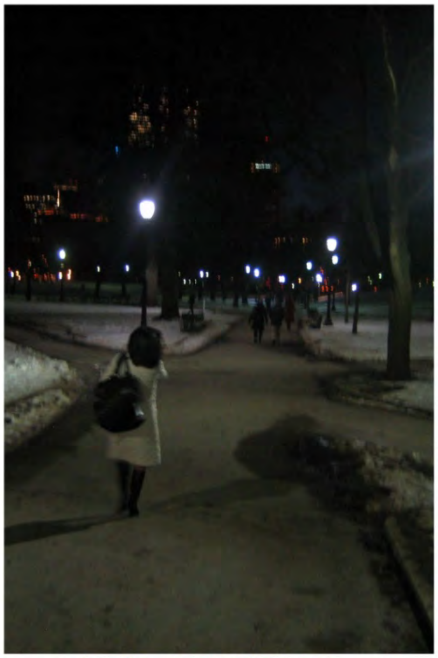
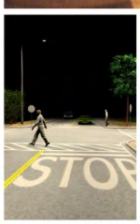


Vermont Agency of Transportation

Lighting Design Guide

2015





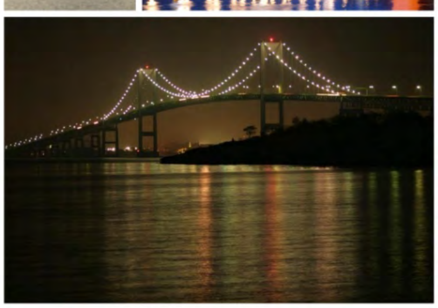
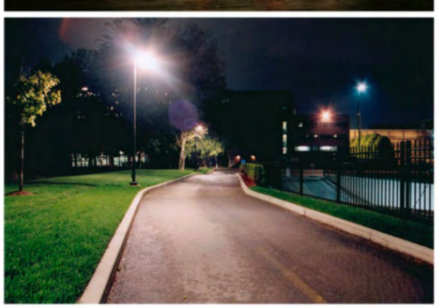





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TABLE OF CONTENTS

DESIGN REQUIREMENTS

EXAMPLE DESIGN

Purpose and Policy

This section describes the benefits of roadway lighting as well as VTRANS policy relating to it.

GENERAL

Purpose

Driving or walking on, or across, a roadway in darkness poses a much greater risk than doing so during the day. Though the number of fatal crashes in daylight versus darkness is about the same, only 25 percent of vehicle-miles traveled occur at night. Because 55 percent of fatalities occur at night, the nighttime fatality rate is three times the daytime rate. Figure 1 provides a graphic illustration of this.

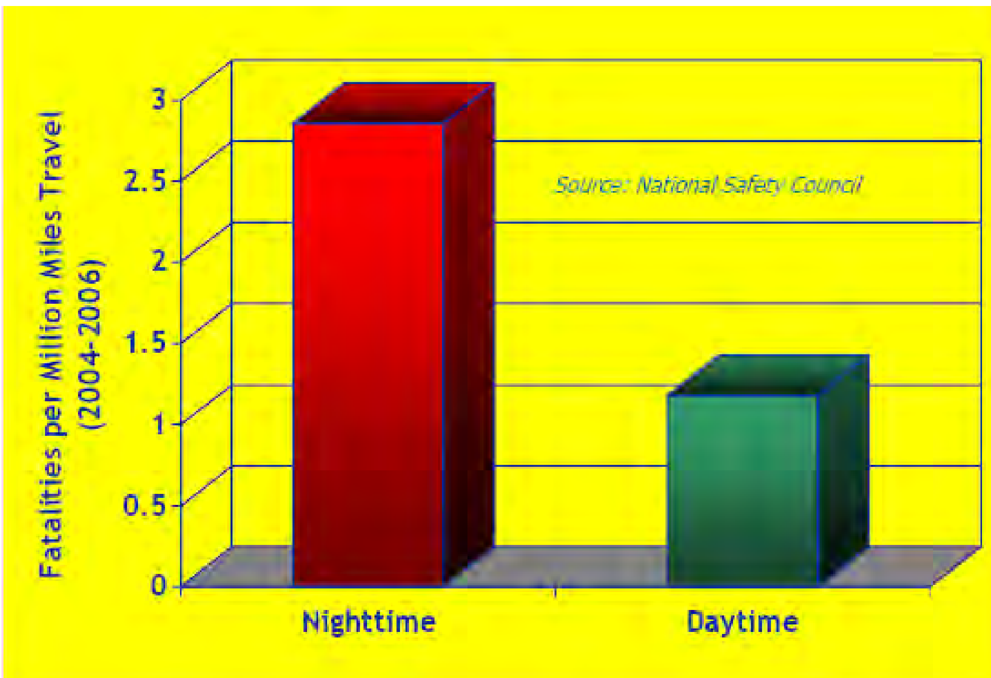


Figure 1: Fatal crash rates for day and night. (Source: National Safety Council)

On a fundamental level, driving is predominantly a visual task. Being able to adequately see the road/street ahead and conflicting traffic and other highway users is integral to the driving task. Lighting significantly improves the visibility of the roadway, increases sight distance and makes roadside obstacles more noticeable to the driver and therefore more avoidable. Roadway lighting is a known and proven safety countermeasure. The positive safety effects of lighting have been documented in various reports or publications. For example, an FHWA/AASHTO international scan documented (1) that many countries showed a 20 to 30 percent reduction in the number of crashes when lighting was installed. Based on a 1996 FHWA annual report for the Highway Safety Improvement Program, the New York Times on March 27, 1998 (2) reported that installing lighting as a safety improvement had the highest benefit/cost ratio of all safety improvements. It was reported that roadway lighting had a benefit cost ratio of 26.8 in an analysis of fatality and injury reduction in vehicle crashes in the 20 year time period between 1974 and 1995. More recently, the FHWA Signalized Intersection Informational Guide (3) reported that adding lighting can reduce nighttime crashes by 50 percent and reduce fatal crashes by 43 percent. There have been many other studies that document similar safety benefits of lighting.

Beyond the traffic safety benefits, lighting also helps with personal security. Roadway lighting often serves the dual and intended purpose of providing a sense of personal safety to pedestrians, bicyclists, and transit users as they travel along and across roadways. Where deep shadows or darkness prevail, a sense of personal security is threatened and walking and bicycling or other desired social and economic activities may become uncomfortable or dangerous. Thus, the preservation of the integrity of the lighting to provide minimum acceptable levels of illumination, for safety and functions, is of great importance to all users of a roadway environment.

Some useful research discussing the effects of road lighting on safety and driver performance include:

- Elvik and Vaa (2004) reviewed 38 studies comparing the impact of lighting on previously unlit roads and found a 64% reduction of fatal accidents, 28% reduction in injury accidents, and 17% reduction in property damage only accidents for lit roadways.
- Per Ole Wanvik (2009) used various study methods and literature review to determine the usefulness of road lighting as a countermeasure and found based on a review of earlier studies that the mean effect of roadway lighting is a 28% reduction in injury accidents, a 60% reduction in fatal accidents, a 45% reduction in injury accidents involving pedestrians, a 35% reduction in injury accidents at rural intersections, and a 50% reduction in injury accidents on freeways.
- Lipinski and Wortman (1976) showed a 45 percent reduction in the night accident rate at rural at grade intersections.
- Walker and Roberts (1976) found a 52% reduction in nighttime accidents at 47 intersections in a 6 year before and after study.
- Minnesota Local Road Research Board (2004) comparing rural intersection locations before and after lighting had been installed indicated that 44% of the intersections showed a reduction in the number of nighttime crashes after lighting was installed.

Technical References

The following references were used in the development of this guidance document, including supplemental information which should be considered in the design and construction of a roadway lighting system.

AASHTO GL-6 Roadway Lighting Design Guide (www.transportation.org)

ANSI/IES RP-8 Standard Practice for Roadway Lighting (www.ies.org)

ANSI/IES RP-22 Standard Practice for Tunnel Lighting (www.ies.org)

IES DG-19 Design Guide for Roundabout Lighting (www.ies.org)

AASHTO RSDG-3 Roadside Design Guide (www.transportation.org)

AASHTO Highway Safety Manual (www.highwaysafetymanual.org)

AASHTO A Policy on Geometric Design of Highways and Streets (www.transportation.org)

VTRANS Roadway Lighting Policy

The Vermont Agency of Transportation will evaluate the use of street lighting on a project by project basis. An early determination (pre-Act 250) should be made regarding the installation of street lighting on a project. Meeting of the warrants shall not obligate the Vermont Agency of Transportation to include street lighting as part of a project.

Some of the factors which the Agency considers in a determination regarding the installation of street lights on a particular project include:

a. Geometric factors - curves, grades, sight distance, lane widths, number of lanes, etc.
b. Operational factors - operating speed, nighttime pedestrian traffic, type of control, level of service, etc.
c. Environmental factors - type and density of development, crime rate, nearby advertising or area lighting, etc.
d. Safety factors - such as ratio of nighttime to daytime accident rate, overall accident rate.
e. Cost factors - benefits derived from lighting in terms of reduced accidents and increased capacity versus the installation and maintenance costs.

If the Agency determines that partial lighting or no lighting is appropriate for a particular project, and a municipality requests additional or continuous lighting for the project, the following shall apply:

a. The municipality shall agree to pay the installation, power and maintenance costs, and take over ownership of all or at least the additional requested lighting which is beyond the scope of the Agency's lighting plan. The Agency would design the lighting plan to AASHTO and FHWA guidelines.
b. If the lighting warrants and anticipated conditions are such that the lighting may be warranted within 5 years of initial construction, the Agency may agree to participate in the initial installation cost.
c. If a particular style or type of lighting is requested, the municipality shall agree to paragraph a.) above and will pay any additional construction costs if their requested design concept is more expensive than the normal agency lighting design. A letter of approval from the municipality should be provided or made a part of the finance and maintenance agreement.
d. If lights are leased by a city or town on existing utility poles that are to be relocated, the existing lights could be reinstalled on the relocated utility poles at the request of the city or town as part of the project providing the Agency has no plans to design lighting for the project.
e. If a light or lights owned and leased by an individual are being removed because of roadway construction, the lighting will be reestablished only as a result of a negotiated agreement with the individual owner as part of ROW proceedings. Such lighting should not be reestablished within the highway right-of-way. Reference is made to: V.S.A. Title 19, Section 1104, which states that artificial lighting shall not create a hazard to users of the highway.

If the agency determines street lighting to be warranted for a project, then it shall be designed to meet the VTRANS lighting guidelines. In addition, lighting materials shall meet the requirements of this document as well as AASHTO and FHWA specifications for breakaway, clear zone or guardrail protection requirements.

When street lighting and landscaping are being considered for the same project, there should be early coordination of the two plans to eliminate conflicts between the two designs. Lighting design should account for all street elements and geometric features.

Federal and State Mandates

In addition to meeting the requirements of this guide document, the designer shall identify any off-site lighting which will detract from the performance of the driver under the required criteria contained within this document. The Vermont statute relating to this issue states:

Title 19: Highways Section 1104. Lighting where hazard

"*The traffic committee may determine if any artificial light creates a hazard to users of a highway and upon finding that a hazard is created may direct that the light be removed or altered as required to eliminate the hazard. The selectmen shall have the same authority on town highways*."

Design Procedure

This section describes the procedure to follow when designing a lighting system for VTRANS.

Design Procedure Outline

Use the following procedure for preparing typical street lighting designs.

Step 1 – Scoping/Concept Phase

Determine whether lighting is warranted through the following steps.

- Request a list of all crashes in the latest five-year period for the project area.
- Request a file sort of the crashes on the "light conditions" category to determine the ratio of nighttime accidents to daytime accidents.
- Request a copy of the June and December hourly list for the nearest applicable continuous traffic count station for the middle year for which crash data are available. Use the 8am to 4pm December and 5am to 8pm June volumes to determine the average daylight traffic. The remaining hours determine the average nighttime traffic. Divide the accident ratio. This figure is used on the evaluation form.
- Fill out the proper evaluation form for the appropriate location or classification of highway. See the “Lighting Warrant” section.
    - If the warranting condition is met, lighting may or may not be installed. See “Purpose and Policy” for additional information.
    - If local and State officials agree to include lighting as part of the project, whether partial or continuous, proceed to step 2.

Step 2 – Preliminary Plans/Lighting Submission

Know the roadway geometrics and prepare preliminary plans

- Obtain the suggested lighting criteria levels and limits from the “Design Criteria” section.
- Develop the appropriate light loss factor based on source, luminaire, and expected maintenance cycle.
- Determine the pole placement, spacing, arm length, wattage, and mounting height.
- Review site, either from a site visit if an existing roadway, or from plans showing proposed topography, profiles, and cross sections.
- Perform calculations for various criteria levels in accordance with the recommendation included in this document.
- Place lighting locations on drawings checking interferences with underground utilities, landscaping, drainage systems. Pole placement needs to be either outside of the roadway clear zone or protected by barrier or equipped with breakaway devices. Locations should also be away from gores and bridge mid-spans (placement at piers is preferred).
- Meet with utility to determine service locations.

After light pole and power locations are established:

- Perform voltage drop calculations on each branch and feeder circuits.
- Add schedule of pole locations and information on each layout sheet.
- Add preliminary details and notes.
- Develop a list of pay items and a preliminary estimate using the computer program HI-EST.
- Add a list of all work to be performed by the contractor.
- Note service locations on drawings and utility requirements and responsibilities.
- A lighting and electrical narrative shall also be included with the lighting review submittal, which includes a description of the lighting and electrical system, criteria values used for design, and luminaire and pole information. Lighting calculations shall be submitted including roadway luminance and illuminance, uniformities, veiling luminance ratio, horizontal and vertical illuminance for sidewalk areas (where applicable), and light trespass values. Voltage drop calculations shall also be submitted as part of this package.

Step 3 – Final Plans

The following work must be performed.

- Develop Lighting based on preliminary plans review comments
- Draft Special Provisions

Step 4 – Pre-Contract Plans

Follow standard operating procedure.

Step 5 – Contract Plans

Follow standard operating procedure.

Step 6 – Construction Phase

This consists of reviewing materials and validating the design in the field:

- Fabrication Drawings shall be submitted to the Project Manager for review, a digital submission is preferred.
- Field inspection of the work and material including lighting levels to verify performance of the lighting system to designed values. Inspection to be performed by the project design team and/or a Consultant to the Agency tasked with the inspections. The AOT Traffic Shop Manager and the District 5 Electrical Maintenance Specialist shall be invited to the field inspection.

Checklist for Design

Scoping / Conceptual Plans

- ☑ Review of crash data
- ☑ Review of traffic data
- ☑ Completion of warranting forms

Preliminary Plans

- ☑ Selection of criteria
- ☑ Selection of lighting equipment
- ☑ Layout and calculations, lighting software output documentation
- ☑ Coordination check with utilities, landscaping, street furniture, and other elements
- ☑ Determine service location
- ☑ Perform voltage drop calculations Develop pay item list and Estimate
- ☑ Prepare plan submission and basis of design report
- ☑ Preliminary Plan review by AOT Traffic Shop Manager and District 5 Electrical Maintenance Specialist

Final Plans

- ☑ Comment resolution
- ☑ Right of Way Plans Complete
- ☑ Draft Special Provisions
- ☑ Final Plan review by AOT Traffic Shop Manager and District 5 Electrical Maintenance Specialist

Pre-Contract Plans

- ☑ ROW Clearance to include all easements and rights for lighting
- ☑ Utility Clearance to include all relocations needed for service locations

Lighting Warrants

This section describes the lighting warrant procedure used by VTRANS.

LIGHTING WARRANTS

Warrants

Lighting warrants assist in evaluating locations where lighting will maximize benefit based on defined conditions or rating systems. Meeting these warrants does not obligate the State or other agencies to provide lighting or participate in its cost. Conversely, local information in addition to warrants, such as roadway geometry, high collision rates, or frequent occurrences of poor weather conditions such as rain. fog, ice, or snow, may influence the decision to install lighting.

Both the American Association of State Highway Officials (AASHTO) warranting system and the Transportation Association of Canada (TAC) warranting system have been included in this guide. The TAC system is intended to supplement the AASHTO system in areas that require a more detailed evaluation or where AASHTO does not provide a warranting method.

AASHTO Warranting System

Warrants for highways, freeways, interchanges and bridges may be undertaken using the American Association of State Highway Transportation Officials (AASHTO) Roadway Lighting Design Guide Warranting System. AASHTO defines warrant for Continuous Freeway Lighting (CFL), Complete Interchange Lighting (CIL) and Partial Interchange Lighting (PIL) based on warrant conditions including:

- Traffic volumes;
- Spacing of freeway interchanges;
- Lighting in adjacent areas;
- Night to day collision rate.

The AASHTO warranting conditions are given below.

Continuous Freeway Lighting

Definition. A continuous lighting system provides relatively uniform lighting on all main lanes and direct connections, and complete interchange lighting of all interchanges within the section. Frontage roads are not normally continuously lighted. The lighting units may be conventional luminaires or high mast assemblies or both.

Continuous lighting may be warranted under one of the conditions described in the following table.

Figure 2: Warranting Conditions for Continuous Freeway Lighting (CFL)

Case	Warranting Conditions
CFL-1	Sections in and near cities where the current average daily traffic (ADT) is 30,000 or greater.
CFL-2	Sections where three or more successive interchanges are located with an average spacing of 1.5 miles or less, and adjacent areas outside the right-of-way are substantially urban in character.
CFL-3	Sections of two miles or more passing through a substantially developed suburban or urban area in which one or more of the following conditions exist: a) local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the freeway b) the freeway passes through a series of developments—such as residential, commercial, industrial and civic areas, colleges, parks, terminals, etc. that include lighted roads, streets, parking areas, yards, etc.—that are lighted c) separate cross streets, both with and without connecting ramps, occur with an average spacing of 0.5 miles or less, some of which are lighted as part of the local street system d) the freeway cross section elements, such as median and borders, are substantially reduced in width below desirable sections used in relatively open country.
CFL-4	Sections where the ratio of night to day crash rate is at least 2.0 times the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate. Where crash data are not available, rate comparison may be used as a general guideline for crash severity.

Complete Interchange Lighting

Definition. Complete interchange lighting is defined as a lighting system that provides relative uniform lighting within the limits of the interchange, including:

- main lanes,
- direct connections,
- ramp terminals, and
- frontage road or crossroad intersections.

Complete interchange lighting may be warranted under one of the conditions described in the following table.

Figure 3: Warranting Conditions for Complete Interchange Lighting (CIL)

Case	Warranting Conditions
CIL-1	Where the total current ADT ramp traffic entering and leaving the freeway within the interchange areas exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.
CIL-2	Where the current ADT on the crossroad exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.
CIL-3	Where existing substantial commercial or industrial development that is lighted during hours of darkness is located in the immediate vicinity of the interchange, or where the crossroad approach legs are lighted for 0.5 mile or more on each side of the interchange.
CIL-4	Where the ratio of night to day crash rate within the interchange area is at least 1.5 times the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate. Where crash data are not available, rate comparison may be used as a general guideline for crash severity.

Partial Interchange Lighting

Definition. Partial interchange lighting is defined as a lighting system that provides illumination only of decision making areas of roadways including:

- acceleration and deceleration lanes,
- ramp terminals,
- crossroads at frontage road or ramp intersections, and
- other areas of nighttime hazard.

Partial interchange lighting may be warranted under one of the conditions described in the following table.

Figure 4: Warranting Conditions for Partial Interchange Lighting (PIL)

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

AASHTO considers it desirable to provide lighting on long bridges in urban and suburban areas even when the approaches are not lighted. On bridges without full shoulders, lighting can enhance both safety and utility of the bridges and is therefore recommended. Where bridges are provided with sidewalks for pedestrian movements, lighting is recommended for pedestrian safety and guidance.

Alternative (expanded) Warranting Method for Roadways and Streets

The warrant system presented in this section is based on the Transportation Association of Canada Guide for the Design of Roadway Lighting which was based on the previous version Roadway Lighting Handbook published by the U.S. Department of Transportation.

The warrant system is based on factors grouped into geometric, operational, environmental, and collision factors. For each factor a numeric rating (R) from 1 to 5 corresponding to the defined criterion is established. Each criterion is assigned a weight (W) to indicate its relative importance. The rating value (R) is multiplied by the weight (W) to obtain a point-score (R x W) for each criterion characteristic, indicating its relative significance. The overall point-score for all items indicates the need for lighting, as well as the relative risk on that road compared with other roadways.

When undertaking a warrant analysis, the length of roadway segment being analyzed should be as long as possible, and should take into account future development. Where the roadway classification or roadway land use classification changes, a separate warrant analysis should be considered for each roadway section. Where classifications are relatively constant along the segment of roadway under consideration, a single warrant analysis may be undertaken.

Classification factors listed on the warrant sheets are defined as follows:

Geometric Factors

Includes key geometric factors listed for the length of roadway to which the warrant is being applied.

These include:

- Number of lanes
- Lane width
- Number of median openings (per km)
- Driveways and entrances per kilometer
- Horizontal curve radius
- Vertical Grade
- Sight distance
- Parking

The worst case rating factors (R) shall apply for the entire length of road being considered. The weighted value is very high for sharp horizontal curve radii.

Operational Factors

Includes operational factors for the entire length of roadway to which the warrant is being applied. These include:

- Signalized intersections
- Left turn lanes
- Median width
- Operating of posted speed
- Pedestrian activity (conflict) levels are defined as high, medium or low in ANSI/IES RP-8 Recommended Practice for Roadway Lighting:

    1. High – Areas with significant numbers of pedestrians expected to be on the sidewalks or crossing the streets during darkness. Examples include downtown retail areas, near theaters and performance venues, transit terminals.
    2. Medium – Areas where lesser numbers of pedestrians utilize the sidewalks and streets at night. Examples include downtown office areas, blocks with public facilities, apartments, parks and transit lines.
    3. Low – Areas with very low volumes of night pedestrian usage. Examples include suburban neighborhoods, residential developments and rural areas.

The worst case rating factors (R) shall apply for the entire length of road being considered. The weighted value is high for pedestrian activity level.

Environmental Factors

Includes environmental factors for the entire length of road to which the warrant is being applied. These include:

- Percentage of development adjacent to the roadway - Adjacent development must be a reasonable distance from the roadway and must tie into the roadway for which the warrant is being undertaken via a driveway or intersection which generates a reasonable amount of traffic. Determining the amount of ambient lighting present in an area depends on the judgment of the individual performing the warrant analysis. As a general guide, the following ambient lighting definitions may be applied:

1. Sparse – Would typically include rural freeways and highways with little or no development outside of city boundaries.
2. Moderate – Would typically include rural or urban roads with some building lighting and development outside of commercial areas. Areas with residential and industrial development will typically have moderate ambient lighting.
3. Distracting – Would typically be downtown commercial areas with well-lighted building exteriors adjacent to the roadway. Distracting lighting can also include that from fuel stations, automotive sales lots and other commercial development where lighting is used to attract attention to businesses.
4. Intense – Would typically be areas with large advertising signs, sports lighting, and other intense light sources adjacent to the roadway. Intense sources can be found in both rural and urban areas.

- Area classification
- Distance from development to roadway
- Ambient lighting
- Raised median curb

The worst case rating factors (R) shall apply for the entire length of road being considered. The weighted value is high for ambient lighting.

Crash Factors

Includes the night-to-day collision ratio for the given length of road to which the warrant is being applied. As the warrant point-score for this category is heavily based on night-to-day collision ratios, it is essential that detailed and well-defined collision data be applied. Where collision ratios are not known professional judgment shall be applied using collision statistics from similar roads where data is available.

Where a low number of collisions have been recorded (i.e., two at night, and one during the day), lighting may meet the warrant collision ratio, but due to the low numbers may be of less benefit than for other areas with similar ratios and higher numbers.

On the following pages are examples of scorecards on which warranting conditions for a given roadway, interchange or conflict area can be tabulated. Lighting is warranted where a total point-score of 60 or more is reached. If the night-to-day collision ratio is 2:1 or greater, lighting is automatically warranted, regardless of the overall point-score.

Lighting may be prioritized solely on the basis of the point-scores, or in conjunction with a benefit-cost analysis. Benefits would typically be based on the potential reduction in collision frequency and severity. Depending on road authority practice, costs would typically include the initial cost of the lighting system, its ongoing (electricity) costs, and its maintenance costs. Initial costs may be substantial if a power source is not present.

Road Name______________
From________ to__________
City______________________
Warrant Undertaken by________
Company name_____________
Date______________________

Warrants for Lighting Arterial, Collector and Local Roads

Item No.	Classification Factor	Rating Factor 'R'					Weight 'W'	Enter 'R' Here	Score 'R' x 'W'	
		1	2	3	4	5				
	Geometric Factors (See Note 6)									
1	Number of Lanes	%4	5	6	7	^8	0.15			
2	Lane Width (m)	>3.6	3.4 to 3.6	3.2 to 3.4	3.0 to 3.2	<3.0	0.35			
3	Median Openings/km	<2.5 or 1-Way	2.5 to 5.0	5.0 to 7.2	7.2 to 9.0	>9.0 or No Median	1.40			
4	Driveways and Entrances/km	<20	20 to 40	40 to 60	60 to 80	>80	1.40			
5	Horizontal Curve Radius (m)	>600	450 to 600	225 to 450	175 to 225	<175	5.90			
6	Vertical Grades (%)	<3	3 to 4	4 to 5	5 to 7	>7	0.35			
7	Sight Distance (m)	>210	150 to 210	90 to 150	60 to 90	<60	0.15			
8	Parking	Prohibited	Loading	Off Peak	One Side	Both Sides	0.10			
						Subtotal Geometric Factors				**G**
	Operational Factors									
9	Signalized Intersections (%)	80 to 100	70 to 80	60 to 70	50 to 60	0 to 50	0.15			
10	Left Turn Lane	All Major Intersections or 1-Way	Substantial Number of Major Intersections	Most Major Intersections	Half of Major Intersections	Infrequent Number or TWTL (See Notes 1 & 3)	0.70			
11	Median Width (m)	>10	6 to 10	3 to 6	1.2 to 3	0 to 1.2	0.35			
12	Operating or Posted Speed (km/h) (See Note 5)	%40	50	60	70	^80	0.60			
13	Pedestrian Activity Level (See Note 2)			Low	Medium	High	3.15			
						Subtotal Operational Factors				**O**
	Environmental Factors									
14	Percentage of Development Adjacent to Road (%) (See Note 4)	nil	nil to 30	30 to 60	60 to 90	>90	0.15			
15	Area Classification	Rural	Industrial	Residential	Commercial	Downtown	0.15			
16	Distance from Development to Roadway (m) (See Note 4)	>60	45 to 60	30 to 45	15 to 30	<15	0.15			
17	Ambient (off Roadway) Lighting	Nil	Sparse	Moderate	Distracting	Intense	1.38			
18	Raised Curb Median	None	Continuous	At All Intersections (100%)	At Most Intersections (51% to 99%)	At Few Intersections (%50%) (See Note 7)	0.35			
						Subtotal Environmental Factors				**E**
	Collision Factors									
19	Night-to-Day Collision Ratio	<1.0	1.0 to 1.2	1.2 to 1.5	1.5 to 2.0	>2.0 (See Note1)	5.55			
						Subtotal Collision Factors				**A**
						G + O + E + A = Total Warranting Points				
						Warranting Condition			60.00	
						Difference ±			-60.00	**D**

Notes:

1 Lighting Warranted
2 Pedestrian Activity Level
3 Two-Way Left Turn Lane
4 Development Defined as Commercial, Industrial or Residential Buildings
5 85th Percentile Night Speed Should Be Used if Available, Otherwise Posted Speed Shall Be Used
6 Worst Case Geometric Factors for a Segment of Roadway Shall Apply
7 Also Includes Isolated Medians (Non-Continuous) Between Intersections.

Road Name__________________
From__________ to____________
City________________________
Warrant Undertaken by__________
Company name________________
Date________________________

Warrants for Lighting Freeways (See Note 2)

Item No.	Classification Factor	Rating Factor 'R'					Weight 'W'	Enter 'R' Here	Score 'R' x 'W'	
		1	2	3	4	5				
	Geometric Factors (See Note 4)									
1	Number of Lanes	≦4	5	6	7	≧8	0.15			
2	Lane Width (m)	>3.6	3.4 to 3.6	3.2 to 3.4	3.0 to 3.2	<3.0	0.30			
3	Median Width (m)	>12	7.5 to 12	3.5 to 7.5	1.2 to 3.5	<1.2	0.30			
4	Shoulder Width (m)	>3	2.5 to 3	1.8 to 2.5	1.2 to 1.8	<1.2	0.30			
5	Off Roadway Embankment Slopes	>6:1	6:1	4:1	3:1	<3:1	0.30			
6	Horizontal Curve Radius (m)	>3500	1750 to 3500	1750 to 875	575 to 875	<575	4.90			
7	Vertical Grades (%)	<3	3 to 4	4 to 5	5 to 7	>7	0.25			
8	Interchange Frequency (No. per km)	>6.5	5.0 to 6.5	3.5 to 5.0	1.5 to 3.5	<1.5	1.85			
						Subtotal Geometric Factors				G
	Operational Factors									
9	Level of Service (Night, at any Hour)	A	B	C	D	≧E	3.05			
							Subtotal Operational Factors			O
	Environmental Factors									
10	Percentage of Development Adjacent to Road (%)	nil	nil to 24	25 to 50	50 to 75	75 >	1.85			
11	Distance from Development to Roadway (m) (See Note 3)	>60	45 to 60	30 to 45	15 to 30	<15	1.85			
							Subtotal Environmental Factors			E
	Collision Factors									
12	Night-to-Day Collision Ratio	<1.0	1.0 to 1.2	1.2 to 1.5	1.5 to 2.0	>2.0 (See Note 1)	4.90			
							Subtotal Collision Factors			A
							G + O + E + A = Total Warranting Points			
							Warranting Condition		60.00	
							Difference ±		-60.00	D

Notes:

1 Lighting Warranted
2 Operating Speed 80 km/hr (95th percentile night speed should be used if available, other wise posted speed shall be used
3 Development Meaning Commercial, Industrial, Residential Buildings
4 Worst Case Geometric Factors for a Segment of Roadway Shall Apply

Warranting Method for Intersections

The warrant system presented is based on the Transportation Association of Canada Guide for the Design of Roadway Lighting with some modifications to points required for full intersection lighting, partial intersection lighting, or delineation lighting. The warranting system is based on geometric, operational, environmental and collision factors.

The critical factors used to determine the need for illumination include the following:

- Traffic volumes (particularly on the cross street).
- The presence of crosswalks.
- Nighttime collisions that may be attributed to the lack of illumination.
- The extent of raised medians.
- Several secondary factors are also considered in the warrant, but are given less weight in the overall point-score. In the warrant, traffic volumes and nighttime collisions are given greater weight than raised medians, which can be designed, marked, or modified to reduce the risk associated with its presence in the roadway.

The following terminology is used with respect to the amount of lighting, as determined by the warrant system:

- Full Lighting – Denotes lighting covering an intersection in a uniform manner over the traveled portion of the roadway.
- Partial Lighting – Denotes lighting of key decision areas, potential conflict points, and/or hazards in and on the approach to an intersection. Partial lighting may also guide a driver from one key point to the next, and (if sufficient luminaires are used) place the road user on a safe heading after leaving the lighted area.
- Delineation Lighting – Denotes lighting that marks an intersection location for approaching traffic, lights vehicles on a cross street, or lights a median crossing.

Based on the warrant analysis preformed and tabulated on the scorecard shown on the next page, the following defines the need for full, partial or delineation intersection lighting:

- If the intersection is signalized, full lighting is warranted.
- If the intersection is not signalized, the need for and the amount of lighting is indicated by comparing the point-score obtained from the warrant form categories to the following criteria:

    1. Full Lighting – Is warranted where a total point-score of 240 or more points.
    2. Partial Lightning – Is warranted where the point-score is between 151 and 239 points.
    3. Delineation Lighting - Is warranted where the point-score is between 120 and 150,
    4. No Lighting – Generally, a point-score under 120 indicates that lighting is not warranted. This score indicates that neither the critical operational warranting factor (substantial traffic volumes) nor the critical collision warranting factor (repeated nighttime collisions) is present.

Lighting may be prioritized solely on the basis of the point-scores, or in conjunction with a benefit-cost analysis. Benefits would typically be based on the potential reduction in collision frequency and severity at the intersection. Depending on road authority practice, costs would typically include the initial cost of the lighting system, its ongoing (electricity) costs, and its maintenance costs. Initial costs may be substantial if a power source is not present at the intersection.

Roundabouts are always warranted for lighting due to the geometry of the roundabout and limitations of fixed headlights.

Road Name________________
From________ to__________
City_____________________
Warrant Undertaken by________
Company name______________
Date_____________________

Warrants for Intersection Lighting (See Note 2)

Item No.	Classification Factor	Rating Factor 'R' 0	1	2	3	4	Weight Subcategory (If Applicable)	Weight 'W'	Enter 'R' Here	Score 'R' x 'W'	
	Geometric Factors (G)										
1	Channelization	None	Right and/or Left Turn Lanes on Minor Approach Only	Right Turn Lane(s) Only on Major Leg(s)	Left Turn Lane(s) on Major Leg(s)	Left and Right Turn Lanes on All Legs	Raised and Operating Speed Less than 70 km/h on at Least One Channelized Approach or	15			Only **ONE** 'R' Value Is To Be Entered for These Three Rows!
							Raised and Operating Speed Less than 70 km/h or More on at Least One Channelized Approach or	20			
							Painted Only	5			
2	Approach Sight Distance on the Most Constrained Approach (Relative to Recommended Minimum Intersection Sight Distance)	100% or More	75% to 99%	50% to 74%	25% to 49%	<25%		10			
3	Horizontal Curvature (Radius) at or Immediately Before Intersection on Any Leg for Posted Speed Limit of:										
	110 km/hr :	Tangent	>1800 m	1150 to 1800 m	750 to 1150 m	<750 m		5			
	90 or 100 k/hr :	Tangent	>1400 m	950 to 1400 m	600 to 950 m	<600 m					
	70 or 80 km/h :	Tangent	>950 m	550 to 950 m	340 to 550 m	<340 m					
	60 km/h :	Tangent	>575 m	320 to 575 m	190 to 320 m	<190 m					
4	Angle of Intersection or Offset Intersection	90 Degree Angle	80 or 100 Degree Angle	–	70 or 110 Degree Angle	<70 or > 110 Degree or Offset Intersection		5			
5	Downhill Approach Grades at or Immediately Before Intersection on Any Leg	<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	>7.0% OR Exceeds Maximum Gradient for Type and Speed of Road		3			
6	Number of Legs	–	3	4	5	6 or More		3			
								Subtotal Geometric Factors			G
	Operational Factors (O)										
	If the Intersection is singalized, illumination is Warranted.										
	If the Intersection is NOT Signalized, Points should be Calculated on the Basis of EITHER the AADT Factor or the Signalization Warrant Factor.										
7	Either AADT (2-Way) (See Note 1):										
	On Major Road and	<1000	1000 to 2000	2000 to 3000	3000 to 5000	>5000		10			Only **ONE** 'R' Value Is To Be Entered for These Two Rows!
	On Minor Road	<500	500 to 1000	1000 to 1500	1500 to 2000	>2000		20			
	or Signalization Warrant (See Note 1)	Intersection Not Signalized and Volume-Based Signal Warrant is Less than 20% Satisfied	Intersection Not Signalized and Volume-Based Warrant is 20% to 40% Satisfied	Intersection Not Signalized and Volume-Based Warrant is 40% to 60% Satisfied	Intersection Not Signalized and Volume-Based Warrant is 60% to 80% Satisfied	Intersection Not Signalized and Volume-Based Warrant is Over 80% Satisfied		30			
8	Regular Nighttime Hourly Pedestrian Volume (See Note 2)	No Pedestrians	Up to 10	10 to 30	30 to 50	Over 50		10			
9	Intersecting Roadway Classifications	No Primary Road Involved	Primary/Rural Major, Primary Rural Minor, or Primary/Designated Community Access	Primary/Secondary	Primary/Primary	Intersection Includes Divided Highway		5			
10	Operating Speed or Posted Speed Limit on Major Road (See Note 3)	50 km/h or Less	60 km/h	70 km/h	80 km/h	90 km/h or Over		5			
11	Operating Speed or Posted Speed Limit on Minor Road (See Note 3)	50 km/h or Less	60 km/h	70 km/h	80 km/h	91 km/h or Over		5			
								Subtotal Operational Factors			O
	Environmental Factors (E)										
12	Lighted Development Within 150 m Radius of Intersection	–	In One Quadrant	In Two Quadrants	In Three Quadrants	In Four Quadrants	5.00	5			
								Subtotal Environmental Factors			E
	Collision Factors (A)										
13	Average Annual Nighttime Collision Frequency (See Note 4) or Rate over Last Three Year (Only Collisions Potentially Attributable to Inadequate Lighting)	0 Collisions per Year	1 Collision Per Year	--	3 or More Collisions Per Year OR At Least 1.5 Collisions per Million Entering Vehicles per Year and an Average Ratio of All Night-to-Day Collisions of at Least 1.5		1 or 2 Collisions per Year	15			Only **ONE** 'R' Value Is To Be Entered for These Two Rows!
							3 or More Collisions per Year or Rate ^1.5 Collisions/MEV	30			
								Subtotal Collision Factors			A
								G + O + E + A = Total Warranting Points			
								Warranting Condition			
								Difference ±			D

Notes:

1 If the intersection is not signalized, the user should choose EITHER the AADT factor OR the signalization factor. The points from either factor, but not both factors, may be used for the warrant point calculations.
2 The number of certain types of vulnerable pedestrians should be factored to reflect their increased need for visibility.
The number of child pedestrians (ages 12 and under) should be multiplied by two, and the number of senior pedestrians (age 65 and over) should be multiplied by 1.5.
3 85th percentile nighttime speed should be used, if available. Otherwise the posted speed may be used.
4 Reported collisions, rounded to the nearest whole number.

Design Criteria

This section describes the lighting performance and lighting levels used by VTRANS.

LIGHTING DESIGN CRITERIA

This section includes the criteria for lighting design of various installations. These include roadways (freeways and expressways), streets (lower speed roads often with pedestrians), intersections and roundabouts, parking areas, bikeways, pedestrian paths and sidewalks, as well as other associated areas. The values are, in general, in accordance with the AASHTO Roadway Lighting Design Guide as well as documents prepared by the Illuminating Engineer Society (IES).

Definitions

Freeway: A divided highway with full control of access.

> Freeway A: 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: All other divided roadways with full control of access.

Expressway: A divided highway with partial control of access.

Major: That part of the roadway system that serves as the principal network for through-traffic flow. The routes connect areas of principal traffic generation and important rural roadways entering and leaving the city. These routes are often known as “arterials,” “thoroughfares,” or “preferentials.” They are sometimes subdivided into primary and secondary categories; however, such distinctions are not necessary in roadway lighting. These routes primarily serve through traffic and secondarily provide access to abutting property.

Collector: Roadways servicing traffic between major and local streets. These are streets used mainly for traffic movements within residential, commercial and industrial areas. They do not handle long, through trips. Collector streets may be used for truck or bus movements and give direct service to abutting properties.

Local: Local streets are used primarily for direct access to residential, commercial, industrial, or other abutting property. They make up a large percentage of the total street system, but carry a small proportion of vehicular traffic.

High Pedestrian: Areas with significant numbers of pedestrians expected to be on the sidewalks or crossing the streets during darkness. Examples are downtown retail areas, and areas near theaters, concert halls, stadiums, and transit terminals. (approx. over 100 pedestrians during the first hour of darkness).

Medium Pedestrian: - Areas where lesser numbers of pedestrians utilize the streets at night. Typical examples are downtown office areas, blocks with libraries, apartments, neighborhood shopping areas, industrial areas, parks, and streets with transit lines (approx. 11 to 100 pedestrians during the first hour of darkness).

Low Pedestrian: - Areas with very low volumes of night pedestrian usage. These can occur in any of the cited roadway classifications, but typical examples include suburban single family streets, very low density residential developments, and rural or semi-rural areas (approx. 10 or fewer pedestrians during first hour of darkness).

Roadway Lighting Criteria

Roadway lighting in the US is evolving to the luminance based system used extensively in the rest of the world. Illuminance is still calculated and used for testing the predicted system performance during construction but the criteria is stated as luminance.

The maximum veiling luminance ratios shown in the Figures 7 & 8 are a predictor of the disability glare generated by the lighting system. It is stated as the max amount of veiling luminance produced (usually by the closest luminaire) divided by the average pavement luminance for the installation.

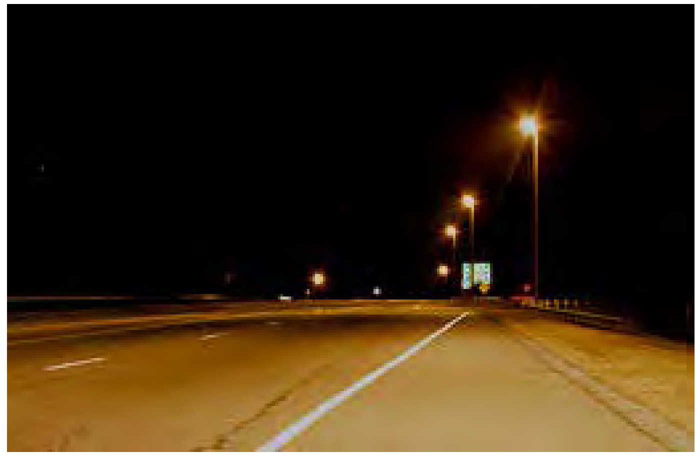


Figure 5: Freeway Lighting

Street Lighting Criteria

Street lighting values can vary greatly based on expected pedestrian volumes for the area. Pedestrian volumes also vary depending upon the time of night. The design criteria values are included below but other modifications are included in the adaptive lighting section of this document.

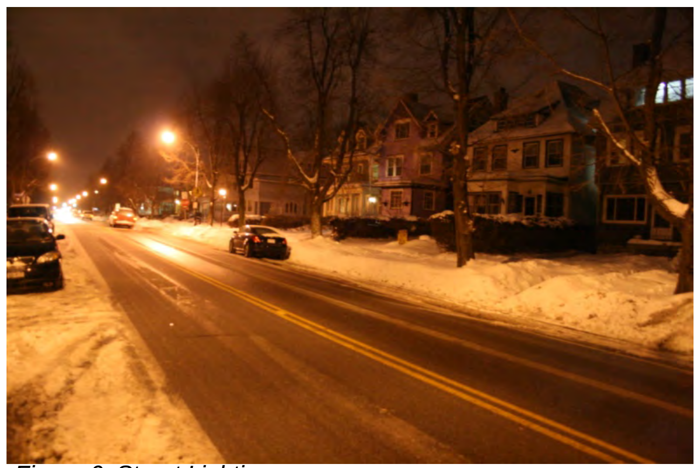


Figure 6: Street Lighting

Figure 7: Recommended Freeway Lighting Luminance Values

ROAD CLASSIFICATION		AVG. LUMIN. L_{avg} (cd/m^2)	MAX UNIFORM. RATIO L_{avg}/L_{min}	MAX UNIFORM. RATIO L_{max}/L_{min}	MAX VEILING LUMIN. RATIO L_{vmax}/L_{avg}
ROAD TYPE					
Freeway Class A		0.6	3.5	6.0	0.3
Freeway Class B		0.4	3.5	6.0	0.3
Expressway		1.0	3.0	5.0	0.3

Figure 8: Recommended Street Lighting Luminance Values

STREET AND AREA CLASSIFICATION		AVG. LUMIN. L_{avg} (cd/m^2)	MAX UNIFORM. RATIO L_{avg}/L_{min}	MAX UNIFORM. RATIO L_{max}/L_{min}	MAX VEILING LUMIN. RATIO L_{vmax}/L_{avg}
STREET	PEDESTRIAN AREA CLASSIFICATION				
Major	High	1.2	3.0	5.0	0.3
	Medium	0.9	3.0	5.0	0.3
	Low	0.6	3.5	6.0	0.3
Collector	High	0.8	3.0	5.0	0.4
	Medium	0.6	3.5	6.0	0.4
	Low	0.4	4.0	8.0	0.4
Local	High	0.6	6.0	10.0	0.4
	Medium	0.5	6.0	10.0	0.4
	Low	0.3	6.0	10.0	0.4

Pedestrian Lighting Criteria

High Pedestrian Conflict Area:

Commercial areas in urban environments may have high nighttime pedestrian activity. It is important to provide systems that will increase the visibility of pedestrians. Since the visual environment is much more cluttered, and a high probability for detection of pedestrians is required, the use of horizontal and vertical illuminances are recommended for design. The tables include recommended horizontal and vertical illuminances for pedestrian areas. Vertical illuminance is measured at a height of 1.5 m (5 ft) in both directions and parallel to the main pedestrian flow. Glare from the luminaires must be restricted by paying careful attention to luminaire mounting heights, lamp wattage, and photometric distribution.

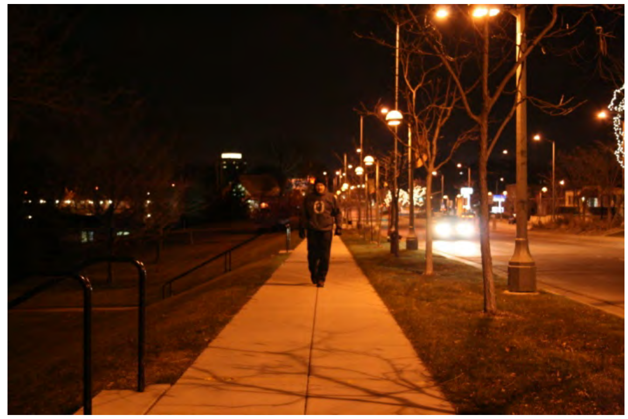


Figure 9: Lighting for Pedestrians

Figure 10: Recommended Values for High Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways			
	E_{avg} fc (lux)	E_{Vmin} fc (lux)	E_{avg}/E_{min} *
Mixed Vehicle and Pedestrian	2.0 (20)	1.0 (10)	4.0
Pedestrian Only	1.0 (10)	0.5 (5)	4.0

E_{avg} – minimum maintained average horizontal illuminance at pavement
E_{min} - minimum horizontal illuminance at pavement
E_{Vmin} - minimum vertical illuminance at 5 ft (1.5m) above pavement
* Horizontal only

Medium Pedestrian Conflict Areas:

Intermediate areas have moderate night pedestrian activities. These areas may typically be those near community facilities such as libraries and recreation centers. Safety for the pedestrians as well as providing guidance to primary travel ways are key elements in the design of a lighting system in these areas. These values do not consider areas with increased crime and vandalism.

Figure 11: Recommended Values for Medium Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways			
	E_{avg} fc (lux)	E_{Vmin} fc (lux)	E_{avg}/E_{min} *
Pedestrian Areas	0.5 (5)	0.2 (2)	4.0

E_{avg} – minimum maintained average horizontal illuminance at pavement
E_{min} - minimum horizontal illuminance at pavement
E_{Vmin} - minimum vertical illuminance at 5 ft (1.5m) above pavement
* Horizontal only

Low Pedestrian Conflict Areas:

The lighting system in residential areas may allow both driver and pedestrian to visually orient in the environment, detect obstacles, identify other pedestrians, read street signs, and recognize landmarks. These values do not consider areas with increased crime and vandalism.

Figure 12: Recommended Values for Low Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways			
	E_{avg} fc (lux)	**E_{Vmin} fc (lux)**	**E_{avg}/E_{min}***
Rural/Semi-Rural Areas	0.2 (2)	0.06 (0.6)	10.0
Low Density Residential *(2 or fewer dwelling units per acre)*	0.3 (3)	0.08 (0.8)	6.0
Medium Density Residential *(2.1 to 6.0 dwelling units per acre)*	0.4 (4)	0.1 (1)	4.0

E_{avg} – minimum maintained average horizontal illuminance at pavement
E_{min} - minimum horizontal illuminance at pavement
E_{Vmin} - minimum vertical illuminance at 1.5m above pavement
* Horizontal only

Intersection and Roundabout Criteria

The recommended illuminance values at intersections of continuously lighted streets, defined as the prolongation of the intersecting roadway edges. Other traffic conflict areas should be provided with illuminance values 50 percent higher than recommended for the street. This is based on the principle that the amount of light should be proportional to the classification of the intersecting routes and equal to the sum of the values used for each separate street. If an intersecting roadway is illuminated above the recommended value, then the intersection illuminance value should be proportionately increased. Roundabouts are also illuminated to the same values as intersections whether the approach roads are continuously lighted or not.

Figure 13: Recommended Values for Intersections and Roundabouts

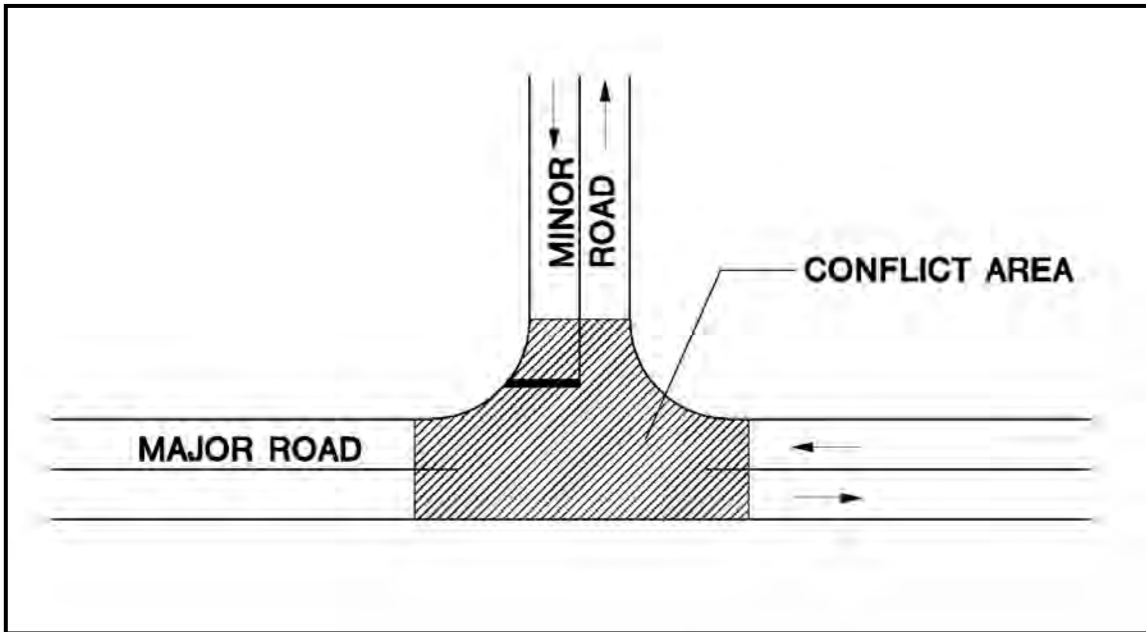
Illumination for Intersections and Roundabouts				
Functional Classification	**Average Maintained Illumination at Pavement by Pedestrian Area Classification in fc (lux)**			**E_{avg}/E_{min}**
	High	**Medium**	**Low**	
Major/Major	3.4 (34)	2.6 (26)	1.8 (18)	3.0
Major/Collector	2.9 (29)	2.2 (22)	1.5 (15)	3.0
Major/Local	2.6 (26)	2.0 (20)	1.3 (13)	3.0
Collector/Collector	2.4 (24)	1.8 (18)	1.2 (12)	4.0
Collector/Local	2.1 (21)	1.6 (16)	1.0 (10)	4.0
Local/Local	1.8 (18)	1.4 (14)	0.8 (8)	6.0

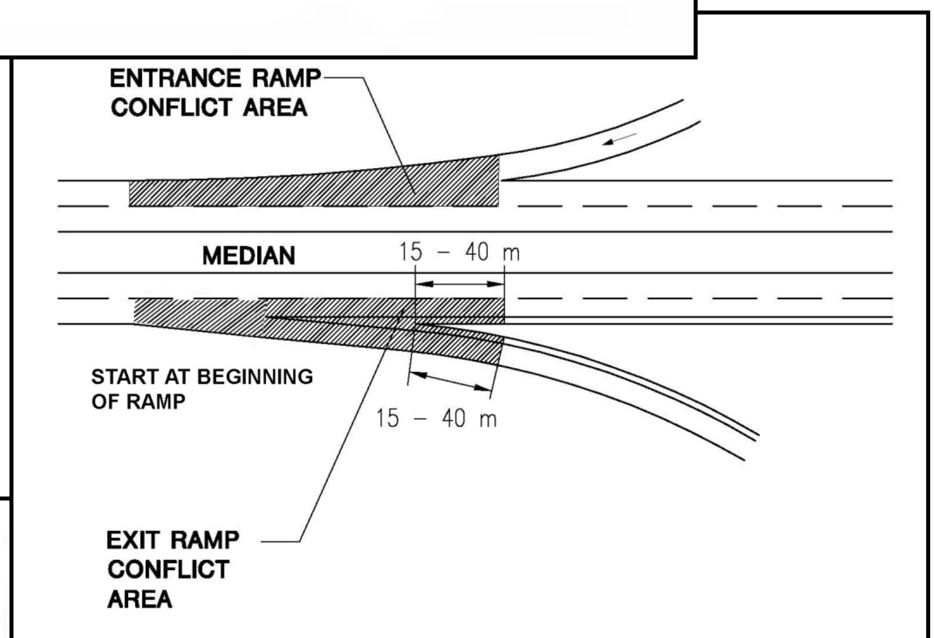
Isolated Intersections and Interchanges (Partial Lighting)

Under certain circumstances, lighting may be appropriate at an isolated intersection or interchange where continuous lighting does not exist. In this situation the application of partial lighting would be appropriate.

Partial lighting consists of a lighting system that is put in place to provide lighting at points of potential conflict. It is not considered continuous but some of the rules that apply to continuous lighting will apply in the design of partial lighting such as pole placement, calculation procedures, etc.

In the case of isolated intersections and interchanges the conflict area is, by definition, that area that encompasses all of the conflict points.





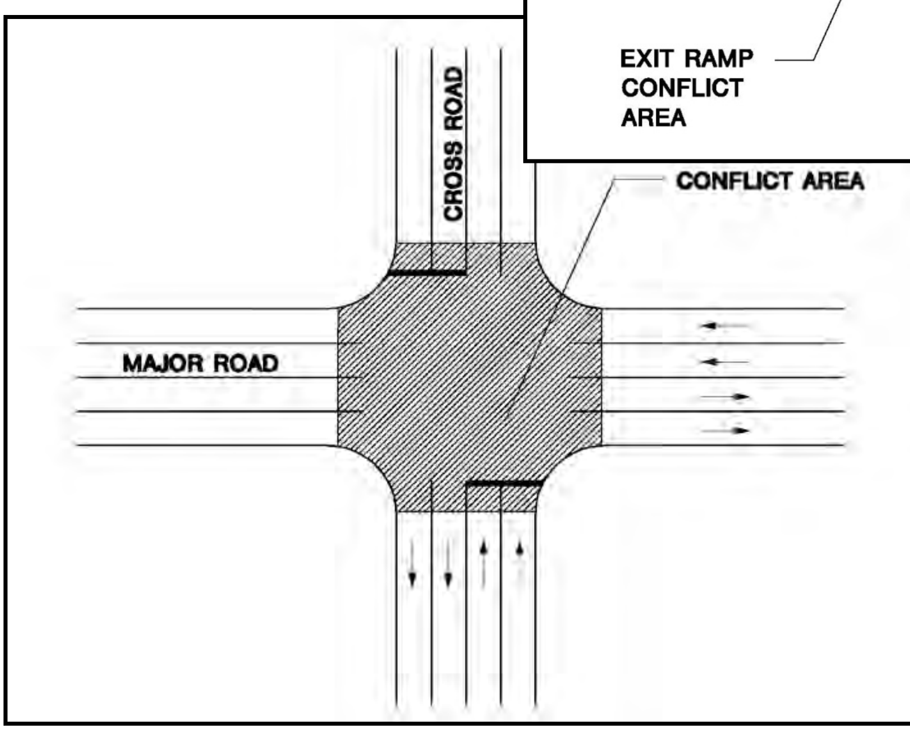


Figure 14: Typical Intersection Conflict Areas

In order to carry out the calculations necessary for partial lighting at isolated intersections and interchanges and at railroad grade crossings, it will be a requirement to meet the levels of illuminance and uniformity ratios as outlined in the table below:

Figure 15: Recommended Lighting Levels for Isolated Intersections and Interchanges

Road Classification	Pavement Classification			Uniformity Ratio E_{avg}/E_{min}
	R1 fc.(lux)	R2 & R3 fc (lux)	R4 fc (lux)	
Roadway Lighting				
Freeway Class A	0.6 (6.0)	0.9 (9.0)	0.8 (8.0)	3.0
Freeway Class B	0.4 (4.0)	0.6 (6.0)	0.5 (5.0)	3.0
Expressways	0.6 (6.0)	0.9 (9.0)	0.8 (8.0)	3.0
Street Lighting				
Major	0.6 (6.0)	0.9 (9.0)	0.8 (8.0)	3.0
Collector	0.4 (4.0)	0.6 (6.0)	0.5 (5.0)	4.0
Local	0.3 (3.0)	0.4 (4.0)	0.4 (4.0)	6.0

Because of the nature of the calculations to be carried out in these instances, it is suggested that a determination of Veiling Luminance Ratio is not a valid requirement because it cannot be calculated. It is, however, a recommendation that in order to minimize glare, the use of luminaires with zero uplight and low high angle candela be a requirement in all instances where the installation of partial lighting is under consideration.

Beacon Lighting

When simple identification of an isolated intersection is required, then the use of beacon lighting is applicable.

As the definition implies, beacon lighting consists of a single luminaire installed simply for the purpose of “marking” the presence of an intersection. For this reason, calculations are not a requirement. However, in order to reduce glare, only low wattage lamps (generally below 9,000 lumens, for example) and low mounting heights should be used, and the installation should not adversely affect the safe operation of the roadway.

Intersections of High Speed, High Traffic Density, Roadways

A continuous lighting system will usually provide sufficient surrounding illuminance to reveal the features of the entire scene so that drivers will know where they are and where they are going at all times. An inadequately lit interchange may lead to confusion for the driver, by giving misleading clues due to a random placement of the luminaires.

When continuous lighting of the entire interchange area is not provided, it may be desirable to extend the limits of the conflict area to include site specific areas of complexity such as intersections, points of access and egress, curves, steep hills, etc. In these cases, lighting should be extended beyond the illustrated conflict areas as shown in the figures above. The reasons for this are:

- Traffic merging into a major roadway from an access road is often slow in accelerating to the speed on the major roadway. The lighting along this area for a distance beyond the access point extends visibility and facilitates the acceleration and merging process.
- Diverging traffic lanes merit extremely careful consideration because these are areas where motorists are most frequently confused.
-

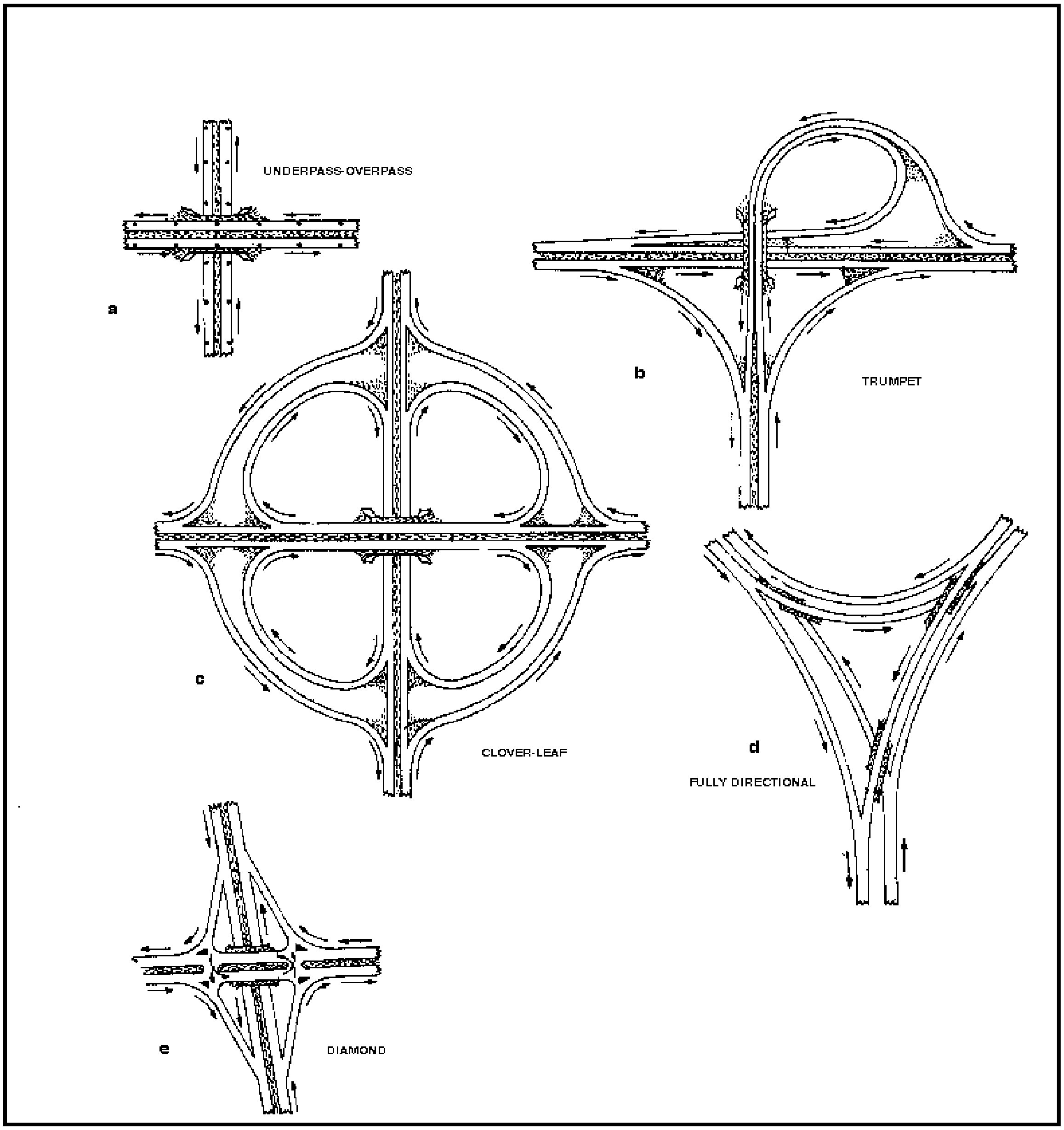


Figure 16: High Speed High Density Intersections

Roundabouts

Roundabouts should be designed to meet the lighting levels recommended in the Intersection and Roundabout table. Crosswalks in roundabouts should have a vertical illuminance level at 1.5m in height, along the center line of the crosswalk, equal to the horizontal illuminance values given in the table. This vertical illuminance value should be calculated in the direction of the approaching driver.

In order to obtain these values, the placement of the pole at roundabouts with crosswalks should be on the approach side of the crosswalk. A reasonable distance for initial calculations is typically 0.7 mounting heights in front of the crosswalk but then must be adjusted in distance, pole height, and optical distribution, to obtain the recommended values.

Figure 17: Roundabout Layouts

Parking Areas

Parking areas utilize a minimum value criteria on both the horizontal surface of the lot as well as a vertical surface assumed to be 5 ft(1.5 m) in height. This criteria is used to define the lowest value allowed in order to see an obstruction or identify and detect a pedestrian in the parking lot. Values are also given for basic lot design as well as enhanced security which assumes a requirement of facial recognition.

Figure 18: Recommended Parking Area Values

		Basic[1]	Enhanced Security[2]
Minimum Horizontal Illuminance[3]	lux[4]	2	5
	fc[2]	0.2	0.5
Uniformity Ratio, Maximum to Minimum[6]		20:1	15:1
Minimum Vertical Illuminance[7]	lux[8]	1	2.5
	fc[5]	0.1	0.25

For preliminary design, an average value of 1 fc (10 lux) could be used for basic and an average value of 2.5 fc (25 lux) could be used for enhanced security in order to estimate the number of required pole and wattage. Final design however should meet the minimum requirements shown.

Safety Rest Areas

Safety rest areas generally include areas adjacent to freeways and expressways with limited access. These areas for the purpose of this document are broken down to the following sub-areas.

- entrance and exit
- interior roadways
- parking areas
- activity areas
- main lanes

These have been defined for separate consideration as each is to be used for a specific and different purpose. The design, however, should also consider the interrelationship of all of these areas.

The light values recommended in this section are the average maintained values as previously defined in this guide. The following guidelines should be used except as noted at the beginning of this chapter.

Figure 19: Recommended Maintained Lighting Levels for Rest Areas—Illuminance

Location	Foot-candles	Lux	Uniformity Ratio
Entrance and Exit Gores* and Main Lanes	0.6	6	3:1 to 4:1
Interior Roadways	0.6	6	3:1 to 4:1
Parking Areas	1.0	11	3:1 to 4:1
Active Areas:			
• Major	1.0	11	3:1 to 4:1
• Minor	0.5	5	6:1

* The illuminance values for entrance and exit gores and for interior roadways are for R3 surfaces. If an R1 surface is used, the values may be reduced by approximately 25 to 30 percent.

This table assumes a rural setting. For rest areas in urban settings levels will be increased using the higher values included in the street lighting criteria section

Figure 20: Recommended Maintained Lighting Levels for Rest Areas—Luminance

Location	L_{avg}		Uniformity		Veiling Luminance Ratio*
	cd/m^2	Foot Lamberts	L_{avg}/L_{min}	L_{max}/L_{min}	$Lv_{(max)}/L_{avg}$
Entrance and Exit Gores	0.4	0.12	3.5:1	6:1	0.3:1
Interior Roadways	0.4	0.12	3.5:1	6:1	0.3:1
Parking Areas & Activity Areas	Use Illuminance Method				

* The above uniformity ratios are the maximum allowable. Lower numerical ratios produce better uniformity and are desirable.

This table assumes a rural setting. For rest areas in urban settings levels will be increased using the higher values included in the street lighting criteria section

Crosswalks

An extensive study was conducted by the Federal Highway Administration (FHWA) and Virginia Tech Transportation Institute (VTTI) concerning the lighting of crosswalks.

The initial static experiment used the time it took for an observer to detect the pedestrian or surrogate target as a metric for visibility, while the dynamic experiment used the distance at which pedestrians or surrogate targets were identified as the metric. Experimental condition variables included lamp type (high-pressure sodium, metal halide), vertical illuminance level (0.6, 1.0, 2.0, and 3.0 fc), color of pedestrian clothing (white, black, and denim), position of the pedestrians and surrogates, and the presence of glare."

The finding and recommendations of the study are:

- A vertical illuminance level of 2.0 fc (20 lux) measured at 5 ft (1.5 m) from the road surface allowed drivers to detect pedestrians in midblock crosswalks at adequate stopping distances under rural conditions.
- A higher level of vertical illuminance may be required for crosswalks when
    1. There is a possibility of glare from opposing vehicles.
    2. The crosswalk is located in an area with high ambient light levels.
    3. The crosswalk is located at a lighted intersection.
- The luminaire selected will influence the best mounting location and height of the luminaire with respect to the crosswalk.
- The vertical illuminance level that allowed drivers to detect pedestrians at adequate distances was the same for HPS and MH sources; however, MH or other white light sources may provide better facial recognition and comfort for pedestrians.
-

The report also includes some placement guidance positioning poles before the crosswalks:

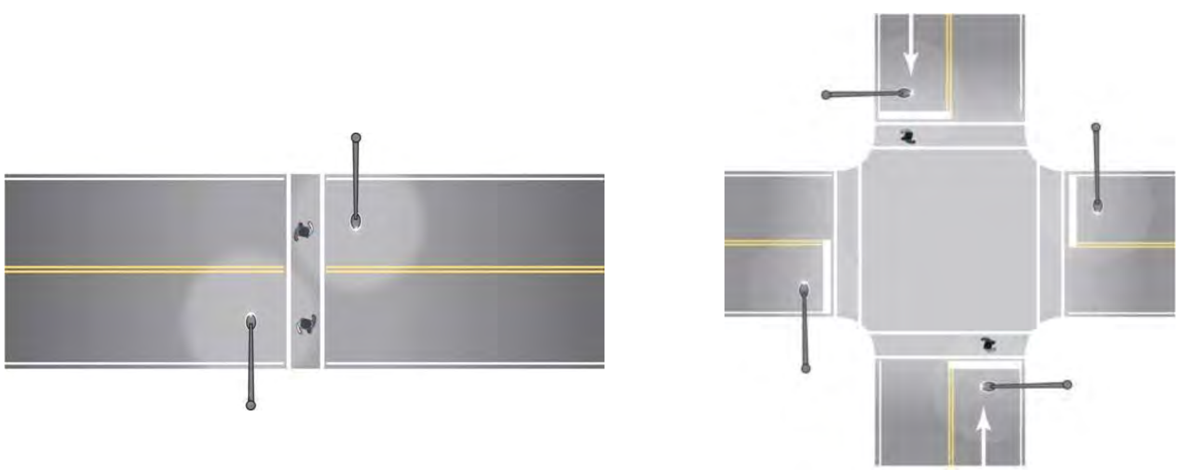


Figure 21: Suggested Crosswalk Pole Locations

Railroad Grade Crossings

The lighting of railroad grade crossings may be effective in reducing nighttime crashes and should be considered under the following circumstances (ref: FHWA Railroad-Highway Grade Crossing Handbook, Second Edition August 2007):

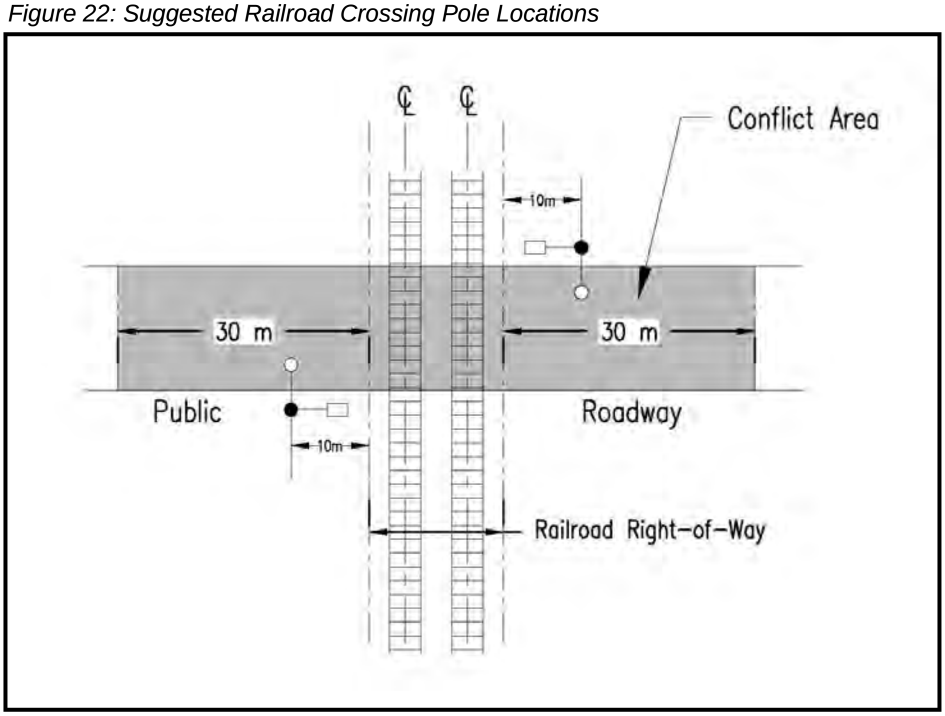
- Night-time train operations.
- Low train speeds.
- Blockage of the crossing for long periods at night.
- An accident history that indicates that motorists often fail to detect trains or traffic control devices at night.
- Horizontal and/or vertical alignment of the highway approach(es) are such that the vehicle headlight beams do not fall on the train until the vehicle has passed the safe stopping sight distance.
- Long dark trains (e.g. coal trains)
- Restricted sight or stopping distance in rural areas.
- Humped crossings where oncoming vehicle headlights are visible under the train.
- Where the location of the crossing is difficult for a motorist to identify.

Lighting at, and adjacent to, the crossing may be installed to supplement other traffic control devices where an engineering analysis determines that better visibility of the crossing and trains is required.

The intent of railroad grade crossing lighting is to light the conflict area of the crossing. The conflict area is defined as the complete road cross section, including the shoulders, to a distance of 30 meters in front of the crossing in both directions.

In addition to lighting the conflict area of a railroad grade crossing, it is desirable to provide added visibility of the side of the train cars. This is achieved by adding auxiliary lights (noted as rectangles in the figure) facing the train cars. Figure 22 illustrates the area to be lighted.

Figure 22: Suggested Railroad Crossing Pole Locations



In the conflict area of a railroad grade crossing, the levels of illuminance and uniformity ratios should be as recommended for partial lighting of isolated intersections.

A determination of Veiling Luminance Ratio is not valid because it cannot be calculated. It is recommended that in order to minimize glare, luminaires with zero uplight and low high angle candela be used.

To provide vertical illuminance of the train cars, 10 lux minimum average should be maintained on the vertical plane of the train car for each track, along the centerline of each track for each roadway approach**.** The limits of the calculation area should extend from the track level to 4 meters above and across the conflict area.

Walkways and Bikeways

Walkways and bikeways separated from the roadway right-of-way shall meet the levels specified in the table below. The area adjacent to the walkway or bikeway, for a distance of 6 feet to 15 feet (2m to 5m) depending on the location, shall have a lighting level of at least 1/3 of the specified lighting level for the walkway or bikeway.

Figure 23: Recommended Walkway/Bikeway Values

Recommended Illumination
(Values in lux)

	Average Conditions		Special Conditions[1]	
	Avg. Maintained Illuminance Levels Horizontal Levels (E Avg.)[2]	**Horizontal Avg. to Min. Average**	**Min. Maintained Avg. Vertical Levels (E Avg.)[3]**	**Avg. to Min. Ratio**
Walkway Class				
Sidewalks along streets by Area Classifications*				
Commercial	10	4:1	20	5:1
Intermediate	5	4:1	10	5:1
Residential	2	10:1	5	5:1
Park Walkways & Class I Bikeways	5	10:1	5	5.1
Pedestrian Tunnels	20	4:1	55	5:1
Pedestrian Overpasses	2	10:1	5	5:1
Pedestrian Stairways	5	10:1	10	5:1

***AREA CLASSIFICATIONS**

a) **Commercial**—A business area of a municipality where ordinarily there are many pedestrians during night hours. This definition applies to densely developed business areas outside, as well as within, the central part of a municipality. The area contains land use which attracts a relatively heavy volume of nighttime vehicular and/or pedestrian traffic on a frequent basis.

b) **Intermediate**—Those areas of a municipality often characterized by moderately heavy nighttime pedestrian activity such as in blocks having libraries, community recreation centers, large apartment buildings, industrial buildings, or neighborhood retail stores.

c) **Residential**—A residential development, or a mixture of residential and small commercial establishments, characterized by few pedestrians at night. This definition includes areas with single homes, town houses, and/or small apartment buildings. Certain land uses, such as office and industrial parks, may fit into any of the above classifications. The classification selected should be consistent with the expected nighttime pedestrian activity.

[1]There are conditions and situations which may suggest that increased vertical illuminances are appropriate to increase the perception of safety and reduce criminals' opportunities to operate under the cover of darkness. Vertical illuminances can improve facial recognition, recognition of peripheral elements and peripheral movement, and minimize deep shadows when compared to simply designing toward horizontal illuminance criteria. In densely populated areas, areas where nighttime activity is intermittent throughout the entire night, areas where architectural configurations provide opportunities for significant shadows, where narrow/deep entryways are frequent, where dense and high (1.2 meters; 4 feet and higher) landscaping occurs for great stretches, where pedestrians are likely to be alone and on a recurring schedule (e.g., shift workers walking to bus stops, walking home), where crime has been recorded as a community problem and/or where community officials predict future nighttime disturbances (based on anticipated future land use and development), consideration should be given to invoking the "Special Conditions" criteria.

[2]Values measured or calculated at ground level.

[3]Values measured or calculated (1.5 meters; 5 feet) above pavement, in both directions, parallel to the direction of travel on the walkway or bikeway.

Light Trespass Criteria

The amount of light extending beyond the limits of the roadway right-of-way can be considered a nuisance by abutters as well as wasted energy. The IES has established recommended limits of light trespass based on the expected ambient lighting conditions in certain use zones. These recommendations also use different values based on time of day noted as pre-curfew and post-curfew. Roadway lighting is expected to meet the pre-curfew conditions for installations where adaptive lighting is not used.

The zone classifications and descriptions are as follows:

E1: Low ambient lighting
Areas where lighting might adversely affect flora and fauna or disturb the character of the area. The vision of human residents and users is adapted to low light levels. Lighting may be used for safety and convenience but it is not necessarily uniform or continuous. After curfew, lighting may be extinguished or reduced as activity levels decline.

E2: Moderate ambient lighting
Areas of human activity where the vision of human residents and users is adapted to moderate light levels. Lighting may typically be used for safety and convenience but it is not necessarily uniform or continuous. After curfew, lighting may be reduced as activity levels decline.

E3: Moderately high ambient lighting
Areas of human activity where the vision of human residents and users is adapted to moderately high light levels. Lighting is generally desired for safety, security and/or convenience and it is often uniform and/or continuous. After curfew, lighting may be reduced as activity levels decline.

E4: High ambient lighting
Areas of human activity where the vision of human residents and users is adapted to high light levels. Lighting is generally considered necessary for safety, security and/or convenience and it is mostly uniform and/or continuous. After curfew, lighting may be reduced in some areas as activity levels decline.

The levels recommended for these areas are given in the table below. These values are lux values at the property line for a meter aimed at the closest luminaire or cluster of luminaires. For ease the calculations can be done using vertical illuminance at 1.5m in height aiming away from the property.

Figure 24: Recommended Light Light Trespass Values

Environmental Zone	Pre-Curfew Limitations*	Post-Curfew Limitations*
E1	1.0 (0.10)	0.0 (0.00)**
E2	3.0 (0.30)	1.0 (0.10)
E3	8.0 (0.80)	3.0 (0.30)
E4	15.0 (1.50)	6.0 (0.60)

Aesthetic Lighting Values

Accent lighting is sometimes added to prominent structures such as bridges and monuments. The amount of light required will depend on the ambient lighting in the immediate area. For example, a structure in a bright urban area will need more light to achieve a desired aesthetic effect than a structure in a darker, more rural, setting. The reflectance of the material is also a key element in the amount of lighting required. A dark structure requires more light applied to its surface than a light surface would in order to achieve the same apparent brightness.

Below are some basic recommendations of the illuminance of surfaces based on their surroundings. These levels are only a guide and need to be evaluated by a lighting designer experienced in the lighting of buildings and monuments.

Figure 25: Suggested Aesthetic Lighting Values

Area Description	*Average Target Illuminance vertical foot-candles (lux)*
Bright Surroundings and Light Surfaces	5 (50)
Bright Surroundings and Medium Light Surfaces	7 (70)
Bright Surroundings and Dark Surfaces	10 (100)
Dark Surroundings and Light Surfaces	2 (20)
Dark Surroundings and Medium Light Surfaces	3 (30)
Dark Surroundings and Medium Dark Surfaces	4 (40)
Dark Surroundings and Dark Surfaces	5 (50)

Work Zone Lighting

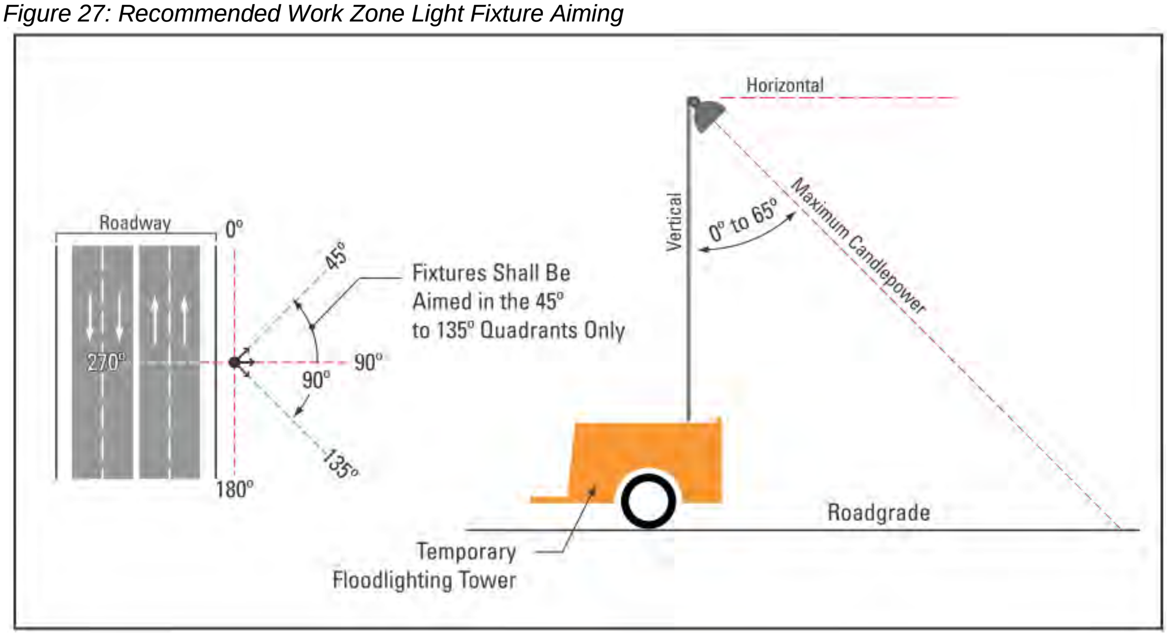
The lighting of work zones has two different functions. On is to provide adequate illumination for workers in the work zone to perform necessary tasks. The other is to provide motorists some supplemental lighting to help guide them through the work zone as well as compensate for the eye adaptation changes that take place because of the work zone lighting. The recommended values of lighting within the work zone, as recommended by a recent NCHRP study, are as follows:

Figure 26: Work Zone Lighting Values

Category	Minimum Illuminance Level	Area of Illumination	Application	Example Areas and Activities for Illumination
1	54 lux	General illumination through spaces	Large size visual task; low accuracy; general safety requirements	Excavation; sweeping and cleaning; movement areas in work zones; movement between tasks
2	108 lux	General illumination of tasks around equipment	Medium size visual task; low to medium contrast; medium accuracy; safety on around equipment	Paving; milling; concrete work around paver, miller and other construction equipment
3	216 lux	Illumination on task	High size visual task; low contrast; high accuracy and fine finish	Crack filling; pot filling; signalization or similar work requiring extreme caution and attention

The bright lighting required for the work zone changes a driver's adaptation so that an unlit road can be difficult to navigate. It is very important that temporary construction lights be aimed correctly and shielded so as not to provide disability glare for the motorist. Figure 27 below offers some guidance on aiming restrictions adjacent to travel lanes

Figure 27: Recommended Work Zone Light Fixture Aiming



Design Requirements

This section describes the design elements that are required for VTRANS roadway lighting projects.

Summary of Key Lighting and Electrical Design Elements

Lighting

- Maximum pole height is 35'. Typical pole shall be 35' with 6' tapered elliptical support arm unless approved by VTRANS in preliminary design.
- Pole shall be anodized aluminum unless approved by VTRANS in preliminary design.
- Breakaway transformer bases shall be used on all poles unless located where a risk is created for pedestrians. Refer to AASHTO Roadside Design Guide for reference.
- Lighting calculations shall be in accordance with this guide performed in AGI 32.

Electrical

- Typical conductor size for lighting circuits shall be #6 AWG copper between poles and #10 AWG copper in pole to luminaire to allow for voltage drop and provide mechanical strength unless otherwise approved by VTRANS. Voltage drop calculations shall be prepared to validate conductor size.
- Typical 120V branch circuit overcurrent protection shall be on single- pull 20A circuit breaker.
- Typical 240V branch circuit overcurrent protection shall be on double-pull 20A circuit breaker.
- 30% spare capacity shall be designed into service, distribution, and branch circuit systems.
- Typical street lighting utilization voltage shall be a 240/120V single phase service. Branch circuits shall alternate connections to phase conductors to adjacent light poles.
- Breakaway fuse holders and splices shall be used in all breakaway bases

LIGHTING DESIGN LAYOUT AND MODIFICATIONS

The lighting design criteria section provides the lighting levels and other criteria required for lighting designs for the Agency. Other considerations also go into the placement of lighting equipment as well as possibly adjusting some of the criteria values. This section describes some of those items.

System Layout and Geometry

The design approach from roadways typically starts with initial calculations, using the roadway optimizing tool in lighting software such as AGI 32, to establish maximum allowable spacing requirements for poles.

Figure 28: AGI 32 Screen Views

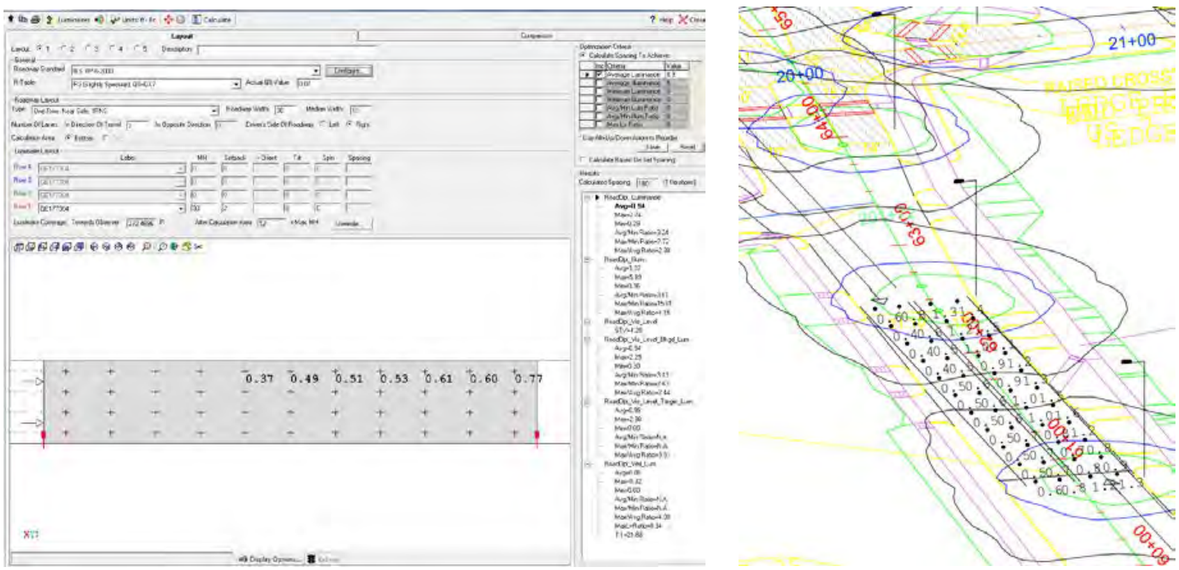
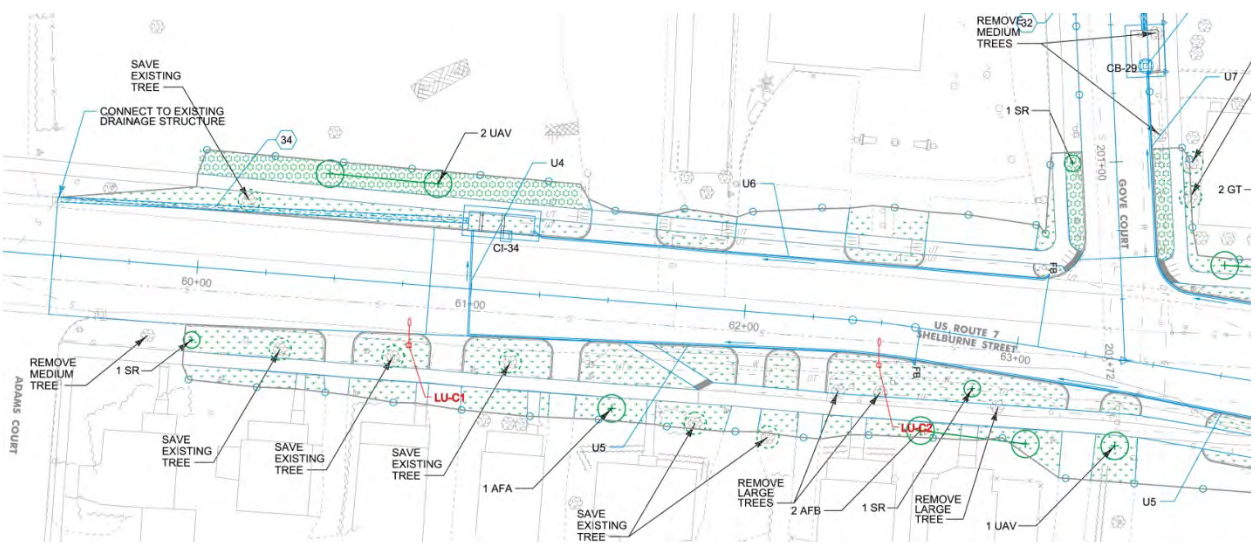


Figure 29: Layout Geometry



The designer would then work with plans of the proposed or existing roadway, locating poles in systematic and orderly arrangements on a plan showing all of the highway elements, utilities, landscaping, street furniture, and building and ROW limits. The pole locations then need to be checked against the roadway profile and cross section drawings to determine the actual installation condition for the poles as well as their maintainability.

The lighting industry has defined standard pole spacing layout designations. These standard pole spacing layout designations are one-sided lighting, opposite lighting, staggered lighting, and median lighting and are illustrated in Figure 30.

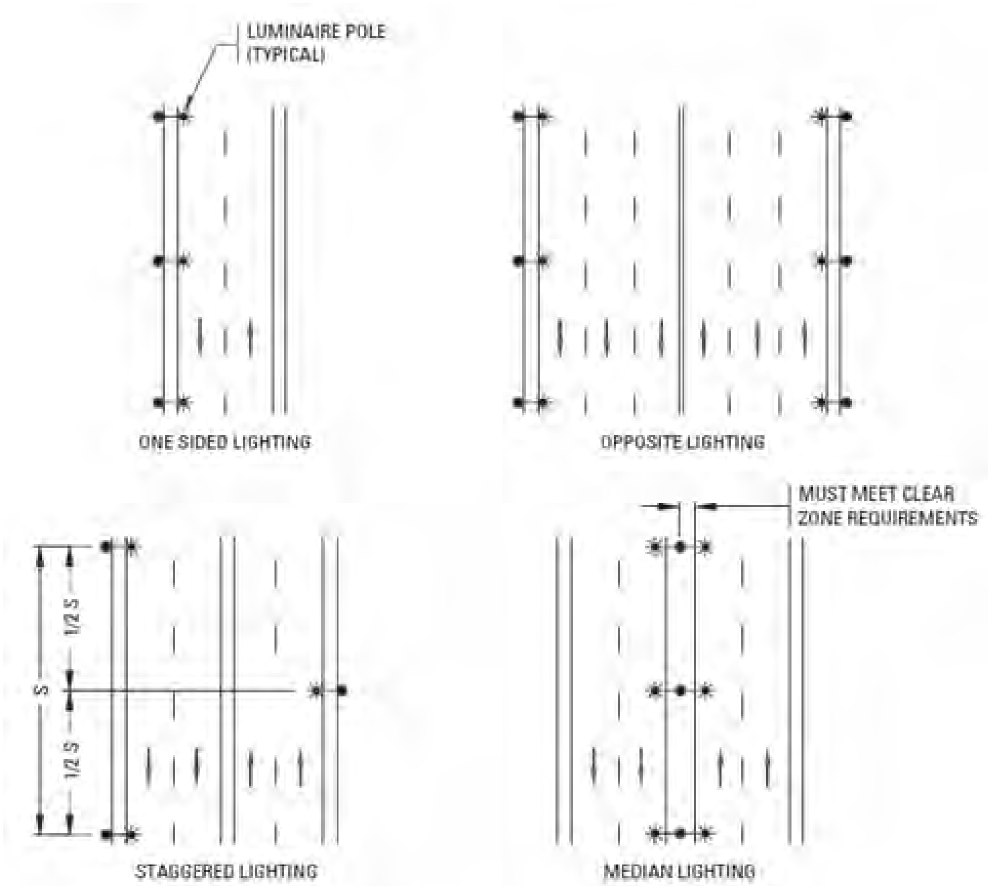


Figure 30: Standard Pole Spacing Layouts

Typically, one-sided spacing is used on roadways with one to three lanes; staggered spacing is typically used on roadways with three to six lanes, and opposite spacing is typically used on roadways with five or more lanes. Median lighting is typically used where the median is wide enough to accommodate poles and meet clear zone requirements, or where the poles are protected by barriers. From a capital cost standpoint, median lighting may be very cost effective as the number of poles required may be reduced by 50 percent over opposite lighting. However, median lighting may cost more to maintain.

VTRANS prefers one sided or opposite lighting with the luminaire located above the paved shoulder area from a maintenance standpoint. The consultant, however, will evaluate each project from a layout and cost perspective and consult with VTRANS engineering and maintenance staff for approval of the design approach.

For pole layout on collector/major/local streets to be coordinated with intersecting streets, the design should locate poles at start points such as cross street and then space the poles evenly within the maximum pole spacing defined by the calculations. The pole spacing may also need to be adjusted to suit driveways and utility conflicts.

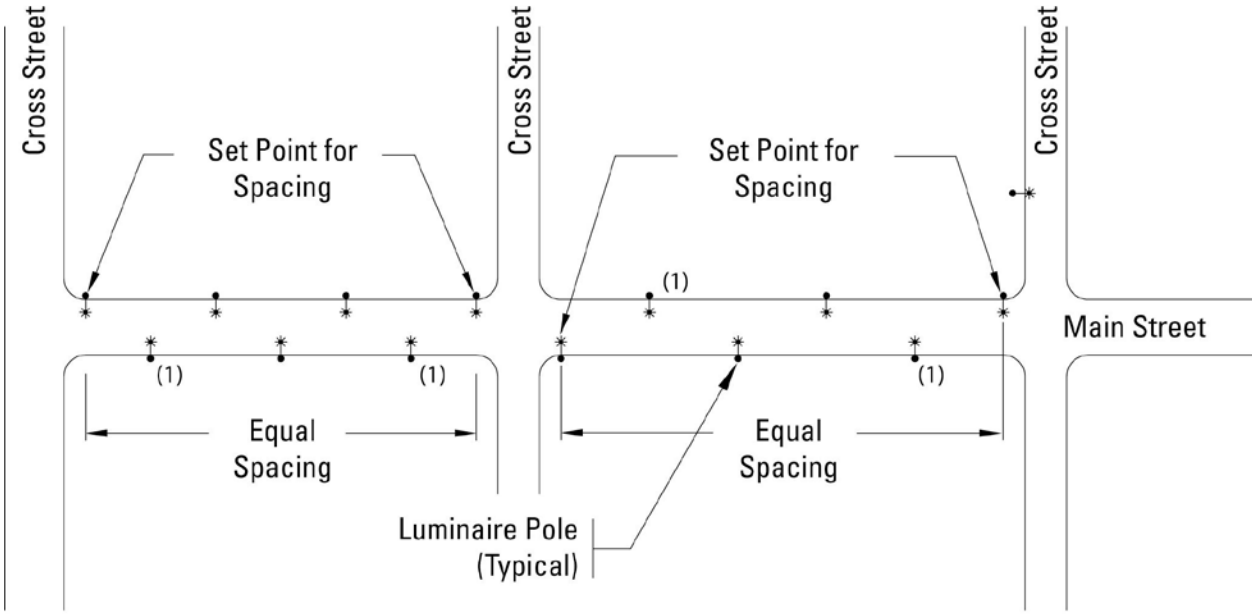


Figure 31: Adjusted Pole Spacing Layout

For highmast lighting the lighting calculation process is slightly different than for a typical roadway. It is recommended the designer develop lighting templates for a variety of highmast pole arrangements using various fixture quantities and distributions. This can be accomplished using various combinations of individual luminaires clustered on a given pole to create the most effective overall distribution of light through trial and adjustment. By combining efficient templates, the designer is able to produce optimal light distribution for the given road geometry. The variables will include mounting height, number of luminaires, optics, and orientation of optics, wattage, light source, and photometrics.

The templates will show the pole location with luminance or illuminance levels using contour lines. The contour lines should represent different levels of illuminance or luminance. Typically templates are developed in asymmetrical (long and narrow) or symmetrical (circular) patterns to suit road geometrics. The templates should be arranged on the site plan to show approximate pole locations, either digitally in a computer aided design (CAD) program as shown in Figure 32.

This method will give a rough pole layout and allow for optimization through trial and adjustment. Once the pole locations and pole distributions have been optimized, a lighting calculation should be undertaken for the entire interchange, defining lighting levels on the roadway. The lighting calculations will require further refinement, using trial and adjustment, until the desired levels are achieved. Highmast design will require many calculations and trial and adjustment cycles to provide an optimized design.

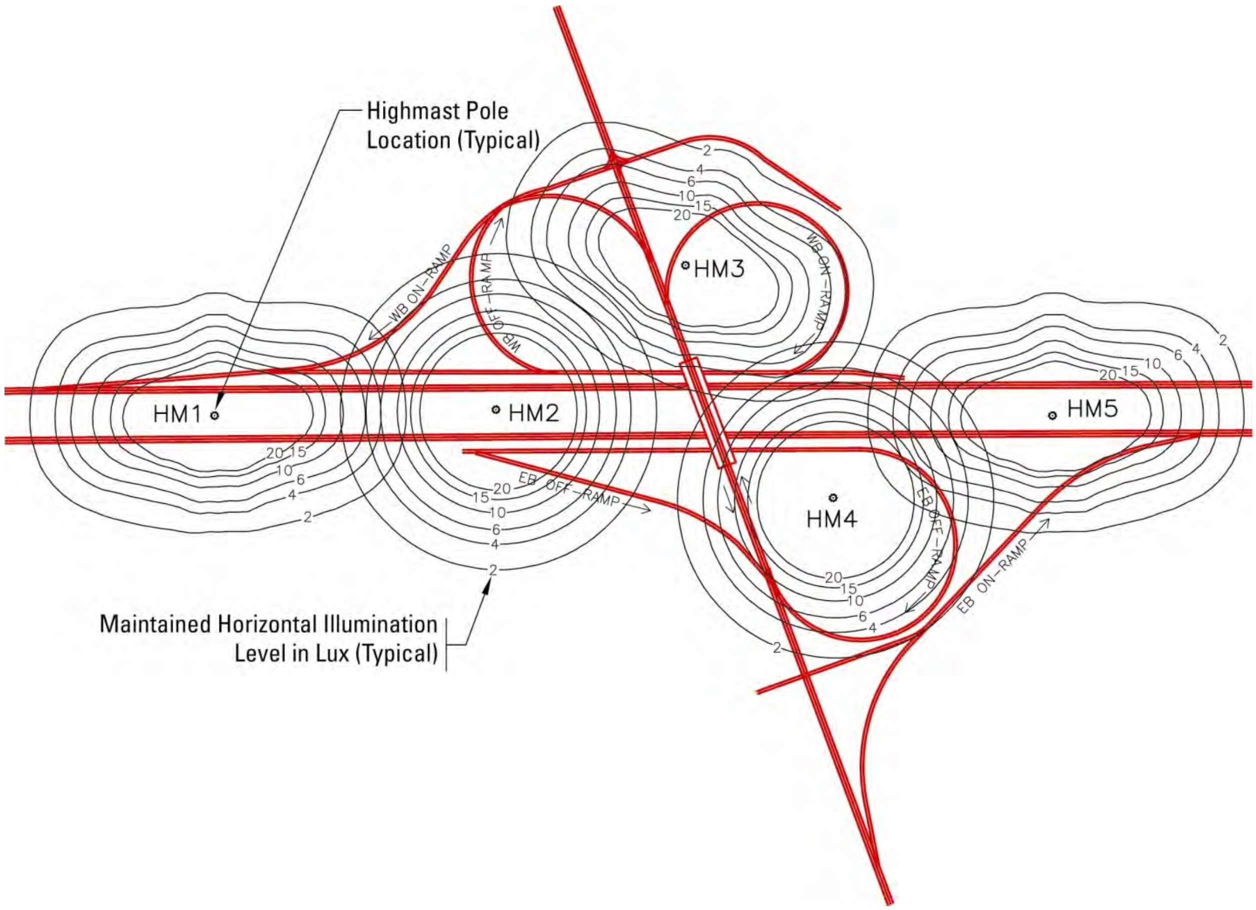


Figure 32: Template Driven High Mast Pole Layout

Roadside Hazards

As lighting is a road safety enhancement, poles should be placed so that they are not hazardous to errant motor vehicles. Therefore, poles should be located so as not to compromise the safety of the road user.

Where lighting is required on roadways with small radius horizontal curvature, poles should be positioned on the inside of the curve to reduce the potential for impacts by errant vehicles that overrun the entry to the curve. Where poles cannot be positioned on the inside of the curve, they should be located outside of the entry overrun areas as illustrated in the figure below.

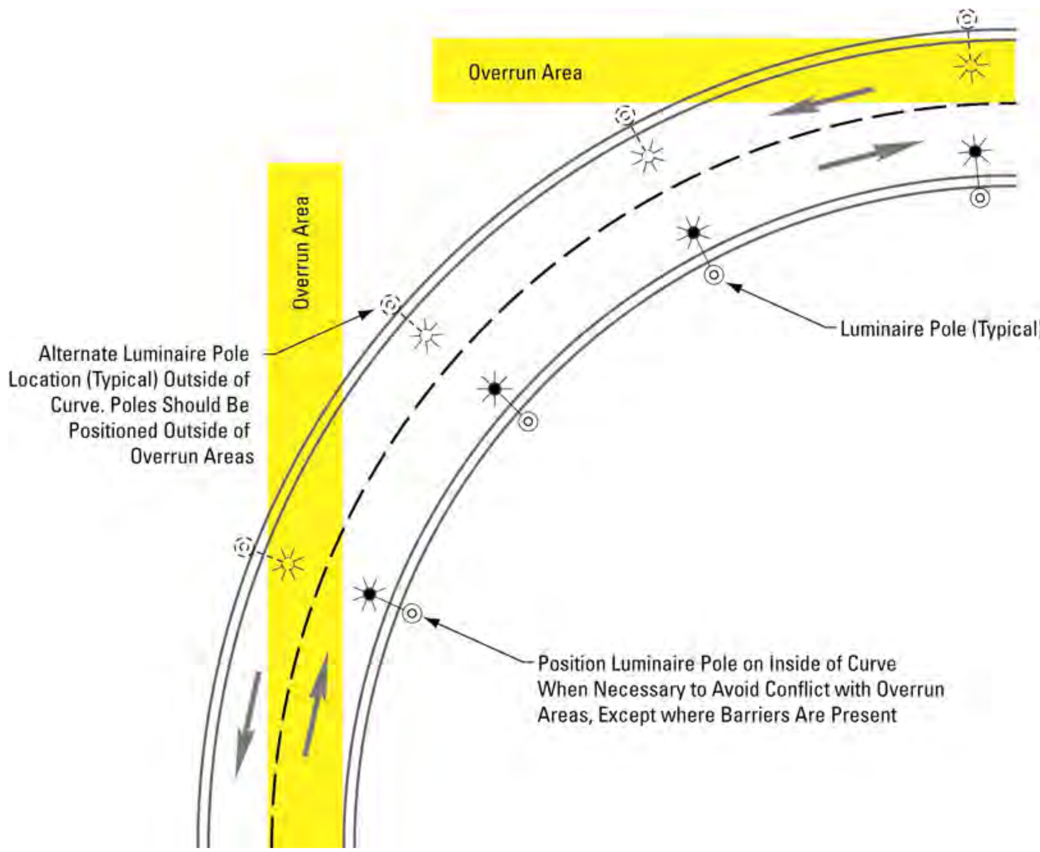


Figure 33: Pole Spacing on Curves

Poles should be offset away from the roadway a sufficient distance to minimize any potential hazard to drivers. In urban areas with curbs and gutters, poles should be placed at the back of the sidewalks to reduce the potential contact with motor vehicles. On highways and freeways, poles should be placed outside the clear zone or have a suitable breakaway device if placed within the clear zone.

A breakaway device typically attaches between the foundation and the pole to allow the pole to break away upon impact by a motor vehicle. Refer to Figure 35 for breakaway base characteristics when struck by a motor vehicle.

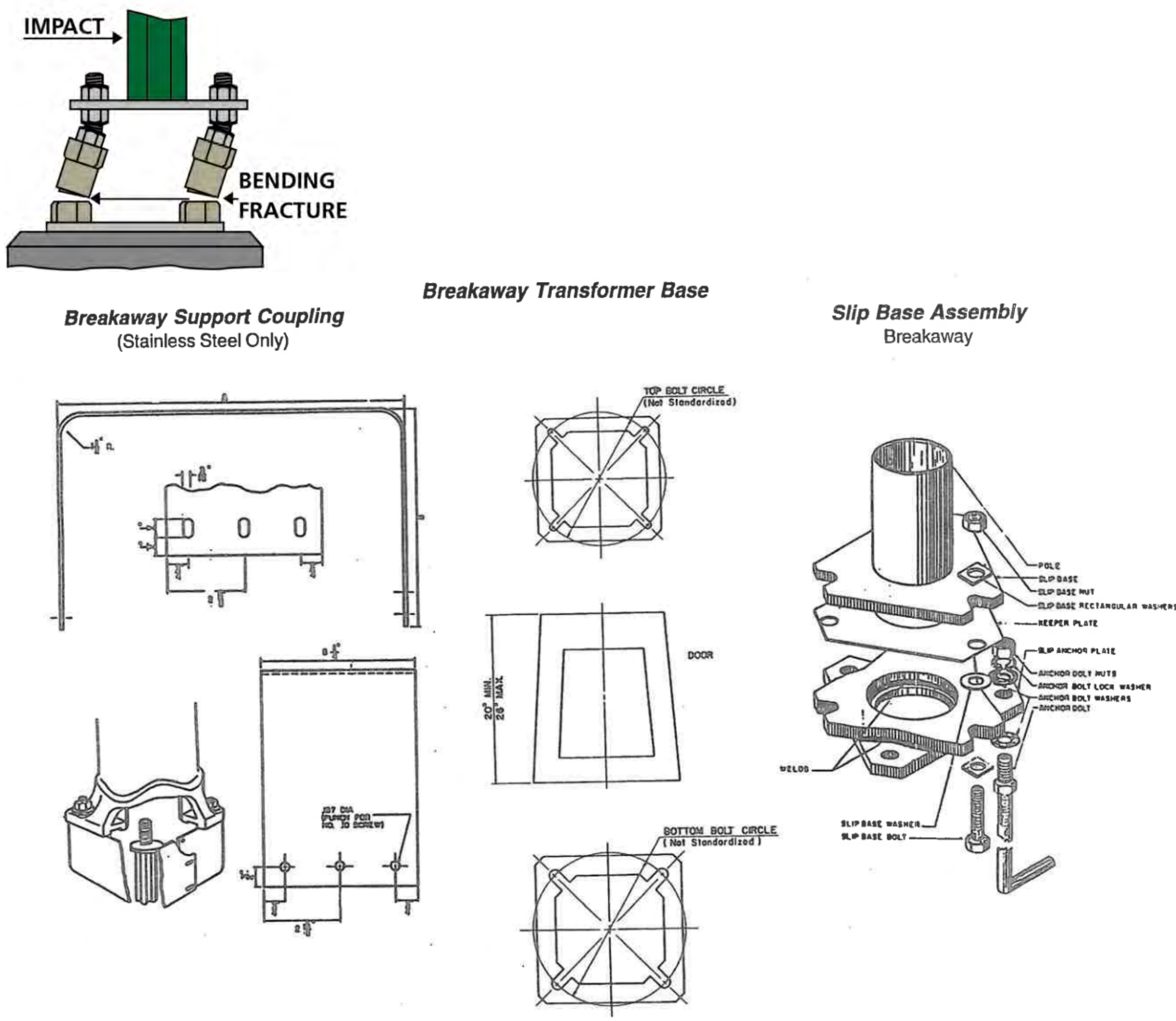


Figure 34: Breakaway Support Details

The clear zone is defined as the roadside border area adjacent to the roadway to be kept clear of fixed objects, which may be traversed by errant vehicles. Determining the clear zone is a function of design speed, traffic volumes, the presence of fill and cut slopes, the steepness of the slopes and the horizontal curvature of the road.

Refer to the AASHTO Roadside Design Guide for definitions of clear zone and requirements. VTRANS requires the use of transformer bases on all of their poles, unless the designer considers them not suitable for the installation and requests approval for the use of another type or a non-breakaway design.

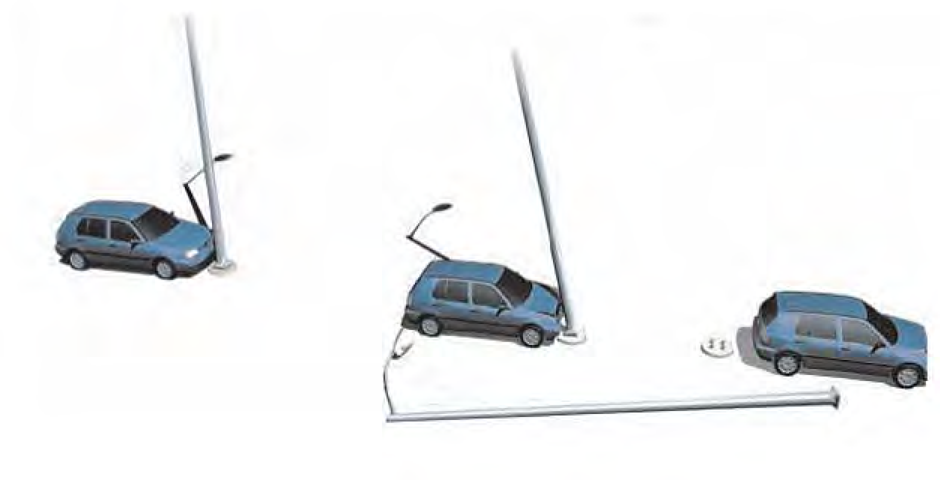


Figure 35: Pole with Breakaway Device

Adaptive Lighting

Adaptive lighting describes a lighting system that can be adjusted based on time of day use changes. For street and pedestrian lighting there are currently many dimming and step switching systems which are available to control the output of luminaires.

Several international standards now or soon will address adaptive lighting. The Institute of Lighting Engineers in the UK has issued Technical Report 27 Code of Practice for Variable Lighting Levels for Highways. The International Commission on Illumination is currently revising CIE 115 Lighting of Roads for Motor and Pedestrian Traffic to include advice for adaptive lighting. Both of these organizations have taken the approach that if the criteria for use changes based on the time of day then the lighting level required also changes.

For this guide lighting levels are based on the road type and the pedestrian volumes. For example a major road will require 1.2 cd/m2 when pedestrian levels are high but only require 0.6 cd/m2 when pedestrian volumes are low. Therefore, if a lighting system is equipped with dimming equipment, the lighting level can be changed based on the expected pedestrian volumes. This also applies to the pedestrian area lighting which is also based on pedestrian volumes.

If adaptive lighting is used in an installation all of the lighting criteria must be met for the operating conditions at that time. If a lighting system is dimmed to meet the low pedestrian volume values, the installation must continue to meet the required uniformity ratio and veiling luminance ratio given in this recommended practice.

Light Source Color Impacts and Modifiers

Much research has been done and is ongoing in the area of the color or more specifically, the spectral content, of a light source and its impact on visual performance. It has been observed that white light can produce the same visibility as a yellow/gold source at a lower design level in situations where the ambient light level is low (less than 3 cd/m^2). While the effect is accepted, how to apply it is a point of ongoing discussion. Because of this VTRANS has adopted the policy proposed by the IES Roadway Lighting Committee to allow mesoptic multipliers to be used to adjust the recommended design illuminance value in application of roads with speeds of 25 mph or less.

This, however, applies to very few VTRANS controlled roadways so the spectral content of sources or modifications to designs based on the S/P (scotopic/photopic) ratios of the source shall not be considered in project designs.

Luminaire Classifications

The IES has adopted a new way of classifying luminaires replacing the older classification system of cutoff, semicutoff, and noncutoff. These systems offer a more precise description of the distribution of a luminaire.

LCS - Luminaire Classification System

A new method referred to as the Luminaire Classification System (LCS) has been developed to better define luminaire distribution and efficiency. IESNA TM-15 Luminaire Classification System for Outdoor Luminaires defines this system in more detail. The LCS replaces the traditional IESNA luminaire cutoff classification system which uses designations like cutoff, non-off, semi-cutoff, and full cut-off. The traditional system was very limited as it only assessed the light distribution at very high angles and above horizontal.

The LCS defines a method of evaluation and comparison of outdoor luminaires. It provides a basic model which defines maximum lumens within defined angles within primary areas. The primary LSC areas are forward light, back light, and up-light zones as defined in the left panel of figure 36. Each of these zones is further broken into solid angles within the area. An example of the forward light zone and uplight zones are shown in the right panels of figure 36

The sum of percentages of lamp lumens within these three primary areas is equal to the photometric luminaire efficiency. The LCS enables designers to evaluate and compare the distribution of lumens for various types of luminaire optics, thus assisting in the selection of the luminaire most appropriate for the application. An example of measurements for various luminaires is defined in figure 37.

The benefit of this system is that it allows a designer to better select the optimal optics for a given application while at the same time reducing light trespass impacts and sky glow. The new classification system is intended to be used as a tool to assess the light output of luminaires.

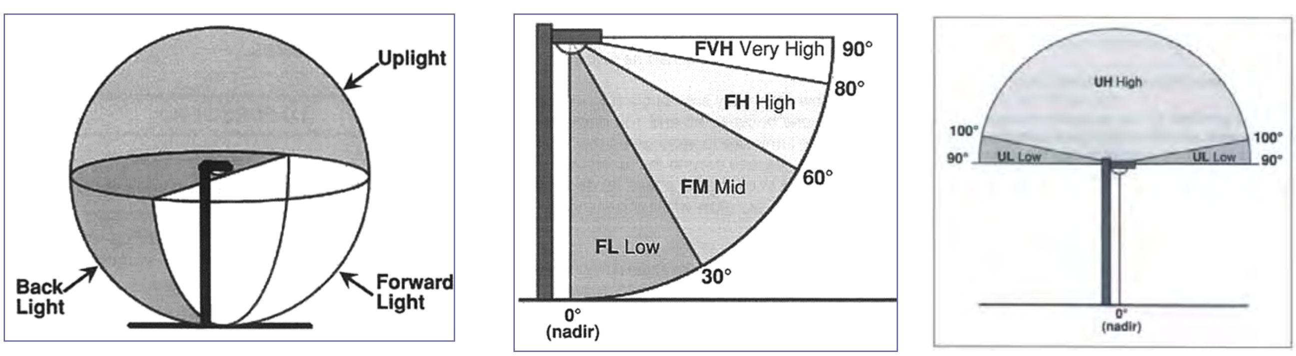


Figure 36: Lamp Lumen Zones and Front Light Zone (from IESNA TM-15)

The LCS zones for various luminaire optical systems are calculated and shown in the figure below. Through lighting photometric analysis software a designer can use the LCS assess the percentage of lumen output in the various zones. This is very useful when comparing luminaire optical system and how light is distributed from various luminaries. Figure 39 shows an example of what the data looks like from the manufacturer.

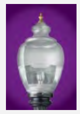
Metal Halide	 Internal Refractor Optic (250 W Type V)	 External Refractor Optic (250 W Type V)	 Louvered Reflector Optics (250 W Type III)	 Hydro-formed Refractor Optics with Horizontal Lamp (250 W Type I)	 Sag Lens Refractor Optics (250 W Type III)	 Sag Lens Refractor Optics (250 W Type I)	 Sag Lens Refractor Optics (100 W Type I)
Forward Light							
Luminaire Lumens	4133.4	5405.6	6306.5	6487.6	10115.6	10557.0	3716.3
% Lamp Lumens	19.70%	25.70%	30.00%	29.50%	46.00%	48.00%	45.90%
FL (0˚-30˚)	0.20%	0.90%	1.20%	2.40%	7.40%	13.10%	12.60%
FM (30˚-60˚)	5.40%	3.70%	14.40%	15.30%	27.20%	24.80%	23.40%
FH (60˚-80˚)	8.90%	17.30%	12.90%	11.20%	11.20%	10.00%	9.60%
FVH (80˚-90˚)	5.10%	3.80%	1.40%	0.50%	0.20%	0.10%	0.20%
Back Light							
Luminaire Lumens	4133.4	5352.5	4220.2	4880.5	5384.3	7138.1	2465.6
% Lamp Lumens	19.70%	25.50%	20.10%	22.20%	24.50%	32.40%	30.40%
BL (0˚-30˚)	0.20%	0.90%	0.80%	2.30%	5.40%	7.70%	7.20%
BM (30˚-60˚)	5.40%	3.60%	9.40%	13.20%	14.50%	17.00%	16.10%
BH (60˚-80˚)	8.90%	17.10%	8.80%	6.00%	4.40%	7.60%	7.00%
BVH (80˚-90˚)	5.10%	3.90%	1.00%	0.70%	0.10%	0.10%	0.10%
Up-light							
Luminaire Lumens	9997.6	2477.0	957.5	163.2	0.0	0.0	0.0
% Lamp Lumens	47.60%	11.80%	4.60%	0.70%	0.00%	0.00%	0.00%
UL (90˚-100˚)	10.70%	2.40%	1.40%	0.50%	0.00%	0.00%	0.00%
UH (100˚-180˚)	37.00%	9.40%	3.20%	0.20%	0.00%	0.00%	0.00%

Figure 37: LCS Comparison

For VTRANS projects luminaires shall be classified with the following limits:

Uplight high (% lamp): 0.0
Uplight low (% lamp): 0.0
Back very high (% lamp): 0.2
Back high (% lamp): 10.0
Front very high (% lamp): 0.5

BUG Rating System

Similar to the LCS the IESNA developed the Backlight-Up-light-Glare (BUG) rating system which establishes back (B), up-light (U), and glare (G) zonal lumen limits for luminaires.

Each category (backlight, up-light, and glare) consists of specific regions that surround the luminaire. Each region has specific upper limit criteria that must be met to obtain the rating. All of the criteria must be met for a luminaire to obtain the generalized B, U, or G rating. So, the rating for a specific metric is set by the lowest (highest zonal lumen value) performance criterion within the metric. The limits vary according to the lighting zone (LZ1 – LZ4) in which the luminaire is located.

Once this calculation is performed for each of the three metrics, the composite BUG rating can be reported. Forward, Back and Up-light Zones and Forward Light Zones show the BUG regions. Solid angle references are based on a sphere of data points around a luminaire.

Backlight considers the light leaving a luminaire in the opposite direction from the main aiming angle of the light. This is the percent lamp lumens or the luminaire lumens distributed behind a luminaire between 0º vertical (nadir) and 90º vertical. Within a lighting zone, the backlight rating will change depending on the luminaire's proximity to the property line. Backlight is evaluated for high (60º–80º), medium (30º–60º) and low (0º–30º) areas.

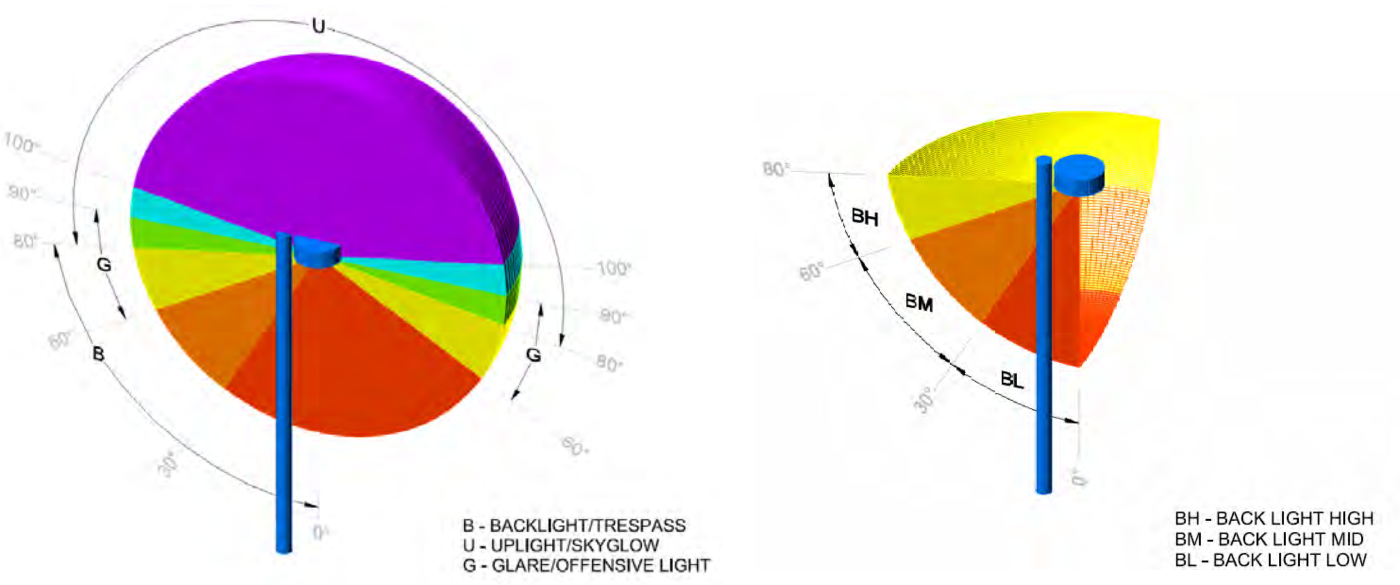


Figure 38: Backlight – Uplight - Glare (BUG) Ratings

Up-light measures the total light propagating from the luminaire in a near-horizontal or above-horizontal direction. This is an overall measure of the amount of light directly leaving the luminaire that may be associated with sky-glow. This measures the percent lamp lumens or the luminaire lumens distributed above a luminaire between 90º and 180º vertical. Up-light is evaluated for high (sky-glow: 100º–180º), low (90º–100º), forward light very high (80º–90º), and backlight very high (80º–90º).

Glare considers the light leaving a luminaire in the angles that are most likely to be a source of nuisance (or disabling) to passers-by either within or outside the property boundaries. The light that causes glare is also sometimes presumed to be a source of light trespass problems. However, in most cases, glare complaints are due to the brightness of the source and not because of spill light levels. For this reason, it is treated separately from the Backlight metric. Glare is evaluated for forward light very high and backlight very high (80º–90º), forward light medium (60º–80º) and backlight medium (60º–80º).

Note that the Up-light and Glare regions overlap as do the Glare and Backlight regions. While Glare is generally only considered important up to horizontal, the Up-light region has been shown to be important below horizontal, down to about 80°. Since these criteria regions are not intended to be additive or comprehensive to the complete output of the luminaire, this overlap is not a calculation inconsistency.

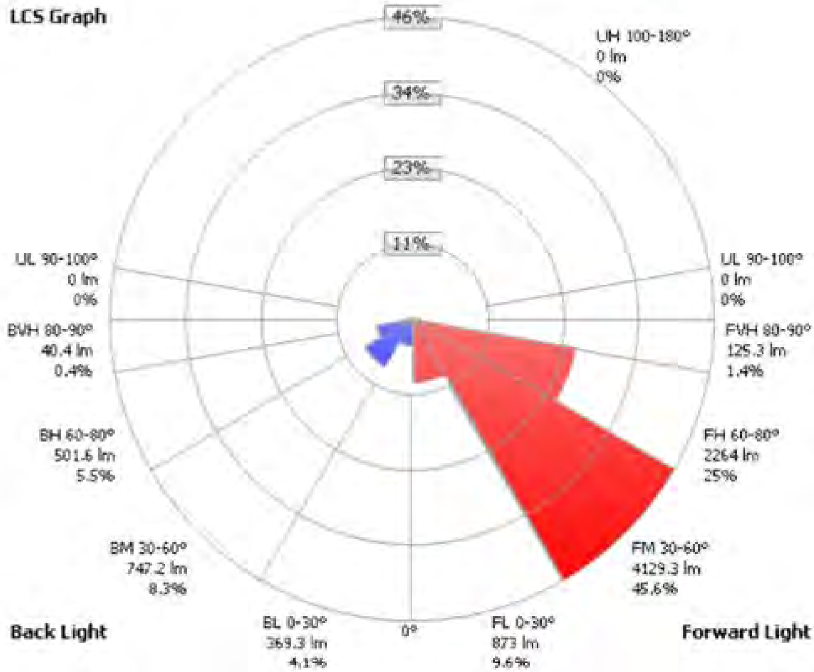
The region from directly below the luminaire forward to 60° is not considered in any of the criteria regions. This region is generally considered the ‘safe’ region of lumen output, where the light from a luminaire will be falling on the task area in an effective manner, and is also the region where the majority of lumens are outputted. Beyond this unmeasured region, the light may begin to be a source of glare, light trespass, sky-glow, or other concerns.

For VTRANS projects luminaires shall be classified with a maximum BUG rating of B2-U0-G2. Most LED luminaires now have BUG ratings which are documented in the photometric file as shown in Figure 39

OUTDOOR PHOTOMETRIC REPORT
CATALOG: LEDG 060 70 5K AS 2H L2

AcuityBrands.

LCS Graph



Scale = Max LCS %

Trapped Light: 0.9lm, 0%

ROADWAY SUMMARY

DISTRIBUTION:	TYPE II, VERY SHORT	
MAX CD, 90 DEG VERT:		0
MAX CD, 80 TO <90 DEG:		2,436.0
	LUMENS	% LAMP
DOWNWARD STREET SIDE:	7,391.6	81.7%
DOWNWARD HOUSE SIDE:	1,658.4	18.3%
DOWNWARD TOTAL:	9,050.0	100%
UPWARD STREET SIDE:	0	0%
UPWARD HOUSE SIDE:	0	0%
UPWARD TOTAL:	0	0%
TOTAL LUMENS:	9,050.0	100%

LCS TABLE

BUG RATING	**B2 - U0 - G2**	
FORWARD LIGHT	LUMENS	LUMENS %
LOW(0-30):	873.0	9.6%
MEDIUM(30-60):	4,129.3	45.6%
HIGH(60-80):	2,264.0	25%
VERY HIGH(80-90):	125.3	1.4%
BACK LIGHT		
LOW(0-30):	369.3	4.1%
MEDIUM(30-60):	747.2	8.3%
HIGH(60-80):	501.6	5.5%
VERY HIGH(80-90):	40.4	0.4%
UPLIGHT		
LOW(90-100):	0	0%
HIGH(100-180):	0	0%
TRAPPED LIGHT:	0.9	0%

Figure 39: Example of Published Luminaire Classifications for a Roadway Light Fixture

LIGHTING ELECTRICAL SYSTEM

This section presents guidelines and procedures that may assist the Designer in selecting the type and size of an electrical service for a lighting system. It also presents guidelines determining the size of lighting cables, determining the voltage drop on lighting circuits, and determining the type and number of connector kits used.

The electrical system for lighting is designed after the lighting system is fully designed. The luminaires are selected and the poles have been laid out in their final locations. The following is a list of the basic steps to follow when designing the electrical system for lighting:

1. Determine Power Source
   a. Location
   b. Size

2. Define Electrical Requirements Based on Selected Luminaires

3. Circuit Layout, Wire Size and Voltage Drop

4. Connector Kits

Power Source

Power source refers to the local power company's standard supply of electricity at secondary distribution systems, i.e., the system voltage supplied by the power company at the project site. Generally, a lighting system for an isolated intersection requires a single phase, 120/240 volts, 3-wire service. The first number, that is 120V, refers to the phase to neutral voltage in the transformer. The second number, that is, 240 volts refers to the phase-to-phase voltage. VTRANS prefers to use the 120/240 V service.

For larger projects such as interchanges and continuous roadway lighting, electrical services may be via either a single phase, 120/240 volts, 3-wire service or a 3-phase, 277/480 volts, 4-wire service. Three-phase circuits are composed of three single-phase circuits where the source voltages for each phase are 120 degrees apart. VTRANS prefers to split interchanges into smaller systems and use multiple 120/240 volt, 3 wire service if possible.

For information on the existing service, the designer could obtain data on the service type, circuits, and cable sizes either from as-built plans, VTRANS, or by coordinating a field visit to the site.

Selecting Power

Evaluating the electrical service size and type is the responsibility of the designer. Generally, a higher operating voltage will allow the design of a more efficient and cost effective system, but for simplicity and consistency VTRANS preference is to use a 60 Amp 120/240 Voltage service.

Luminaires are generally supplied in two types: a multi-tap which can operate on 120, 207, 240, or 277 voltage systems or fixed voltage. LED driver for luminaires are either fixed or autosensing within ranges of 120V-277V and 347V-480V. The designer should always specify a multi-tap system or autosensing driver in order to avoid problems with wrong luminaires installed in wrong systems. VTRANS policy is to utilize 120V and/or 240V luminaires.

For servicing non-signalized intersections, a 120/240V, 3-Wire, single phase service should be selected. A metered service pedestal is normally specified for a project with less than 8 luminaires. This is a typical design and requires each luminaire to have individual photocell control.

Selecting the Service Connection

The designer is responsible for the coordination with the power company on the availability of service within the proximity of the proposed installation location. Coordination with the power company should begin in the preliminary stages and should continue throughout the project. The designer should initiate the coordination activity with a telephone call and a follow-up letter with a preliminary concept layout of the lighting design. All correspondence should be documented and kept for reference throughout the project.

Determining Service Load

The electrical service required is dependent on several things, but the key item is the current required for the luminaires to operate. Each type of luminaire for each wattage size requires a different operating current at the specified operating voltage.

Lamp Type	Bulb Watts	Line to Line Voltage		Line Watts
		120V	240V	
HPS	100	1.2	0.6	127
HPS	150	1.6	0.9	189
HPS	200	2.1	1.0	253
HPS	250	2.6	1.3	312
HPS	400	3.9	2.0	475

Figure 40: Typical Operating Current for Common Lamps and Ballasts

In order to determine the required load of a proposed system, the designer may follow two steps.

1. Identify the total number of luminaires and the types of lamp such as 250 High Pressure Sodium. Include any luminaire within the system, signing and roadway.

2. Calculate the total load of the lighting system, based on the desired line voltage and operating current data as shown in Figure 40. The total amperage may be determined as follows:

$$\sum \left({}^{\#lamps}\!/\!_{type} \right) \times (current)$$

Equation 1: Minimum Total Amperage

LED luminaires do not have standard source size and loads. The operating current is also variable depending on the desired performance characteristics and output of the LED. The consumed load for these sources can best be found in the photometric test report used in performing the calculations for the project.

Electrical Distribution Equipment

Equipment is pole or stanchion mounted and refers to the meter socket, external disconnect switch and over current device. Equipment is usually housed in a weather tight enclosure and is installed on the side of the road where it can be easily accessed for maintenance. It performs the following functions:

1. Distributes electrical energy (current) to individual luminaires via lighting circuits.

Circuit Layout, Wire Size and Voltage Drop

After determining the service to be used for the lighting system, the next steps are to lay out the circuits, determine wire to be used, and calculate voltage drops. These three activities are interdependent, meaning that they are part of an iterative process to achieve an optimal system. There are also several methodologies to determine the same results. This section is directed toward the NEC equations and applications of calculations.

Circuit Layout

Circuits are run from the distribution equipment to the lights. Each circuit has a unique number designation. Following are some general guidelines for laying out circuits in a lighting system:

- For a 120/240V single phase, 3 wire system circuits are run together in groups of two circuits.
- Luminaires should always have alternating circuits so that if one circuit goes out, the one next to it will still be operating

The maximum number of luminaires allowed per circuit is a function of the line voltage, voltage drop, operating current of luminaire, circuit breaker trip size, and the length of the circuit run. All of these variables are interrelated to each other. VTRANS prefers the use of 20A circuits leaving 30% spare capacity on each circuit for future loads.

As a matter of safety, the Designer should not load the circuit to more than 80 percent of its capacity.

Optimal Cable Size

Generally, underground wiring for lighting is either #6 AWG or #4 AWG. Number 4 AWG cables are used for larger installations with longer circuit runs that may have higher voltage drop. The resistance of a larger size cable is lower than the resistance of a smaller size cable and, therefore, will generate a lower voltage drop over the same distance. VTRANS prefers #6 AWG for main branch circuit runs and #10 AWG cables used inside poles feeding luminaires.

The National Electric Code (NEC) has different requirements for cables that are #4 AWG or larger than for cables that are #6 AWG and smaller. It is important to follow all NEC requirements..

Voltage Drop Calculations

In order to assure that the luminaires on the lighting system have the proper operating current delivered to them, it is critical to determine the voltage drop on each circuit, including all branches. A branch circuit is any subsection of a circuit that may be diverged in a non-linear path to service other lighting devices on the same circuit. Branch circuits begin on the load side of the circuit breakers.

Voltage drops should be computed at each lighting pole or sign luminaire in an incremental order. For planning, however, the designer may also check the voltage drop at the last pole with the longest circuit run with the assumption that all loads occur at the last pole location. This procedure is only used for a quick checking of the most critical voltage drop on a circuit. VTRANS requires pole-by-pole voltage drop computations on each of the lighting circuits, for all roadway and interchange projects. The maximum allowed voltage drop for any given circuit should not exceed 5% of the operating voltage.

The procedure to determine the voltage drop is as follows:

1. Lay out the preliminary circuits.
2. Define a preliminary wire size.
3. For each circuit, determine the length of a circuit run between the electrical source and the load, i.e., the lighting standard.
4. Compute the voltage drop for each circuit based on the following equations:

$$\frac{2 \times L \times R \times I}{1000}$$

Equation 2: NEC Voltage Drop for Single Phase, 3 Wire Circuit

$$\frac{0.866 \times 2 \times L \times R \times I}{1000}$$

Equation 3: NEC Voltage Drop for 3 Phase, 4 Wire Circuit

Where,

L = one way length of circuit (feet)

R = conductor resistance (ohms per thousand feet). This is dependent on the wire size and is looked up in tables from the NEC handbook.

I = load current (amps)

The equation is based on the NEC Handbook.

Once the preliminary run of the voltage drop is computed, if the drop is unacceptable then it is necessary to go through this process again with either a new circuit layout or a different wire size, or possibly both, until an acceptable and efficient system is achieved.

The NEC voltage drop equation is based on a conductor temperature of 75°C. Since resistance will increase with a temperature increase, the NEC equation will produce a higher, more conservative voltage drop.

LIGHTING VOLTAGE DROP CALCULATION

PROJECT NAME:	VTRANS Sample	**PROJECT No.**	52460CP		
AREA OR LOCATION	Typical Interchange Approach	**SUBMITTAL DATE:**	dd/mm/yyyy		
CIRCUIT DESCRIPTION	Load Center #4 - Lighting (South of Load Center)	**PREPARED BY:**	Sean O'Rourke	**DATE:**	8.5.12
SERVICE VOLTAGE:	240 VOLTS L-L	**CHECKED BY:**		**DATE:**	
CIRCUIT VOLTAGE	120 VOLTS L-N	**BASIS:**	250W Cobra Head		
CIRCUIT NO.:	Circuit #1	**SUBMITTAL No.:**			
SPECIAL NOTES:	Load Center #4 - Lighting located at on ramp Calculation is typical for Circuits 3 and 5 since load is distributed evenly				

BASED ON NEC TABLE 9 (1999) EFFECTIVE Z @ 75 C, UNCOATED COPPER, .85 POWER FACTOR IN PVC Conduit

USING THE FOLLOWING FORMULA: VD=(L (feet) *I * rseg (ohms/1000'))/1000'

GIVENS	
60 CYCLE AC RESISTANCE	
ONE WIRE (CU) in PVC Cond.	
WIRE SIZE	75 DEG C
(#AWG)	Z eff (OHMS/1000')
4	0.29
3	0.23
2	0.19
1'	0.16
10	0.13
20	0.11
40	0.074
250	0.066
300	0.059

INPUT DATA								CALCULATED RESULTS					
Pole Number	Fixture Location Station	DISTANCE - One Way (feet) (L)	WIRE SIZE (AWG)	NUMBER OF WIRES CONDUCTORS	TEMPERATURE FOR CONDUCTOR RESISTANCE DEGREE "C"	FIXTURE SIZE (Rated) (Input VA)	NUMBER OF FIXTURES (ea location)	CONDUCTOR RESISTANCE (OHMS/1000') (r)	FIXTURE AMPERAGE (i)	SEGMENT RESISTANCE (Rseg=L*r/1000')	TOTAL AMPERAGE (I)	SEGMENT VOLTAGE DROP (V=I*Rseg)	ACCUMULATED VOLTAGE DROP (V1seg+V2seg+...)
8244	11031	306	40	4	75	257	1	0.07400	2.14167	0.023	27.842	0.630	0.630
8242	11630	599	40	4	75	257	2	0.07400	4.28333	0.044	25.700	1.139	1.770
8241	11934	304	40	4	75	257	1	0.07400	2.14167	0.022	21.417	0.482	2.251
8238	12842	908	40	4	75	257	1	0.07400	2.14167	0.067	19.275	1.295	3.547
8235	13758	916	40	4	75	257	1	0.07400	2.14167	0.068	17.133	1.161	4.708
8232	14670	912	40	4	75	257	1	0.07400	2.14167	0.067	14.992	1.012	5.720
8229	15582	912	40	4	75	257	2	0.07400	4.28333	0.067	12.850	0.867	6.587
8227	16112	530	40	4	75	257	1	0.07400	2.14167	0.039	8.567	0.336	6.923
8226	16332	220	40	4	75	257	2	0.07400	4.28333	0.016	6.425	0.105	7.027
8224	16846	514	40	4	75	257	1	0.07400	2.14167	0.038	2.142	0.081	7.109
									0.00000		0.000		
									0.00000		0.000		
									0.00000		0.000		
									0.00000		0.000		

MAXIMUM VOLTAGE DROP:	7.11
PERCENT VOLTAGE DROP:	2.96%
CONDUCTOR SIZE:	O.K.

Figure 41: Example of Voltage Drop Calculations, NEC Method

Specifying Electrical Distribution Equipment

The electrical distribution equipment is determined based on the combined load on all circuits.

Connected Load

The connected load refers to the total current and power in each circuit. It is defined by power (kilowatts KW) and current (amps).

The power is determined by summing the line wattage of each luminaire on the circuit.

Poles

This term refers to the number of electrical connection points of the circuit breaker. A single-pole overcurrent device is normally used on all VTRANS lighting projects operating at 120V, while two-pole connection system is the standard for VTRANS lighting projects operating at 240V.

Frame Size

The frame size refers to the amperage size of the main circuit breaker. A frame size of 100 or 200 amps is normally used on highway lighting projects. All conductors need to be sized per NEC for the installed breaker size.

Trip Size

The trip size refers to the amperage size of each branch circuit breaker. It is primarily used to safely disconnect the circuit in the event of an overload on the circuit breaker. For lighting, the normal operating load shall not exceed 80% of the trip size. Spare capacity is in additional to this. A trip size of 20 ampere is normally used on VTRANS lighting projects.

Connector Kits

Connector kits serve two purposes in a typical lighting design. First, connector kits are used for making a serviceable waterproof splice connection of lighting cables for each conductor or duct cable in electrical junction devices such as electrical manholes. Secondly, connector kits are used to connect branch circuit conductors to the luminaire (ballast circuit) conductors in the handhole or transformer base of lighting structures.

There are four types of connector kits; In-Line Fused, In-Line Unfused, Fused Y, and Unfused Y. Fused connectors provide safety measures against knockdown of lighting poles, which causes the cables in the splice box to be disconnected without exposing any of the internal cable wiring. Note that all fuse holders, splices and connector kits used in Break-away poles need to be waterproof.

1. *Fused vs. Unfused*: When a branch circuit conductor must be connected to the luminaire a fused connector shall be used. If a branch circuit conductor is being spliced in a junction device an unfused connector should be selected. Neutrals are never fused.

2. *In-line vs. "Y" Connection: In-line connector kits are* used in structures for continuous runs of cables. In-line connectors may be unfused when used in underground handholes and fused when used in pole bases. "Y" connector kits are used where a single duct cable must be spliced and branched in multiple directions.

Lighting Legend

The lighting legend includes symbols and detail callouts that provide the following information for each proposed pole and luminaire: type of luminaire and mounting detail, type and size of cable or wires required, the number and type of connector kits, the station number and offset, the pole number, the mounting height and mast arm length and the circuit number.

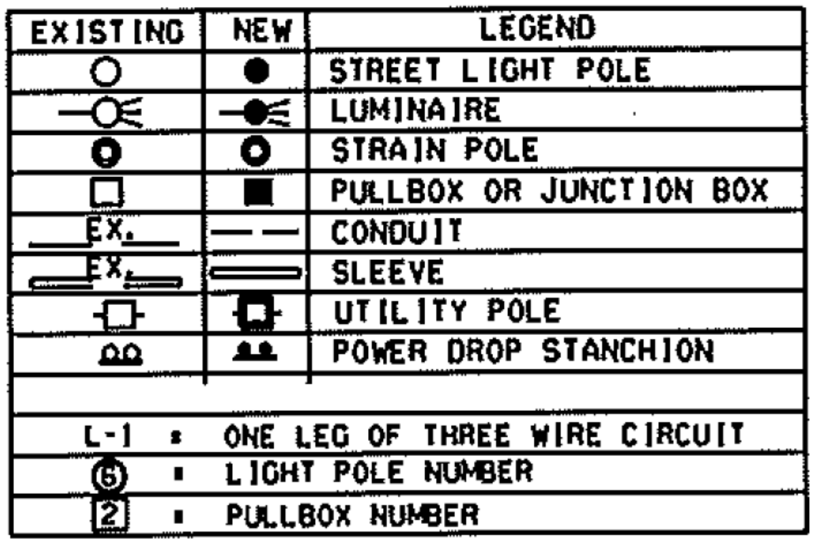


Figure 42: VTrans Standard Drawing Symbols

Example Design

The design example included steps through the lighting design process for a project

LIGHTING DESIGN EXAMPLE

This section includes an example for the lighting design of a roundabout. This example only covers the requirements for the lighting design described in Step 1 & 2 in the Design Procedure section of this guidance document.

Step 1 – Scoping

Gather information about the existing condition and proposed conditions as well as traffic data, crash data, and prepare a warrant analysis. Approximate nighttime pedestrian counts are also required.

Example of Crash Data (obtained from VTRANS)

Page: 14

Vermont Agency of Transportation
General Yearly Summaries - Crash Listing: State Highways and All Federal Aid Highway Systems
From 01/01/05 To 12/31/09 General Yearly Summaries Information

Date: 02/22/2010

Route: US-7 Continued ...

Reporting Agency/ Number	Town	Mile Marker	Date MM/DD/YY	Time	Weather	Contributing Circumstances	Direction Of Collision	Number Of Injuries	Number Of Fatalities	Direction	Road Group
0403/9296-05	Burlington	1.2	06/06/2005	15:43	Cloudy	No improper driving, Inattention, Failed to yield right of way	No Turns, Thru moves only, Broadside ^<	0	0	N	SH
0403/10150-05	Burlington	1.2	07/19/2005	13:19	Cloudy	No improper driving, Followed too closely	Rear End	0	0		SH
0403/10984-05	Burlington	1.2	07/29/2005	13:37	Clear	Unknown	Left Turn and Thru, Broadside v<--	0	0		SH
0403/10681-05	Burlington	1.2	07/30/2005	13:07	Clear	Unknown	Rear End	0	0		SH
0403/13890-05	Burlington	1.2	10/12/2005	* 17:15	Cloudy	Other improper action, Unknown	Same Direction Sideswipe	0	0	N	SH
0403/7075-06	Burlington	1.2	05/03/2006	08:15	Rain	No improper driving, Failed to yield right of way, Visibility obstructed	Left Turn and Thru, Angle Broadside -->v--	0	0	S	SH
0403/3992-07	Burlington	1.2	03/16/2007	08:20	Clear	No improper driving, Failed to yield right of way	No Turns, Thru moves only, Broadside ^<	0	0	N	SH
0403/4456-07	Burlington	1.2	03/17/2007	*19:58	Snow	Inattention, Failed to yield right of way, No improper driving	Left Turn and Thru, Same Direction Sideswipe/Angle Crash vv--	0	0	S	SH
VT0040100/2008-1480	Burlington	1.2	01/23/2008	(15:18)	Clear	Inattention, No improper driving	Rear End	0	0	N	SH
VT0040100/2008-11811	Burlington	1.2	06/09/2008	15:06	Clear	Inattention, No improper driving	Rear End	0	0	W	SH
VT0040100/2008-20693	Burlington	1.2	09/12/2008	01:45	Clear	No improper driving	Head On	0	0		SH
VT0040100/2009-11906	Burlington	1.2	05/28/2009	10:15	Rain	Followed too closely, No improper driving	Rear End	0	0	S	SH
VT0040100/09-13016	Burlington	1.2	06/09/2009	14:55	Clear	No improper driving		0	0	N	SH
VT0040100/09130 16	Burlington	1.2	06/09/2009	14:55	Clear	No improper driving		0	0		SH
VT0040100/09BU1 3023	Burlington	1.2	06/09/2009	15:38	Cloudy	No improper driving, Distracted	Rear End	0	0	S	SH
VT0040100/09-23462	Burlington	1.2	09/28/2009	* 20:19	Rain	Inattention, No improper driving	Rear End	0	0	S	SH
0403/4332-05	Burlington	1.23	03/08/2005	09:15	Snow	Driving too fast for conditions, Followed too closely, No improper driving	Rear End	0	0	N	SH
0403/2199-06	Burlington	1.23	02/02/2006	* 05:52	Cloudy	No improper driving, Failed to yield right of way	Left Turn and Thru, Same Direction Sideswipe/Angle Crash vv--	0	0		SH

Example of Traffic Data (obtained from VTRANS)

Traffic Section	AADT		DHV		%T		%D		ESALs	
	2013	2033	2013	2033	2013	2033	2013	2033	2013~2033	2013~2053
North Leg: Alt US 7	12,600	13,200	1,400	1,500	0.9	1.6	54	54	2,180,000	5,350,000
Northeast Leg: US 7	5,400	5,700	510	540	1.4	2.4	59	59	1,596,000	3,890,000
East Leg: Ledge Rd	1,200	1,300	110	120	0	0	57	57	109,000	250,000
South Leg: US 7	18,800	19,700	2,000	2,100	1.0	1.7	54	54	3,882,000	9,482,000
West Leg: Locust St	1,500	1,600	160	170	0	0	61	61	181,000	411,000

Prepare Warrant Analysis

The design guide includes a Lighting Warrants section outlining the warrant procedures for VTRANS roadways. In that section it is stated the "roundabout are always warranted for lighting due to the geometry of the roundabout and limitations with fixed headlights".

No additional warranting analysis is required for this project.

Step 2 – Preliminary Plans

The roundabout consists of a 5 leg intersection being replaced with a roundabout at the intersections of major and local streets.

Obtain Recommended Lighting Levels

Lighting levels are given in the Design Criteria section of the guidance document. For a project like this, several different requirements need to be met for the roundabout, approach roadway, crosswalks, sidewalks, and light trespass. The criteria from the document recommends the following:

For this area nighttime pedestrian volumes were found to be Medium (between 11 and 100 pedestrians during the first hour of darkness). The intersecting roads have a functional classification of Major and Local.

Major /Local Roundabout, Medium Pedestrian

Maintained horizontal illuminance – 2.0 fc (20 lux)
Eavg/Emin uniformity - 3.0
Crosswalk Illuminance (equal to horizontal requirements) – 2.0 fc (20 lux)
The horizontal illuminance is calculated on the road surface only. The crosswalk illuminance is the illuminance on a plane directed towards the approaching driver at a Safe Sight Stopping Distance.

Approach Roadways
Major Roadway, Medium Pedestrian
Maintained Average Luminance – 0.9 cd/m^2
Lavg/Lmin uniformity – 3.0
Lamx/Lmin uniformity – 5.0
Maximum veiling luminance ratio – 0.3

Local Roadway, Medium Pedestrian
Major Roadway, Medium Pedestrian
Maintained Average Luminance – 0.5 cd/m^2
Lavg/Lmin uniformity – 6.0
Lamx/Lmin uniformity – 10.0
Maximum veiling luminance ratio – 0.4

Sidewalk Area
Maintained horizontal illuminance – 0.5 fc (5 lux)
Minimum vertical illuminance – 0.2 fc (2 lux)
Horizontal uniformity Eavg/Emin – 4.0
The vertical illuminance value is given as a minimum point, along the sidewalk, in both travel directions. It is noted that immediately adjacent to the fixture these values can be excluded from the calculation.

Light Trespass

The area around this roundabout would be classified as an E2 or E3 lighting zone. Due to the school activity adjacent to the site it is assumed to be and E3. Since the lighting system will not be dimmed or extinguished then pre-curfew values apply. Values can be applied to either the property line or at the location of obtrusive light concern which for roadways will typically be the residence.

Maximum illuminance – 0.8 fc (8 lux)
The illuminance value is the amount of light striking a meter pointed at the nearest light source. The research was based on excluding all other sources but for the purpose of typical roadway calculations, all of the sources can be considered

Determine Light Loss Factor

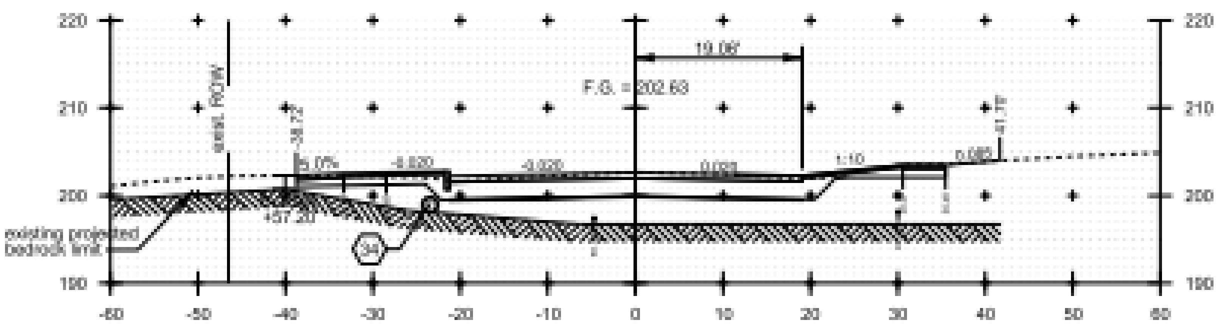
Many components go into determining a light loss factor for a source. These include the estimate lumen maintenance of the source, projected dirt depreciation and cleaning cycle, and other equipment related factors. The method for determining LLF is described in ANSI/IES RP-8 Standard Practice for Roadway Lighting.

For VTRANS projects, a LLF of 0.70 will be used unless otherwise calculated and accepted by VTRANS.

Review Site and Proposed Work

Review site and proposed work for topography, obstructions, landscaping, utilities, retaining walls, and other obstructions which need to be accounted for in pole placement and lighting calculations.

It is important to not only consult plans for coordination issues but also to evaluate profile and cross section drawings.



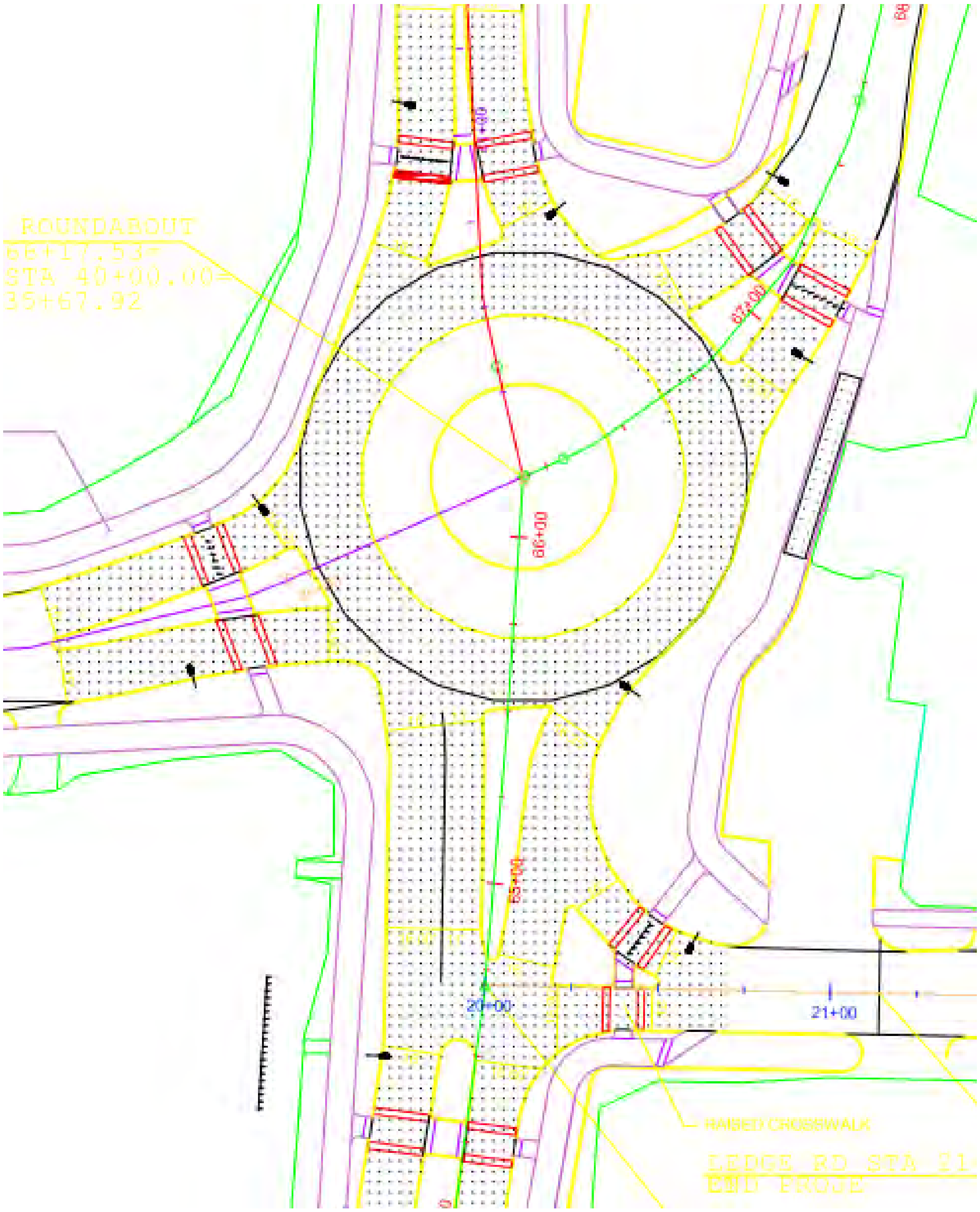
60+50

Perform Calculations and Layout

Calculation should be performed in the lighting software AGI 32 for calculation review by VTRANS. Other software may be used but calculations must then be submitted with a licensed copy of the software to allow review of the calculations.

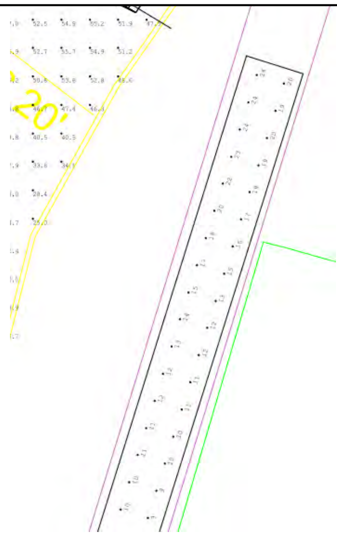
Roundabout Grid

Illuminance fc (Lux)
Average= 2.67 (26.71) Maximum= 5.3 (57.3)
Minimum=0.89 (8.9) Avg/Min=3.00
Max/Min=6.44



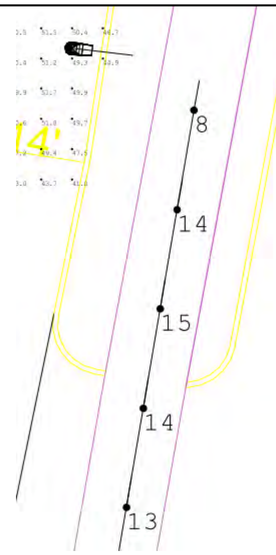
Sidewalk Horizontal

Illuminance- fc (Lux)
Average=1.5 (15) Maximum= 2.4 (24)
Minimum=0.9 (9) Avg/Min=1.67
Max/Min=2.67



Sidewalk Vertical

Illuminance- fc (Lux)
Average= 1.28 (12.8) Maximum=1.5 (15)
Minimum= 0.8 (8) Avg/Min=1.60
Max/Min=1.88

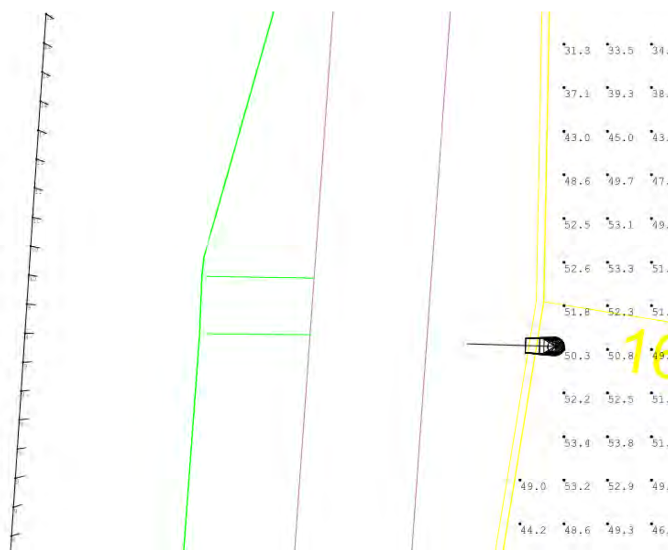


Crosswalk

Illuminance-fc (Lux)
Average=2.04 (20.4) Maximum=2.22 (22.2)
Minimum= 1.77 (17.7) Avg/Min=1.15
Max/Min=1.25

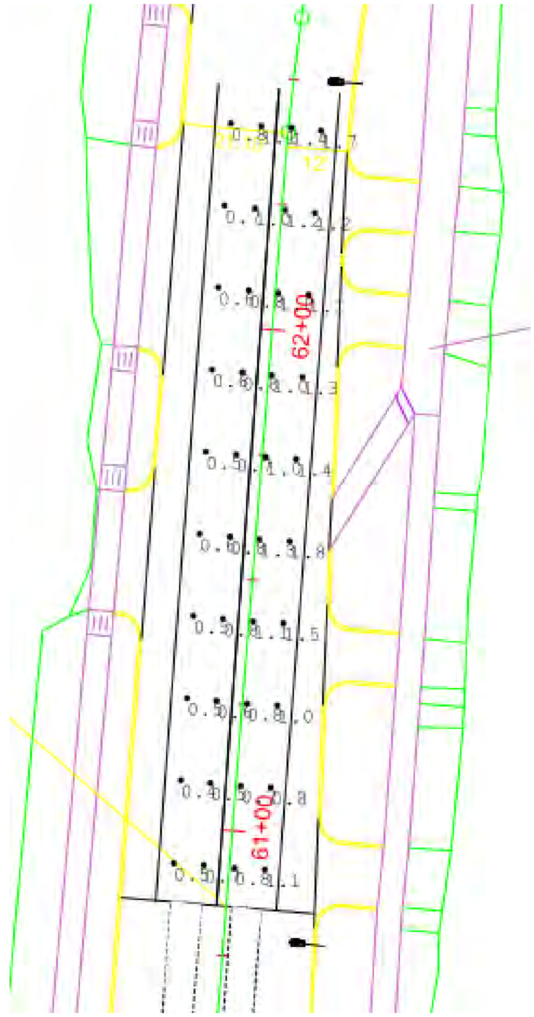
Light trespass

Illuminance-fc (Lux)
Average=0.98 (9.80) Maximum=1.2 (12)
Minimum=0.4 (4) Avg/Min=2.45
Max/Min=3.00



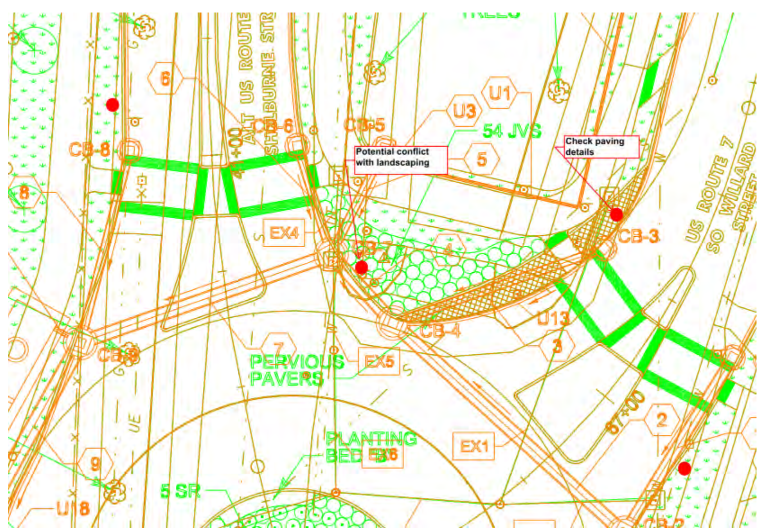
Road_Luminance
Luminance (Cd/SqM)
IES RP-8-2000
Average=0.92 Maximum=1.8
Minimum=0.4 Avg/Min=2.30
Max/Min=4.50 Max/Avg=1.96

Road_Veil_Lum
Veiling Luminance (Cd/SqM)
IES RP-8-2000
Average=0.08 Maximum=0.19
Minimum=0.02 Avg/Min=4.00
Max/Min=9.50 Max/Avg=2.38
MaxLvRatio=0.21



The calculations performed for this roundabout show compliance with all of VTRANS lighting standards with the exception of the light trespass limits which calculate a maximum of 1.2 fc (12 lux) with the allowable for this lighting zone of 0.9 fc (9 lux). This results should be discussed with VTRANS in order to evaluate if the conditions warrants exceeding the recommendations included in this guide or whether selective house-side shields should be used as part of this project.

A conflict drawings should also be prepared to discuss with other disciplines potential conflict with landscaping or paved areas. Underground utilities should simply be avoided in design.



Glossary of Terms

This section defines the terminology of roadway lighting

Accommodation: the process by which the eye changes focus from one distance to another.

Adaptation: the process by which the visual system becomes accustomed to more or less light or of a different color than it was exposed to during an immediately preceding period. It results in a change in the sensitivity of the eye to light.

Arrangement: the repeating pattern of luminaires on a roadway. Usually described as opposite, staggered, one-side, center-suspended, or median mounted.

Ballast: a device used with an electric-discharge lamp to obtain the necessary circuit conditions (voltage, current and waveform) for starting and operating.

Beacon lighting: a single luminaire that will identify the presence of an intersection or an interchange or potential conflict with other traffic and physical features and will serve as a warning or marker.

Bifurcation area: the triangular shaped area between two diverging lanes, beyond the point of physical separation of one lane from the other. This area is immediately beyond the decision point where a driver must commit to one lane or the other, and lies in the direct line of travel of an overrunning vehicle.

bidirectional reflectance-distribution function (BRDF): the ratio of the differential luminance of a ray reflected in a given direction to the differential luminous flux density incident from a given direction of incidence, which produces it.

Bikeway: any road, street, path, or way that in some manner is specifically designated as being open to bicycle travel, regardless of whether such facilities are designated for the exclusive use of bicycles or are to be shared with other transportation modes.

Brightness: see **luminance** and **subjective brightness.**

Candela, cd: the SI unit of luminous intensity. One candela is one lumen per steradian. Formerly candle. (See Figure 43.)

Candela per square meter, Cd/m^2 :the SI unit of luminance equal to the uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of one lumen per square meter or the average luminance of any surface emitting or reflecting light at that rate.

Candlepower, cp: luminous intensity expressed in candelas. (It is no indication of the total lumen output)

Central (foveal) vision: the seeing of objects in the central or foveal part of the visual field, approximately two degrees in diameter. It permits seeing much finer detail than does peripheral vision.

Contrast sensitivity: the ability to detect the presence of luminance differences. Quantitatively, it is equal to the reciprocal of the contrast threshold.

Contrast see **Luminance Contrast**.

Contrast Threshold: the minimal perceptible contrast for a given state of adaptation of the eye. It also is defined as the luminance contrast detectable during some specific fraction of the times it is presented to an observer, usually 50 percent.

Conflict: A conflict occurs whenever the paths followed by vehicles diverge, merge or cross

Conflict Area: *Is* an area of a roadway where the motorist's special attention is required in order to interpret the functional features (e.g. bullnose) and / or activities (e.g. pedestrians, turning vehicles, railroad grade crossing) of the roadway, in order to make a decision on their driving routine. It is that area which encompasses all of the conflict points.

Conflict Points: Points at which conflicts can occur.

Continuous Lighting: A fixed overhead lighting system designed to provide a specific level of illuminance, luminance and uniformity of light on the roadway throughout a highway complex.

Crosswalk: see **pedestrian crosswalk**.

Diffuse reflectance: the ratio of the flux leaving a surface or medium by diffuse reflection to the incident flux.

Directional reflectance: the reflectance in a given direction from an incident ray reaching the surface or medium from a given direction. See **bidirectional reflectance-distribution function**.

Disability glare: glare resulting in reduced visual performance and visibility. It often is accompanied by discomfort. See **veiling luminance**.

Discomfort glare: glare producing discomfort. It does not necessarily interfere with visual performance or visibility.

Entrance Ramp Conflict Area: That area of an entrance ramp from the bullnose (covering both the ramp lane(s) and the right through lane) to the end of the ramp taper.

Exit Ramp Conflict Area: That area of an exit ramp *and the right through lane* from the beginning point of the bifurcation area (neutral area) to the end of the gore area and extended 15 to 40 meters-dependant on the design speed- <u>for both the ramp lane(s) and the right through lane.</u>

Foot-candle, fc: the unit of illuminance when the foot is taken as the unit of length. It is the illuminance on a surface one square foot in area on which there is a uniformly distributed flux of one lumen, or the illuminance produced on a surface all points of which are at a distance of one foot from a directionally uniform point source of one candela.

Glare: the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort, or loss in visual performance and visibility. See **disability glare**, **discomfort glare**.

Intersection: the general area where two or more roadways (highways) join or cross, including the roadway and roadside facilities for traffic movement within it.

Intersection Conflict Area: That area of an intersection that is extended to cover the conflict area

Lambertian Surface: a surface that emits or reflects light in accordance with Lambert's cosine law. A Lambertian surface has the same luminance regardless of viewing angle.

Lamp: a generic term for an artificial source of light.

Lamp life: the average life of a lamp defined as the total operating hours at which 50 percent of any group of lamps is still operating.

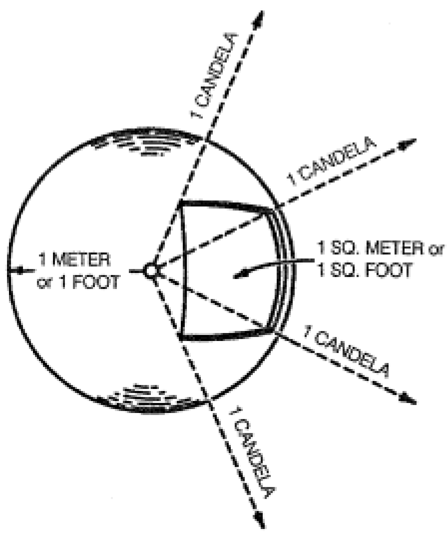


Figure 43 - Relationship between candelas, lumens, lux, and foot-candles:

A uniform point source (luminous intensity or candlepower = one candela) is shown at the center of a sphere of unit radius whose surface has a reflectance of zero. The illuminance at any point on the sphere is one lux (one lumen per square meter) when the radius is one meter, or one foot-candle (one lumen per square foot) when the radius is one foot. The solid angle subtended by the area A,B,C,D is one steradian. The flux density is therefore one lumen per steradian, which corresponds to a luminous intensity of one candela as originally assumed. The sphere has a total area of 4 (or 12.57) square units (square meters or square feet), and there is a luminous flux of one lumen falling on each unit area. Thus the source provides a total of 12.57 lumens.

High mast lighting: illumination of a large area by means of a group of luminaires which are designed to be mounted in fixed orientation at the top of a high support or pole (generally 20 meters or higher).

Illuminance, E: the density of the luminous flux incident on a surface; it is the quotient of the luminous flux by the area of the surface when the latter is uniformly illuminated.

Illuminance (lux or foot-candle) meter: an instrument for measuring illuminance on a plane. Instruments which accurately respond to more than one spectral distribution (color) are color corrected. Instruments which accurately respond to more than one spatial distribution of incident flux are cosine corrected. The instrument is comprised of some form of photo-detector with or without a filter, driving a digital or analog readout through appropriate circuitry.

Intensity: a shortening of the terms luminous intensity and radiant intensity.

Lamp lumen depreciation factor, LLD: the multiplier to be used in calculations to relate the initial rated output of light sources to the anticipated minimum output based on the relamping program to be used.

Lamp post: a support or pole provided with the necessary internal attachments for wiring and the external attachments for the bracket and/or luminaire.

Light loss factor, LLF: a factor used in a lighting calculation after a given period of time and under given conditions. It takes into account temperature and voltage variations, dirt accumulation on luminaire surfaces, lamp lumen depreciation, maintenance procedures, equipment and ballast variations. Formerly called maintenance factor.

Line of sight: the line connecting the point of observation and the point of fixation.

Lumen, lm: the SI unit of luminous flux. Radiometrically, it is determined from the radiant power. Photometrically, it is the luminous flux emitted within a unit solid angle (one steradian) by a point source having a uniform luminous intensity of one candela.

Luminaire: a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply. Sometimes includes ballasts and photocells.

Luminaire cycle: the distance between two luminaires along one side of the roadway. Note: this may not be the same as luminaire spacing along the centerline considering both sides of the road. (See **spacing**.)

Luminaire dirt depreciation factor, LDD: the multiplier to be used in lighting calculations to reduce the initial light level provided by clean, new luminaires to the light level that they will provide due to dirt collection on the luminaires at the time at which it is anticipated that cleaning procedures will be instituted.

Luminance, L (cd/m^2): the quotient of the luminous flux at an element of the surface surrounding the point, and propagated in directions defined by an elementary cone containing the given direction, by the product of the solid angle of the cone and area of the orthogonal projection of the element of the surface on a plane perpendicular to the given direction. The luminous flux may be leaving, passing through, and/or arriving at the surface. Note: In common usage the term "brightness" usually refers to the strength of sensation which results from viewing surfaces or spaces from which light comes to the eye. This sensation is determined in part by the definitely measurable luminance defined above and in part by conditions of observation such as the state of adaptation of the eye.

Luminance contrast: the relationship between the luminances of an object and its immediate background.

Luminance meter: an instrument for measuring the luminance of an object or surface. Instruments which accurately respond to more than one spectral distribution (color) are color corrected. The instrument is comprised of some form of a lens system and aperture creating an image on a photodetector, driving a digital or analog readout through appropriate circuitry.

Luminous efficacy of a source of light: the quotient of the total luminous flux emitted by the total lamp power input. It is expressed in lumens per watt.

Luminous flux density at a surface: the luminous flux per unit area at a point on a surface. Note: this need not be a physical surface; it may equally well be a mathematical plane.

Luminous intensity, I (cd): the luminous flux per unit solid angle in a specific direction. Hence, it is the luminous flux on a small surface normal to that direction, divided by the solid angle (in steradians) that the surface subtends at the source.

Lux, lx: the SI unit of illuminance. It is the illuminance on a surface one square meter in area on which there is a uniformly distributed flux of one lumen, or the illuminance produced at a surface all points of which are at a distance of one meter from a uniform point source of one candela.

Mesopic Vision: the state of eye adaptation at light levels between 10 cd/m^2 and 0.001 cd/m^2, where both the brightness sensing rods and color sensing cones are aiding in visibility. A typical situation for nighttime roadway lighting levels.

Mean lamp lumens: the mean lumen output of a lamp is calculated by determining the area beneath the lumen maintenance characteristic curve of that source over a given period of time and dividing that area by the time period in hours.

Mounting height, MH: the vertical distance between the roadway surface and the center of the apparent light source of the luminaire.

Overhang, OH: the horizontal distance between a vertical line passing through the luminaire light center and the curb or edge of the travelled roadway.

Partial Lighting: Partial Lighting refers to lighting installed at the decision areas of isolated interchanges and intersections whereby it provides visibility of potential conflicts with other traffic and physical features.

Pedestrian crosswalk: an area designated by markings for pedestrians to cross the roadway.

Pedestrian way: a sidewalk or pedestrian walkway, usually paved, intended for pedestrian usage.

Photopic Vision: the state of eye adaptation at light levels greater than 10 cd/m^2 where the color sensing receptors in the eye are active aiding in the visibility of detail and fine color distinction. A typical situation for daytime roadway lighting levels.

Point of fixation: a point or object in the visual field at which the eyes look and upon which they are focused.

R-table: a table for a particular pavement type which provides reduced luminance coefficients in terms of the variable angles, beta and tan gamma.

Reaction time: the interval between the beginning of a stimulus and the beginning of the response of an observer.

Scotopic Vision: the state of eye adaptation at light levels less than 0.001 cd/m^2 where the color sensing receptors in the eye are inactive eliminating the visibility of color and detail. A typical situation for moonless nighttime lighting levels.

Setback: the lateral offset of the pole center from the face of the curb or edge of the travelled way.

Spacing: the distance between successive luminaires measured along the center line of the street. See **luminaire cycle**.

Spacing-to-mounting height ratio, S/MH: the ratio of the distance between luminaire centers, along the center line of the street, to the mounting height above the roadway.

Subjective brightness: the subjective attribute of any light sensation given rise to the perception of luminous intensity, including the whole scale of qualities of being bright, lightness, brilliant, dim, or dark.

Traffic conflict area: area on a road system where a strong potential exists for collisions between vehicles or between vehicles and pedestrians.

Veiling luminance: a luminance superimposed on the retinal image which reduces its contrast. It is this veiling effect produced by bright sources or areas in the visual field that results in decreased visual performance and visibility.

Visibility: the quality or state of being perceivable by the eye. In many outdoor applications, visibility is sometimes defined in terms of the distance at which an object can be just perceived by the eye. In indoor and out- door applications it usually is defined in terms of the contrast or size of a standard test object, observed under standardized view-conditions, having the same threshold as the given object.

Visibility index, VI: a measure closely related to **visibility level** sometimes used in connection with road lighting applications.

Visibility level, VL: a contrast multiplier to be applied to the visibility reference function or provide the luminance contrast required at different levels of task background luminance to achieve visibility for specified conditions relating to the task and observer.

Visual angle: the angle subtended by an object or detail at the point of observation. It usually is measured in minutes of arc.

Walkway: a sidewalk or pedestrian way.