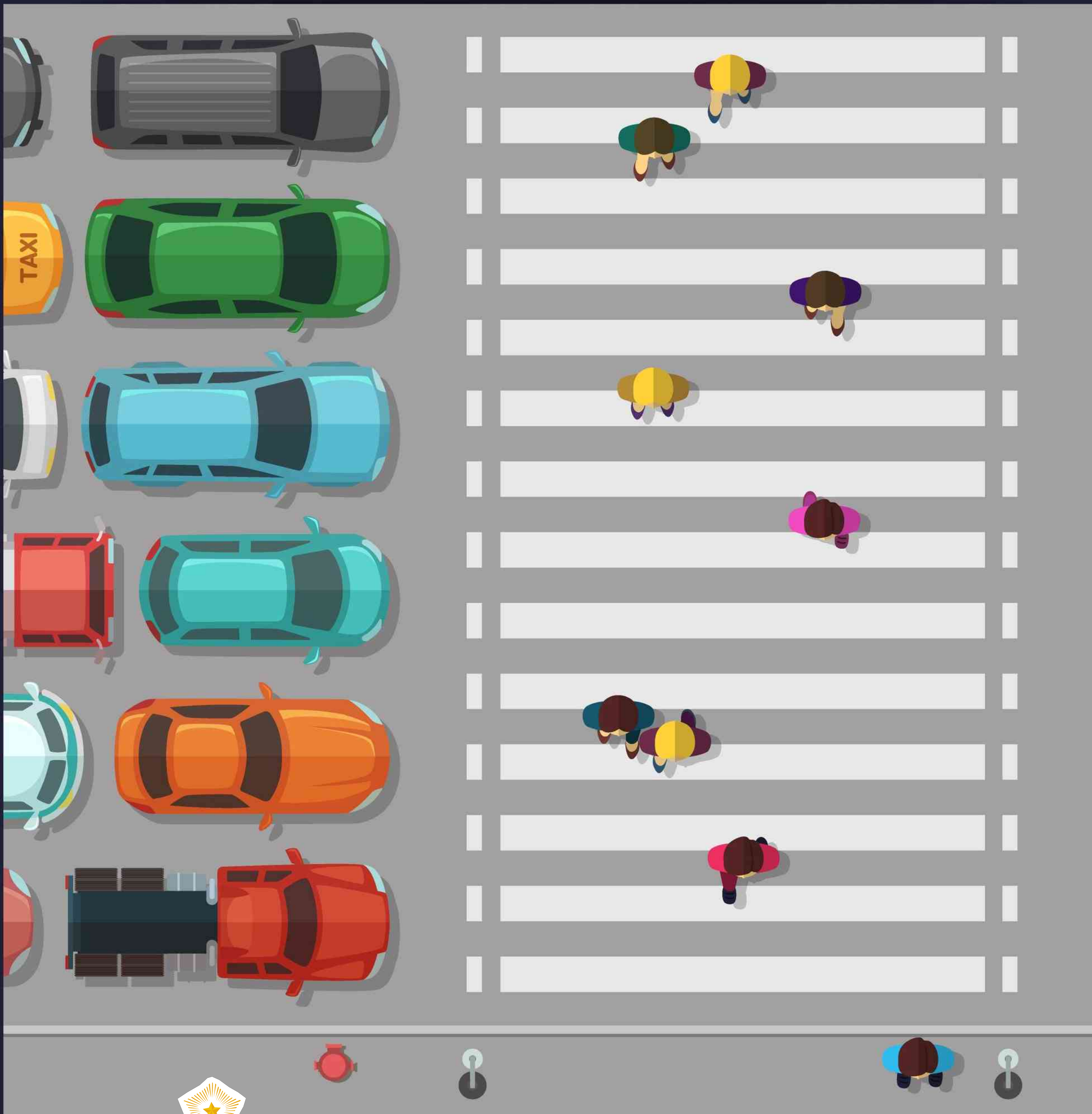


August 2024

LIGHTING DESIGN GUIDELINE FOR PEDESTRIAN CROSSWALKS

MaineDOT

Michael Baker INTERNATIONAL

Contents

1. Introduction

1.1. Background

MaineDOT is focused on improving the safety of pedestrians in and around crosswalks throughout the state of Maine. According to FHWA, lighting for crosswalks is one of several proven transportation safety countermeasures that can reduce pedestrian nighttime crashes at intersections by 42%. However, numerous transportation industry lighting guidelines discuss aspects of pedestrian lighting design, but none are comprehensive. The existing guidelines vary slightly in terminology, warrant requirements, design criteria, and design methods which can make it challenging for industry professionals.

In 2023, MaineDOT commissioned a study to evaluate several roadway lighting design documents recently published by industry professionals and organizations such as the U.S. Department of Transportation (USDOT), Federal Highway Association (FHWA), American Association of Transportation Officials (AASHTO), Transportation Association of Canada (TAC), Illuminating Engineering Society (IES), Virginia Tech Transportation Institute (VTTI), and Pacific Northwest National Labs (PNNL).

The goal of the 2023 MaineDOT study was to identify existing pedestrian lighting design guidelines which best represented MaineDOT roadways and/or design new guidelines where none existing. The results of this study have been compiled and presented here in the *MaineDOT Lighting Design Guideline for Pedestrian Crosswalks.*

Figure 1-1. Images. A variety of recently published roadway lighting handbooks, guides, recommended practice, research reports, and primers associated with intersections, crosswalks, and pedestrian lighting applications.

1.2. Purpose of this Guideline

The *MaineDOT Lighting Design Guideline for Pedestrian Crosswalks* was prepared with the assistance of Michael Baker International, Inc. and is disseminated under the sponsorship of MaineDOT in the interest of information exchange. MaineDOT's goal is to provide high-quality information to serve government, industry, and the public in a manner that promotes public understanding. This document does not constitute a standard, specification, or regulation. It is a guideline that shall be used for *guidance only* and does not endorse products, manufacturers, or organizations. Trademarks, names, or images that appear in this report have only been provided because they are considered essential to the objective of the guideline.

MaineDOT and Michael Baker International, Inc. assume no liability for the use of the information contained in this guideline. The contents of this guideline do not have the force and effect of law and are not meant to bind the public in any way. This guideline is intended only to provide clarity to the public and contains non-binding technical information. Users of this guideline are still required to comply with all laws, agency policies, applicable statutes, and regulations.

Figure 1-2. Rendering. LED Luminaire with optics uniquely designed for pedestrian crosswalks.
(Image courtesy of Cyclone Lighting)

Roadway lighting design applications that are not included in this guideline include Highways/Freeways, Streets (Major/Minor Arterials, Major/Minor Collectors, Local Roads), Interchanges (Toll Plazas, Acceleration/Deceleration Lanes/Ramps, Termini), Rest Areas, Alleys, Pedestrian Plazas, Pedestrian Sidewalks, Parking Lots, Bridges, Underbridge, and Tunnel lighting. Designers are encouraged to refer to the primary reference documents listed in this guideline for assistance with these applications.

This guideline presents recommended standard practices and design guidance for pedestrian crosswalk lighting applications. Good engineering practices and sound engineering judgement shall be used in determining the required solutions for lighting design. Variations to these guidelines may be considered provided they are supported by proper engineering principles and sound judgement. Design variations from this guideline must be submitted to MaineDOT for evaluation and approval.

1.3. Primary References

The pedestrian lighting design guidelines presented here have been developed in accordance with generally accepted engineering practices for roadways, intersections, and pedestrian crosswalk applications. The terminology and definitions included in this guideline have been simplified for the user and may vary slightly from other lighting references. Existing lighting documents, studies, tables, and recommendations have been referenced when appropriate. This document is a guideline that shall be used for guidance and reference only. It does not replace judgement by a licensed professional engineer. This document does not create a standard, specification or regulation, and applicable code requirements should be verified and adhered to for all projects. MaineDOT and Michael Baker International, Inc. do not endorse products, manufacturers, or organizations. Trademarks, names, or images that appear in this report have been provided only where considered essential to the objective of the guideline.

The following documents have been used as primary references for this document.

- AASHTO. 2001. *A Policy on Geometric Design of Highway and Streets (Green Book).* 4th Ed. Washington D.C.: American Association of State Highway and Transportation Officials.
- AASHTO. 2001*. Guidelines for Geometric Design of Very Low Volume Local Roads (Little Green Book)*. Washington D.C.: American Association of State Highway and Transportation Officials.
- AASHTO. 2018. *Roadway Lighting Design Guide*. Washington D.C.: American Association of State Highway and Transportation Officials.
- ANSI/IES. 2021. *Recommended Practice for Design and Maintenance of Roadway and Parking Facility Lighting,* RP-8-21. New York, NY: Illuminating Engineering Society.
- FHWA. 2008. *Informational Report on Lighting Design for Midblock Crosswalks, Report No. FHWA-HRT-08-053.* Washington D.C.: Federal Highway Administration.
- FHWA. 2013. *Highway Functional Classification Concepts, Criteria and Procedures*. Washington D.C.: Federal Highway Administration.
- FHWA 2020. *Research Report: Street Lighting for Pedestrian Safety, Report No. FHWA-SA-20-062*. Washington D.C.: Federal Highway Administration.
- FHWA. 2022. *Pedestrian Lighting Primer, Report No. FHWA-SA-21-087*. Washington D.C.: Federal Highway Administration Office of Safety.
- FHWA. 2023*. FHWA Lighting Handbook, Report No. FHWA-SA-23-004*. Washington D.C.: Federal Highway Administration Office of Safety.
- Robert G. Davis, Andrea M. Wilkerson, Bruce R. Kinzey 2019*. Luminaire Dirt Depreciation (LDD): Field Data from Several Exterior Lighting Projects*. LEUKOS, 15:1, 55-63.
- TAC 2006. *Guide for the Design of Roadway Lighting, PTM-LIGHTING06*. Ottawa, Ontario, Canada. Transportation Association of Canada.
- VTTI 2021. *Roadway Lighting's Effect on Pedestrian Safety at Intersection and Midblock Crosswalks, Report No. FHWA-ICT-21-023*. Bhagavathula, Gibbons, and Kassing.
- Wilkerson AM, Sullivan GP, Davis RG. 2016. *LED system performance in a trial installation – two years later: Final report prepared in support of the DOE Solid-State Lighting Technology GATEWAY Demonstration Program.* Washington (DC): U.S. Department of Energy. PNNL Report No. 25356.

1.4. The Lighting Design Process

The purpose of this guideline is to provide users with a singular reference for designing pedestrian lighting for intersection crosswalks and midblock crosswalks in the State of Maine. The lighting design process for these applications has been broken down into the following steps.

NOTE: Before beginning the lighting design process, it is important that the designer fully understands the pedestrian lighting terminology (see Section. 2), the types of lighting classifications (see Section 3), the types of roadway classifications (see Section 4), and types of intersection classifications (see Section 5).

Step 1. Select Application. Select one of the two pedestrian lighting applications.
- Intersection crosswalk
- Midblock crosswalk

Step 2. Select Approach Roadway Type. Select the type of lighting along each approach roadway *(See Section 5).*
- Continuous lighting
- Non-continuous lighting
- No lighting

Step 3. Complete Warrant. Determine if lighting is automatically warranted (or) complete the MaineDOT *Warrant for Pedestrian Lighting at Intersection Crosswalks (See Section 6).*
- Automatically warranted
  - Midblock crosswalk
  - Signalized intersection
  - Non-signalized intersection with continuous lighting along one or more approach roadways
  - Non-signalized intersection with a history of a pedestrian crash
  - Non-signalized intersection in close proximity to locations where children, elderly, or persons with disability will be present.
- Complete the Warrant Calculation

Step 4. Select the Intersection Lighting Classification. Based on the warrant, identify the type of intersection lighting *(See Section 7).*
- Full Intersection Lighting
- Partial Intersection Lighting
- Intersection Crosswalk Lighting

Step 5: Select Design Criteria. Gather the roadway characteristics and identify the lighting design criteria.
- Horizontal Illuminance and Uniformity (from AASHTO) *(See Section 8).*
  - Functional Classification
  - Area Classification
  - Pavement Classification (use R2)
- Vertical Illuminance and Uniformity (1fc avg. maintained, 4:1) *(See Section 10).*

Step 6. Layout Horizontal Illuminance Grid. Identify the application's geometric boundaries and layout the horizontal illuminance calculation grid. *(See Section 8).*

Step 7. Layout Vertical Illuminance Grid. Identify the vehicular-to-pedestrian conflict points and layout the vertical illuminance calculation grid(s) *(See Section 10).*

Step 8. Select Luminaire. Select the LED Luminaire (wattage/lumens, optical distribution, & 4000K) and mounting height.

Step 9. Select Pole Locations. Coordinate with existing/proposed conditions (e.g.: underground and overhead utilities, traffic poles, etc.) and identify the pole locations to create a positive contrast.

Step 10. Complete Calculations. Calculate the horizontal and vertical average-maintained illuminance and uniformity levels. If needed, adjust luminaire wattage/lumens, optics, locations, and/or height to reach the recommended design criteria.

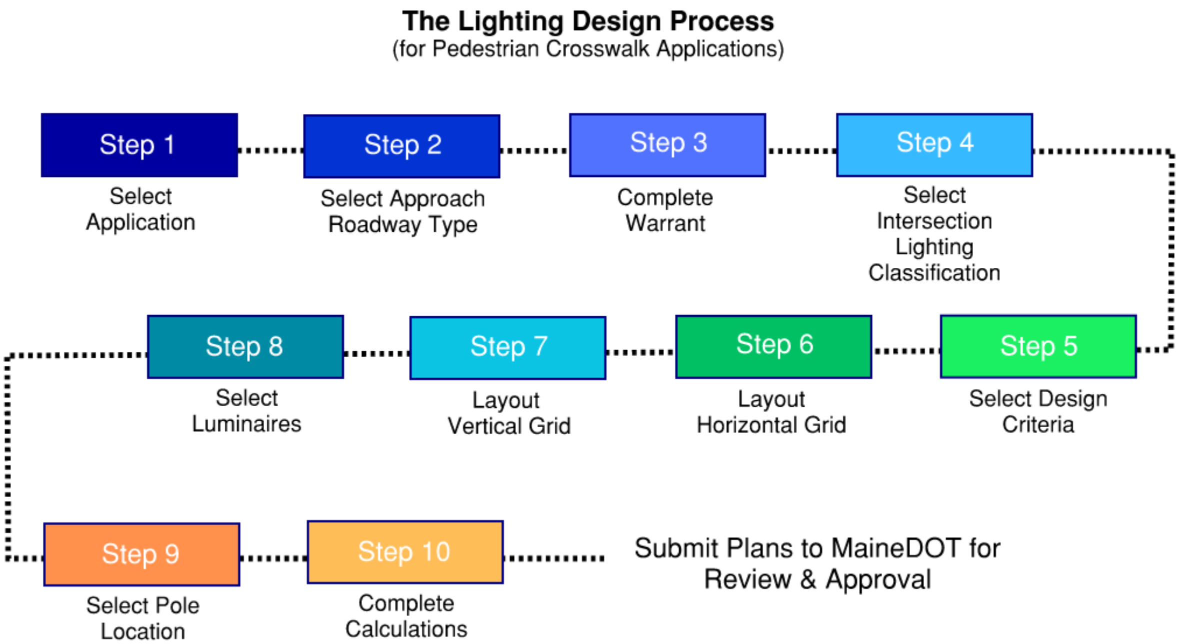


Figure 1-3. Illustration. The Lighting Design Process.

2. Lighting Terminology

2.1. The Four Key Lighting Terms

When designing pedestrian crosswalk lighting, it is important to understand the fundamental terminology used by the lighting industry to describe the quantity of light. These four key lighting design terms include:

Luminous Flux (lumens, l). The light generated by a light source is referred to as *luminous flux* and is measured in *lumens (l)*. The total lumen output of a light source is the sum of light emitted in all directions.

Luminous Intensity (candelas, cd). The concentration of light in a particular direction is referred to as *luminous intensity* and is expressed in *candelas (cd)*.

Illuminance (lumens/ft^2, footcandle, fc) or (candelas/m^2, lux). The measurement of the total quantity of light (lumens) falling onto a surface per unit area is referred to as *illuminance*. The unit of illuminance is *footcandle (fc),* where one footcandle is equal to one lumen per square foot; or *lux (lx),* where one lux is equal to one lumen per square meter.

Luminance (cd/m^2). The measurement of the amount of light that bounces off a surface and is reflected back to an observer in a particular direction is called *luminance*. The unit of luminance is measured in *`cd/m^2*.

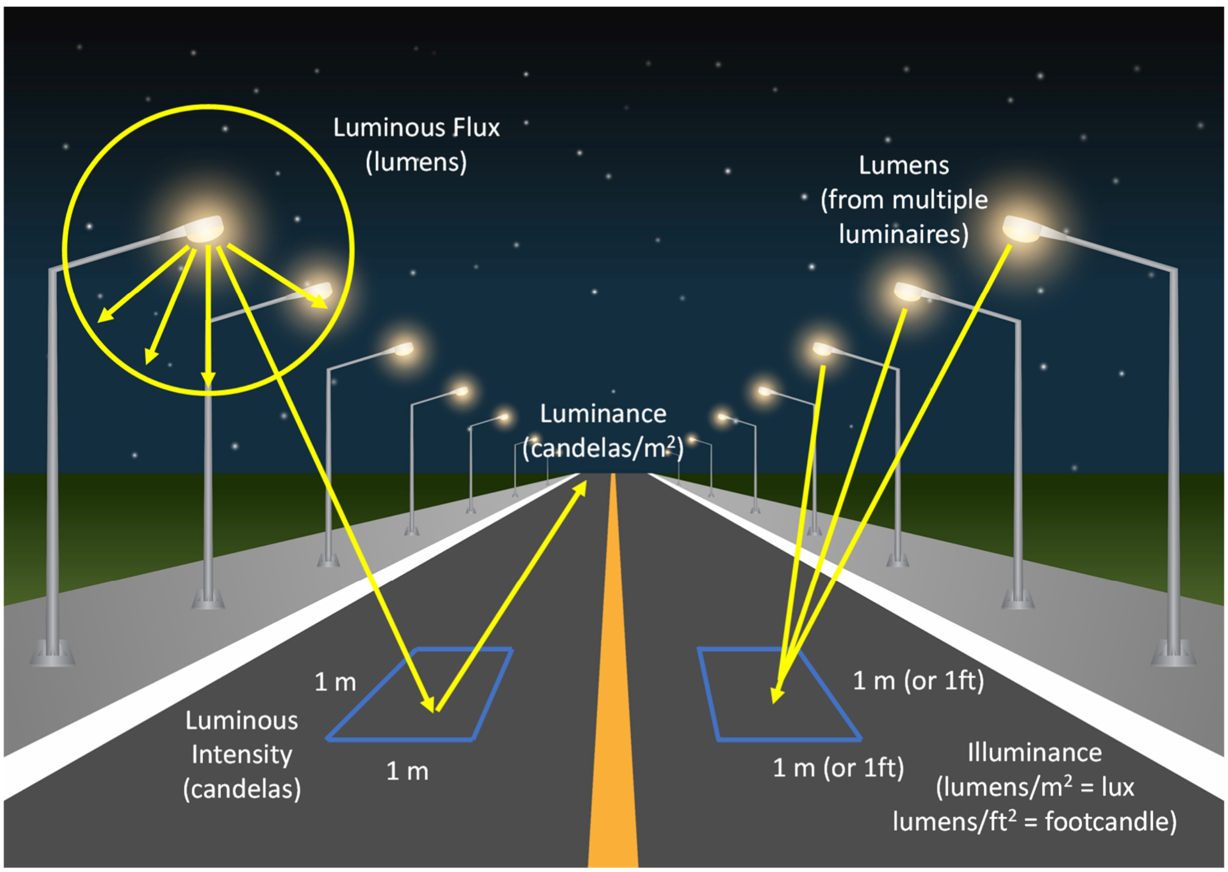


Figure 2-1. Illustration. Luminous flux, luminous intensity, illuminance, and luminance.

2.2. Components of a Luminaire

A complete lighting fixture, collectively referred to as a *luminaire*, consists of the housing, lamp or LEDs, ballast or driver, optics (reflectors, refractors, lenses), heat sink, and internal wiring. While legacy roadway luminaires use HID lamps, newer roadway luminaires use more efficient LEDs.

High-Intensity Discharge Lamps (HID). *HID* is a term used for a variety of lamps such as High-Pressure Sodium (HPS), Metal Halide (MH), and Mercury Vapor (MV). These lamps were originally manufactured in a variety of standard wattages and standard lumen outputs for roadway applications such as 70W, 100W, 150W, 200W, 250W, and 400W. HID lamps emit luminous flux in all directions, and they require an external reflector or refractor to aim the light in its desired direction. An HID requires a ballast in order to operate.

Figure 2-2. Photos. Various HID Lamps. (Left) HPS, (Middle) MH, and (Right) MV.

Light Emitting Diodes (LEDs). *LEDs* are a newer technology used in roadway luminaires, typically consisting of arrays of discreet LEDs that are mounted to an LED board. Multiple boards can be mounted inside a luminaire housing to provide various lumen packages. Unlike HID lamps, LED luminaires can be offered in hundreds of different wattages, color temperature, and optical distributions, which can make selecting the right product overwhelming for designers. LEDs only produce luminous flux in a forward direction and can use precisely molded lenses to aim the lumens from each LED in desired direction. LEDs require a driver in order to operate.

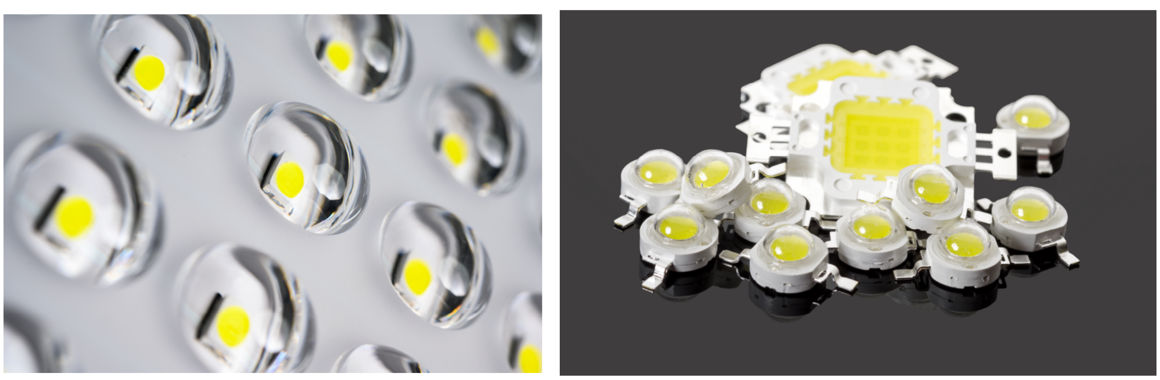


Figure 2-3. Photos. (Left) Rows of discreet LEDs mounted to circuit board. (Right) LEDs with and without molded optics.

Luminous Efficacy. HID Lamps and LEDs both require power to produce light. The ratio of the amount of power (measured in watts) that is required to produce a specific quantity of luminous flux is referred to as *luminous efficacy,* measured in *lumens/watt*. When calculating the total wattage for a luminaire, the designer need to account for both the wattage of the light source and the additional wattage that is consumed by the HID's ballast or the LED's driver. For example, a 400W MH may require a ballast that draws an additional 35W. A 120W LED that produces an equal number of lumens compared to an HID may only require a driver that draws 1W.

HID Ballasts. HID lamps operate on alternating current (AC). The normal voltage provided by the power distribution system is insufficient to start an HID lamp. HID lamps require a voltage spike to jump-start the electric arc in the bulb, which excites the gases inside it and causes it to glow. A *ballast* is used by HID lamps to perform this task. Once the HID lamp is started, the ballast regulates the voltage back down to a reasonable level for normal lamp operation. Without the ballast, an HID lamp would quickly overheat and fail.

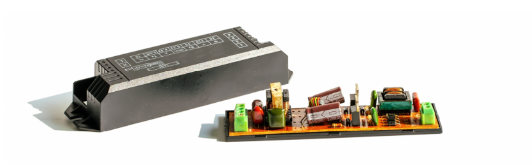


Figure 2-4. Photo. HID Ballast with internal electrical components.

LED Drivers. Since LEDs operate on direct current (DC), *drivers* are needed to convert the incoming current from AC to DC. There are various types of LED drivers that can be used for roadway lighting including ON/OFF, dimming (0-10V), DALI (0-10V dimming plus communication of data), and D4i (drivers for IoT).

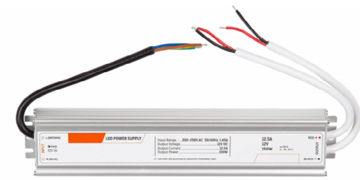


Figure 2-5. Photo. LED Driver.

Smart LED Drivers. New smart LED drivers (such as D4i drivers, aka drivers for IoT) can work seamlessly with networked lighting control systems to help operation and maintenance departments work more efficiently. D4i drivers are dimmable, have internal power supplies to power control devices, and can be factory programmed to store and communicate static data pertaining to the luminaire and driver asset such as the catalog numbers, lumen output, optical distribution, and color temperature. In addition, D4i drivers can communicate energy, performance, operational, and maintenance data associated with a roadway luminaire such as voltage fluctuations, operating timers, overheating, and other characteristics to help proactively identify issues before the luminaire fails.

Figure 2-6. Photos. NEMA/ANSI C136.41 7-pin receptacle with control node.

Smart LED Control Nodes. The new D4i driver data can be communicated through a lighting control node, which can be mounted to a NEMA/ANSI 7-pin C136.41 compliant receptacle on top of the luminaire. The control node can then communicate its own data (GPS location, tilt sensors, etc.), along with the D4i driver's energy, performance, and diagnostic data, via a cellular, wireless mesh, or LoRaWAN network. The data can then be communicated through a gateway and/or to a centralized lighting management system (CMS). The data can then be used by end-users in dashboards, reports, work orders, alarms, and even mapped to other software (like ArcGIS, Inframaps, etc.) to monitor the health and help proactively maintain a roadway lighting control system. The goal of any lighting control system is to minimize any down time and to increase the safety of pedestrians and the traveling public.

Figure 2-7. Illustration. Assembly of a contr5ol node, 7-pin receptacle and luminaire.

Luminaire Efficiency. The percentage of lumens that are able to exit a luminaire in relation to the number of lumens produced by an HID lamp or array of LEDs is referred to as *luminaire efficiency*. HID luminaires require an internal reflector or exterior refractor to help aim the lumens emitted by the lamp in the direction they need to go. As a result, lumens get trapped inside the luminaire housing making them significantly less efficient than LED luminaires. Legacy HID luminaires that are retrofitted with LED retrofit lamps will have an added level of inefficiency. The direction of light emitted from generic LED retrofit lamps can be significantly different than the light emitted from the exact type of HID lamp the luminaire was originally designed for. Legacy luminaires with reflectors and refractors are not able to aim the precise beam spreads associated with LEDs, which causes retrofit luminaires to be glarey and unable to deliver the lumens to the intended target roadway.

Figure 2-8. Photos. (Left) An HID luminaire with an internal aluminum reflector, (Middle) an HID luminaire with external glass refractor, (Right) LED roadway-style luminaire that does not need a reflector or refractor.

2.3. Tools for Measuring Light

The following are terms used by the lighting industry when measuring the quantity of light for several types of applications.

Figure 2-9. Photo. An illuminance meter.

Figure 2-10. Photo. A luminance meter.

Illuminance Meter (aka Light Meter). A handheld tool that can be used in the field to measure actual illuminance is referred to as an *illuminance meter*. When measuring light in the field, it is important that the reader is aware of their surroundings and does not accidentally block any supplemental light that could contribute to the measurement. A light meter with an extended cable for the photo sensor is preferred. Light meters can be calibrated to measure light in fc or lux.

Luminance Meter. A handheld tool that can be used in the field to measure photometric brightness is referred to as a *luminance meter*. It measures the amount of emitted or reflected light from a surface and is displayed in *cd/m²* or *ft-Lambert*.

Lighting Analysis Software. *A* calculation tool that uses *.ies files to accurately model the quantity and direction of light emitted from a luminaire is referred to as *lighting analysis software*. It can also predict the amount of light incident on a surface (illuminance), or light reflected from a surface (luminance). Visual and AGi32 are two popular software used by the transportation industry. MaineDOT requires designers to use AGi32 for pedestrian crosswalk lighting calculations as it has the features necessary to accurately model vertical illuminance.

Variable Light Meter (i.e., aimable). When using a physical illuminance meter in the field or a virtual illuminance meter in lighting analysis software, the meter will need to be aimed in various directions based on the type of calculation performed. To accurately measure horizontal illuminance on a road surface, the meter needs to be aimed normal to the surface (i.e., up). To accurately measure vertical illuminance in a pedestrian crosswalk, a *variable light meter* is required which is capable of aiming each calculation point in the direction of the on-coming car for both thru-lanes and turning lanes. *(Note: Variable light meters are discussed further in Section 10-Vertical Illuminance.)*

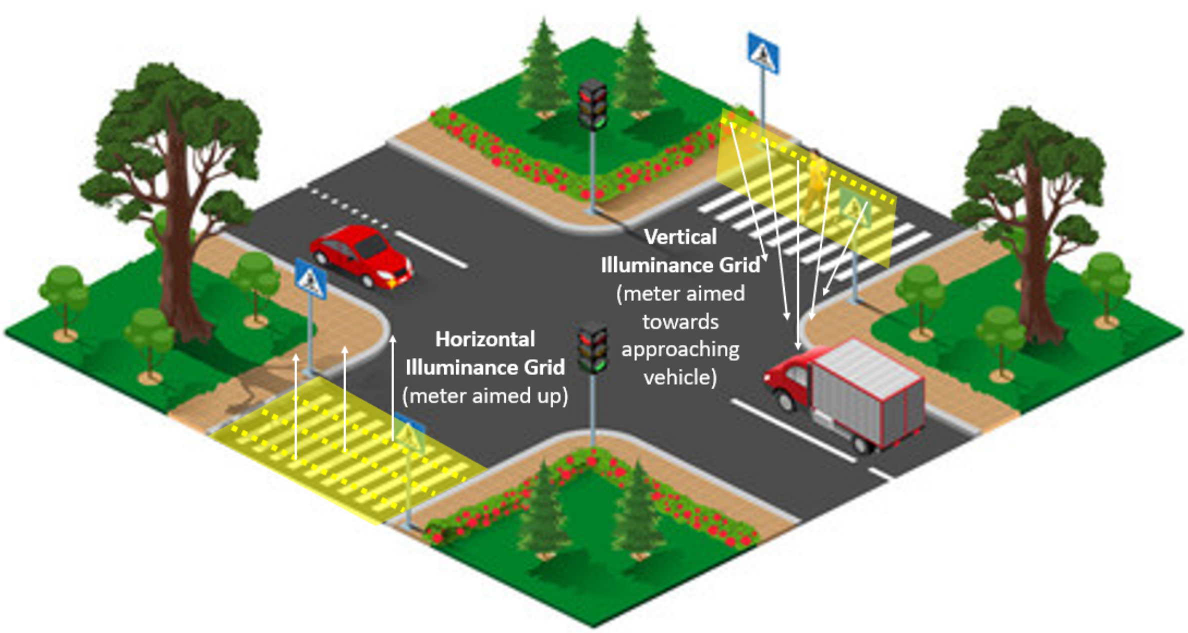


Figure 2-11. Illustration. Virtual meter aiming for horizontal and vertical calculation grids.

***.ies Files**. To model the light output from a luminaire in a lighting analysis software, luminaire manufacturers provide designers data files, with the extension **.ies.* These files are generated by UL-certified testing laboratories using a machine called a goniophotometer and a sphere. *.ies files are produced in a standard format that can be used by various lighting analysis software and they document the characteristics of each luminaire and its light sources. These characteristics include:

- [MANUF] Manufacturer
- [LUMCAT] Luminaire Catalog Number
- [LUMINAIRE] Description of Luminaire, IES Roadway Classification, & Kelvin Temperature
- [DISTRIBUTION] IES Distribution Types & BUG Rating
- [INPUTWATTAGE] Total Wattage of the LEDs and Driver(s)
- [VOLTAGE] Ideal Operating Voltage
- [LUMENS] Initial Lumen Output

Figure 2-12. Photo. A luminaire being prepared for testing using a goniophotometer. *(Photo courtesy of Shayna Bramley)*

```
IESNA:LM-63-2002
[TEST] CSA 700P9
[ISSUEDATE] 10/2/2023
[TESTLAB] SCALED PHOTOMETRY
[MANUFAC] American Electric Lighting
[LUMCAT] ATB0 P203 R3 4K
[LUMINAIRE] Autobahn Small P203 Package Roadway Type III 4000K/5000K
[DISTRIBUTION] TYPE III, SHORT, BUG RATING: B2 - U0 - G2
[_TOTALLUMINAIRELUMENS] 10260
[_INPUTWATTAGE] 70
[_LAMPTYPE] LED
[_MOUNTING] ARM
[_PRODUCTID] 51371ce3-26c9-4475-856a-f215a7148736
[_SERIES] ATB0
[_SERIESID] 824685
[_AMBIENT] 25.0 DEG C
[_POWERFACTOR] 0.9948
[_ATHD] 8.75%
[_CURRENT] 0.57
[_VOLTAGE] 120.06
[_STABILIZATION] 42:20.1 STABLE
[_POWER VARIATION] 0.96%
[_LIGHT VARIATION] 0.49%
[_LUMENS] 10609.29
[_END VOLTS] 120.07
[_END CURRENT] 0.57
[_END POWER] 68.35
TILT=NONE
1  -1  0.969561807202729  73  19  1  1  0.68  0.99  0
1  1  70
0  2.5  5  7.5  10  12.5  15  17.5  20  22.5  25  27.5  30
32.5  35  37.5  40  42.5  45  47.5  50  52.5  55  57.5  60
62.5  65  67.5  70  72.5  75  77.5  80  82.5  85  87.5  90
92.5  95  97.5  100  102.5  105  107.5  110  112.5  115
117.5  120  122.5  125  127.5  130  132.5  135  137.5  140
142.5  145  147.5  150  152.5  155  157.5  160  162.5  165  167.5  170  172.5  175  177.5  180
0  10  20  30  40  50  60  70  80  90  100  110  120  130  140  150  160  170  180
1549  1605  1643  1696  1757  1804  1835  1885  1949  2016
2090  2190  2325  2488  2660  2821  2975  3125  3286  3416
3455  3382  3315  3161  2714  1861  1009  721  541  408
318  251  211  186  170  115  0  0  0  0  0  0  0  0  0
```

Figure 2-13. Image. Example of an *.ies data file for a typical LED roadway luminaire.

Autobahn Series ATB0
Roadway Lighting

PERFORMANCE PACKAGE

ATB0	Distribution	Input Watts	2700K		3000K		4000K/5000K	
			Lumens	LPW	Lumens	LPW	Lumens	LPW
P201	R2	36	4,983	137	5,473	151	5,488	150
	R3		4,952	136	5,107	140	5,553	152
	R3L		4,693	130	4,851	135	5,105	142
	R4		5,045	139	5,130	141	5,346	147
	R5		5,084	142	5,384	148	5,387	150
P202	R2	49	6,429	132	7,100	147	7,203	148
	R3		6,390	131	6,679	137	7,237	148
	R3L		6,037	123	6,233	127	6,567	134
	R4		6,517	136	6,749	140	6,906	144
	R5		6,560	137	6,988	146	6,951	146
P203	R2	70	9,005	130	10,050	144	10,150	147
	R3		8,951	129	9,471	134	10,260	148
	R3L		8,422	120	8,658	124	9,161	131
	R4		9,494	137	9,673	139	10,060	145
	R5		9,188	134	9,784	142	9,736	142
P204	R2	88	11,007	125	11,800	136	12,410	141
	R3		10,940	124	11,490	132	12,470	141
	R3L		10,147	115	10,494	119	11,038	125
	R4		11,485	132	11,900	136	12,170	139
	R5		11,230	131	11,780	137	11,900	138
P205	R2	102	12,339	121	12,650	125	13,920	137
	R3		12,264	120	13,110	139	14,130	138
	R3L		11,346	111	11,794	116	12,341	121
	R4		13,051	130	13,680	136	13,830	138
	R5		12,589	127	13,080	132	13,340	135

Figure 2-14. Image. A portion of an LED roadway luminaire's muti-page specification sheet, demonstrating the various combination of optical distributions, input watts, and Kelvin temperatures avaialble. Each combination has its own *.ies file so it can be accurately modeled in lighting analysis software.

2.4. Methods for Measuring Light

Depending on the lighting application (long straight roadways, intersections, pedestrian crosswalks, etc.) different calculation methods are used to accurately model the quantity of light emitted from a luminaire. Each method is designed for maximum safety per the application so that a driver can immediately see the roadway and/or pedestrians and objects in front of them.

The Illuminance Method. The *illuminance method* is used to measure the amount of light that falls horizontally onto the roadway surface or vertically onto a pedestrian in a crosswalk, measured in *fc (lumens/ft^2)* or *lux (lumens/m^2)*. The illuminance method is preferred for applications in which the driver's line of sight may need to change (from viewing straight ahead to a wider field of view) over a short period of time. Roadway examples where the illuminance method is preferred include when a driver approaches a curved ramp or steep road, roadway with parked cars, midblock crosswalk, and intersections with or without crosswalks.

Horizontal Illuminance. The measurement calculated by placing a grid of illuminance calculation points within a defined horizontal area on the ground for an intersection or crosswalk, with the virtual light meter aimed normal to the road surface, is called *horizontal illuminance*. This method is used to model the amount of light a driver will see on the ground as they approach an intersection or crosswalk. For intersection and crosswalk applications, the points within the horizontal illuminance calculation grid shall be spaced no greater than 5' x 5' on center at grade.

Vertical Illuminance. The measurement calculated by placing a line of illuminance calculation points at a specific height above a road surface, and points are aimed in the direction of oncoming vehicles, is called *vertical illuminance*. This method is used to model the amount of light a driver will see on a pedestrian who is within a crosswalk. For crosswalk applications, the points along the vertical calculation line shall be spaced 2’ on center, at 5’ above grade, and centered in the middle of the crosswalk. The virtual light meter for each vertical illuminance grid shall be aimed in the direction of the oncoming traffic.

Figure 2-15. Photos. Applications in which the illuminance method is preferred. (Top-left) Curved ramp, (Top-right) steep road, (Bottom-left) parked cars along a roadway, (Bottom-right) pedestrian crosswalks.

The Luminance Method. The method of lighting calculation recommended for new, long, straight roadway applications in which the driver’s line of sight is consistently directly in front of them for a long period of time is called the *luminance method*. The luminance method calculates the amount of light that is reflected back from the surface of a roadway which is 272.5ft in front of a driver and assumes the driver’s eye is at 4.5ft. However, the quantity of lighting reflected from a surface can vary significantly based upon the age of the road surface, time of day (glare during dusk

Figure 2-16. Photos. Examples of roadways with varying surface reflectances.

and dawn), and weather (rain, fog, and snow glare). *(Note: This guideline does not go into detail on this calculation method, as it is not used for pedestrian crosswalk applications.)*

Uniformity Ratio. The measurement of the average-maintained illuminance level within a calculation grid in comparison to the lowest average-maintained illuminance level is referred to as the *uniformity ratio*. The lower the ratio, the more uniform the light is within the calculation grid. The uniformity ratio for roadway lighting should be measured in *average maintained/minimum fc* which includes light loss factors to represent the average amount of light that will be present over time. Recommended uniformity ratios for intersection and pedestrian crosswalk lighting applications range from 3:1 to 4:1.

Figure 2-17. Photos. Examples of roadway lighting uniformity. (Top) Poor roadway uniformity (>6:1). (Bottom) Good roadway uniformity <4:1).

Surround Ratio. For pedestrian crosswalk applications, additional light surrounding the primary design area can help increase a feeling of safety. The *surround ratio* is the average horizontal illuminance approximately 15' outside the intersection or crosswalk to the average horizontal illuminance within the intersection or crosswalk. Lighting the area adjacent to the primary task helps motorists see approaching pedestrians. A surround ration of 0.5:1 is recommended for crosswalks. However, additional surround light should be evaluated for each application and shall be designed to minimize light trespass onto areas where light is not desired.

Figure 2-18. Photo. Example of surround light adjacent to a pedestrian crosswalk.

Luminance Ratio. The ratio between the luminance (brightness) of any two object in a driver's visible field of view is referred to as the *luminance ratio*. For any object to stand out from its background, a minimum ratio of 4:1 is recommended.

Figure 2-19. Photos. An example of various luminance ratios within in a driver's field of view. (Left) A roadway lit by vehicle headlights. (Middle) A deer in the roadway that has a high luminance ratio compared to its background. (Right) A deer in the roadway that has a very low ratio compared to its background.

For a zebra crossing that is lit with an appropriate horizontal illuminance for safety, the luminance of the road (dark pavement) versus the stripping (white lines) provides a luminance ratio greater than 4:1. As the stripping fades, the luminance ratio decreases, making the crosswalk less safe for pedestrians. For a crosswalk with appropriate level of vertical illuminance, the luminance of the pedestrian in the crosswalk versus their background should also be greater than 4:1. In areas with high background luminance (such as retail areas), this ratio can be harder to achieve. When high background luminance is present, vertical illuminance levels shall be increased proportionately.

Figure 2-20. Photos. (Left) A newly painted crosswalk with high luminance ratio for striping. (Right) An older crosswalk with low luminance ratio for striping.

2.5. Factors that Affect Light Output

The calculation of the horizontal illuminance on a roadway pavement on day one of an installation is referred to as *initial illuminance*. The calculation of the horizontal illuminance within an area of roadway pavement, while incorporating light loss factors into the calculation, is referred to as *maintained illuminance*. Maintained illuminance is intended to represent the light level at a future point in time (such as 10 years after initial installation). *Average maintained illuminance* is the average of all points within a calculation grid.

Light Loss Factors. Various hardware and environmental factors, referred to as *light loss factors (LLF)*, can dimmish the number of lumens emitted by a luminaire over time. The three most common light loss factors used in roadway lighting calculations include *lamp lumen depreciation (LLD)*, *luminaire dirt depreciation (LDD)*, and *luminaire surface depreciation (LSD)*. LLF = LLD + LDD + LSD. Typical LLF used in roadway lighting calculations is 0.85 (85%) for LEDs and 0.65 (65%) for HIDs. However, LLFs may vary and should be evaluated for each application.

Lamp Lumen Depreciation (LLD). The percentage of initial lumens emitted by a luminaire over a set period due to degradation of the light source is referred to as *lamp lumen depreciation (LLD)* or *lumen maintenance*. HID lamps depreciate lumen output quickly, whereas LEDs depreciate very slowly. Since LEDs- degrade extremely slow, the industry uses the term L70 to refer to the LED luminaire's end of life. L70 represents the hours in which the LED lumens have depreciated to 70% of their initial output. For LED luminaires, an LLD of 0.95 can be used in the LLF.

Luminaire Dirt Depreciation (LDD). The percentage of initial lumens that are emitted by a luminaire over a set period of time due to dirt buildup on the luminaire's surface and blocks the light output is referred to as *luminaire dirt depreciation (LDD)*. A luminaire's environment and the physical shape of a luminaire can factor into the accumulation of dirt. For most LED roadway lighting applications, the industry typically uses a LDD of 0.9. For luminaires with textured glass, acrylic or polycarbonate refractors an additional 5-10% LDD should be added to the LLF calculation.

Luminaire Surface Depreciation (LSD). For luminaires the utilize acrylic or polycarbonate molded refractors to aim the light in the direction needed, the surface can degrade over time resulting in a *luminaire surface depreciation (LSD)*. Acrylic and polycarbonate are both organic, petroleum-based compounds and will eventually break down when exposed to heat and UV radiation; the use of these types of molded refractors shall be avoided whenever possible.

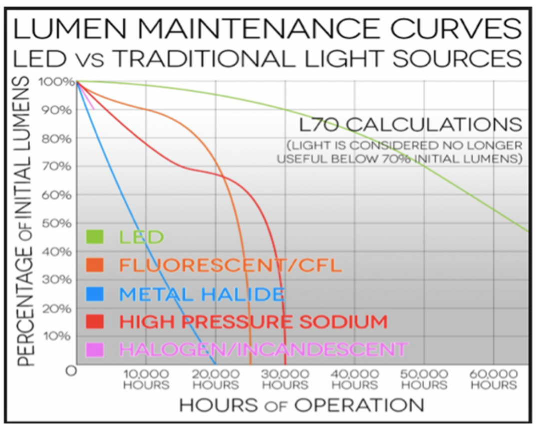


Figure 2-21. Graph. Example of lumen depreciation curves for various types of light sources *(Source: foreverlight.com)*

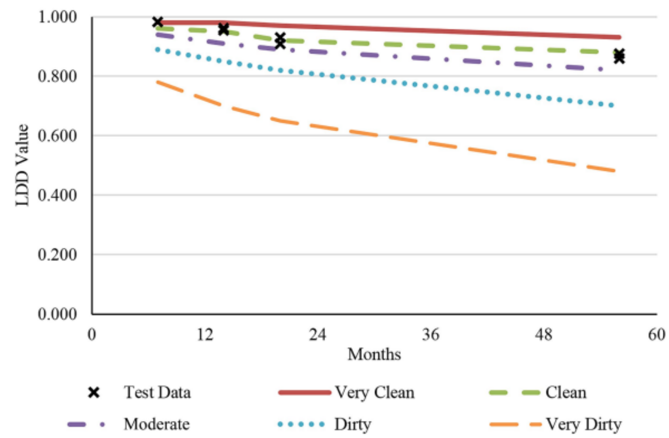


Figure 2-22. Graph. Measured dirt depreciation values compared with IES values compared with IES estimated values from RP-36-15, for five different environmental conditions. *(Source: Robert G. Davis, Andrea M. Wilkerson, Bruce R. Kinzey 2019. Luminaire Dirt Depreciation (LDD): Field Data from Several Exterior Lighting Projects. LEUKOS, 15:1, 55-63*

Figure 2-23. Photos. (Left) Roadway luminaire with new clean glass refractor. (Right) Roadway luminaire dirt depreciation.

2.6. The Electrical Characteristics of Light

In addition to designing the illuminance, luminance, and uniformity levels for lighting, a designer should understand the electrical characteristics associated with lighting in order to specify the correct product. The primary electrical terms include voltage, amps, mA, resistance, voltage drop, and wattage.

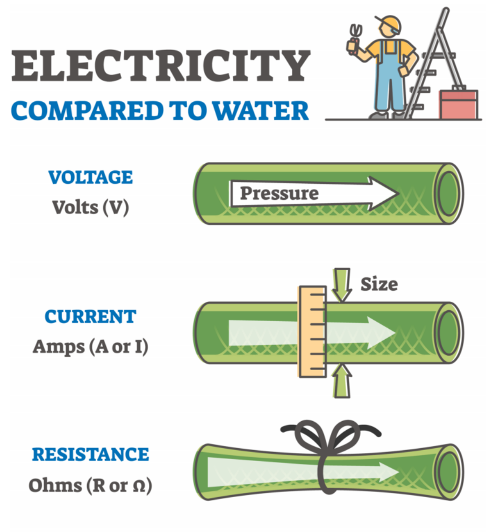


Figure 2-24. Illustration. An explanation of electricity compared to water.

Voltage (V)). The *voltage* of street lighting may vary based on the available utility service. Typical applications include 120V/1-phase, 208V/3-phase, 240V/1-phase, 277V/1-phase, or 480V/3-phase. LED drivers can be rated for multi-volt operation such as 120V-240V, 277-480V, or 120-600V.

Amps (A or I). The quantity of electrical current that can flow through a cable is measured in *amps (A)*. At the same voltage, a power cable with a larger diameter can provide more current than a cable with a smaller diameter. As a result, larger diameter cables can provide power to a larger quantity of luminaires.

mA Rating. Since LEDs run on direct current (DC) and not alternating current (AC), they require a driver to transform the current from AC to DC. LED drivers are rated for different *mA ratings* ranging from 350mA to 1200mA. The higher the mA used, the more lumens that can be emitted from the same LED. However, over-driving LEDs with a higher mA increases the heat within the luminaire and can shorten the driver's overall lifetime. If given a choice, specifying LED luminaires that have drivers with lower mA ratings is preferred.

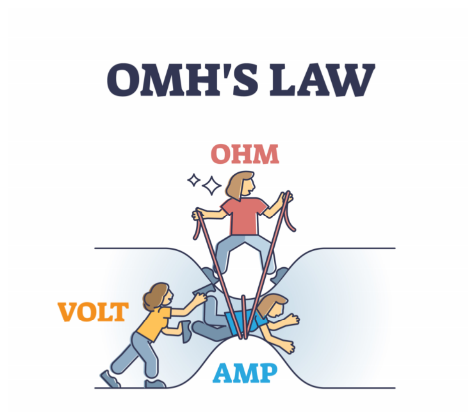


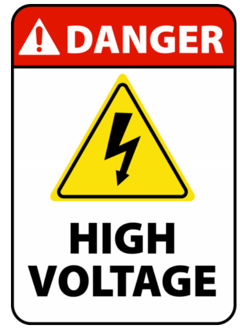
Figure 2-25. Illustration. Ohm's Law (Volts = Amps x Resistance)

Resistance (Ohms, R). This opposition to the flow of current through a conductor is called *resistance* and it is measured in *ohms*.

Voltage Drop (%). The difference in voltage between the beginning and end of a cable due to the cable's inherent resistance, or impedance, to current flow is called *voltage drop*. For two cables with the same properties (diameter and material), a longer cable will be subjected to more voltage drop than a shorter cable. Excessive voltage drop can result in not enough power reaching the light, and this can result in flicker, dimmed light levels, or lights not turning on. The National Electric Code (NFPA 70) recommends that an electrical power distribution system's total voltage drop be no more than 5% (2% from the utility to the lighting panel and 3% from the lighting panel to the luminaire.)

Wattage (Watts, W). The power consumed by a luminaire is referred to as its *wattage*. Wattage is calculated by multiplying a luminaire's voltage (V) times its ampacity (A), W = V x A. The same luminaire can vary in wattage based on the mA setting that is selected for the LED driver.

2.7. Troubleshooting LED Failures



LED luminaires have been known to fail due to several unanticipated issues such as transient voltages and surge events. Properly selecting the correct electrical characteristics of a luminaire for each application will help avoid these types of issues after installation.

Voltage Fluctuation. In remote areas, the utility's power may suffer from *voltage fluctuation* that can vary in duration and level. Fluctuations can be caused by loose/faulty wiring, failing transformers, downed power lines, electromagnetic interference (lightning), and dirty utility power.

Voltage Swells. A sustained (multi-second) voltage variance of +/-5% is considered within the acceptable range for most LED drivers and these are referred to as *voltage swells*. Some LED drivers are rated for fluctuations up to +/- 10%. When reviewing a luminaire manufacturer's spec sheet, look for the LED driver's acceptable voltage range. If the range is very small, driver failures can occur when large voltage fluctuations occur.

Voltage Spikes (aka Surges). Environmental conditions such as lightning strikes or extreme weather can cause unplanned, short-term (milli-second) high *voltage spikes*. ANSI C136.2-2018 provides surge protection requirements for luminaires and has broken these down into three categories: *Typical Spikes (6kV), Enhanced Spikes (10kV), and Extreme Spikes (20kV)*. LED Drivers use surge protective devices (SPDs), such as thermally protected metal oxide varistors (MOVs), to divert voltage spikes away from the LED by forming a connection with the ground wire. However, MOVs have a finite life expectancy based on surge frequency, duration, and intensity. For example, an LED Driver with an SPD rating of 20kV may be able to withstand 1-20kV surges, 15-10kV surges, or 100-1kV surges. The SPD rating of an LED driver is available on most LED luminaire manufacturer spec sheets. For roadway applications a minimal SPD rating of 20kV is recommended. Supplemental fuse connector kits in poles and SPD nodes mounted to 7-pin receptacles can add additional layers of surge protection.

Figure 2-26. Photo. Examples of metal oxide varistor (MOV) used to protect against electric

Short Circuit. Electricity wants to flow along the path of least resistance back to ground. The intended path is referred to as the long path. When a shorter path is provided, electricity will seek this route, known as a *short circuit*. Short circuits can occur when the outer protective sheathing of a cable is frayed due to deterioration, vermin chewing through them, or nails or screws puncturing them. Short circuits can also occur when cables come in contact with water or other conductive material. When a short circuit occurs, properly sized circuit breakers will trip to avoid potential sparks and fires.

Figure 2-27. Photo. A short circuit caused cables to catch on fire.

3. Lighting Classifications

3.1. General Classification of Light

Light that is emitted from a luminaire can be described based on its ability to successfully illuminate its desired application. These general descriptions include *useful light*, *light trespass*, *spill light*, *glare,* and *sky glow*.

Useful Light. Lumens that are emitted from a luminaire and land on the intended target area, this light is referred to as *useful light*.

Light Trespass. Lumens that are emitted from a luminaire and do not land on the intended target area are referred to as *light trespass*. Light Trespass should be avoided whenever possible. Designers can refer to ANSI/IES *RP-8-21* for maximum allowable levels for light trespass based on environmental zone ratings.

Glare. Lumens that are emitted from a luminaire at higher angles and do not land on the intended target area are referred to as *glare*. There are several types of glare that can be created from a luminaire including *discomfort glare* and *disability glare*. Lumens emitted at higher angles can produce both discomfort and disability glare. While discomfort glare can cause a sense of pain or annoyance, disability glare is so severe that it prevents an individual from seeing adequately.

Sky Glow (aka Light Pollution). Lumens emitted above 90 degrees or lumens that are reflected off surfaces and bounce back into the atmosphere can contribute to *sky glow*, cause disability glare, and cause discomfort glare. Whenever possible, it is recommended that all lumens emitted from a roadway luminaire are below 90 degrees horizontal to prevent sky glow. Luminaires that utilize an external refractor to control the light (like the globe-style) are unable to fully control all of the lumens that are emitted, are less efficient, and contribute to sky glow and glare. Tilting a full-cutoff luminaire without appropriate shielding can also cause glare. Many roadway luminaire styles are now offered with a full-cutoff option (0% uplight), which should be considered whenever possible.

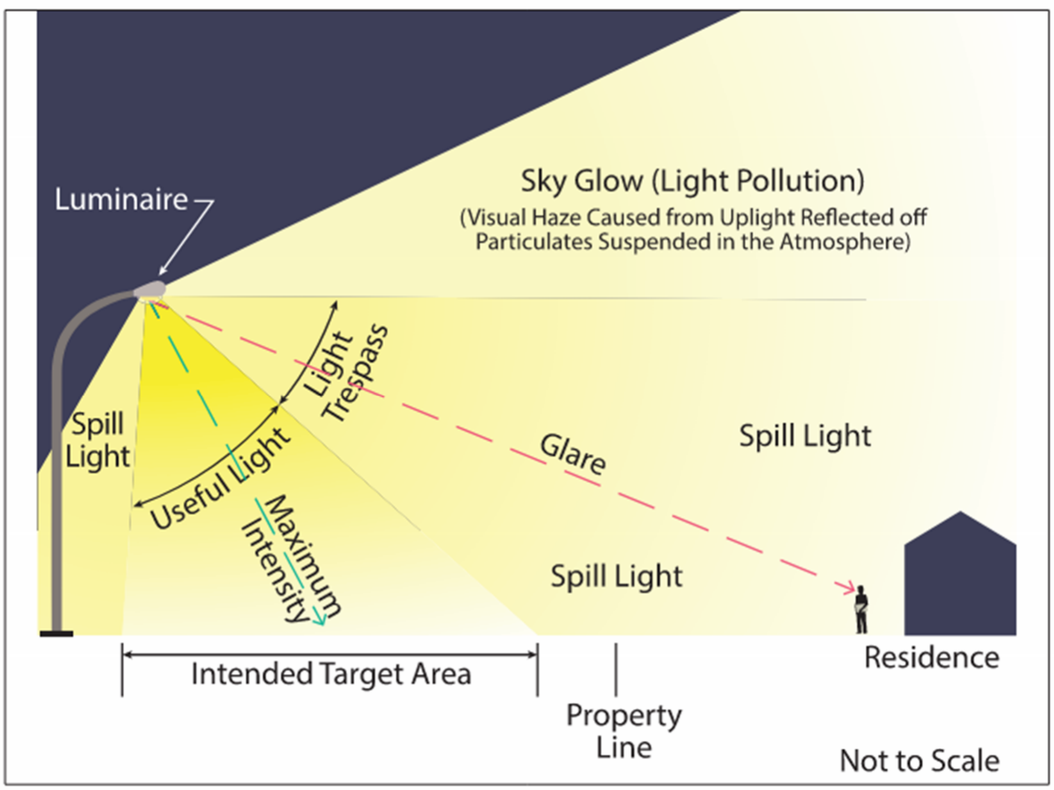


Figure 3-1. Illustration. The components of obtrusive light (not to scale). *(Source: IES RP-8-21, Fig. 4-1.)*

Figure 3-2. Photos. Disability glare occurs when excessive amount of light, in a driver's field of view, enters the eye and is then scattered around the area of the eye's retina. The physical size of the scattered area within the eye increases with age, resulting in an increased susceptibility of glare for older drivers.

Dark Sky International (darksky.org) is an organization that is dedicated to restoring the nighttime environment and protecting communities from the harmful effects of light pollution through outreach, advocacy, and conservation. When designing lighting for the safety of pedestrians and the traveling public, it is important to understand that poorly designed lighting can also have negative effects on the environment. A luminaire is referred to as *'dark sky compliant'* when it has zero light emitted above the horizontal plane of the luminaire, such as the 'Better' and 'Best' luminaires shown in Fig. 3-3.

Note: Designers shall avoid over-lighting roadways, as more light is not always better. Depending on the color and texture of a roadway, a portion of the light that lands on the roadway's surface can be reflected back up into the sky.

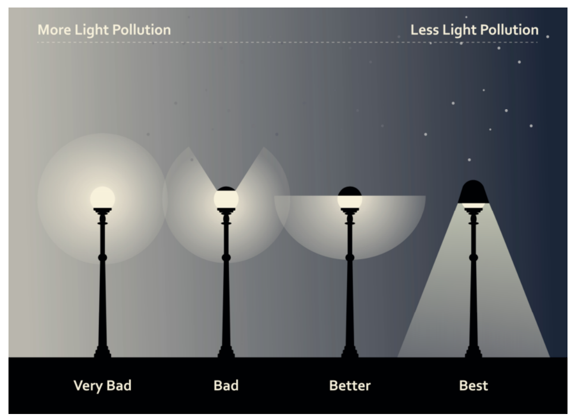


Figure 3-3. Illustration. Images of luminaire styles compared to their ability to reduce sky glow and light

Figure 3-4. Photos. (Left) Examples of the night sky in Arcadia National Park, Maine that is visible when there is minimal sky glow from artifical lighting. (Right) Sky glow and glare that can be seen from a few non-cutoff roadway lights in Portland, Maine.

3.2. IES Luminaire Classification Systems (LCS and BUG)

As LED luminaires became more prevalent, there became a need to further describe the range of useful light emitted from a luminaire. This resulted in the creation of the *luminaire classification system (LCS)*, which is also referred to as a luminaire's *BUG rating*. BUG is an acronym for backlight, uplight, and glare.

Prior to the luminaire classification system and BUG rating scale, roadway luminaires were referred to as either *full-cutoff* (all light emitted below 90 degrees), *semi-cutoff* (some light emitted above 90 degrees), or *non-cutoff* (large amount of light emitted above 90 degrees). This terminology is still used as a generic term to describe the light that is emitted from a luminaire, but the formal terminology used by the lighting industry, luminaire manufacturers on their specification sheets, and lighting analysis software is LCS and BUG.

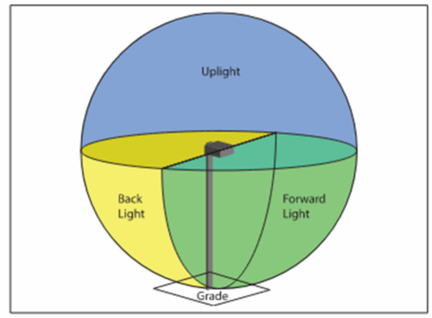


Figure 3-5. Illustration. The three primary solid angles of the Luminaire Classification System (LCS). *(IES RP-8-21, Ch.2, Fig. 2-24.)*

Backlight (B). The amount of light directed behind a luminaire is referred to as *backlight*. For roadway applications which are concerned with light trespass, a luminaire with minimal backlight should be considered. However, when a surround ratio is desired for an application to increase the perception of safety, luminaires with backlight should be considered.

Uplight (U). Any light directed above the horizontal plane of the luminaire's photometric center is referred to as *uplight*. Luminaires that are able to direct all of their light below 90 degrees have a higher luminaire efficiency, are able to be spaced further apart, and utilize less energy to achieve the same light level than luminaires that emit unnecessary uplight. Whenever possible, luminaires with an uplight rating of "0" should be used for all roadway luminaires to prevent sky glow.

Forward Light (aka Glare, G). The amount of light that is directed in front of a luminaire is referred to as *forward light*. When forward light is emitted at high angles (between 75 and 90 degrees), it can contribute to discomfort and disability glare.

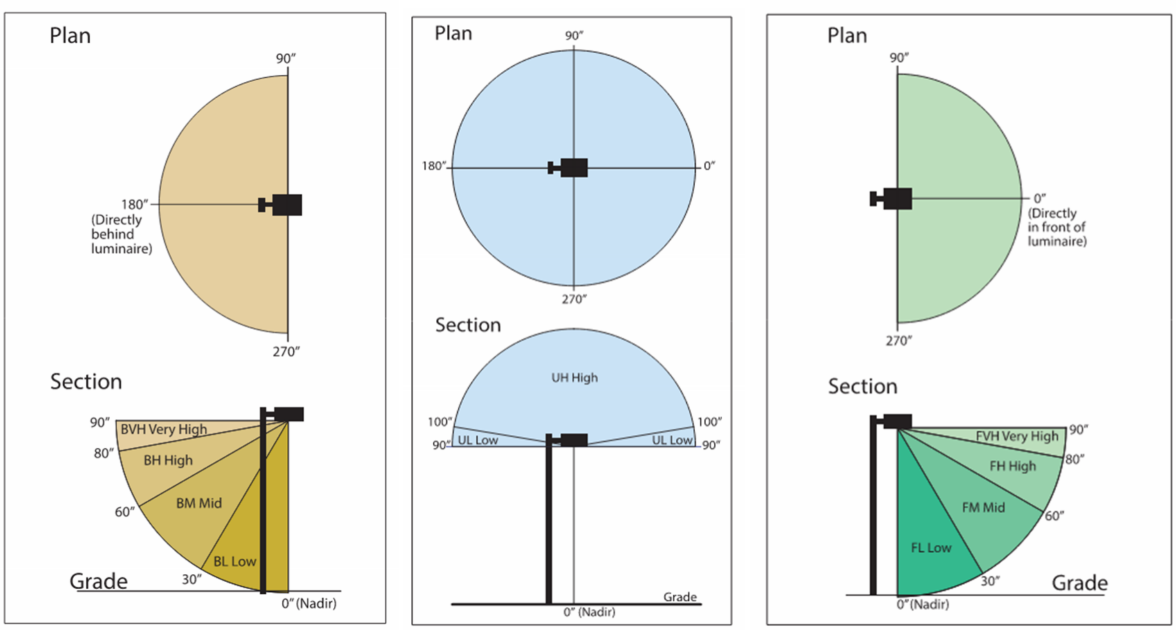


Figure 3-6. Illustration. Plan and elevation views of the distribution of backlight, uplight, and forward light and the range of degrees used to further classify each type. *(IES RP-8-21, Ch.2, Fig. 2-27, 2-28, and 2-26)*

The following two figures show examples of two pedestrian-style luminaires and their associated BUG rating. The traditional globe-style luminaire *(Fig. 3-7)* has a BUG rating of B2-U3-G3, while the full-cutoff luminaire *(Fig. 3-8)* has a BUG rating of B1-U0-G1.

While the luminaire efficacy rating (LER) of the globe-style luminaire is higher (153 lumens/watt) than that of the full-cutoff luminaire (134 lumens/watt), the full-cutoff luminaire will produce more illuminance on the ground than the globe-style because a good proportion of the globe-style lumens are not useful. The lumens that are emitted above 90-degrees contribute to sky glow and light pollution, and the lumens emitted above 75-dgrees contribute to disability glare.

Note: For pedestrian and roadway luminaires, MaineDOT recommends considering full-cutoff luminaires with an uplight rating of 'U0' whenever possible.

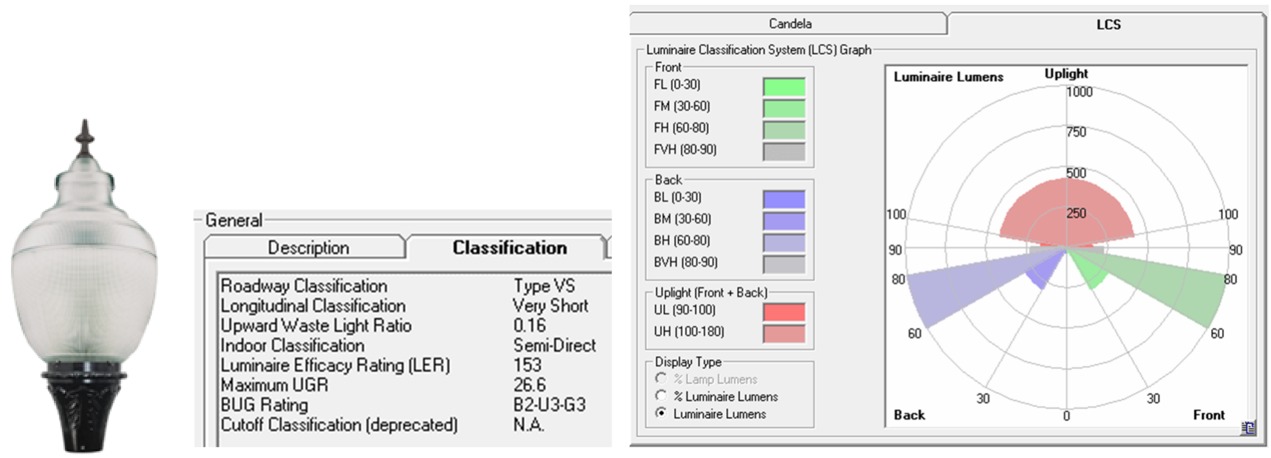


Figure 3-7. Halophane AWDE3 Washington luminaire. This is a globe-style luminaire with a BUG Rating of B2-U3-G3 and a significant amount of uplight, as shown in red. *(Luminaire Photo courtesy of Acuity Brands. Other images from Agi32.)*

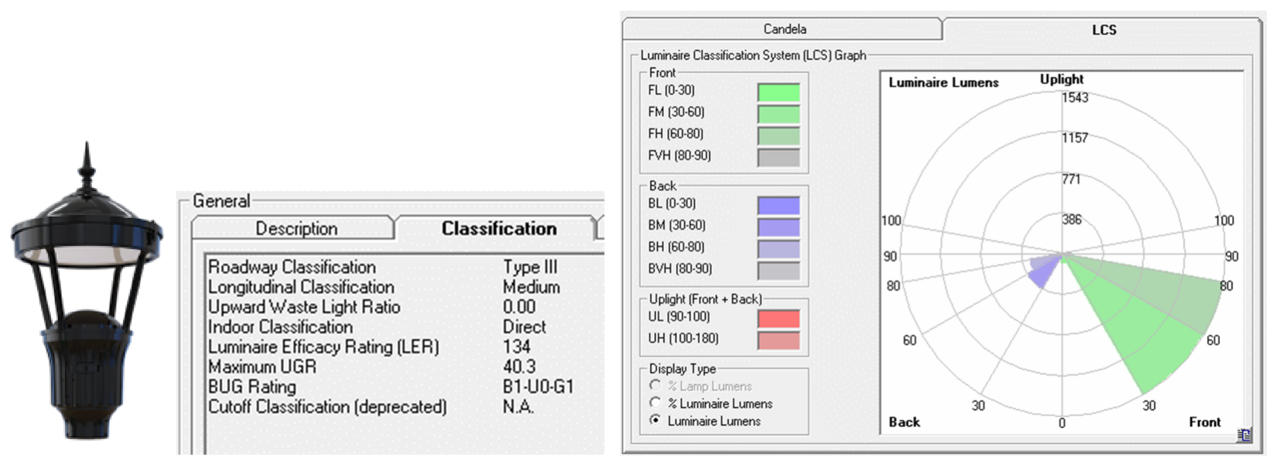


Figure 3-8. Halophane PUCL3 Taft luminaire. This is a full-cutoff luminaire with a BUG Rating of B1-U0-G1. There is zero uplight emitted from this luminaire. *(Luminaire Photo courtesy of Acuity Brands. Other images from AGi32.)*

Figure 3-9. Photos. (Left) Example of non-cutoff pedestrian luminaires that cause glare, sky glow, and fail to provide adequate light on their intended target, the ground. (Right) Example of full-cutoff pedestrian luminaires that minimize glare, sky glow, and properly lights the pedestrian path.

3.3. IES Classifications for Roadway Lighting

Useful light that is emitted from a luminaire can be further classified by identifying the direction of maximum candelas in relation to a roadway and proportional to its mounting height (MH). *Transverse Classifications Type II, III, IV, V*, and *VS* are used to describe a luminaire's distribution *across* the roadway which is represented by the 50% of maximum candela intensity point. *Longitudinal Classifications Type Short (S), Medium (M),* and *Long (L)* are used to describe a luminaire's distribution *parallel to the* roadway.

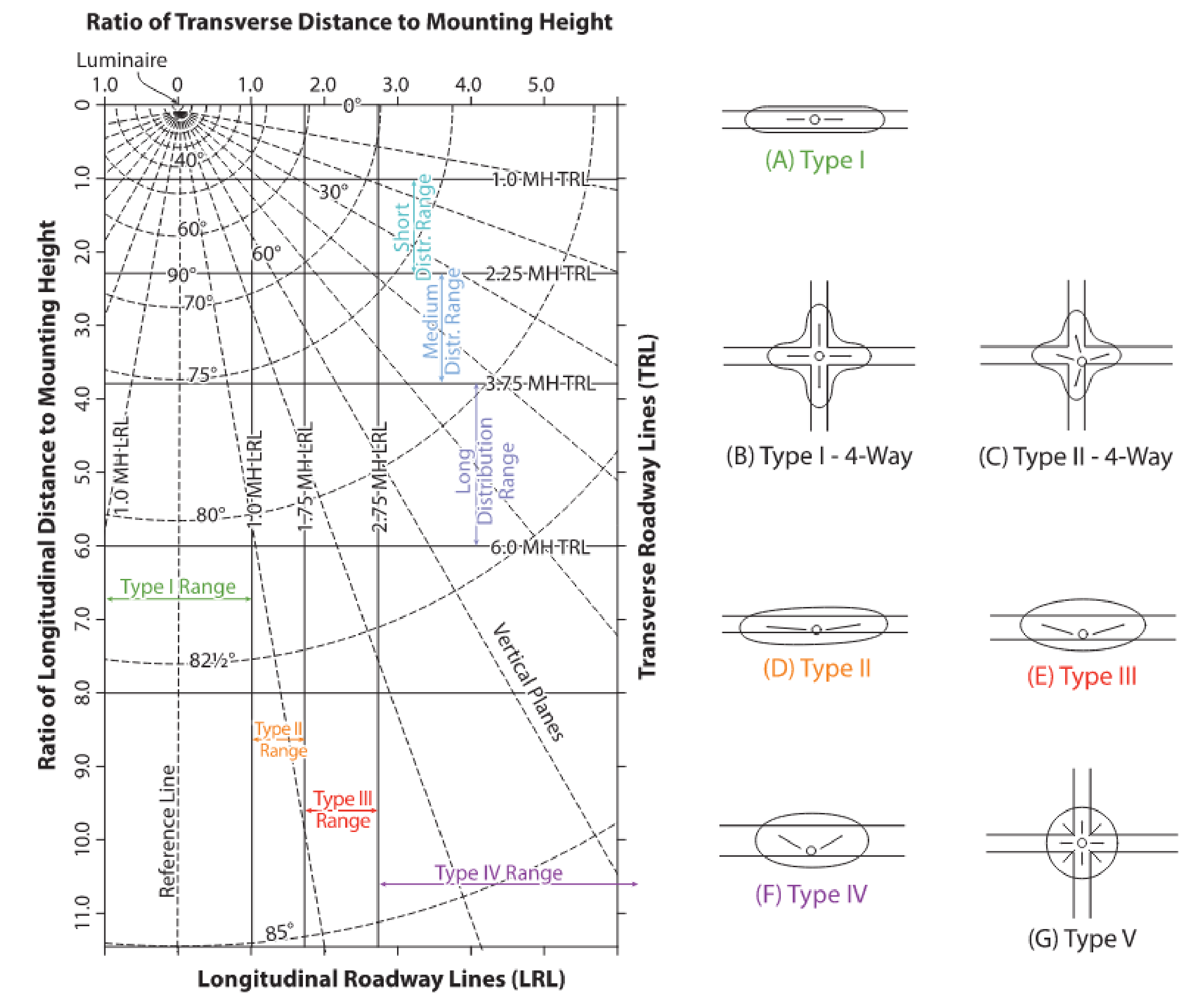


Figure 3-10. Plan view of roadway coverage for different types of luminaires. *(IES RP-8-18, Fig. 2-21.)*

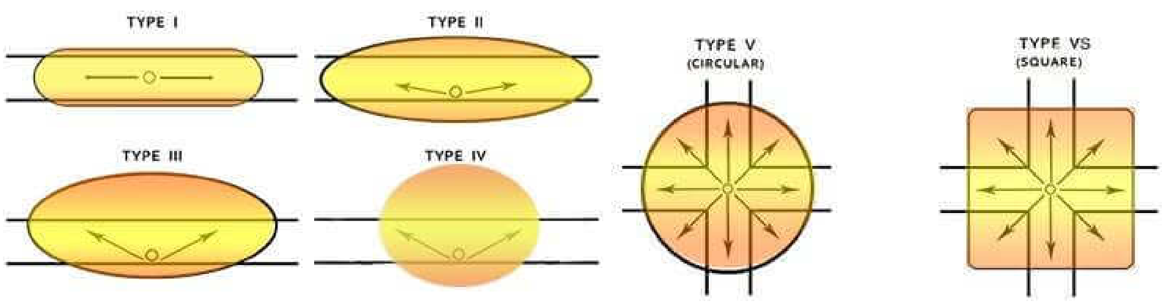


Figure 3-11. IES Classifications for a luminaire's transverse distribution of light. *(IES RP-8-21)*

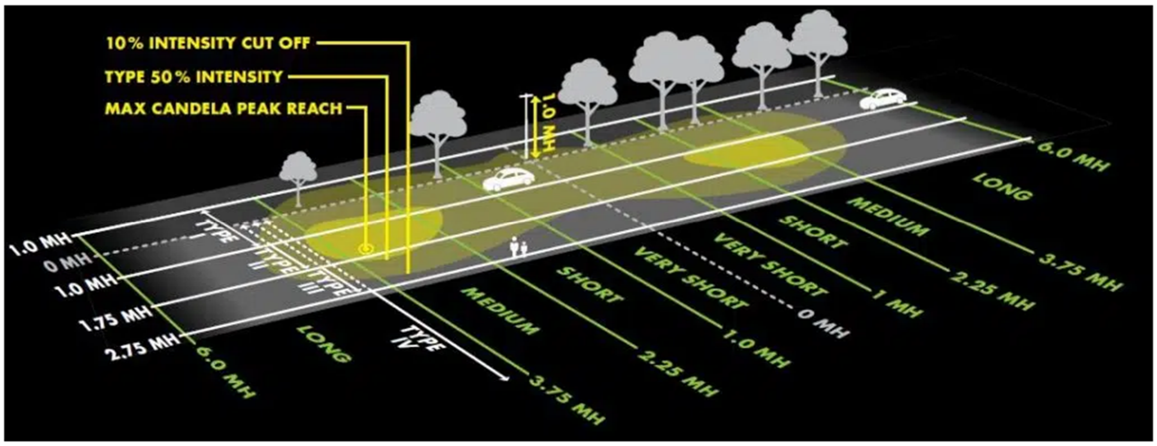


Figure 3-12. Illustration. IES Classifications for horizontal and vertical distributions of light in relation to its mounting height
(Source: https://www.zgsm-china.com/blog/light-distribution-of-outdoor-luminaire-and-their-applications.html)

Candela Distribution Curve. A luminaire's maximum luminous intensity in both the horizontal and vertical direction are referred to as *candela distribution curves* and can be viewed in lighting analysis software. These curves are useful to verify the luminaire's IES roadway classification, longitudinal classification, and ensuring the orientation of the luminaire is correct when it is placed on a calculation grid. Candela distribution curves are plotted on a 3D coordinate system and represent the concentration of lumens emitted from a luminaire in various planes. *.ies files document a luminaire's maximum candela output in 2.5-degree increments both horizontally and vertically, similar to latitude and longitude lines of the earth. Although lighting calculation software may only model two candela distribution curves for the user to see (max vertical and max horizontal), all of the candela data is included in photometric calculations.

The following figures demonstrate the IES roadway and longitudinal classifications for a globe-style luminaire (see Fig. 3-13) and a full-cutoff style luminaire (see Fig. 3-14) as seen in the AGi32 lighting analysis software.

The red candela distribution curve represents the *IES transverse classification*. The globe-style luminaire is classified as *Type VS* and the full-cutoff luminaire is classified as *Type III*.

The blue candela distribution curve represents the *IES longitudinal classification*. The globe-style luminaire is classified as *Very Short,* and the full-cutoff luminaire is classified as *Medium*.

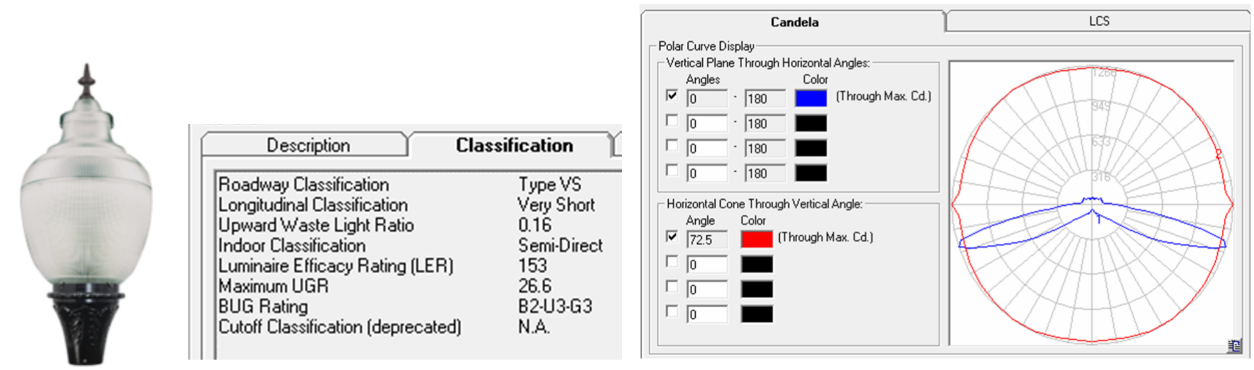


Figure 3-13. Halophane AWDE3 Washington luminaire. This is a globe-styler luminaire with a roadway classification of Type VS (red iso-curve) and a longitudinal classification of Very Short (blue iso-curve). *(Luminaire Photo courtesy of Acuity Brands. Other images from Agi32)*

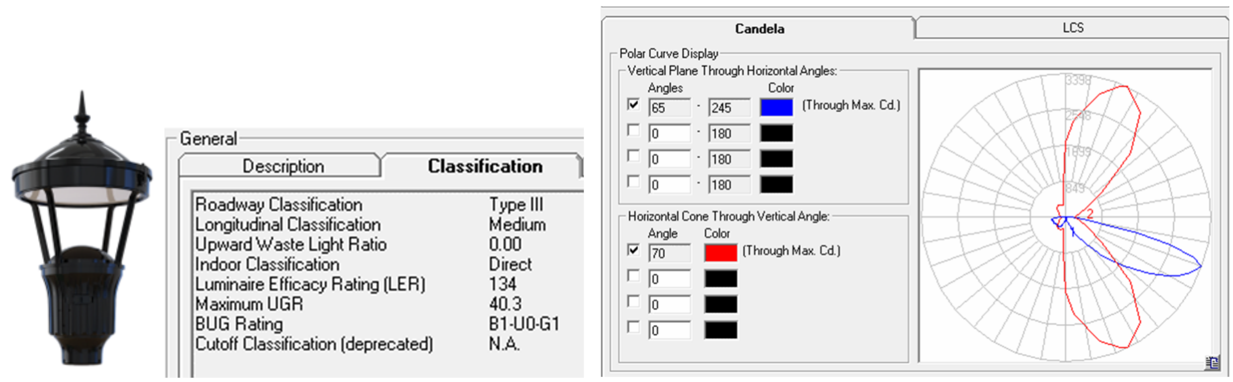


Figure 3-14. Halophane PUCL3 Taft luminaire. This is a full-cutoff luminaire with a roadway classification of Type III (red iso-curve) and longitudinal classification of Medium (blue iso-curve). *(Luminaire Photo courtesy of Acuity Brands. Other images from AGi32)*

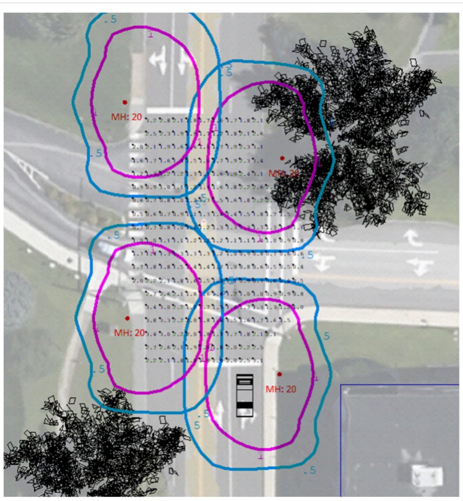


Figure 3-15. Illustration. Iso-footcandle lines representing 0.5 fc (blue) and 1.0 fc (purple) levels on the ground. *(Image created in Agi32)*

Iso-footcandle Line (isolines). Lighting design is often referred to as a puzzle and the optical distribution required to evenly light different applications will vary. The optical distribution of a luminaire will also vary based upon a luminaire's mounting height. To help designers visualize how to space luminaires based upon the quantity of lumens that are landing on a surface based upon the mounting height of the luminaire, *iso-footcandle lines* are used. An iso-footcandle line is plotted on a flat calculation grid and represent a user-defined llluminance levels (e.g., 0.5 fc or 1 fc). Iso-footcandle lines are specific to the luminaire and do not include the contribution of lumens from nearby luminaires. They help designers visually orient a luminaire's optics and then space luminaires evenly to achieve the desired illuminance levels.

Figure 3-16. Rendering. Example of a mid-block pedestrian crosswalk that is lit by a luminaire with new pedestrian crosswalk optics that have been specifically designed to enhance both the horizontal and vertical illuminance within the crosswalk. The luminaire's iso-footcandle lines are also shown. *(Image courtesy of the Cyclone Lighting, Inc, an Acuity Brand.)*

3.4. How the Eye Works

To help identify the ideal LED color temperature for pedestrian crosswalk applications, a designer needs to understand how the human eye works. To help us see, our eyes consist of rod and cones. Rods are used at night to differentiate between black and white and provide visual acuity and peak when viewing blue wavelengths of light. Cones are used during the day to see color. We have three types of cones, each peaking in either the red, green, or blue wavelengths of light.

Daylight is the ideal light source, as it can render all colors of the visible spectrum. However, artificial light such as HIDs and LEDs are only able render a portion of the visible spectrum. It is the relationship of the artificial light source and the human eye that is important to understand when designing lighting. In general, the technology behind LEDs enables them to render many more colors of the visible light spectrum compared to HID lamps.

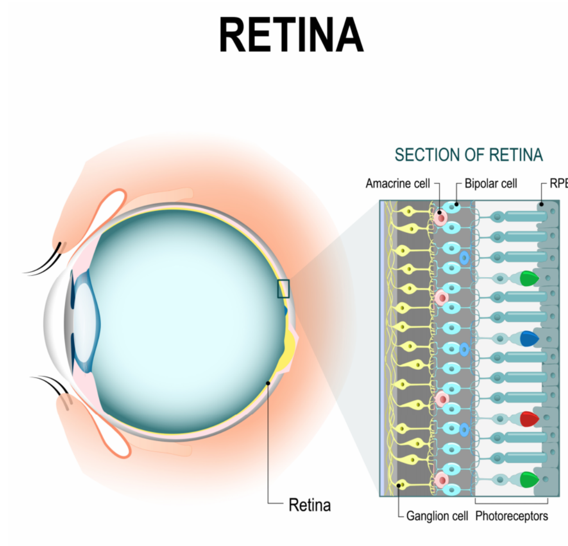


Figure 3-17. Illustration. The retina of the eye showing the types of photoreceptors, rods and cones (red, green, and blue).

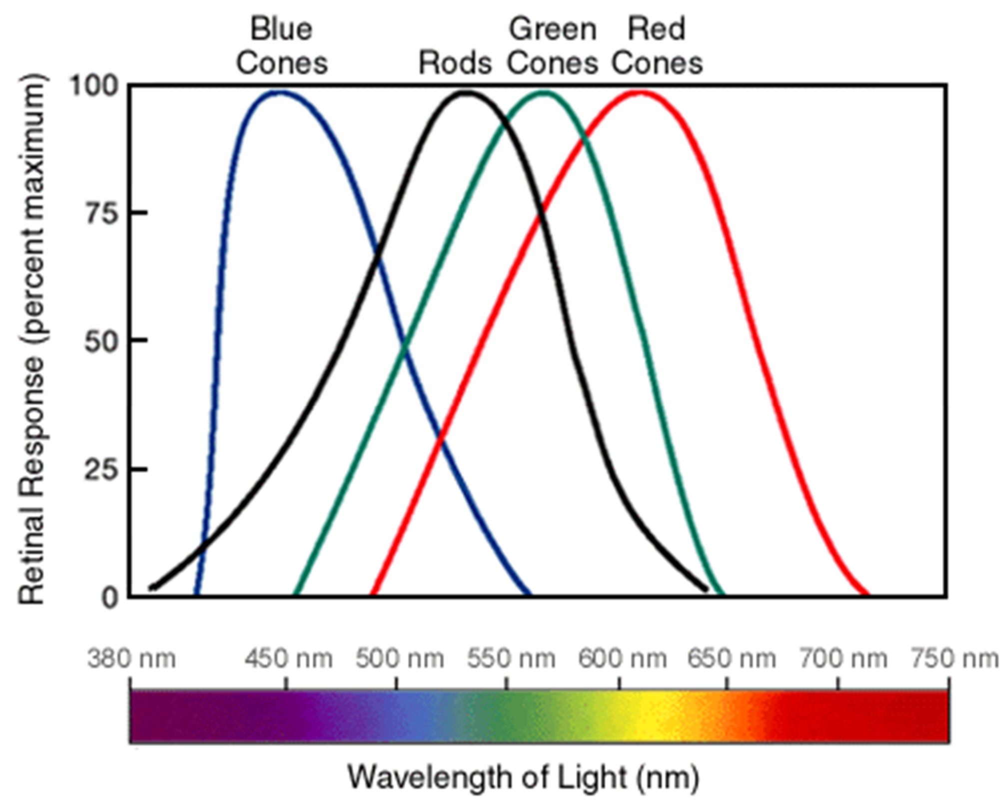


Figure 3-18. The peak wavelength of light for the eye's rods and cones.

3.5. Correlated Color Temperature (CCT)

When comparing the color of light for LED roadway luminaires, we refer to the light sources' *correlated color temperature (CCT)*, which is measured in degrees *Kelvin (K)*. The Kelvin scale used for lighting is based on the color of light that can be seen after heating up a black body radiator to certain temperatures, similar to a blacksmith forging a piece of metal *(see Fig. 47)*. At lower temperatures a black body radiator glows an orange color. As the black body radiator's temperature increases, the same black body radiator begins to glow yellow, then white, and eventually blue. The Kelvin temperature is thereby *correlated* to the color of light emitted. Kelvin temperatures are now used to describe the color of light emitted from an artificial light source.

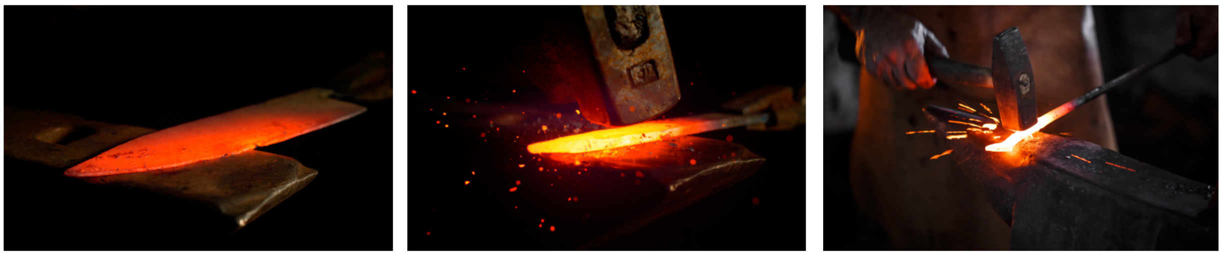


Figure 3-19. Photos. Glow of light emitted when metal is heated to various temperatures.

CCT for LEDs. Standard correlated color temperatures used by the lighting industry for LEDs include 2700K, 3000K, 3500K, 4000K, and 5000K *(see Fig. 48)*. The majority of LEDs are made from Indium Galide and, in their natural form, produce a blue light. In order to create white light, a yellow phosphor coating is overlayed on top of the LED. This process is referred to as *Stoke's Shift*. The thicker the phosphor coating, the less blue light is emitted, and the light appears warmer. Thinner phosphor coatings allow more blue light to be emitted and the light appears cooler.

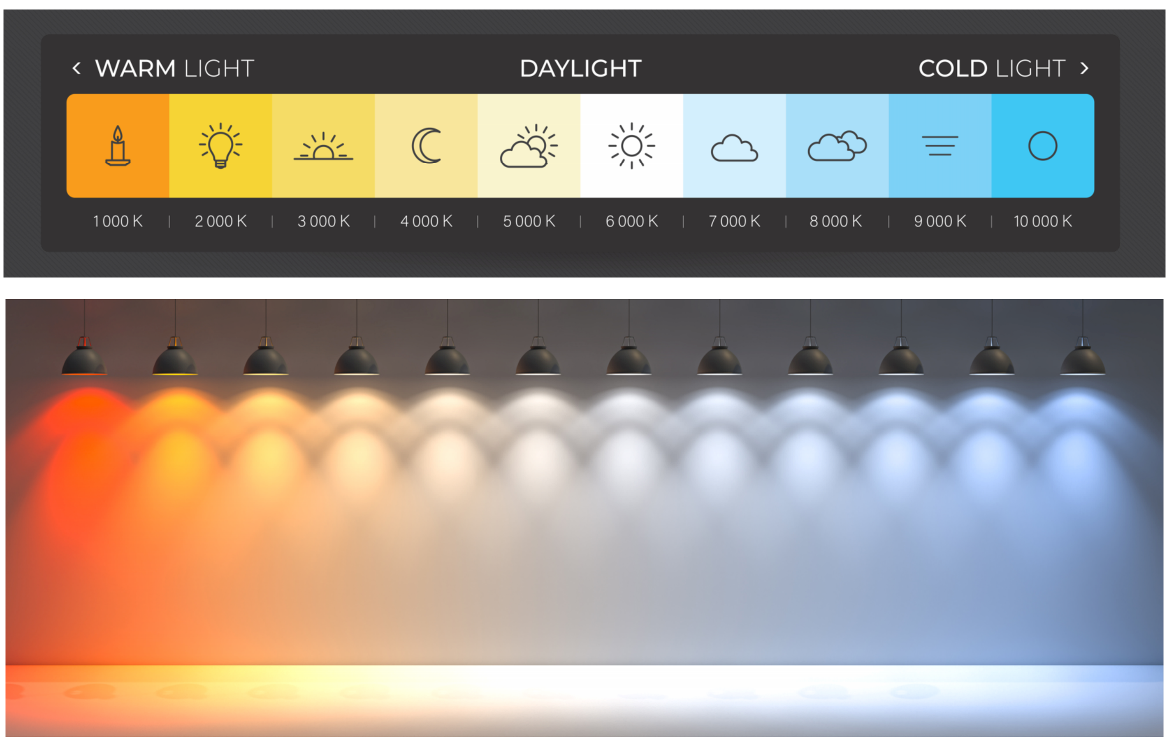


Figure 3-20. Illustration. Color temperature of light measured in degree Kelvin.

Color temperature plays a significant role in the design of roadway lighting. Based on numerous studies and the science behind the human eye, different Kelvin temperatures are better for different applications.

When comparing lower (orange, warmer appearance) and higher (blue, cooler appearance) Kelvin temperature LED light sources, scientific studies have shown the following:

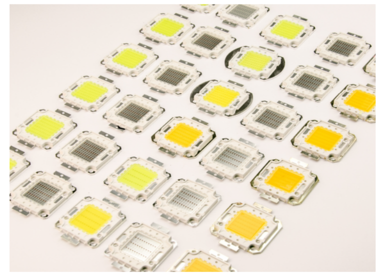


Figure 3-21. Photo. A circuit board with three different Kelvin temperature LEDs.

- **Enhanced Visibility & Safety.** Higher color temperatures (cool) provide better visibility and enhance contrast. As a result, higher cooler temperatures have been proven to reduce accidents, enhance road safety, and help prevent crime.
- **Impact of Street Ambiance.** Lower color temperatures (warm) tend to provide a cozier and inviting glow. While higher color temperatures (cool) create a modern and crisp atmosphere.
- **Energy Efficiency.** Higher color temperatures (cool) are able to emit more lumens per watt than lower color temperatures (warm) and consume less energy to produce the same amount of light.
- **Circadian Rhythm.** Higher color temperatures (cool) suppress melatonin production, leading to alertness and increased productivity during nighttime hours. Lower color temperatures (warm) promote relaxation and better sleep, which is not desired for drivers in a vehicle.
- **Color Rendering.** LEDs with color temperatures the mid-range (4000K) tend to provide better color rendering across the visible spectrum than those at the extreme high (5000K) or low color (3000K) temperature range, which helps to provide better color contrast between objects.
- **Detection Distance.** The detection distance between a driver and pedestrian is shorter with higher color temperatures (cool) when compared to those with lower color temperatures (warm).

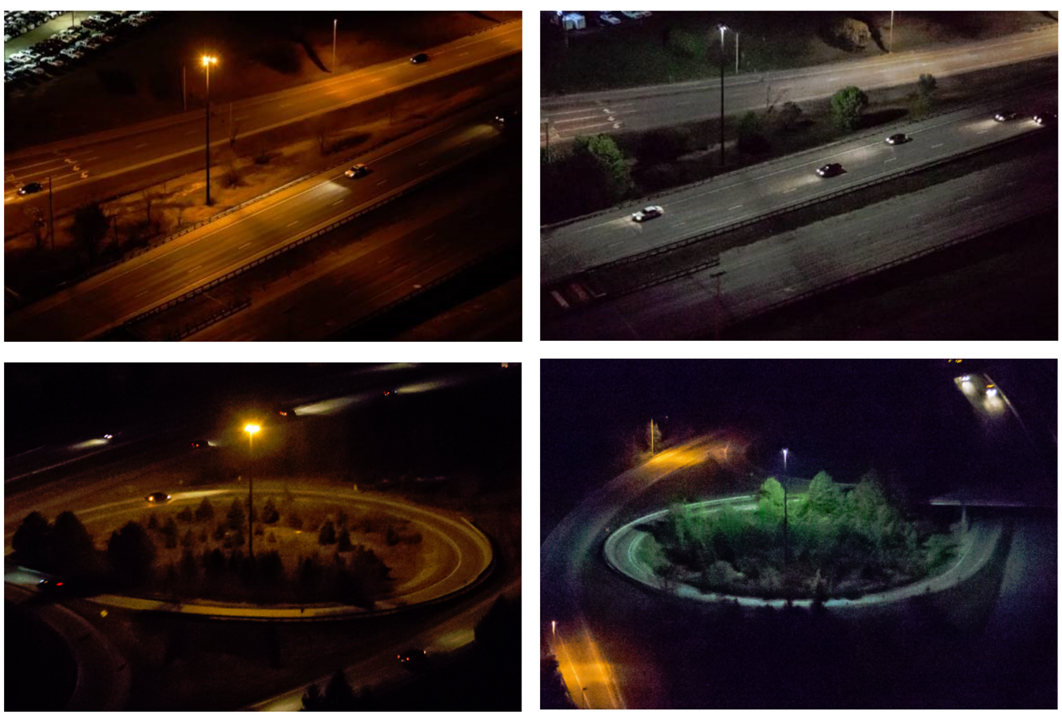


Figure 3-22. Photos. MaineDOT roadways lit with different Kelvin Temperature lamps. (Left) Roadways lit with 3000K High Pressure Sodium lamps. (Right) The same roadways after it was retrofitted with 4000K LED luminaires.
(Photos courtesy of MaineDOT)

3.6. Color Temperature for Crosswalks

The preferred color of light can be very *subjective* based upon its *objective*. In one's house or at a fancy restaurant, the warm glow of a fireplace or dim lighting is intended to provide a cozy ambiance. However, when it comes to a doctor's office, industrial or manufacturing facility, and roadways, the objective of the lighting changes from cozy to safety.

The goal when lighting a crosswalk is to maximize pedestrian safety and to accomplish this requires an understanding of the *spectral power distributions (SPD)* of light. The SPD graph of a light source demonstrates the intensity of photons emitted at particular wavelength. The visible light spectrum consists of wavelengths between 400-700 nanometers. LEDs with different Kelvin temperatures will have different SPD graphs. Low Kelvin Temperature LEDs (3000K, perceived as warm) will have a higher concentration towards the yellow wavelengths (550-650nm). High Kelvin Temperature LED (5000K, perceived as cool) will peak in the blue wavelengths (400-500nm). Kelvin Temperatures in the middle range (4000K) typically have a balanced range of wavelengths across the entire visible light spectrum, peaking in both the warm and cool *(see Fig. 3-23)*.

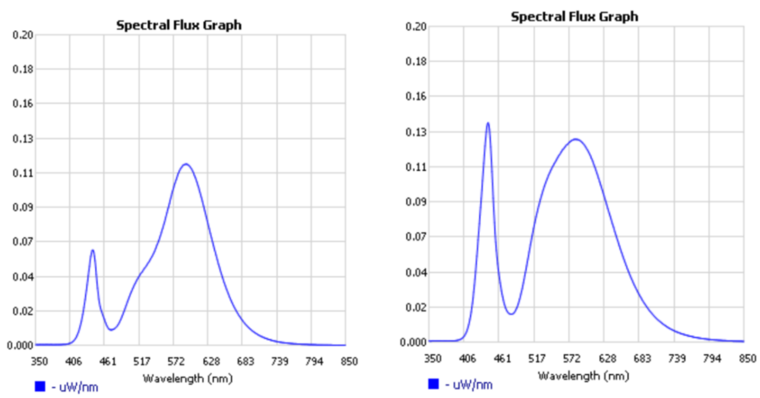


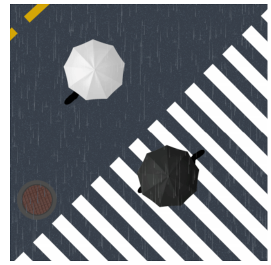
Figure 3-23. Graphs. The spectral distribution graphs for a typical LED roadway luminaire. (Left) 3000K LED. (Middle) 4000K LED. (Right) 5000K LED. 4000K is able to peak in both the warm and cool wavelengths, which stimulates both the rods and cones in our eyes, enhacing vision. *(Source: Spec sheet for an Autobahn luminiare from Acuity Brands.)*

When selecting the color temperature of a light source for pedestrian applications it is important to remember the number one goal, which is *safety*. The LED must be capable of producing a high enough intensity of light in the blue wavelengths to maximize *visual contrast* (using the eye's rods) while also producing a high enough intensity of light in all other wavelengths to maximize *color contrast* (using the eye's cones). In general, LEDs in the 4000K range provide a perfect balance of wavelengths to *maximize the safety for pedestrians* in crosswalk applications.

Note: MaineDOT recommends all pedestrians luminaires to be 4000K with a high color rendering index (CRI).

Figure 3-24. Photos. Example of crosswalk with different Kelvin Temperatures. (Left) 2700K HID and (Right) 4000K LEDs.

3.7. Contrast



When designing the lighting for pedestrians in a crosswalk to maximize safety, the concept of *visible contrast* is extremely important.

Contrast Threshold. The minimal perceptible contrast that allows an observer to distinguish an object from its surrounding is referred to as the *contrast threshold.* The threshold level will vary based on the size of an observer's field of view.

Negative/Positive Contrast. When a pedestrian appears darker than the background it's referred to as *negative contrast*. When a pedestrian appears brighter than the background it is referred to as *positive contrast*. Industry standards suggest that objects can easily stand out when the luminance value of an object is four times that of its surroundings.

Figure 3-25. Photos. (Left) Positive contrast. (Right) Negative contrast.

Color Contrast. Contrast can be achieved through black and white (using the rods in our eyes) or through colors (using the R-G-B cones in our eyes). However, since we cannot control the color of clothing a pedestrian wears, it's important that pedestrian lighting is designed for both types of contrast. The designer's goal shall be to use artificial light to achieve a similar perceived level of black and white contrast and color contrast at night, as seen during the day.

Figure 3-26. Illustration. Color of clothing versus driver detection distance through headlights alone.

Example of Visual Contrast. Figure 3-27 has two photos of the Maine State House in Augusta viewed from different angles at night. A viewer's eye is naturally drawn to the brightest image in their field of view. For the image on the left, a viewer's eye is drawn to the brightest image in their field of view first, which is the glare from the non-cutoff pedestrian lights, and then the State House behind it. For the image on the right, a viewer's eye is drawn to the pyramid sculpture and the State House first, and then the short concrete bollards with embedded lighting. The location, height, and style of luminaires (full cutoff vs. non-cutoff) can create different luminance contrasts, which draws the eye to different locations. For crosswalks, the goal is for the luminance of the pedestrian to be brighter than their surroundings, so the driver's eye notices them first.

Figure 3-27. Photos. The Maine State House at night. The human eye is naturally drawn to brighter objects within the immediate field of view.

Figure 3-28. Image. The horizontal contrast of black and white striping in a crosswalk can be obscured by snow. Vertical illuminance provides a second level of contrast to help view pedestrians in the same crosswalk.

Figure 3-29. Photo. A pedestrian crosswalk near the Maine Capitol building in Augusta. The black and white striping in the crosswalks struggles for contrast due to the reflection of other lighting in the roadway.

4. Roadway Classifications

To design lighting, one needs to be able to identify the characteristics of roadways and intersections, which include their *FHWA Functional Classification*, *AASHTO Area Classification*, and *AASHTO Pavement Classification*. These three classifications are used by AASHTO to help identify the appropriate lighting design criteria for roadway applications including average-maintained horizontal illuminance level and uniformity ratios.

4.1. Functional Classification System (FHWA)

The *Functional Classification System* was developed by FHWA and is currently used by several transportation organizations to categorize roadways. These classifications help define the role a particular roadway segment plays in serving the flow of traffic through a network of independent roadways and toward various destinations. The recommended level of illumination for each roadway varies based on their functionality.

Roadways are assigned to one of several possible FHWA Functional Classifications within a hierarchy according to the type of travel service (mobility and accessibility) the roadway provides. These service functions are further broken down by the following characteristics:

- Distance served
- Access points
- Speed limit
- Distance between routes
- Usage (Average Annual Daily Traffic, AADT)
- Significance
- Number of travel lanes

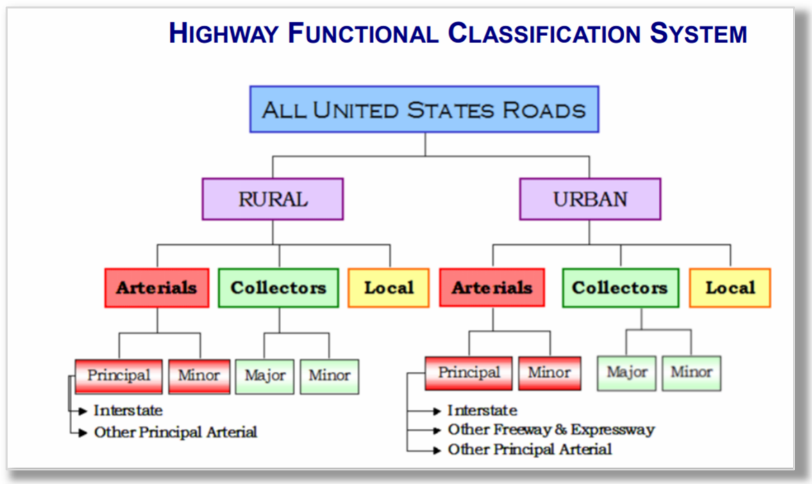


Figure 4-1. The FHWA Highway Functional Classification System organizational chart.

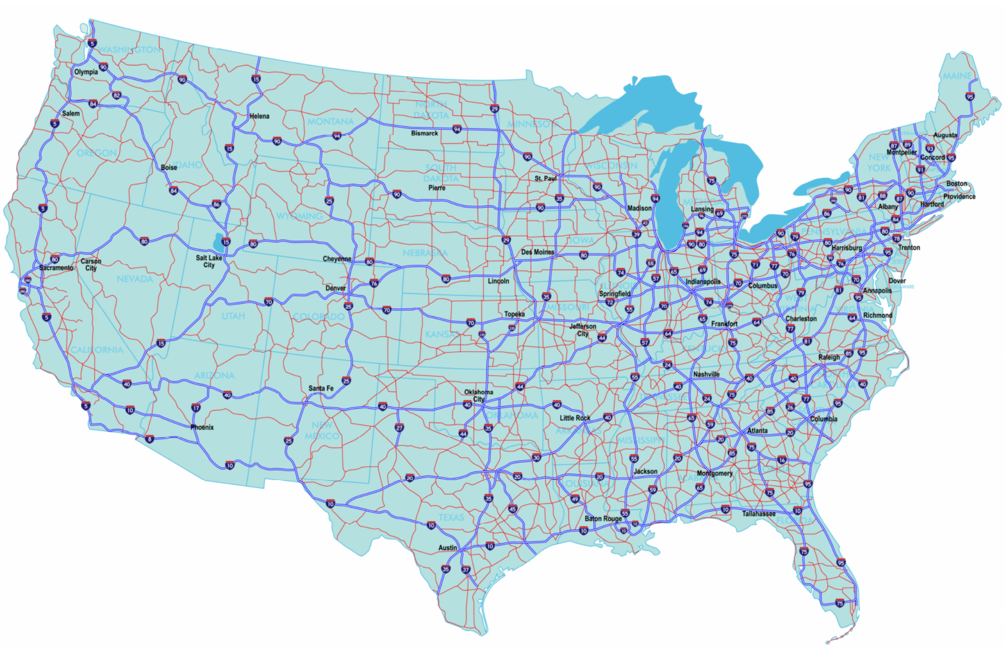


Figure 4-2. Illustration. Map of U.S. Interstates.

4.2. Highway Corridor Priority (MaineDOT)

In addition to the traditional FHWA Functional Roadway Classifications, MaineDOT uses an additional roadway classification system called *Highway Corridor Priority (HCP)*. To better serve their residents with the same level of service, MaineDOT has divided the state into five Regions: *Northern*, *Eastern*, *Western*, *Midcoast*, and *Southern (See Fig. 4-5)*. While the FHWA's Functional Classifications are intended to have the same roadway characteristics throughout the United States, MaineDOT Highway Corridor Priorities do not have the same characteristics throughout the state of Maine. For example, a roadway designated as HCP1 in the Northern Region may have a lower AADT and longer distances between routes than a roadway designated as HCP1 in the Southern Region. MaineDOT's five geographic Highway Corridor Priority regions aims to ensure that regions with lower population densities are provided the same level of service as those with higher population densities.

Note: FHWA and HCP classifications are 'similar' but not exact. MaineDOT recommends designers to use HCPs for completing the MaineDOT Warrant for Pedestrian Lighting at Intersection Crosswalks and FHWA Functional Classifications for identifying AASHTO recommended lighting design criteria.

- ***HCP1*** – *'similar' to a Principal Arterial*
- ***HCP2*** – *'similar' to a Minor Arterial*
- ***HCP3*** – *'similar' to a Major Collector*
- ***HCP4*** – *'similar' to a Minor Collector*
- ***HCP5*** – *'similar' to a Local Road*

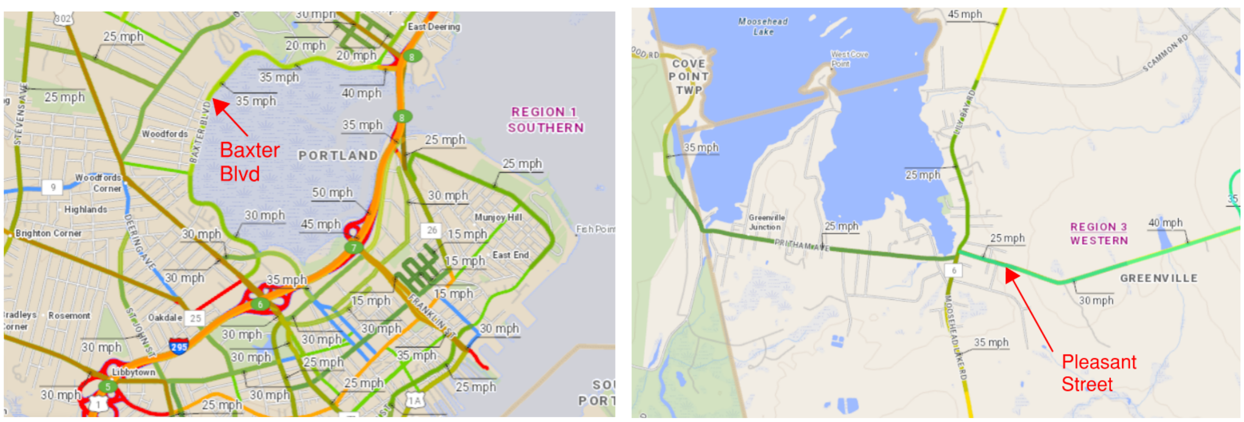


Figure 4-3. Screenshots from www.maine.gov/mdot/mapviewer. (Left) Baxter Boulevard, Portland is in Region 1-Southern, is an FHWA Major Collector, has a speed limit of 35 mph, and is designated as a MaineDOT HCP4. (Right) Pleasant Street, Greenville is in Region 3-Western, is an FHWA Minor Collector, has a speed limit of 25 mph, and is also designated as MaineDOT HCP4. Both roadways would be classified with the same HCP to complete a lighting warrant, but they could have different AASHTO lighting design criteria based on their FHWA Functional Classification.

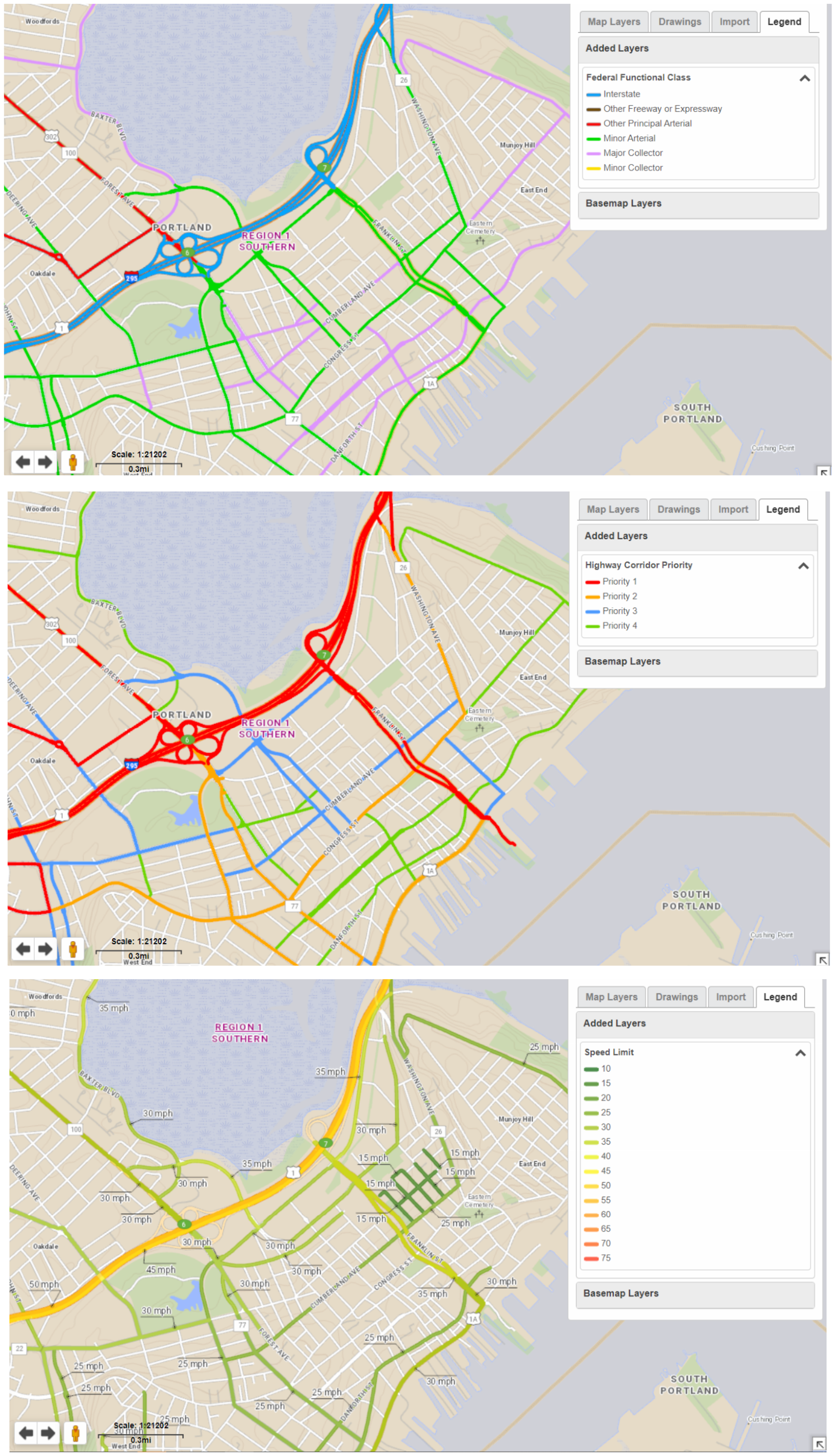


Figure 4-4. Screenshots Portland, Maine from www.maine.gov/mdot/mapviewer/. Comparison of different classifications for the same roadways. (Top) The roadways are colored per their FHWA Functional Classifications. (Middle) The same roadways are colored per their MaineDOT Highway Corridor Priority (HCP). (Bottom) The same roadways are colored per their posted speed limit.

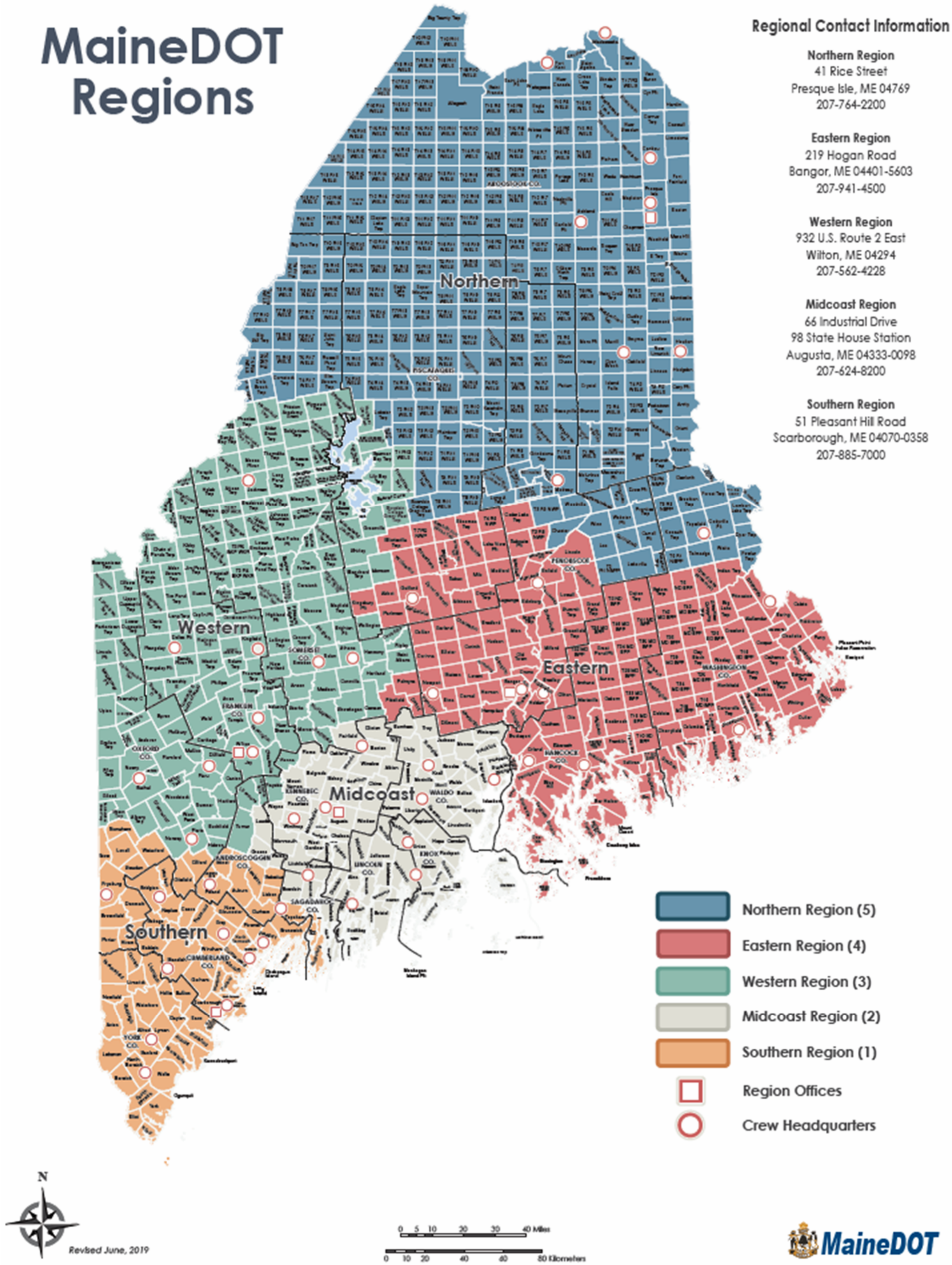


Figure 4-5. The five regions designated by MaineDOT for their Highway Corridor Priority (HCP) categories.

4.3. IES Roadway Classification

In lieu of the FHWA's Functional Classification for Roadways, which is used by AASHTO and the majority of the Transportation industry, the Illuminating Engineering Society (IES) uses its own classification for roadways, which includes Freeway A, Freeway B, Expressway, Major, Collector, and Local. Although the IES classifications are *'similar'* to FHWA, how a designer interprets their definitions can result in different recommended illumination design criteria for intersections and intersection crosswalks when compared to AASHTO's recommendations.

Note: Be Careful. Unlike the FHWA and MaineDOT HCPs which classify roadways based on several roadway characteristics (one of which is AADT), the IES only uses ADT to classify intersection roadways. Per IES RP-8-21 Sec. 12.1.2, "Major (M) Roadway have over 3,500 vehicles ADT, Collector (C) Roadways have 1,500 to 3,500 vehicles ADT, and Local (L) Roadways have 100 to 1,500 vehicles ADT". The IES's ADT quantities for Major, Collector, and Local do not correspond one-to-one with typical FHWA Functional Classifications and do not correspond with MaineDOT Highway Corridor Priorities.

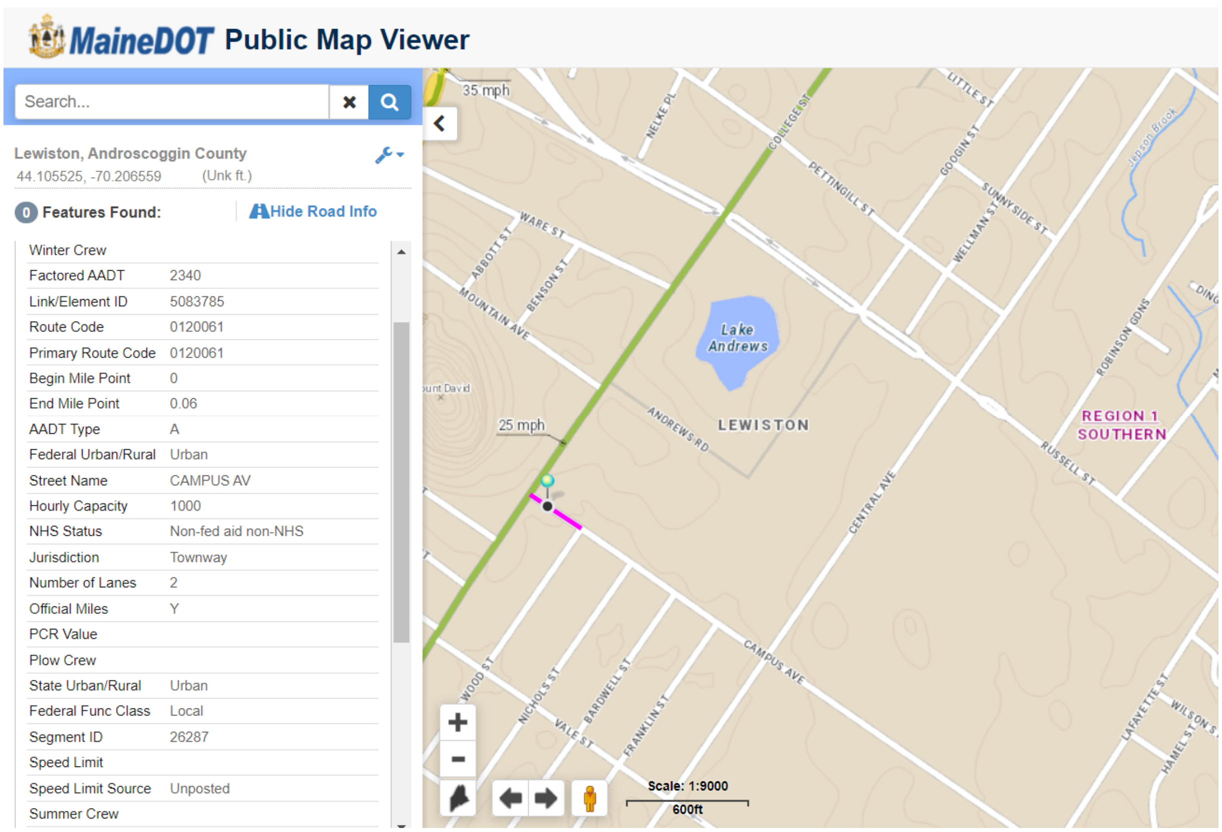
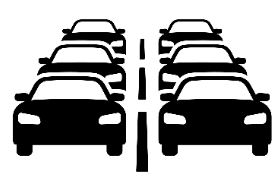


Figure 4-6. Screenshot from MaineDOT Map Viewer. Campus Avenue in Lewiston, Maine has an AADT of 2340, Federal Functional Classification of Local, and is an HCP5. Based on the AADT, IES would classify this road as a Collector, not a Local, resulting in different recommended lighting design criteria.

4.4. Annual Average Daily Traffic

Per FHWA and AASHTO, *the Annual Average Daily Traffic (AADT, Traffic Volume)* is the average volume of cars traveling along a roadway each day. This number could represent the *Actual Traffic Volume* (total for 365 days/365) or be a *Factored Traffic Volume* (number/typical day x 365) of vehicles. (Note: IES refers to this as simply ADT, not AADT).



4.5. Comparison of Roadway Classifications (FHWA, MaineDOT, & IES)

The following is a general comparison of the FHWA, MaineDOT, and IES definitions for roadway\ classifications. AASHTO uses the FHWA classifications, and TAC uses the IES classifications. MaineDOT uses its own HCP classification, which is similar to FHWA. This terminology will become critical later on when selecting the lighting design criteria presented by AASHTO and IES.

Principal Arterial (FHWA). MaineDOT classifies all of the following sub-types of Principal Arterial roadways as ***HCP1***.

- **Interstate (FHWA)** – This is the highest roadway classification, designed and constructed with mobility and long-distance in mind. Interstates are officially designated by the Secretary of Transportation.
- **Other Freeways (FHWA)** - These are roadways that have travel lanes separated by a physical barrier and have full control of access.
  - **Freeway A (IES)** - Roadways with great visual complexity and high traffic volumes. Usually, this type of freeway will be found in major metropolitan areas in or near the central core and will operate at or near design capacity through some of the early morning or evening hours of darkness.
  - **Freeway B (IES)** – All other divided roadways with full control of access.
- **Expressways (FHWA and IES)** – These are roadways that have travel lanes separated by a physical barrier and have limited control of access.

Other Principal Arterials (FHWA) – These roadways serve major centers of metropolitan areas, provide a high degree of mobility, and can also provide mobility through rural areas. They are also separated by a physical barrier but provides access to abutting parcels such as driveways and at-grade intersections with other roadways. IES and MaineDOT group these roads under Principal Arterials. MaineDOT also classifies these Other Principal Arterial roadways as ***HCP1***.

Minor Arterial (FHWA). Minor Arterial roads provide service for trips of moderate length, serve geographic areas that are smaller than their higher Principal Arterial counterparts and offer connectivity to the higher Principal Arterial system. IES refers to Minor Arterials as Major. MaineDOT typically classifies these types of roadways as ***HCP2***.

Major Collector (FHWA). Collectors are Roadways that gather traffic from Local Roads and funnel them to the Arterial network. Major Collectors provide higher mobility; are longer in length; serve higher densities areas; have higher speed limits; are spaced at greater intervals; have higher annual average traffic volumes; and may have more travel lanes than their Minor Collector counterparts. IES does not use this classification. MaineDOT typically classifies these types of roadways as ***HCP3***.

Minor Collector (FHWA). Minor Collectors which offer more access than Major Collectors; are shorter in length; server lower density areas; have lower speed limits; and fewer signalized intersections. IES also refers to these roadways as Minor Collectors. Maine DOT typically classifies these types of roadways as ***HCP4***.

Local (FHWA). Local roadways are streets which are primarily for direct access to residential, commercial, industrial, or other abutting property. They make up the largest percentage of the total street system. IES also refers to these roadways as Local. MaineDOT typically classifies these types of roadways as ***HCP5***.

Figure 4-7. Illustration. Example of state highway signs, per MUTCD.

5. Intersection Classifications

The geometry and characteristics of an intersection can vary greatly. Intersections can vary in size, quantity and width of lanes, type of lanes, presence of medians or islands, roadway pavement surface, number of approach legs, geometric configuration, and traffic control devices. According to AASHATO's *A Policy on Geometric Design of Highways and Streets*, an intersection is defined as the general area where two or more streets cross, including the roadway and roadside facilities, for traffic movements within the area. This typically includes all area up to the stop bars.

5.1. Approach Roadway Classifications

An intersection is classified by the type of roads that intersect it. One road is referred to as the *Major Road* (also referred to as the *Primary Road*) and the other is the *Minor Road* (also referred to as the *Secondary Road).*

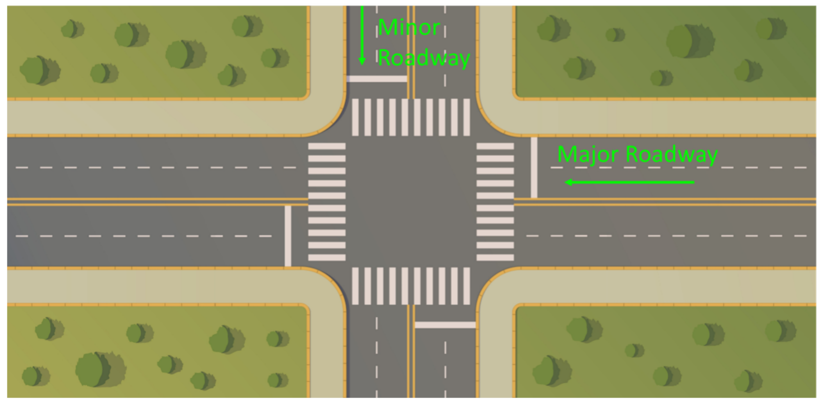


Figure 5-1. Illustration. Major and Minor Roadways approaching an intersection.

The Major/Primary and Minor/Secondary Roads of an intersection can have the same or different FHWA functional classification. If an intersection's Major/Primary and Minor/Secondary Roads do not have the same functional classification, the more stringent classification shall be used when selecting the horizontal illumination level and uniformity.

Note: The terms Major and Minor used to classify the approach roads have no correlation to the FHWA terms Major and Minor used to describe Arterials and Collectors.

5.2. Area Classification

While the FHWA Functional Classifications focus on the accessibility and mobility of roadways, AASHTO's *Area Classification* focuses on the level of vehicle and pedestrian traffic on a roadway. Both FHWA Functional Classifications and Area Classifications are used by AASHTO to identify the recommended lighting design criteria for a roadway. Area Classifications are not dependent on a specific quantity of pedestrians.

Commercial. That portion of a municipality in a business development where ordinarily there are large numbers of pedestrians and a heavy demand for parking space during periods of peak traffic or a sustained high pedestrian volume and a continuously heavy demand for off-street parking space during business hours. This definition applies to densely developed business areas outside of, as well as those that are within, the central part of a municipality.

Intermediate. The portion of a municipality that is outside of a downtown area but generally within the zone of influence of a business or industrial development is often characterized by a moderately heavy nighttime pedestrian traffic and a somewhat lower parking turnover than is found in a commercial area. This definition includes densely developed apartment areas, hospitals, public libraries, and neighborhood recreational centers.

Residential. A residential development, or a mixture of residential and commercial establishments, is characterized by few pedestrians and a low parking demand or turnover at night. This definition includes areas with single-family homes, townhouses, and/or small apartments. Regional parks, cemeteries, and vacant lands are also included.

5.3. Pedestrian Activity Levels

In lieu of using FHWA's Area Classification, the ANSI/IES *RP-8-21* uses *Pedestrian Activity Levels* to select the design criteria for intersections. Although MaineDOT does not recommend designers use the IES lighting design criteria for MaineDOT pedestrian crosswalk applications, the definitions for the IES's pedestrian activity levels have been provided in this guideline for reference.

High Pedestrian. This applies to areas where significant numbers of pedestrians are expected to be crossing the streets during the hours of darkness. Examples are urban commercial areas, downtowns, or city centers with high levels of nighttime activity. Per IES, an area with high pedestrian activity will have 100* or more pedestrians over the one-hour period with the highest average annual nighttime pedestrian volume.

Medium Pedestrian Activity. This applies to areas where lesser numbers of pedestrians are expected to be crossing the streets during the hours of darkness. These are typically urban commercial or industrial areas that have some or all of the following types of development: multifamily residential, community buildings, neighborhood shopping, and transit lines. An area with medium pedestrian activity will have 11-to-99* pedestrians over the one-hour period with the highest average annual nighttime pedestrian volume.

Low Pedestrian Activity. This applies to areas where fewer nighttime pedestrians are expected to be crossing the streets during the hours of darkness. This level of activity can occur in any of the cited roadway classifications but is typical of small urban streets with single-family homes and low-density residential developments. An area with low pedestrian activity will have 10* or fewer pedestrians over the one-hour period with the highest average annual nighttime pedestrian volume.

**Note: The IES uses the same numeric quantities for high, medium, and low pedestrians across the country. However, the State of Maine has a much lower population density than other states and uses lower numeric quantities to classify pedestrian activity.*

5.4. Pavement Classification

The *Pavement Classification* of a roadway is critical when using the luminance method for lighting calculations as the reflectance of the roadways surface is needed for the classification. MaineDOT recommends that designers use R2 for all lighting design applications.

- **R1.** Portland-cement concrete
- **R2.** Asphalt aggregate consists of a minimum of 60% gravel passing a 3/8-in sieve
- **R3.** Asphalt, rough texture
- **R4.** Asphalt, smooth texture

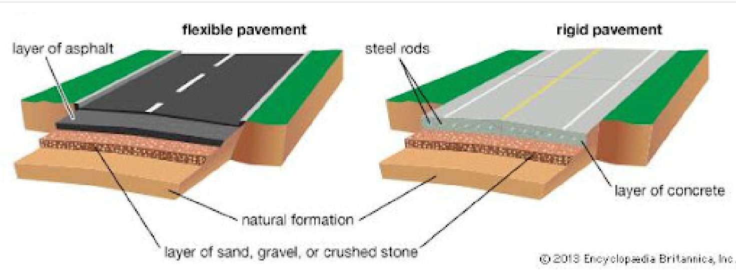


Figure 5-2. Illustration. Two types of road construction, asphalt, and concrete. *(Source: 2018 Encyclopedia of Britannia, Inc.)*

5.5. Approach Roadway Lighting Classifications.

The roadway approaching an intersection can be classified by the type of existing lighting that has been installed. These classifications are useful when identifying the horizontal boundary of an intersection and its crosswalk(s).

Continuous Approach Lighting. A roadway that leads to an intersection and has existing roadway lighting installed, and the installed lighting has been designed in accordance with AASHTO or the local jurisdiction's recommended illuminance and uniformity, is referred to as having *continuous lighting*. The lighting is even and continuous for at least 3x the *safe stopping distance*, based on the roadway's speed limit, prior to the intersection.

Non-continuous Approach Lighting. A roadway that leads to an intersection and has existing lighting installed, but the installed lighting is sporadic, non-uniform, and does not comply with AASHTO or the local jurisdiction's recommended illuminance and uniformity, is referred to as having *non-continuous lighting*. An example of this could be utility-owned lighting mounted on wooden poles that do not proven even illumination along the entire length of the approaching roadway. The lighting is intermittent and merely used as a beacon to draw attention.

Non-lit Approach Lighting. This refers to a roadway that leads to an intersection that has no lighting.

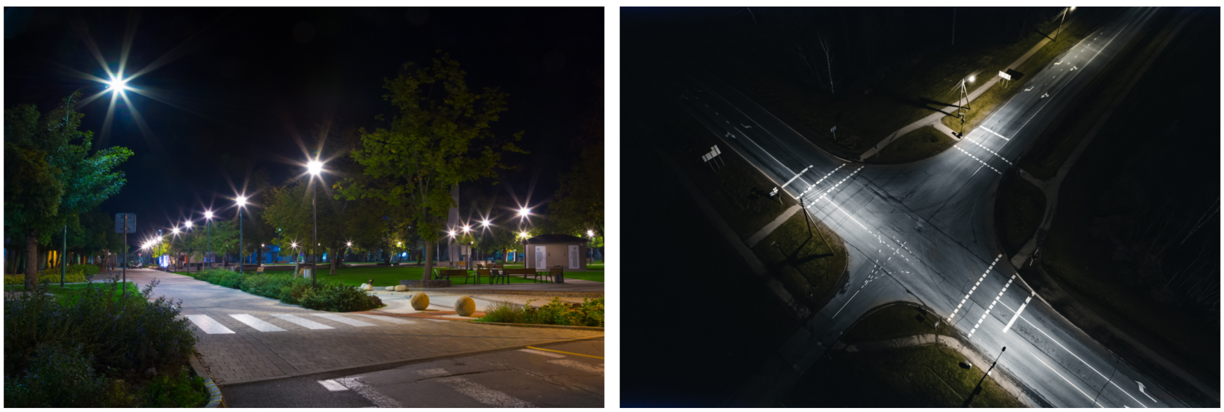


Figure 5-3. Photos. (Left) Continuous lighting approaching an intersection. (Right) Non-continuous lighting approaching an intersection.

6. Lighting Warrants

6.1. What is a Lighting Warrant?

A *lighting warrant* is a prescriptive method (either a specific design factor or a sum of several weighted design factors) used to determine if lighting is a suitable safety countermeasure for a specific roadway application. The result of a lighting warrant does not create an obligation for states, cities, towns, or villages to provide lighting. Warrants are intended to provide the minimum requirements and help prioritize locations for installing lighting to increase pedestrian safety.

The following is a list of common industry references and warrants for lighting applications.

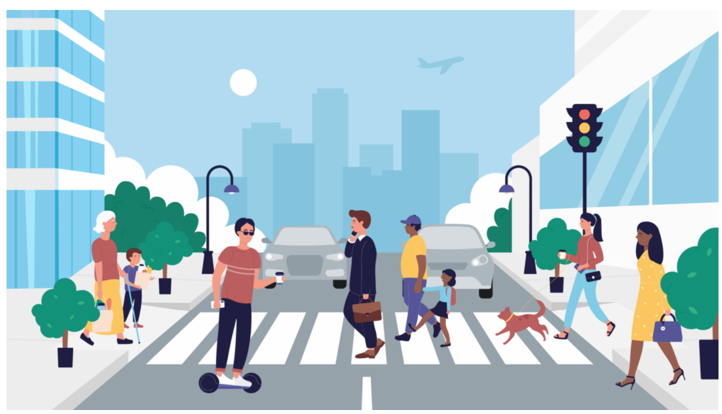
Lighting References with No Warranting Criteria:

- **FHWA 2023. *Lighting Handbook* –** This handbook does not include warrants for roadway lighting applications. However, the Handbook does refer designers to documents by AASHTO and TA for warranting lighting.
- ***ANSI/IES 2021. RP-8-21, Recommended Practice: Lighting Roadway and Parking Facilities (2021)*** – This recommended practice does not include warrants for roadway lighting applications. However, the document does refer designers to documents by others.

Lighting References with Warranting Criteria:

- **AASHTO 2018. *Roadway Lighting Design Guide* –** This design guide provides lighting warrants for *Principal Arterial* roadway applications such as freeways, interchanges, and bridges.
- **TAC 2006. *Guide for the Design of Roadway Lighting*** – This guide provides warrants for lighting on non-major roadway applications such as *Minor Arterials, Collectors, Local roads,* and *Intersections*.
- **Local Jurisdictions** – Some state DOTs, cities, towns, and villages may have their own lighting design manual that includes warrants for various lighting application specific to their needs.

6.2. Why Do We Need a New Warrant?



Until now, a published comprehensive lighting warrant focused on enhancing the safety of pedestrians and bicyclists at intersection crosswalks did not exist.

According to FHWA, crosswalks at intersections are considered part of the intersection's boundaries. In the past, many state DOTs and local jurisdictions simply deferred their designers to the *TAC Guide for the Design of Roadway Lighting* which includes a specific *Warrant for Intersection Lighting.* By default, if the results of completing the TAC warrant recommends lighting for the intersection, the crosswalks were included in the intersection's boundaries. However, the current TAC *Warrant for Intersection Lighting* focuses on weighted factors associated *only* with vehicular safety, and the warrant is not tailored for the roadway characteristics and population densities of different cities (i.e., New York City vs. Portland, Maine).

Although the TAC *Warrant for Intersection Lighting* is very comprehensive, it has not been recently updated, and it lacks several of the critical design factors recently identified in the FHWA *Pedestrian Lighting Design Primer* that are used by designers to assess the needs for pedestrian lighting for safety. It also lacks several design factors that were recently identified in the 2023 MaineDOT pedestrian crosswalk study. These additional roadway factors which have an effect on the level of pedestrian safety include:

- A pedestrian crash history
- Immediate proximity to locations where children will be present (schools/parks/recreation centers)
- Immediate proximity to locations where persons with disabilities will be present
- Immediate proximity to locations where the elderly will be present (nursing homes, community centers, houses of worship)
- High ambient light levels or high background luminance
- Presence of disability glare
- Frequency of inclement weather
- Presence of parking along the street
- History of crime against pedestrians
- History of speeding (+10mph)

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

Figure 6-1. Table. Common factors identified by industry professionals to assess pedestrian lighting needs.
(FHWA Pedestrian Lighting Primer, Table 1.)

6.3. Automatic Warrants for Pedestrian Lighting

Warrants for pedestrian lighting do not always need to be a comprehensive calculation of weighted factors. Sometimes, one factor is enough to warrant lighting. Across the US and Canada, various state DOTs and local jurisdictions have assessed their local needs and pre-identified automatic warranting factors that are unique to their location. These factors may vary from state to state, and city to city. Automatic warrants simply make it easy for a designer to quickly identify roadway applications where lighting is known to help increase the safety of pedestrians and bicyclists.

MaineDOT Automatic Warrants for Pedestrian Lighting. MaineDOT has pre-identified several roadway applications where lighting is *automatically warranted* for a pedestrian crosswalk. These applications shall be considered first for additional lighting when funding is available. If any of the following scenarios exist, a complete lighting warrant is not needed, unless the goal is to prioritize one location over another. MaineDOT automatic warrant applications include:

- ✓ All midblock crosswalks
- ✓ Crosswalks at a signalized intersection
- ✓ Crosswalks at unsignalized intersections where:
    - at least one approach leg is *continuously lit* in accordance with either IES or AASHTO design criteria
    - History of at least one pedestrian or bicyclist crash
    - Immediate proximity to locations where children, elderly, or persons with disabilities will be present (e.g., schools, parks, hospitals)

6.4. MaineDOT Warrant for Pedestrian Lighting at Intersection Crosswalks

A *Lighting Warrant Analysis* can be performed for applications where lighting is not automatically warranted. Although enhanced visibility at crosswalks via lighting is a proven safety countermeasure and should be considered for every application, funding is not always available. Due to the sheer volume of crosswalks across the United States, the intent of a lighting warrant analysis for pedestrian crosswalk applications is to help *prioritize* locations that would benefit from additional lighting as funding becomes available. In addition, a pedestrian lighting warrant can help identify the appropriate *Intersection Lighting Classification* for the intersection *(See Section 7).* The warranting process for lighting can be tedious, but the negative factors identified may help highlight other roadway improvements that may also help increase pedestrian safety (such as slightly modifying the road geometry, speed, etc.)

The new MaineDOT ***Warrant for Pedestrian Lighting at Intersection Crosswalks*** uses nineteen roadway classification factors to help prioritize when additional lighting is highly likely to increase pedestrian safety. These factors have been organized into the following four primary categories:

- *Geometry Factors*
- *Operational Factors*
- *Environmental Factors*
- *Safety Factors*

The MaineDOT *Warrant for Pedestrian Lighting at Intersection Crosswalks* is an Excel spreadsheet that can be used by design professionals to document the factors of a specific intersection. Users can populate the blank fields, such as location, coordinates, mph, and AADT and add images for future reference. Users can also highlight the ratings that have been selected for each factor. A blank copy of a Warrant is shown on the following page.

Note: Prior to design, Designers shall visit the MaineDOT website to download the latest version of the Warrant for their needs. The Warrant presented in this guideline is intended to be a living document and may be updated by MaineDOT at any time. The images shown are subject to change, and the designer is responsible for contacting MaineDOT for the latest version prior to designing their projects. A completed Warrant with all relevant backup data should be submitted to MaineDOT with each lighting design submission for intersections with crosswalks.

MaineDOT Warrant for Pedestrain Lighting at Intersection Crosswalks

Location:	*Street 1, Street 2, City, County*
Coordinates:	*Latitude & Longitude*

Directions:

1. *Identify if lighting is automatically warranted per MaineDOT Guideline for Lighting Pedestrian Crosswalks.*
2. *If lighting is not automatically warranted, complete the spreadsheet below. Factors shall be gathered through field visits, Google Earth, and* *maine.gov/mdot/mapviewer.*
3. *If the total sum is 150+, then Partial Intersection Lighting Is warranted. If the total is 100+, then Intersection Crosswalk Lighting is warranted. <100 Lighting is not warranted.*

Insert Images of Intersection Here

Item No.	Warrant Classification Factor		Rating Factor (R) 0	1	2	3	4	Weight Factor	Weight (W)	Enter (R) Here	Score (WxR)
Geometry Factors											
1	**Channelization** *(Only one of the three Weight Factors shall be used)*		None	Dedicated Right and/or Left Turn Lanes on Minor Approach Only	Dedicated Right Turn Lane(s) on Major Leg(s)	Dedicated Left Turn Lane(s) on Major Leg(s)	Left and Right Turn Lanes on all Legs	Raised Channelization and Design Speed Less than 45mph on at Least One Channelized Approach	15	0	0
											OR
								Raised Channelization and Design Speed More 45mph+ on at Least One Channelized Approach	25	0	0
											OR
								Painted Channelization Only	5	0	0
2	**Measured Approach Sight Distance on the Most Constrained Approach (Relative to Recommended Minimum Intersection Sight Distances)**		100% or More	75% to 99%	50% to 74%	25% to 49%	<25%		10	0	0
	AASHTO ISD Case:	Insert ISD Case Here									
	Major Rd. Speed Limit:	Insert mph Here									
	Design Speed (Speed Limit +5mph):	Insert mph Here									
	Recommended Min. ISD:	Insert ISD here									
	Measured Sight Distance:	Insert MSD here									
3	**Horizontal Curvature (Radius) at or Immediately Before Intersection on Any Leg**	65mph	Tangent	>6000ft	4000-6000ft	2500-4000ft	<2500ft		5	0	0
		55 or 60mph	Tangent	>5000ft	3000-5000ft	2000-3000ft	<2000ft				
		40 or 50mph	Tangent	>3000ft	2000-3000ft	500-2000ft	<500ft				
		35mph or less	Tangent	>2000ft	1000-2000ft	500-1000ft	<500ft				
4	**Angle of Intersection or Offset Intersection:**	Insert Angle Here	90 Degree Angle	80-89 or 100-109 Degree Angle	74-79 or 110-115 Degree Angle	70-74 or 115-120 Degree Angle	<70 or >120 Degree or Offset Intersection		5	0	0
5	**Downhill Approach Grade at or Immediately Before Intersection on Any Leg:**	Insert Grade Here	<3.0%	3.1 to 3.9% and Meets Design Guidelines for Type and Speed of Road	4.0 to 4.9% and Meets Design Guidelines for Type and Speed of Road	5.0 to 7.0% and Meets Design Guidelines for Type and Speed of Road	>7% or Exceeds Gradiant for Type and Speed of Road		3	0	0
6	**Number of Legs**		3	4	5	6	6 or More		3	0	0
									Subtotal of Geometric Factors (G)		**0**
Operational Factors											
7	**AADT on Major Road:**	Insert Approach 1 Here Insert Approach 2 Here	<1000	1001 to 2000	2001 to 3000	3001 to 5000	>5000		20	0	0
8	**AADT on Minor Road:**	Insert Approach 3 Here Insert Approach 4 Here	<500	501 to 1000	1001 to 1500	1501 to 2000	>2000		20	0	0
9	**Regular Nighttime Hourly Pedestrain Volume**		1 or 2	3 to 10	10 to 30	31 to 50	Over 50		20	0	0
10	**Intersection Roadway Classification** *(Per MaineDOT Highway Corridor Priority)*		No Arterial Roads Involved (No HCP1 or HCP2)	Arterial (HCP1 or HCP2) and Collector or Local (HCP3, HCP4, or HCP5)	Principal Arterial (HCP1) and Minor Arterial (HCP2)	Principal Arterial (HCP1) and Principal Arterial (HCP1)	Intersection includes Divided Highway		5	0	0
	Major Road:	Insert Major Rd Here									
	Minor Road:	Insert Minor Rd Here									
11	**Posted Speed Limit on Major Rd.**	Insert mph Here	30mph or less	35mph	40mph	50mph	55mph+		5	0	0
12	**Posted Speed Limit on Minor Rd.**	Insert mph Here	30mph or less	35mph	40mph	50mph	55mph+		5	0	0
									Subtotal of Operational Factors (O)		**0**
Environmental Factors											
13	**Lighted Development Within 500ft Radius of Intersection** *(aka High Ambient Light Levels or High Background Luminance)*		None	In One Quadrant	In Two Quadrants	In Three Quadrants	In Four or more Quadrants		5	0	0
14	**Presence of Disability Glare as Driver Approaches Crosswalk** (e.g. nearby non-cutoff street lights, flood lights)		none	1 leg	2 legs	3 legs	4+ legs		5	0	0
15	**Frequency of Inclliment Weather** *(Ability to see crosswalk markings consistentyl throughout the year due to local weather conditions such as Rain, Fog, Snow)*		Low Frequency		Average Frequency		High Freqeuncy		5	0	0
16	**Presence of Parking or Obstructions** *(Factors that could block view of pedestrians in or approaching a crosswalk)*		No	1 leg	2 legs	3 legs	4 or more legs		5	0	0
									Subtotal of Environmetnal Factors (E)		**0**
Safety Factors											
17	**Totall Nighttime Crashes over last 3 years** *(*Only between dusk-dawn)*	Insert # Here	0 Crashes	1 Crashes	2 Crashes	3 Crashes	More than 3 Crashes	1 or 2 Crashes	15	0	0
											OR
								3 or More Crashes	30	0	0
					OR:						
	TotalfCrashes over last 10 years *(*Occurs at Anytime of the Day)*	Insert # Here	0 Crashes	<10 Crashes	<20 Crashes	<30 Crashes	30+ Crashes		15	0	0
18	**History of Crime Against Pedestrians** *(or Perceived Feeling of Safety for Pedestrians)*		Feels Extremely Safe	Feels Safe	Does Not Feel Safe	-	History of Crime Against Pedestrians		5	0	0
19	**History of Speeding** (+10mph)		No	Yes					5	0	0
									Subtotal of Safety Factors (S)		**0**
									Total Warrant Points = G + O + E + S		**0**

Figure 6-2. Image. MaineDOT *Warrant for Pedestrian Lighting at Intersection Crosswalks.*

6.5. Geometry Factors

6.5.1. Factor 1. Channelization.

Channelization. This is a device used as a delineation alert to guide travelers' safety through an intersection or along a roadway using pavement marking, curbing, and vertical devices such as an *island* or *median*. These devices are intended to separate the direction of traffic, restrict certain vehicle movements, and/or direct traffic to a particular location. The effectiveness of *channelization* from a vehicle safety perspective has been documented in several FHWA studies. However, channelization typically lengthens the distance for a pedestrian crossing the street, and cars that are stopped at an adjacent turn lane can obstruct a driver's view of a pedestrian. The following is a list of terms to help identify the approach roadway's Warrant rating for channelization.

Approach Legs. Each roadway approaching an intersection is also referred to as a *leg*. When these approach legs have different FHWA Functional Classifications, one roadway is defined as the Major Road and the other roadway is defined as the Minor Road.

Lane Types. Each approach leg of an intersection can have different types of lanes which are used to direct the traffic flow in a particular direction. These types of lanes include *thru lanes, left turn lanes* and/or *right turn lanes*. Approach legs can have various quantities of lane types and lane widths. Therefore, no two intersections are exactly alike.

Geometry Factors		
1	**Channelization** *(Only one of the three Weight Factors shall be used)*	
2	**Measured Approach Sight Distance on the Most Constrained Approach (Relative to Recommended Minimum Intersection Sight Distances)**	
	AASHTO ISD Case:	Insert ISD Case Here
	Major Rd. Speed Limit:	Insert mph Here
	Design Speed (Speed Limit +5mph):	Insert mph Here
	Recommended Min. ISD:	Insert ISD here
	Measured Sight Distance:	Insert MSD here
3	**Horizontal Curvature (Radius) at or Immediately Before Intersection on Any Leg**	65mph
		55 or 60mph
		40 or 50mph
		35mph or less
4	**Angle of Intersection or Offset Intersection:**	Insert Angle Here
5	**Downhill Approach Grade at or Immediately Before Intersection on Any Leg:**	Insert Grade Here
6	**Number of Legs**	

Figure 6-3. Screenshot of the Geometry Factors in MaineDOT *Warrant for Pedestrian Lighting at Intersection Crosswalks.*

Channelization Types. Islands or medians that are used for channelization can be *flush* (painted) or *raised* (curbed). The goal of channelization is to reduce points of conflict by physically separating traffic flow beyond normal painted lane lines. For example, a center median forces a vehicle to make a wider, proper turn rather than cutting through an intersection. When incorporating crosswalks at an intersection, islands, and medians can provide additional places of refuge for pedestrians. However, they also increase the quantity of locations in which proper pedestrian lighting levels shall be designed.

6.5.2. Factor 2. Minimum Intersection Sight Distance (ISD).

To reduce potential crashes, a driver who approaches an intersection requires a triangular area that is clear of obstructions before they can safely proceed through the intersection or make a turn.

Clear Site Triangle. A *clear site triangle* is a triangular area at an intersection formed from two specific points: a driver's *decision point* and the *intersection stopping sight distance (ISD)*. Objects blocking a driver's view of the clear site triangle (such as parked cars, buildings, walls, and raised grades) can create unsafe locations for both vehicles and pedestrians.

Decision Point. For an intersection with a stop sign or a traffic signal, the *decision point* is where an approaching driver stops and decides on how best to proceed. For a minor road, the decision point is set 18' back from the curb along the major road (see Figure. 66). For an intersection without a control device, the decision point would be equal to the AASHTO decision stopping distance based on the vehicle's speed (which is not covered in this guideline).

Intersection Sight Distance (ISD). For an intersection, the necessary horizontal distance between the driver's decision point along the minor road and an oncoming vehicle along the major road, which allows enough time for a driver to decide on how to proceed safely, is referred to as the *intersection sight distance*. The ISD distances will vary based on the type turning movement of the minor road's approach vehicle and the type of stop control.

AASHTO ISD Case Types. AASHTO has identified seven typical *ISD case types* for calculating the ISD, based on the type of traffic control at the intersection and turning movement. The first step is for a designer to identify which ISD case best represents their intersection. For a complete description of how to calculate the ISD for each unique scenario, refer to *AASHTO Green Book 7th Ed. 2018*.

- ***Case A –*** *Intersections with no traffic control*
- ***Case B –*** *Intersections with Stop Control on the Minor Road*
    - ***B1 –*** *Left turn from Minor Road*
    - ***B2 –*** *Right turn from Minor Road**
    - ***B3 –*** *Minor Road Crossing over Major Road**
- ***Case C*** *– Intersections with Yield Control on the Minor Road*
    - ***C1*** *– Minor Road Crossing*
    - ***C2*** *- Left or Right from Minor Road*
- ***Case D*** *– Intersections with Traffic Signal Control*
- ***Case E*** *– Intersections with All-Way Stop**
- ***Case F*** *– Left Turns from Major Roads**
- ***Case G*** *– Roundabouts*

Additional AASHTO ISD Variables. Each AASHTO ISD case type can be further broken down by additional variables. The tables included in this guideline can be used by a designer to help identify the ISD for the standard ISD application listed below. For non-standard applications, designers shall consult with a Traffic Engineer to help determine the ISD for that intersection**.

- **Standard ISD Application (*Case B2, B3, E, & F)**
    - Intersection with stop control on the minor road approach, traffic signal, or all-way stop
    - Driver's eye and object's height in the crosswalk are both at passenger car level
    - Both major road and minor road approaches are at grade level
    - Major road is an undivided, two-way, two-lanes per approach, with no additional turning lanes
- **Non-Standard ISD Applications ***Consult a Traffic Engineer for Assistance***
    - Intersection with yield control on a minor road
    - Intersection with no traffic control
    - Left turn from a major road
    - Roundabouts
    - Driver's eye at a truck level
    - Minor road approach grade is greater than 3%
    - Major road is divided with a median barrier
    - Additional left or right turn lanes in either approach direction

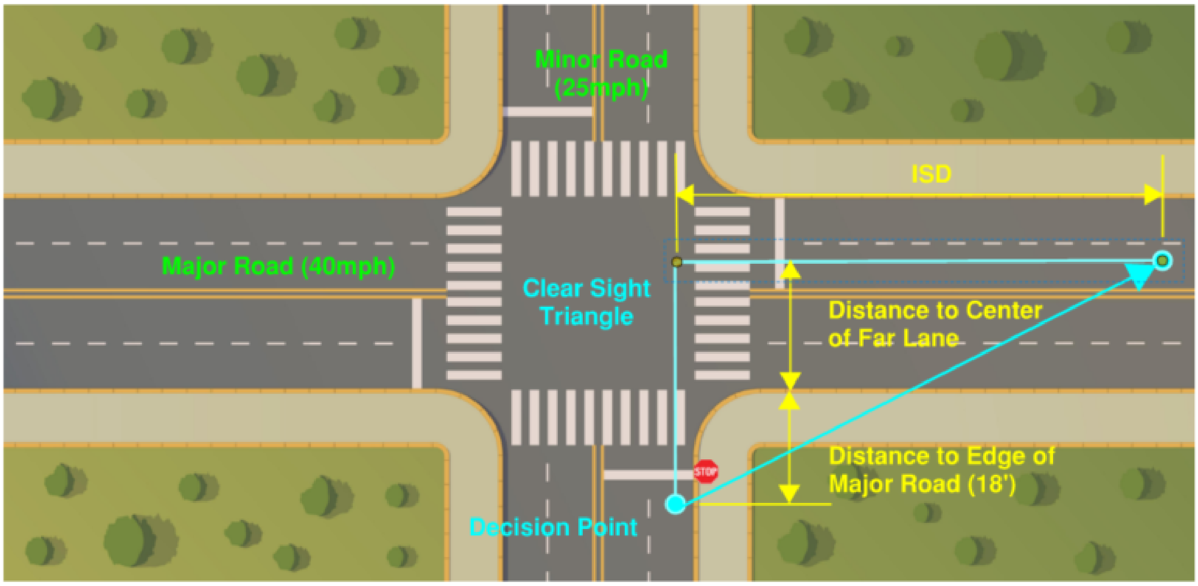


Figure 6-4. Illustration. Stop Control on Minor Road & Right Turn from Minor Road (AASHTO ISD Case B2, B3, E & F).

Standard ISD Application: Right Turn from Minor Road

Design Speed (mph)	Stopping Sight Distance (ft)	Intersection Sight Distance for Passenger Cars (ft)	
		Calculated	Design
15	80	143.3	145
20	115	191.1	195
25	155	238.9	240
30	200	286.7	290
35	250	334.4	335
40	305	382.2	385
45	360	430.0	430
50	425	477.8	480
55	495	525.5	530
60	570	573.3	575
65	645	621.1	625
70	730	668.9	670
75	820	716.6	720
80	910	764.4	765
Note: The given intersection sight distances are for a stopped passenger car to turn right onto, or cross, a two-lane road with no median and minor road approach grades of 3 percent or less. For other conditions, the sight distance must be recalculated.			

Figure 6-5. Table. Design ISD to be used ONLY for Cases B2, B3, E, & F (*Source. A Policy on Geometric Design of Highway and Streets, AASHTO, Table 9-8. 9-41*)

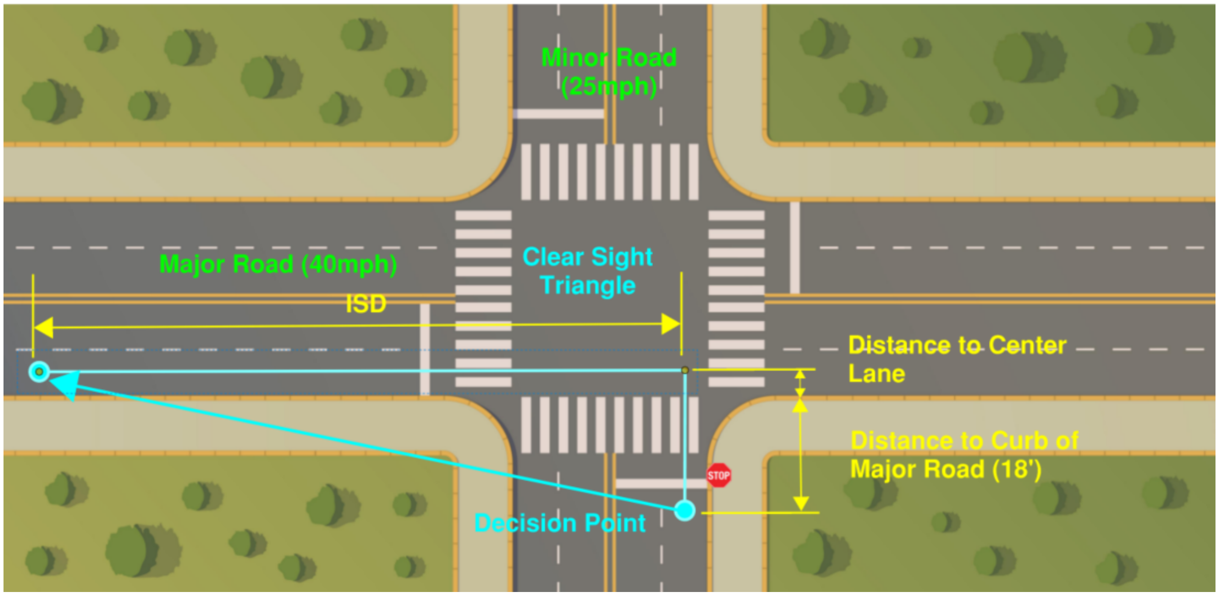


Figure 6-6. Illustration. Stop Control on Minor Road & Left Turn from Minor Road (AASHTO ISD Case B1, E, & F).

Standard ISD Application: Left Turn from Minor Road

Design Speed (mph)	Stopping Sight Distance (ft)	Intersection Sight Distance for Passenger Cars (ft)	
		Calculated	Design
15	80	165.4	170
20	115	220.5	225
25	155	275.6	280
30	200	330.8	335
35	250	385.9	390
40	305	441.0	445
45	360	496.1	500
50	425	551.3	555
55	495	606.4	610
60	570	661.5	665
65	645	716.6	720
70	730	771.8	775
75	820	826.9	830
80	910	882.0	885
Note: The given intersection sight distance values are for a stopped passenger car to turn left onto a two-lane road with no median and minor road approach grades of 3 percent or less. For other conditions, the sight distance must be recalculated.			

Figure 6-7. Table. Design ISD to be used ONLY for Cases B1, E, & F. (*Source. A Policy on Geometric Design of Highway and Streets, AASHTO, Table 9-8. 9-41*).

Speed of MaineDOT Roadways. Designers can visit www.maine.gov/mdot/mapviewer.com and enter in the address of the street or intersection you are looking for to help identify the exact speed of the major road and minor road approaches.

Speed Limit (Posted Speed). This is the speed one would see on a posted sign along the roadway and the operating speed limit a driver should not exceed. This is also the speed that will be listed on www.maine.gov/mdot/mapviewer.com. The *speed limit* shall be used in the MaineDOT warrant's Operational Factor #11 and #12 and the warrant's Safety Factor #19.

MaineDOT Design Speed *(Speed Limit + 5mph).* This is the speed that shall be used by designers for designing roadways. The *design speed* is equal to the *speed limit* plus an additional 5 mph. Design speed shall be used in the MaineDOT warrant's Geometry Factor #2 for identifying the intersection sight distance.

Measured Sight Distance. The *actual* field *measured sight distance* is the horizontal distance from the driver's decision point along the Minor Road (3.5' above the road surface) to a point along the Major Road (also at 3.5' above the road surface) based on existing obstructions at the intersection.

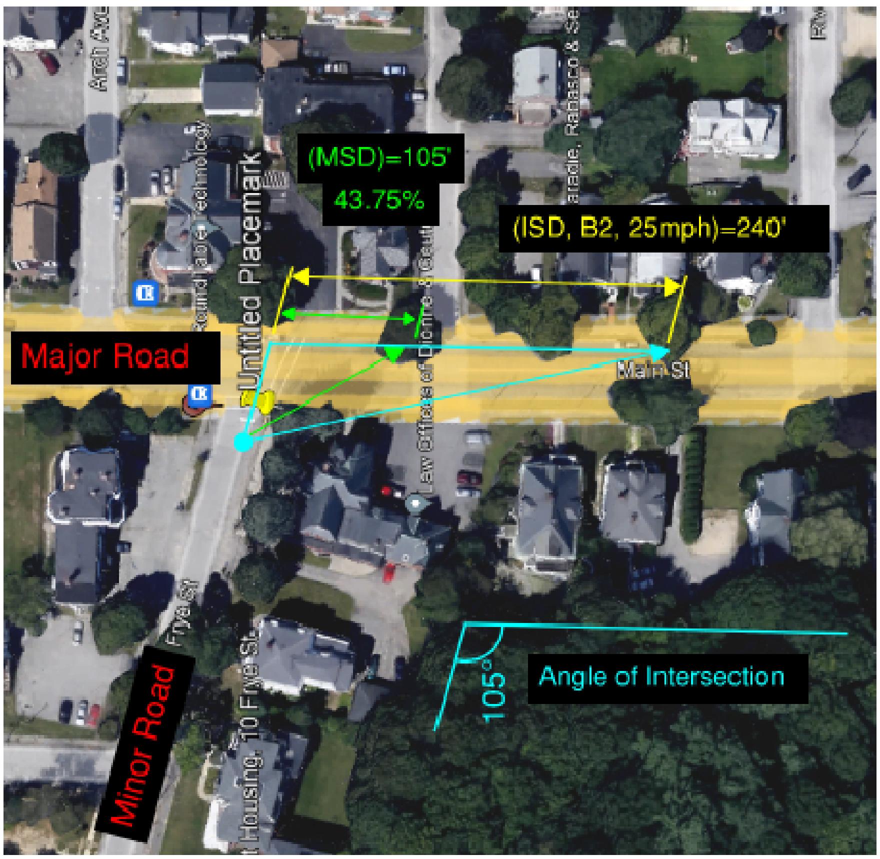


Figure 6-8. Illustration. AASHTO ISD Case B2 (Right Turn from Stop). Major Road (Main Street) and Minor Road (Frye Street) in Lewiston, Maine.

6.5.3. Factor 3: Horizontal Curvature.

This is the radius of the roadway at or immediately before the intersection on any leg.

6.5.4. Factor 4: Angle of Intersection.

Ideally, every intersection should be designed to have roadways cross at a 90-degree angle, but this is not always the case. The more extreme the approach angle is (deviation from 90 degrees), the higher the risk of pedestrian crashes. Intersections in which the intersecting angles are 60 degrees or less are considered skewed and can negatively affect pedestrian safety, especially when the measured approach sight distance is below the recommended level.

6.5.5. Factor 5: Downhill Approach Grade of Road.

The grade of a road is a measure of the road's steepness/slope as it rises and falls along its route. For pedestrian lighting applications, a road with a steep downhill approach grade that is not appropriate for the type and speed of the road can have a negative effect on pedestrian safety. Additionally, a road with a steep upward approach and a crosswalk at the top of the hill can also have a poor clear sight line which can negatively affect pedestrian safety. A roadway with a grade of 3% or higher is considered significant and included in the warrant.

6.5.6. Factor 6: Type of Intersection

Based on their geometry, there are several types of intersection. These include a *T-intersection* (3 legs), a *Y-intersection* (3 legs), an *X-intersection* (4-leg), a *crossroad* (4-leg), *misaligned*, *skewed*, *roundabouts*, and others. The more complex an intersection is, the higher the chance of vehicular and pedestrian crashes.

Figure 6-9. Photo. T-Intersection at Saco Ave and Staples Street in Old Orchid Beach, Maine,

Figure 6-10. Photo. Y-Intersection at Saco Ave and Old Orchid Street in Old Orchid Beach, Maine.

Figure 6-11. Photo. Misaligned intersection along Saco Avenue in Old Orchid Beach, Maine.

Figure 6-12. Photo. Skewed Intersection at Saco Ave and Union Ave in Old Orchid Beach, Maine.

6.6. Operational Factors

To help identify the operational factors of a roadway in the state of Maine, designers should visit www.maine.gov/mdot /mapviewer.com. This site provides a large quantity traffic of data for each roadway. However, some operational factors may require the assistance of a Traffic Engineer or a site survey.

Operational Factors		
7	AADT on Major Road:	Insert Approach 1 Here
		Insert Approach 2 Here
8	AADT on Minor Road:	Insert Approach 3 Here
		Insert Approach 4 Here
9	Regular Nighttime Hourly Pedestrain Volume	
10	Intersection Roadway Classification *(Per MaineDOT Highway Corridor Priority)*	
	Major Road:	Insert Major Rd Here
	Minor Road:	Insert Minor Rd Here
11	Posted Speed Limit on Major Rd.	Insert mph Here
12	Posted Speed Limit on Minor Rd.	Insert mph Here

Figure 6-13. Operational factors in the MaineDOT *Warrant for Pedestrian Lighting at Intersection Crosswalks*.

6.6.1. Factor 7 and 8: Intersection Annual Average Daily Traffic (AADT).

The total AADT of an intersection is the sum of the *highest* AADT for the Major Road approach leg and the highest AADT for the Minor Road approach leg. This information can be found at *www.maine.gov/mdot /mapviewer.com.* Different sections of the same road can have very different AADTs. For example, the AADT for a road that approaches an intersection from the north can have a different AADT for the same road as it approaches the same intersection from the south. Reviewing the AADT for each approach leg before selecting the highest quantity is important.

6.6.2. Factor 9: Pedestrian Volume.

For lighting warrants, the average number of pedestrians crossing a street at an intersection crosswalk or midblock crosswalk per hour, *at night*, during a regular period of time is referred to as the *pedestrian volume*. For example, measuring the quantity of pedestrians during a once-a-year outdoor street festival would not be considered a 'regular' period of time. For most lighting design applications, the quantity of pedestrians shall be measured between dusk and sometime before midnight. The dusk time will vary based on the day of the year, and the end time will vary based upon the closing time of nearby activities such as a supermarkets, restaurants, retail stores, etc. The day of the year and hour of the day with the highest *typical* quantity of nighttime pedestrians shall be used. Designers can request the pedestrian volumes for their location from MaineDOT, perform a field study, or use engineering judgment.

6.6.3. Factor 10: Intersection Roadway Classification (HCP).

This FHWA Functional Classification and HCP for an intersection's Major and Minor approach legs can be located on *www.maine.gov/mdot/mapviewer.* MaineDOT prefers designers use the Highway Corridor Priority level for the pedestrian lighting warrant.

6.6.4. Factor 11 and 12: Posted Speed.

For MaineDOT roadways, the posted speed of a roadway can be found on *www.maine.gov/mdot/mapviewer.* If a speed limit is not listed, it can be assumed to be 25mph.

6.7. Environmental Factors

Environmental Factors	
13	**Lighted Development Within 500ft Radius of Intersection** *(aka High Ambient Light Levels or High Background Luminance)*
14	**Presence of Disability Glare as Driver Approaches Crosswalk** (e.g. nearby non-cutoff street lights, flood lights)
15	**Frequency of Incliment Weather** *[Ability to see crosswalk markings consistentyl throughout the year due to local weather conditions such as Rain, Fog, Snow)*
16	**Presence of Parking or Obstructions** *(Factors that could block view of pedestrians in or approaching a crosswalk)*

Figure 6-14. Screenshot. List of Environmental Factors to be considered in the MaineDOT *Warrant for Pedestrian Lighting at Intersection Crosswalks.*

6.7.1. Factor 13: Lighting Development.

High ambient light levels adjacent to an intersection crosswalk can affect the contrast and luminance ratio between a pedestrian in a crosswalk and their surroundings. The term *lighted development* refers to an area within 500ft of an intersection that produces high background luminance. High luminance could result from commercial signage, retail storefronts, building façade lighting, parking lots, ballfields, and others.

When evaluating the need for pedestrian lighting it is critical that the designer is able to visit the site at night and evaluate the background luminance of a pedestrian in crosswalk from each vehicular approach. Crosswalks with higher background luminance will require higher vertical illuminance levels in order to maintain the recommended luminance threshold of 4:1.

6.7.2. Factor 14: Presence of Disability Glare.

As mentioned earlier in this guideline, glare can be broken down into various types including discomfort glare and disability glare. The *presence of disability glare* shall include glare that is only present in the driver's intended field of view. For example, the glare from the sun or a roadway luminaire mounted 30' to 100' in the air does not qualify. A driver should be focused on the roadway ahead of them, not up in the air.

Examples of disability glare include sustained lighting that prevents a driver from safely performing their task. This may include extremely bright or distracting commercial signage, glare from a building façade at certain times of the day, non-cutoff pedestrian luminaires, and poorly aimed flood lights. Although disability glare from the headlights of oncoming vehicles exists, it is not intended to be included in this factor.

6.7.3. Factor 15: Frequency of Inclement Weather.

This guideline is designed for applications within the State of Maine, so *a 'High Frequency' of inclement weather* will always be the Rating chosen. However, if this Warrant was being applied in Florida, 'Low Frequency' would be more appropriate. A 'High Frequency' represents weather conditions that reduce the contrast ratio between the crosswalk's zebra stripes. These weather conditions include excessive leaves during the fall, snow season, Maine's mud season, and rainy spring.

6.7.4. Factor 16. Presence of Parking or Obstructions.

The *presence of parking or obstructions* can prevent a vehicle approaching a crosswalk from the advanced warning needed to slow down and prevent a crash. Although the presence of a stop sign requires a car to actually stop before proceeding through an intersection, many drivers don't stop until they are within the crosswalk. For roadways with buildings extremely close to a sidewalk and crosswalk, a driver may need to creep into the crosswalk to see if there are any cars coming in the opposite direction.

6.8. Safety Factors

When warranting the lighting for a pedestrian crosswalk, only *one* vehicle/pedestrian or vehicle/bicyclist collision is needed to automatically warrant lighting.

However, if an intersection is not automatically warranted, there are a few additional factors recently identified in the FHWA *Pedestrian Lighting Primer, 2023*, which should be considered when identifying the level of safety.

6.8.1. Factor 17. Crash History.

Various types of crashes can occur along roadways, intersections, roundabouts, and pedestrian crosswalks. The details associated with crashes on MaineDOT roadways can be located at [www.maine.gov/mdot/mapviewer.](www.maine.gov/mdot/mapviewer)

Safety Factors		
17	**Totall Nighttime Crashes over last 3 years** *(*Only between dusk-dawn)*	Insert # Here
	TotalfCrashes over last 10 years *(*Occurs at Anytime of the Day)*	Insert # Here
18	**History of Crime Against Pedestrians** *(or Perceived Feeling of Safety for Pedestrians)*	
19	**History of Speeding** (+10mph)	

Figure 6-15. Screenshot. List of Safety Factors to be considered in the MaineDOT *Warrant for Pedestrian Lighting at Intersection Crosswalks.*

Total Nighttime Crash History (over last 3 years). If a particular intersection with a pedestrian crosswalk(s) has a history of nighttime vehicular crashes, the probability of a future nighttime crash occurring within a crosswalk increases. A vehicular-to-vehicular crashes can be a precursor to a vehicle-to-pedestrian crash.

Total Crash History (over the Last 10 Years). If a particular intersection with a pedestrian crosswalk(s) has a significant history of vehicle-to-vehicle crashes, at any time of the day, this can indicate not only an issue with the intersection's geometry, operational, and environmental factors but also an issue with a driver's expectation at the intersection. For example, an intersection that would normally have a low traffic volume during the week, but surges during a weekend, can surprise a non-local. If the geometry, operational, and environmental factors cannot be changed, and there is a high level of crashes, then incorporating proven safety countermeasures, such as lighting, should be considered.

Crash Rate. *Some warrants request the crash rate of an intersection as an effective tool to measure the relative safety of a particular intersection. The ratio of crash frequency (crashes per number of years) to vehicle exposure (number of vehicles entering the intersection from both approaches) results in a crash rate. However, crash rate does not accurately represent the population density and volume of traffic for the State of Maine and is not used in the warrant.*

$$R = \frac{1{,}000{,}000 \times C}{365 \times N \times V}$$

Where:
C *= Total number of intersection-related crashes in the study period*
N *= Number of years of data*
V *= Traffic Volumes entering the intersection daily*
R *= Crash rate for the intersection expressed as crashes per million entering vehicles (MEV)*

Example: ***Main Street and Frye Street, Lewiston, Maine.***
C = 19 (over 10 years)
N = 10 years
V *= Maine Street heading South: 13,280*
Main Street heading North: 14,240
Frye Street heading West: 1,270
Total = (14,240 + 1,270) = ***15,510 AADT*** *(worst case)*

$$R = \frac{1{,}000{,}000 \times 19}{365 \times 10 \times 15{,}510} = 0.34$$

6.8.2. Factor 18. History of Crime Against Pedestrians.

Crime against pedestrians can be related to a lack of well-designed lighting within an area. Good lighting that complies with the recommended design illuminance, uniformity ratio, black/white contrast for visual acuity, color rendering capabilities, minimal sky glow, and minimal glare is a proven method to reduce crime. Therefore, a history of pedestrian crime can be a red flag to help identify pedestrian areas that may not have been on the radar, perhaps due to a lower crash history.

6.8.3. Factor 19. History of Speeding.

If a roadway or intersection has a *history of speeding*, the probability of vehicle-to-vehicle crashes increases, and if there is a pedestrian crosswalk, the probability of a vehicle-to-pedestrian crash will also increase.

6.9. Calculating the Total Warranting Points.

In addition to the four primary warrant classification factors that are present in the MaineDOT Pedestrian Lighting Warrant (Geometry, Operational, Environmental, and Collision), there are a few additional warrant terms designer need to understand which includes the *Rating Factor (R)*, *Weight* Factor (*W)*, and *Warranting Points (WxR)*.

Rating Factor (R). Within a particular warrant classification factor are sub-factors. Each sub-factor is associated with a *rating factor* from 0-to-5. The lowest value (0) indicates that the sub-factor will have minimal benefit from additional pedestrian lighting. The highest value (4) indicates a sub-classification that will have a significant safety benefit from additional lighting.

Weight (W). In addition to the rating (0-4) of sub-factors, the primary classification factors also have different weights (3-30). The *weight* of a classification factor refers to the level of benefit additional pedestrian lighting would have in relation to all factors. Weight (W) is multiplied by the Rating Factor (R) to determine the final score. The weight for the Channelization Factor is further broken down into three sub-weights. Only one sub-weight should be used in the calculated score.

Total Warranting Points (WxR). Once all of the four major warrant classification factors are subtotaled, they are then summed to determine the *total warranting points*. Total points of *150 or greater warrants Partial Intersection Lighting*. Total points of *100 or greater warrants Intersection Crosswalk Lighting*.

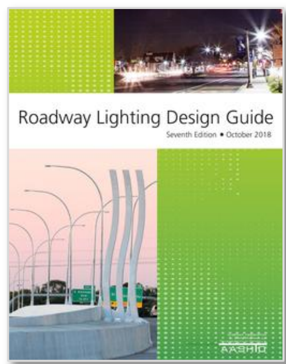
Note: The key to increasing safety of pedestrians in crosswalks is visibility and the key to visibility is contrast. If the desired visual contrast cannot be achieved through lighting alone, then designers should recommend that additional pedestrian safety countermeasures, such as rectangular rapid flashing beacons (RRFB), be incorporated. These beacons will provide the additional visual contrast to help a driver recognize a non-typical roadway situation is approaching and have time to react safely.

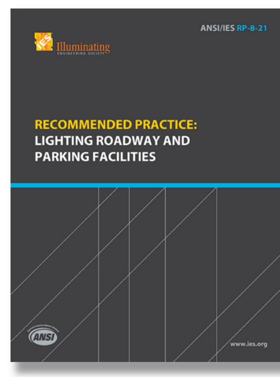
7. Intersection Research: Horizontal Illuminance

Lighting design criteria for intersections and intersection crosswalks consists of horizontal illuminance, uniformity, and vertical illuminance. The design criteria for these applications can be found in several resources, but the recommended levels vary slightly between the documents. The purpose of this guideline is to explain how to use each resource and compare them so designers can make the best decision for their application.

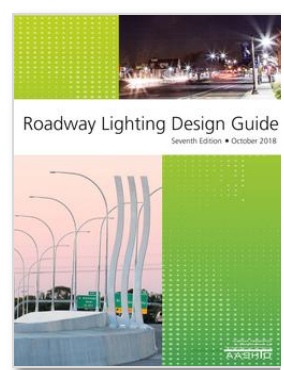
The following two references were evaluated for the recommended lighting design criteria for the horizontal illuminance and uniformity for intersections and intersection crosswalks:

- AASHTO. 2018. *Roadway Lighting Design Guide*. Washington D.C.: American Association of State Highway and Transportation Officials.
- ANSI/IES. 2021. *Recommended Practice for Design and Maintenance of Roadway and Parking Facility Lighting,* RP-8-21. New York, NY: Illuminating Engineering Society.





7.1. AASHTO Design Criteria



The AASHTO *Roadway Lighting Design Guide, 2018,* is the *preferred* reference for selecting the pedestrian lighting design criteria for MaineDOT applications. Designers shall use the Guide's *Table 3-5a* to select the design criteria for the average maintained horizontal illuminance and uniformity. Before using the table, designers shall pre-identify the following criteria:

- Major (Primary) Approach Roadway's Functional Classification
- Minor (Secondary) Approach Roadway's Functional Classification
- Area Classification
- Pavement Classification
- Major (Primary) Approach Roadway's existing field-measured illuminance level (if applicable)
- Minor (Secondary) Approach Roadway's existing field-measured illuminance level (if applicable)

AASHTO Recommended Horizontal Illuminance. The recommended AASHTO horizontal average-maintained illuminance for the intersection and crosswalk shall be based on the intersection's individual Major and Minor approach roadway's design criteria. The following is a breakdown of the design criteria based on the four MaineDOT Intersection Scenarios.

- **AASHTO Scenario 1. Full Intersection Lighting and 2 Approach Roadways Lit.**
  - Intersection: Major Road fc + Minor Road fc
  - Crosswalks: Major Road fc + Minor Road fc
- **AASHTO Scenario 2. Full Intersection Lighting and 1 Approach roadway Lit.**
  - Intersection: Major Road fc (min)
  - Crosswalks: Major Road fc + Minor Road fc
- **AASHTO Scenario 3: Partial Intersection Lighting (Approach roadways are not lit, Warrant of 150+)**
  - Intersection: Major Road fc
  - Crosswalks: Major Road fc
- **AASHTO Scenario 4: Intersection Crosswalk Lighting (Approach roadways are not lit, Warrant of 100+)**
  - Intersection: not required
  - Crosswalks: Major Road fc

AASHTO Adjusted Illuminance. If the existing field-measured horizontal illuminance for either the Major and/or Minor approach roadways is above the recommended value, the field-measured values shall be used, and intersection and crosswalk fc levels and adjust proportionately.

AASHTO Uniformity. The recommended illuminance uniformity ratio for an intersection shall be based on the Major Approach Roadway.

Table 3-5a. Illuminance and Luminance Design Values (U.S. Customary)

Roadway and Walkway Classification[a]	Area Classifications	Illuminance Method						Luminance Method			Additional Values (both Methods)
		Average Maintained Illuminance (E_{avg})				Minimum Illuminance E_{min}	Illuminance Uniformity Ratio E_{avg}/E_{min}	Average Maintained Luminance			Veiling Luminance Ratio
		R1	R2	R3	R4			L_{avg}	Uniformity		
	General Land Use	(footcandles) (min)	(footcandles) (min)	(footcandles) (min)	(footcandles) (min)	(footcandles)	Avg/min (max)[b]	cd/m² (min)	L_{avg}/L_{min} (min)	L_{max}/L_{min} (max)	$L_{v(max)}/L_{avg}$ (max)[c]
Principal Arterials:											
Interstate and other freeways	All	0.6	0.6	0.6	0.6	0.2	4:1	0.4[d]	3.5:1	6:1	0.3:1
Other Principal Arterials (partial or no control of access)	Commercial	1.1	1.6	1.6	1.4	As uniformity ratio allows	4:1	1.2	3:1	5:1	0.3:1
	Intermediate	0.8	1.2	1.2	1.0		4:1	0.9	3:1	5:1	0.3:1
	Residential	0.6	0.8	0.8	0.8		4:1	0.6	3.5:1	6:1	0.3:1
Minor Arterials	Commercial	0.9	1.4	1.4	1.0		4:1	1.2	3:1	5:1	0.3:1
	Intermediate	0.8	1.0	1.0	0.9		4:1	0.9	3:1	5:1	0.3:1
	Residential	0.5	0.7	0.7	0.7		4:1	0.6	3.5:1	6:1	0.3:1
Collectors	Commercial	0.8	1.1	1.1	0.9		4:1	0.8	3:1	5:1	0.4:1
	Intermediate	0.6	0.8	0.8	0.8		4:1	0.6	3.5:1	6:1	0.4:1
	Residential	0.4	0.6	0.6	0.5		4:1	0.4	4:1	8:1	0.4:1
Local	Commercial	0.6	0.8	0.8	0.8		6:1	0.6	6:1	10:1	0.4:1
	Intermediate	0.5	0.7	0.7	0.6		6:1	0.5	6:1	10.1	0.4:1
	Residential	0.3	0.4	0.4	0.4		6:1	0.3	6:1	10:1	0.4:1
Alleys	Commercial	0.4	0.6	0.6	0.5		6:1	0.4	6:1	10.1	0.4:1
	Intermediate	0.3	0.4	0.4	0.4		6:1	0.3	6:1	10:1	0.4:1
	Residential	0.2	0.3	0.3	0.3		6:1	0.2	6:1	10:1	0.4:1
Sidewalks	Commercial	0.9	1.3	1.3	1.2		3:1	Use illuminance requirements			
	Intermediate	0.6	0.8	0.8	0.8		4:1				
	Residential	0.3	0.4	0.4	0.4		6:1				
Pedestrian Ways and Bicycle Ways[e]	All	1.4	2.0	2.0	1.8		3:1				

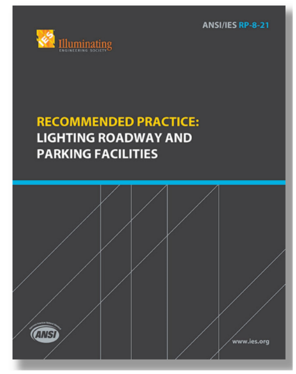
[a] See AASHTO's *A Policy on Geometric Design of Highways and Streets* (1) for roadway and walkway classifications.
[b] Higher uniformity ratios are acceptable for elevated ramps near high-mast poles.
[c] $L_{v(max)}$ refers to the maximum point along the pavement, not the maximum in lamp life. The Maintenance Factor applies to both the L_v term and the L_{avg} term.
[d] Use 0.6 for R1 surface.
[e] Assumes a separate facility. For Pedestrian Ways and Bicycle Ways adjacent to roadway, use roadway design values. Use R3 requirements for walkway or bikeway surface materials other than the pavement types shown. Other design guidelines such as IES or CIE may be used for pedestrian ways and bikeways when deemed appropriate.

Notes:
1. Meet either the Illuminance design method requirements or the Luminance design method requirements and meet veiling luminance requirements for both the Illuminance and the Luminance design methods.
2. There may be situations when a higher level of illuminance or luminance is justified. The higher values for freeways may be justified when deemed advantageous by the agency to mitigate off-roadway sources.
3. Physical roadway conditions may require adjustment of spacing determined from the base levels of illuminance indicated above.

Figure 7-1. Table. AASHTO *Roadway Lighting Design Guideline, Table 3-5a. Illuminance and Luminance Design Values.*

7.2. ANSI/IES Design Criteria

Note: The terminology, methodology, and design criteria recommended by ASNI/IES RP-8-21 for the average maintained horizontal illuminance and uniformity within a crosswalk varies from AASHTO. MaineDOT recommends that designers use AASHTO for selecting horizontal design criteria for roadways, intersections, and crosswalks. The following information has been provided for reference only.



When using the *ANSI/IES RP-8-21* to select the design criteria for the average-maintained horizontal illuminance and uniformity, the designer shall pre-identify the following criteria:

- Major (Primary) Approach Roadway's Functional Classification
- Minor (Secondary) Approach Roadway's Functional Classification
- Pedestrian Activity Level Classification
- Pavement Classification
- Major (Primary) Approach Roadway's existing field-measured illuminance level (if applicable)
- Minor (Secondary) Approach Roadway's existing field-measured illuminance level (if applicable)
- High existing field-measured background luminance (for vertical illuminance)

IES Horizontal Illuminance. There are two separate tables presented by IES for intersection lighting. ANSI/IES *RP-8-21, Table 12-1* is provided for *Full Intersection Lighting with continuous lighting on both approach roadways* only and the illuminance levels provided are *intended* to be the sum of the recommended individual illuminance levels for the primary and secondary approach roadways. ANSI/IES *RP-8-21, Table 12-2* is provided for *Partial Intersection Lighting* only and the illuminance levels provided are intended to be the recommended individual illuminance level for the primary approach road.

Illuminance for Intersections				
Functional Classification	Pedestrian Activity Level Classification			E_{avg}/E_{min}
	High	Medium	Low	
Major/Major	34/3.2	26/2.4	18/1.7	3.0
Major/Collector	29/2.7	22/2.0	15/1.4	3.0
Major/Local	26/2.4	20/1.9	13/1.2	3.0
Collector/Collector	24/2.2	18/1.7	12/1.1	4.0
Collector/Local	21/2.0	16/1.5	10/0.9	4.0
Local/Local	18/1.7	14/1.3	8/0.7	6.0

Figure 7-2. Table. IES *RP-8-21, Table 12-1. Pavement Illuminance Criteria for Full Intersection Lighting (lux/fc). Assumes a Pavement Classification of R2 or R3.*

Road Classification	Pavement Classification			Uniformity Ratio
	R1 lux/fc	R2 & R3 lux/fc	R4 lux/fc	E_{avg}/E_{min}
Major	6/0.6	9/0.8	8/0.7	3.0
Collector	4/0.4	6/0.6	5/0.5	4.0
Local	3/0.3	4/0.4	4/0.4	6.0

Figure 7-3. Table. IES *RP-8-21, Table 12-2. Pavement Illuminance Criteria for Partial (Isolated) Intersection Lighting.*

7.3. AASHTO vs. IES Design Criteria

The following are the current differences between the AASHTO *Roadway Lighting Design Guide* and ANSI/IES *RP-8-21* lighting design criteria for horizontal illuminance at an intersection.

1. Roadway Classifications. Currently, ASNI/IES *RP-8-21* uses definitions for Major, Collector, and Local roadways which do not match the FHWA Functional Roadway Classifications or MaineDOT's definitions for Highway Corridor Priorities. IES only bases their roadway classifications of Major, Collector, and Local on ADT and does not consider other characteristics of roadways in their definition. This can cause Local roadways with high ADTs to be mis-classified as Principal Arterials, which can lead to unnecessary over-lighting.

2. Illuminance vs. Luminance. Unlike AASHTO, ANSI/IES *RP-8-21* does not provide illuminance criteria for individual roadways, only luminance criteria. The recommended illuminance in an intersection should be directly proportional to the illuminance of the approaching roadways to ensure contrast in the crosswalks. Since IES does not recommend illuminance for roadways, there is no way to ensure the IES's recommended illuminance levels for intersections provides the appropriate contrast with the roadway's designed levels for pedestrian safety.

3. Area vs. Pedestrian Classification. ANSI/IES *RP-8-21 Table 12-1* recommends different intersection illuminance levels based upon the level of pedestrians, in addition to the roadway levels approaching it. However, the level of pedestrians for typical Maine DOT roadways does not align with IES's definitions for high-medium-low pedestrians. AASHTO uses Area Classification instead of Pedestrian Levels to narrow down the appropriate light levels for each Roadway Classification.

4. Field Conditions. ANSI/IES *RP-8-21* does not address intersections in which approach roadways are over lit. For example, if actual field conditions measure illuminance levels well above those recommended, then the intersection levels shall be increased proportionately to ensure contrast is maintained for safety.

8. Intersection: Horizontal Illuminance – MaineDOT Design Criteria

8.1. Intersection Lighting Classifications

Per FHWA, crosswalks at an intersection and the area up to a stop bar is considered part of the intersection. MaineDOT automatically warrants *Full Intersection Lighting* when the intersection is signalized or either approach roadway is continuously lighted to AASHTO or IES recommended light levels. However, when there are only stop signs, yield signs, or no signage, and the approach roadways are not uniformly lit, a lighting warrant analysis shall be completed to identify if lighting is warranted. If lighting is warranted the sum of the weighted factors will determine if *Partial Intersection Lighting or Intersection Crosswalk Lighting* is recommended.

Full Intersection Lighting (Continuous Lighting on Both Approach Legs). *(Automatically Warranted)* This scenario focuses on lighting both vehicular and pedestrian conflict points within the intersection when *both approach legs have continuous lighting*. The average maintained horizontal illuminance level of the entire intersection and crosswalks shall be equal to the sum of the recommended average-maintained illuminance levels of the Major and Minor approach roadways, to ensure contrast between the intersection and roadways is achieved. The intersection shall have a uniformity equal to the recommended level for the Major roadway. *(See Fig. 8-1)*

Full Intersection Lighting (Continuous Lighting on One Approach Leg). *(Automatically Warranted)* This scenario focuses on lighting both vehicular and pedestrian conflict points when only *one approach leg has continuous lighting*. The vehicular conflict points in the middle of the intersection should have *at least* the same average maintained horizontal illuminance level as the lit roadway. The average maintained horizontal illuminance level of the crosswalks shall be equal to the sum of the recommended average-maintained illuminance levels of the Major and Minor approach roadway. The crosswalks and the non-crosswalk intersection areas may be combined into one calculation grid (if designed to the same fc level) or separate calculation grids (if designed to separate fc levels). Each grid shall have a uniformity equal to the recommended level for the major roadway. *(See Fig. 8-2)*

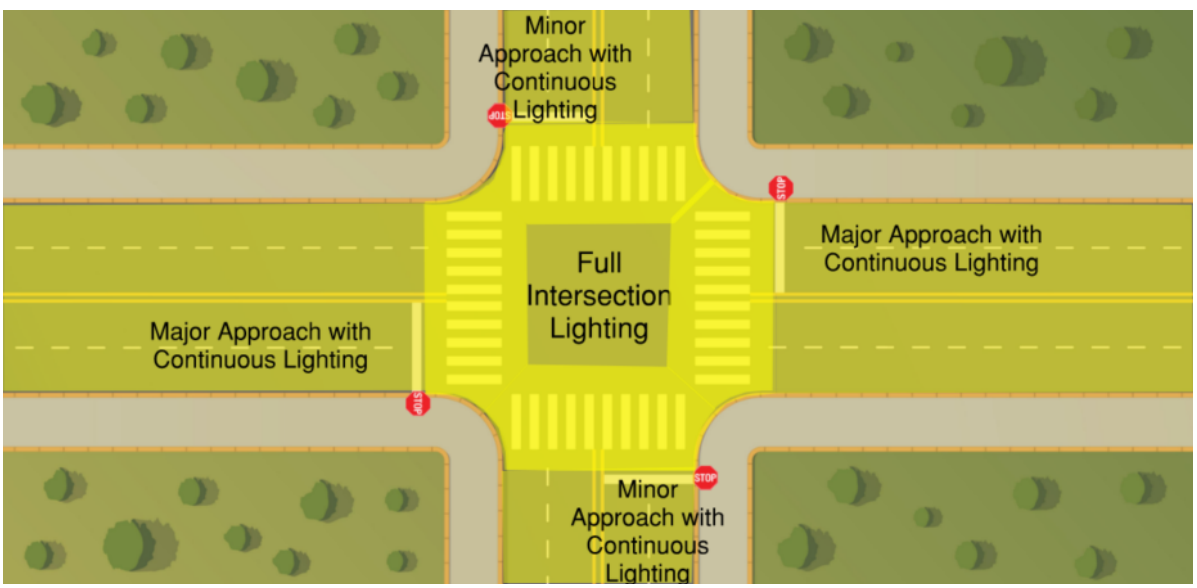


Figure 8-1. Illustration. Full Intersection Lighting with continuous lighting on both Major and Minor Approach Roadways.

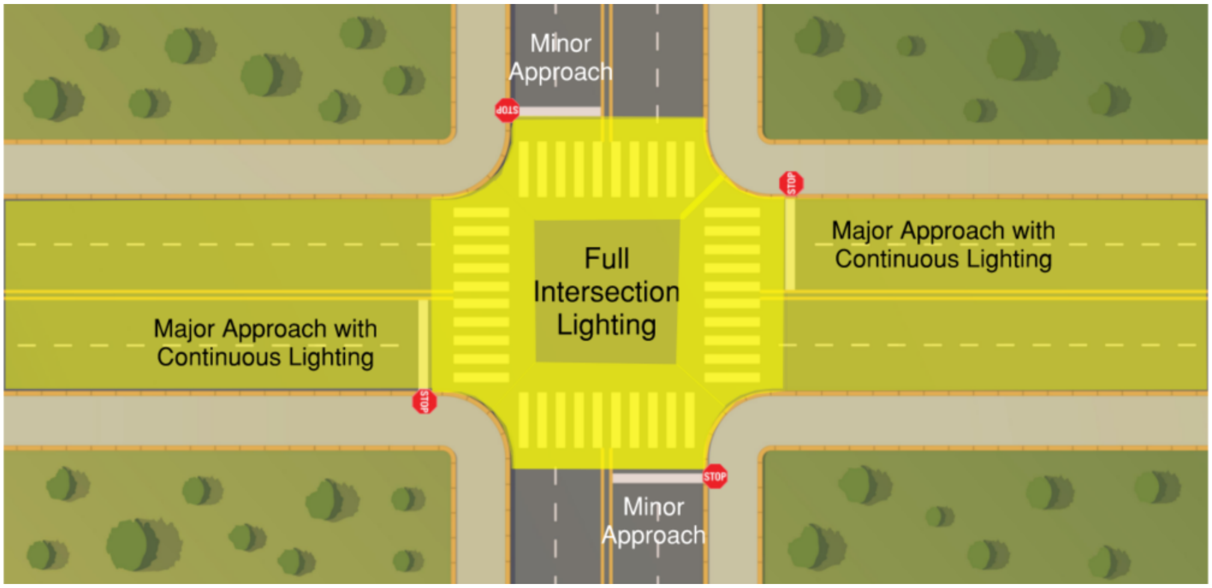


Figure 8-2. Illustration. Full Intersection Lighting with continuous lighting on the Major Approach Roadway.

Partial Intersection Lighting. *(Warranted when Total is 150 or greater)*. This scenario focuses on lighting the vehicular and pedestrian conflict points to increase safety when *neither of the approach roadways has continuous lighting*. The recommended average maintained horizontal illuminance value of the entire intersection, including the crosswalks, shall equal the recommended level for the Major Road approach, and shall have a uniformity equal to the recommended level for the Major Road. With Partial Intersection Lighting, the Minor Road is not considered in the design criteria. *(See Fig. 8-3)*

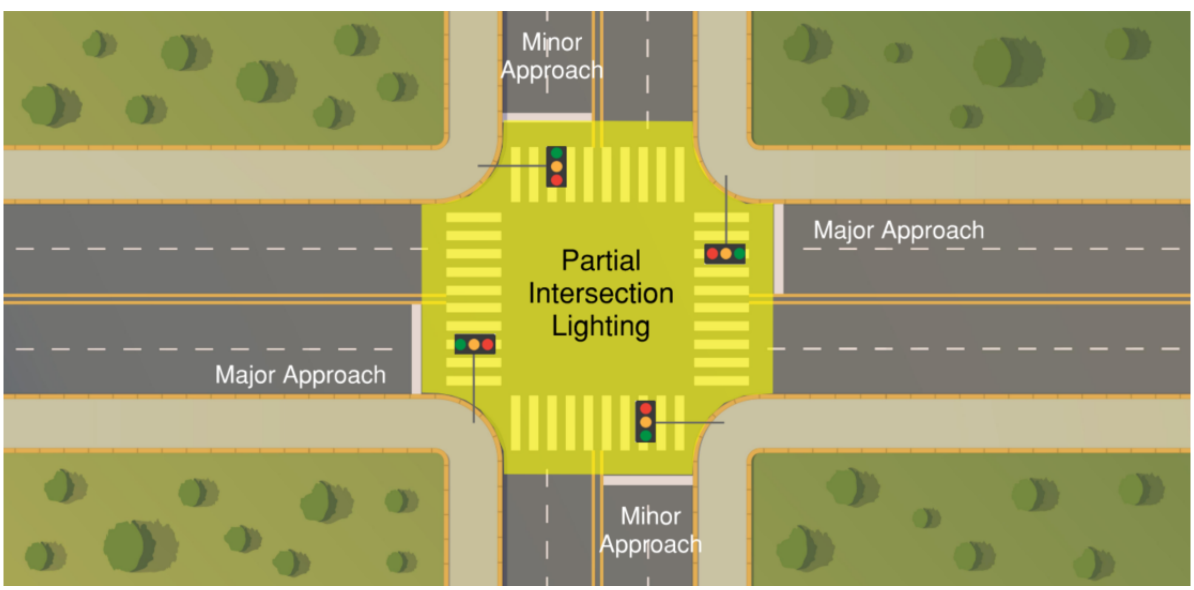


Figure 8-3. Illustration. Partial Intersection Lighting.

Intersection Crosswalk Lighting. *(Warranted when Total is 100-149)*. This scenario focuses on lighting only the pedestrian conflict points within the crosswalk to increase awareness of pedestrians when *neither of the approach roadways has continuous lighting, and the total calculated Warrant points are lower than that required for Partial Intersection Lighting*. The recommended average horizontal illuminance value and uniformity for the crosswalks for Intersection Crosswalk Lighting is the same as Partial Intersection Lighting, which is the recommended level for the Major Road approach. However, for Intersection Crosswalk Lighting, the middle of the intersection is not *required* to be lit, but it can be designed as Partial Intersection Lighting for added safety. *(See Fig. 8-4)*

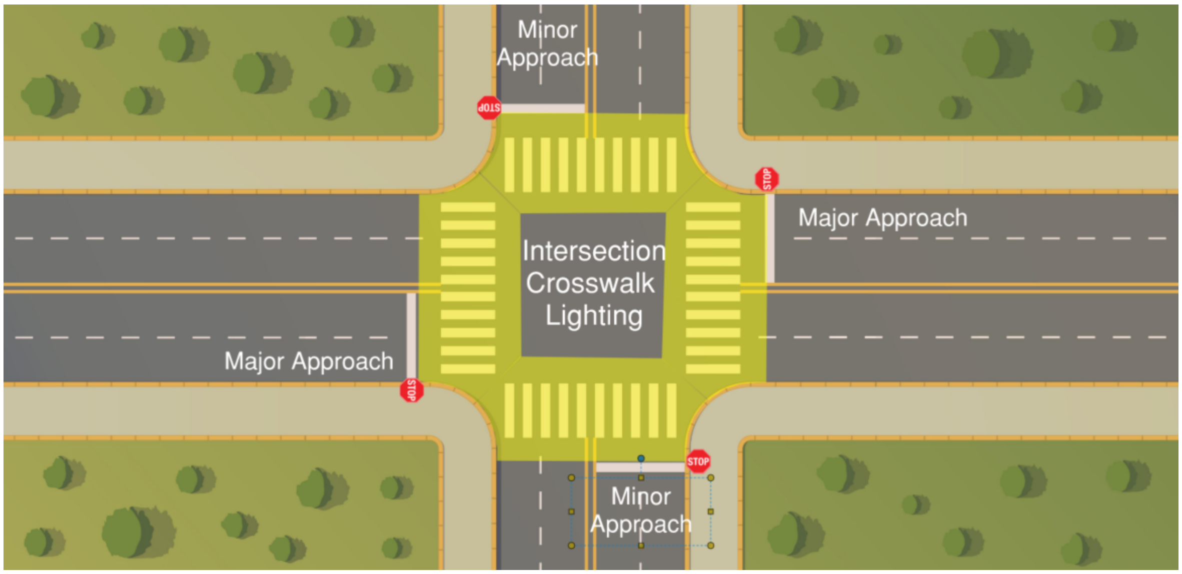


Figure 8-4. Illustration. Intersection Crosswalk Lighting.

Adjustment for Contrast. As seen in Fig. 7-1 through 7-4, *contrast* is the key to lighting pedestrian crosswalks for safety. A crosswalk needs to be able to stand out from the surrounding area, which for intersections are the Major and Minor Approach Roadways. If the existing roadway and/or intersection is lit to a level that is above the AASHTO fc levels, the fc level for the crosswalk shall be increased proportionately to ensure contrast is maintained. Once the *Intersection Lighting Classification* is identified, designers can utilize AASHTO to identify recommended average horizontal illuminance levels and uniformity for the intersection and/or the intersection's crosswalks.

Note: Full Intersection Lighting (with Continuous Lighting on One Approach) and Intersection Crosswalk Lighting are unique to MaineDOT. ANSI/IES RP-8-21's uses the definitions of Full Lighting (Continuous Lighting on Both Approaches), Partial Lighting, and Delineation Lighting. RP-8-21 does not discuss intersections with continuous lighting on one approach roadway. Unlike RP-8-21, MaineDOT does not use Delineation Lighting as a recommended approach for crosswalks. If a crosswalk has been identified to be lit, MaineDOT recommends that it be lit uniformly across the road to protect pedestrians approaching for either side.

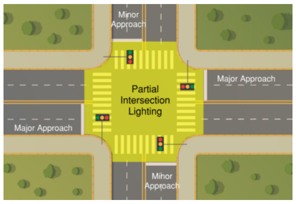
8.2. Horizontal Illuminance Design Criteria

MaineDOT recommends designers use AASHTO Roadway Lighting Design Guide Table 3-5a to determine the recommended illuminance levels for approach roadways, intersections, and pedestrian crosswalks at intersections. *(See Sec. 7.1)*

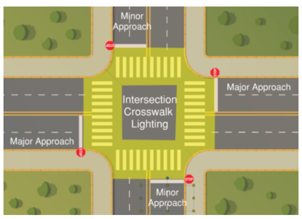
8.3. Horizontal Illuminance Calculation Grid

The geometry and characteristics of an intersection can vary greatly. They can vary in size, roadway surface, number of thru and turning lanes, presence of medians and islands, and number and angle of approach legs.

According to AASHATO's *A Policy on Geometric Design of Highways and Streets*, an intersection is defined as the general area where two or more streets cross, including the roadway and roadside facilities, for traffic movements within the area. The physical boundaries identified by a designer for the intersection's horizontal illuminance calculation grid can significantly affect on the average maintained horizontal illuminance and uniformity.



Full or Partial Intersection Lighting Horizontal Grid. MaineDOT recommends that the horizontal calculation grids for an intersection shall be based on the warranted Intersection Lighting Design Scenario. For Full or Partial Intersection Lighting Design Scenarios, the horizontal calculation grid shall include the intersection, the crosswalks, dedicated turning lanes separated by an island, and all areas up until the stop bars. Additional areas can be added for complex geometric configurations. Calculation points shall be placed 5' x 5' on center on the ground. *(See Fig. 7-8)*



Intersection Crosswalk Lighting Horizontal Grid. For Intersection Crosswalk Lighting, the width of the horizontal calculation grid shall include the crosswalk plus at least half the width of the crosswalk on either side and all area up until the stop bar. The length shall include the entire width of the crosswalk from curb to curb. If a sidewalk is present and sidewalk lighting is not provided, the calculation grid may extend onto the sidewalk for added safety. Islands and medians where pedestrians may travel shall be included in the horizontal calculation grid.

Figure 8-5. Illustration. Intersection of Main Street and Veterans Memorial Bridge Entrance Ramp in Lewiston, Maine. For Full Intersection lighting the horizontal calculation grid include the intersection, crosswalks, and all area up to the stop bars. If there is no stop bar present on an approach leg, engineering judgement shall be used to identify the intersection's boundary and any additional area to ensure the safety of pedestrians.

Note: Designers shall obtain approval from MaineDOT on the layout and boundaries of an intersection's horizontal calculation grid before proceeding with the design.

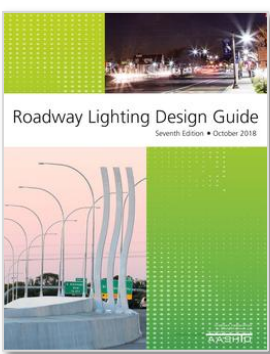
9. Intersection Research: Vertical Illuminance

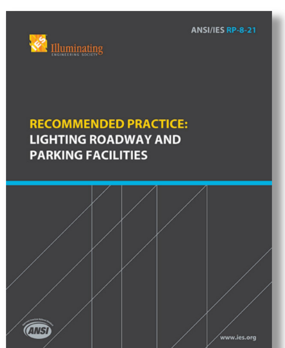
In addition to horizontal illuminance and uniformity within an intersection and its crosswalk, it is important to consider vertical illuminance within the crosswalk to enhance the contrast ratio between a pedestrian and their background. One of the first studies completed on the importance of vertical illuminance was published by FHWA in 2008 for midblock crosswalks, but this design method did not gain national recognition until recently due to the transportation industry's push toward Vision Zero. Vision Zero initiatives include adding proven safety countermeasures to eliminate pedestrian crashes within crosswalks, such as enhanced lighting at crosswalks.

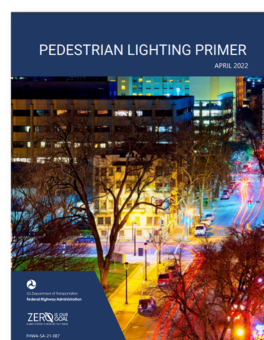
As part of the MaineDOT Pedestrian Lighting Study, the vertical illuminance design criteria within the following reports and guidelines were evaluated, compared to one another, and then modeled in AGi32 for practicality. The results of this study demonstrate the importance for designers to question recommendations mentioned in reference documents before blindly applying them, the importance for designers to make sure that the recommendations are being used in the correct context, and the ability for designers to adjust recommended levels as needed based on unique site conditions.

The following reference documents were evaluated by MaineDOT for the recommended vertical illuminance and uniformity within a crosswalk at intersections. In addition, a 2023 study was performed by MaineDOT regarding the practicality of the design criteria mentioned in these existing references. An explanation of the findings from each reference and the findings from the study follows, along with MaineDOT's recommended design criteria for vertical illuminance in intersection crosswalks. The references are listed here in chronological order.

- AASHTO. 2018. *Roadway Lighting Design Guide*. Washington D.C.: American Association of State Highway and Transportation Officials.
- ANSI/IES. 2021. *Recommended Practice for Design and Maintenance of Roadway and Parking Facility Lighting,* RP-8-21. New York, NY: Illuminating Engineering Society.
- VTTI 2021. *Roadway Lighting's Effect on Pedestrian Safety at Intersection and Midblock Crosswalks, Report No. FHWA-ICT-21-023*. Bhagavathula, Gibbons, and Kassing.
- FHWA. 2022. *Pedestrian Lighting Primer, Report No. FHWA-SA-21-087*. Washington D.C.: Federal Highway Administration Office of Safety.







9.1. AASHTO Design Criteria

The AASHTO *Roadway Lighting Design Guide* (2018) does not provide vertical illuminance design criteria for intersection crosswalks, but it does emphasize its importance. The AASHTO guide encourages pedestrians are to be rendered in a positive contrast by placing lighting poles along the approach, ahead of the crosswalk.

9.2. ANSI/IES Design Criteria

ANSI/IES RP-8-21 (2021) mentions the concept of vertical illuminance for pedestrians in several sections. Two sections are included referenced here, Sec. 12.3.1.4 and 12.5.2. In Section 12.3.1.4 IES emphasizes the importance of vertical illuminance for high pedestrian conflict areas and/or when there is full lighting on the approach legs. In Section 12.5.2 IES recommends the vertical illuminance level to equal the horizontal level.

- In <u>*Sec. 12.3.1.4 Crosswalks*, IES States the following</u>: *"While in most cases the recommended horizontal illuminance for an intersection can be achieved by using combination signal and luminaire poles, a key consideration is that this arrangement will not typically provide optimal vertical illuminance within the crosswalk area. For Intersections with high pedestrian conflict and/or full lighting on the approach roads, improving vertical illumination in the crosswalk should be considered. This can be accomplished by installing separate light poles in advance of the stop bars. This will improve the visibility of pedestrians in the crosswalk for motorists approaching an intersection."*

- In <u>*Sec. 12.5.2 Vertical Illuminance Recommendations*,</u> IES states the following: *"If vertical illumination is desired in crosswalks to improve pedestrian visibility, it is recommended that the maintained average vertical levels meet or exceed the maintained average horizontal levels for the intersection. For example, if the recommendations for the horizontal lighting levels at an intersection are 27 lux, then the vertical lighting level recommended in the crosswalk at a height of 1.5 m should be 27 lux or greater. It is recommended that the vertical illuminance grid be located at a height of 1.5 m (5 ft) along the centerline of the crosswalk, extend to the edge of the roadway, and have points spaced at 0.5 meters (1.65 ft) for each driving direction. The light meter should be pointed toward the approaching driver's eye height, assumed to be 1.5 m (5 ft) above grade."*

9.3. FHWA-ICT-21-023 Report

A study was recently completed by the Virginia Tech Transportation Institute (VTTI) on lighting at intersections and crosswalks. The report on the study was titled, *Roadway Lighting's Effect on Pedestrian Safety at Intersection and Midblock Crosswalks, Report No. FHWA-ICT-21-023* (Bhagavathula, Gibbons, and Kassing, 2021)

The study compared an intersection with four different lighting designs (i.e., placement of poles in relation to where pedestrians cross). Each lighting design was illuminated to three different levels (0.7 fc, 1.3 fc, and 2.2 fc). The study was performed on a singular intersection with no continuous lighting on the approach roadways (aka Partial Intersection Lighting).

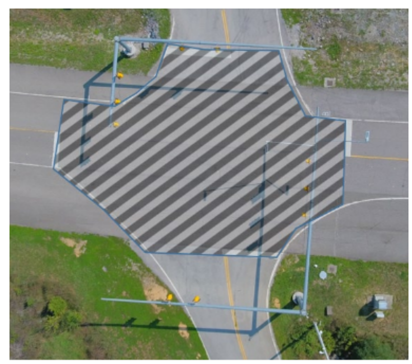


Figure 9-1. Illustration. Intersection that was used for the FHWA-ICT-21-023 Report.

- The results of the study concluded that luminaires mounted in the approach roadways ahead of the crosswalk created the greatest positive contrast on the pedestrian and achieved the highest level of sight detection for approaching drivers. This study reiterates the importance of designing vertical illuminance for crosswalks as previously mentioned by AASHTO and IES references.
- The results of the study determined that when both approach legs are not lit, there was no perceived benefit (aka increased sight detection distance for a driver) when the vertical illuminance on a pedestrian in a crosswalk was greater than 1 fc. As a vehicle approached a pedestrian (<100 ft), the headlights of the car took over and any benefit from vertical illuminance from roadway luminaires became insignificant.
- When the data from the VTTI study was identified further, it was noted that for the intersection design with pedestrian lighting placed ahead of the crosswalk, the ideal placement, the average vertical illuminance on the pedestrian in the crosswalk ranged from 53% to 60% of average the horizontal illuminance.

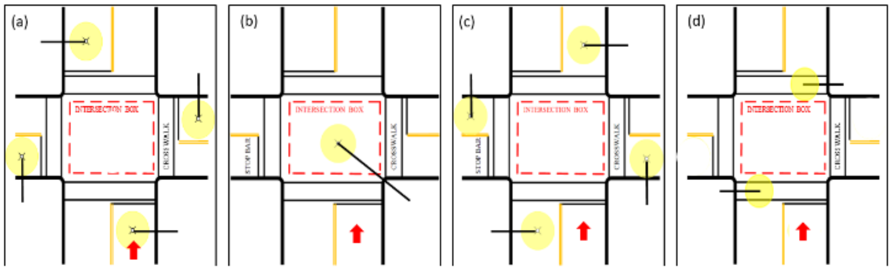


Figure 9-2. Illustration. Intersection lighting design evaluated in the FHWA-ICT-21-023 study. The intersection was illuminated with four lighting design configurations: (a) illuminated approach, (b) illuminated box, (c) illuminated exit, and (d) illuminated with luminaires on the signal mast arm. (FHWA-ICT-21-023, 2021)

Lighting Design	Light Level	Average Horizontal Illuminance lx (fc)	Maximum Horizontal Illuminance lx (fc)	Minimum Horizontal Illuminance lx (fc)	Average Vertical Illuminance at a height of 1.5 m (4.9 ft.) lx (fc)
Approach	Low	8 (0.7)	14.4 (1.3)	3.8 (0.4)	4.3 (0.4)
Approach	Medium	14 (1.3)	25.2 (2.3)	6.7 (0.6)	8.4 (0.8)
Approach	High	24 (2.2)	43.2 (4.0)	11.5 (1.1)	12.7 (1.2)
Box	Low	8 (0.7)	18.3 (1.7)	0.9 (0.1)	2.3 (0.2)
Box	Medium	14 (1.3)	29.5 (2.7)	1.3 (0.1)	3.8 (0.4)
Exit	Low	8 (0.7)	14.5 (1.3)	4.1 (0.4)	4.0 (0.4)
Exit	Medium	14 (1.3)	25.3 (2.4)	7.2 (0.7)	8.2 (0.8)
Exit	High	24 (2.2)	43.4 (4.0)	12.4 (1.2)	12.8 (1.2)
IDOT	Low	8 (0.7)	13.1 (1.2)	2.6 (0.2)	3.5 (0.3)
IDOT	Medium	14 (1.3)	22.9 (2.1)	4.6 (0.4)	6.3 (0.6)
IDOT	High	24 (2.2)	39.2 (3.6)	7.9 (0.7)	9.6 (0.9)

Figure 9-3. Table. Horizontal and Vertical Illuminance Levels at the Intersection. (FHWA-ICT-21-023)

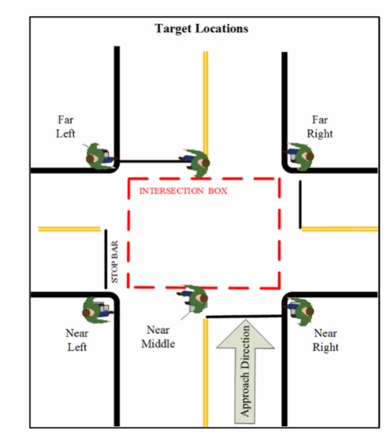


Figure 9-4. Illustration. Pedestrian locations used in the intersection detection task for the *FHWA-ICT-21-023* report. (FHWA-ICT-21-023)

9.4. FHWA Pedestrian Primer Design Criteria

The FHWA *Pedestrian Lighting Primer (2022)* is a newly published document that includes a wide array of terminology and recommendations for pedestrian lighting. For intersection crosswalks, the Primer discusses vertical average illuminance and CCT, but does not include horizontal illuminance or uniformity.

The Primer's recommended average vertical illuminance for an intersection crosswalk is a fixed level (30 lux vertical, 2.8 fc). If we apply the ANSI/IES *RP-8-21's* recommendation for the vertical illuminance in a crosswalk to meet or exceed the recommended maintained average horizontal illuminance levels for an intersection, a 2.8 fc vertical illuminance level is *very high*.

For example, when compared to AASHTO, 2.8 fc is equal to the recommended average horizontal illuminance for an intersection located in a Commercial Area with Minor Arterials as both approach legs (1.4 fc + 1.4 fc = 2.8 fc). *Therefore, the FHWA Primer's fixed recommended vertical illuminance level of 2.8 fc is ONLY appropriate for Full Intersection Lighting applications with continuous lighting along both approach legs, very high pedestrian volumes, and high background luminance. For all other applications the FHWA Pedestrian Lighting Primer recommended vertical illuminance level of 2.8 for intersections is extremely high and difficult for designers to comply with.*

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

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

Figure 9-5. Table. Recommended design criteria for pedestrian facilities (not required under FHWA regulations). Additional footnotes are not shown.
(FHWA Pedestrian Lighting Primer, Table 3. 2023.)

9.5. MaineDOT Vertical Illuminance Study

After an analysis and comparison of AASHTO, IES, VTTI, and FHWA references for vertical illuminance within a pedestrian crosswalk, MaineDOT modeled several existing intersections to help identify which reference's recommended vertical illuminance and uniformity was best suited for the intersection crosswalks in the state of Maine.

The results of one of the intersections studied, at Capitol Street and Sewell Street in Augusta, Maine, have been included in this guideline to represent the typical findings as a result of the MaineDOT study. The Halophane PUCL3 Lantern style luminaire was used for the study with Type 2 optics, 4000K, and various wattages, at a mounting height of 28'.

- **The AASHTO and IES horizontal design criteria are slightly different.** Both Capital Street and Sewell Street are classified as Minor Arterials, Commercial, with a Pavement of R2. Three of the four approach legs have continuous lighting. Therefore, Full Intersection Lighting is automatically warranted. Per AASHTO, the recommended average-maintained horizontal illuminance and uniformity for the intersection is 2.8 fc with a uniformity of 4:1. Per IES, the recommended average-maintained horizontal illuminance is 2.4 fc and uniformity of 3:1.
- **A luminaire on either side of the crosswalk is needed to achieve horizontal fc levels and uniformity.** Due to the geometry of the intersection, number of lanes, and the length of the crosswalks, a design that used four 58W LED luminaires, mounted at 28' and located near to stop bars ahead of the crosswalk was modeled and found to be unable to provide uniform lighting across the entire crosswalk. Next, a design that used eight 58W LED luminaires, mounted at 28' and located near the stop bars ahead of the crosswalk on either side of the roadway was modeled (to ensure positive contrast). The design with eight luminaires was able to achieve an average-maintained horizontal fc level of 2.52 and a uniformity of 3.1:1 across the entire intersection and its crosswalks. This design was within an acceptable range of the AASHTO and IES recommended horizontal design criteria.
- **The vertical illuminance levels were approximately 50% of the horizontal levels.** After a design for horizontal illuminance was established, the first four vertical calculation grids (for the thru lanes) were added to the center of each crosswalk at 5' above grade and aimed in the direction of the approach vehicle. The resulting vertical illuminance was similar to the findings of the 2021 VTTI study. The average

maintained vertical illuminance of all four grids was 1.04 fc, less than half of the horizontal illuminance (2.52). *(See Fig. 9-6)*

- **IES and FHWA recommended vertical illuminance levels were not achievable without over-designing the intersection.** IES RP-8-18 recommends the vertical fc levels be designed to equal the horizontal (between 2.4 fc and 2.8 fc). The FHWA Pedestrian Lighting Primer recommends the vertical illuminance be 3.0 fc. The intersection was re-modeled several times in an attempt to achieve the IES or FHWA recommended criteria. Using the same eight locations, the highest wattage LED luminaire offered by the manufacturer for the luminaire style was selected at 117W, approximately twice as much wattage as the original 58W design. Using the 117W LED luminaire, the study was only able to achieve an average vertical illuminance of 1.85 fc and the new horizontal illuminance level of the intersection was increased to 4.5 fc, nearly twice the recommended level.

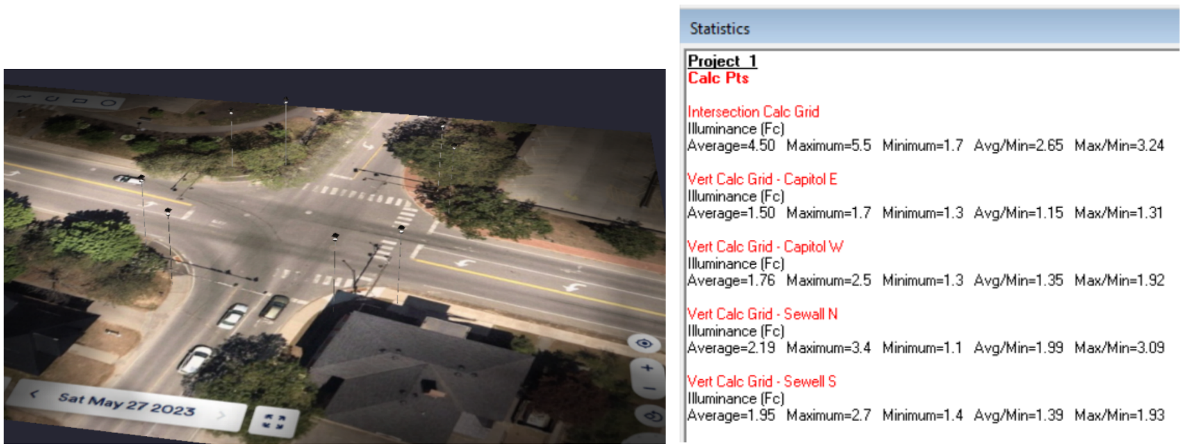


Figure 9-6. Rendering and statistics of an intersection modeled with eight 117W LED luminaires in an attempt to achieve the IES/ANSI RP-8-21 or FHWA Pedestrian Lighting Primer's recommended vertical illuminance of 2.8 fc. While the average vertical illuminance falls short of the 2.8 fc criteria, the average horizontal illuminance is unintentional altered from 2.5 fc to 4.5 fc.

10.Intersections: Vertical Illuminance – MaineDOT Design Criteria

10.1. Vertical Design Criteria

When it comes to vertical illuminance, one fc level does not fit all applications. The key to increasing pedestrian safety in a crosswalk is to provide enough uniform vertical illumination on a pedestrian before the approaching vehicle's headlights are able to take over. By *pre-lighting* a pedestrian along the entire length of a crosswalk, the amount of time a driver has to detect a pedestrian in the crosswalk increases, which allows for a longer distance for a driver to react. Once the driver reaches the crosswalk, the illumination provided by the roadway lighting is negligible compared to the illumination provided by a vehicle headlights.

Maine DOT recommends that the average maintained vertical illuminance for a crosswalk in an intersecton is designed to be at least 1.0 fc. Levels above 1.0 fc are allowed, but they may not provide any additional safety benefit for pedestrians. For intersections with mutliple crosswalks, the lowest average maintained vertical illuminance for any individual crosswalk shall be at least 1.0 fc.

10.2. Vertical Calculation Grids

The recommended location and quantity of vertical calculation grids for a crosswalk vary depending on the geometry of the intersection and the location of pedestrian crosswalks. MaineDOT completed a study in 2023 to identify the recommended vertical calculation grid length, quantity per approach, and meter aiming direction.

Grid Placement. All vertical illumination design methods place the calculation grid in the center of the crosswalk, at a height of 5 ft above grade, with points spaced no greater than 2 ft on center. All points in each grid shall be aimed in the direction of the oncoming vehicle.

Grid Quantity. The exact quantity of vertical calculation grids required for an intersection shall be based on the physical geometry of each intersection, type of lanes, quantity of lanes, presence of medians or islands, and the location of crosswalks. In general, there are three types of vertical grids for crosswalks. One grid for the through lanes, one grid for right turn lanes, and one grid for left turn lanes. We call this the *3-Grid Approach Method (See Fig. 10-1).* The grid for the through lanes may be broken up into two separate grids for wider intersections.

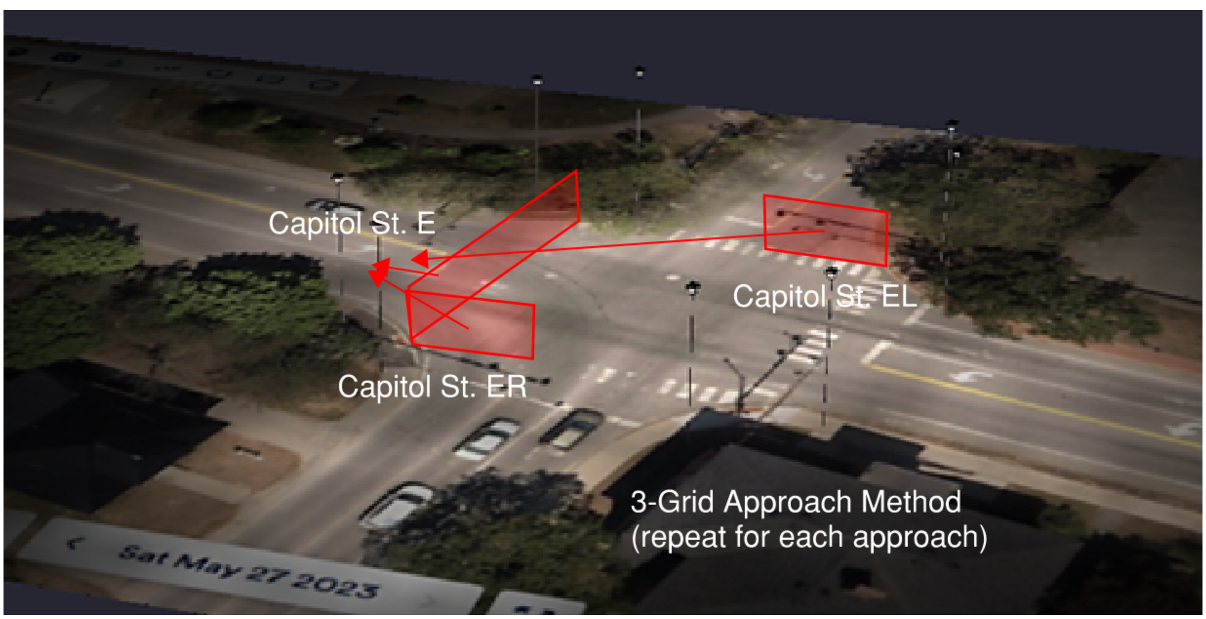


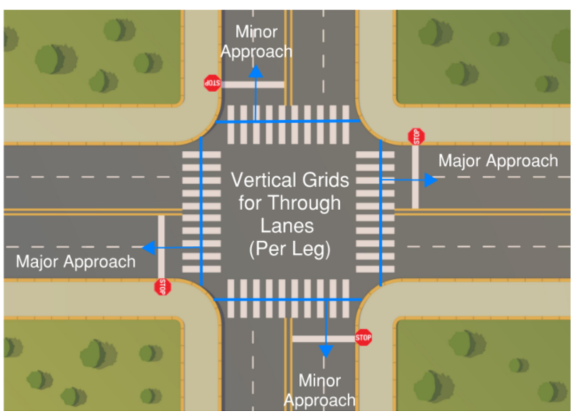
Figure 10-1. Illustration. Isometric Illustration of the 3-Grid Approach method for one leg of an intersection.

- **Grid 1. Vertical Grid per Thru Lane.**

  Vertical Grid per Thru Lane (per Leg). For this calculation method, the vertical Illuminance grid shall extend the width of both the approach lanes and oncoming lanes (i.e., from access ramp to access ramp) representing a pedestrian as they walk across the entire leg of the intersection. This method shall be used for roadways with one or two lanes of traffic in either direction, or one lane in each direction with parking along either side. Although the grid crosses both approach and exit lanes, the virtual light meter shall be aimed in the geographic middle of the approach roadways.

  Vertical Grid per Thru Lane (per Approach Lanes). For this calculation method, the vertical Illuminance grid shall only extend the width of the approach's through lanes (from access ramp to center of roadway), representing a pedestrian as they walk across half of the road. This method shall be used for roadways wider than two lanes in either direction. The virtual meter shall be aimed in the geographic middle of the approach roadways. If there is no crosswalk along the immediate approach, a crosswalk along the opposite side of the intersection may be used.

- **Grid 2. Vertical Grid per Right Turn.** For this calculation method, the vertical illuminance grid shall extend from the access ramp and then along the length of the crosswalk onto which the vehicle is making a right turn. The virtual meter shall be aimed in the geographic middle of the approach's right turn lane.
- **Grid 3. Vertical Grid per Left Turn.** For this calculation method, the vertical illuminance grid shall extend from the access ramp and then along the length of the crosswalk onto which the vehicle is making a left turn. The virtual meter shall be aimed in the geographic middle of the approach's left turn lane.



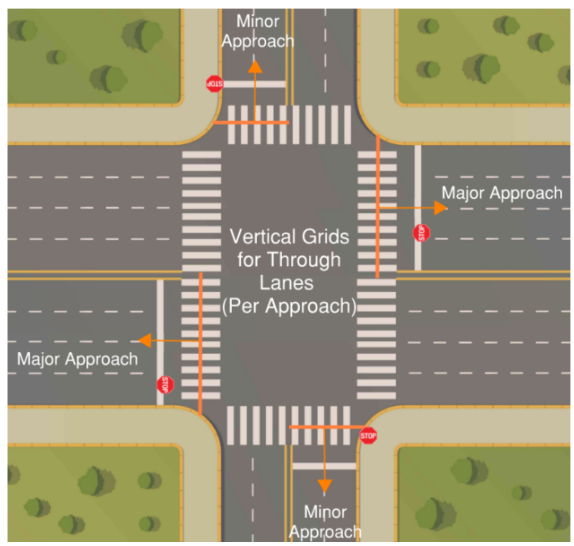


Figure 10-2. Illustration. Vertical Grid per Thru Lanes. (Left) Grid width per entire leg. (Right) Grid width per approach lanes only.

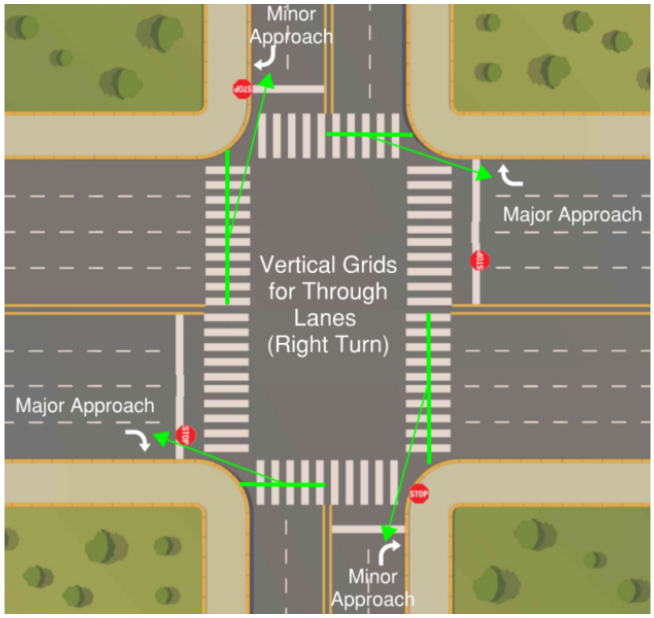


Figure 10-3. Illustration. Vertical Grids per Right Turn.

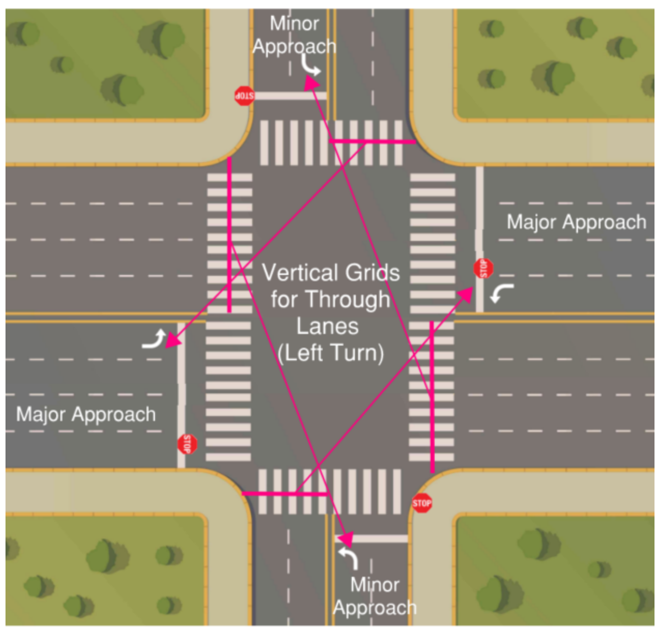


Figure 10-4. Illustration. Vertical Grids per Left Turn.

Adjusted Vertical Illuminance. The required average maintained vertical illuminance level for a pedestrian in a crosswalk may increase based on the background luminance. For a Partial Intersection Lighting application in a rural area where the background luminance level is very low, an average maintained vertical illuminance of 1.0 fc may be all that is needed. For a Full Intersection Lighting application with high background luminance, an average maintained vertical illuminance of 2 fc may be needed to provide the visual contrast for a pedestrian to stand out from their surroundings.

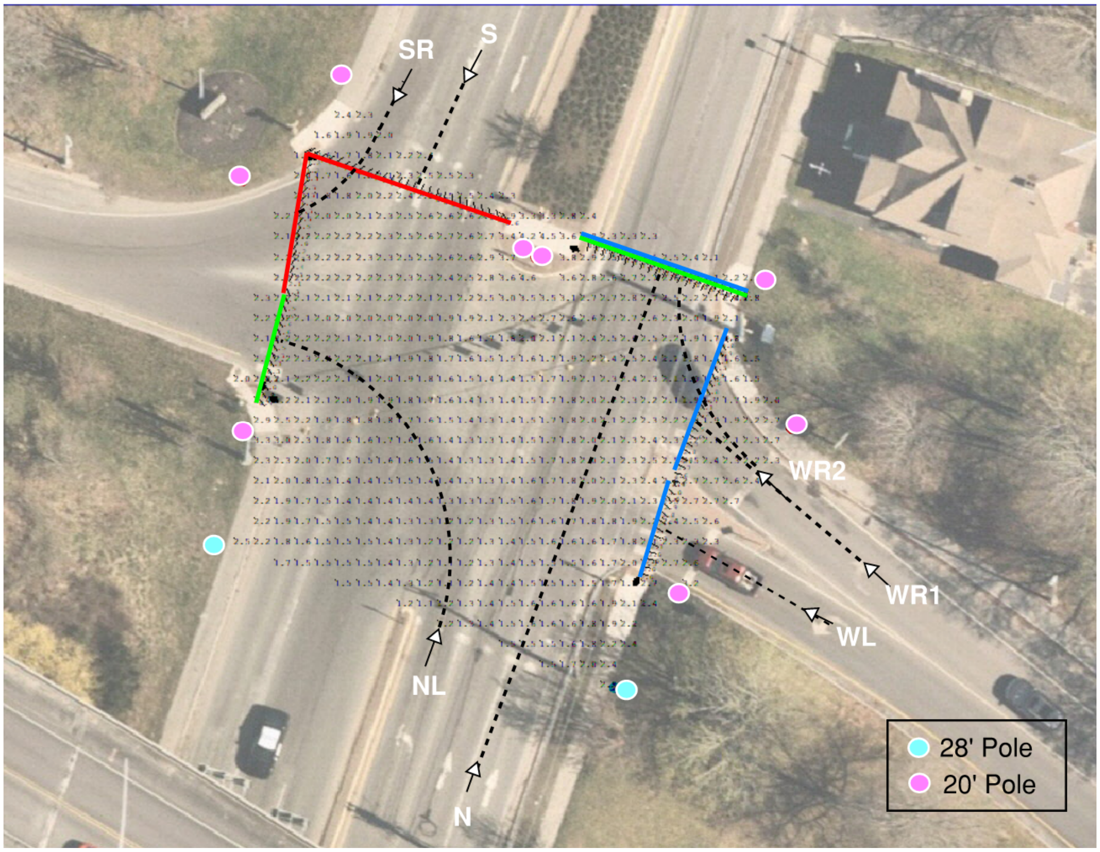
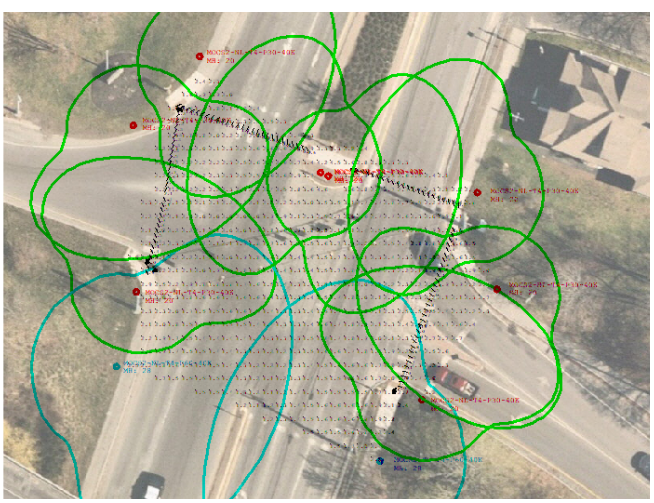


Figure 10-5. Illustration. Vertical calculation grids for Main Street (N, NL, S, SR) and the exit ramp from Veterans Memorial Bridge (WL, WR1, WR2). This is a unique intersection requiring a total of 7 vertical calculation grids based on the location of the crosswalks, one-way and two-way roadways, island, medians, dedicated left turn lanes, and dedicated right turn lanes.



Statistics

Project_1
Calc Pts

Horizontal Calc Grid
Illuminance (Fc)
Average=2.02 Maximum=4.6 Minimum=1.1 Avg/Min=1.84 Max/Min=4.18

Vertical Grid N
Illuminance (Fc)
Average=1.06 Maximum=1.3 Minimum=0.9 Avg/Min=1.18 Max/Min=1.44

Vertical Grid NL
Illuminance (Fc)
Average=1.32 Maximum=1.6 Minimum=0.9 Avg/Min=1.47 Max/Min=1.78

Vertical Grid S
Illuminance (Fc)
Average=1.02 Maximum=1.5 Minimum=0.6 Avg/Min=1.70 Max/Min=2.50

Vertical Grid SR
Illuminance (Fc)
Average=1.64 Maximum=2.4 Minimum=1.1 Avg/Min=1.49 Max/Min=2.18

Vertical Grid W
Illuminance (Fc)
Average=2.47 Maximum=3.0 Minimum=2.0 Avg/Min=1.24 Max/Min=1.50

Vertical Grid WR1
Illuminance (Fc)
Average=1.97 Maximum=2.8 Minimum=0.7 Avg/Min=2.81 Max/Min=4.00

Vertical Grid WR2
Illuminance (Fc)
Average=1.28 Maximum=1.8 Minimum=0.5 Avg/Min=2.56 Max/Min=3.60

Figure 10-6. Illustration. The intersection of Main Street and Veterans Memorial Bridge in Lewiston, Maine.

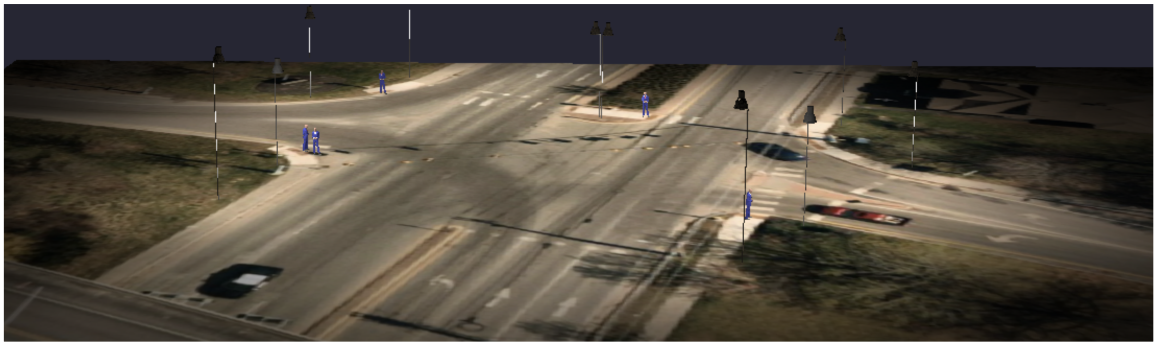
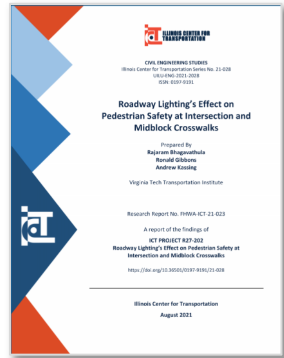


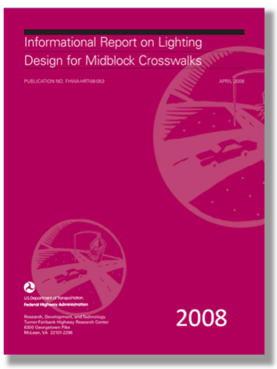
Figure 10-7. Rendering. The intersection of Main Street and Veterans Memorial Bridge in Lewiston, Maine. Due to the unique geometry of this intersection, there are 7 vertical illuminance grids required. The location and quantity of vertical calculation grids shall be based on the needs of each individual intersection and the flow of traffic.

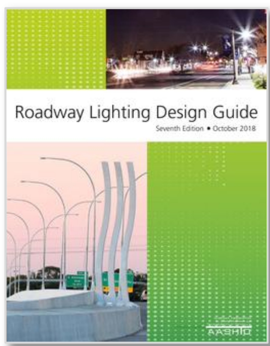
11.Midblock Crosswalk Research: Horizontal & Vertical Illuminance

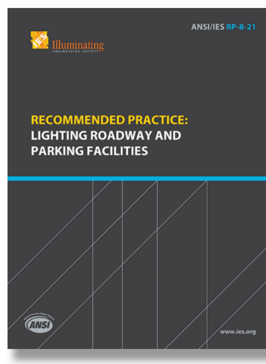
The following reference documents were evaluated by MaineDOT for the recommended horizontal illuminance, vertical illuminance, and uniformity within a midblock crosswalk. In addition, a 2023 study was performed by MaineDOT regarding the practicality of the design criteria mentioned in these existing references. An explanation of the findings from each reference and the findings from the study follows, which has been used to identify MaineDOT recommended design criteria. The references are listed here in chronological order.

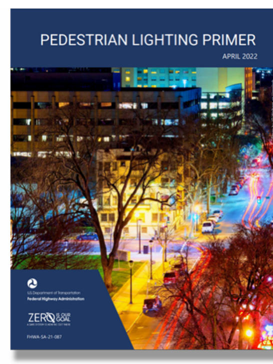


- FHWA 2008. *Informational Report on Lighting Design for Midblock Crosswalks, FHWA-HRT-08-053*
- AASHTO 2018. *Roadway Lighting Design Guide*.
- ANSI/IES 2021. *Recommended Practice for Design and Maintenance of Roadway and Parking Facility Lighting,* RP-8-21.
- FHWA 2022. *Pedestrian Lighting Primer*
- VTTI 2021. *Roadway Lighting's Effect on Pedestrian Safety at Intersection and Midblock Crosswalks, FHWA-ICT-21-023*









11.1. FHWA/VTTI Report FHWA-HRT-08-053 Design Criteria

The 2008 FHWA *Informational Report on Lighting Design for Midblock Crosswalks*, FHWA-HRT-08-053 was one of the first comprehensive studies on the recommended lighting design criteria for midblock crosswalks. The study was performed in 2008 by FHWA and VTTI, before the universal adoption of LED for roadway lighting in lieu of HPS and MH. The findings and recommendations of the study are as follows:

- A vertical illuminance level of 20 lx (2.0 fc) measured at 1.5 m (5 ft) from the road surface allowed drivers to detect pedestrians in midblock crosswalks at adequate stopping distances under rural conditions. This references a roadway that does not have uniform, continuous lighting along the approach in either direction.
- A higher level of vertical illuminance might be required for crosswalks if there is a possibility of glare from opposing vehicles, located in an area with high ambient light levels.
- The report does not discuss horizontal illuminance in a crosswalk.

11.2. AASHTO Design Criteria

Although AASHTO *Roadway Lighting Design Guide, 7th Edition* does not specifically discuss how to illuminate a midblock crosswalk, but AASHTO does provide recommend horizontal illuminance and uniformity for the roadway's classification, which is useful for the basis of midblock crosswalk design.

11.3. ANSI/IES Design Criteria

For the design of midblock crosswalks, *ANSI/IES RP-8-21 Section 12.5.1* references the findings of the FHWA/VTTI 2008 *International Report on Lighting Design in Midblock Crosswalks. In Section 12.6 Midblock Crosswalks,* IES discusses the need for positive contrast on a pedestrian and provides one example of the positive contrast that was created by placing a pole 5m (15 ft) ahead of the crosswalk. The recommendations from IES for midblock crosswalks are sporadic and pop up in various sections throughout the document. The following are excerpts and a summary of the ANSI/IES RP-8-18 recommendations for midblock crosswalk lighting.

- In Section *12.6.2.1* IES emphasizes the need for coordinating the lighting design of midblock crosswalks with other elements that may limit pole placement and mounting height such as roadway geometry, overhead structures, sidewalks, bikeways, street furniture, signage, traffic signals, underground and overhead utilities.
- In *Section 11.7.1* IES states "*for this recommended practice, luminance is the selected design method for straight highways and streets; horizontal and vertical illuminance comprise the selected method for pedestrian areas, and horizontal illuminance is used for intersections and interchanges."*
- In Section 12.6.3.1 IES recommends the horizontal *luminance* on the roadway for the midblock crosswalk shall meet or exceed the recommended IES luminance levels of the roadway. *Note: The use of luminance as a metric for pedestrian crosswalk applications is not recommended by the lighting industry.*
- In *Section 12.6.3.2* IES states "*research shows that maintained average vertical illuminance in crosswalks of 20 to 40 lux (2.0 to 4.0 fc) will benefit visibility of the pedestrian. Research is ongoing as to what is the optimal level. It is recommended the designer consider a level of 20 lux (2.0 fc) for areas with low pedestrian conflict, 30 lux for areas with medium pedestrian conflict, and 40 lux (4.0 fc) for areas with high pedestrian conflict."*
- In *Section 12.6.4* IES explains the "design calculations of midblock crosswalks may include both vertical illuminance calculations within the crosswalk and luminance calculations along the approach roadway if it is continuously lighting. If the roadway approaching the crosswalk is not lighted, luminance calculations are not required.
- The IES does not discuss horizontal illuminance design criteria for midblock crosswalks.

11.4. FHWA Pedestrian Primer Design Criteria

The newest document released by FHWA is the 2023 *Pedestrian Lighting Primer,* and it appears to default to the recommendations originally outlined in the 2008 FHWA *Informational Report on Lighting Design for Midblock Crosswalks* for average illuminance with a midblock crosswalk of 20 lux. Designers should note that the primer misuses the IES *RP-8-21's* recommendation for average luminance in their table. The average luminance IES recommends for a midblock crosswalk is for a uniformly, continuously lit straight roadway approaching the

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

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

Figure 11-1. Table. Recommended design criteria for pedestrian facilities (not required under FHWA regulations). Additional footnotes are not shown. *(FHWA Pedestrian Lighting Primer, Table 3. 2023.*

midblock crosswalk, not the crosswalk itself. The Primer does not discuss horizontal illuminance within the crosswalk.

11.5. FHWA/VTTI FHWA-ICT-21-023 Design Criteria

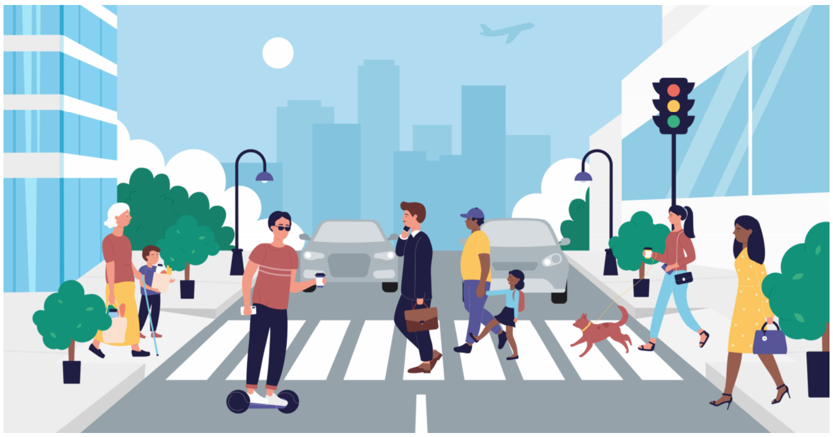
The results of the 2021 FHWA/VTTI Report titled *Roadway Lighting's Effect on Pedestrian Safety at Intersection and Midblock Crosswalks* recommend the following design criteria for midblock crosswalks.

- Illuminated to an average vertical illuminance of 10 lux (0.9 fc) to ensure optical visibility of pedestrians.
- Where overhead lighting is available, midblock crosswalk lighting designs that render the pedestrian in a positive contrast are recommended to increase pedestrian visibility.
- Locate luminaires in front of the crosswalk to ensure pedestrians are rendered in positive contrast.
- Pedestrian crossing treatments like rectangular rapid flashing beacons, flashing signs, etc. should be used in conjunction with overhead lighting or crosswalk illuminators at the established vertical illuminance to ensure optimal pedestrian visibility at midblock crosswalks.
- Higher light levels than 1.0 lux (0.9 fc) at midblock crossings, when the approach road is not continuously lit, did not significantly increase the driver's ability to detect pedestrians.

12.Midblock Crosswalks – MaineDOT Design Criteria

12.1. Horizontal and Vertical Illuminance

Currently, neither of the five existing roadway lighting design references mentioned in the previous section covers horizontal illuminance for midblock crosswalks. Instead, they focus on vertical illuminance in the crosswalk and the luminance of the roadway. However, the lighting industry is moving away from luminance as a metric for roadways due to its inability to represent real-world conditions, and the luminance method has never been considered appropriate for pedestrian areas. All references emphasize the importance of positive contrast for the pedestrian. MaineDOT recommends that midblock crosswalks be designed using both vertical and horizontal illuminance design criteria. The recommendation varies if the approach roadway is unlit or continuously lit.



Horizontal Illuminance. MaineDOT recommends the average maintained horizontal illuminance for a midblock crosswalk to be based on the AASHTO Table 3-5a for the functional classification, area classification, and pavement classification of the roadway. The horizontal illuminance level shall vary depending if whether the approach roadway is uniformly lit.

- **Unlit Approach Roadway.** For this application, the recommended average maintained horizontal illuminance for the midblock crosswalk shall be equal to the AASHTO recommended illuminance and uniformity for the roadway.
- **Continuous Lighting along Approach.** For this application, the recommended average maintained horizontal illuminance for the midblock crosswalk shall be at least 50% greater than the AASHTO recommended illuminance for the roadway to ensure contrast and equal to the AASHTO recommended uniformity ratio for the roadway.
- **Adjustment for High Existing Illuminance Levels.** If the continuous lighting along the approach provides an illuminance level above the AASHTO recommended illuminance, the actual field measured level shall be used as the baseline and the average maintained horizontal illuminance for the midblock crosswalk shall be at least 50% greater.

Vertical Illuminance. MaineDOT recommends the average maintained vertical illuminance for a midblock crosswalk to be based on the recent VTTI study to avoid over lighting, especially in rural areas. However, the horizontal illuminance level may vary depending on the existing conditions.

- **Unlit Approach Roadway)** For this application, MaineDOT recommends the average maintained vertical illuminance for the midblock crosswalk shall be at least 1.0 fc with a uniformity ratio of 4:1 or better.
- **Continuous Lighting along Approach.** For this application, MaineDOT recommends the average maintained vertical illuminance for the midblock crosswalk to also be 1.0 fc with a uniformity ratio of 4:1 or better.
- **Adjustment for High Existing Illuminance or Luminance Levels.** If the continuous lighting along the approach provides an illuminance level above the AASHTO recommended illuminance, or there is a high

level of background luminance, the recommended the average maintained vertical illuminance for the midblock crosswalk may be increased to 2.0 fc with a uniformity ratio of 4:1 or better.

12.2. Horizontal Calculation Grid

The horizontal illumination calculation grid recommended by MaineDOT for midblock crosswalks shall be a polygon that includes the crosswalk and half the width of the crosswalk on either side. If a sidewalk is present, and not lit by other methods, the horizontal calculation grid may extend the width of the sidewalk as well to provide surround light for added safety. Calculation points shall be spaced no greater than 5’ x 5’ on center and the grid shall be placed on the road surface. The light meter shall be aimed perpendicular to the surface.

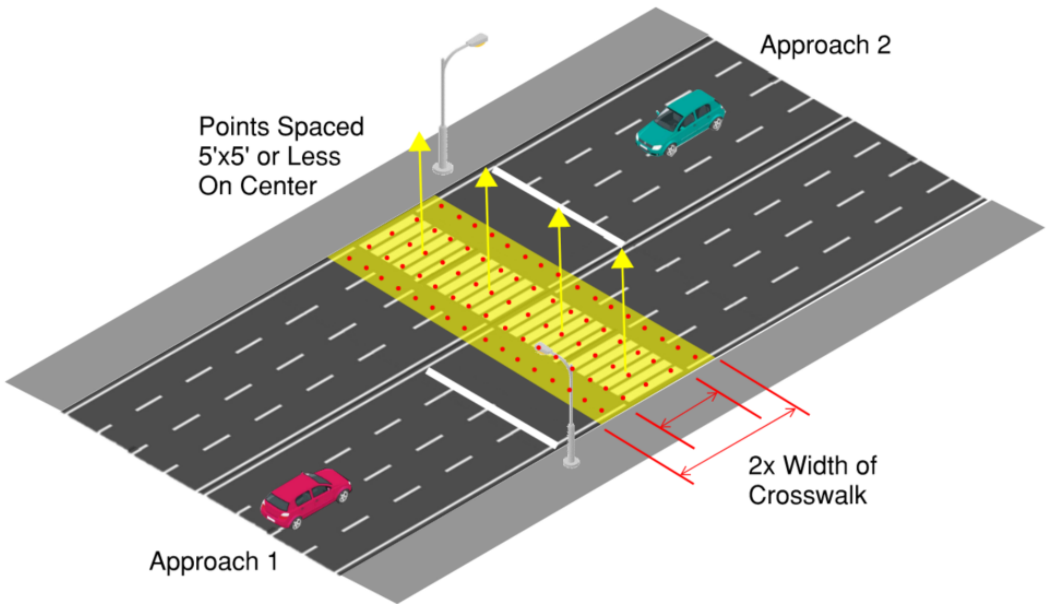


Figure 12-1. Illustration. Horizontal illumination calculation grid.

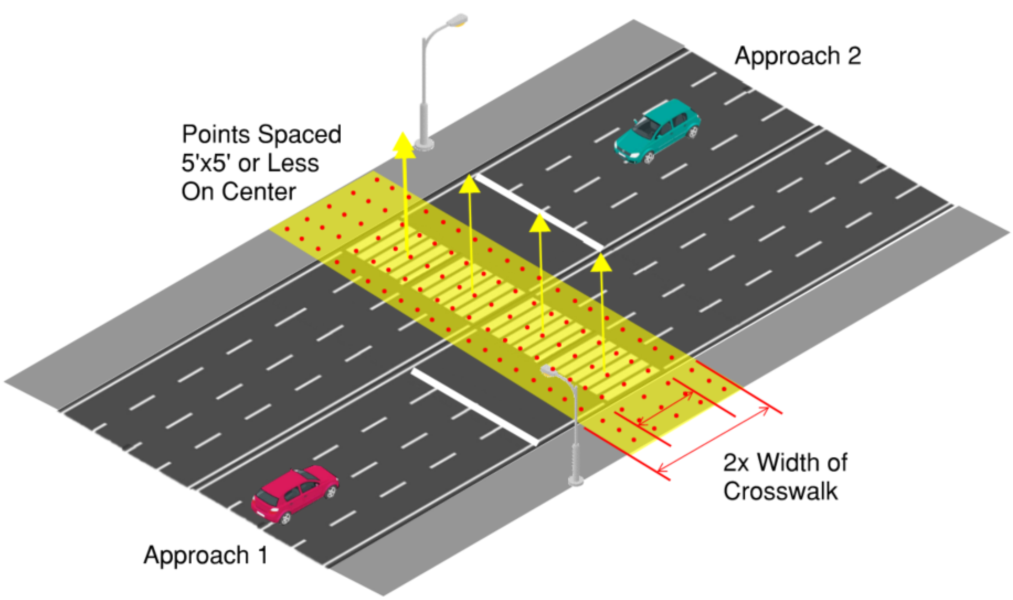


Figure 12-2. Illustration. Horizontal illumination calculation grid extended onto sidewalk for added safety.

12.3. Vertical Calculation Grid

The vertical illumination calculation grid recommended by MaineDOT for midblock crosswalks shall be a horizontal line that is placed in the center of the crosswalk, 5’ above grade, with points spaced no greater than 2’ on center. The light meter shall be aimed in the direction of the approach vehicle at a distance that is equal to one safe stopping distance based on the design speed of the roadway (5mph above the posted speed). One grid shall be used for each direction of traffic. The width of the vertical illuminance grid depends on the number of lanes in the roadway.

Narrow Roadways. This option shall be used for roadways with 1 to 2 lanes in either direction. These lanes can be traveling lanes or parking. One vertical illuminance calculation grid shall be used for each approach, and it shall extend the entire width of the roadway from curb to curb.

Wide Roadways. This option shall be used for roadways with 3 or more lanes in either direction. The lanes can be traveling lanes or parking. One vertical illuminance calculation grid shall be used for each approach; however, it shall only extend the width of the approach lanes.

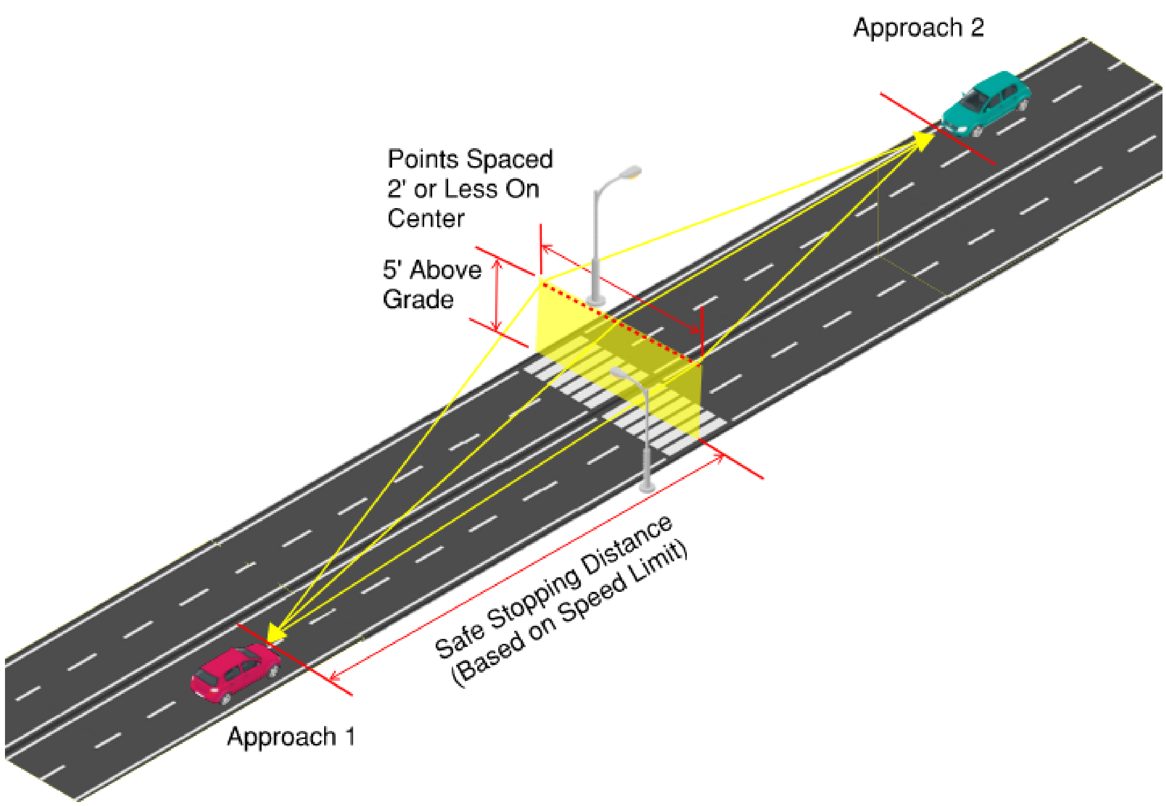


Figure 12-3. Illustration. One vertical illuminance calculation grid across the entire roadway for each approach.

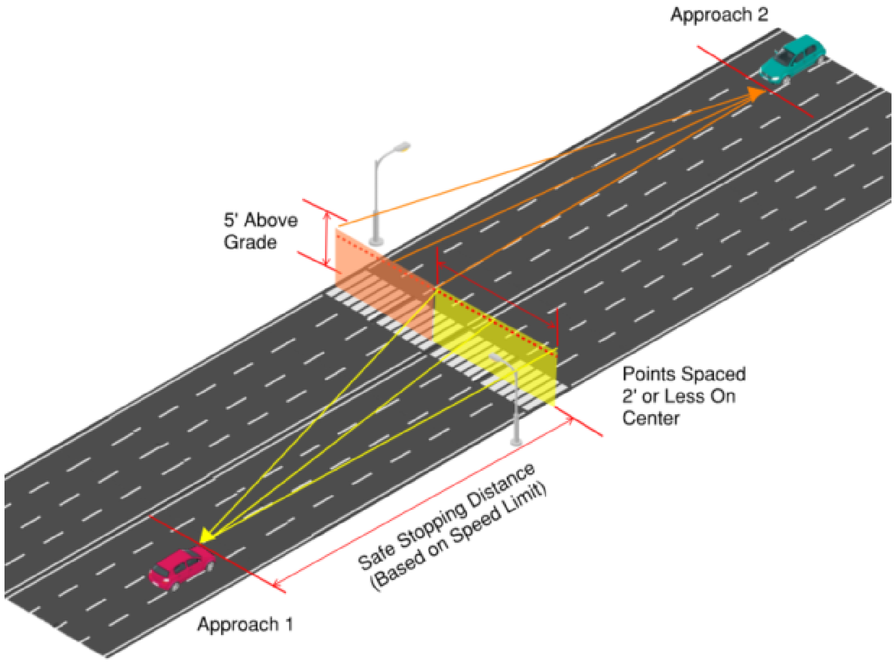


Figure 12-4. Illustration. One vertical illuminance calculation grid across only the approach lanes for wider roadways.

Table 3-1. Stopping Sight Distance on Level Roadways

U.S. Customary

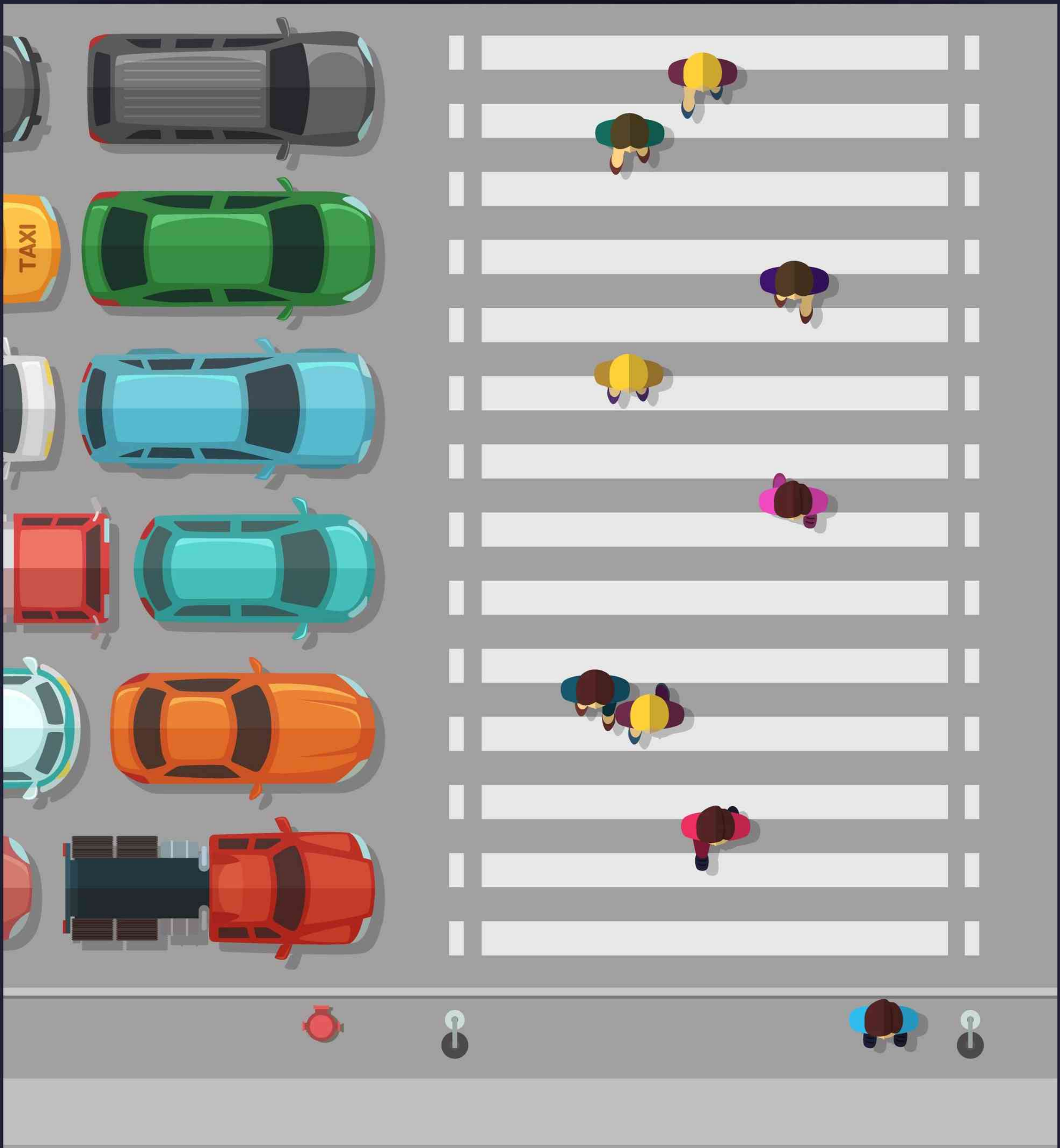
Design Speed (mph)	Brake Reaction Distance (ft)	Braking Distance on Level (ft)	Stopping Sight Distance Calculated (ft)	Stopping Sight Distance Design (ft)
15	55.1	21.6	76.7	80
20	73.5	38.4	111.9	115
25	91.9	60.0	151.9	155
30	110.3	86.4	196.7	200
35	128.6	117.6	246.2	250
40	147.0	153.6	300.6	305
45	165.4	194.4	359.8	360
50	183.8	240.0	423.8	425
55	202.1	290.3	492.4	495
60	220.5	345.5	566.0	570
65	238.9	405.5	644.4	645
70	257.3	470.3	727.6	730
75	275.6	539.9	815.5	820
80	294.0	614.3	908.3	910
85	313.5	693.5	1007.0	1010

Metric

Design Speed (km/h)	Brake Reaction Distance (m)	Braking Distance on Level (m)	Stopping Sight Distance Calculated (m)	Stopping Sight Distance Design (m)
20	13.9	4.6	18.5	20
30	20.9	10.3	31.2	35
40	27.8	18.4	46.2	50
50	34.8	28.7	63.5	65
60	41.7	41.3	83.0	85
70	48.7	56.2	104.9	105
80	55.6	73.4	129.0	130
90	62.6	92.9	155.5	160
100	69.5	114.7	184.2	185
110	76.5	138.8	215.3	220
120	83.4	165.2	248.6	250
130	90.4	193.8	284.2	285
140	97.3	224.8	322.1	325

Note: Brake reaction distance predicated on a time of 2.5 s; deceleration rate of 11.2 ft/s² [3.4 m/s²] used to determine calculated sight distance.

Figure 12-5. AASHTO Safe Sight Distance on a Level Road. (AASHTO…)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