

NIGHTTIME VISIBILITY FOR SAFETY

# INFORMATIONAL REPORT ON LIGHTING DESIGN FOR CROSSWALKS

December 2024



Source: Getty Image



U.S. Department of Transportation  
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FHWA-SA-24-025

## Acknowledgements

This document is an update to the 2008 *Informational Report on Lighting Design for Midblock Crosswalks*. In addition to new material developed specifically for the update and based on emerging research and practice, it carries forward some content from the 2008 report that remains relevant. It also includes content from FHWA's *Pedestrian Lighting Primer* (FHWA, 2022).

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## SI\* (MODERN METRIC) CONVERSION FACTORS

### APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	square millimeters	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yard	0.836	square meters	m <sup>2</sup>
ac	acres	0.405	hectares	ha
mi <sup>2</sup>	square miles	2.59	square kilometers	km <sup>2</sup>
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft <sup>3</sup>	cubic feet	0.028	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup>				
<b>MASS</b>				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
<b>TEMPERATURE (exact degrees)</b>				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
<b>ILLUMINATION</b>				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m <sup>2</sup>	cd/m <sup>2</sup>
<b>FORCE and PRESSURE or STRESS</b>				
lbf	poundforce	4.45	newtons	N
lbf/in <sup>2</sup>	poundforce per square inch	6.89	kilopascals	kPa

### APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
<b>AREA</b>				
mm <sup>2</sup>	square millimeters	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	10.764	square feet	ft <sup>2</sup>
m <sup>2</sup>	square meters	1.195	square yards	yd <sup>2</sup>
ha	hectares	2.47	acres	ac
km <sup>2</sup>	square kilometers	0.386	square miles	mi <sup>2</sup>
<b>VOLUME</b>				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m <sup>3</sup>	cubic meters	35.314	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.307	cubic yards	yd <sup>3</sup>
<b>MASS</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
<b>TEMPERATURE (exact degrees)</b>				
°C	Celsius	1.8C+32	Fahrenheit	°F
<b>ILLUMINATION</b>				
lx	lux	0.0929	foot-candles	fc
cd/m <sup>2</sup>	candela/m <sup>2</sup>	0.2919	foot-Lamberts	fl
<b>FORCE and PRESSURE or STRESS</b>				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in <sup>2</sup>

\*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.  
(Revised March 2003)

# Table of Contents

<b>Chapter 1: Introduction</b> .....	<b>1</b>
<i>Pedestrian Fatalities in the U.S.</i> .....	2
Midblock and Intersection Crosswalk Characteristics and Crash Data Trends .....	5
<i>Benefits of Lighting for Pedestrian Safety and Security</i> .....	6
<i>How to Use This Report</i> .....	7
<i>Key Reference Materials</i> .....	8
<b>Chapter 2: Visibility Concepts</b> .....	<b>10</b>
<i>Illuminance</i> .....	10
Horizontal Illuminance .....	10
Vertical Illuminance.....	11
Semi-Cylindrical Illuminance .....	11
<i>Luminance</i> .....	12
<i>Factors Affecting Pedestrian Visibility</i> .....	12
Visual Background.....	12
Diffuse Reflectance .....	13
Contrast.....	14
Types of Vision .....	18
<b>Chapter 3: Midblock Crosswalk Lighting Design Considerations</b> .....	<b>19</b>
<i>Assessment of Potential Lighting Needs</i> .....	19
<i>Selection of Design Criteria</i> .....	21
Primary Design Criteria .....	22
Luminaire Placement .....	24
Secondary Design Criteria .....	25
<i>Equipment Selection and Other Design Considerations</i> .....	29
Luminaire Selection.....	29
IES Distribution Type .....	29
Luminaire Classification System (LCS) .....	31
Vertical Illuminance Visualization .....	32
Mounting Type .....	35
Pedestrian Scale Lighting .....	35
Effects of Landscaping and Structures .....	36
Lamp Type.....	37
Transition Lighting.....	38
<i>Control Strategy</i> .....	38
Adaptive Lighting .....	38
<i>Design and Verification</i> .....	39
<i>Crosswalk Illuminators</i> .....	39

<i>Additional Treatments to Improve Midblock Crosswalk Visibility</i> .....	40
High-Visibility Crosswalk Markings .....	40
Signing and Marking Improvements .....	42
Rectangular Rapid-Flashing Beacons (RRFBs) and Pedestrian Hybrid Beacons (PHBs).....	43
Parking Restrictions and Curb Extensions .....	44
Pedestrian Refuge Islands .....	45
<b>Chapter 4: Intersection Crosswalk Lighting Design Considerations .....</b>	<b>46</b>
<i>Assessment of Potential Lighting Needs</i> .....	46
<i>Design Criteria</i> .....	47
<i>Light Pole Layouts at Intersections</i> .....	47
Wider Intersection Approaches .....	49
Roundabouts.....	51
<i>Additional Treatments to Improve Intersection Crosswalk Visibility</i> .....	52
<b>Chapter 5: Design Examples .....</b>	<b>54</b>
<i>Example Scenario – Midblock Crossing</i> .....	54
Assess Potential Lighting Needs .....	55
Select Design Criteria .....	55
Select Equipment .....	56
Determine Control Strategy .....	57
Design and Verification .....	57
<i>Example Scenario - Roundabout</i> .....	61
Assess Lighting Needs .....	62
Select Design Criteria .....	62
Select Equipment .....	62
Determine Control Strategy .....	63
Design and Verification .....	63
<b>Chapter 6: Summary and Recommendations .....</b>	<b>69</b>
<b>References.....</b>	<b>71</b>

# List of Figures

FIGURE 1. GRAPHIC. PEDESTRIAN FATALITIES PER YEAR AND PEDESTRIAN FATALITIES PER YEAR AS A PERCENT OF TOTAL TRAFFIC FATALITIES. SOURCE: NHTSA.....	3
FIGURE 2. GRAPHIC. PEDESTRIAN FATALITIES PER YEAR IN DARK AND NON-DARK CONDITIONS AND NIGHT-TO-DAY PEDESTRIAN FATALITY RATIO. SOURCE: NHTSA.....	4
FIGURE 3. GRAPHIC. PERCENT OF PEDESTRIAN FATALITIES THAT OCCURRED IN DARK CONDITIONS BY RACE (2012-2021). SOURCE: NHTSA.....	4
FIGURE 4. GRAPHIC. HORIZONTAL, VERTICAL, AND SEMI-CYLINDRICAL ILLUMINANCE DIAGRAMS. SOURCE: FHWA.....	11
FIGURE 5. PHOTOGRAPH. VISUAL BACKGROUND FOR DRIVER IN A VEHICLE OBSERVING A PEDESTRIAN AT 61 M (200 FT) AND AT 305 M (1,000 FT) FROM THE PEDESTRIAN. SOURCE: FHWA.....	13
FIGURE 6. EQUATION. LUMINANCE OF A DIFFUSELY REFLECTING SURFACE.....	14
FIGURE 7. EQUATION. WEBER CONTRAST.....	14
FIGURE 8. PHOTOGRAPH. NEGATIVE CONTRAST (TOP) AND POSITIVE CONTRAST (BOTTOM). SOURCE: IES.....	15
FIGURE 9. EQUATION. WEBER CONTRAST (REDEFINED WITH OBJECT REFLECTANCE AND VERTICAL ILLUMINANCE).....	15
FIGURE 10. EQUATION. VISIBILITY LEVEL (VL).....	17
FIGURE 11. GRAPHIC. EXAMPLE OF THE SNELLEN EYE EXAM.....	18
FIGURE 12. GRAPHIC. TYPICAL CALCULATION GRID FOR MIDBLOCK CROSSWALKS PER IES RP-8-22. SOURCE: FHWA.....	24
FIGURE 13. GRAPHIC. TYPICAL LIGHT POLE ARRANGEMENT FOR A MIDBLOCK CROSSWALK. SOURCE: FHWA.....	25
FIGURE 14. GRAPHIC. EXAMPLE SPECTRAL POWER DISTRIBUTIONS OF VARIOUS ROADWAY LUMINAIRES. SOURCE: FHWA.....	26
FIGURE 15. GRAPHIC. DETECTION DISTANCE FOR RURAL HIGHWAY BY LIGHT TYPE AND LUMINANCE. SOURCE: FHWA.....	27
FIGURE 16. PHOTOGRAPH. EXAMPLE OF GLARE FROM A LIGHT SOURCE. SOURCE: FHWA.....	28
FIGURE 17. GRAPHIC. GENERAL REPRESENTATION OF IES DISTRIBUTION TYPES. MODIFIED FROM IES RP-8-22. SOURCE: FHWA.....	30
FIGURE 18. GRAPHIC. FORWARD, BACKWARD AND UPWARD ZONES FOR LCS. SOURCE: IES.....	31
FIGURE 19. GRAPHIC. SAMPLE LUMINAIRE CLASSIFICATION SYSTEM (LCS) REPORT. SOURCE: AGI32, LIGHTING ANALYSTS 2024.....	32
FIGURE 20. GRAPHIC. VERTICAL ILLUMINANCE DISTRIBUTION FROM CROSSWALK LUMINAIRE. SOURCE: AGI32, LIGHTING ANALYSTS 2024.....	33
FIGURE 21. GRAPHIC. VERTICAL ILLUMINANCE DISTRIBUTION FROM CROSSWALK LUMINAIRE, ALTERNATIVE LUMINAIRE. SOURCE: AGI32, LIGHTING ANALYSTS 2024.....	34
FIGURE 22. GRAPHIC. DETECTION DISTANCE BY LIGHT TYPE AND LUMINANCE. SOURCE: FHWA.....	36
FIGURE 23. PHOTO. EXAMPLE OF TREES IN CONFLICT WITH LIGHT POLES. SOURCE: GOOGLE EARTH.....	37
FIGURE 24. PHOTOGRAPH. MIDBLOCK CROSSWALK WITH (RIGHT) AND WITHOUT (LEFT) CROSSWALK ILLUMINATORS. SOURCE: IIHS.....	40
FIGURE 25. GRAPHIC. MUTCD GUIDANCE FOR CROSSWALK MARKINGS. SOURCE: FHWA.....	41
FIGURE 26. PHOTO. A PEDESTRIAN CROSSES THE ROAD AT A MIDBLOCK CROSSWALK USING HIGH-VISIBILITY CROSSWALK MARKINGS. SOURCE: VHB.....	41
FIGURE 27. GRAPHIC. REGULATORY SIGNS FOR CROSSWALK LOCATIONS. SOURCE: FHWA.....	42
FIGURE 28. GRAPHIC. WARNING SIGNS FOR CROSSWALK LOCATIONS. SOURCE: FHWA.....	42
FIGURE 29. GRAPHIC. IN-STREET PEDESTRIAN CROSSING SIGN. SOURCE: FHWA.....	43
FIGURE 30. PHOTOGRAPH. RECTANGULAR RAPID FLASHING BEACON (RRFB). SOURCE: FHWA.....	44
FIGURE 31. PHOTOGRAPH. PEDESTRIAN HYBRID BEACON (PHB). SOURCE: FHWA.....	44
FIGURE 32. PHOTOGRAPH. EXAMPLE OF CURB EXTENSIONS AT A PEDESTRIAN CROSSWALK (FHWA, N.D.). SOURCE: FHWA.....	45
FIGURE 33. GRAPHIC. PLAN VIEW SKETCH OF CURB EXTENSIONS AT A PEDESTRIAN CROSSWALK. SOURCE: FHWA.....	45
FIGURE 34. GRAPHIC. ILLUSTRATION OF INTERSECTION LIGHTING POLE ARRANGEMENTS: A) ILLUMINATED APPROACH, B) CENTER LIGHTING, C) ILLUMINATED EXIT, D) ILLUMINATED WITH LUMINAIRES ON SIGNAL MAST ARM (IDOT DESIGN) (ADAPTED FROM FHWA).....	48
FIGURE 35. GRAPHIC. POTENTIAL LIGHTING LAYOUT FOR CROSSWALKS AT WIDE INTERSECTION APPROACHES. SOURCE: FHWA.....	50
FIGURE 36. GRAPHIC. POTENTIAL LIGHTING LAYOUT FOR VERY WIDE INTERSECTION APPROACHES (ADAPTED FROM FDOT, 2022).....	50
FIGURE 37. GRAPHIC. TYPICAL LIGHTING LAYOUT FOR A ROUNDABOUT. SOURCE: AASHTO (2018).....	52
FIGURE 38. GRAPHIC. EXAMPLE OF A TRAIL CROSSING LIKE THE EXAMPLE SCENARIO. SOURCE: VHB.....	55
FIGURE 39. GRAPHIC. EXAMPLE LED PENDANT ROADWAY LUMINAIRE (GOOGLE MAPS, 2021).....	56
FIGURE 40. GRAPHIC. SOFTWARE RENDERING OF FINAL LIGHTING DESIGN FOR MIDBLOCK TRAIL CROSSING EXAMPLE SCENARIO. SOURCE: VHB.....	60

FIGURE 41. ILLUSTRATION OF A RURAL, ONE LANE ROUNDABOUT. SOURCE: FHWA. ....	61
FIGURE 42. GRAPHIC. EXAMPLE LED COBRAHEAD ROADWAY LUMINAIRE MOUNTED TO WOOD POLE. SOURCE: FHWA. ....	63
FIGURE 43. GRAPHIC. SOFTWARE RENDERING OF FINAL LIGHTING DESIGN FOR EXAMPLE SCENARIO. SOURCE: VHB.....	68

# List of Tables

TABLE 1. RP-8-22 RECOMMENDED VERTICAL ILLUMINANCE LEVELS FOR MIDBLOCK CROSSWALKS..... 23

TABLE 2. LIGHTING DESIGN AND LIGHT LEVEL RECOMMENDATIONS FOR INTERSECTIONS (BHAGAVATHULA ET AL., 2021)). ..... 49

TABLE 3. SELECTED DESIGN CRITERIA FOR EXAMPLE SCENARIO 1..... 56

TABLE 4. SUMMARY OF INITIAL LIGHTING DESIGN CRITERIA AND CALCULATION RESULTS..... 58

TABLE 5. SUMMARY OF REVISED LIGHTING DESIGN CRITERIA AND CALCULATION RESULTS..... 59

TABLE 6. SUMMARY OF FINAL LIGHTING DESIGN CRITERIA AND CALCULATION RESULTS..... 60

TABLE 7. SELECTED DESIGN CRITERIA FOR EXAMPLE SCENARIO 2..... 62

TABLE 8. SUMMARY OF INITIAL LIGHTING DESIGN CRITERIA AND CALCULATION RESULTS..... 65

TABLE 9. SUMMARY OF REVISED LIGHTING DESIGN CRITERIA AND CALCULATION RESULTS..... 66

TABLE 10. SUMMARY OF FINAL LIGHTING DESIGN CRITERIA AND CALCULATION RESULTS..... 67

# Chapter 1: Introduction

Properly designed roadway lighting enhances visibility and improves safety for all users at night. This is especially true for pedestrian lighting installations, such as those at midblock and intersection crosswalks. These installations help address the access and mobility needs of pedestrians, including wheelchair and other mobility device users, during critical periods of darkness when the number of pedestrian fatalities increases, even though motorized traffic volumes are lower.

FHWA published the *Informational Report on Lighting Design for Midblock Crosswalks* in 2008 (Gibbons et al., 2008). Since its publication, the research and practicing communities have continued to gain experience and knowledge relevant to lighting design for midblock and intersection crosswalks. Additionally, lighting implementation has benefited from significant technological improvements, including widespread use of solid-state lighting; introduction of concepts more relevant to pedestrian visibility, such as semi-cylindrical illuminance; adaptive lighting; and new research on how primary and secondary design criteria influences pedestrian visibility.

This document serves as an updated version of the 2008 report, continuing the *Informational Report's* role as a key resource for lighting design for midblock and intersection crosswalks. The American Association of State Highway and Transportation Officials (AASHTO) *Roadway Lighting Design Guide, 7<sup>th</sup> Edition* (AASHTO, 2018) is a key resource for lighting designers in the U.S. There have been advancements in lighting technology and new key resources published since 2018 when the AASHTO *Roadway Lighting Design Guide* was last updated. These include National Cooperative Highway Research Program (NCHRP) Research Report 940, *Solid-State Roadway Lighting Design* (Lutkevich et al., 2020a; Lutkevich et al., 2020b); FHWA's *Research Report: Street Lighting for Pedestrian Safety* (Terry et al., 2020), *Pedestrian Lighting Primer* (FHWA, 2022), and *2023 FHWA Lighting Handbook* (Gibbons et al., 2023); and *Recommended Practice: Lighting Roadway and Parking Facilities*, known as RP-8-22 (IES, 2022). This *Informational Report* update fills a current gap by incorporating these new resources, research findings, and lighting technologies with a focus on pedestrian visibility at night. It features current information, reflecting research, equipment, and analysis advancements over the past 16 years. It also expands on discussions related to luminaire types, design principles, design metrics, and other key topics.

The report begins with background on relevant national trends in pedestrian fatalities and the documented benefits of lighting for pedestrian safety and security. The background also includes a description of how to use the informational report and a brief review of key reference materials related to pedestrian visibility and lighting design. Chapter 2 reviews foundational visibility concepts, including key definitions and factors affecting pedestrian visibility. Chapter 3 describes concepts and considerations for midblock crosswalk lighting design, including lighting design criteria, luminaire selection and placement, other lighting design considerations, crosswalk illuminators, and general midblock design and traffic control strategies. Chapter 4 provides information on lighting design for crosswalks at intersections. Chapter 5 contains two practical design examples covering a midblock

crosswalk and an intersection. Chapter 6 concludes the report with a summary and descriptions of key takeaways and future research needs.

## Pedestrian Fatalities in the U.S.

Pedestrian fatalities in the U.S. have been increasing over the past 10 years, both in frequency and as a percent of total U.S. traffic fatalities. Figure 1 shows that over 17 percent of people killed in traffic crashes in 2022 were pedestrians, up from 14 percent in 2013 (NHTSA, 2024).

NHTSA reported that 77 percent of pedestrian fatalities in 2022 occurred in dark conditions (including 35 percent in “Dark – Not Lighted,” 40 percent in “Dark – Lighted,” and 3 percent in “Dark – Unknown Lighting” conditions). This is an increase from 71 percent of pedestrian fatalities in dark conditions in 2013 (NHTSA, 2024). The “Dark-Lighted” category captures a wide range of lighting conditions and points to the importance not only of providing lighting for pedestrian safety, but of providing well-designed lighting. Figure 2 shows that pedestrian fatalities in dark conditions outnumber those in non-dark conditions<sup>1</sup>. Figure 2 also shows that the ratio of night-to-day pedestrian fatalities<sup>2</sup> has been increasing over the past ten years from 2.48 in 2013 to 3.36 in 2022. The increased risk for pedestrians traveling at night becomes even more evident when one considers that only 25 percent of traffic volume occurs after dark (Griffith, 1994; CIE, 2010). In other words, in the last five years, over 3 times more pedestrian fatalities occurred during times when fewer vehicles are on the road.

Data indicate that minority communities experience a disproportionate burden of pedestrian fatalities in dark conditions. Figure 3 shows that the Pacific Islander, American Indian, and Black communities experience the highest percentages of pedestrian fatalities in dark conditions (NHTSA, 2024).

Lighting is one of FHWA’s Proven Safety Countermeasures and can reduce nighttime pedestrian injury crashes at intersections by up to 42 percent, nighttime crashes at rural and urban intersections by 33-38 percent, and nighttime injury crashes on rural and urban highways by 28 percent (FHWA, 2021a).

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<sup>1</sup> Dark conditions are defined in this analysis as “Dark – Not Lighted,” “Dark – Lighted,” and “Dark – Unknown Lighting”. Non-dark conditions capture remaining light condition categories: “Daylight,” “Dawn,” “Dusk,” “Other,” “Not Reported,” and “Unknown.” In other words, the sum of dark and non-dark pedestrian fatalities equals the total number of pedestrian fatalities.

<sup>2</sup> Ratios of night-to-day pedestrian fatalities are defined in this analysis as the ratio of the number of fatalities during dark conditions to the number of fatalities during daylight, dawn, or dusk conditions.

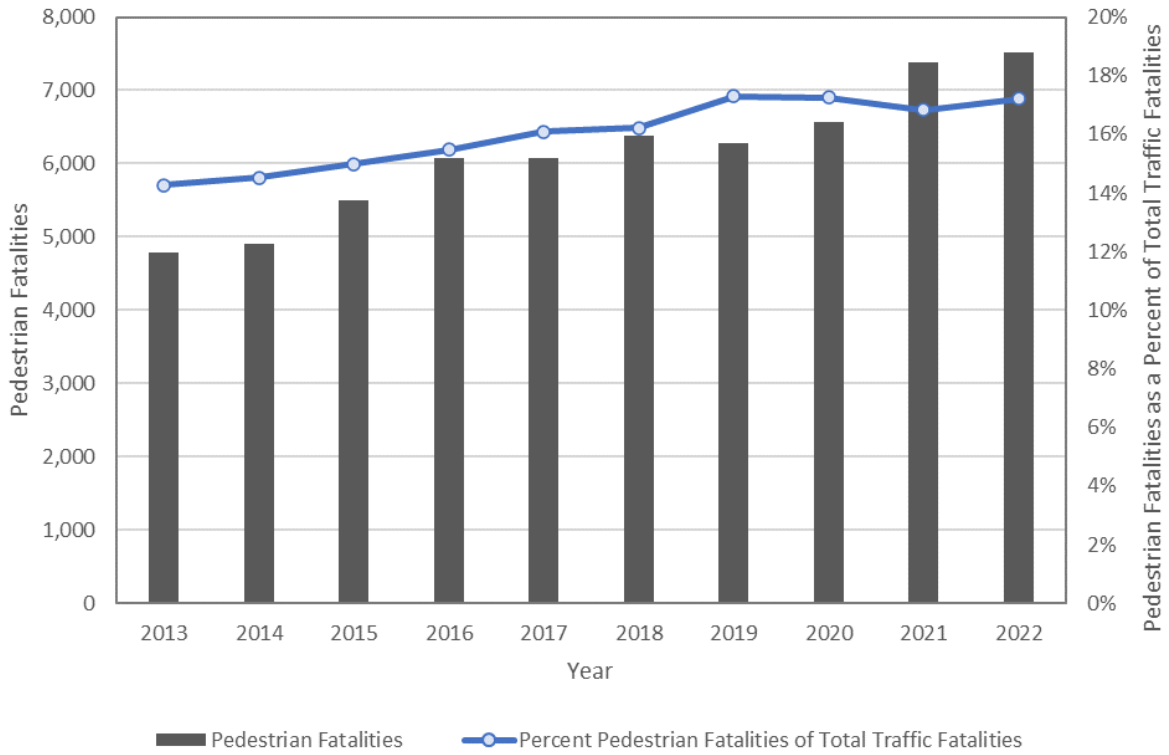


Figure 1. Graphic. Pedestrian fatalities per year and pedestrian fatalities per year as a percent of total traffic fatalities. Source: NHTSA.

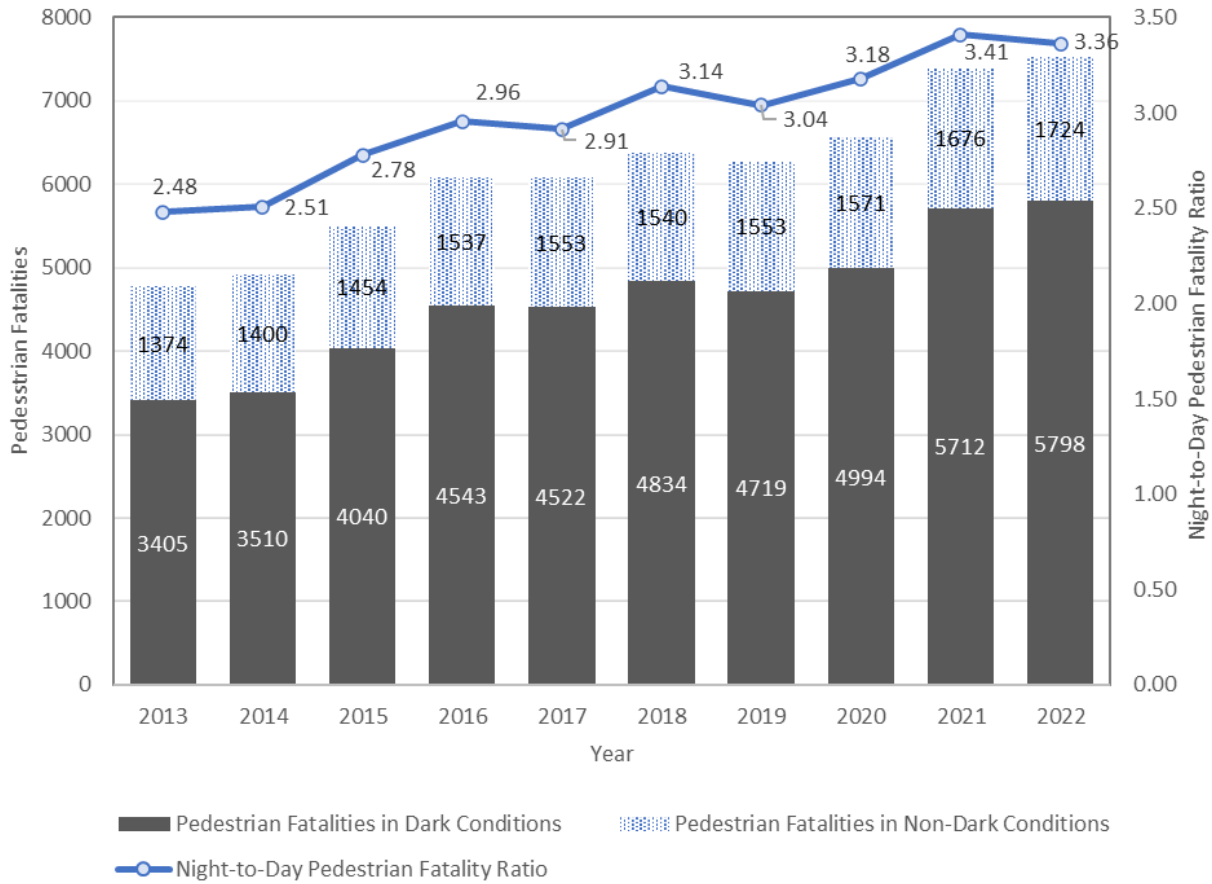


Figure 2. Graphic. Pedestrian fatalities per year in dark and non-dark conditions and night-to-day pedestrian fatality ratio. Source: NHTSA.

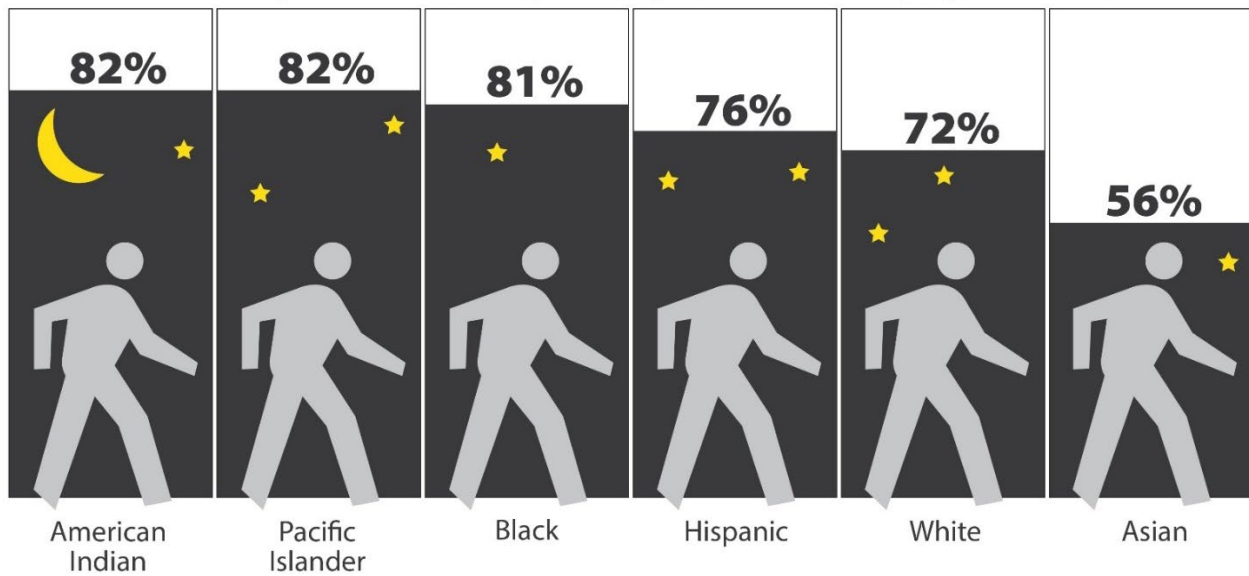


Figure 3. Graphic. Percent of pedestrian fatalities that occurred in dark conditions by race (2012-2021). Source: NHTSA.

## *Midblock and Intersection Crosswalk Characteristics and Crash Data Trends*

Crosswalks are present at both midblock and intersection locations and play a key role in connecting pedestrians to their trip destinations. A midblock crosswalk is any crosswalk that occurs at a location other than an intersection (IES, 2022). Midblock crosswalks enhance the transportation network for pedestrians and other vulnerable road users by facilitating crossings that are not served by existing roadway intersections (NACTO, 2013). Midblock crosswalks are often placed near transit stops, schools, parks, building entrances, retail locations, and other key destinations.

The use of midblock crosswalks and their characteristics can vary greatly depending on the area type, surrounding land use, and other factors that define context and user needs. For example, in dense urban areas with closely spaced signalized intersections, pedestrians may be more likely to walk to the nearest signalized intersection to cross. But in less dense urban, suburban, or rural areas, blocks are longer, traffic signals are less frequent, and signal cycles are longer. Requiring pedestrians to navigate to the nearest intersection to cross in these types of areas is less convenient for pedestrians and does not provide pedestrians with adequate levels of accessibility and connectivity to their destinations (FHWA, 2006). Implementing midblock crosswalks improves connectivity but must also be done in a way that recognizes context and prioritizes safety. For example, midblock crosswalks on lower-volume, lower-speed roadways may be relatively simple to implement, while midblock crosswalks across multi-lane, higher-volume, and/or higher-speed roadways may require additional treatments to alert drivers, slow vehicle speeds, and reduce the complexity of the crossing movement for pedestrians.

Lighting is particularly important at midblock crosswalks because drivers may be less expectant of crossing pedestrians at these locations during nighttime travel than at intersections. Lighting at midblock crosswalks helps bring a driver's attention to the midblock crossing location and detect pedestrians from longer distances.

Crosswalks at intersections are also an important component of a transportation network. Intersections represent key connection points between different roads and therefore serve to facilitate network connectivity for all road users. Intersections feature conflict points, which are points where the paths of different road user movements cross, merge, or diverge, including the locations where motor vehicle paths intersect with pedestrian crosswalks. Marked intersection crosswalks help designate how pedestrians should navigate an intersection and indicate to motorists that pedestrians should be expected at the intersection. Lighting is important at intersection crosswalks to assist drivers approaching and navigating through an intersection at night to detect and yield to crossing pedestrians.

NHTSA's national fatal and injury crash databases do not contain a specific data attribute for midblock crosswalks (NHTSA, 2024). The national databases do support assessments of the number of fatalities that have occurred at intersection and non-intersection locations, with non-intersection locations including, but not limited to, midblock crosswalks. Dark conditions are a risk factor for pedestrian fatalities at both location types. From 2013 to 2022, 67 percent of intersection or intersection-related

pedestrian fatalities occurred in dark conditions. Over the same period, 79 percent of non-intersection pedestrian fatalities occurred in dark conditions (NHTSA, 2024). These percentages correspond to night-to-day pedestrian fatality ratios of 2.05 for intersection and intersection-related locations and 3.76 for non-intersection locations (NHTSA, 2024).

## Benefits of Lighting for Pedestrian Safety and Security

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. These studies have resulted in crash modification factors (CMFs)<sup>3</sup> 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. Citing the work of Elvik & Vaa (2004) and Ye et al. (2008), FHWA's Proven Safety Countermeasures<sup>4</sup> resources highlight the following safety benefits of lighting (FHWA, 2021a):

- 42 percent reduction in nighttime injury pedestrian crashes at intersections.
- 33-38% reduction in nighttime crashes at rural and urban intersections.
- 28% reduction in nighttime injury crashes on rural and urban highways.

More recent research is not only capturing the effects of lighting presence, but how safety performance changes as a function of lighting design parameters. 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 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 level of light that is provided.

The ability to take lighting measurements in the field with mobile equipment is continuing to improve knowledge of how different lighting levels and design parameters relate to nighttime crashes. Bhagavathula et al. (2015) collected illuminance measurements from 99 rural intersections in Virginia

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<sup>3</sup> A crash modification factor (CMF) is a multiplicative factor that quantifies the anticipated number or rate of crashes that will occur after implementing a roadway safety countermeasure, compared to pre-implementation conditions. For more information regarding CMFs, visit <https://www.cmfclearinghouse.org/>

<sup>4</sup> The FHWA Proven Safety Countermeasures are a collection of countermeasures and strategies effective in reducing roadway fatalities and serious injuries on highways, with a focus on speed management, intersections, roadway departures, and pedestrians/bicyclists. For more information regarding Proven Safety Countermeasures, visit <https://highways.dot.gov/safety/proven-safety-countermeasures>

with and without lighting. Their model results showed that a one lux increase in the average horizontal illuminance corresponded to a seven percent decrease in the night-to-day crash ratio. In a more recent and expansive study of intersections in Virginia, Li et al. (2020) found that nighttime crashes were related to the minimum illuminance and the illuminance uniformity in the intersection. The analysis showed a 2.9 percent reduction in night-to-day crash ratios for each 1-lux increase of minimum illuminance. A one unit increase in illuminance uniformity<sup>5</sup> of the intersection was associated with a 1.9 percent increase in night-to-day crash ratios. The study focused on horizontal illuminance measurements and did not address vertical illuminance or presence of pedestrians.

In addition to increasing the risk of pedestrian crashes, 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 (Painter, 1996). Women report experiencing fear, real or perceived, at night that significantly constrains their travel behavior (Smith, 2008; Loukaitou-Sideris, 2010). Studies have documented that women suffer disproportionately high rates of victimization, especially from gender violence and theft, at night (Smith, 2008). Well-designed lighting plays a role in reducing women's fear of walking or accessing transit at night (Loukaitou-Sideris, 2010).

Several other studies show that new or improved lighting increases pedestrians' perception of security. Peña-García et al. (2015), for example, surveyed 275 pedestrians in Granada, Spain and found that higher illuminance levels tend to increase perceptions of security. This finding substantiates several other studies that have shown lighting to influence perceptions of security (Loewen et al., 1993; Nasar et al., 1993; Nasar & Jones, 1997). In addition, the type, quality, and distribution of lighting also affect perceived security (Boyce et al., 2000; Haans & de Kort, 2012; Markvica et al., 2019; Portnov et al., 2020).

New or improved lighting can increase security and encourage pedestrian activity at night, including 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).

## How to Use This Report

This informational report is directed at transportation planners, designers, and operations personnel involved in enhancing safety, accessibility, and mobility of all users of a road network. It can serve as an introduction to pedestrian lighting design for crosswalks, especially in combination with some of the additional reference materials presented in the following section. It may be particularly valuable for transportation safety practitioners and other agency staff who may not be directly involved in lighting

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<sup>5</sup> Li et al. (2020) used an illuminance uniformity definition for the crash analysis that was (maximum illuminance – minimum illuminance) / average illuminance. Therefore, an increase in this ratio means a less uniform lighting design.

design but would benefit from an increased understanding of the basic principles, benefits, and design considerations for lighting pedestrian crosswalks.

Some readers may read through the whole report; doing so will provide a well-developed understanding of key lighting terminology and design considerations at midblock and intersection crosswalks, and which design resources to use. Other readers may find this report more useful as a reference for specific, focused topics and can use the table of contents to navigate to a particular chapter or section.

It is important that a qualified lighting designer perform the actual steps of lighting design using the resources described in the following paragraphs and finalize any design plans.

## Key Reference Materials

There are several key lighting design and warranting guidance documents that serve as the basis for roadway lighting design in the U.S. The American National Standards Institute (ANSI) and the Illuminating Engineering Society (IES) published *Recommended Practice: Lighting Roadway and Parking Facilities*, known as RP-8-22 (IES, 2022). This document includes lighting design criteria for roadways and other facilities, including roadway segments, tunnels, intersections, and parking areas. Some sections of RP-8-22 deal specifically with midblock and intersection crosswalks, including content on lighting measurements, design considerations, issues, and recommendations as well as a design example with calculations.

As highlighted in the introduction to this report, AASHTO published the seventh edition of the *Roadway Lighting Design Guide* in 2018 (AASHTO, 2018). The guide reviews lighting systems and recommends minimum design criteria. It also provides some guidance on warranting lighting installations.

In 2022, AASHTO released the first edition of the *Solid-State Lighting Guide*, a design, maintenance, and operations guide specific to solid-state lighting (SSL) technology using light-emitting diodes (LEDs). This guide is a companion to the *Roadway Lighting Design Guide*. It is based on research conducted through the National Cooperative Highway Research Program (NCHRP) and is also detailed in NCHRP Research Report 940, *Solid-State Roadway Lighting Design* (Lutkevich et al., 2020a; Lutkevich et al., 2020b).

There are other key resources that provide information on nighttime visibility and lighting design research findings, guidance, and key considerations. The *2023 FHWA Lighting Handbook* is a resource for lighting designers and policy makers to inform processes for evaluating lighting needs and benefits, with the goal of improving safety through optimal lighting installation (Gibbons, et al., 2023). FHWA's *Pedestrian Lighting Primer* was published as an introductory resource for transportation practitioners interested in understanding the safety and security benefits, as well as the key design considerations, of pedestrian lighting (FHWA, 2022). It draws on the FHWA research report *Street Lighting for Pedestrian Safety* that documents the benefits of pedestrian lighting as determined through visibility research (Terry et al., 2020). The Transportation Association of Canada's (TAC) *Guide for the Design of Roadway Lighting* provides guidance on the planning and design of outdoor lighting for various types of roadway

and pedestrian facilities (TAC, 2006). The TAC Guide includes warrant worksheets for different facility and site types that evaluate the need for lighting based on various geometric, operational, and environmental factors. The worksheets, which employ a point score system, are based on the format first proposed in NCHRP Report 152 (Walton & Rowan, 1974).

FHWA's [Safe Transportation for Every Pedestrian \(STEP\)](#) initiative promotes effective, proven countermeasures for increasing pedestrian safety at uncontrolled midblock crosswalks (FHWA, 2021b; Blackburn et al., 2018). One of the STEP countermeasures is crosswalk visibility enhancements, which includes lighting as well as signing, markings, and geometric design elements such as curb extensions. STEP developed materials to promote this countermeasure, including a tech sheet, video, and other products (FHWA, 2018; FHWA, 2019).

FHWA encourages States and communities to adopt and implement Complete Streets policies that prioritize the safety of all users in transportation network planning, design, construction, and operation. Section 11206 of the Bipartisan Infrastructure Law defines Complete Streets standards or policies as those that "ensure the safe and adequate accommodation of all users of the transportation system, including pedestrians, bicyclists, public transportation users, children, older individuals, individuals with disabilities, motorists, and freight vehicles." There is no one-size-fits-all approach to Complete Streets. Identifying community context and needs is necessary to provide equitable streets and networks that prioritize safety, comfort, and connectivity for all users of the transportation system.

Designs that prioritize safety and access for all users may include features such as sidewalks, bicycle lanes, dedicated bus lanes, accessible public transportation stops, safe and accessible crosswalks, median refuge islands, pedestrian and bicycle signals, curb extensions, narrower travel lanes, lighting, and roundabouts.

A Complete Streets design model includes:

- Measures to set and design for appropriate speeds.
- Separation of different user types in time and space.
- Improvement of connectivity and access for pedestrians, bicyclists, and transit riders, including people with disabilities.
- Implementation of Proven Safety Countermeasures to address safety issues.

Complete Streets can help improve safe access for all users, particularly on urban and suburban non-freeway arterials, and on rural arterials that serve as main streets in smaller communities.

# Chapter 2: Visibility Concepts

There are several important metrics that define the performance of a light source. Illuminance and luminance are measures of light incident on a surface or emitted from a source, respectively, and are the most common metrics for measuring the quantity of light. Contrast is the measurable visible difference between a person or object and its background and a significant determinant of how visible an object is. Lighting design guidelines consider these basic metrics and concepts; however, a wide variety of other visual factors and individual differences make universal standards for visibility difficult to generalize.

Design criteria and recommended practices are guided by basic measures of lighting levels such as average and average-to-minimum ratios. RP-8-22, a key reference identified in Chapter 1, includes criteria for average luminance, illuminance, and uniformity ratios for various road classifications (IES, 2022). The AASHTO *Roadway Lighting Design Guide* provides recommended lighting levels using illuminance criteria (AASHTO, 2018). Both publications consider various characteristics of the design facility, which influence the recommended quantity and uniformity of light, including roadway classification, pedestrian activity level, and other factors. FHWA regulations do not require the use of these sources or the procedures they contain.

## 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*

Horizontal illuminance is measured in a horizontal orientation (see figure 4), defining the amount of light falling on a horizontal plane such as a road surface. 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; Rea, 2000; Eloholma et al., 2006; Terry et al., 2016). Previous studies have indicated that nighttime crashes at intersections can be mitigated by an increase in the horizontal illuminance level (Ando & Kanoshima, 2002; Minoshima et al., 2006; Oya, Bhagavathula et al., 2015; Li et al. (2020). However, there may be an optimal point beyond which no additional benefit is gained from further increasing horizontal illuminance.

## Vertical Illuminance

Vertical illuminance defines the amount of light falling on a vertical plane or surface (see figure 4). Vertical illuminance helps road users detect and identify 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. To characterize glare experienced by drivers from a lighting design, measurements of vertical illuminance are typically recorded at the eye level of drivers oriented to their path of travel. To characterize the amount of vertical illuminance falling on a pedestrian intended to be seen by drivers, the measurement is oriented towards the direction of approaching drivers at a measurement height of 1.5 m (5 ft) from the ground to represent the height of a standing adult pedestrian. Research has shown that driver detection distances of pedestrians increase with increasing levels of vertical illuminance in crosswalks (Edwards & Gibbons, 2008). Again, there may be an optimum vertical illuminance no additional pedestrian visibility benefit is gained from further increasing vertical illuminance.

## Semi-Cylindrical Illuminance

Whereas vertical illuminance is a measure of the amount of light falling on a flat surface in the vertical plane, semi-cylindrical illuminance is a measure that represents the amount of light falling on an upright semi-cylinder (see figure 4). It is the average vertical illuminance on the curved surface of the upright semi-cylinder in figure 4 (Gibbons et al., 2023). Semi-cylindrical illuminance may more accurately represent the visibility of pedestrians and recognition of facial features since it helps account for the three-dimensional nature of pedestrians. It may also be a particularly helpful metric in urban settings with a significant amount of ambient light. Semi-cylindrical illuminance is 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. Like vertical illuminance, research indicates that higher levels of semi-cylindrical illuminance correspond to an increase in pedestrian detection distance (Terry et al., 2020).



Figure 4. Graphic. Horizontal, vertical, and semi-cylindrical illuminance diagrams. Source: FHWA.

# Luminance

Luminance is the amount of light that reflects 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 ( $\text{cd}/\text{m}^2$ ) or non-SI units of footlambert (fL), where one fL is equal to  $3.426 \text{ cd}/\text{m}^2$ . 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. The *2023 FHWA Lighting Handbook* notes that “luminance is a much better metric than illuminance because it considers not only the amount of light that reaches a surface, but also how much of that light is reflected toward the driver” (Gibbons et al., 2023). At night, drivers may be able to detect objects and pedestrians sooner as the average luminance of the roadway increases (He et al., 1997; Lewis, 1999; Cuvalci & Ertas, 2000; Gibbons et al., 2015). However, the following sections will highlight that this will also depend on other factors that affect visibility.

## Factors Affecting Pedestrian Visibility

In addition to the common lighting metrics used to define the quantity of light provided and reflected, there are other elements that influence a viewer’s ability to detect and identify pedestrians in and around the roadway, including the visual background, reflectance, and contrast. The following sections provide a summary of additional factors affecting pedestrian visibility at night.

### *Visual Background*

The visual background for most crosswalks consists of the roadway and the general environment surrounding the roadway. The general environment surrounding the roadway can vary significantly depending on the area type and land use. Roads in urban and suburban areas are more likely to have the types of adjacent features that increase background luminance. For example, bright off-roadway lighting installations such as those at gas stations, banks, or shopping areas increase background luminance and can reduce pedestrian contrast, making pedestrian detection more difficult. The concept of contrast is discussed later in this section.

Another reason that background luminance affects pedestrian detection is that background luminance is not uniform. The background is dependent on the driver’s perspective while approaching a pedestrian. This can depend on the type of background, which will vary by area type, and by road geometrics (e.g., horizontal curvature, vertical grade). In figure 5, a driver’s view approaching a pedestrian in the roadway is shown at distances of 61 m (200 ft) and 305 m (1,000 ft) from the pedestrian. Red arrows point to the pedestrian crossing the roadway. Figure 5 shows that the background against which the pedestrian is viewed changes as the vehicle approaches the pedestrian. At 305 m (1,000 ft), the pedestrian is primarily seen against the environment around the roadway (e.g., the sky and unlit distant background), whereas at 61 m (200 ft) the lower half of the pedestrian is seen against the bright background of the lit roadway. A lighting system should be designed to provide

adequate performance even with a bright background. Typically, the brighter the background, the higher the vertical illuminance that is provided at a pedestrian crossing.



*Figure 5. Photograph. Visual background for driver in a vehicle observing a pedestrian at 61 m (200 ft) and at 305 m (1,000 ft) from the pedestrian. Source: FHWA.*

Ambient lighting is a significant contributing factor to high levels of background luminance. Locations that are surrounded by developed land uses may experience a higher level of ambient lighting. Common sources of ambient lighting include parking lots, gas stations, restaurants, hotels, banks, and industrial sites. While discussed in the context of higher background luminance levels at intersections, the 2008 informational report noted that vertical illuminance level of 30 lux is considered a conservative estimate of desired design criteria with higher levels of ambient lighting (Gibbons et al., 2008) and highlighted additional research is needed to study the effects of this specific issue.

## ***Diffuse Reflectance***

Light incident on a surface is either absorbed or reflected. There are three types of reflectance: specular, diffuse, and retroreflection. Under specular reflectance, the light is reflected at an equal and opposite angle from the angle of incidence (both angles measured from the normal of the surface). Diffuse reflectance occurs when the light is reflected in all directions, with the amount of reflected light in any given direction proportional to the cosine of the angle between the direction of reflection and the normal of the surface. Retroreflection occurs when light is reflected back toward the source of illumination. Pedestrian clothing tends to produce more diffuse reflectance. Thus, the properties of a diffuse reflector are used to calculate the luminance of a pedestrian under roadway lighting. The general equation for the luminance of a diffuse reflector is shown in figure 6 as a function of

illuminance and the Lambertian reflectance. Lambertian reflectance is a property of a surface that represents the amount of light reflected by the surface in all directions.

$$L = \frac{\rho \times E}{\pi}$$

Figure 6. Equation. Luminance of a diffusely reflecting surface.

Where,

$L$  = observed luminance

$\rho$  = Lambertian reflectance (unitless value less than 1)

$E$  = illuminance

## Contrast

Contrast is the measurable visible difference between an object and the object's background. There are two types of contrast: color contrast and luminance contrast. Color contrast is the measurable difference between two colors and luminance contrast is the measurable difference in apparent brightness between an object and its background.

Weber contrast is one method of measuring luminance contrast, which considers the difference in the object luminance and background luminance divided by the background luminance. The formula for Weber Contrast is presented in Figure 7. When the object appears brighter than the visual background, the weber contrast is positive, ranging from zero to infinity. When the background appears brighter than the object (i.e., the object appears in silhouette), the weber contrast is negative with a value ranging from negative one to zero. Figure 8 depicts a pedestrian in negative and positive contrast.

$$\text{Weber Contrast} = \frac{L_{\text{object}} - L_{\text{background}}}{L_{\text{background}}}$$

Figure 7. Equation. Weber contrast.

Where,

$L_{\text{object}}$  = object luminance

$L_{\text{background}}$  = background luminance



Figure 8. Photograph. Negative contrast (top) and positive contrast (bottom). Source: IES.

By substituting the object luminance with a specific reflectance ( $\rho_{Object}$ ) and the vertical illuminance ( $E_{vertical}$ ), contrast may be rewritten as shown in figure 9.

$$C = \frac{\left( \frac{\rho_{Object} \cdot E_{vertical}}{\pi} - L_{Background} \right)}{L_{Background}}$$

Figure 9. Equation. Weber contrast (redefined with object reflectance and vertical illuminance).

In this formula, if the object of interest is a pedestrian, the reflectance ( $\rho_{Object}$ ) is determined by the pedestrian's clothing. The vertical illuminance on the pedestrian ( $E_{vertical}$ ) is provided by a light source (e.g., roadway lighting, headlight), and the background luminance ( $L_{background}$ ) is determined by the location of the crosswalk in the roadway and the surrounding environment. Vertical illuminance is the main parameter controlled by the designer for midblock crosswalk lighting. Although a public agency

has little influence over pedestrians' clothing selections, high reflectance clothing will certainly improve detection. Research showed that the detection distance for a pedestrian dressed in white clothing was higher than that for a pedestrian dressed in denim or black clothing, regardless of illuminance level (Edwards & Gibbons, 2008). Public outreach regarding high reflectance clothing may have a positive influence on pedestrian safety; however, this should not be relied upon as an effective safety strategy.

The type of pavement material also impacts the contrast of pedestrians at night. Typically, an asphalt road will reflect far less light than a concrete surface will, resulting in a lower background luminance and therefore higher contrast for pedestrians at locations with high vertical illuminance. Designers should be aware of the potential visibility impacts of the pavement material. Future asphalt overlays over an existing concrete surface would affect pavement reflectance characteristics (IES, 2022).

### ***Contrast Polarity***

As mentioned above and illustrated in Figure 8, contrast can be either negative or positive. Whether an object is seen in negative or positive contrast is referred to as contrast polarity. RP-8-22 notes that while historically, the use of negative contrast was thought to be beneficial for pedestrian detection, research is showing that positive contrast for pedestrian detection has many advantages, especially when considering that an approaching vehicle's headlamps reinforces positive contrast (IES, 2022). Pedestrian visibility studies conducted in Switzerland showed that rendering pedestrians in positive contrast (i.e., pedestrians are illuminated from the approach side of a vehicle, rendering them brighter than the background) reduced pedestrian-vehicle crashes by two-thirds (Wilken et al., 2001).

At distances less than 30 m (100 ft), the vertical illuminance provided by vehicle headlamps will typically result in an object having a higher luminance than a roadway background, resulting in the desired positive contrast; however, at distances greater than 100 m (330 ft), background luminance can often exceed the luminance of a pedestrian, resulting in negative contrast. For the intermediate range from 30-100 m (100-330 ft), the contrast polarity will depend on several factors, including the presence of fixed roadway lighting, the reflectance of the road surface, the reflectance of the pedestrian (i.e., clothing), and the intensity profile of the vehicle's headlamps. A well-designed pedestrian lighting system will provide adequate vertical illuminance to allow for motorists to detect pedestrians at these longer distances to allow additional time for reaction and braking.

### ***Contrast Variance***

Contrast variance refers to the uniformity of contrast across an entire object of interest. Objects in a real-world environment typically have varying contrast levels rather than a single, perfectly uniform contrast. Both Figure 5 and Figure 8 show examples of this. The contrast can change from negative to positive and vary in magnitude. In the context of pedestrian lighting, a pedestrian's clothing may be a source of contrast variance, with darker fabrics providing less contrast than brighter fabrics when viewed against the same background. Different background surfaces behind the pedestrian may also contribute to contrast variance. Depending on the extent of contrast variance, the detectable portion of a pedestrian and detection distance may be limited, with drivers most readily identifying the portions of

a pedestrian in high contrast. Lighting designers do not have direct control of contrast variance but should be aware of its effects.

## **Visibility Level**

An object in the visual field has a theoretical threshold contrast: the minimum luminance contrast at which the object can be detected (Adrian, 1989). The threshold contrast is a function of the visual size of the object (typically described by the visual angle,  $\alpha$ , of the object), the length of time an observer is looking at the object, the adaptation luminance ( $L_{adaptation}$ ) of the observer, and the age of the observer. An object at threshold contrast has a probability of detection of 50 percent. Therefore, to promote reliable detection of objects or pedestrians on or along the roadway, lighting conditions should provide an actual contrast that is greater than the threshold contrast. The ratio of the actual contrast to threshold contrast is defined as the visibility level (VL). VL provides a measure of the visibility conditions and is one way to evaluate the performance of lighting installations. In the case of a crosswalk, a higher VL for a given condition indicates that a pedestrian is more easily seen than an installation with a lower VL. The equation for VL is shown in figure 10.

$$VL = \frac{C_{Actual}}{C_{Threshold}} = \frac{C_{Actual}}{f(\text{ObjectSize } (\alpha), \text{Age}, L_{adaptation}, \text{ObservationTime } (t))}$$

*Figure 10. Equation. Visibility level (VL).*

VL can be modified by changes in the threshold contrast or the actual contrast; however, many of the factors from which threshold contrast is derived are not controllable by a lighting designer. The age of the observer and the observation time cannot be changed, and neither can the visual size of the object, which is determined by the distance from the observer to the object of interest. This means that adaptation luminance and actual contrast are the only values that may be influenced by a designer to modify VL.

For roadway applications, the luminance of the road surface is the adaptation luminance of the observer. Therefore, an increase in roadway luminance will increase the threshold contrast while also decreasing the actual contrast. This often results in a reduction of VL. For crosswalk lighting, where the lighting system used to illuminate the pedestrians also illuminates the background road surface, designers should strive to achieve a balance between the level of roadway (background) luminance and the vertical illuminance provided for pedestrian visibility.

## Types of Vision

The background luminance of an object determines its contrast and determines the type of vision the human eye will use. The human eye has three operating states that are sensitive to different lighting conditions: photopic, scotopic, and mesopic vision.

Photopic vision is responsible for the perception of color and thrives mainly during the day when plenty of light is available. Photopic vision predominantly uses the cones of the eye, located in the fovea, and is responsible for visual acuity. Cones are sensitive to direct light, have high visual acuity, and losing them can cause legal blindness (Boyce, 2009).

Scotopic vision is nearly opposite of photopic vision in that it utilizes rods instead of cones. Rods have low visual acuity, are sensitive to scattered light, and are present throughout the retina of the eye with a sharp decline in the fovea. Scotopic vision is engaged in low light situations and a loss of rods results in night blindness (Boyce, 2009).

Finally, mesopic vision is a combination of the responses from photopic and scotopic vision (FHWA, 2023). Mesopic vision is typically engaged in twilight conditions and when driving at night. Mesopic vision occurs when driving at night because the fovea is typically focused on where the headlamps shine and the shroud of night results in a surrounding dark environment (Boyce, 2009). Mesopic visual acuity can be measured separately using pre-made filters available for a back-lit Snellen eye exam. A Snellen exam uses a chart of letters to determine visual acuity based on the smallest letters that can be identified by the observer. An example Snellen Eye Exam is shown figure 11.

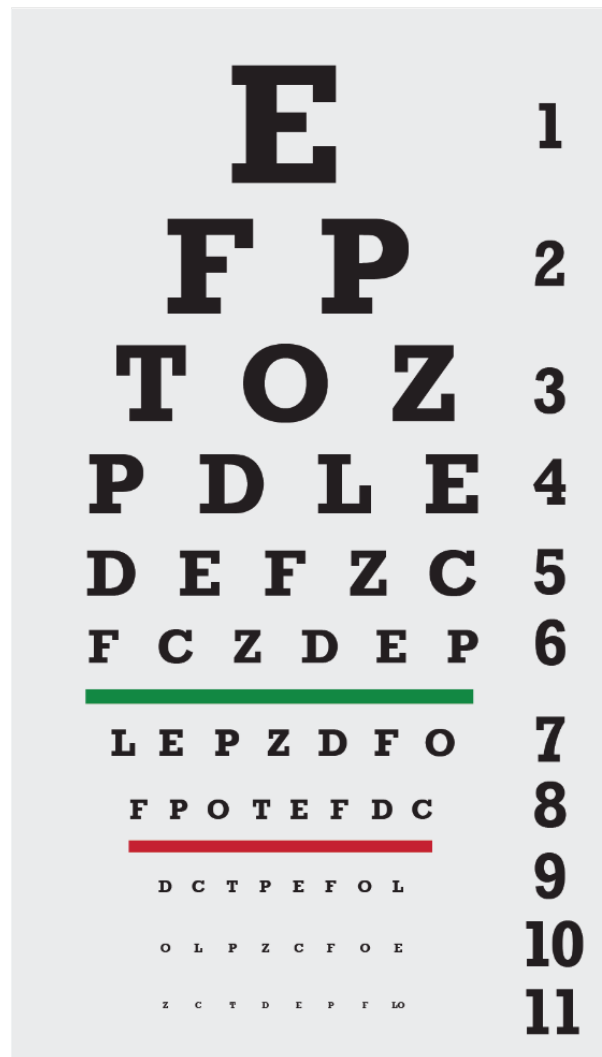


Figure 11. Graphic. Example of the Snellen Eye Exam.

# Chapter 3: Midblock Crosswalk Lighting Design Considerations

FHWA's *Pedestrian Lighting Primer* explained that lighting design accounts for a variety of factors and considers a number of outcomes, including safety and comfort for all road users, impacts to the environment, and energy consumption (FHWA, 2022). It describes the lighting design process in five general steps:

1. Assess potential lighting needs.
2. Select design criteria.
3. Select equipment.
4. Determine control strategy.
5. Design and verify.

This chapter provides general considerations related to these five steps in the context of lighting design for midblock crosswalks. It is not intended to supersede lighting design resources that an agency uses to guide its lighting design practices.

## Assessment of Potential Lighting Needs

The need for roadway lighting is frequently assessed using lighting warrants or sets of conditions evaluated at a study site to inform the decision of whether to install lighting. Lighting warrants commonly include assessments of the amount of traffic (motorized and nonmotorized), roadway geometry, surrounding environment, and crash history. Lighting practitioners in the U.S. 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, 7<sup>th</sup> Edition* (AASHTO, 2018).
- Transportation Association of Canada (TAC) *Guide for the Design of Roadway Lighting* (TAC, 2006).
- NCHRP Report 152 *Warrants for Highway Lighting* (Walton & Rowan, 1974).

The 2023 *FHWA Lighting Handbook* includes a chapter on warranting that brings together key warranting approaches and describes their scope and coverage. For example, the handbook references AASHTO's *Roadway Lighting Design Guide* for highway, freeway, interchange, and bridge lighting warrants. The handbook references warrants in the TAC *Guide for the Design of Roadway Lighting* for major, collector, and local roads as well as for intersections. The TAC warrants are based on the approach taken in NCHRP Report 152, *Warrants for Highway Lighting*. The 2023 *FHWA Lighting Handbook* also describes the application of CMFs to help determine if roadway lighting is expected to

be a cost-effective safety investment at a location. The handbook highlights that there is no defined warranting system for pedestrians, but that a weighted score that captures pedestrian needs is included in warranting point score systems for roadways and intersections, such as that in the *TAC Guide for the Design of Roadway Lighting*. The *TAC Guide for the Design of Roadway Lighting* addresses midblock lighting, noting that midblock crosswalks should always be illuminated if there is nighttime pedestrian activity, regardless of roadway condition.

The 2023 *FHWA Lighting Handbook* also describes the characteristics, limitations, and ongoing work related to lighting warrants (Gibbons et al., 2023). The handbook recommends that a jurisdiction develop a master lighting plan rather than allowing third parties to use warrants to decide whether to light:

*Lighting master plans define the purpose of lighting and contain area maps with road types, classifications, land use, pedestrian and cyclist routes, parks, and other infrastructure information. They can also contain information regarding luminaires and poles, light sources, lighting levels, design criteria, design and construction specifications, historical considerations, and recommendations. This information is combined in a single, organized package that becomes the basis for lighting projects (Gibbons et al., 2023).*

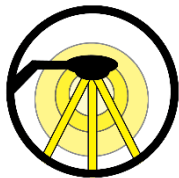
The study by Li et al. (2020) demonstrated how the ability to collect in-field lighting measurements is improving the ability to draw linkages between lighting levels and nighttime crash reductions and how this information can then inform a transportation agency's policies and practices related to both lighting needs assessments and lighting design.

# Selection of Design Criteria

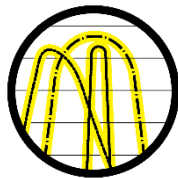
Once a need for lighting in the study area is established, lighting design criteria are then established. The selected design criteria for general roadway lighting applications are typically a combination of primary criteria and secondary criteria:

- **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.

Design criteria are achieved by careful selection and balancing of various factors. There are five general factors that a lighting designer can control to influence the performance of roadway lighting:



Lighting level



Spectral Power  
Distribution  
(SPD)



Spatiality



Timing

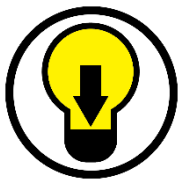


Duration

- **Lighting Level** is the amount of light provided by the lighting system. Metrics for lighting level may include luminance and illuminance measures on the design facility, or the level of lumens emitted from a luminaire. For more information regarding lighting levels, refer to the Primary Design Criteria section of this report.
- **Spectral Power Distribution (SPD)** characterizes the color qualities of a light source by identifying the intensity of light emitted from a source across a range of wavelengths, particularly within the visible spectrum of light. For more information regarding SPD, refer to the Secondary Design Criteria section of this report.
- **Spatiality** is the spatial or dimensional distribution and direction of light emitted from a source. For more information regarding spatiality, refer to the Equipment Selection section of this report.
- **Timing** is the time of day that light is provided by the system.
- **Duration** is the length of time that light is actively provided for a facility. For more information regarding timing and duration, refer to the Control Strategy section of this report.

These factors may be adjusted to meet the intended design criteria. The lighting level and spatiality are adjusted to meet the primary criteria selected for a site. All five factors can affect the secondary criteria. Lighting designers should be aware of the impacts of each factor and how they relate to each other.

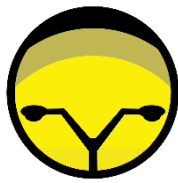
Each factor can contribute to the following outcomes:



**Energy  
Conservation**



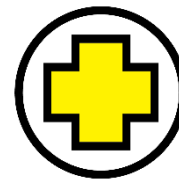
**Usability  
(Safety and  
Security)**



**Skyglow**



**Impact to  
Environment**



**User Health**



**User  
Preference**

For example, if a luminaire is selected for a design that has inappropriate spatial distribution of light for the application, that luminaire selection may result in increased energy consumption and skyglow due to wasted light, along with other potential negative impacts on the environment. Research has also shown that the lighting level has a significant impact on surrounding flora and fauna, greater even than spectral content of the light (Gaston & Bennie, 2014; Schroer & Hölker, 2016; Falcon et al., 2020).

Lighting design involves selecting an effective combination of the five design factors that will both meet the intended design criteria, while limiting unintended drawbacks of the performance of the lighting system. This principle of lighting design, as well as considerations specific to these overarching factors and outcomes, will be evident in the subsequent content on both midblock and intersection crosswalk lighting.

## ***Primary Design Criteria***

Primary design criteria and recommended practices are guided by basic measures of lighting levels such as average and average-to-minimum ratios. *RP-8-22, Recommended Practice: Lighting Roadway and Parking Facilities*, identifies criteria for average luminance, illuminance, and uniformity ratios for various road classifications (IES, 2022). The *AASHTO Roadway Lighting Design Guide* provides recommended lighting levels using illuminance criteria (AASHTO, 2018).

Primary design criteria for midblock crosswalks focus on providing sufficient vertical illuminance for reasons provided in Chapter 2. The previous 2008 version of FHWA's *Informational Report on Lighting Design for Midblock Crosswalks* noted 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). *RP-8-22* notes the following for vertical illuminance in midblock crosswalks:

*Research shows that maintained average vertical illuminance in crosswalks of 20 to 40 lux will benefit the visibility of the pedestrian. It is recommended that the designer consider a level of 20 lux for areas with low pedestrian conflict, 30 lux for areas with medium pedestrian conflict and 40 lux for areas with high pedestrian conflict.*

These recommended vertical illuminance values by pedestrian conflict/activity level and based on RP-8-22 are shown in table 1.

Table 1. RP-8-22 Recommended Vertical Illuminance Levels for Midblock Crosswalks.

Facility	Pedestrian Conflict (Activity Level)	Target Average Vertical Illuminance
Midblock crosswalk	Low (0-10 pedestrians per hour)	20 lux (1.9 fc)
	Medium (11-99 pedestrians per hour)	30 lux (2.8 fc)
	High (100+ pedestrians per hour)	40 lux (3.7 fc)

At the time of its publication, RP-8-22 noted that research into the optimal level of vertical illuminance was ongoing. Bhagavathula et al. (2021a) measured pedestrian detection distances at both intersection and midblock crosswalks under different lighting designs. The study’s findings reinforced the principle that the best visual performance (i.e., longest pedestrian detection distances) occur when the lighting design renders the pedestrian in higher positive contrast. Bhagavathula et al.’s findings also indicated that lower levels of vertical illuminance than previously reported by Gibbons et al. (2008) and recommended in RP-8-22 could provide adequate visibility. The authors concluded that **“Midblock crosswalks should be illuminated to a minimum average vertical illuminance of 10 lux (0.9 fc). Beyond this light level there is not a statistically significant increase in drivers’ visibility of pedestrians.”** Bhagavathula et al. (2021a) therefore recommended a minimum required average vertical illuminance of 10 lux (0.9 fc) for midblock crosswalks for luminaires in front of the crosswalk in each travel direction (the desired staggered layout as discussed later in the document) as well as for crosswalk illuminators (also discussed later in the document).

As noted in Chapter 2, designers should consider the amount of ambient light present, understanding that high levels of ambient light may require higher levels of vertical illuminance to achieve sufficient visibility of pedestrians. Additional research is needed to more fully understand the impact of ambient lighting on nighttime visibility and safety performance.

Lighting design for private sites often follow separate design criteria and review procedures than those used for roadway lighting. Agencies should coordinate closely with zoning or land use committees to minimize the potential negative impacts of ambient light on road user visibility. Development ordinances should be regularly assessed and updated to appropriately limit light output, trespass, and glare, and careful reviews of site plans should occur during the permitting process.

Per RP-8-22, the average vertical illuminance of midblock crosswalks is based on measurements for a series of points 1.5 meters (5 ft) in height, along the centerline of the crosswalk, extending to the edge of the roadway, and spaced at 0.5 meters (1.6 ft) for each driving direction (see figure 12).

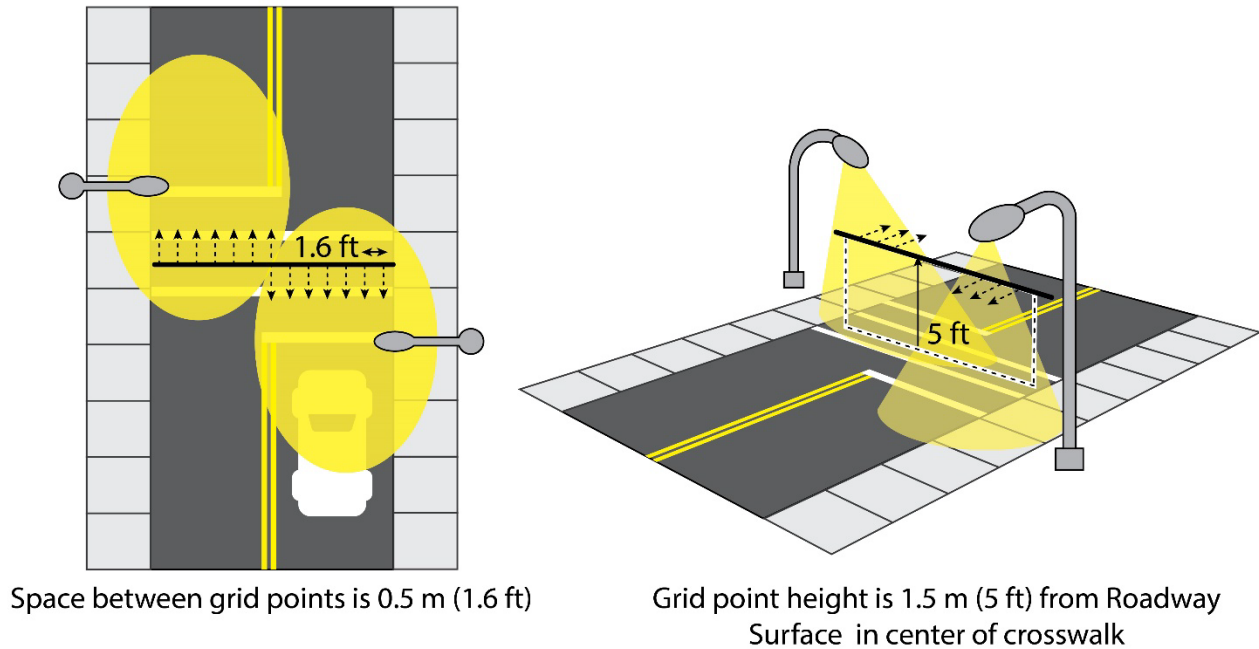


Figure 12. Graphic. Typical calculation grid for midblock crosswalks per IES RP-8-22. Source: FHWA.

RP-8-22 recommends that, if the roadway with the midblock crosswalk is continuously lighted, the horizontal luminance of the roadway should meet or exceeded recommended levels in RP-8-22's Chapter 11.

## Luminaire Placement

Luminaire placement at crosswalks has historically involved locating poles directly over the crosswalk, or even behind the crosswalk. These placements do not provide the desired vertical illuminance necessary to improve visibility of pedestrians. Luminaires should be in advance of the crosswalk for each direction of vehicle travel, typically no less than 10 ft (3m). This is sometimes called a staggered arrangement, an example of which is shown in figure 13. The precise location of the luminaire is dependent upon the equipment selection, as each model of luminaire has a unique distribution and intensity of light output. Designers may use photometric analysis software to fine-tune and verify individual pole locations to maximize the vertical illuminance in the crosswalk.

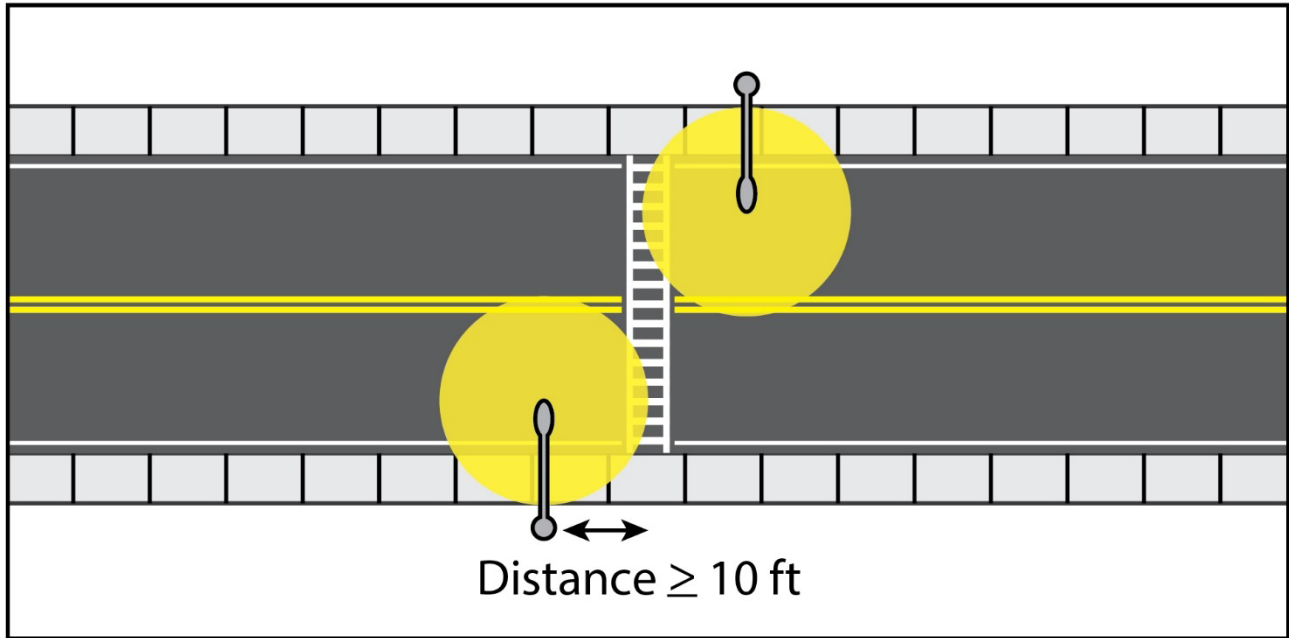


Figure 13. Graphic. Typical light pole arrangement for a midblock crosswalk. Source: FHWA.

## Secondary Design Criteria

Secondary design criteria help guide the characteristics, selection, and placement of the light sources. Agencies or municipalities may provide policies or master plans that influence the selection of secondary design criteria. This section discusses secondary criteria related to spectral power distribution, correlated color temperature of the light source, glare, surround ratio, and light trespass.

**Spectral Power Distribution (SPD)** is a characterization of the intensity of various wavelengths of light emitted from a source. This information is typically presented in a graph that shows which colors of the visible spectrum are most prominent (see figure 14, for example). Some light sources may have a relatively flat distribution across all wavelengths, while others may have pronounced peaks of intensity of one or more wavelengths. White LEDs often have a sharp peak in intensity in the blue wavelengths. Each light source has a unique SPD.

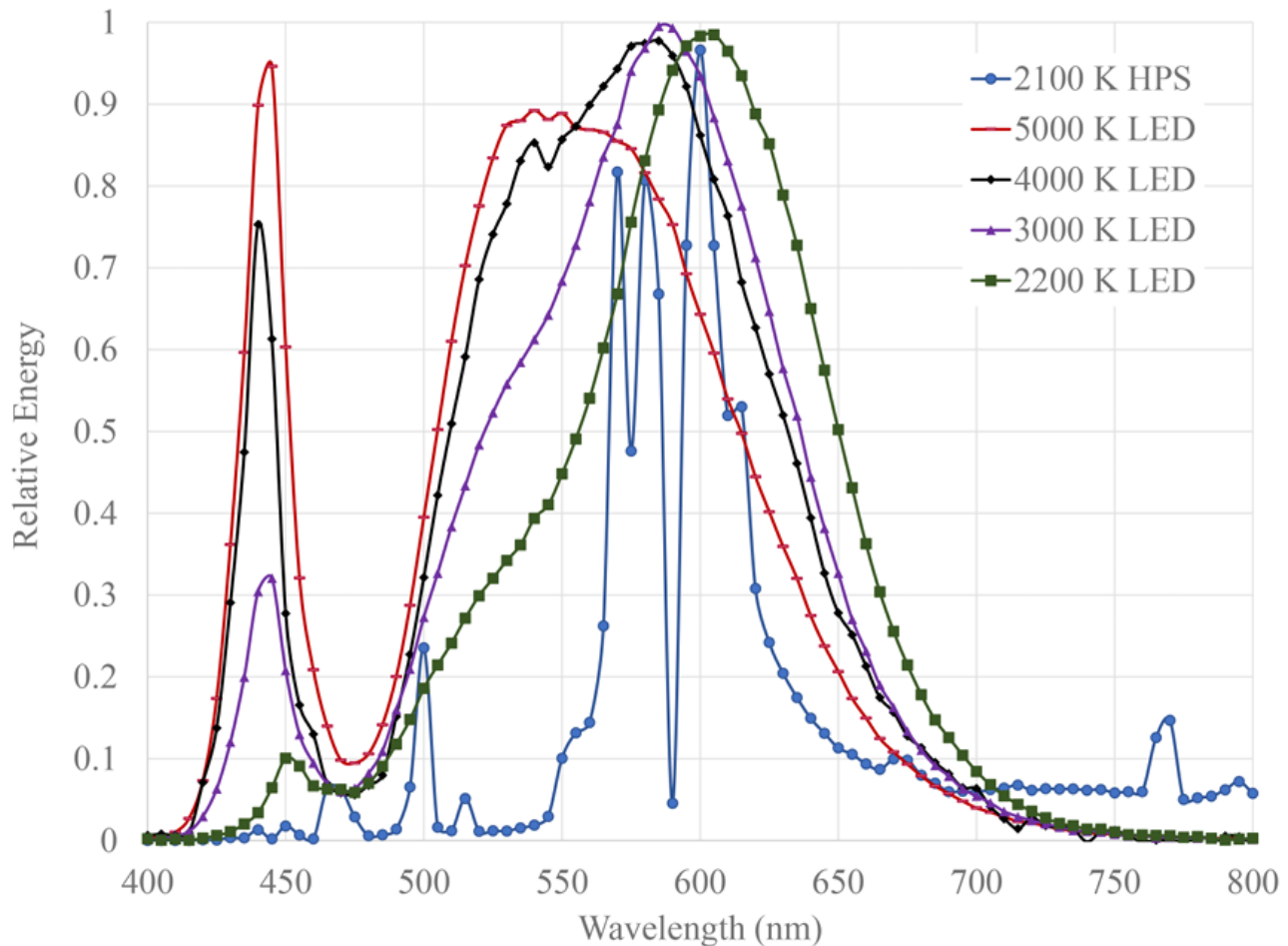


Figure 14. Graphic. Example Spectral Power Distributions of various roadway luminaires. Source: FHWA.

Although SPD is regarded as a more precise metric for specifying the characteristics of light, SPD has not yet been widely adopted as the standard metric in lighting practice. Correlated Color Temperature (CCT) is often used in practice as a proxy for SPD. Rather than a plot of intensities across all wavelengths, CCT is a single measure of the apparent color output of a light source, measured in degrees Kelvin (K) (IES, 2022). 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. CCT remains widely used and is generally easier to understand than SPD. However, by using a single measure for apparent color, some information may be lost by using CCT instead of SPD. For example, two light sources with identical CCTs may have significantly different impacts on flora and fauna. The *2023 FHWA Lighting Handbook* notes that SPD should be used when assessing lighting sources for environmental impacts (Gibbons et al., 2023).

When used, CCT considerations can be applied to any type of light source. It typically becomes important with LED light sources, as the technology of LED lighting allows for a wide range of available CCT options. Other types of light sources do not allow the same flexibility. LED luminaires allow for a

wide range of CCTs that the designer may select, typically ranging from 2,700 K to 6,000 K for outdoor applications.

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 15 (Terry et al., 2020).

The *2023 FHWA Lighting Handbook* highlights a growing need to understand the relationships between roadway light level, melatonin suppression, and driver alertness and health. One of the first such empirical studies conducted by Bhagavathula et al. (2021b) and cited in the *FHWA Lighting Handbook* concluded that there were no differences between 4000K LED roadway lighting, 2100K HPS roadway lighting, and no roadway lighting in terms of salivary melatonin suppression as well as subjective and objective measures of alertness.

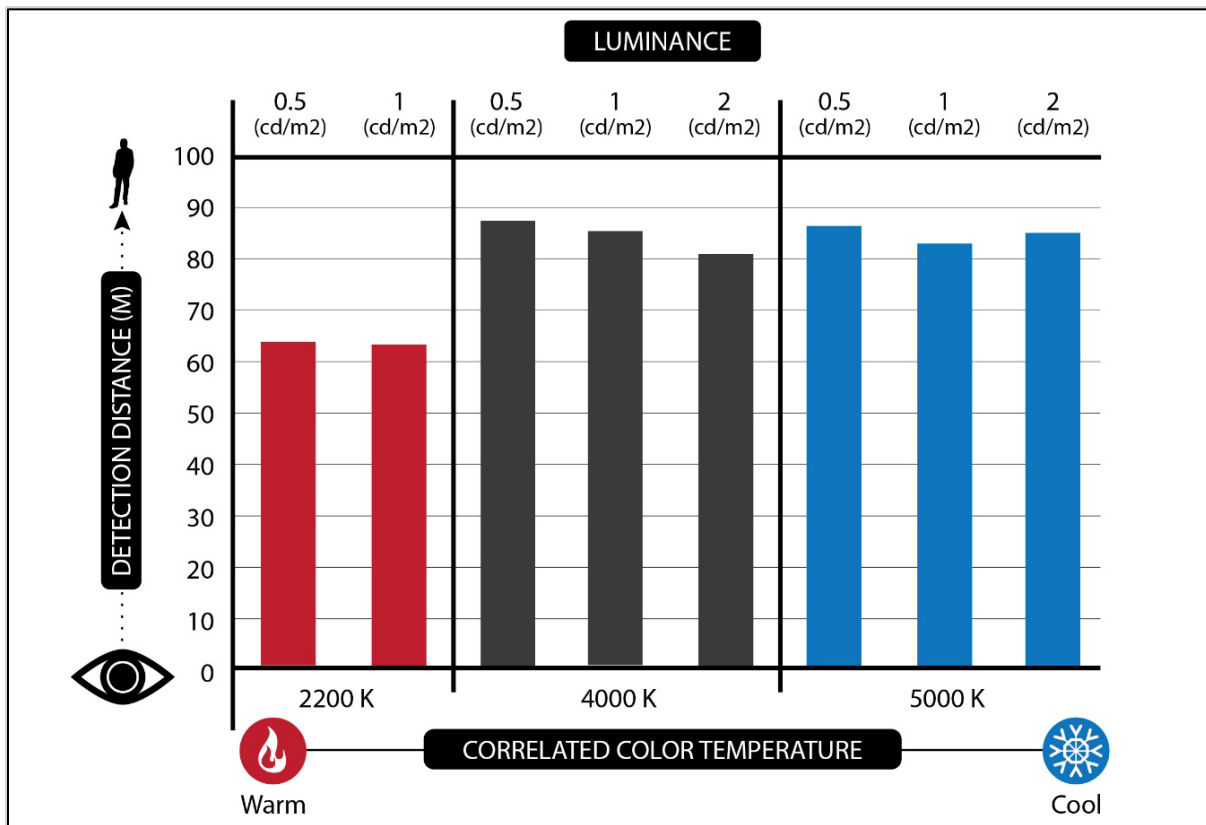


Figure 15. Graphic. Detection distance for rural highway by light type and luminance. Source: FHWA.

**Glare.** Glare is associated with difficulty seeing or discomfort due to a light source in direct view of the observer (IES, 2022). Glare may occur from any light source, including roadway luminaires, ambient light, and vehicle headlights. 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. RP-8-22 provides recommended maximum allowable levels for glare (IES, 2022). Glare can become a potential issue for pedestrian scale lighting (6.5m in height or lower), when the light source is in more of a direct line of sight to observers. Glare also increases in proportion to the amount of light emitted from a source. It is important for the designer to balance the need to provide an effective light level while minimizing excessive glare. Figure 16 shows an example of glare from a light source. In the presence of high levels of glare, research indicates that increasing the vertical illuminance results in improvement of pedestrian detection distances. The *Pedestrian Lighting Primer* (FHWA, 2022) recommends an additional 2 semi-cylindrical lux or 0.5 cd/m<sup>2</sup> to overcome the increase in glare associated with lower mounting heights.



Figure 16. Photograph. Example of glare from a light source. Source: FHWA.

**Surround ratio** is 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. A surround ratio of at least 80 percent may provide benefits for the detection of objects and pedestrians both in and near the roadway.

**Light trespass** occurs when excess light 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 limits. 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. Recommended limitations on light trespass often become more stringent in areas of environmental sensitivity. RP-8-22 provides recommended maximum allowable levels for light trespass based on environmental zone ratings (IES, 2022). Environmental zones are determined by surrounding land use and development.

## Equipment Selection and Other Design Considerations

After the design criteria for a project location have been established, lighting equipment is selected for the design. The following sections cover various aspects of equipment selection and other design considerations.

### *Luminaire Selection*

Luminaires are often selected based on an inventory of existing lighting installations or preferences and policies of the responsible agency. When feasible, equipment is selected to minimize the total light output while meeting the goals of the project and the design criteria. Characteristics of luminaires that affect the product selection are discussed in the following sections.

### *IES Distribution Type*

IES distribution type refers to a classification system that describes the lateral and longitudinal pattern of light 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 RP-8-22 (IES, 2022). General representations of IES distribution types are presented in figure 17.

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. Selection of a Type I or Type II luminaire allows for more light to be directed toward the design facility while limiting light trespass when the facility is narrow and linear. The direction of light from a Type I or Type II luminaire typically provides greater vertical illuminance at longer distances from the pole location. As the design facility becomes wider, selection of a Type III or even Type IV may be necessary to effectively light the more distant (from the luminaire) portions of the design facility. Type V luminaires provide even distribution of light in all directions, usually in a circular or square pattern. Type V luminaires may be beneficial for lighting open public areas and parking lots but are not desirable for crosswalk and intersection

applications due to wasted backward light. Designers should select luminaire types on a case-by-case basis and adjust pole locations as appropriate to achieve the desired vertical illuminance.

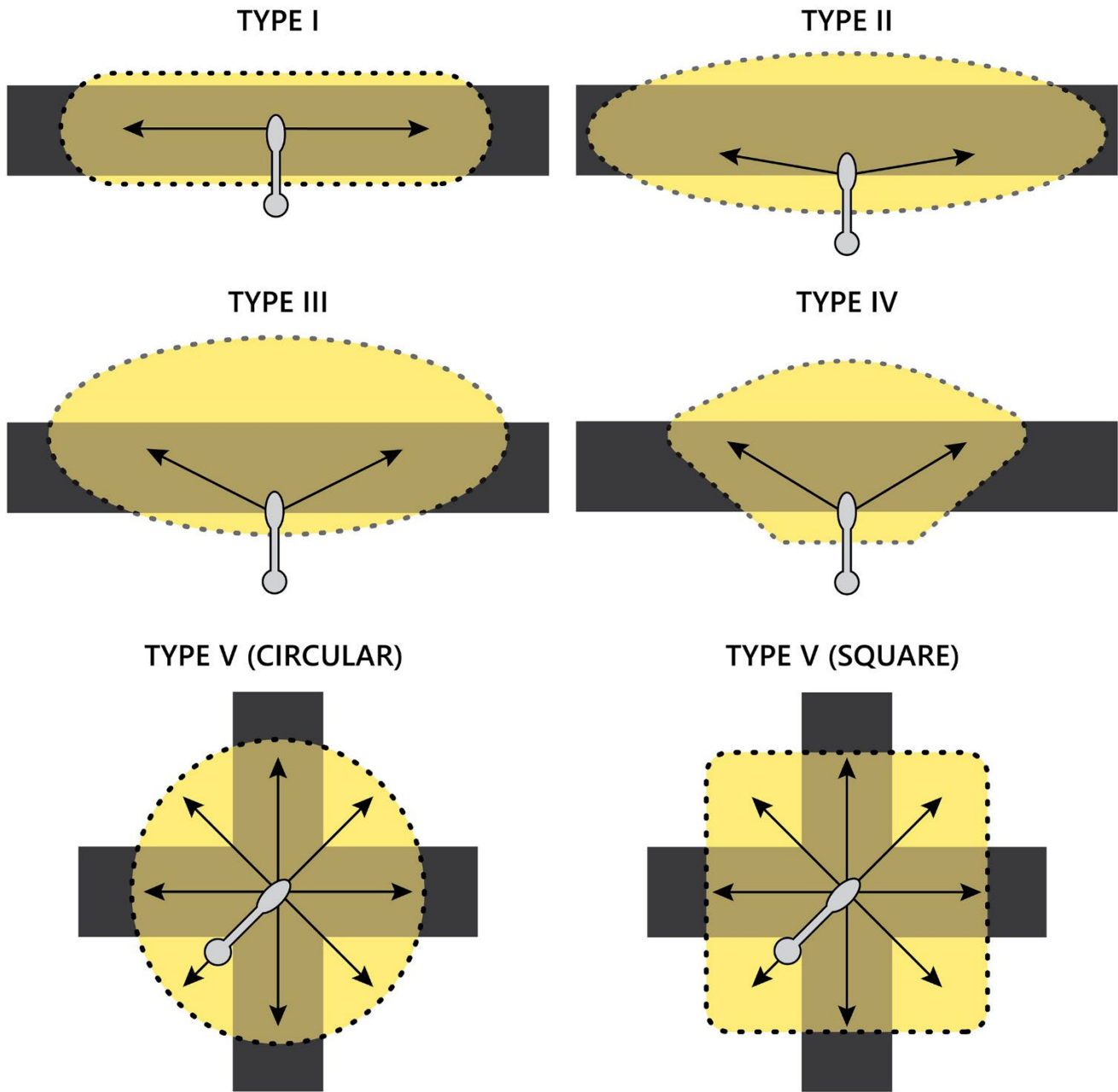


Figure 17. Graphic. General representation of IES distribution types. Modified from IES RP-8-22. Source: FHWA.

## Luminaire Classification System (LCS)

The Luminaire Classification System (LCS) for outdoor lighting defines the quantity of light from a single luminaire that is directed in angles of interest to the designer. The light output is measured in lumens and as a percentage of total lumen output in the forward, backward, and upward directions. The LCS further subdivides these categories into more specific angles and zones. Each zone is defined by a range of angles from nadir (directly below/under the light source). A graphical representation of each of these classification zones is depicted in figure 18.

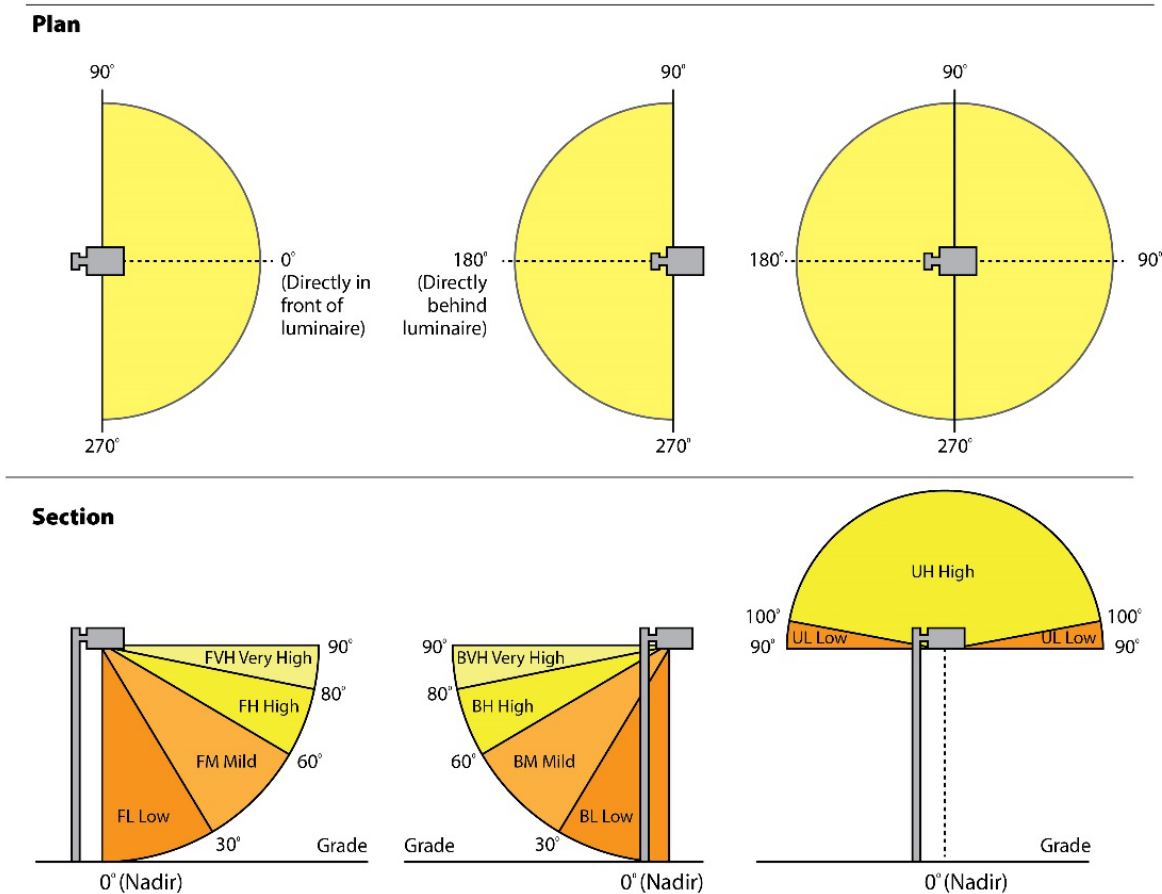


Figure 18. Graphic. Forward, backward and upward zones for LCS. Source: IES.

The information provided in a LCS report may be useful to identify the general orientation and spread of light from a particular luminaire. A sample LCS report is depicted in figure 19. An LCS report may serve as a preliminary screening tool to identify luminaires specific for crosswalk or other pedestrian lighting, where vertical illuminance is desirable for the pedestrian zones. Luminaires with a higher proportion of light output in the mid zones (FM and/or BM), and high zones (FH and/or BH) will direct light in a more horizontal direction. An increase in horizontally traveling light typically results in higher vertical illuminance, which is desirable for pedestrian lighting. Luminaires with a significant amount of light output in low zones (FL and/or BL) may be more applicable for general roadway or surface

lighting. Designers try to balance the benefits of higher light angles providing more vertical illuminance for pedestrian visibility with the drawbacks of excessive light in the high and very high zones (FH, FVH, BH, and BVH), which contribute to increased glare. A carefully selected luminaire will allow for increased pole spacing, resulting in lower installation and maintenance costs while still achieving the desired design criteria.

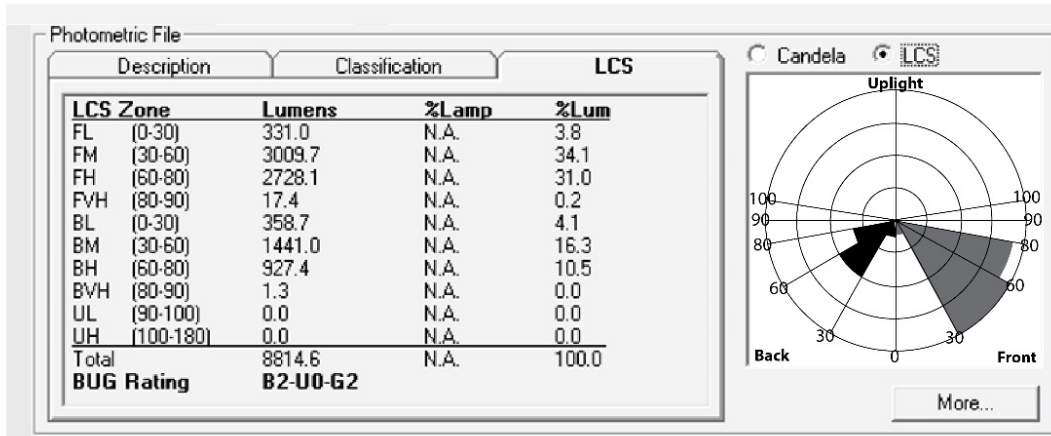


Figure 19. Graphic. Sample Luminaire Classification System (LCS) report. Source: AGi32, Lighting Analysts 2024.

## Vertical Illuminance Visualization

The suitability of a luminaire can be visualized using lighting design software tools. When evaluating if a selected luminaire is appropriate for pedestrian lighting, it is critical to consider the horizontal component of light, measured as vertical illuminance. Lighting design software may be used to estimate the vertical illuminance at a height of 1.5 m (5 ft) as recommended in RP-8-22. The resulting values, when plotted as isolines, show the region of a facility that meets or exceeds the desired vertical illuminance criteria, which is assumed to be 20 lux for this example midblock crosswalk. In figure 20, the vertical illuminance does not meet the desired values of 20 or more lux. In addition, the peak intensity is slightly offset from the center of the crosswalk. This may be corrected by adjusting the pole location.

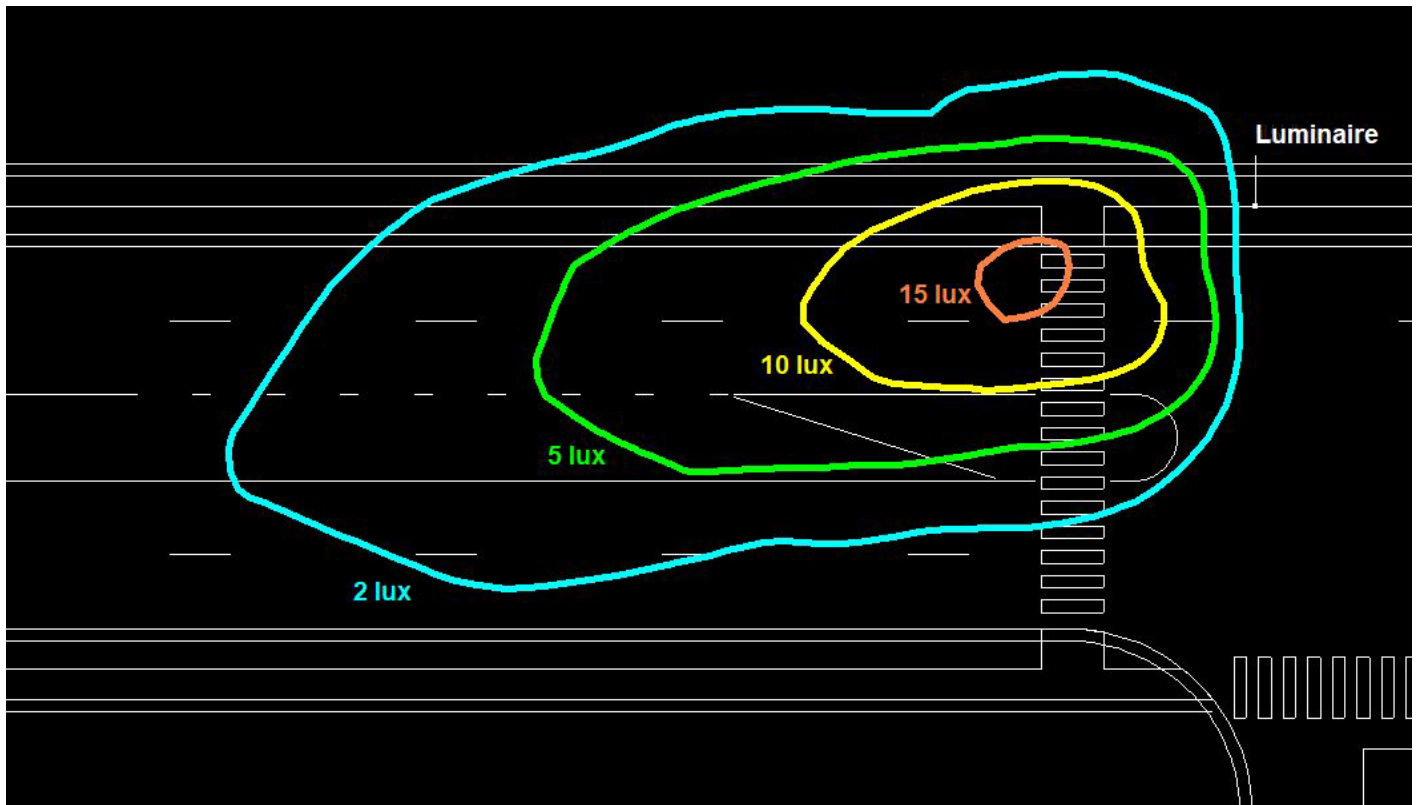


Figure 20. Graphic. Vertical illuminance distribution from crosswalk luminaire. Source: Agi32, Lighting Analysts 2024.

The graphic in figure 21 provides software output for an alternative luminaire with similar wattage and lumen output. However, the different distribution of light from this luminaire becomes evident when looking at the plot. The selected luminaire provides a minimum of 20 lux throughout the crosswalk area for vehicles approaching the crosswalk from the right. The peak intensity of vertical illuminance is centered on the crosswalk, indicating an ideal pole location.

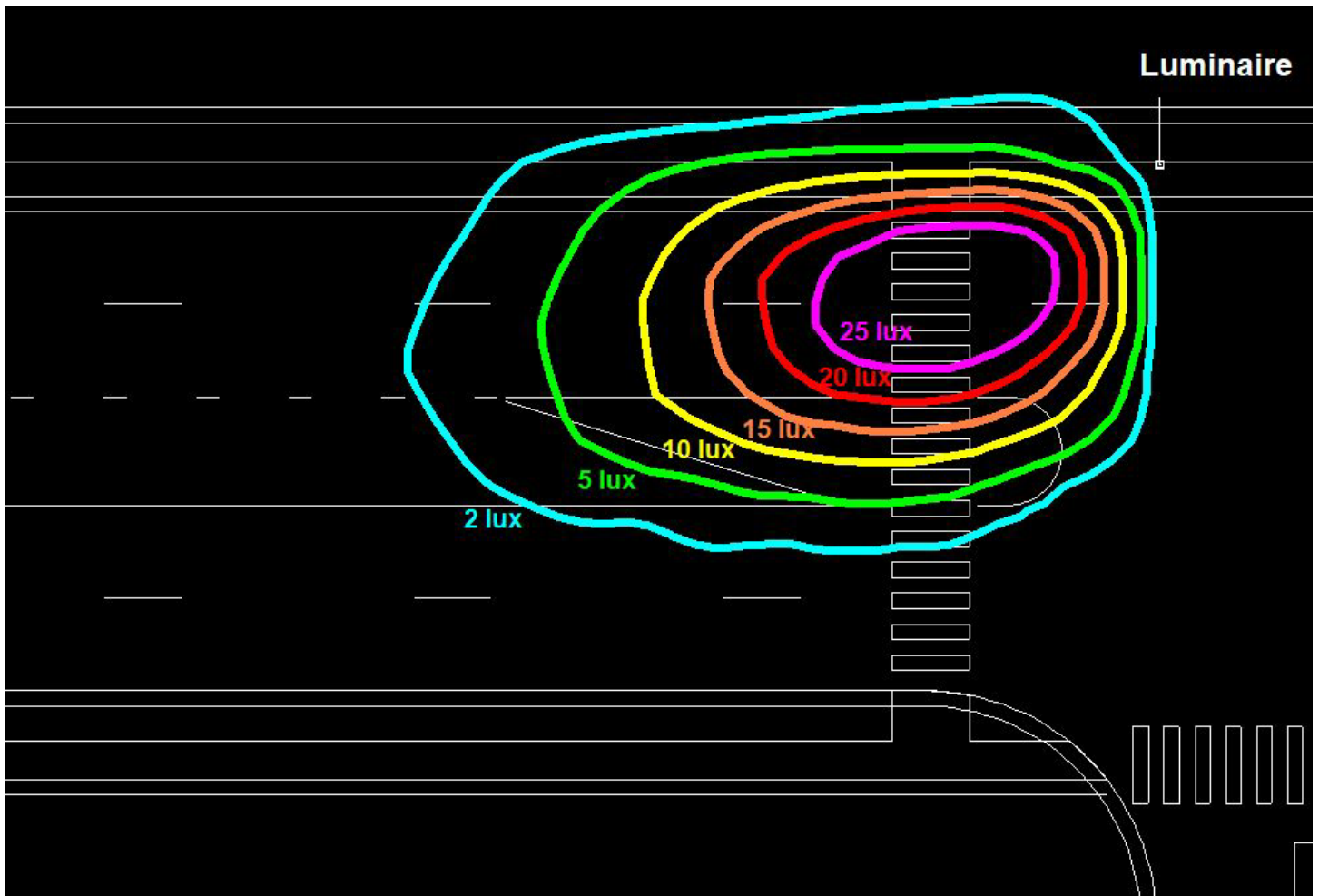


Figure 21. Graphic. Vertical illuminance distribution from crosswalk luminaire, Alternative Luminaire.  
Source: Agi32, Lighting Analysts 2024.

## ***Mounting Type***

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 lighting for pedestrian facilities. Sometimes, the selected mounting height is lower than in lighting systems installed exclusively for roadway lighting. Luminaire mounting heights for roadway applications is often 30 to 50 ft (9 to 15 m). Pedestrian scale lighting is typically mounted at a height of less than 20 ft (6 m) and may be selected for aesthetic or historical reasons.

## ***Pedestrian Scale Lighting***

In the FHWA research report *Street Lighting for Pedestrian Safety*, researchers compared the detection distances for drivers of motor vehicles when viewing pedestrians when under pedestrian scale lighting and road scale lighting. 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 22 shows the two-way interaction between light type and luminance for pedestrian scale lighting using data from the report. Based on the findings of this research, mounting heights of less than 6.5 m or 20 ft are expected to provide improved visual performance in areas where pedestrians are present. There is an expected trend downward in the detection distances when going from higher luminance levels ( $2 \text{ cd/m}^2$ ) to medium ( $1 \text{ cd/m}^2$ ) to low ( $0.5 \text{ cd/m}^2$ ). For road scale, the higher luminance produced longer detection distances as expected, but average detection distances for low and medium luminance levels 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  $0.5 \text{ cd/m}^2$  allows for the lighting performance to overcome the increase in glare associated with lower mounting heights.

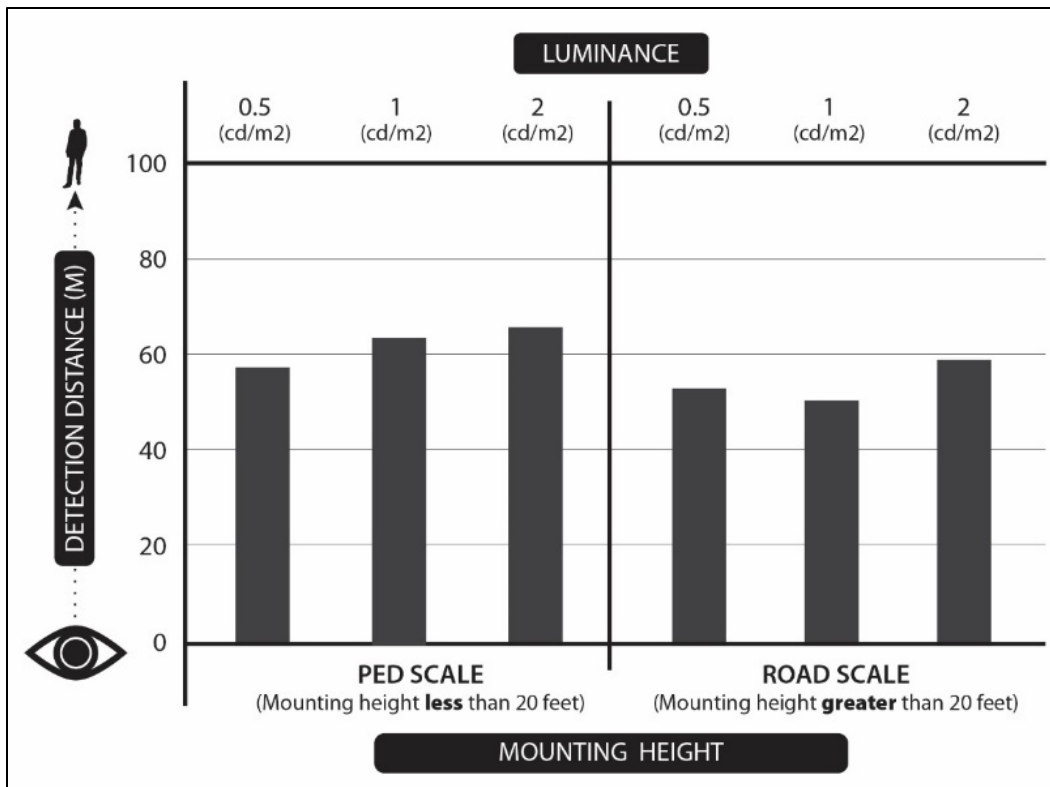


Figure 22. Graphic. Detection distance by light type and luminance. Source: FHWA.

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 can allow the designer to balance the benefits of pedestrian scale mounting heights with the increased energy consumption. Luminaires are available in a range of wattage options while maintaining the desired aesthetic qualities.

## Effects of Landscaping and Structures

In the built environment, fixed objects may partially obscure a luminaire, resulting in shadows or reduced light levels on the design facility. Elements such as bridge overpasses buildings, and other structures may completely block light travel. If fixed objects are expected to be a lighting design constraint, they can be modeled in a lighting design software to assist with pole placement. Deciduous trees and shrubs placed near light poles can become a significant limiting factor during warm seasons (figure 23). When feasible, light pole locations should be selected to avoid interference from landscaping features and structures that may block light in the roadside environment. Routine maintenance may be necessary to prevent trees and landscaping from interfering with the distribution of light.



*Figure 23. Photo. Example of trees in conflict with light poles. Source: Google Earth.*

## **Lamp Type**

Light emitting diode (LED) roadway lighting installations increased rapidly during the 2010s to become the predominant type of roadway lighting used on U.S. roadways, overtaking high pressure sodium (HPS) as the leading technology (Elliott & Lee, 2020). LED lighting has inherent benefits over other light sources, including increased energy efficiency, improved optics, color rendition, and ranges of SPD, CCT, and wattage options. LEDs often allow for precise application of light to the design facility, with less wasted light and significantly less upward light, when oriented downward. Due to the differences in these lighting technologies, designers must carefully evaluate and select the most appropriate LED alternative to replace outgoing HPS lighting for retrofit projects. This is especially true if existing light poles are to remain in place and the designer is unable to adjust pole locations. If existing light poles can be replaced, selection of LED alternatives may allow for greater pole spacing.

Designers should take care to select LED fixtures that meet the needs of a particular design. Factors to consider include, but are not limited to, wattage, IES distribution type, SPD, CCT, and glare. Luminaires considered for installation should be modeled and selected using a lighting design software package.

Alternative lamp types that may be installed include high pressure sodium (HPS) and metal halide (MH). HPS lamps, although widespread before the broad use of LED lighting, are now being phased out of production. Replacement HPS lamps may be difficult to find. HPS produces an amber light, while MH produces a white or bluish-white light. Research has not shown a significant difference in detection of a black-clothed pedestrian under HPS and MH lighting; however, pedestrians dressed in denim were detected at longer distances under MH lighting. The same lighting level (i.e., meeting lighting design criteria), is recommended regardless of the selected lamp type.

## *Transition Lighting*

When road users travel into and out of highly lit and unlit areas, they may experience an effect like glare that is known as transient adaptation (Terry et al., 2016). RP-8-22 discusses situations where illumination on one roadway or section of roadway may be significantly higher than adjacent areas (IES, 2022). Such situations may include work zones, tunnels, or intersections between higher-volume arterial roadways and lower-volume local streets. They may also include areas where only intersections are lighted and intersection approaches or roadway segments are not (Terry et al., 2016). Transition lighting is additional lighting implemented adjacent to these areas to gradually change the level of lighting the user experiences and mitigate the effects of transient adaptation. Lighting designers should pay special attention to the presence of midblock crosswalks in areas where transient adaptation is a concern and can design transition lighting if appropriate for the crosswalk presence and location.

## **Control Strategy**

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 simple 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.

## *Adaptive Lighting*

Adaptive lighting is a design strategy where the light output is dynamic and is adjusted as conditions change (Gibbons et al., 2014). This typically involves lighting that dims when road users are not detected in the area and then increases to full light levels when users are detected. The dynamic nature of adaptive lighting, including its precise dimming and instant-on capability, is made possible by solid-state lighting technology. Adaptive lighting holds promise for reducing energy consumption, light trespass, and skyglow (DOE, 2019). Other benefits may include longer service life of lighting hardware and lower maintenance costs.

Adaptive lighting can be particularly applicable to pedestrian facilities, including midblock crosswalks. In areas where pedestrian activity is high during the evening hours but low during the late-night hours, the lighting system can be designed to dim when the pedestrian volume decreases. Generally, adaptive lighting systems are not designed to turn off completely, as there is an expectation that a facility with lighting installed will remain lit during all hours of darkness. Instead, the system may be designed to maintain a low level of light. When combined with pedestrian detection at a midblock crosswalk location, adaptive lighting may have an added benefit of indicating to approaching motorists that a pedestrian is in the area.

FHWA developed the report *Design Criteria for Adaptive Roadway Lighting* to present criteria and design levels for adaptive roadway lighting based on analyses of safety and lighting performance

(Gibbons et al., 2014). The research used pedestrian presence as a parameter for developing the design criteria, and the report includes design criteria for pedestrian areas.

## Design and Verification

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. Chapter 5 of this document provides examples illustrating this iterative approach.

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 latest edition of the *AASHTO Roadside Design Guide* (AASHTO, 2011).

## Crosswalk Illuminators

Traffic control product manufacturers have developed bollard type or post-mounted high-intensity crosswalk illuminators. Figure 24 depicts a motorist's view of a midblock crosswalk with and without crosswalk illuminators. These crosswalk illuminators may be desirable in locations where overhead lighting is unattainable. Bollards may be used in combination with other TCD treatments including rectangular rapid flashing beacons (RRFBs). As this is an emerging technology and the capability of LED lighting continues to evolve rapidly, additional research should be performed to study the performance of this crosswalk lighting treatment. One known study, however, showed promising results for their use. Bhagavathula et al. (2021a) concluded that, where overhead lighting is not available, crosswalk illuminators can be used to illuminate midblock crosswalk locations, as they render pedestrians in positive contrast. Bhagavathula et al.'s (2021a) test track study showed that the crosswalk illuminators used in their study "had detection distances that were comparable to the best overhead crosswalk lighting designs (staggered and positive contrast) at an average vertical illuminance of 10 lux (0.9 fc) and beyond."

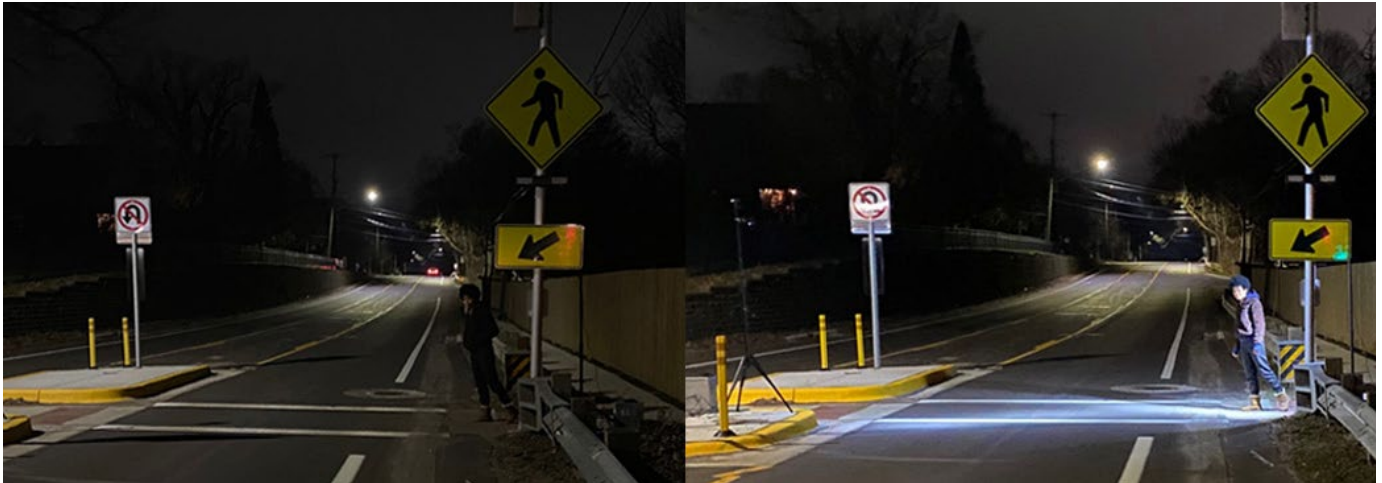


Figure 24. Photograph. Midblock crosswalk with (right) and without (left) crosswalk illuminators.  
Source: IIHS.

## Additional Treatments to Improve Midblock Crosswalk Visibility

There are several countermeasures and treatments that can be applied at midblock crosswalk locations to improve visibility in both daylight and dark conditions. These treatments increase driver attentiveness and awareness of the crosswalk, indicate that a pedestrian is crossing or waiting to cross, and/or improve visibility for both crossing pedestrians and approaching motorists. Many of these treatments can be applied in combination, depending on the characteristics of the individual crosswalk. However, it is important to note that these treatments do not serve as a replacement for overhead lighting or crosswalk illuminators with respect to achieving adequate detection distances at night. Pedestrian crossing treatments deployed in combination with lighting greatly increase pedestrian visibility compared to pedestrian crossing treatments alone (Bhagavathula et al., 2021a).

### *High-Visibility Crosswalk Markings*

High-visibility crosswalk markings can use several different patterns, but they all incorporate longitudinal or diagonal lines (i.e., lines parallel to the direction of vehicle travel). The most common pattern is the continental, or longitudinal bar, though others including bar pair and ladder are also considered high visibility (Schroeder et al., 2023). Figure 25 depicts a variety of crosswalk markings and indicates the high-visibility options while figure 26 shows a pedestrian using a crosswalk with high-visibility markings.

Research has shown that drivers are able to detect high-visibility midblock crosswalk markings farther in advance of the crosswalk than basic transverse crosswalk markings, including during nighttime (Fitzpatrick et al., 2010). Additionally, high-visibility crosswalk markings were associated with higher driver yielding rates, by around 14 percent on average (Schroeder et al., 2023). For these reasons, high-

visibility crosswalk markings are preferred at midblock crossing locations compared to transverse crosswalk markings (Blackburn et al., 2018). The Manual on Uniform Traffic Control Devices (MUTCD) provides standards and recommendations on crosswalk markings (FHWA, 2023).

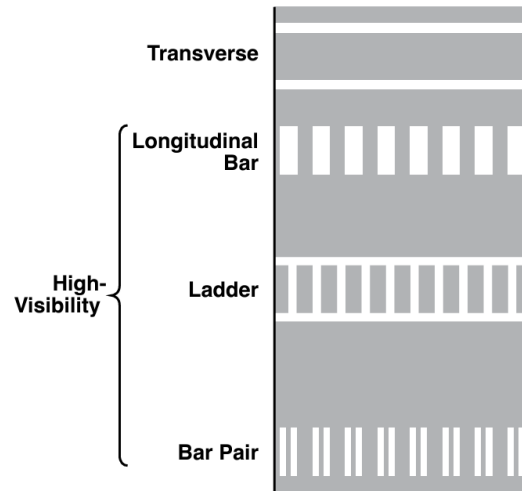


Figure 25. Graphic. MUTCD guidance for crosswalk markings. Source: FHWA.



Figure 26. Photo. A pedestrian crosses the road at a midblock crosswalk using high-visibility crosswalk markings. Source: VHB.

## Signing and Marking Improvements

There are several signs that can be implemented at or in advance of midblock crosswalks to increase driver awareness of the crosswalk. Regulatory signs include the Yield Here to (Stop Here for) Pedestrians (R1-5 series) sign, shown in figure 27. This sign is placed 20 to 50 feet (6.1 to 15.2 meters) in advance of the crosswalk on uncontrolled multilane approaches and is used in combination with yield line or stop line pavement markings.

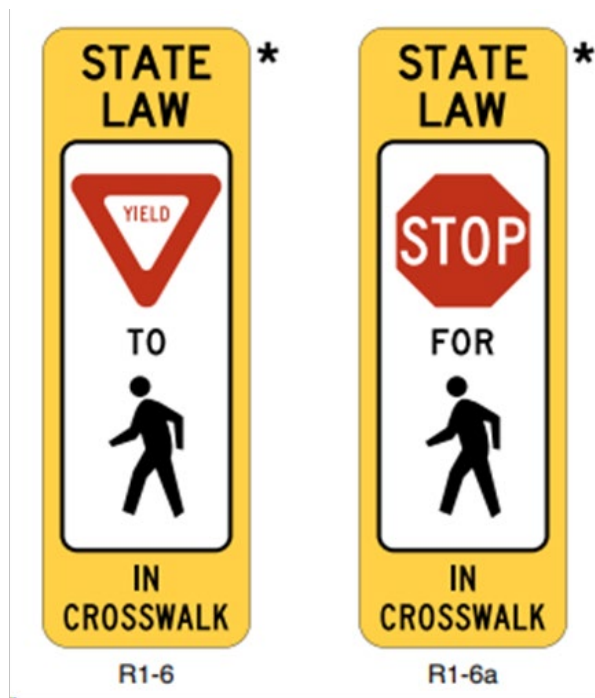


Figure 27. Graphic. Regulatory signs for crosswalk locations. Source: FHWA.

The Pedestrian Crossing (W11-2) warning sign can be placed at the crosswalk, either overhead or post-mounted. If post-mounted, it can be paired with a diagonal downward-pointing arrow (W16-7P) plaque. It can also be placed in advance of the crosswalk with an "AHEAD" plaque. The In-Street Pedestrian Crossing (R1-6 series) sign can also be used at midblock crosswalks and can be placed either in between travel lanes or in a median. These signs are depicted in figure 28 and figure 29. The MUTCD provides guidance on the implementation of these signs (FHWA, 2023).



Figure 28. Graphic. Warning signs for crosswalk locations. Source: FHWA.



\* The legend STATE LAW is optional. A fluorescent yellow-green background color may be used instead of yellow for this sign.

Figure 29. Graphic. In-street pedestrian crossing sign. Source: FHWA.

## ***Rectangular Rapid-Flashing Beacons (RRFBs) and Pedestrian Hybrid Beacons (PHBs)***

RRFBs and PHBs are two different types of pedestrian-actuated beacons for use at otherwise uncontrolled midblock crosswalk locations. RRFBs are used in combination with a sign, such as a Pedestrian Crossing (W11-2) sign and include two rectangular yellow LED lights that flash with high frequency when activated (Blackburn et al., 2018). RRFBs enhance the conspicuity of midblock crosswalks and indicate to approaching drivers that there is a pedestrian about to cross or currently crossing the road. RRFBs have been shown to be especially effective at multilane crossings where the posted speed limit is less than 40 mph (Blackburn et al., 2018). A typical RRFB installation is depicted in figure 30.

PHBs can be effective countermeasures at crosswalks that cross higher-speed roadways. A PHB consists of two red traffic signal lenses above a single yellow lens, arranged in a triangle shape. Once activated by a pedestrian, the PHB displays a sequence of flashing and solid lights that indicate the pedestrian walk interval and signals when motorists can proceed (Blackburn et al., 2018). PHBs are typically recommended for midblock crosswalks where vehicle speeds and/or volumes are higher, but where traffic signal warrants have not been met. A typical PHB installation is depicted in figure 31.



*Figure 30. Photograph. Rectangular Rapid Flashing Beacon (RRFB). Source: FHWA.*



*Figure 31. Photograph. Pedestrian Hybrid Beacon (PHB). Source: FHWA.*

## ***Parking Restrictions and Curb Extensions***

Parking restrictions and curb extensions are two treatments that can improve both motorists' visibility of crossing pedestrians and pedestrians' visibility of oncoming vehicles. Agencies should consider restricting parking on the approaches to all midblock crosswalks, and the setback distance should increase as the vehicle speeds increase (Blackburn et al., 2018). Similar considerations apply to the placement of transit stops near midblock crosswalks. Curb extensions, or bulbouts, bend the curb line outward into the street or parking lane, effectively extending the sidewalk. This reduces the length of the crosswalk and improves sight distance for both pedestrians and motorists. They are particularly

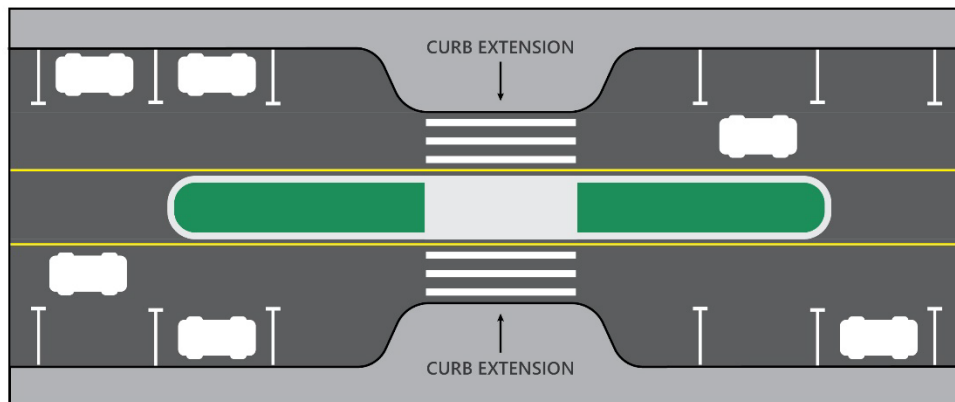
helpful where parking exists close to midblock crosswalks (Blackburn et al., 2018). A typical installation of curb extensions is depicted in figure 32 and figure 33.

## ***Pedestrian Refuge Islands***

A pedestrian refuge island is a special type of median with an area where pedestrians can wait while crossing the road (Blackburn et al., 2018). They allow pedestrians to focus only on one direction of traffic at a time while determining an appropriate gap to cross, improving pedestrian sight distance and reducing the complexity of the crossing movement. They can also improve driver visibility of pedestrians by giving crossing pedestrians a defined place to cross.



*Figure 32. Photograph. Example of curb extensions at a pedestrian crosswalk (FHWA, n.d.). Source: FHWA.*



*Figure 33. Graphic. Plan view sketch of curb extensions at a pedestrian crosswalk. Source: FHWA.*

# Chapter 4: Intersection Crosswalk Lighting Design Considerations

Crosswalk lighting design at intersections follows the same general five-step process laid out at the start of Chapter 3 for midblock crosswalks. This chapter provides additional detail related to this process of designing lighting for crosswalks at intersections. It is not intended to supersede lighting design resources that an agency uses to guide its lighting design practices.

The MUTCD defines a crosswalk as (FHWA, 2022, p. 16):

- a) "that part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs or in the absence of curbs, from the edges of the traversable roadway, and in the absence of a sidewalk on one side of the roadway, the part of a roadway included within the extension of the lateral lines of the sidewalk at right angles to the center line;
- b) any portion of a roadway at an intersection or elsewhere distinctly indicated as a pedestrian crossing by pavement marking lines on the surface, which might be supplemented by contrasting pavement texture, style, or color."

By this definition, a crosswalk exists at an intersection as the extension of the sidewalk or shoulder across the intersection. This applies whether that crosswalk is marked or unmarked (Zegeer et al., 2005). In other words, while a crosswalk can only exist at a midblock location if it is marked, intersections can have marked and/or unmarked crosswalks. Most jurisdictions have laws that allow pedestrians to cross at any crosswalk, regardless of whether the crosswalk is marked, unless another law specifically prohibits pedestrians from crossing at that location; however, crosswalk markings should be installed to improve visibility of pedestrians and other road users. Given these definitions, crosswalk lighting design at intersections should be based on the pedestrian activity at and around the intersection, rather than the presence of marked crosswalks at the intersection.

## Assessment of Potential Lighting Needs

Chapter 3 described how State and local agencies will typically reference lighting warrants to inform a decision of whether to install lighting at a location, including at an intersection. Intersection lighting warrants in the *TAC Guide for the Design of Roadway Lighting* (TAC, 2006), for example, consider geometric characteristics (e.g., sight distance, horizontal and vertical alignment of the approach roadways, intersection skew), operational factors (e.g., traffic volume, pedestrian volume), and crash history. The discussion on lighting warrants and lighting master plans in Chapter 3 is relevant to intersections.

# Design Criteria

Once it is determined that an intersection will be lit, lighting designers will identify lighting design criteria. Design criteria for intersections typically address average horizontal illuminance and horizontal illuminance uniformity and differ by roadway classification of the intersecting roads and level of pedestrian activity.

Crosswalks are collocated with intersections. It is important to note that the levels of vertical illuminance needed for pedestrians in the crosswalks may not be achieved by intersection lighting layouts designed to achieve horizontal illuminance requirements. Pole locations and equipment selection should be carefully considered and verified in a lighting design software package to confirm that vertical illuminance is sufficient in crosswalks at intersections.

RP-8-22 notes that “For intersections with high pedestrian conflict and/or full lighting on the approach roads, improving vertical illumination in the crosswalk should be considered... This will improve the visibility of pedestrians in the crosswalk for motorists approaching the intersection.”

RP-8-22 then describes that “if vertical illumination is desired in crosswalks to improve pedestrian visibility, it is recommended the maintained average vertical levels meet or exceed the maintained average horizontal design levels for the intersection.” As already noted in Chapter 3 and referenced in RP-8-22, maintained average vertical illuminance in crosswalks of 20 to 40 lux could benefit the visibility of the pedestrian. However, research for midblock crosswalks shows that lower levels of vertical illuminance could be adequate for visibility (Bhagavathula et al., 2021a). The example intersection application in Chapter 5 of this informational report applies the RP-8-22 recommendation, achieving average vertical levels that meet or exceed the maintained average horizontal design levels for the intersection.

Bhagavathula et al. (2021a) also showed that the horizontal illuminance achieved at the intersection will affect pedestrian visibility and their recommendations for minimum average horizontal illuminance depended on the lighting pole layout, discussed in the next section.

## Light Pole Layouts at Intersections

Light poles at intersections are generally arranged into one of several common layouts, including approach lighting, exit lighting, center lighting, and combination signal support lighting. Figure 34 depicts these layout alternatives. Approach lighting involves luminaires located on the right-hand side of each approach at the intersection, with poles located in advance of the crosswalks. Center lighting involves one or more poles located at the corners of the intersection, with luminaires directed diagonally into the center of the intersection. Exit lighting involves luminaires located on the right-hand side of the outbound lanes, located beyond the crosswalks. Combination signal support lighting includes luminaires mounted directly onto traffic signal supports. The location of signal supports may vary depending on the signal design needs of the intersection, although it may be ideal to locate the poles in advance of crosswalks when feasible as discussed later in this section.

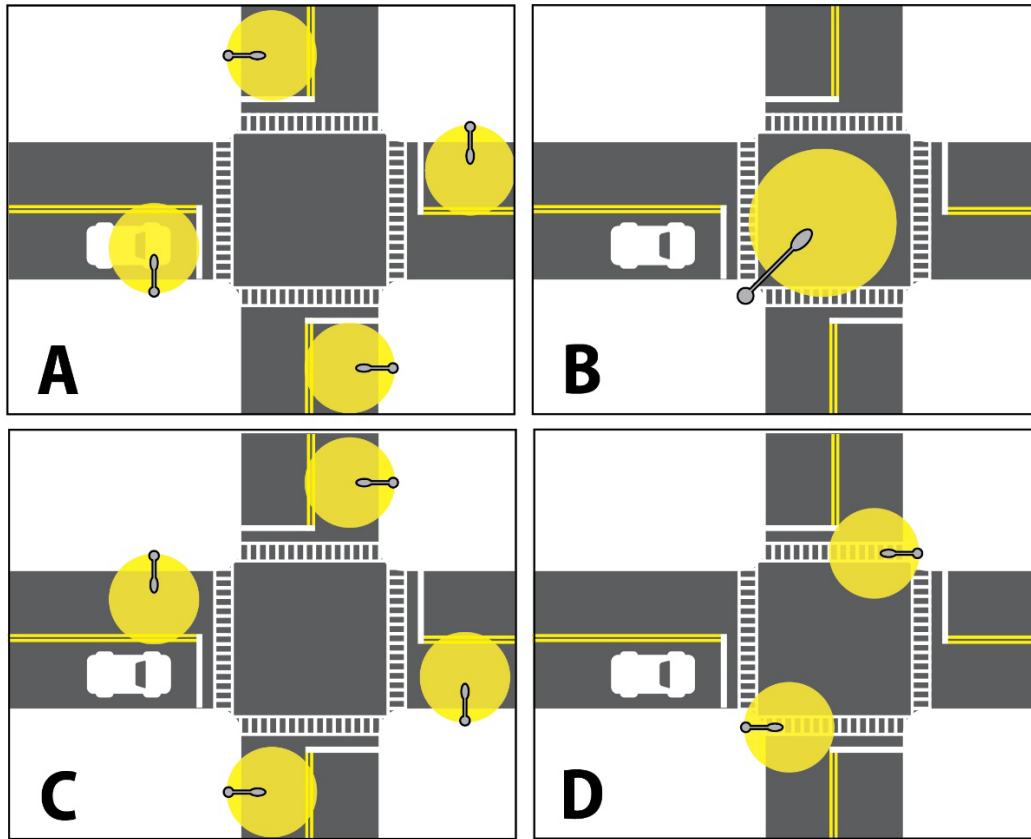


Figure 34. Graphic. Illustration of intersection lighting pole arrangements: a) illuminated approach, b) center lighting, c) illuminated exit, d) illuminated with luminaires on signal mast arm (IDOT design) (adapted from FHWA).

Bhagavathula et al. (2021a) studied the effects of each layout on the visibility of pedestrians to drivers. The research showed that pole layout did not have a significant effect on visibility of pedestrians as long as an average horizontal illuminance of 14 lux (1.3 fc) is maintained in the intersection and no glare from opposing vehicles is present. When average horizontal illuminance levels are less than 14 lux, approach lighting outperformed other layouts with greater detection distances of pedestrians in crosswalks.

Additionally, the research showed that, when glare from opposing vehicles was present, an average horizontal illuminance of 14 lux (1.3 fc) resulted in detection distances greater than stopping sight distance for the study location except for the exit configuration. An average horizontal illuminance level of at least 24 lux (2.2 fc) was found sufficient to offset the effect of glare in the exit lighting layout.

Based on this research, approach lighting may be the most favorable layout when feasible, given the increased performance in low light conditions and when glare is present.

Bhagavathula et al. (2021a) provided the horizontal illuminance recommendations based on pedestrian visibility shown in table 2 along with the following additional considerations:

- The values are based on no ambient lighting being present at the intersection. The presence of ambient lighting may necessitate using higher values than what is shown in the table.
- The values in this table are minimum average light levels for achieving longer pedestrian detection distances based on the designs evaluated in the research.
- The research looked at the simplest type of intersection with no curves, skew angles, or other more complicated alignment or geometry. The results of this study may not apply to other types of intersection characteristics.

Table 2. Lighting Design and Light Level Recommendations for Intersections (Bhagavathula et al., 2021).

<b>Intersection Lighting Design (location of luminaires)</b>	<b>Average Horizontal Illuminance lux (fc)</b>
<b>Approaches</b>	14 (1.3)
<b>Exits</b>	24 (2.2)
<b>Luminaires located on signal mast arm directly over crosswalk</b>	14 (1.3)

## ***Wider Intersection Approaches***

Wider roadways that form intersection approaches present unique challenges with crosswalk lighting. Wider intersection approaches may have at least four lanes, possibly with a median and turn lanes. As the length of a crosswalk increases, the intensity of light provided at the most distant end of a crosswalk becomes weaker, and the desired vertical illuminance criteria may not be met.

In these cases, multiple luminaires may be required to provide adequate vertical illuminance across the entire crosswalk. As one example, the graphic in figure 35 shows a second luminaire located in the center median. Care must be taken to check that the roadside design requirements of the appropriate agency are met (AASHTO, 2011).

If placing a luminaire in the median is not an option, a wide throw luminaire (Type III or some Type IV) may provide greater illuminance at a farther distance from the pole. Designers may also consider adjustments to mounting height and bracket arm lengths to address the challenges of wide roadways.

The Florida Department of Transportation (FDOT) recently adopted a layout for lighting wide intersections that includes a combination of entrance, exit and center lighting on all approaches (see figure 36; FDOT, 2022). The FDOT approach uses the combination of several common layouts to achieve consistent levels of vertical illuminance throughout the entire length of long crosswalks at wider intersections.

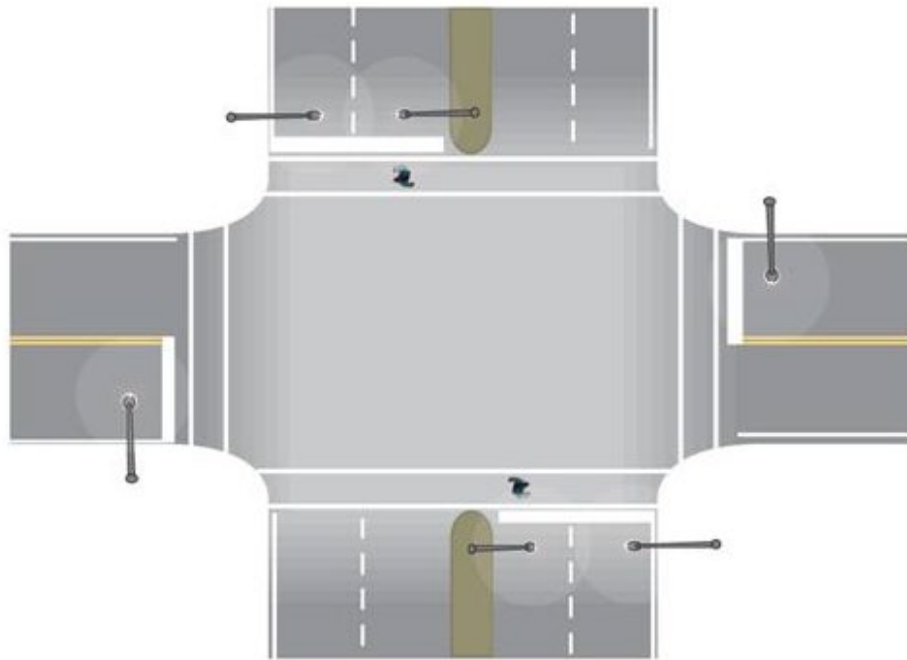


Figure 35. Graphic. Potential lighting layout for crosswalks at wide intersection approaches. Source: FHWA.

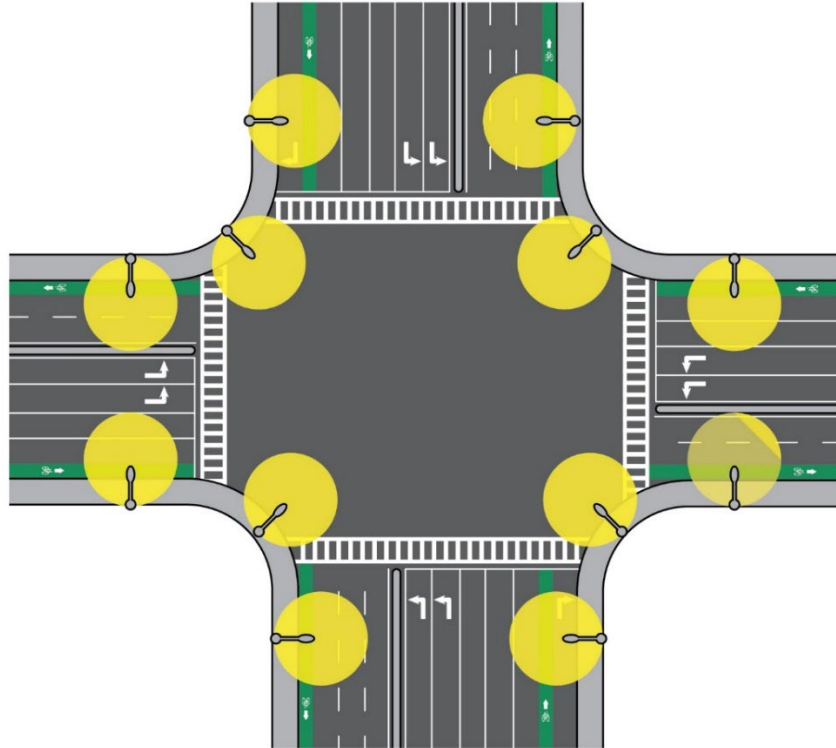


Figure 36. Graphic. Potential lighting layout for very wide intersection approaches (adapted from FDOT, 2022).

## Roundabouts

Typical modern roundabouts are characterized by unique approach geometry that helps reduce approach speeds and affects the intersection of vehicle and pedestrian movements. Pedestrians need to judge gaps in traffic in only one direction at a time at a roundabout; however, the pedestrian crossings are usually uncontrolled. NCHRP Report 672, *Roundabouts: Informational Guide (Second Edition)*, points out that the slower speeds combined with well-defined crossings and splitter islands result in relatively high rates of motorists yielding to pedestrians at most roundabouts. The *Roundabouts: Informational Guide* recommends lighting at all roundabouts to, among other purposes, provide visibility of the key conflict areas and of other users within the roundabout. Effective crosswalk lighting at roundabouts improves the visibility of pedestrians navigating the roundabout.

Crosswalk lighting design principles for roundabouts are like those for traditional intersections, with design criteria for average horizontal illuminance within the circulating lane(s) and average vertical illuminance in crosswalks. As with crosswalks at other locations, vertical illuminance is measured at a height of 5 feet (1.5 meters) above the roadway surface and in the direction of approaching conflicting traffic.

Existing design guidelines recommend that light poles at roundabouts are located along the outer perimeter of the circulating lanes, with additional approach lighting in advance of any marked crosswalks. Pole locations are located and verified with lighting design software to determine that the desired vertical illuminance values are obtained in each crosswalk. A typical lighting layout for roundabouts is depicted in figure 37.

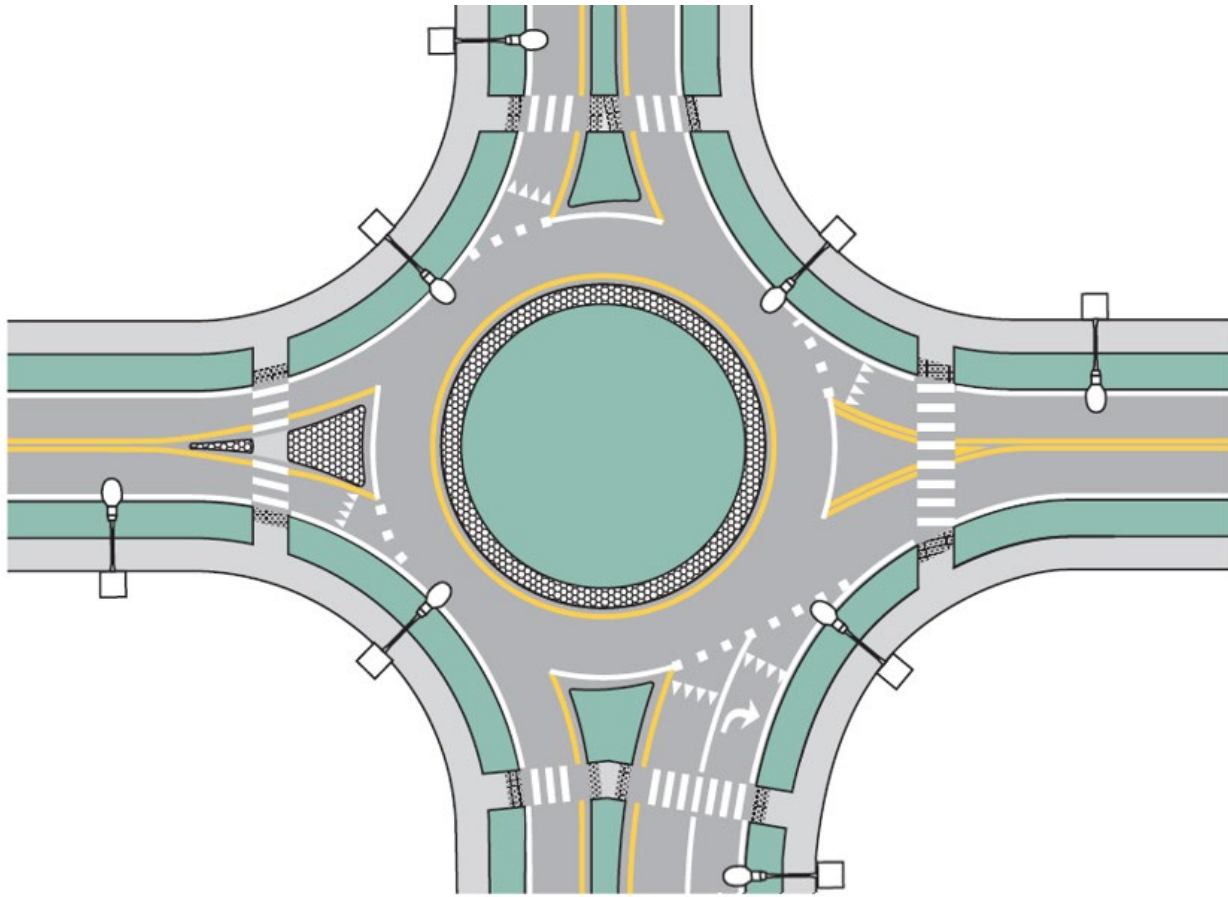


Figure 37. Graphic. Typical lighting layout for a roundabout. Source: AASHTO (2018).

Light poles are sometimes located in the center of a roundabout; however, this layout is not recommended due to the poor contrast created with a central light source. Driver visibility of signs, pavement markings and pedestrians will be negatively affected.

Similarly, roundabouts may be illuminated with high mast lighting, especially when they are located at freeway interchanges. High mast lighting allows for desired uniformity of horizontal illuminance, but generally provides little vertical illuminance and is not the appropriate application when pedestrians are anticipated to be crossing the intersection. High mast lighting may be appropriate in the absence of pedestrian activity.

## Additional Treatments to Improve Intersection Crosswalk Visibility

There are several treatments aside from lighting that can be applied at intersections to improve crosswalk visibility in dark conditions. These treatments increase driver attentiveness and awareness of the crosswalk, reduce the complexity of the crossing movement for pedestrians, and/or improve sight

distance for both crossing pedestrians and approaching motorists. Many of these treatments can be applied in combination, depending on the characteristics of the intersection.

There are several midblock crosswalk visibility treatments detailed in Chapter 3 that can also be applied at intersection crosswalks. These include high-visibility crosswalk markings, pedestrian refuge islands, parking restrictions, and curb extensions. PHBs can also be applied at intersections in certain cases as described in the MUTCD (FHWA, 2023). Refer to Chapter 3 for descriptions of these treatments. Other intersection-specific safety treatments are featured in FHWA's Proven Safety Countermeasure resources, a collection of countermeasures that have been shown to be effective in reducing fatalities and serious injuries (FHWA, 2021a). Examples include a leading pedestrian interval (LPI), which gives pedestrians the opportunity to enter the crosswalk at a signalized intersection 3-7 seconds before the parallel motor vehicle movements are given a green indication (FHWA, 2021c) and backplates with retroreflective borders, which are added to traffic signal heads to improve the visibility of the signal head to drivers (FHWA, 2021d).

# Chapter 5: Design Examples

The design examples included in this chapter detail typical scenarios for lighting crosswalks. They present the key characteristics of each location and illustrate the application of the information in Chapter 3 and Chapter 4 of this informational report. These examples do not cover all potential scenarios related to lighting for pedestrian safety but are designed to demonstrate the information provided in the previous sections of this report.

Each example begins by describing the scenario and progresses through sections for each of the steps in the process laid out in Chapter 3:

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

## Example Scenario – Midblock Crossing

This scenario focuses on a segment of a suburban, two-lane, local roadway, with a midblock trail crossing and a marked crosswalk. An abandoned railway has recently been converted to a multi-use trail that intersects the roadway. The area around the trail is developing rapidly. The trail has become a popular destination for recreation and connects to key local destinations, including a community center, sports fields, and residential areas. The trail sees medium pedestrian activity near the crossing (typically around 40 pedestrians per hour during the evening hours). The road exhibits low vehicle volumes with a pattern of directional commuter traffic during the peak hours. Figure 38 shows a rendering of a two-lane road with a midblock trail crossing with marked crosswalk, like the scenario used in this example.

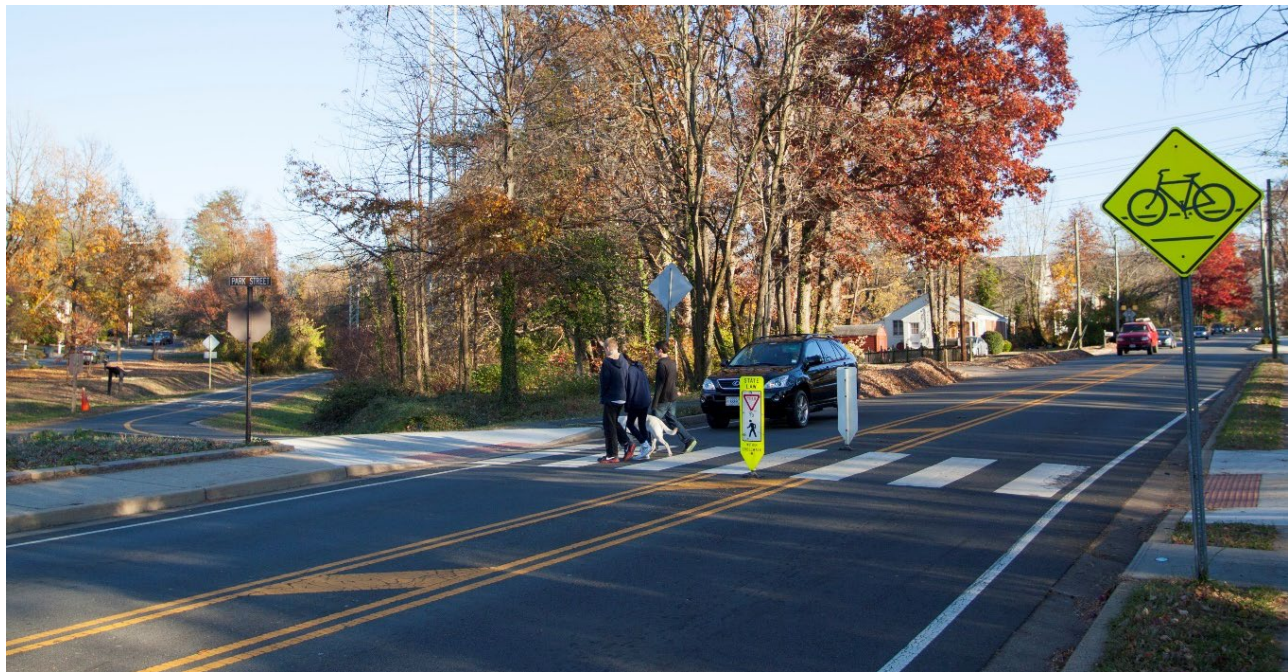


Figure 38. Graphic. Example of a trail crossing like the example scenario. Source: VHB.

## ***Assess Potential Lighting Needs***

The first step is to identify the lighting needs in the given scenario. The designer and maintaining agency should be aware of the role that lighting plays for users of the trail located in the study area, and for motorists on the roadway as they approach the crosswalk. In this case, the maintaining agency's policy is to provide lighting at all midblock crosswalks. This trail crossing is consistently used by bicyclists and pedestrians, including during dark hours early in the morning and late in the evening. By providing crosswalk lighting, the trail users will have a more consistent experience at night with increased feelings of comfort and personal security.

## ***Select Design Criteria***

The next step is to select the lighting design criteria for each of the facility types identified. This example primarily 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. Chapter 3 contains more information and resources regarding secondary criteria.

RP-8-22 provides recommended light levels based on the pedestrian activity level in the area. This example consists of a midblock crossing on a local roadway with a medium pedestrian activity level. Following recommendations provided in RP-8-22, crosswalks with a medium pedestrian activity level should be provided an average vertical illuminance of 30 lux. The chosen luminaires will have a CCT of 3000 K to 4000 K. Table 3 summarizes the criteria for example Scenario 1. Refer to Chapter 3 for a detailed discussion of lighting design criteria.

Table 3. Selected design criteria for example scenario 1.

Pedestrian facility characteristics	Average Illuminance	CCT (LED only)
<b>Midblock crosswalk</b>	30 lux vertical	3000 K to 4000 K

## 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. Selection of luminaires is often based on local inventory and standards. In this case, the trail crossing is located near a historic district, and the maintaining agency desires a decorative style of luminaire, consistent with other nearby roadway lighting. This design will use pendant style LED luminaires with a decorative pole and bracket arm (see figure 39). By selecting a light fixture that the maintaining agency already uses elsewhere, the new installation will provide ease of maintenance and a sense of familiarity for road users. The design will use a color temperature within the 3000 K to 4000 K range presented in table 3, 114 W of power and an IES distribution of Type II (illustrated in figure 17). Type II provides a shallower distribution angle that will result in greater longitudinal illumination of the crosswalk while also casting light onto the roadway.



©2021 Google Street View.

Figure 39. Graphic. Example LED pendant roadway luminaire (Google Maps, 2021).

The selected initial mounting height is 40 feet (12.2 m), which is the typical preference of the local agency for roadway lighting. One pole will be positioned on each side of the roadway in advance of the marked crosswalk to provide a positive contrast as described in Chapter 2 and Chapter 3.

Refer to Chapter 3 for a detailed discussion of lighting equipment selection.

## ***Determine Control Strategy***

The lighting control strategy determines when and at what level the lighting operates. Although outdoor lighting has traditionally operated on a “dusk to dawn” schedule, the crosswalk location in this example is isolated from other lighting systems and the roadway is otherwise dark. Pedestrian volumes on the trail diminish significantly later at night, with no pedestrians observed between the hours of 10 pm and 5 am. For this example, the maintaining agency has decided to implement an adaptive control system, dimming the lighting system to fifty percent after the hours of 10:00 pm, and returning to full power at 5:00 am as pedestrian activity resumes in the morning. This will reduce the energy consumption of the lighting system, while also lessening the impact of glare on motorists when the system is dimmed. The design will be completed to meet the target design criteria when the system is at full power. The agency will continue to monitor the location for future adjustments to the schedule. Future development and seasonal changes may justify a change in the dimming schedule.

Methods for applying adaptive lighting technologies are included in RP-8-22. These methods are not required under FHWA regulations unless they are incorporated by reference into the regulations. Refer to Chapter 3 of this report for more information on control strategies, including a discussion of adaptive lighting in the context of lighting for pedestrians.

## ***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 (e.g., luminance, illuminance) 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 RP-8-22). All vertical illuminance points are located 5 ft (1.5 m) above the roadway surface to represent the typical height of a pedestrian, with a spacing of 1.6 ft (0.5 m). Vertical illuminance measurements are oriented toward approaching motorists for each travel lane.

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.

Pole locations are selected to achieve design goals; however, they may also be highly constrained due to roadway geometrics, utility conflicts, or other obstacles. They should be placed in advance of crosswalks to create positive contrast (as discussed in Chapter 3). Additionally, pole locations are often adjusted during the design process as needed based on the calculated photometric results, until the target design criteria are met and a pole layout is finalized. For this initial calculation, the poles are located five feet (1.5 meters) in advance of the crosswalk in either direction.

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 for this example. The criteria and results are shown in table 4, where the bolded rows indicate items that did not meet the target criteria. 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, the design must be revised to provide higher average vertical illuminance in the crosswalk area.

*Table 4. Summary of initial lighting design criteria and calculation results.*

<b>Calculation Summary – Initial Design</b>				
<b>Calculation Zone</b>	<b>Calculation Type</b>	<b>Units</b>	<b>Target Criteria</b>	<b>Calculation Results</b>
			<b>Average</b>	<b>Average</b>
<b>Midblock Crosswalk (Eastbound)</b>	<b>Vertical Illuminance</b>	<b>Lux</b>	<b>30</b>	<b>5.7</b>
<b>Midblock Crosswalk (Westbound)</b>	<b>Vertical Illuminance</b>	<b>Lux</b>	<b>30</b>	<b>7.1</b>
<b>Note: Additional lighting design criteria recommended in RP-8-22 should be evaluated and considered for uniformity and glare.</b>				

The designer may choose to increase the wattage of the luminaire to achieve greater vertical illuminance levels; however, this will result in an increase in energy consumption and may provide excessive light. To provide a more efficient and targeted application of light, a logical next step is to adjust the pole locations to optimize the amount of vertical illuminance provided in the crosswalk based on the selected fixture. After evaluating several different offset distances, it was determined that an offset of 25 ft (7.6 m) from the crosswalk is optimal for this luminaire.

Upon calculating the results again with the photometric analysis software package, the results show that the vertical illuminance has improved, but is still too low to meet the target design criteria. Table 5 summarizes the criteria and results, with the items that did not meet criteria shown in bold.

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

Calculation Summary – Revised Design				
Calculation Zone	Calculation Type	Units	Target Criteria	Calculation Results
			Average	Average
<b>Midblock Crosswalk (Eastbound)</b>	<b>Vertical Illuminance</b>	<b>Lux</b>	<b>30</b>	<b>12.4</b>
<b>Midblock Crosswalk (Westbound)</b>	<b>Vertical Illuminance</b>	<b>Lux</b>	<b>30</b>	<b>12.9</b>
<b>Note: Additional lighting design criteria recommended in RP-8-22 should be evaluated and considered for uniformity and glare.</b>				

At this point in the design process, the pole location has been adjusted. It is not desirable to increase the wattage of each fixture. Therefore, further revisions to the design may include selection of a different fixture, adjustment of the pole arm length, or adjustments to the mounting height of the luminaire.

Because the deficiency in calculated results is the vertical illuminance levels, selecting a lower mounting height may benefit the vertical illuminance. For the next iteration, rather than select the agency’s standard 40-ft (12.2 m) mounting height for roadway lighting, a lower mounting height of 30 ft (9.1 m) is chosen.

The photometric analysis software package calculates the results one more time, which show that the resulting design now meets the design criteria for vertical illuminance. Table 6 shows the key criteria and results, and figure 40 shows a software rendering of the final lighting design.

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

Calculation Summary – Final Design				
Calculation Zone	Calculation Type	Units	Target Criteria	Calculation Results
			Average	Average
Midblock Crosswalk (Eastbound)	Vertical Illuminance	Lux	30	31.1
Midblock Crosswalk (Westbound)	Vertical Illuminance	Lux	30	32.4

**Note: Additional lighting design criteria recommended in IES RP-8-22 should be evaluated and considered for uniformity and glare.**

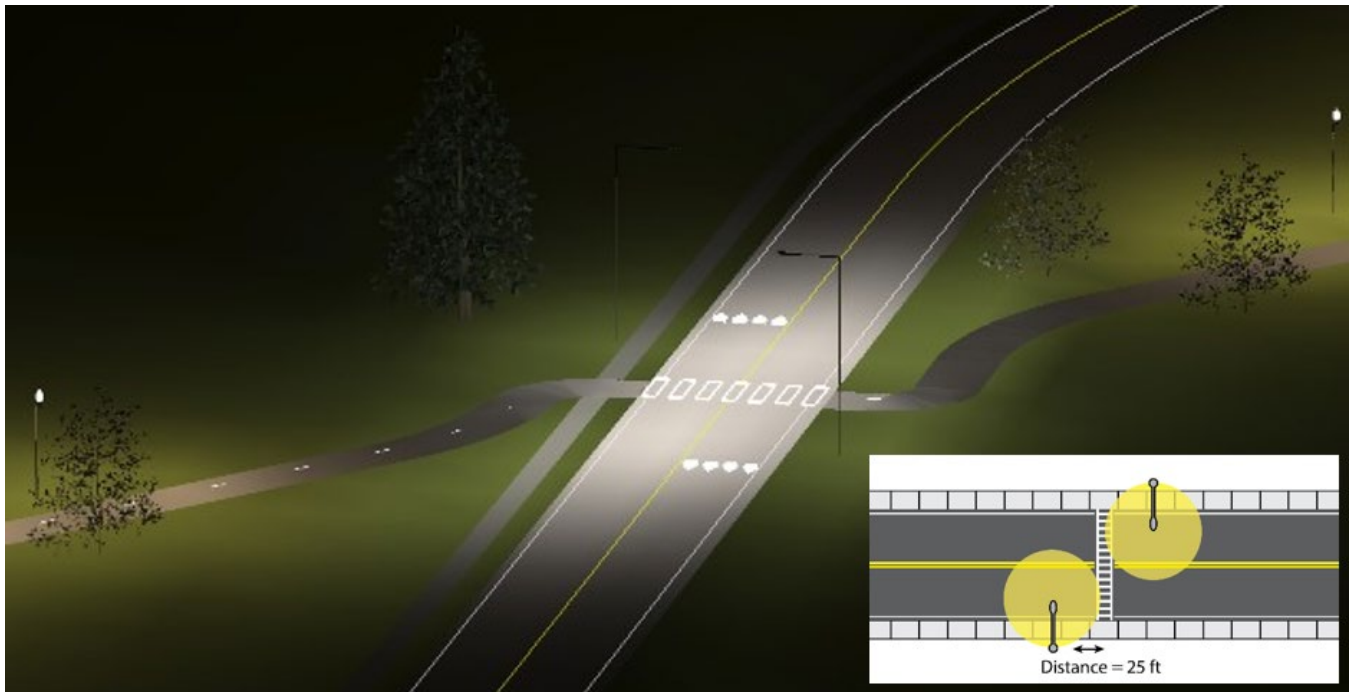


Figure 40. Graphic. Software rendering of final lighting design for midblock trail crossing example scenario. Source: VHB.

## Example Scenario - Roundabout

This scenario focuses on a rural roundabout with two intersecting collector roadways. Roundabouts are included in FHWA's Proven Safety Countermeasures. As noted in Chapter 4 of this report, the ability for roundabouts to manage speeds on the approaches and the need for pedestrians to judge approaching traffic in only one direction at a time assists with pedestrian crossing maneuvers. Well-defined crossings and splitter islands at roundabouts also result in relatively high rates of motorists yielding to pedestrians. However, pedestrian crossings at roundabouts are usually uncontrolled. Therefore, lighting is particularly valuable in establishing nighttime visibility of pedestrians. NCHRP Report 672, *Roundabouts: Informational Guide (Second Edition)*, recommends lighting at all roundabouts to provide visibility of the key conflict areas and of other users within the roundabout. Note that although this example features a roundabout, the same basic principles and a similar design approach is followed for traditional at-grade intersections.

The roundabout is situated on the outskirts of a small rural town, in between the Main Street retail area and a newly built high school located on a formerly agricultural property. It is the first roundabout to be constructed in the county, and the project generated significant public interest. The roundabout sees a low but consistent volume of pedestrians, with high school students walking through the location on their way to and from school and seasonal agriculture workers walking to and from the nearby fields for work. Many school events occur in the evenings and the peak pedestrian volumes sometimes occur in dark conditions, depending on the time of year. Figure 41 shows a rural one-lane roundabout, like the scenario used in this example.



Figure 41. Illustration of a rural, one lane roundabout. Source: FHWA.

## Assess Lighting Needs

The first step is to identify the lighting needs in the given scenario. The designer and maintaining agency should be aware of the role that lighting plays for users of the roundabout, including both pedestrians and motorists. In this case, the maintaining agency has recently adopted a new policy to provide lighting at all alternative intersections and roundabouts where there is nighttime pedestrian activity.

## Select Design Criteria

To determine the primary design criteria for this example, the designer refers to RP-8-22 for recommended light levels based on the functional classification of the roadways. This example consists of two collector roadways, which requires an average horizontal illuminance of 16 lux. Crosswalks within the roundabout should have an average vertical illuminance equal to or greater than the calculated horizontal illuminance. The chosen luminaires will have a CCT of 3000 K to 4000 K. Table 7 summarizes the criteria for example Scenario 2.

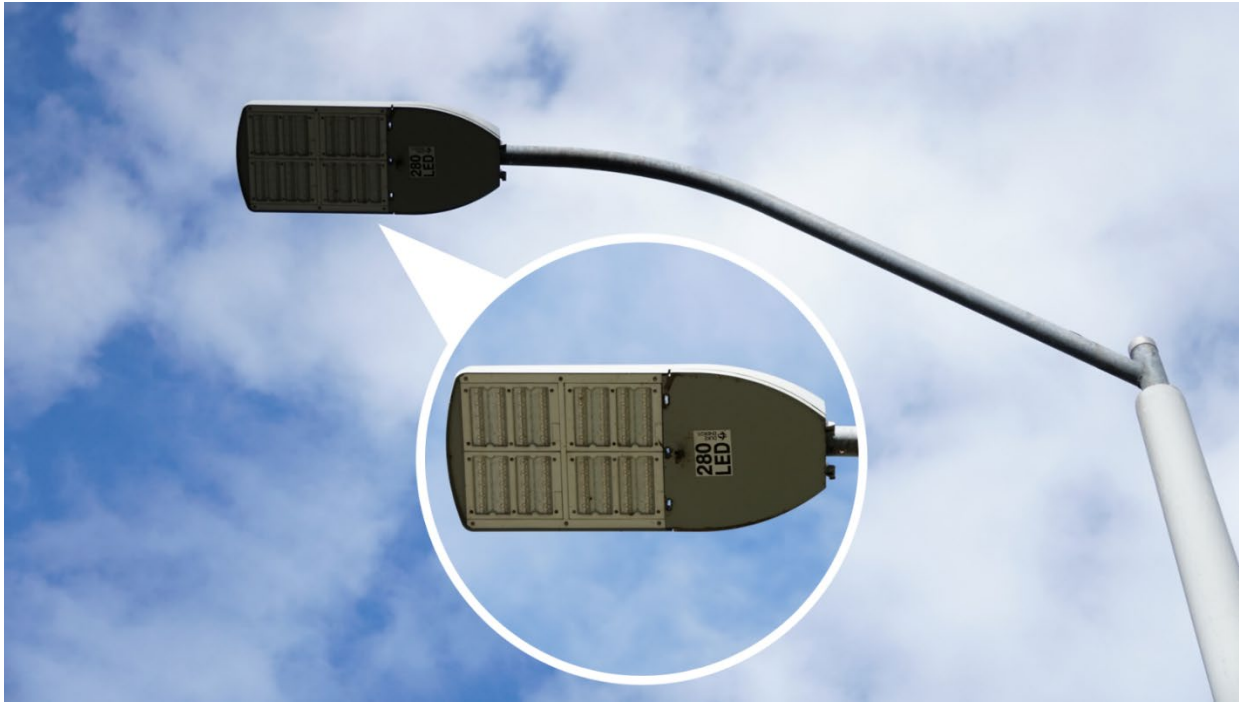
Refer to Chapter 3 and Chapter 4 for a detailed discussion of lighting design criteria.

*Table 7. Selected design criteria for example scenario 2.*

Facility	Average Illuminance	CCT (LED only)
Roundabout	16 lux horizontal	3000 K to 4000 K
Crosswalk	Equal or greater than roundabout horizontal illuminance	3000 K to 4000 K

## Select Equipment

The next step is to select lighting equipment that will enable the design to meet the identified criteria. In this example, the roundabout is in a rural area. Historical significance and aesthetics are of less concern at this specific location, and the designer selects a cost-effective cobra head luminaire which will be mounted to wood utility poles. The design will use a color temperature within the 3000 K to 4000 K range presented in table 7, 175 W of power, and an IES distribution of Type III (as illustrated previously in figure 17).



*Figure 42. Graphic. Example LED cobrahead roadway luminaire mounted to wood pole. Source: FHWA.*

A roadway scale mounting height is selected for this example. Although a design may be completed with lower pedestrian scale mounting heights, the luminaire selected is intended for roadway applications. In this case, the lighting system also serves to illuminate the roundabout and vehicular approaches. Higher mounting heights result in more uniform application of light with a fewer number of poles, and therefore a lower overall cost to install and maintain. The initial layout will utilize a mounting height of 35 feet (10.7 meters).

Refer to Chapter 3 for a detailed discussion of lighting equipment selection, including the trade-offs between roadway scale lighting and pedestrian scale lighting.

## ***Determine Control Strategy***

In this example, the lighting system will use traditional dusk-to-dawn operation. A photocell will be installed with each luminaire, which will turn the lighting system on and off based on the ambient light in the vicinity. This will allow appropriate seasonal variation in the operating hours of the lighting system as the night becomes longer during winter and shorter during summer. Refer to Chapter 3 of this report for more information on control strategies.

## ***Design and Verification***

The roundabout design is imported into a photometric design software for calculating the resulting light levels of the proposed lighting system. All vertical illuminance points are located 5 ft (1.5 m) above the roadway surface to represent the typical height of a pedestrian, with a spacing of 1.6 ft (0.5 m). Vertical illuminance measurements are oriented toward approaching motorists for each travel lane.

Horizontal illuminance points are laid out in a grid pattern, within the limits of the roundabout, with a spacing of 5 ft. RP-8-22 recommends that the grid spacing does not exceed 2 m (6.6 ft). Illuminance in the center island is not calculated and does not count toward the average illuminance in the roundabout. A total light loss factor of 0.85 is applied to each luminaire IES file.

Pole locations are selected based on the typical lighting layout recommended by the AASHTO *Roadway Lighting Design Guide* (figure 37), with one pole on each approach in advance of the marked crosswalks, and four poles evenly spaced around the circulating lanes, located at the midpoint between the approaches (AASHTO, 2018).

The photometric analysis software calculates results for the design. The horizontal illuminance is much higher than the targeted 16 lux, and therefore several crosswalk locations fail to achieve the target vertical illuminance of equal to or greater than horizontal illuminance with the initial design. The criteria and results are shown in table 8, where the bolded rows indicate items that did not meet the target criteria.

Given that the horizontal illuminance is more than double the target value, the next iteration of this design will utilize a lower wattage luminaire. The designer reviews available options of the same luminaire model, selecting a 105 W option that produces roughly half the amount of light (measured in lumens) compared to the 175 W model.

In addition, to increase the amount of vertical illuminance that reaches the crosswalks, the designer chooses a Type II distribution instead of a Type III option. This change will result in a longer, narrower distribution of light from each luminaire. The designer recalculates the photometric results, and finds that the horizontal illuminance is appropriate, slightly exceeding the targeted average. Vertical illuminance values for each crosswalk should exceed the average horizontal illuminance in the roundabout. The results show that the crosswalks on inbound travel lanes meet this criterion, but the crosswalks on outbound lanes do not. Table 9 summarizes the criteria and results, with the items that did not meet criteria shown in bold.

Table 8. Summary of initial lighting design criteria and calculation results.

Calculation Summary – Initial Design				
Calculation Zone	Calculation Type	Units	Target Criteria	Calculation Results
			Average	Average
Roundabout	Horizontal Illuminance	Lux	16	41.0
Crosswalk (Northbound – In)	Vertical Illuminance	Lux	41*	44.6
Crosswalk (Northbound – Out)	Vertical Illuminance	Lux	41*	32.1
Crosswalk (Southbound – In)	Vertical Illuminance	Lux	41*	47.7
Crosswalk (Southbound – Out)	Vertical Illuminance	Lux	41*	22.9
Crosswalk (Eastbound – In)	Vertical Illuminance	Lux	41*	48.2
Crosswalk (Eastbound – Out)	Vertical Illuminance	Lux	41*	24.1
Crosswalk (Westbound – In)	Vertical Illuminance	Lux	41*	47.2
Crosswalk (Westbound – Out)	Vertical Illuminance	Lux	41*	30.6

\* Vertical illuminance value adjusted to match the actual average horizontal illuminance in the roundabout.

Note: Additional lighting design criteria recommended in *RP-8-22* should be evaluated and considered for uniformity and glare.

Table 9. Summary of revised lighting design criteria and calculation results.

Calculation Summary – Revised Design				
Calculation Zone	Calculation Type	Units	Target Criteria	Calculation Results
			Average	Average
<b>Roundabout</b>	<b>Horizontal Illuminance</b>	<b>Lux</b>	<b>16</b>	<b>17.7</b>
<b>Crosswalk (Northbound – In)</b>	Vertical Illuminance	Lux	18*	18.3
<b>Crosswalk (Northbound – Out)</b>	<b>Vertical Illuminance</b>	<b>Lux</b>	<b>18*</b>	<b>13.1</b>
<b>Crosswalk (Southbound – In)</b>	Vertical Illuminance	Lux	18*	18.3
<b>Crosswalk (Southbound – Out)</b>	<b>Vertical Illuminance</b>	<b>Lux</b>	<b>18*</b>	<b>8.2</b>
<b>Crosswalk (Eastbound – In)</b>	Vertical Illuminance	Lux	18*	18.3
<b>Crosswalk (Eastbound – Out)</b>	<b>Vertical Illuminance</b>	<b>Lux</b>	<b>18*</b>	<b>7.8</b>
<b>Crosswalk (Westbound – In)</b>	Vertical Illuminance	Lux	18*	18.4
<b>Crosswalk (Westbound – Out)</b>	<b>Vertical Illuminance</b>	<b>Lux</b>	<b>18*</b>	<b>8.9</b>
<p><b>* Vertical illuminance value adjusted to match the actual average horizontal illuminance in the roundabout.</b></p> <p><b>Note: Additional lighting design criteria recommended in IRP-8-22 should be evaluated and considered for uniformity and glare.</b></p>				

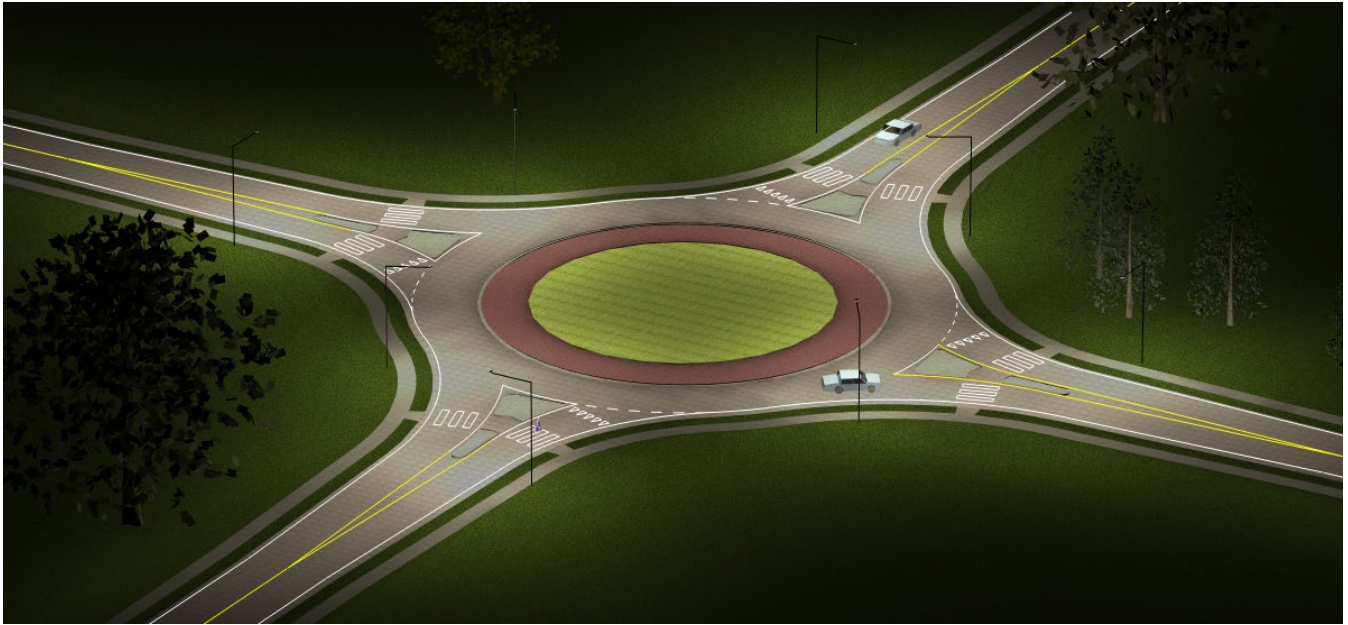
Now that the design provides the correct level of horizontal light and some crosswalks receive sufficient vertical illuminance, the design can incorporate some minor adjustments. By fine-tuning pole locations to increase vertical illuminance on the remaining crosswalks, the designer should be able to establish a layout that meets the target criteria. Since it is the crosswalks on outbound travel lanes that need more vertical illuminance, the poles located around the roundabout can be repositioned and reoriented. Each pole is moved closer to the roundabout and angled slightly more toward the nearest crosswalk.

The photometric analysis software package calculates the results one more time, which show that the resulting design now meets the design criteria for horizontal illuminance in the roundabout and vertical illuminance in all crosswalks. Table 10 shows the key criteria and results, and figure 43 shows a software rendering of the final lighting design.

Table 10. Summary of final lighting design criteria and calculation results.

Calculation Summary – Final Design				
Calculation Zone	Calculation Type	Units	Target Criteria	Calculation Results
			Average	Average
<b>Roundabout</b>	Horizontal Illuminance	Lux	16	17.1
<b>Crosswalk (Northbound – In)</b>	Vertical Illuminance	Lux	18*	18.3
<b>Crosswalk (Northbound – Out)</b>	Vertical Illuminance	Lux	18*	19.3
<b>Crosswalk (Southbound – In)</b>	Vertical Illuminance	Lux	18*	18.3
<b>Crosswalk (Southbound – Out)</b>	Vertical Illuminance	Lux	18*	19.2
<b>Crosswalk (Eastbound – In)</b>	Vertical Illuminance	Lux	18*	18.3
<b>Crosswalk (Eastbound – Out)</b>	Vertical Illuminance	Lux	18*	18.8
<b>Crosswalk (Westbound – In)</b>	Vertical Illuminance	Lux	18*	18.4
<b>Crosswalk (Westbound – Out)</b>	Vertical Illuminance	Lux	18*	19.4

\* Value adjusted to match the actual average horizontal illuminance in the roundabout.  
 Note: Additional lighting design criteria recommended in IES *RP-8-22* should be evaluated and considered for uniformity and glare.



*Figure 43. Graphic. Software rendering of final lighting design for example scenario. Source: VHB.*

These examples presented the key characteristics of the location and illustrated the application of the crosswalk lighting design process described in Chapter 3 and Chapter 4, 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 layouts are achieved. The average illuminance metrics for each various type of facility are met or exceeded with the selected lighting designs.

# Chapter 6: Summary and Recommendations

This report is intended to be used by transportation planners, designers, and operators who are involved in improving the safety, accessibility, and mobility of all road users of a roadway network. The report serves as an introduction to the concepts of pedestrian lighting design, and when used in combination with the referenced design guidance and standards, provides a foundation for understanding the various considerations for lighting midblock crosswalks and crosswalks at intersections. The report will be a valuable resource to transportation safety practitioners and other staff who seek an increased understanding of the basic principles, benefits, and design considerations for lighting pedestrian crosswalks. Lighting design incorporates a broad range of factors and considerations and includes coordination with multiple stakeholders. These stakeholders include, for example, zoning or land use committees, which can play key roles in helping to minimize the potential negative impacts of ambient light on roadway lighting performance.

This report is an update to the 2008 *Informational Report on Lighting Design for Midblock Crosswalks*. Significant advancements in roadway lighting technology and research have occurred since 2008, including widespread adoption of LED lighting. This report provides a background on basic concepts and references additional guidance related to the use of LED lighting for pedestrian facilities. LED lighting has inherent benefits over other light sources and allow for precise application of light to the design facility, with less wasted light. Designers must carefully evaluate and select the most appropriate LED alternative when completing retrofit projects. This is especially true if existing light poles are to remain in place and the designer is unable to control pole locations.

Chapter 1 introduces the report, including a summary of relevant pedestrian crash data trends in the US, a brief review of literature on the benefits of lighting for pedestrian safety and security, and descriptions of key reference materials for the reader to review in conjunction with the report. Chapter 2 reviews visibility concepts and terminology, establishing a basic understanding of the factors that affect pedestrian visibility and inform lighting design. Chapter 3 describes considerations for midblock crosswalk lighting design including lighting design criteria, luminaire selection and placement, other lighting considerations, and additional midblock design strategies. Chapter 4 provides information on lighting design for crosswalks at intersections. Chapter 5 provides practical design examples focused on a midblock crosswalk and an intersection with nighttime pedestrian activity.

The development of this report has revealed several key areas where continued research can fill gaps in knowledge and further improve the effectiveness of crosswalk lighting design. Much of the existing pedestrian lighting research, including both crash data research and lighting design research, has focused generally on nighttime conditions or at intersections. Increased research focus on midblock crosswalks may uncover additional considerations that are specific to these locations. Research on the

effects of ambient light on visibility, especially as it relates to pedestrian visibility in crosswalks, is another key area of focus for future work.

The study by Li et al. (2020) demonstrates how the ability to collect in-field lighting measurements is improving the ability to draw linkages between lighting levels and nighttime crash reductions. These types of findings can then inform a transportation agency's policies and practices related to both lighting needs assessments and lighting design. These more modern safety assessments to-date have primarily focused on aggregate groupings of crashes at intersections. Findings specific to pedestrian and bicyclist crashes at intersection and especially non-intersection and midblock locations are needed to further demonstrate lighting effectiveness and inform agency policies and practices. As lighting technology continues to improve and evolve, it is important for researchers to conduct robust evaluations of the effectiveness of lighting installations, especially at crosswalks. This includes evaluating the safety performance and other effects of new and innovative products as they continue to be released. One example of this includes adaptive lighting systems specifically designed for installation at crosswalks. These systems are expected to receive increased interest in the coming years as agencies seek to reduce costs associated with lighting, including wasted light.

As prior research has established, lighting pedestrian crosswalks is crucial to increasing the safety performance of the roadway network for all road users. This report supports the deployment of lighting and other countermeasures to improve nighttime visibility at midblock and intersection crosswalks, providing a safer transportation network for pedestrians at night.

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