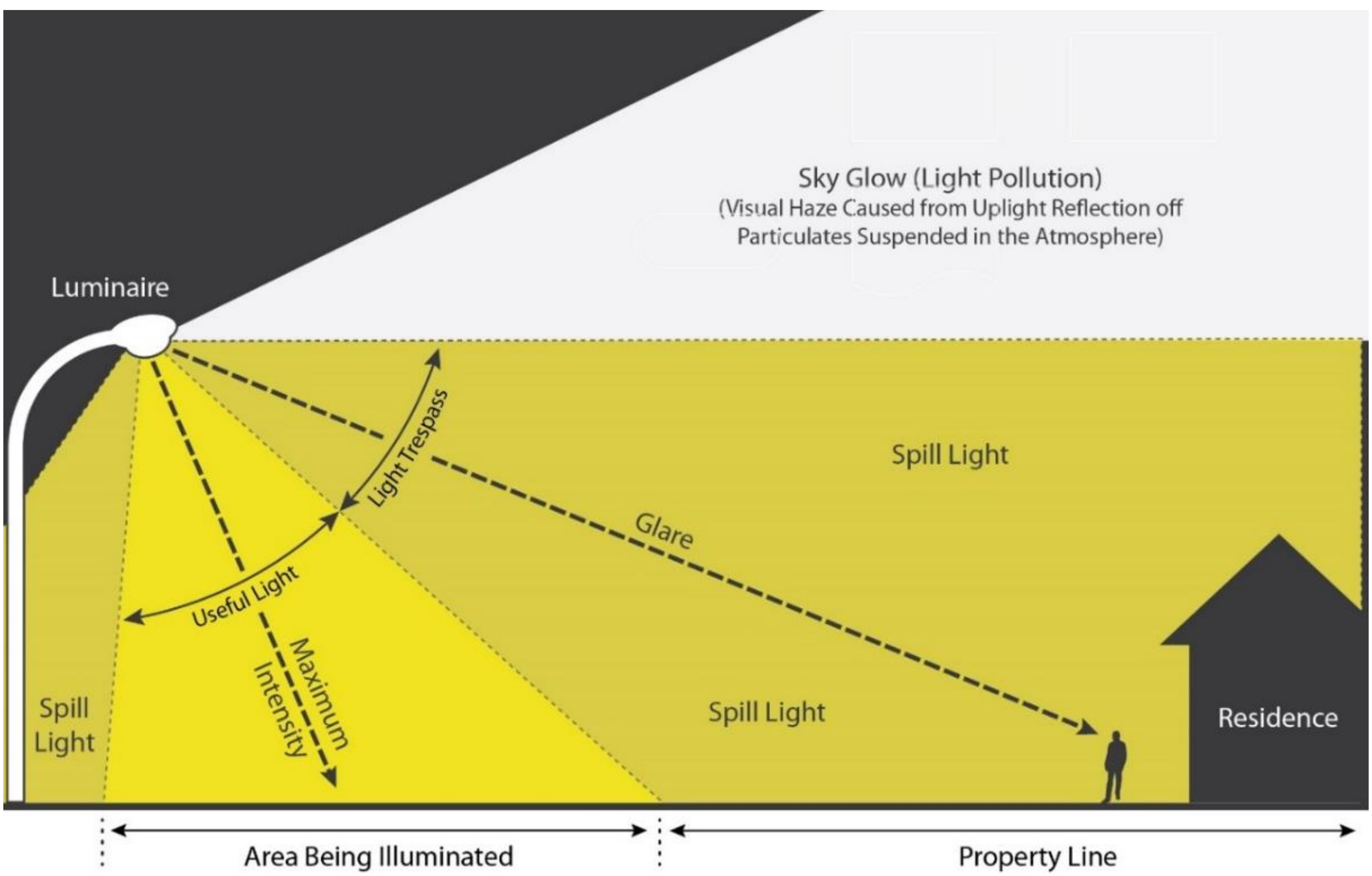


Figure 11. Graphic. Light trespass, glare, and sky glow. Source: FHWA.

2.2.3. Pedestrian Considerations for Design Criteria

This section of the primer outlines the general steps for determining lighting design criteria for pedestrian facilities. The steps bring together information from two FHWA research and informational reports on pedestrian lighting, *Street Lighting for Pedestrian Safety* and FHWA's *Informational Report on Lighting Design for Midblock Crosswalks*, as well as other commonly referenced lighting resources, such as IES RP-8-18 (Terry et al., 2020; Gibbons et al., 2008; IES, 2018).

Determine the type of pedestrian facility and level of pedestrian activity

This primer generally classifies pedestrian facilities into one of three categories based on the research from which the primer is based. The bullet list below describes these categories and the respective basis for lighting design criteria in this primer within those categories.

- **Pedestrian Facility Type – Marked Crosswalks (midblock and intersections).** Marked crosswalks indicate locations for pedestrians to cross a roadway and signify to motorists to yield to them (FHWA, 2013a). Design criteria for lighting of a crosswalk is provided in FHWA's *Informational Report on Lighting Design for Midblock Crosswalks* (Gibbons et al., 2008). While the underlying research was focused on midblock crosswalks, the conclusion of the informational report translates the findings to potential criteria for crosswalks at intersections.
- **Pedestrian facilities adjacent to the roadway.** A category of pedestrian facilities adjacent to (but not crossing) a roadway captures sidewalks and walkways (i.e., "pedestrian lanes") that provide people with space to travel within the public ROW that is separated from roadway vehicles. These facilities also serve as places for children to walk, run, skate, ride bikes, and play (FHWA, 2013b). Design criteria for lighting of these facilities is provided in the FHWA research report *Street Lighting for Pedestrian Safety* and are a function of pedestrian activity levels as defined in IES RP-8-18 (Terry et al., 2020; IES, 2018). The research documented in the FHWA report *Street Lighting for Pedestrian Safety* focused on the abilities of drivers to detect children on pedestrian facilities positioned approximately 5 to 7 ft (1.5 to 2 m) to the right of the driving lane. This distance coincides with the positioning of a sidewalk. The behaviors and decision making of children are not always predictable and the safety of a child in proximity to a roadway increases when the driver is aware of the child. This highlights the need to provide adequate pedestrian lighting at this distance from the roadway. The research in the FHWA report *Street Lighting for Pedestrian Safety* also studied the ability of pedestrians to identify potential trip-and-fall hazards in their path on these adjacent facilities.
- **Separated pedestrian pathway.** Lighting for pedestrian areas that do not cross and are not adjacent to or within a roadway is designed to meet a different set of objectives and criteria, as no vehicle-to-pedestrian interaction is anticipated. Recommended design criteria for these facilities are not the focus of this primer and are anticipated in other, upcoming informational resources.

Pedestrian lighting design criteria in the previously cited resource documents sometimes vary as a function of a general categorization of pedestrian activity. The following definitions are adapted from IES RP-8-18 and are referenced throughout this document, though they are not legally binding under FHWA regulations:

- **Low (10 or fewer pedestrians per hour)** – Areas with very low volumes of pedestrians during hours of darkness. Examples may include suburban streets with single family dwellings, very low-density residential developments, and rural or semi-rural areas.
- **Medium (11-100 pedestrians per hour)** – Areas where lesser numbers of pedestrians are expected during hours of darkness. Examples may include downtown office areas, libraries, apartments, neighborhood shopping, industrial, parks, and streets with nearby transit lines.
- **High (over 100 pedestrians per hour)** – Areas with significant numbers of pedestrians expected during hours of darkness. Examples may include downtown retail areas, theaters, concert halls, stadiums, and transit terminals.

Determine illuminance criteria

Illuminance criteria provided in different resource documents vary by the type of pedestrian facility and by the level of pedestrian activity.

Marked Crosswalks: Midblock - For crosswalk locations, FHWA's *Informational Report on Lighting Design for Midblock Crosswalks* found that an average vertical illuminance of 20 lux in the crosswalk, measured at a height of 1.5 m (5 ft) from the road surface, provided adequate detection distances in most circumstances (Gibbons et al., 2008).

Intersections - The FHWA's *Informational Report on Lighting Design for Midblock Crosswalks* stated that while no specific research has been performed that addresses the higher background luminance typically found at intersections and the greater cognitive demands on drivers as they approach an intersection, the informational report considered a level of 30 vertical lux a conservative estimate of the lighting level required for adequate visibility (Gibbons, et al., 2008).

Adjacent pedestrian facilities - For pedestrian facilities adjacent to (but not crossing) a roadway (e.g., sidewalks and walkways), the FHWA research report *Street Lighting for Pedestrian Safety* suggests the use of illuminance criteria measured in semi-cylindrical (SC) lux where pedestrian activity is high (more than 100 pph) (Terry et al., 2020). The report recommends 10 SC lux at these locations, and notes that additional light beyond this level does not increase visibility. The same report recommends 2 vertical lux for these facilities where pedestrian activity is low (0 to 10 pph) to medium (11 to 100 pph).

Determine pavement luminance based on area type and pedestrian volume

IES RP-8-18 provides criteria for roadway luminance based on both the classification of the roadway and the identified level of pedestrian activity (IES, 2018). Table 2 provides a summary of the IES RP-8-18 criteria. The criteria are not required under FHWA regulations.

Table 2. Recommended roadway luminance criteria by street classification and pedestrian activity (from IES RP-8-18, not required under FHWA regulations).

Street Classification	Pedestrian Activity Classification	Average Luminance L_{avg} (cd/m^2)	Average Uniformity Ratio L_{avg}/L_{min}	Maximum Uniformity Ratio L_{max}/L_{min}	Maximum Veiling Luminance Ratio $L_{v,max}/L_{avg}$
Major	High	1.2	3.0	5.0	0.3
	Medium	0.9	3.0	5.0	0.3
	Low	0.6	3.5	6.0	0.3
Collector	High	0.8	3.0	5.0	0.4
	Medium	0.6	3.5	6.0	0.4
	Low	0.4	4.0	8.0	0.4
Local	High	0.6	6.0	10.0	0.4
	Medium	0.5	6.0	10.0	0.4
	Low	0.3	6.0	10.0	0.4

L_{avg}: Maintained average pavement luminance
L_{min}: Minimum pavement luminance
$L_{v,max}$: Maximum veiling luminance

The research documented in the FHWA research report *Street Lighting for Pedestrian Safety* suggests maintaining a minimum average luminance on adjacent pedestrian facilities for visibility of pedestrians to drivers and for pedestrians' visibility of their walking path (Terry et al., 2020). The minimum average luminance level depends on the area type classification within the previously determined level of pedestrian activity. The following bullet list highlights these suggested luminance criteria:

- For high pedestrian volume facilities and school zones:
  - Urban environments – 2 cd/m2 average
  - Rural environments – 1 cd/ m2 average

- For low to medium pedestrian volume facilities:
  - Urban environments – 1 cd/m2 average
  - Rural environments – use typical road luminance recommended in RP-8-18, shown in table 2.

Lighting designers can also use typical road luminance values recommended in IES RP-8-18 along crosswalks (IES, 2018).

The average luminance provided by a design along an adjacent pedestrian facility is determined along a grid of calculation and measurement points aligned along the pedestrian path. This line of calculation points along the path should be spaced at no more than 2 m (6.6 ft).

Select Light Source CCT: Special Considerations

CCT is a measure of the apparent color output of a light source, measured in degrees Kelvin (K). CCT considerations can be applied to any type of light source, but typically becomes important with LED light sources, as the technology of LED lighting allows for a wide range of available CCT options, whereas other types of light sources do not allow the same flexibility.

In the FHWA research report *Street Lighting for Pedestrian Safety*, researchers evaluated CCT selection on the visual performance of drivers in detecting pedestrians. The researchers compared pedestrian detection distances under three LED light sources ranging from 2200 to 5000 K. Results determined the detection distances under the 2200 K LEDs were significantly shorter than the 4000 K and 5000 K LEDs under the same luminance levels as shown in figure 12 (Terry et al., 2020).

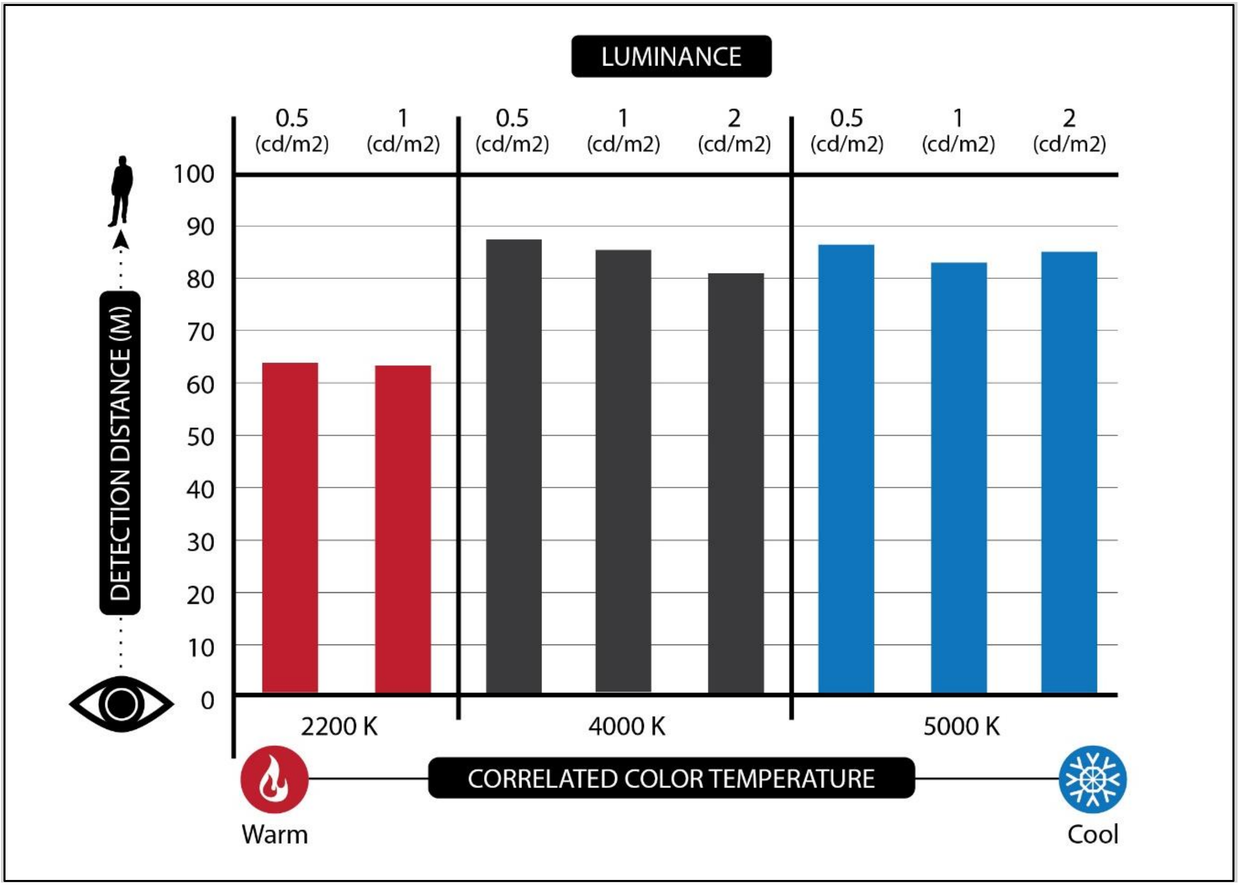


Figure 12. Graphic. Detection distance for rural highway by light type and luminance. Source: FHWA.

Since the development and popularization of LED roadway lighting, research has suggested that the light spectrum used in LED roadway lighting, particularly of higher Kelvin ratings, can disrupt melatonin production, resulting in poorer sleep quality and the overall health of those near the roadway. When selecting the spectral content of a light source, a range of 3000 K to 4000 K obtains a balance between the potential negative impacts on health and the potential benefits to road user visibility. Achieving such a balance remains an active topic of discussion in public health and lighting professions. The American Medical Association Council on Science and Public Health, for example, encourages the use of 3000K or lower to minimize potential negative health and environmental effects (AMA, 2016). State and local agencies, or other governing bodies responsible for lighting decisions, may decide to consider lower CCT values in environmentally sensitive areas or areas where the lighting system is near a residential area. Clear communication and documentation of such considerations will provide a record of stakeholder discussions and trade-off analysis that led to an informed decision.

Summary of Lighting Design Criteria for Pedestrian Facilities

The information in table 3 presents design criteria for pedestrian facilities based on the steps in the previous sections of this document. Values presented are for areas where the pedestrian lighting is provided by a roadway scale luminaire (6.5m or 20 ft or higher). For pedestrian scale lighting (6.5m in height or lower) an additional 2 vertical lux and 0.5 cd/m2 are added to the criteria to overcome additional glare resulting from the use of a lower mounting height. Figure 13 presents a flowchart of this design criteria selection process, depicting the roadway factors and road user characteristics that influence the design. These steps as shown in figure 13 are recommended by IES and AASHTO but are not required under FHWA regulations. The flowchart is included to illustrate a typical criteria selection process.

Table 3. Recommended design criteria for pedestrian facilities (not required under FHWA regulations)[1].

Pedestrian facility characteristics		Light Source Characteristics			
		Average Illuminance	Average Luminance		CCT (LED only)
			Rural	Urban	
Intersection crosswalk		30 lux vertical	*	*	3000 K to 4000 K
Midblock crosswalk		20 lux vertical	*	*	3000 K to 4000 K
Facility adjacent to roadway	Low[2] to Medium[3] Pedestrian Activity	2 lux vertical	*	1 cd/m^2	3000 K to 4000 K
	High[4] Pedestrian Activity and/or School Zones	10 lux SC	1 cd/m^2	2 cd/m^2	3000 K to 4000 K

*Use minimum maintained average pavement luminance criteria from RP-8-18.

1 Values are for roadway scale luminaire heights (6.5m or 20 ft or higher). For pedestrian scale lighting (6.5m in height or lower), add 2 vertical lux and 0.5 cd/m2 to the criteria to overcome increased glare resulting from the use of a lower mounting height.

2 Low Pedestrian Activity (10 or fewer pedestrians per hour) – Areas with very low volumes of pedestrians during hours of darkness. Examples may include suburban streets with single family dwellings, very low-density residential developments, and rural or semi-rural areas.

3 Medium Pedestrian Activity (11-100 pedestrians per hour) – Areas where lesser numbers of pedestrians are expected during hours of darkness. Examples may include downtown office areas, libraries, apartments, neighborhood shopping, industrial, parks, and streets with nearby transit lines.

4 High Pedestrian Activity (over 100 pedestrians per hour) – Areas with significant numbers of pedestrians expected during hours of darkness. Examples may include downtown retail areas, theaters, concert halls, stadiums, and transit terminals.

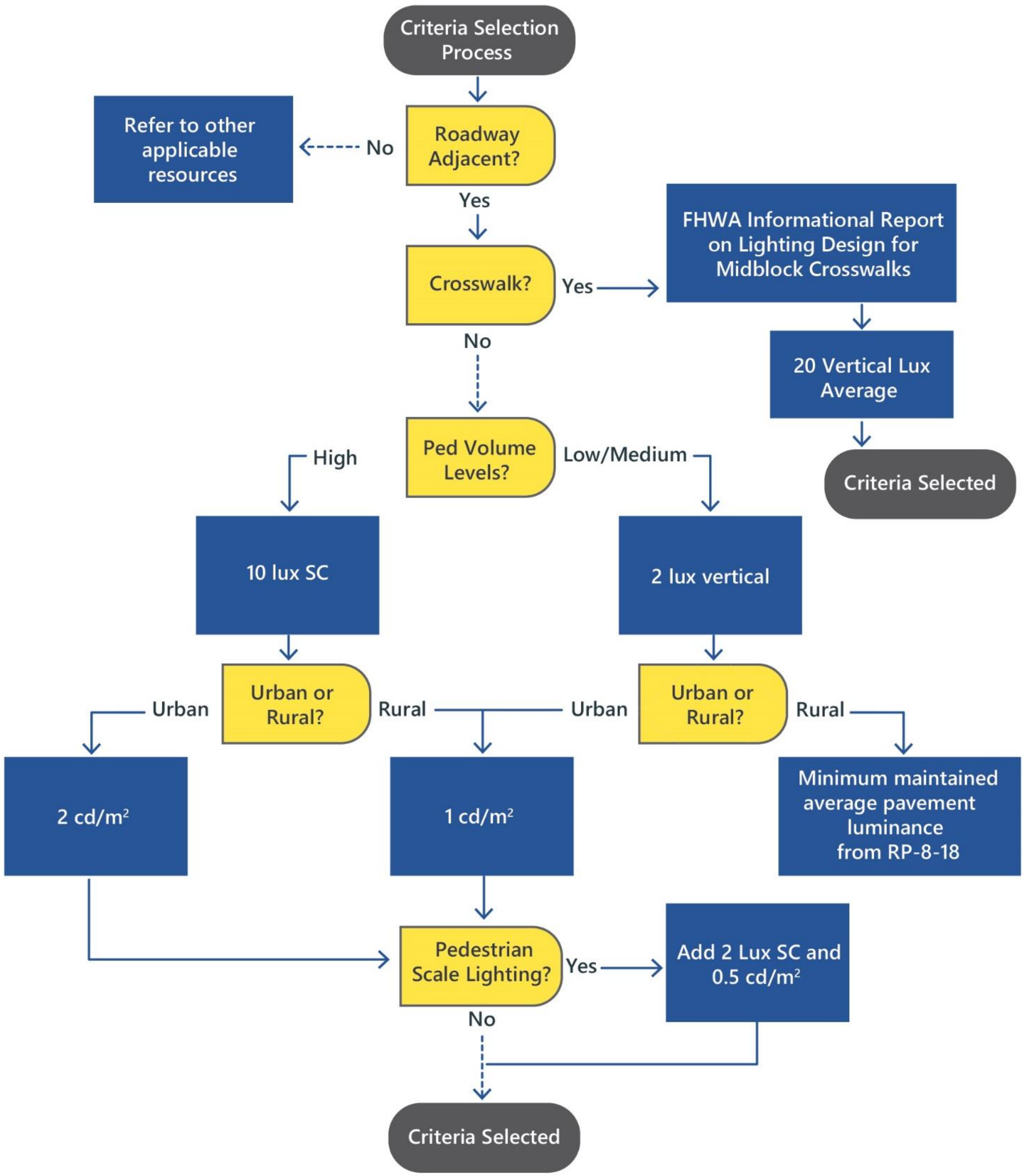
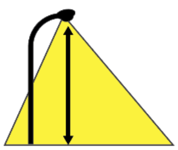


Figure 13. Graphic. Recommended pedestrian lighting criteria selection flowchart (not required under FHWA regulations). Source: FHWA.

2.3. Equipment Selection

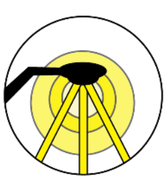
2.3.1. General Principles of Equipment Selection

After the design criteria for a project location have been selected, lighting equipment is selected for the design. Luminaires are often selected based on an inventory of existing lighting installations or preferences and policies of the local agency. When feasible, equipment is selected to minimize the total light output while meeting the goals of the project and the design criteria. Some of the elements that are considered when selecting lighting equipment and luminaires include:



Luminaire mounting height – The distance from ground level to the light source.

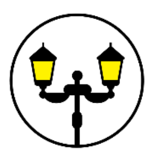
Luminaire wattage – The power used by a luminaire to produce light. Luminaires with higher wattage levels typically produce more light.



IES light distribution – A classification system that describes the lateral and longitudinal pattern of light that is produced by a luminaire. Distribution types range from Type I (very linear output) to Type V (circular output). Definitions and classification of light distribution types is included in IES RP-8-18 (IES, 2018), though the definitions and classification are not required under FHWA regulations. General representations of IES distribution types are presented in figure 14.

BUG Rating – A rating system that indicates the amount of backlight (B), uplight (U), and glare (G) that is produced by a luminaire, with each value rated on a scale from 0 to 5. Higher BUG ratings may indicate that light is being directed away from the target facility or into the night sky. BUG ratings are described in ANSI/IES TM-15-20, *Luminaire Classification System for Outdoor Luminaires* (ANSI/IES, 2020). FHWA regulations do not include requirements based on BUG ratings.

Correlated color temperature (CCT) (refer to Section 2.2.)



Aesthetics – Luminaires are often selected for decorative design characteristics.

Many properties of the selected equipment are interrelated. For example, a particular mounting height will influence the selection of luminaire wattage to appropriately meet design criteria. Designers consider these properties and how they affect one another when selecting or recommending lighting equipment for a given project.

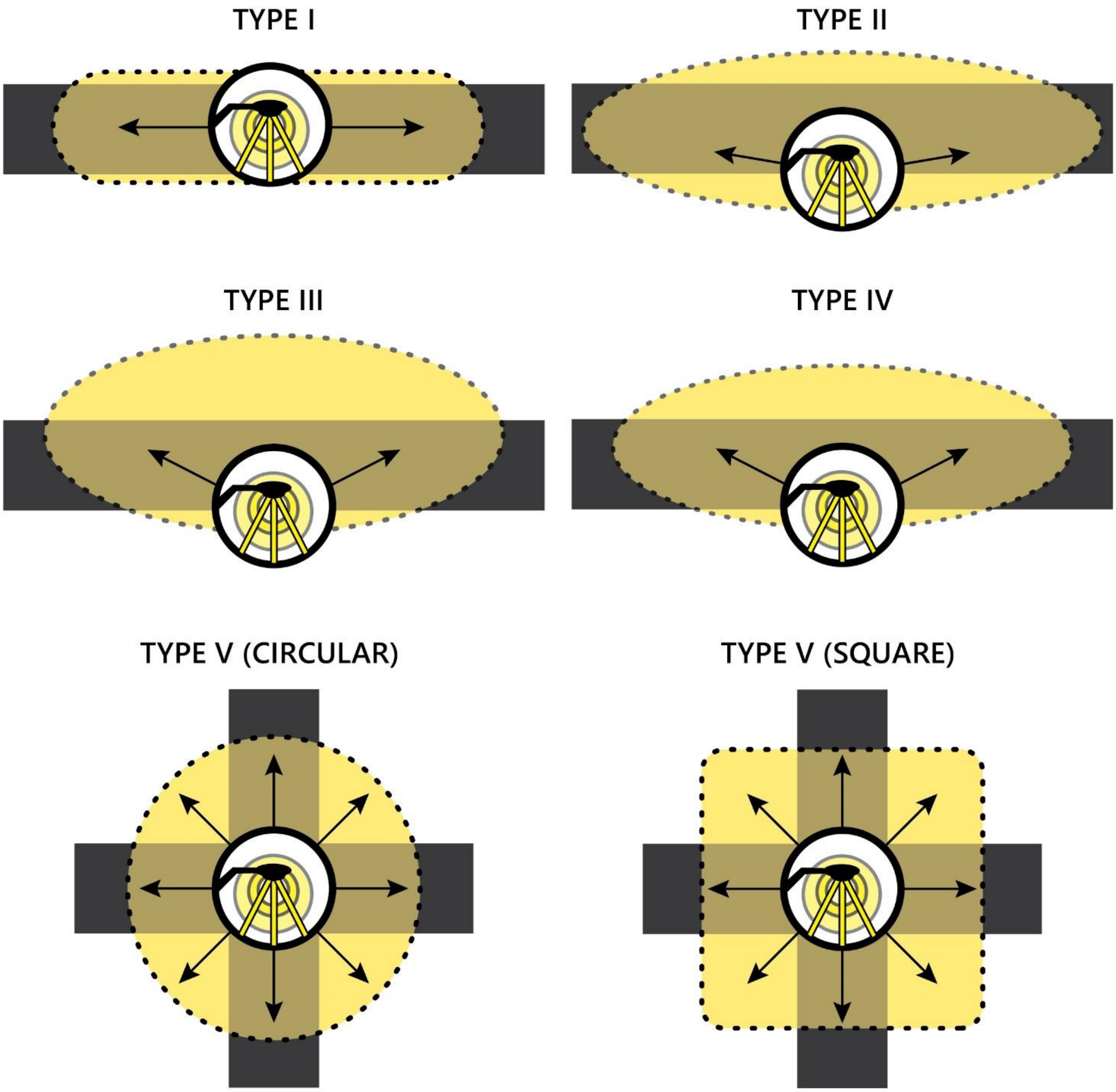


Figure 14. Graphic. General representation of IES distribution types. Modified from IES RP-8-18. Source: FHWA.

2.3.2. Pedestrian Considerations for Equipment Selection

One of the primary factors in selecting equipment is the mounting height of the luminaire, which is typically measured from the pavement surface to the light source. Luminaire mounting height plays a significant role in designing for pedestrian lighting facilities, and sometimes, the selected mounting height is lower than in lighting systems installed exclusively for roadway lighting.

In the FHWA research report *Street Lighting for Pedestrian Safety*, an experiment compared the detection distances for drivers of motor vehicles when viewing pedestrians when under pedestrian scale lighting (mounting height less than 6.5 m or 20 ft) and road scale lighting (mounting height greater than 6.5 m or 20 ft). Results of the experiment indicate an increase in detection distance when pedestrian scale lighting was present. Detection distances also increased with higher levels of pavement luminance (Terry et al., 2020). Figure 15 shows the two-way interaction between light type and luminance for pedestrian scale lighting. The figure is based on the FHWA research report *Street Lighting for Pedestrian Safety* (Terry et al., 2020). Based on the findings of this research, mounting heights of less than 6.5 m or 20 ft provide improved visual performance in areas where pedestrians are present. There is an expected trend downward from higher luminance levels (2 cd/m^2) to medium (1 cd/m^2) to low (0.5 cd/m^2). For road scale, the higher luminance produced longer detection distances as expected, but low and medium averages were not significantly different.

A disadvantage of pedestrian scale lighting is an increase in the glare produced by the light source, as these lower luminaires are closer to the line of sight of the driver. When pedestrian scale lighting is used, an additional 2 semi-cylindrical lux or 0.5 cd/m^2 allows for the lighting performance to overcome the increase in glare associated with lower mounting heights.

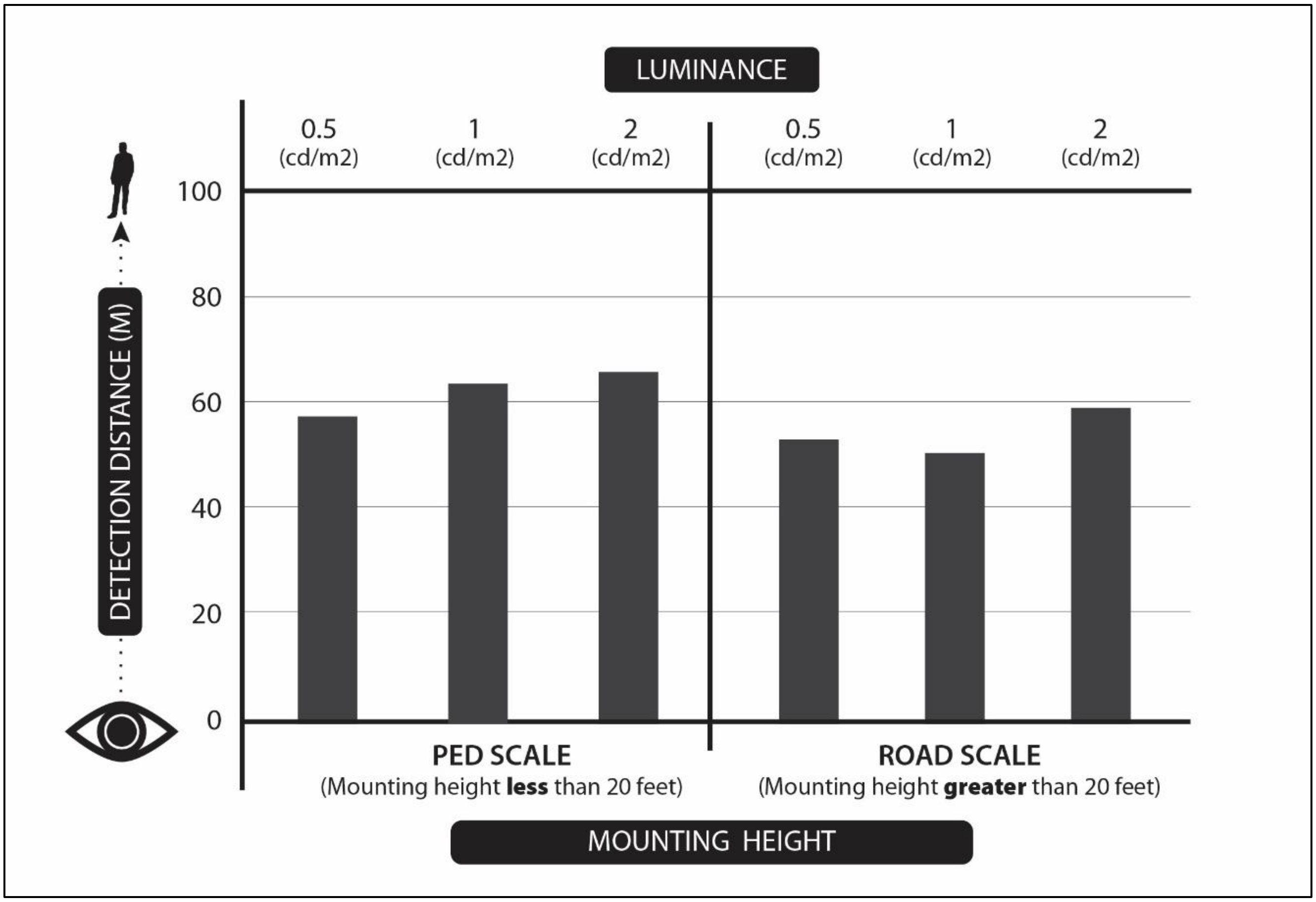


Figure 15. Graphic. Detection distance by light type and luminance. Source: FHWA.

Lower mounting heights are typically associated with a decrease in pole spacing to achieve the desired design criteria, since the effective area illuminated by each light source becomes smaller. As the pole spacing decreases, the required total number of poles for a lighting system increases. Selection of appropriate wattage for the luminaires allows the designer to balance the benefits of pedestrian scale mounting heights with the increased energy consumption. Many luminaires are available in a range of wattage options while maintaining aesthetics.

Selection of appropriate IES distribution type is especially relevant when considering pedestrian lighting systems. Distribution types are selected with the facility and pole layout in mind and can considerably affect the required pole spacing and efficiency of the lighting system. For pedestrian facilities that tend to be relatively narrow and linear in nature, selection of a Type I or Type II luminaire allows for more light to be directed toward the design facility while limiting light trespass. Figure 16 shows a conceptual example of variable mounting heights within the public right-of-way to achieve the visibility needs of different road users.

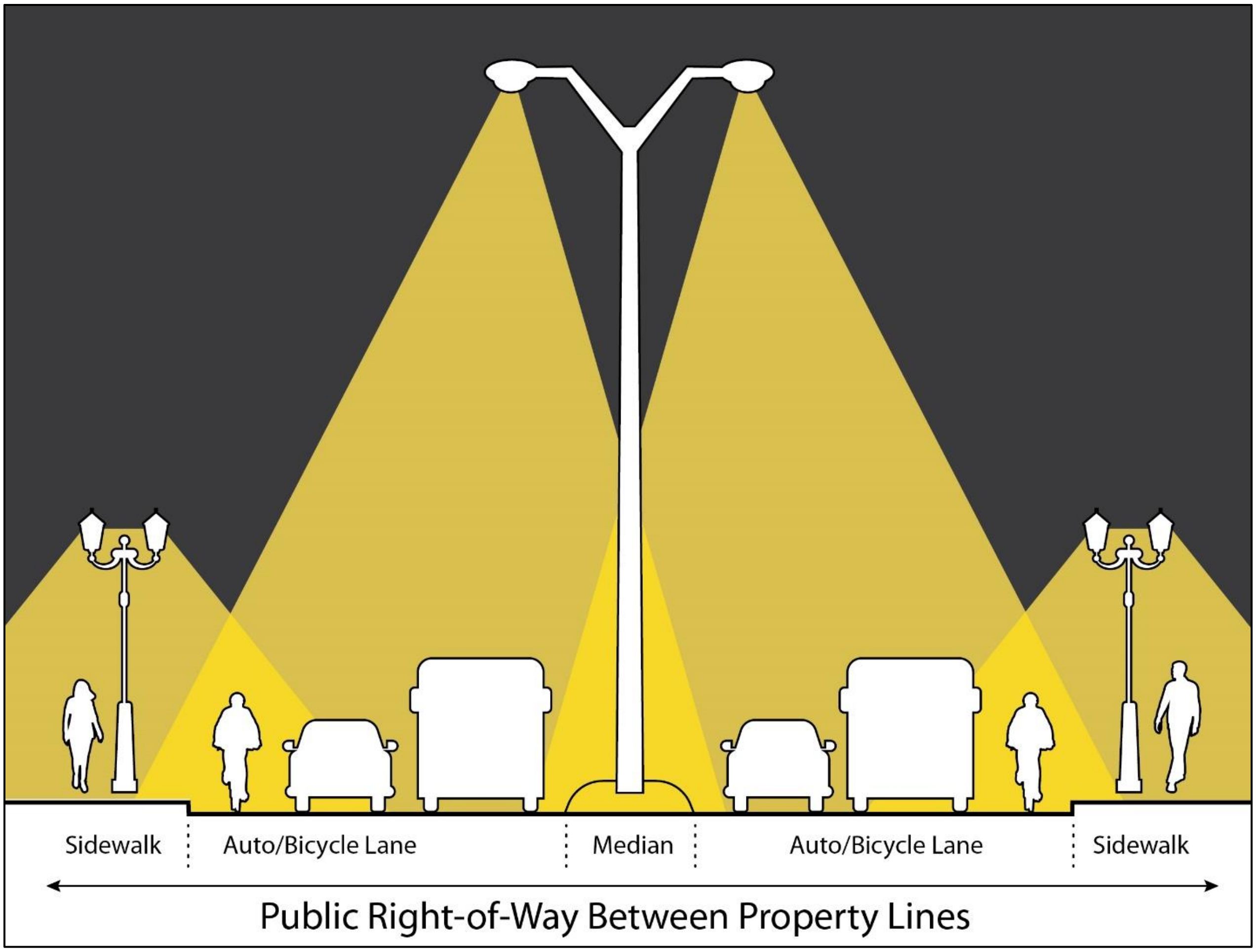


Figure 16. Graphic. Variable mounting heights within public right-of-way. Source: FHWA.

2.4. Determination of Control Strategy

2.4.1. General Principles of Control Strategies

A lighting control system is a set of hardware and software that adjusts power and light output for a lighting installation. Control strategies vary from a simply on/off setting triggered at dusk and dawn, to fully adjustable dimming controls that respond to a programmable schedule or motion in the project area. The designer's selection of the proper control strategy is based on input from the maintaining agency and local community, as well as on characteristics of the project location, including vehicle or pedestrian activity.

2.4.2. Pedestrian Considerations for Control Strategies

Adaptive lighting, an approach to lighting that adjusts the light output based on the presence or volume of road users, is a lighting control strategy that is particularly beneficial when applied to pedestrian lighting systems. An FHWA report, *Design Criteria for Adaptive Roadway Lighting*, provides a proposed set of adaptive lighting criteria to assist in the decision of whether to provide adaptive lighting (Gibbons et al., 2014a). Its companion report, *Guidelines for the Implementation of Reduced Lighting on Roadways*, establishes the criteria for determining appropriate lighting levels based on roadway characteristics and usage (Gibbons et al., 2014b).

Common application of an adaptive lighting system includes dimming of the lighting system based on pedestrian count data. In areas where pedestrian volumes are high (more than 100 pph) during the evening hours and low (0 to 10 pph) in late night hours, an adaptive lighting control system can be dims the light output when pedestrian volumes, and corresponding recommended design criteria, decrease. Adaptive lighting systems may also be programmed for special events and time of day schedules, which is particularly beneficial in school zones and public parks.

Where adaptive lighting is used, varying levels of light output can be programmed, but turning off the lighting system completely can cause potential risks or concerns for the local community. Dimming may not be noticeable to the casual observer; however, once lighting has been installed, there is a general expectation that the facility will remain lit during hours of darkness. In cases where low pedestrian volumes occurring during certain hours of the night do not warrant lighting, the adaptive lighting system can be programmed to maintain a low level of lighting.

2.5. Design and Verification

2.5.1. General Design Process

Once the need for lighting has been established, and the designer has selected design criteria, lighting equipment, and control strategy, the lighting system is then designed in a photometric analysis software package. There are several market ready software tools capable of detailed illuminance, luminance, and glare calculations. Using site survey data and the selected lighting equipment, the designer can use this software to develop a three-dimensional model of a proposed light pole layout. The photometric analysis provides calculated results for illuminance, luminance, glare, and other metrics that are used to evaluate the proposed lighting layout. The calculated photometric results are then compared to both the primary and the secondary criteria. If the criteria are not appropriately met, the layout is refined through a change in pole spacing, offset from the roadway, mounting height, or luminaire selection. This iterative process continues until the design is optimized, when the selected design criteria are met while minimizing the number of poles and luminaires.

Pole placement is a critical step in the design process that, in addition to affecting the lighting results, includes consideration of local and State requirements, utility conflicts, and ease of maintenance, among other factors. Additional information about pole placement is included in the AASHTO *Roadside Design Guide, 4th Edition* (AASHTO, 2011).

2.5.2. Pedestrian Considerations for the Design Process

The process of developing a photometric model and selecting a lighting layout for pedestrian lighting systems is similar to other roadway lighting designs; however, there are some key elements of a pedestrian lighting system for the designer to consider, including light pole placement, contrast, and calculation grid location.

Often, the overall layout of light poles on a pedestrian facility may be governed by one or several critical pole locations. For example, midblock crossings and intersections may require a particular pole location to provide the optimal vertical illuminance and positive contrast of pedestrians in a marked crosswalk. Contrast is the measurable visible difference between a target and the target's background. Positive contrast results in the target being brighter than its background and negative contrast results in the target being darker than its background, as illustrated in figure 17. FHWA's *Informational Report on Lighting Design for Midblock Crosswalks* provides additional information regarding proper light pole location (Gibbons et al., 2008). Placement of these critical pole locations first, before locating other poles based on a set spacing, results in improved contrast and visual performance in midblock crossings.

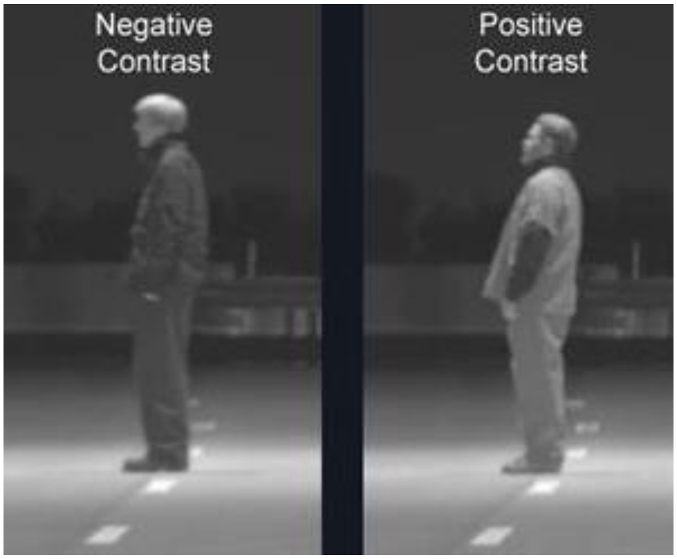


Figure 17. Photograph. Examples of negative and positive contrast. Source: FHWA.

For the calculation and the verification of the lighting in the pedestrian sidewalks areas, locate the calculation grid centered in the design area with a maximum spacing of 2 m (6.5 ft) between grid points in each direction. Calculation points for vertical or semi-cylindrical illuminance should be located at a height of 1.5 m (5 ft) above the pavement surface and centered in the sidewalk or pathway.

3. Design Example

The design example included in this chapter details a typical scenario for lighting pedestrian facilities. It presents the key characteristics of the location and illustrates the application of the process described in Section 2. This example does not cover all potential scenarios related to lighting for pedestrian safety, but it is designed to demonstrate the information provided in the previous sections of this primer. The example begins by describing the scenario and progresses through sections devoted to each of the steps in the process laid out in Section 2, as follows:

1. *Assessment of potential lighting needs.*
2. *Selection of design criteria.*
3. *Equipment selection.*
4. *Determination of control strategy.*
5. *Design and verification.*

3.1. Example Scenario

This scenario focuses on a segment of an urban five-lane arterial roadway running between two intersections, as shown in figure 18. On the north side of the subject roadway is a park and on the south side is an elementary school, served by a driveway. This segment of the roadway is marked as a school zone, and there is a transit stop in the study area that serves the park and school. The peak hourly pedestrian volumes occur just before and after school hours, as this street is used by many students and families living in the nearby neighborhoods to access the school and park. It is also used frequently outside of school hours. The peak pedestrian volumes sometimes occur in dark conditions, depending on time of year.

Figure 19 shows a rendering of an urban five-lane arterial with a midblock crosswalk and a transit stop, similar to the scenario used in this example.

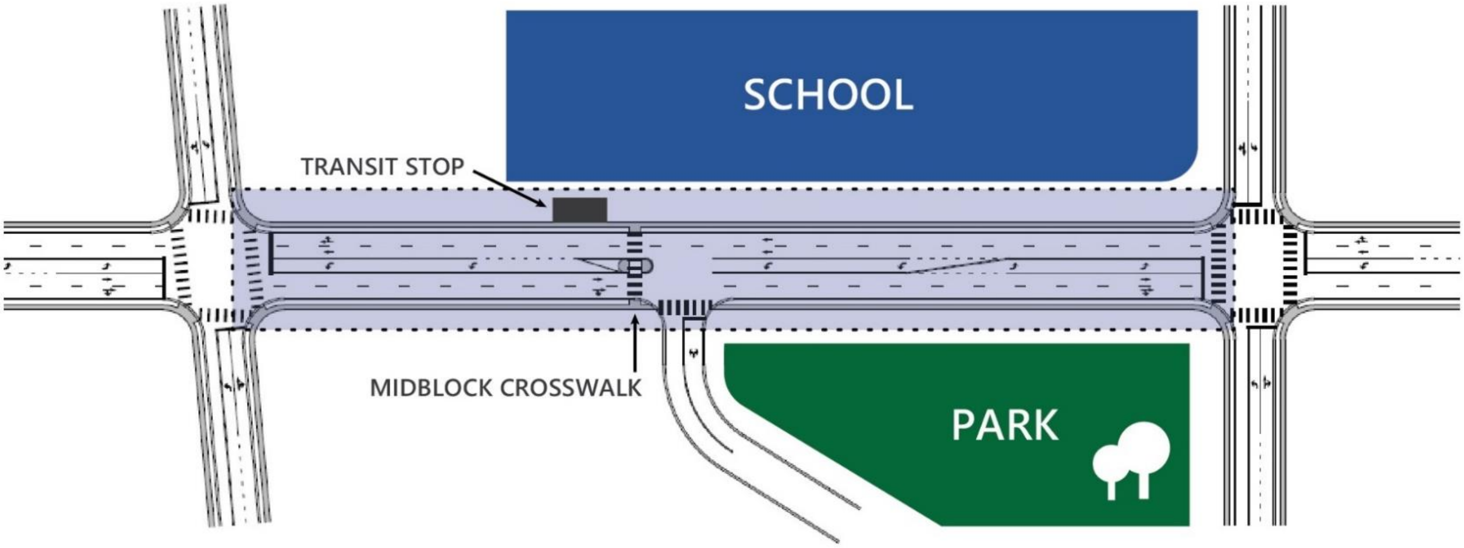


Figure 18. Graphic. Sketch of example scenario. Source: FHWA.

Figure 19. Graphic. Rendering of urban five-lane arterial with midblock crosswalk and transit stop similar to the example scenario. Source: The Greenway Collaborative, Inc.

3.2. Assess Lighting Needs

The first step is to identify the lighting needs in the given scenario. This example includes several different pedestrian facility types. There are intersection crossings at the two intersections, with marked crosswalks on all four approaches of each intersection. There is a midblock crosswalk near the school driveway to connect the school property to the park. Finally, there are sidewalks along both sides of the subject roadway. In addition to these pedestrian facilities, there is also the roadway itself to be considered in the lighting design process. The designer should also be aware of the role that lighting plays both in terms of safety and security for users of the transit stop located in the study area.

Note that this example will focus on the area of the subject roadway between the two intersections, inclusive of the inner crosswalks across the major road at each intersection (as indicated by the shaded area in figure 18). However, the process and criteria for lighting the intersection crosswalks not included in the shaded area would be the same as the process illustrated in this example.

3.3. Select Design Criteria

The next step is to select the lighting design criteria for each of the facility types identified. This example focuses on primary criteria, or the desired lighting levels that the system is designed to provide in the project area. The designer can also consider secondary criteria, such as aesthetics or ability to limit light trespass. Section 2.2.2 contains more information and resources regarding secondary criteria.

As previously noted, this example contains marked crosswalks (both midblock and at intersections) and pedestrian facilities adjacent to the roadway (i.e., sidewalks). Table 3 in Section 2.2.3 of this document summarizes the design criteria for these pedestrian facilities. The table of criteria is recreated below as table 4 and the criteria selected based on the characteristics of the example are denoted with bolded text. Intersection crosswalks should have an average of 30 lux vertical illuminance. Midblock crosswalks should have an average of 20 lux vertical illuminance. There are two options for average illuminance of adjacent pedestrian facilities, or sidewalks, depending on pedestrian activity. In this case, since the subject roadway is in a school zone, the sidewalks should have 10 lux semi-cylindrical illuminance. The average luminance of the roadway should be 2 cd/m^2 since the study area is urban and the subject roadway is in a school zone. Finally, the chosen luminaires should have a CCT of 3000 K to 4000 K at all locations.

Refer to section 2.2 for a detailed discussion of lighting design criteria.

Table 4. Selected design criteria for example scenario[1].

Pedestrian facility characteristics		Light Source Characteristics			
		Average Illuminance	Average Luminance		CCT (LED only)
			Rural	Urban	
Intersection crosswalk		**30 lux vertical**	*	*	**3000 K to 4000 K**
Midblock crosswalk		**20 lux vertical**	*	*	**3000 K to 4000 K**
Facility adjacent to roadway	Low[2] to Medium[3] Pedestrian Activity	2 lux vertical	*	1 cd/m^2	3000 K to 4000 K
	High[4] Pedestrian Activity and/or School Zones	**10 lux SC**	1 cd/m^2	**2 cd/m^2**	**3000 K to 4000 K**

*Use minimum maintained average pavement luminance criteria from RP-8-18.

1 Values are for roadway scale luminaire heights (6.5m or 20 ft or higher). For pedestrian scale lighting (6.5m in height or lower), add 2 vertical lux and 0.5 cd/m2 to the criteria to overcome increased glare resulting from the use of a lower mounting height.

2 Low Pedestrian Activity (10 or fewer pedestrians per hour) – Areas with very low volumes of pedestrians during hours of darkness. Examples may include suburban streets with single family dwellings, very low-density residential developments, and rural or semi-rural areas.

3 Medium Pedestrian Activity (11-100 pedestrians per hour) – Areas where lesser numbers of pedestrians are expected during hours of darkness. Examples may include downtown office areas, libraries, apartments, neighborhood shopping, industrial, parks, and streets with nearby transit lines.

4 High Pedestrian Activity (over 100 pedestrians per hour) – Areas with significant numbers of pedestrians expected during hours of darkness. Examples may include downtown retail areas, theaters, concert halls, stadiums, and transit terminals.

3.4. Select Equipment

The next step is to select lighting equipment that will enable the design to meet the identified criteria. Lighting equipment selection typically depends on local inventory and the preferences of the local agency. In this case, the lighting design will use the roadway cobrahead style LED luminaires (see figure 20). Selection of luminaires is often based on local inventory and standards, and in this example, cobrahead luminaires have been selected for consistency within the local municipality, which in turn results in ease of maintenance and familiarity to road users. The design will use a color temperature of 3000 K (which is within the recommended range presented in table 3), 204 W of power, and an IES distribution of Type II (as illustrated previously in figure 14). Type II provides a shallower distribution angle that will result in greater longitudinal illumination of the sidewalks while also casting light onto the roadway.

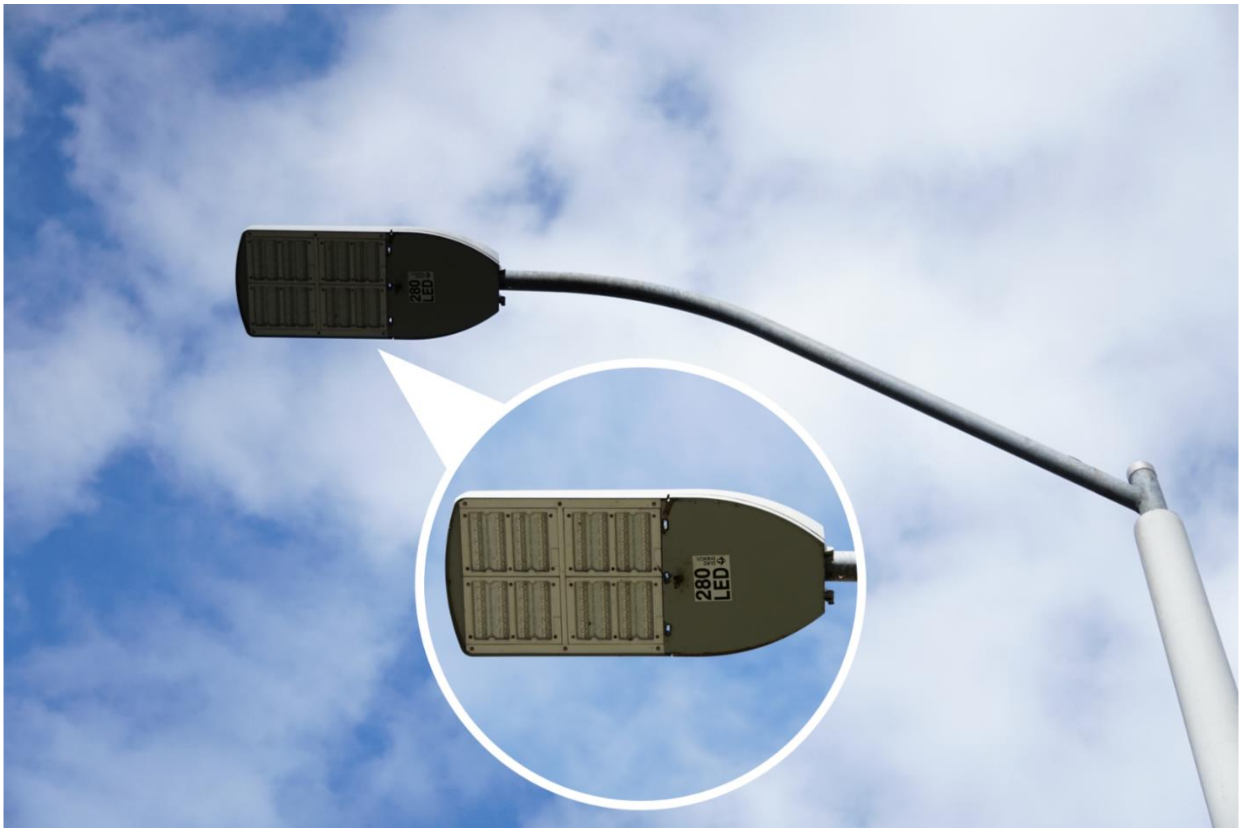


Figure 20. Graphic. Example LED cobrahead roadway luminaire. Source: FHWA.

Given the width of the roadway cross-section, the use of pedestrian scale mounting heights (20 feet or less) alone may not provide adequate illumination or uniformity across all roadway travel lanes. Therefore, a roadway scale mounting height, or a combination of pedestrian scale and roadway scale luminaires, is more appropriate to meet the design goals. Additionally, the cobrahead luminaires that are selected for use are intended for roadway scale mounting heights. For this example, the luminaires will be mounted at a height of 35 feet. They will be positioned on both sides of the roadway in a staggered layout to adequately light the entire width of the pavement and adjacent pedestrian facilities.

Refer to section 2.3 for a detailed discussion of lighting equipment selection, including the trade-offs between roadway scale lighting and pedestrian scale lighting.

3.5. Determine Control Strategy

The lighting control strategy determines when and at what level the lighting operates. In this example, the lighting system will use traditional photocell “dusk-to-dawn” operation.

For locations with variable pedestrian volumes and where lighting impacts to the surrounding area are of concern, consideration may be given to the use of adaptive lighting systems. Methods for applying adaptive lighting technologies are included in IES RP-8-18 as well as NCHRP Research Report 940, *Solid-State Roadway Lighting Design Guide, Volume*

2: Research Overview (Lutkevich et al., 2020). These methods are not required under FHWA regulations. Refer to section 2.4 of this primer for more information on control strategies, including a discussion of adaptive lighting in the context of lighting for pedestrians.

3.6. Design and Verification

After identifying design criteria, selecting equipment, and determining the control strategy, the remaining step is to design the lighting system and verify that it meets the design criteria. This is done using a photometric analysis software package, of which there are several options that operate in a similar manner. The discussion presented in this example should apply generally to all of them.

The software works by calculating the lighting metrics (luminance, illuminance, etc.) at points laid out across the study area in grid pattern, based on a given selection and layout of light sources. The grid is established based on existing guidance, with roadway illuminance points (per IES RP-8-18) and semi-cylindrical illuminance points (per CIE, 2000). All vertical and semi-cylindrical illuminance points are located 4.9 ft (2 m) above the roadway surface to represent the typical height of a pedestrian, with a maximum spacing of 6.5 ft. Roadway luminance points are located with a maximum spacing of 16.4 ft.

For each of the luminaire models selected for a given design, a data file (IES file format) typically provided by the lighting manufacturer is imported into the lighting software. The data file includes information about the luminaire's spatial light distribution and intensity for use in the lighting model. When importing IES files, a light loss factor (LLF) is typically applied to account for depreciation of light output over time. During the lifecycle of a lighting installation, light output is expected to decrease due to dirt and dust accumulation, lamp lumen depreciation and ambient temperature changes, among other physical and environmental factors. Therefore, a light loss factor checks that a lighting design will meet the selected design criteria throughout the expected service life. For this design, a total light loss factor of 0.85 is applied to each luminaire IES file, which is typical for many LED light sources.

The first step is to identify critical locations where luminaire placement is either important to achieve design goals, or highly constrained due to roadway geometrics, utility conflicts, or other obstacles. These critical luminaires are often located near midblock crossings or intersections. They should be placed in advanced of crosswalks to create positive contrast (as illustrated previously in figure 17). In this example, the critical luminaires are the two at the midblock crosswalk and one each at the intersection crosswalks, as shown in figure 21. They are placed behind the sidewalk. Critical luminaire locations may also include areas where existing utility conflicts, driveways, or landscaping significantly influence the placement of a pole.

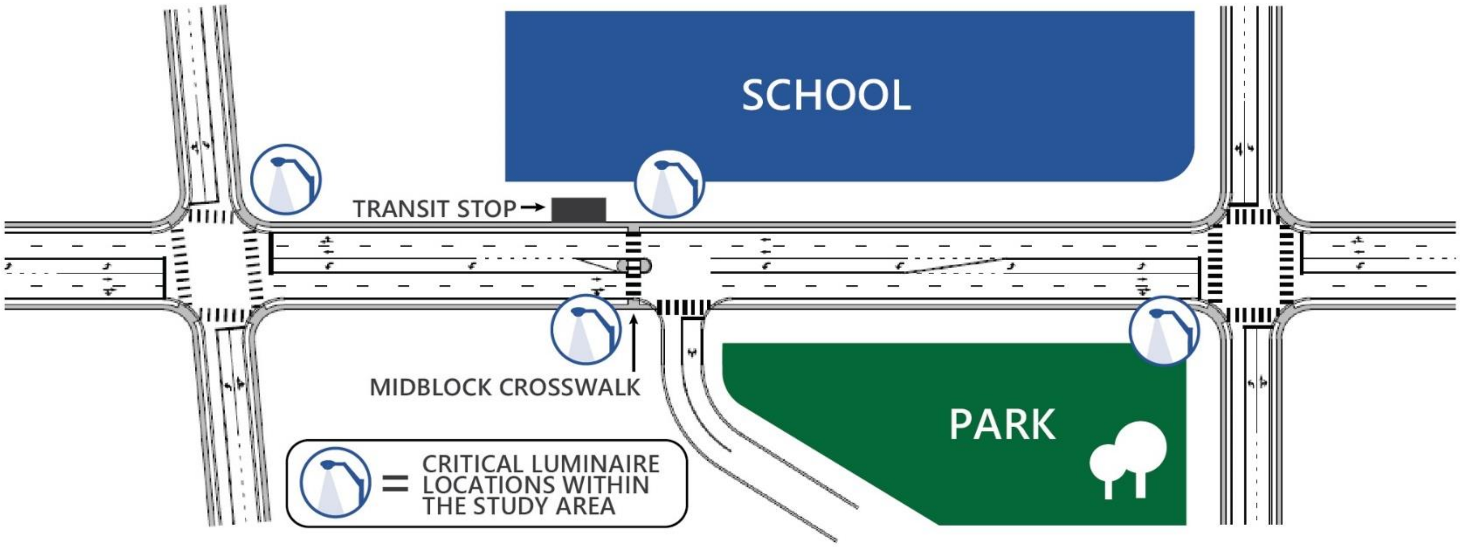


Figure 21. Graphic. Critical luminaire locations within the study area. Source: FHWA.

Once the locations of the critical luminaires have been selected, the designer continues by filling in the remaining space behind the sidewalk along both sides of the roadway with luminaires in a staggered layout, trying to keep roughly equal spacing between them. In this case, the placements result in approximately 200 ft between light poles. This spacing is a reasonable starting point, however the design process will determine whether this spacing is valid or should be revised to achieve the design criteria.

At this point, the photometric analysis software package calculates the results for the design and shows that they are too low to meet the targeted design criteria. The criteria and results are shown in table 5, where the bolded rows indicate items that did not meet the target criteria. As discussed in section 2.5, lighting design relies on an iterative process, so this is not unexpected. Since the calculated average lighting levels are lower than the target design criteria, while the average-to-minimum uniformity ratios are acceptable per RP-8-18 criteria, the design must be revised to provide higher average illuminance in the project area (IES, 2018). The designer may choose to decrease the pole spacing to achieve greater illumination; however, this will result in an increase in the required number of poles. In the interest of reducing construction and maintenance costs by requiring the fewest number of light poles, a logical next step is to increase the input power to each luminaire while keeping all other inputs the same, including the pole spacing. In this example, the next iteration will use a 268 W luminaire from the same manufacturer, an increase from the 204 W luminaire originally selected.

Table 5. Summary of initial lighting design criteria and calculation results.

Calculation Zone	Calculation Type	Units	Target Criteria	Calculation Results
			Average	Average
Midblock Crosswalk	**Vertical Illuminance**	**Lux**	**20**	**19.06**
Intersection Crossing (West)	**Vertical Illuminance**	**Lux**	**30**	**19.26**
Intersection Crossing (East)	**Vertical Illuminance**	**Lux**	**30**	**18.23**
Sidewalk (North)	**SC Illuminance**	**Lux**	**10**	**7.63**
Sidewalk (South)	**SC Illuminance**	**Lux**	**10**	**7.73**
Roadway (Westbound)	**Luminance**	**Cd/m^2**	**2.0**	**1.92**
Roadway (Eastbound)	**Luminance**	**Cd/m^2**	**2.0**	**1.92**

Note: Additional lighting design criteria recommended in IES *RP-8-18* should be evaluated and considered for uniformity and glare.

Upon calculating the results again with the photometric analysis software package, the results show that the midblock crosswalk, sidewalk, and roadway meet the design criteria. However, the intersection crossings do not meet the vertical illuminance requirement, particularly at the grid points towards the centerline of the roadway (furthest from the light poles). Table 6 summarizes the criteria and results, with the items that did not meet criteria shown in bold.

Because in this case the lighting design is not meeting criteria in a targeted location, the design can incorporate some minor adjustments. Although the criteria could be achieved by further increasing the wattage of all luminaires, doing so would over-illuminate much of the project area, and may increase glare. Individual adjustment of pole locations where necessary allows for the design to maintain consistent use of the same luminaires and will not change the calculated results for other areas of the project area which are satisfactory. First, to fine-tune the pole placements at the intersections, the designer can move them closer to the sidewalk and closer to the intersection crosswalk. Additionally, the designer can adjust the mounting height from 35 ft to 30 ft for the pole closest to each intersection crossing. These adjustments will increase the amount of vertical illuminance at the targeted locations.

Table 6. Summary of revised lighting design criteria and calculation results.

Calculation Zone	Calculation Type	Units	Target Criteria	Calculation Results
			Average	Average
Midblock Crosswalk	Vertical Illuminance	Lux	20	25.19
Intersection Crossing (West)	**Vertical Illuminance**	**Lux**	**30**	**25.46**
Intersection Crossing (East)	**Vertical Illuminance**	**Lux**	**30**	**24.10**
Sidewalk (North)	SC Illuminance	Lux	10	10.09
Sidewalk (South)	SC Illuminance	Lux	10	10.21
Roadway (Westbound)	Luminance	Cd/m^2	2.0	2.53
Roadway (Eastbound)	Luminance	Cd/m^2	2.0	2.54

Note: Additional lighting design criteria recommended in IES *RP-8-18* should be evaluated and considered for uniformity and glare.

The photometric analysis software package calculates the results one more time, which show that the resulting design now meets the design criteria for intersection crosswalk illuminance, midblock crosswalk illuminance, sidewalk semi-cylindrical illuminance, and roadway luminance. Table 7 shows the key criteria and results, and figure 22 shows a software rendering of the final lighting design.

Table 7. Summary of final lighting design criteria and calculation results.

Calculation Zone	Calculation Type	Units	Target Criteria	Calculation Results
			Average	Average
Midblock Crosswalk	Vertical Illuminance	Lux	20	25.19
Intersection Crossing (West)	Vertical Illuminance	Lux	30	30.87
Intersection Crossing (East)	Vertical Illuminance	Lux	30	31.29
Sidewalk (North)	SC Illuminance	Lux	10	10.02
Sidewalk (South)	SC Illuminance	Lux	10	10.02
Roadway (Westbound)	Luminance	Cd/m^2	2.0	2.54
Roadway (Eastbound)	Luminance	Cd/m^2	2.0	2.56

Note: Additional lighting design criteria recommended in IES *RP-8-18* should be evaluated and considered for uniformity and glare.

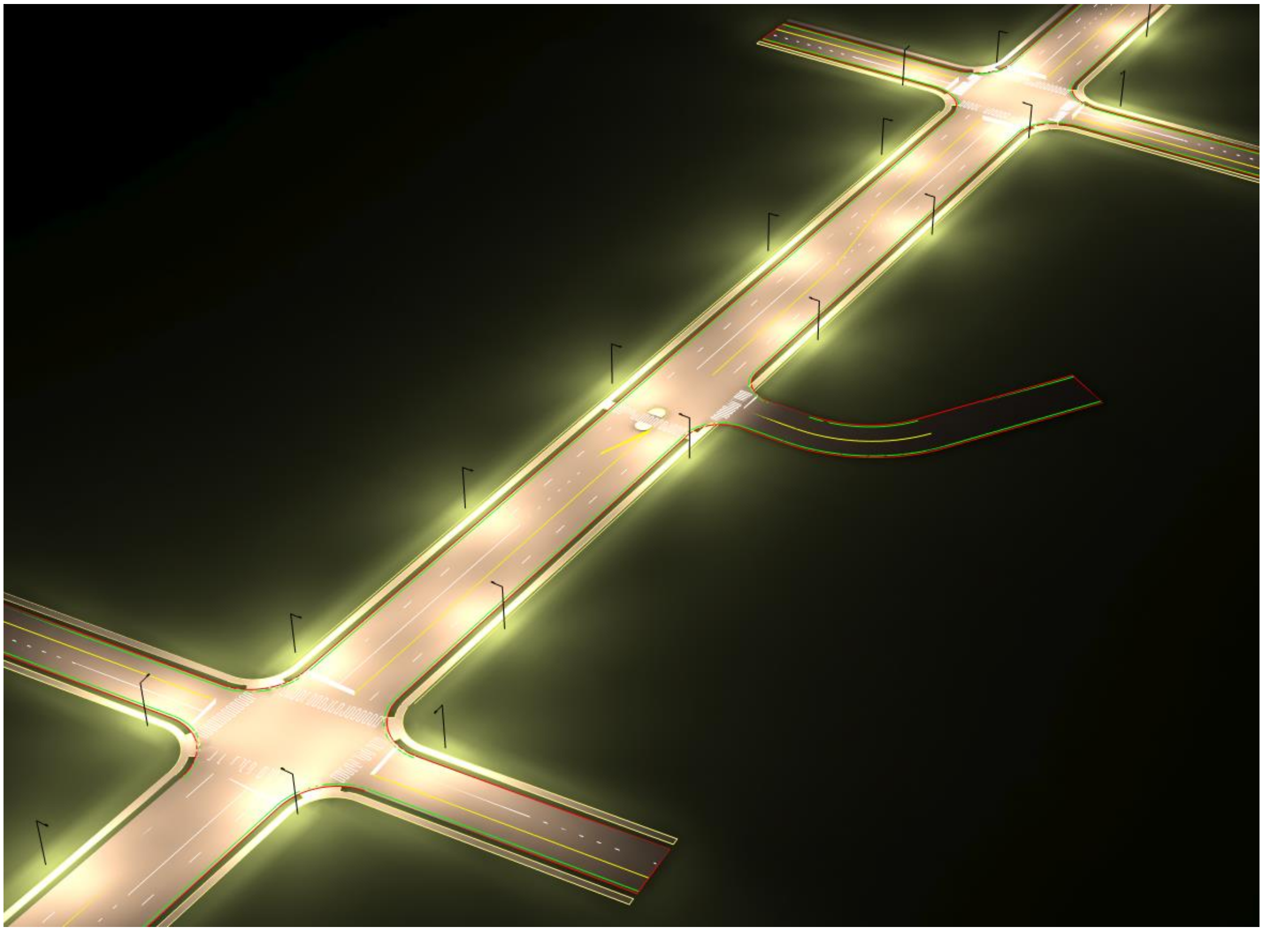


Figure 22. Graphic. Software rendering of final lighting design for example scenario. Source: FHWA.

This example presented the key characteristics of the location and illustrated the application of the pedestrian lighting design process described in Chapter 2, from assessment of lighting needs through design and verification. A comparison of the final calculation results to the selected design criteria reveals that the primary design goals of the lighting layout are achieved. The average luminance and illuminance metrics for each various type of facility (crosswalks, sidewalks, and roadway segments) are met or exceeded with the selected lighting design.

4. Summary and Conclusion

This primer is intended to be a resource for transportation practitioners interested in lighting design considerations for locations with pedestrian activity. The primer highlights how the results from the companion FHWA research report, Street Lighting for Pedestrian Safety (Terry et al., 2020), can complement lighting design information in commonly used lighting design guides.

The **introduction** to the primer establishes an understanding of recent trends in pedestrian safety and security in dark or nighttime conditions. It presents a summary of existing research indicating the benefits of lighting for improving pedestrian safety, citing studies that resulted in CMFs that quantify reductions in the number of vehicle/pedestrian crashes due to lighting ranging from 0.58 (42 percent reduction) to 0.19 (81 percent reduction), depending on crash severity (CMF IDs 435, 436, 440, 441, and 2379). It presents an overview of the relevant existing guidance, as well as gaps identified in the companion research report.

Section 2 walks through the lighting design process, with specific consideration of pedestrian lighting criteria and design considerations. The material in Chapter 2 is organized by the major steps of lighting design:

- Assessment of lighting needs.
- Selection of design criteria.
- Equipment selection.
- Determination of control strategy.
- Design and verification.

For each step of the lighting design process, the primer provides 1) an overview of selected terminology and general lighting design considerations with references to other resources for additional information and 2) specific lighting design considerations for pedestrians. The selection of lighting criteria for pedestrian facilities draws on information from two FHWA research and informational reports on pedestrian lighting: *Street Lighting for Pedestrian Safety* and *Informational Report on Lighting Design for Midblock Crosswalks*, as well as other commonly referenced lighting resources, such as RP-8-18 (Terry et al., 2020; Gibbons et al., 2008; IES, 2018).

Section 3 presents a lighting design example that depicts a typical scenario for lighting pedestrian facilities. The example walks through the site characteristics, design criteria, application of the design approach and interpretation of analysis results, and other considerations.

While not a focus of this primer, evaluating the success of lighting installations and maintaining their performance are key to sustaining lighting benefits over time. Systematic and data-driven maintenance and evaluation approaches can address racial and socio-economic disparities that exist in lighting maintenance processes driven only by self-reporting. In addition, community engagement programs that communicate with residents across geographic, socio-economic, racial, and language boundaries can assess whether lighting investments are meeting community needs.

As this primer has illustrated, lighting of pedestrian facilities is key to increasing the safety performance of the roadway network for all users. Effective pedestrian lighting is a means of addressing the vulnerability of pedestrians during dark conditions and improving the safety and security of all road users spanning different ages and abilities. This primer, along with the companion FHWA research report, *Street Lighting for Pedestrian Safety* (Terry et al., 2020), can help transportation practitioners to realize the benefits of lighting designs and provide safer facilities for pedestrians at night.

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