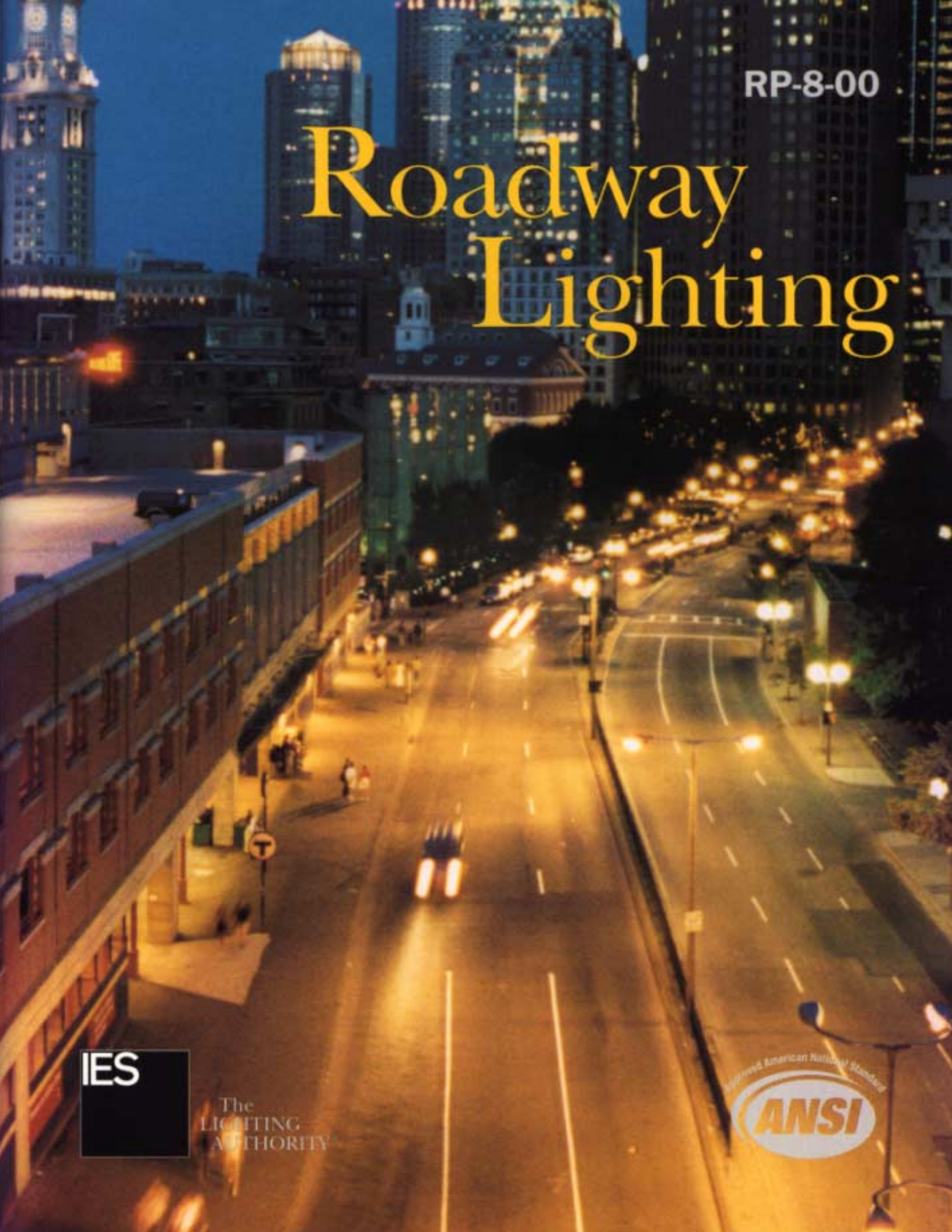
RP-8-00

Roadway Lighting



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American National Standard Practice for Roadway Lighting

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Prepared by:

The Standard Practice Subcommittee of the IESNA Roadway Lighting Committee

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FOREWORD

(This Foreword is not part of the American National Standard Practice for Roadway Lighting, ANSI/IESNA RP-8-2000, but is included for informational purposes only.)

This American National Standard Practice for Roadway Lighting has been approved under the rules of procedure of the American National Standards Institute and under the sponsorship of the Illuminating Engineering Society of North America (IESNA). This document has been revised from the 1993 Practice and introduces the concept of Visibility Level (VL) (refer to **Annex A** and **Annex F**) and its measurement means, Small Target Visibility (STV). The illuminance and luminance (reflected light) methods have been retained from the 1993 practice.

During the 70-year existence of the IESNA Committee on Roadway Lighting, the night use of public ways has grown greatly. Traffic has changed in speed and density. Studies have established a substantial relationship between good fixed lighting and traffic safety. In addition, understanding of the principles of good lighting has advanced. The following earlier publications of the committee reflect progress of the roadway lighting technique through the years.

- *Principles of Streetlighting* 1928
- *Code of Streetlighting* 1930
- *Code of Streetlighting* 1935
- *Code of Streetlighting* 1937
- *Recommended Practice of Streetlighting* 1940
- *Recommended Practice of Street and Highway Lighting* 1945
- *American Standard Practice for Street and Highway Lighting* 1947
- *American Standard Practice for Street and Highway Lighting* 1953
- *American Standard Practice for Roadway Lighting* 1963
- *American Standard Practice for Roadway Lighting* 1972
- *American Standard Practice for*
- *Roadway Lighting* 1977
- *American Standard Practice for Roadway Lighting* 1983
- *American Standard Practice for Roadway Lighting* (reaffirmed) 1993

The present Practice has evolved from these earlier documents, and considers the latest research, international standards, experience, and equipment technology.

An American National Standard represents the consensus of all groups having an essential interest in the provisions of the Standard Practice. The IESNA, as a sponsor, must have the viewpoints of groups interested in roadway lighting represented on the Roadway Lighting Committee.

1.0 INTRODUCTION

1.1 Purpose of this Standard Practice

The primary purpose of this Standard Practice is to serve as the basis for design of fixed lighting for roadways, adjacent bikeways, and pedestrian ways. The Standard Practice deals entirely with lighting and does not give advice on construction. Its purpose is to provide recommended practices for designing new continuous lighting systems for roadways. It is not intended to be applied to existing lighting systems until such systems are redesigned. It has been prepared to advance the art, science, and practice of roadway lighting in North America. Roadway lighting includes pedestrian and bikeway lighting when it is associated with the public right-of-way (**see Figure 2**).

The decision to provide or upgrade roadway lighting at a particular location should be made on the basis of a study of local conditions. Once a decision has been made to provide lighting, this publication provides the basis for designing an appropriate system.

1.2 Purpose of Roadway Lighting

The principal purpose of roadway lighting is to produce quick, accurate, and comfortable visibility at night. These qualities of visibility may safeguard, facilitate, and encourage vehicular and pedestrian traffic. Every designer should provide for those inherent qualities required by the user. A very important consideration is that of making streets and highways useful during hours of darkness as well as during the daytime. Where good visibility is provided through lighting, efficient night use can be made of the large investments in roadways and motor vehicles. Thus, the proper use of roadway lighting as an operative tool provides economic and social benefits to the public including:

(a) Reduction in night accidents, attendant human misery, and economic loss
(b) Aid to police protection and enhanced sense of personal security
(c) Facilitation of traffic flow

(d) Promotion of business and the use of public facilities during the night hours

This Standard Practice is for fixed lighting of the different kinds of public roads, including adjacent pedestrian walkways and associated bikeways, of a quality considered appropriate to modern requirements for night use. The practicability and economy of roadway lighting has been demonstrated. Where appropriate lighting has been installed, the result has often been a marked reduction in night accidents. Pedestrian and vehicular traffic has also been expedited.

1.3 Visual Components of the Driving Task

In order to drive a vehicle on a paved roadway with reasonable confidence, speed, and safety, a driver must visually determine the following:

(a) That the pavement ahead is clear of defects and obstacles for a reasonable distance
(b) The locations of the lane or roadway edges, within which it is intended to maintain the lateral position of the vehicle
(c) The location and meaning of the traffic control devices and signs that affect the "rules of the road"
(d) The present location and future course of moving objects on or near the roadway
(e) The present position of the driver's own vehicle relative to his immediate destination, other objects, and intended turning locations

1.4 Means of Nighttime Lighting

The nighttime lighting for providing visibility or guidance for the driver can come from up to four sources:

(a) Vehicle signals and headlighting systems as required by law
(b) The fixed lighting system covered by this Standard Practice
(c) Traffic signal lights and lighted or retroreflective signs
(d) Extraneous off-roadway light sources

1.5 Night/Day Accident Relationship

Darkness brings increased hazards to users of streets and highways because it reduces the distance they can see. The nighttime fatal accident rate on unlighted roadways is about three times the daytime rate, based on proportional vehicular kilometers/miles of travel. This ratio can be reduced when proper fixed lighting is installed because these lighting systems reveal the environment beyond the range of the vehicle headlights and ameliorate glare from oncoming vehicles by increasing the eye's adaptation level.

Experience has demonstrated that under many circumstances prevailing in North America, it is possible to light urban and suburban streets and highways, so as to reduce the loss of lives and injuries attributable to inadequate visibility. Furthermore, the IESNA Roadway Lighting Committee is of the opinion that the lighting of streets and highways generally is economically practical. These preventive measures can cost a community less than the accidents caused by inadequate visibility.

1.6 Background for Design Criteria

Research has shown that lighting roadways with significant nighttime traffic volume will reduce nighttime accidents. (See **Annex H**, references 1, 2, and 3.) Recent research is concentrating on visibility measurements and results are promising (see **Annex F**). This Standard Practice includes three criteria for designing continuous lighting systems for roadways. These are illuminance, luminance, and Small Target Visibility (STV). Illuminance based design is a simple design approach, which has been historically used in roadway lighting. It calculates the amount of light on the roadway surface. Luminance based design calculates the amount of light directed toward the driver and predicts the luminance of the roadway. STV is a visibility metric, which is used to determine the visibility of an array of targets on the roadway and includes the calculation of target and background luminance, adaptation level, and disability glare. The designer should be familiar with each criterion and may choose the one that meets the needs of the particular situation and design restraints. Consideration may be given to meeting the requirements of two or all of these design criteria.

The illuminance design approach has been shown to be of benefit in reducing pedestrian accidents, reducing fear of crime, and the promotion of business and use of public roads at night. The lighting design for sidewalks, bikeways, intersections, and high mast installations is often best achieved by the use of the illuminance criterion. Luminance has been used internationally by the CIE[4] as the primary method for designing major vehicle traffic routes. STV is a new approach to improve driver safety, which incorporates recent studies of human visual processes. There is currently an active international committee working to develop a visibility recommendation for the design of traffic routes. (CIE Division 4, Technical Committee 4.36, Visibility Design for Roadway Lighting.)

The other parameter in roadway lighting that affects visual performance is the glare from the fixed lighting system. Disability Glare (Veiling Luminance) has been quantified to give the designer information to identify the veiling effect of the glare as a ratio of the maxi-

mum veiling luminance to the average pavement luminance. This gives a better means of evaluating the glare from a lighting system than the method (used in conjunction with the horizontal illuminance criteria) of merely classifying a single luminaire distribution as to the amount of luminous flux above certain vertical angles.

The visual components of the tasks of riding a bicycle and walking are somewhat different than for the driving tasks as just listed in **Section 1.3**. The design criteria for bikeways and pedestrian walkways are discussed in **Section 3.5**.

1.7 Energy Management Implications

The application of this Standard Practice will result in good lighting and achieve effective energy management if the designer and user will utilize:

(a) Efficient luminaires and lamps with distributions suited for the task to be performed
(b) Appropriate mounting heights and luminaire positioning
(c) A good maintenance program to ensure system integrity and to maintain the design lighting level

Changes in the lighting distribution type and/or luminaire locations and spacing may increase visibility without increasing the overall energy consumption of the lighting system.

Research has indicated that certain light source spectral distributions may create higher visibility than others in roadway (non-photopic, i.e., lower light level) lighting situations. These are typically sources with higher blue/green content than the currently popular High Pressure Sodium (HPS) lamps. Research in this area is ongoing but has not yet advanced to the point of application. Some of the research on this subject can be found in **Annex H** references 5 through 8.

1.8 Organization of the Standard Practice

This Practice is divided into the following general subjects: classification of areas, pavements, criteria levels recommended for various classifications; lighting design techniques for roadways, bikeways and pedestrian walkways, and light sources. This document does not cover lighting in tunnels (see ANSI/IESNA RP-22-96), separate bikeways (see IESNA DG-5-94), or parking facilities (see IESNA RP-20-98). Supplemental materials of a more detailed and computational nature are included in the **Annexes**.

2.0 CLASSIFICATION DEFINITIONS

The definitions used in this practice may be used and defined differently by other documents, zoning by-laws, and agencies. When selecting a classification, the area or roadway should best fit the descriptions contained within this document and not how classified by others.

2.1 Roadway, Pedestrian Walkway, and Bikeway Classifications

Freeway: A divided major roadway with full control of access (no crossings at grade). This definition applies to toll as well as non-toll roads.

Freeway A: Roadways with greater 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 through some of the early evening hours of darkness at or near design capacity.

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

Expressway: A divided major roadway for through traffic, with partial control of access and generally with interchanges at major crossroads. Expressways for noncommercial traffic within parks and park-like areas are generally known as parkways.

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 leaving the city. These routes are often known as “arterials,” “thoroughfares,” or “preferentials.” They are sometimes subdivided into primary and secondary; however, such distinctions are not necessary in roadway lighting.

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.

Alley: Narrow public ways within a block, generally used for vehicular access to the rear of abutting properties.

Sidewalk: Paved or otherwise improved areas for pedestrian use, located within public street rights-of-way, which also contain roadways for vehicular traffic.

Pedestrian Walkway: A public walk for pedestrian traffic, not necessarily within the right-of-way for a vehicular traffic roadway. Included are skywalks (pedestrian overpasses), subwalks (pedestrian tunnels), walkways giving access through parks or block interiors, and midblock street crossings.

Isolated Interchange: A grade-separated roadway crossing, which is not part of a continuously lighted system, with one or more ramp connections with the crossroad.

Isolated Intersection: The general area where two or more noncontinuously lighted roadways join or cross at the same level. This area includes the roadway and roadside facilities for traffic movement in that area. A special type is the channelized intersection, in which traffic is directed into definite paths by islands with raised curbing.

Isolated Traffic Conflict Area: A traffic conflict area is an area on a road system where an increased potential exists for collisions between vehicles, vehicles and pedestrians, and vehicles and fixed objects. Examples include intersections, crosswalks and merge areas. When this area occurs on a roadway without a fixed lighting system (or separated from one by 20 seconds or more of driving time), it is considered an isolated traffic conflict area.

Bikeway: Any road, street, path, or way that is specifically designated as being open to bicycle travel, regardless of whether such facilities are designed for the exclusive use of bicycles or are to be shared with other transportation modes. Five basic types of facilities are used to accommodate bicyclists:

Shared lane: shared motor vehicle/bicycle use of a “standard”-width travel lane.

Wide outside lane: an outside travel lane with a width of at least 4.2 m (13.8 ft.).

Bike lane: a portion of the roadway designated by striping, signing, and/or pavement markings for preferential or exclusive use of bicycles.

Shoulder: a paved portion of the roadway to the right of the edge stripe designed to serve bicyclists.

Separate bike path: a facility physically separated from the roadway and intended for bicycle use. (See IESNA DG-5-94, *Lighting for Walkways and Class 1 Bikeways* for requirements in these areas.)

Median: The portion of a divided roadway physically separating the traveled ways for traffic in opposite directions.

2.2 Pedestrian Conflict Area Classifications

The major, collector and local street classifications appropriately describe general conditions of vehicular traffic conflict in urban areas. However, a second type of conflict, which is responsible for a disproportionate number of nighttime fatalities, is the vehicle/pedestrian interaction. The magnitude of pedestrian flow is nearly always related to the abutting land use. Three classifications of pedestrian night activity levels and the types of land use with which they are typically associated are given below:

High - Areas with significant numbers of pedestrians expected to be on the sidewalks or crossing the streets during darkness. Examples are downtown retail areas, near theaters, concert halls, stadiums, and transit terminals.

Medium - Areas where lesser numbers of pedestrians utilize the streets at night. Typical are downtown office areas, blocks with libraries, apartments, neighborhood shopping, industrial, older city areas, and streets with transit lines.

Low - Areas with very low volumes of night pedestrian usage. These can occur in any of the cited roadway classifications but may be typified by suburban single family streets, very low density residential developments, and rural or semi-rural areas.

The choice of the appropriate lighting level for a street is an engineering decision. If needed, one hour pedestrian counts can be taken during the average annual first hour of darkness (typically 18:00 to 19:00 hours). A section of typical land use can be sampled by counting one or two representative blocks, or a single block of unusual characteristics can be counted, perhaps at a different hour, such as discharge from a major event. The volume of pedestrian activity during the hour of count that warrants increased lighting levels is not fixed and represents a local option. Guidelines for possible local consideration are:

Low - 10 or fewer
Medium - 11 to 100
High - over 100

These volumes represent the total number of pedestrians walking on both sides of the street plus those crossing the street at non-intersection locations in a typical block or 200 meter (656 ft.) section. (The added lighting level for pedestrian crossings at intersections is already considered by the increased illumination design for these conflict points as described in **Section 3.6**.)

2.3 Pavement Classifications

The calculation of either pavement luminance or STV requires information about the directional surface reflectance characteristics of the pavement. Studies have shown that most common pavements can be grouped into a limited number of standard road surfaces having specific reflectance characteristics. This data has been experimentally determined and presented in r-Tables.

For purposes of this Practice, pavement reflectance characteristics follow the CIE (Commission International de l'Éclairage) Four Class system. A description of road surface classifications is given in **Table 1**. The classification is based on the specularity of the pavement (S1), and a scaling factor Q_o as determined by the overall "lightness" of the pavement. The normalized Q_o is given in **Table 1** for each of the pavements described. Greater accuracy in predicting VL and pavement luminance can be achieved by evaluating specific pavements as to their S1 ratio and specific Q_o and then choosing the correct r-Table. The S1 ratio and specific Q_o for a pavement can be determined in one of two ways: (1) a core sample can be removed from the pavement and photometered by a qualified laboratory, (2) a field evaluation can be made. (For further information see Annex H, Reference 9.) Actual pavement reflectance and specularity will vary with pavement age and wear.

Wet roadway conditions are not covered in **Table 1**. (Additional tables may be found in Reference 10).

2.4 Performance of Luminaire Light Distributions

2.4.1 Luminaire Selection. The light emanating from a luminaire is directionally controlled and proportioned by the luminaire optical system. Various optical (reflector, refractor or lens) systems exist and each design has its own distribution characteristics, which can often be varied by lamp socket position adjustments, or by using lamps with different light center lengths and arc tube dimensions. A very wide selection of luminaires, each with a somewhat different light distribution, are available with different characteristics depending upon whether they are intended to be used for center mounting, side-of-roadway mounting, for narrow or wide roadways, or for long or short spacings between luminaires. Previously defined luminaire distribution classification systems (ANSI/IESNA RP-8, 1983 (reaffirmed in 1993)) do not aid in selecting luminaires for use with the STV criteria of **Table 4** but can be of some assistance in selecting luminaires for use with the pavement luminance criteria of **Table 3** as well as the illuminance criteria of **Table 2**.

Table 1: Road Surface Classifications

Class	Q_o	Description	Mode of Reflectance
R1	0.10	Portland cement concrete road surface. Asphalt road surface with a minimum of 12 percent of the aggregates composed of artificial brightener (e.g., Synopal) aggregates (e.g., labradorite, quartzite).	Mostly Diffuse
R2	0.07	Asphalt road surface with an aggregate composed of a minimum 60 percent gravel [size greater than 1 cm (0.4 in.)]. Asphalt road surface with 10 to 15 percent artificial brightener in aggregate mix. (Not normally used in North America.)	Mixed (diffuse and specular)
R3	0.07	Asphalt road surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways).	Slightly Specular
R4	0.08	Asphalt road surface with very smooth texture.	Mostly Specular

Upward light from a luminaire or lighting system must be evaluated. Such light generally adds to sky glow and wastes energy. Unless it is desirable in an urban area, it should be minimized.

2.4.2 Luminaire Cutoff Classifications. Luminaire distribution (see **Figure 1**) is described by the following terms:

Full Cutoff: A luminaire light distribution where zero candela intensity occurs at or above an angle of 90° above nadir. Additionally the candela per 1000 lamp lumens does not numerically exceed 100 (10 percent) at or above a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire.

Cutoff: A luminaire light distribution where the candela per 1000 lamp lumens does not numerically exceed 25 (2.5 percent) at or above an angle of 90° above nadir, and 100 (10 percent) at or above a vertical angle 80° above nadir. This applies to all lateral angles around the luminaire.

Semicutoff: A luminaire light distribution where the candela per 1000 lamp lumens does not

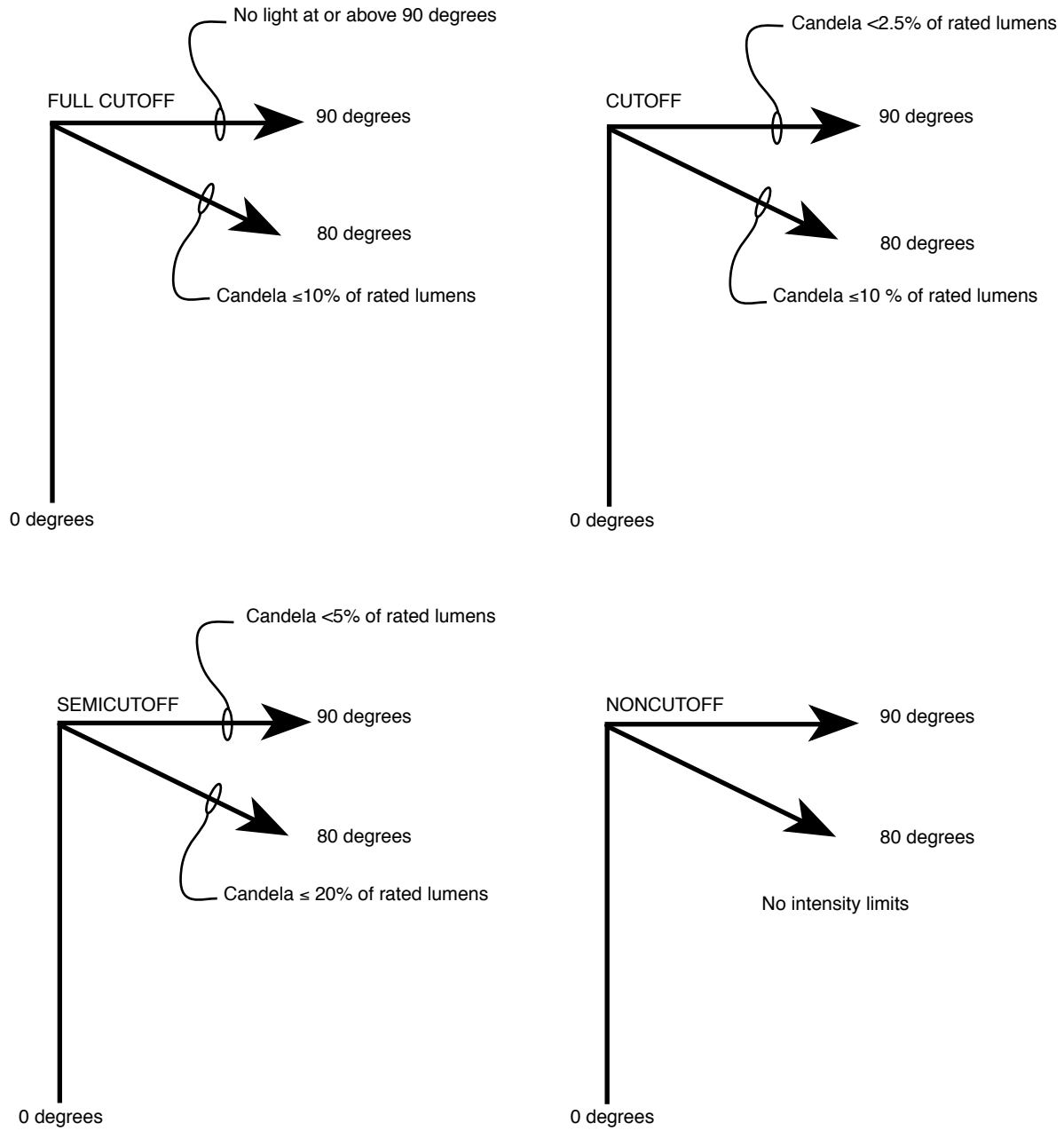


Figure 1. Four different cutoff classifications.

numerically exceed 50 (5 percent) at or above an angle of 90° above nadir, and 200 (20 percent) at or above a vertical angle 80° above nadir. This applies to all lateral angles around the luminaire.

Noncutoff: A luminaire light distribution where there is no candela limitation in the zone above maximum candela.

3.0 DESIGN CRITERIA

This Standard Practice includes three different criteria for use in continuous roadway lighting design. These are illuminance, luminance, and STV. The designer should be familiar with all of these criteria in order to decide which one best addresses the needs of the particular project. Calculation procedures and additional information about these methods are included in the **Annexes**. Consideration should also be given to glare and sky-glow issues stated in **Section 4.6**. For issues about light trespass see IESNA TM-10, *IESNA Technical Memorandum Addressing Obtrusive Light (Urban Sky Glow and Light Trespass) in Conjuction with Roadway Lighting.*

The recommended design values, as well as the uniformity ratios as shown in **Tables 2**, **3**, and **4**, represent the lowest maintained values for the kinds of roadways and walkways in various areas. Numerous installations have been made at higher values. Furthermore, the design values can be made using different combinations of luminaire light distribution, lamp sizes, mounting heights, spacings, and transverse locations. These figures do not represent *initial* readings, but the lowest *in-service* values of systems designed with the proper light loss factor. When design values for continuous roadway lighting vary due to changes in the road or area classification no special transitions are necessary.

This document follows the guidelines of IESNA LM-67-94, *Calculation Procedures and Specification of Criteria for Lighting Calculations*.

3.1 Illuminance Criteria

The illuminance method of roadway lighting design determines the amount of light incident on the roadway surface from the roadway lighting system. Because the amount of light seen by the driver is the portion that reflects from the pavement towards the driver, and because different pavements exhibit varied reflectance characteristics, different illuminance levels are needed for each type. The illuminance criteria gives recommendations for average maintained lux for various road and area classifications depending on the pavement type used. The recommended illuminance values and the uniformity ratio are in **Table 2**. Veiling Luminance Ratios, derived from the luminance calculation method, must also be determined to avoid a lighting system that produces disability glare. (See **Table 2.**)

3.2 Luminance Criteria

The luminance method of roadway lighting design determines how "bright" the road is by determining the amount of light reflected from the pavement in the direction of the driver. The luminance criteria is stated in terms of pavement luminance, luminance uniformity, and disability veiling glare produced by the lighting system. **Table 3** provides the recommended luminance design requirements, uniformity and the relationship between average luminance (L_{avg}) and the veiling luminance (L_v).

3.3 Small Target Visibility (STV) Criteria

The STV method of design determines the visibility level of an array of targets on the roadway considering the following factors:

(a) The luminance of the targets
(b) The luminance of the immediate background
(c) The adaptation level of the adjacent surroundings
(d) The disability glare

The weighted average of the visibility level of these targets results in the STV. The values of STV are included in **Table 4** as well as uniformity ratios and luminance requirements for mitigating the effect on approaching headlights. The veiling luminance ratio component is included in the STV calculation methodology.

3.4 High Mast Lighting

Ordinarily, conventional lighting along streets and highways involve mounting heights of 15 meters (49.2 ft.) or less. Poles of 20 meters (65.6 ft.) or greater height have been utilized in several situations:

- Large parking lots - such as regional shopping centers, and stadiums

- Interchanges and complex intersections in both urban and rural areas and tangent sections with more than six lanes

Opinions differ on whether light levels can be lower when high mast lighting is used, compared with the use of conventional poles of 15 meters (49.2 ft.) or less. Typically, the surround conditions are more uniform with the high mast design and, seeing is easier. Prior editions of ANSI/IESNA RP-8 have allowed lower

lighting levels. Consensus opinion is currently to delete such a differential on the basis that adequate research to justify the lower levels has not been conducted.

High mast lighting typically consists of clusters of three to six or more luminaires mounted on rings, which can be mechanically lowered to near ground levels for servicing.

Designs for high mast lighting can utilize the illuminance method. Unique high mast luminaires and both symmetrical and asymmetrical distributions have been used. Cutoff luminaires are desirable to avoid excessive glare. Large lamps consuming up to 1000 watts are sometimes employed.

Because high mast lighting is a tool for illuminating areas rather than specific sections of roadway, the poles are customarily placed well back from adjacent roadways. Installation cost comparisons between high mast and conventional lighting systems vary widely, depending on the application. High mast lighting for interchanges is frequently less expensive to install than conventional lighting, due to the reduced complexity of conduit and conductor and the smaller number of luminaires and poles required. Other than at interchange locations, conventional lighting usually requires a smaller initial cost.

Maintenance costs for the two types of systems differ greatly. Conventional lighting requires the use of a bucket truck and frequently requires extensive traffic control, such as signs, cones, and lane closures. When poles are mounted on concrete traffic barriers (CTB's), the adjacent traffic lane usually has to be closed, resulting in significant traffic disruptions. One or two persons, without special lift equipment, can usually perform maintenance on a high mast lighting system equipped with a lowering device. High mast lighting may also eliminate the risks involved with having personnel working near high speed traffic.

3.5 Pedestrian and Bikeway Design Criteria

The lighting of streets with pedestrian sidewalks and/or bikeways included as part of the right of way, particularly in urban and suburban areas, differs from that of limited access high speed roadways. The driver's tasks include seeing objects in the roadway as well as pedestrians, parked cars, and other elements. The purpose

Table 2: Illuminance Method - Recommended Values

Road and Pedestrian Conflict Area		Pavement Classification (Minimum Manintained Average Values)			Uniformity Ratio	Veiling Luminance Ratio
Road	Pedestrian Conflict Area	R1 lux/fc	R2 & R3 lux/fc	R4 lux/fc	E_{avg}/E_{min}	L_{vmax}/L_{avg}
Freeway Class A		6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Freeway Class B		4.0/0.4	6.0/0.6	5.0/0.5	3.0	0.3
Expressway	High	10.0/1.0	14.0/1.4	13.0/1.3	3.0	0.3
	Medium	8.0/0.8	12.0/1.2	10.0/1.0	3.0	0.3
	Low	6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Major	High	12.0/1.2	17.0/1.7	15.0/1.5	3.0	0.3
	Medium	9.0/0.9	13.0/1.3	11.0/1.1	3.0	0.3
	Low	6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Collector	High	8.0/0.8	12.0/1.2	10.0/1.0	4.0	0.4
	Medium	6.0/0.6	9.0/0.9	8.0/0.8	4.0	0.4
	Low	4.0/0.4	6.0/0.6	5.0/0.5	4.0	0.4
Local	High	6.0/0.6	9.0/0.9	8.0/0.8	6.0	0.4
	Medium	5.0/0.5	7.0/0.7	6.0/0.6	6.0	0.4
	Low	3.0/0.3	4.0/0.4	4.0/0.4	6.0	0.4

(*Refer to **Section 3.6** for Intersection Lighting*)

and benefits of the lighting system also include pedestrian lighting, security lighting, building facade lighting, and overall aesthetic impact on the community.

Design efforts must include the integration of the lighting system into the surrounding area as well as consideration for its impact on buildings and pedestrians. Other specialized equipment is often required to interface with the street furniture.

This section addresses the lighting needs of adjacent pedestrian and bikeway areas only when the roadway is continuously illuminated. **Figure 2** shows an example of a roadway system with various elements often included within the right of way. Both the recommendations included in this section as well as those for the roadway included in prior sections should be evaluated.

3.5.1 Pedestrian Areas and Bikeways Design Recommendations. Pedestrian areas are divided into three categories.

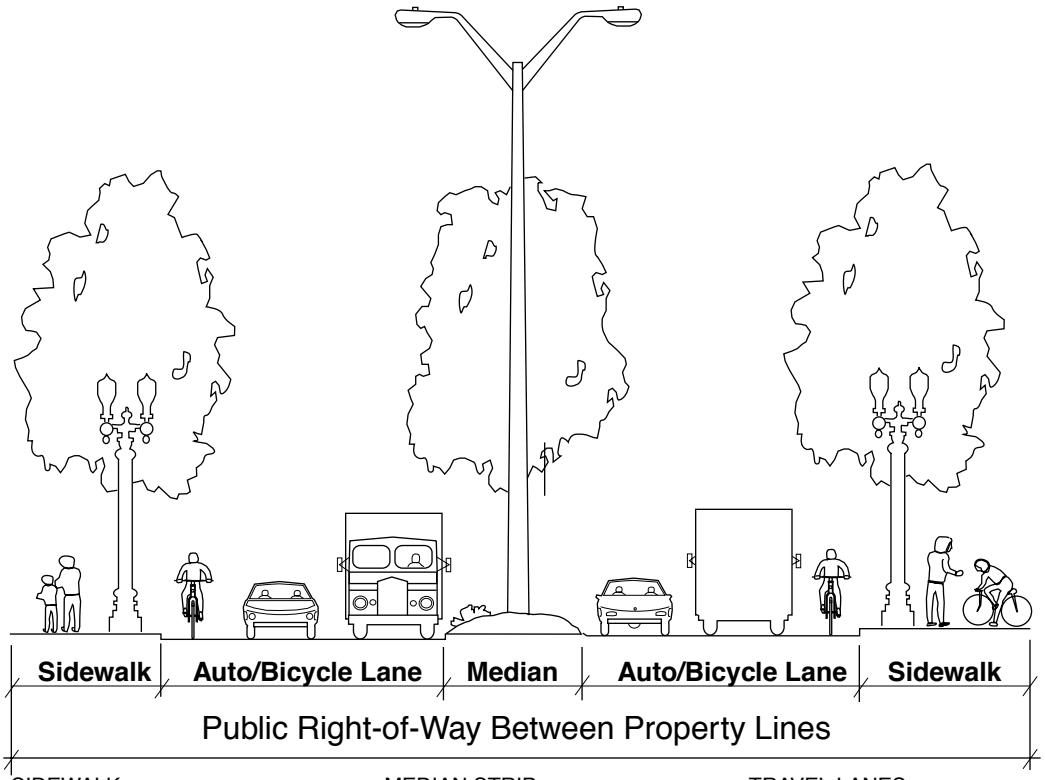
3.5.1.1 High Pedestrian Conflict Areas— Commercial areas in urban environments may have high night pedestrian activities. It is important to provide visibility for a driver to create a reasonably safe environment for the pedestrian and cyclist. Since the reflection characteristics of surfaces vary and are generally unknown during design, use of illuminance values is recommended. Vertical surfaces such as buildings and pedestrians should also be illuminated in order to create a bright environment. **Tables 5, 6,** and **7** include recommended minimum maintained average vertical illuminances for pedestrian areas at a height of 1.5 m (4.9 ft.) in both directions measured parallel to the main pedestrian flow. Glare from the luminaires must be restricted by paying careful attention to luminaire mounting heights, lamp light output, and photometric distribution.

3.5.1.2 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 pedestrian as well as providing guidance to primary travel ways are key elements in the design of a lighting system in

Table 3: Luminance Method - Recommended Values

Road and Pedestrian Conflict Area		Average Luminance	Uniformity Ratio	Uniformity Ratio	Veiling Luminance Ratio
Road	Pedestrian Conflict Area	L_{avg} (cd/m^2)	L_{avg}/L_{min} (Maximum Allowed)	L_{max}/L_{min} (Maximum Allowed)	L_{Vmax}/L_{avg} (Maximum Allowed)
Freeway Class A		0.6	3.5	6.0	0.3
Freeway Class B		0.4	3.5	6.0	0.3
Expressway	High	1.0	3.0	5.0	0.3
	Medium	0.8	3.0	5.0	0.3
	Low	0.6	3.5	6.0	0.3
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

(*Refer to* ***Section 3.6*** *for Intersection Lighting*)



SIDEWALK

Street Light Poles
Utilitly Junction Boxes/Panels
Fire Hydrants
Garbage Containers
Landscaped Areas
Trees
Traffic Signs and Signals
Outdoor Café Tables
Loading Areas / Elevators
Private Overhead Signs
Private Awnings / Marquees
Bus Shelters

MEDIAN STRIP

Left Turn Lane
Plantings
Traffic Signs and Signals
Street Light Poles
Banner Poles
Pedestrian Refuge Areas
Trees
Curbing
Lighting Rail and Bus Platforms

TRAVEL LANES

Normal Vehicular Traffic
Bus Lanes
Street Car or Light Rail Lanes
Bicycle Lanes
Curb Extensions
On Street Parking
Traffic Calming Devices

Figure 2. Typical components within the right-of-way.

these areas. These values do not consider areas with increased crime and vandalism.

3.5.1.3 Low Pedestrian Conflict Areas—The lighting system in residential areas may allow both driver and pedestrian to visually orient in the environment, detect obstacles, observe other pedestrians, read street signs, and recognize landmarks. **Table 7** includes recommended illuminance values. These values do not consider areas with increased crime and vandalism.

3.5.1.4 Pedestrian Bridges over Roadways, Underpasses and Mid-block Crosswalks—Other features such as pedestrian bridges, underpasses, and mid-block crosswalks may require different treatments than for the areas in which they are located.

For underpasses facial recognition and security considerations should be of primary concern because of the limited options for retreat from a hostile individual. Also luminaire mounting restrictions can create problems by causing obstructions/hazards to pedestrians as well making glare control from the luminaires more difficult. Underpasses or pedestrian tunnels may also have daytime lighting needs. The recommendations for the pedestrian areas of the underpass are given in **Table 8**.

Mid-block crosswalks form a special type of "intersection" because pedestrian traffic is in conflict with vehicular traffic on only one street. Special lighting is needed for mid-block crosswalks because these are potentially more hazardous than intersection locations, due to their unexpected nature. For night conditions, the appropriate luminaire locations are

similar to those at street intersections; i.e., to the far right for each direction of approaching travel. Luminaires are typically placed just beyond the crosswalk, on each side of the street. In most cases, this will produce a relatively high illuminance level. The average illuminance level in the crosswalk area should at least be equal to that provided at the intersection of two major streets; i.e., about 34 lux (3.4 fc). (See **Table 9**.)

3.5.2 Calculations Required. Several calculations must be performed in order to properly design a lighting system. These include the requirements for the roadway system as well as those for the pedestrian areas (if different). Calculations should be performed for the roadway area to check conformance with the recommended levels given in **Tables 2, 3,** or **4** and **5**, **6**, **7,** and **8** (if applicable) for pedestrian areas. Veiling luminance calculations must also be performed if using the illuminance or luminance methods. Then illuminance calculations should be performed for the adjacent pedestrian areas to determine the adequacy of the design. The illuminance calculations include the horizontal levels at the walkway as well as the vertical values at each point at a height of 1.5 m (4.9 ft.) in all directions of pedestrian travel. A properly designed system will meet the roadway luminance and veiling luminance requirements (refer to **Annex A** for the appropriate procedures) as well as the pedestrian horizontal and vertical illuminance requirements.

Table 4: Small Target Visibility - Recommended Values

Road and Pedestrian Conflict Area		STV Criteria	Luminance Criteria		
Road	**Pedestrian Conflict Area**	**Weighting Average** VL	L_{avg} cd/m^2 Median <7.3 m	L_{avg} * cd/m^2 Median ≥7.3 m	**Uniformity Ratio** L_{max}/L_{min} (Maximum Allowed)
Freeway "A"		3.2	0.5	0.4	6.0
Freeway "B"		2.6	0.4	0.3	6.0
Expressway		3.8	0.5	0.4	6.0
Major	High	4.9	1.0	0.8	6.0
	Medium	4.0	0.8	0.7	6.0
	Low	3.2	0.6	0.6	6.0
Collector	High	3.8	0.6	0.5	6.0
	Medium	3.2	0.5	0.4	6.0
	Low	2.7	0.4	0.4	6.0
Local	High	2.7	0.5	0.4	10.0
	Medium	2.2	0.4	0.3	10.0
	Low	1.6	0.3	0.3	10.0

Table based on a 60 year old driver with normal vision, an 18 cm x 18 cm (7.1 in. x 7.1 in.) 50 percent reflective target, and a 0.2 second fixation time.

(*Refer to **Section 3.6** for Intersection Lighting*)

* *This column also applies to freeways and expressways where the alignment at the two roadways is independent of each other, or where there is a median barrier sufficient to block the direct view of oncoming headlights or a one way street.*

Table 5: Recommended Values for High Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways/Bikeways			
	E_H lux/fc	E_{Vmin} lux/fc	E_{avg}/E_{min} *
Mixed Vehicle and Pedestrian**	20.0/2.0	10.0/1.0	4.0
Pedestrian Only	10.0/1.0	5.0/0.5	4.0

* Horizontal only

Mixed vehicle and pedestrian refers to those areas where the pedestrians are immediately adjacent to vehicular traffic without barriers or separation. Does not apply to mid-block crossings. (See **Section 3.5.1.4.)

E_H = average horizontal illuminance at walkway/bikeway

E_{Vmin} = minimum vertical illuminance at 1.5 m (4.9 ft.) above walkway/bikeway measured in both directions parallel to the main pedestrian flow

3.6 Intersections

3.6.1 Classification. Typically, about 50 percent of accidents in urban areas, excluding freeways, occur at intersections.[11] The basic classification system for urban surface streets as given in **Section 2.1** include:

Major (M)
Collector (C)
Local (L)

These streets intersect to form six types of intersections; M/M, M/C, M/L, C/C, C/L, and L/L. The Institute of Transportation Engineers (ITE) in Guidelines for Residential Subdivision Street Design[12], has identified the following volumes of average daily traffic (ADT) as typical for each type of street in residential areas:

Major ..... over 3,500 ADT
Collector ..... 1,500 to 3,500 ADT
Local ..... 100 to 1,500 ADT

Note: These street classifications do not apply to the road classifications of **Tables 2, 3**, and **4**, but may be used in determining intersection lighting levels from **Table 9**.

3.6.2 Vehicular Traffic Volumes and Conflicts. Obviously, the volume of traffic at the intersection of one local street with another is quite low. Alternatively, volumes at intersections of local streets with major streets are primarily those on the major street. If the intersecting street is of collector or major type, the total volume is substantially increased due to the traffic on the cross street. Also, denser land uses, such as commercial or industrial, generate higher volumes for all types of streets. The likelihood of pedestrian conflict is also an important consideration.

Driveways onto other roadways are miniature intersections and should be classified accordingly. Those serving a single family home typically generate about ten trips per day; i.e., five vehicles in and five vehicles out and do not require any special lighting. At the other extreme, driveways serving high volume activities, such as regional shopping centers, will be used by thousands of vehicles per day and should be illuminated similar to a major/major intersection.

At the intersection of two streets, both carrying two-way traffic, with no restriction on turning movements and no signal control, a total of 16 vehicular conflict points exist as shown in **Figure 3**. An equal number of pedestrian conflict points exists; i.e., there are four

Table 6: Recommended Values for Medium Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways/Bikeways			
	E_H lux/fc	E_{Vmin} lux/fc	E_{avg}/E_{min} *
Pedestrian Areas	5.0/0.5	2.0/0.2	4.0

* Horizontal only

E_H = average horizontal illuminance at walkway/bikeway

E_{Vmin} = minimum vertical illuminance at 1.5 m (4.9 ft.) above walkway/bikeway measured in both directions parallel to the main pedestrian flow

Table 7: Recommended Values for Low Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways/Bikeways			
	E_H lux/fc	E_{Vmin} lux/fc	E_{avg}/E_{min}*
Rural/Semi-Rural Areas	2.0/0.2	0.6/0.06	10.0
Low Density Residential	3.0/0.3	0.8/0.08	6.0
Medium Density Residential	4.0/0.4	1.0/0.1	4.0

* Horizontal only

E_H = average horizontal illuminance at walkway/bikeway
E_{Vmin}= minimum vertical illuminance at 1.5 m (4.9 ft.) above walkway/bikeway measured in both directions parallel to the main pedestrian flow

crossing vehicular movements for each crosswalk (right turns and left turns from the cross street, and straight ahead from both directions on the street crossed by the walk).

Several studies have identified that the primary benefits produced by lighting of intersections along major streets is the reduction in night pedestrian, bicycle and fixed object accidents.[13, 14]

3.6.3 Pedestrian Visibility. Night visibility of pedestrians typically involves observance by one of two methods–silhouette or reversed silhouette. Reversed silhouette is produced by vehicle headlights in possible combination with any fixed street lighting. The value of direct visibility by headlighting or lights at the intersection, is significantly affected by the reflectivity of the clothing worn by the pedestrian. For a major street with properly designed continuous lighting, the silhouette vision of the pedestrian may actually be enhanced by dark clothing–the darker object is seen against the lighter background.

To maximize visibility of a pedestrian at an intersection, it is preferable to have street lighting configurations as shown in **Annex D**, **Figure D3**. If a major street is intersecting a lesser classification, such as collector or local, these positions will typically provide for reasonable visibility. In **Annex D, Figure D3-b**, **D3-c**, and **D3-d** the far right side light is appropriately located just beyond the crosswalk. The light distribution across the width of pavement will serve to provide high illuminance in the crosswalk area as well as high luminance on the intersection pavement. It will also illuminate the pavement beyond the pedestrian thereby forming a background to the pedestrians silhouette. This far right position is also appropriate for the location of a traffic signal, whether it is bracket mount to a street light pole, is of combination mast arm/street light type, or utilizes ring-around span wire poles.

3.6.4 Recommended Illuminance for Intersections. **Table 9** shows 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. It 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

Table 8: Recommended Values for the Pedestrian Portion of Pedestrian Vehicular Underpasses and Exclusive Pedestrian Underpasses

Maintained Illuminance Values for Walkways/Bikeways			
	E_H lux/fc	E_{Vmin} lux/fc	E_{avg}/E_{min}*
Day	100.0/10.0	50.0/5.0	3.0
Night	40.0/4.0	20.0/2.0	3.0

* Horizontal only

E_H = average horizontal illumination at walkway/bikeway
E_{Vmin} = minimum vertical illumination at 1.5 m (4.9 ft.) above walkway/bikeway measured in both directions parallel to the main pedestrian flow

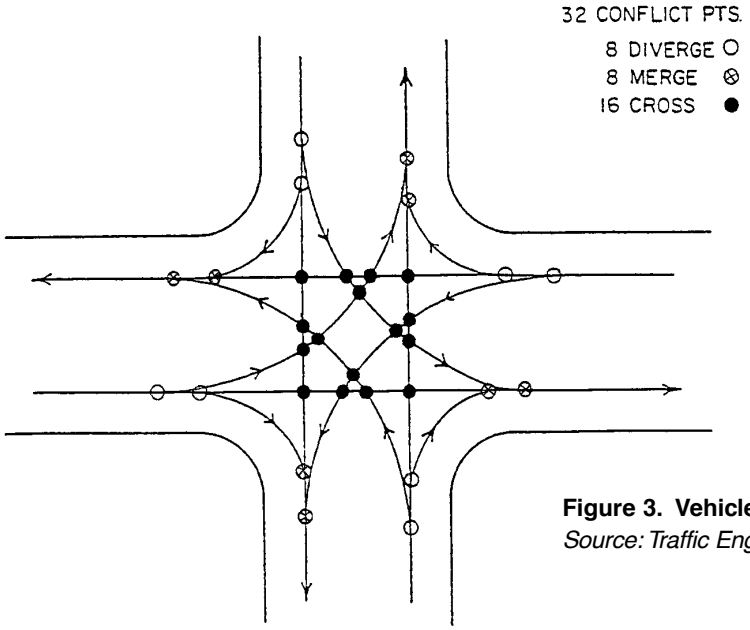


Figure 3. Vehicle conflict points at four way intersections.
Source: Traffic Engineering, McGraw-Hill Book Company, Inc., 1955

the recommended value, then the intersection illuminance value should be proportionately increased.

If the intersecting streets are not continuously lighted a partial lighting system can be utilized as indicated in **Annex D**.

The design procedures for establishing lighting in the non-intersection, or midblock sections of the street, are described under prior sections. Illumination of the intersections is straight forward in that a calculated midblock spacing is reduced across the intersection, which proportionately increases the total lighting of the intersection area. However, if the intersection is wide, produced by large corner radii and width of the crossroad, placing lights at the closest practical points (which is at the end of the curb return radius on the street) may not provide sufficient increased illumination. This is particularly likely to occur at the intersection of two major streets and conceivably could also occur at the intersection of a major street with a wide collector street. In such cases, it is appropriate to also place lighting on the far right side of the cross route. This does not apply to a local intersecting street, where lighting is normally at sufficiently long spacing as to be independent of the intersection at the major street.

4.0 DESIGN CONSIDERATIONS OF PUBLIC RIGHT-OF-WAY LIGHTING

4.1 Design of Public Right-of-Way Lighting

There are several major issues that affect driver visibility that differ when shifting from the rural or the limited access roadway to the urban area. They are a reduction in speed, increase in background luminance, increase in frequency of intersections and driveways, presence of curb parking, and, most importantly, an increase in the number of people. Because of this increase in density, pedestrian or vehicular, and traffic control, a motorist's rate of travel is slower. Background luminance may provide roadway illuminance, glare, and distraction as well as being an aide or a source of confusion to the driver's orientation.

4.2 Appearance and Scale

In areas with heavy pedestrian traffic, luminaire height and pole design should consider and respond to the human scale. This often results in the use of lower pole heights, 3 to 6 meters (9.8 to 19.7 ft.), instead of more typical roadway lighting pole heights of 10 to 15 meters (32.8 to 49.2 ft.). In some cases a combination of both types of poles are needed to meet the needs of the pedestrian as well as the driver. Controlling glare and maximizing system efficiencies are difficult with lower mounting heights. Because of this and other reasons described in this practice the cost of the lighting system in these areas is greater than in lighter pedestrian use areas.

4.3 Visual Task

An effort must be made to completely understand the visual task in a given urban setting. Too often the designer thinks only in terms of the driving task. When designing for areas of congestion or significant interest, allowance needs to be made for the myriad of tasks. These would include seeing pedestrians, dropping off passengers, viewing elements within the streetscape, dealing with traffic tie-ups, reading signs, or other driving tasks related to urban areas. Other users of the

Table 9. Recommended Illuminance for the Intersection of Continuously Lighted Urban Streets
(Based on the values in Table 2 for R2 and R3 pavement classifications)

Illuminance for Intersections				
Functional Classification	**Average Maintained Illumination at Pavement by Pedestrian Area Classification** lux/fc			E_{avg}/E_{min}
	High	Medium	Low	
Major/Major	34.0/3.4	26.0/2.6	18.0/1.8	3.0
Major/Collector	29.0/2.9	22.0/2.2	15.0/1.5	3.0
Major/Local	26.0/2.6	20.0/2.0	13.0/1.3	3.0
Collector/Collector	24.0/2.4	18.0/1.8	12.0/1.2	4.0
Collector/Local	21.0/2.1	16.0/1.6	10.0/1.0	4.0
Local/Local	18.0/1.8	14.0/1.4	8.0/0.8	6.0

urban street right of way, such as pedestrians and bicyclists, will also require adequate lighting for their tasks.

4.4 Integration with Non-Lighting Elements

In urban areas, particularly medium to high pedestrian usage areas, many elements may have to be integrated and coordinated with the lighting system. Some of these elements are noted in **Figure 2**. The locations of light poles need to be coordinated with the street furniture and landscaping. An assessment may be required of the impact that these objects may have on the performance of the lighting system. The designer and owner of the lighting system must look at the installation with all of the non-lighting elements and work to resolve conflicts.

4.5 Vertical Surface Illumination

Illuminated building faces can provide a sense of security and mitigation for the shadows (off the street) created by roadway cut-off luminaires in standard layouts. Adding a small percentage of vertical component to the lighting photometric distribution can provide “fill light” to enliven the architectural facades at night. Care must be exercised in selection of the optical type and equipment placement to avoid creating an obtrusive condition for the motorist or the abutting property users.

4.6 Glare and Sky-Glow Issues

Roadway lighting systems are under increasing scrutiny from various sectors of the public. While the general public is not usually aware of specific design requirements of roadway lighting systems, glare, sky-glow, and aesthetic elements are widely perceived and open to criticism. The lighting designer should become familiar with these issues and be prepared to design a lighting system that meets the needs of the client/owner, while also considering the effect of the lighting system on the general aesthetic environment of the area.

An increasing number of communities are adopting lighting ordinances meant to reduce sky-glow (popularly termed light pollution). This action should put lighting designers on notice that this is a very important issue. There are situations (building facades, landscapes, and central business districts for example) in which lighting aimed upward may sometimes be required. Roadway lighting is not usually one of these situations. Luminous flux above the horizontal does not benefit roadway lighting but can contribute to glare and may be considered visual clutter.

Luminous flux above the horizontal also adds to sky-glow. Many people consider sky-glow undesirable and even offensive. This is an immensely important issue with the astronomical community, professional and amateur, and is particularly annoying when equally effective lighting systems can be designed that reduce or eliminate direct up lighting.

Unless it is essential to have luminous flux aimed above the horizontal, as mentioned in the situations above, non-cutoff luminaires should not be used for new roadway lighting. Non-cutoff luminaires inappropriately used may be considered a waste of energy. Roadway lighting luminaires should at least be semi-cutoff. Cutoff and full cutoff should be strongly considered. When it is necessary to have luminous flux above the horizontal, the designer should be diligent to keep the above horizontal flux as low as practical to accomplish the intended effect. This can be done by using lower wattage luminaires, by shielding, or by luminaire design.

It is generally not good practice to add glare shields to existing roadway lighting luminaires that are a part of a continuous lighting system. The addition of glare shields modifies the photometric distribution of the luminaire and may cause an acceptable lighting system to no longer meet design standards. Luminaire photometrics are rarely measured with external shields installed, hence, the designer will not know how a luminaire with glare shields will perform. A qualified lighting designer should investigate the result of adding glare shields prior to their installation. It may be necessary to change the entire luminaire rather than alter the photometric performance of the existing luminaires.

Knowledge of this subject and implementation of design techniques to reduce or eliminate these problems will enhance the public's perception of the professionalism of lighting designers and will benefit clients through a show of concern for their neighbors and the complete aesthetic environment. For further information on this subject, see IESNA TM-10-99, *IESNA Technical Memorandum Addressing Obtrusive Light (Urban Sky Glow and Light Trespass) in Conjuction with Roadway Lighting*, IESNA RP-33-99, *Lighting for Exterior Environments*, and CIE Report 126, 1997, *Guidelines for Minimizing Sky Glow*.

4.7 Transition Lighting

Transition lighting is a technique intended to provide the driver with a gradual reduction in lighting levels and glare when leaving a lighting system. Some factors that may influence the justification for a transition lighting area are:

(a) Radical reduction in roadway cross section
(b) Severe horizontal or vertical curvature of the roadway
(c) Change from a very high lighting level

It is recommended that the use of transition lighting be at the option of the designer after a study of the conditions at a specific location. Should transition lighting be used, the techniques for providing a transition are many, and can be applied to all types of lighting systems with varying degrees of complexity.

Decreases in pavement luminance are usually accomplished by extending the lighting system beyond normal limits, but partially interrupting the required geometric arrangement of luminaires. For example, a two-side opposite or staggered spacing arrangement would continue per design to the normal lighting limits. At this point luminaires would be omitted from the exiting side of the roadway, but continued for one to six cycles beyond the normal limits on the approach side, depending on road speed and luminaire coverage. Generally, with high mast lighting, this can be accomplished with a one-pole installation on the entering side of the lighting system. In this case, it may not require extending the lighting limits as may be needed for lower mounting heights. Designer judgement should be used with various geometric arrangements to effect any transitional change.

Annex A

Calculation and Measurement Parameters

(This Annex is not part of the *American National Standard Practice for Roadway Lighting*, RP-8-00, but is included for informational purposes only. For the sake of clarity and simplicity only SI units are given in the examples and used in the calculations.)

Annex A – Calculation and Measurement Parameters

A1 Introduction

This section defines the formulae and assumptions used to perform calculations to evaluate the criteria in this Practice.

Illuminance is the density of luminous flux (light) incident on a surface. (See **Annex G**.) It is measured using a light-sensitive cell. If the cell surface is horizontal it is termed horizontal illuminance or if the cell is vertical it is called vertical illuminance. Pavement luminance is the luminous intensity per unit projected area reflecting off the roadway surface towards an observer. Object luminance is the luminous intensity per unit projected area reflected off the surface of an object towards an observer. In order to make STV calculations it is necessary to; select a point on the roadway, select an object or target surface orientation, select an observer position and orientation, be able to describe the directional reflectance characteristics of the surface (the pavement, the object surface, or both), and to know the angular distribution of light from each luminaire contributing significantly to the luminance of that surface.

A2 Assumed and Standard Conditions

For calculations to determine if a lighting installation meets the recommendations of RP-8 the following are assumed. The observer is located on a line parallel to the centerline of the roadway that passes through the calculation point. The observer is located at a distance of 83.07 meters from that point. The eye height of the observer is 1.45 meters which results in a downward direction of view of one degree. The pavement is level and the surface homogeneous. The surface of the target is assumed to be perfectly diffuse and vertical. The pavement surface is assumed to be dry and to have directional light reflectance characteristics which are expressed in terms of a reduced luminance coefficient as described in **Section A6**.

The calculation and measurement grid shall be in accordance with **Figure A4**. Calculations and measurements may be made at additional points but designers should use only the grid points for determining compliance with recommended averages, percentiles, maximums, and minimums.

Only fixed lighting luminaires installed for the purpose of providing roadway and pedestrian lighting are to be considered in the calculations. The distribution of those luminaires is assumed to be represented by a table of luminous intensities (I Tables) which provide specific values of luminous intensities in appropriate angular directions so that linear interpolation yields results accurate within five percent.

A3 Accuracy of Calculations

The accuracy of calculations for pavement luminance and STV depends upon the following factors:

(a) The lighting design must incorporate a Light Loss Factor (LLF) (see **Section A11**) into all calculations.

(b) Whether or not the photometric data used to determine the luminous intensity at a particular angle correctly represents the output of the lamp and luminaire.

(c) Whether or not the directional reflectance table represents accurately the reflectance of the surface.

A4 Calculation of Illuminance and Pavement Luminance

Angles relating to the calculations of illuminance, pavement luminance and light emission from the luminaire are shown in **Figure A1**.

Formula and Units. When the luminaire output is in candela, and the distances in meters, then the illuminance is in lux and luminance is in candela per square meter.

$$E_h = \frac{I(\phi,\gamma) \times (\cos\gamma)^3 \times LLF}{H^2}$$

$$L = \frac{I(\phi,\gamma) \times r(\beta,\gamma) \times LLF}{MF \times H^2}$$

where:

- E_h = Horizontal Illuminance from one individual luminaire
- L = Pavement Luminance from one individual luminaire at point P
- I = Intensity at angles gamma and phi
- r = Reduced coefficient of reflectance at angles gamma and beta
- MF = Multiplying Factor used by the r-Table (often 10,000)
- H = Luminaire mounting height above the pavement surface (meters)
- LLF = Light Loss Factor

The total horizontal illuminance or luminance at point P is the sum of the values calculated for all contributing luminaires.

Summary of Pavement Luminance Data. Pavement luminance data is summarized in terms of the average of the pavement luminance at all grid points. Uniformity ratios are calculated as follows: the average-to- minimum ratio is determined by dividing the average luminance at all grid points by the value for the lowest grid point; the maximum-to-minimum ratio is determined by dividing the highest luminance value at any grid point by the lowest luminance value at any grid point.

A5 Calculating Target Luminance

Angular relationships between the luminaire, the surface of a vertical target and the observer are as shown in **Figure A2**.

Formula and Units. Units are related in the same manner as in **A4**. The reflectance of the target surface is assumed to be Lambertian.

$$L_t = \frac{I(\phi,\gamma) \times (\mathrm{Cos}\gamma)^2 \times \mathrm{Sin}(\gamma) \times [\mathrm{Cos}\,(90-\phi)] \times 0.5 \times \mathrm{LLF}}{[H - (0.5 \times TH)]^2 \times \pi}$$

where:

L_t = Luminance from one individual luminaire
I = intensity at angles gamma and phi
H = Luminaire mounting height above the pavement surface (meters)
LLF = Light Loss Factor
0.5 = Reflectance Factor (diffuse)
TH = Target Height (typically, 0.18 m)

The total target luminance is the sum of the values calculated for all contributing luminaires.

A6 r-Tables

Directional reflectance characteristics of a surface are a function of three angles as shown in **Figure A1**. Since the normal line of a driver's vision is downward and at points some distance ahead of the vehicle, a viewing direction (alpha) of 1 degree downward has been selected. The data can then be shown as a two dimensional array. This Standard Practice has adopted the angular nomenclature and format of the CIE and is shown in **Tables A1** through **A4**. The r values shown in the tables are not pure reflectance but are the reflectance q at angle beta and gamma multiplied by the cosine cubed of gamma and then multiplied by

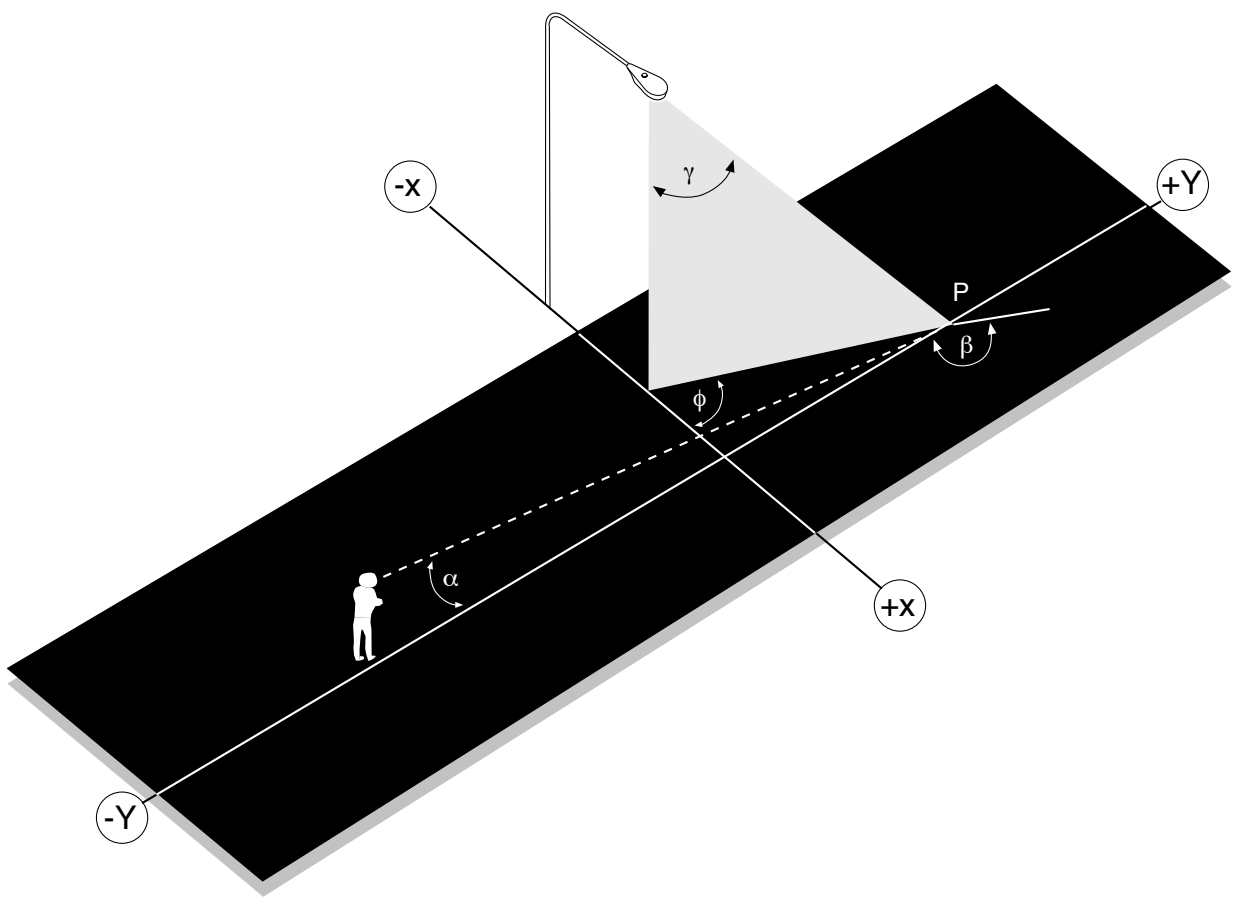


Figure A1. Orientation for illuminance and luminance calculations.

a factor (MF), which is often 10,000, so that they are larger integer numbers.

Pavement classification systems. When many pavement samples are photometered and the directional reflectance characteristics are analyzed, it becomes apparent that natural groupings occur and it is possible to represent a group of typical pavements by a single r-Table. Since the color of aggregates and binders change with little change in directional characteristics, accuracy can be increased if the Q_o is expressed separately. And a ratio of the standard Q_o and the specific Q_o of a particular pavement is used in the calculations.

A7 Calculation of Veiling Luminance

Angular relationships between the luminaire, the observer and the light source are as shown in **Figure A1**. In this Standard Practice the veiling luminance associated with point P is calculated for the observer located at 83.07 meters from point P. The observer is located as explained in **Section A1** and is looking at point P (see **Figure A3**).

Formula and units. Units are related in the same manner as in **Section A4**.

$L_v = K/\theta^n$, $n = 2.3 - 0.7 \times \log_{10}(\theta)$ for $\theta < 2$, $n = 2$ for $2 \leq \theta$

where:

L_v	=	Veiling Luminance from one individual luminaire
K	=	10 × (Vertical illuminance at the plane of a 25-year-old observer's eye)
θ	=	Angle in degrees

The veiling luminance due to all light sources (Lv) is the sum of the veiling luminance of all of the individual contributing sources.

A8 Calculation of Target Visibility

Small Target Visibility (STV) is a weighted average of the values of target Visibility Level over a grid of points on an area of roadway for one direction of traffic flow.

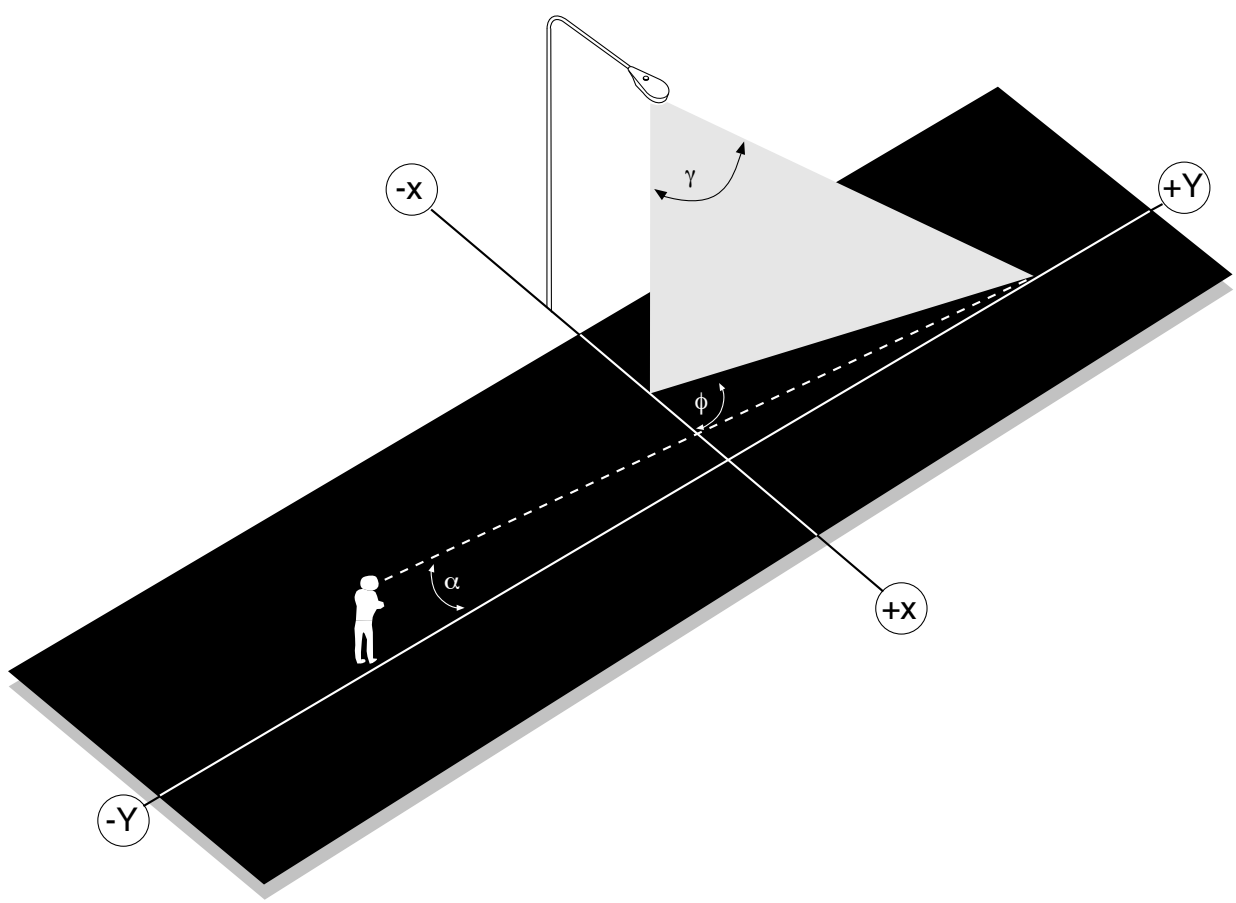


Figure A2. Orientation for target luminance calculations.

Table A1: r-Table for Standard Surface R1

6 tan γ	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655
0.25	619	619	619	619	610	610	610	610	610	610	610	610	610	601	601	601	601	601	601	601
0.5	539	539	539	539	539	539	521	521	521	521	521	503	503	503	503	503	503	503	503	503
0.75	431	431	431	431	431	431	431	431	431	431	395	386	371	371	371	371	371	386	395	395
1	341	341	341	341	323	323	305	296	287	287	278	269	269	269	269	269	269	278	278	278
1.25	269	269	269	260	251	242	224	207	198	189	189	180	180	180	180	180	189	198	207	224
1.5	224	224	224	215	198	180	171	162	153	148	144	144	139	139	139	144	148	153	162	180
1.75	189	189	189	171	153	139	130	121	117	112	108	103	99	99	103	108	112	121	130	139
2	162	162	157	135	117	108	99	94	90	85	85	83	84	84	86	90	94	99	103	111
2.5	121	121	117	95	79	66	60	57	54	52	51	50	51	52	54	58	61	65	69	75
3	94	94	86	66	49	41	38	36	34	33	32	31	31	33	35	38	40	43	47	51
3.5	81	80	66	46	33	28	25	23	22	22	21	21	22	22	24	27	29	31	34	38
4	71	69	55	32	23	20	18	16	15	14	14	14	15	17	19	20	22	23	25	27
4.5	63	59	43	24	17	14	13	12	12	11	11	11	12	13	14	14	16	17	19	21
5	57	52	36	19	14	12	10	9.0	9.0	8.8	8.7	8.7	9.0	10	11	13	14	15	16	16
5.5	51	47	31	15	11	9.0	8.1	7.8	7.7	7.7										
6	47	42	25	12	8.5	7.2	6.5	6.3	6.2											
6.5	43	38	22	10	6.7	5.8	5.2	5.0												
7	40	34	18	8.1	5.6	4.8	4.4	4.2												
7.5	37	31	15	6.9	4.7	4.0	3.8													
8	35	28	14	5.7	4.0	3.6	3.2													
8.5	33	25	12	4.8	3.6	3.1	2.9													
9	31	23	10	4.1	3.2	2.8														
9.5	30	22	9.0	3.7	2.8	2.5														
10	29	20	8.2	3.2	2.4	2.2														
10.5	28	18	7.3	3.0	2.2	1.9														
11	27	16	6.6	2.7	1.9	1.7														
11.5	26	15	6.1	2.4	1.7															
12	25	14	5.6	2.2	1.6															

Q_o = 0.10; S1 = 0.25; S2 = 1.53

Table A2: r-Table for Standard Surface R2

6 tan γ	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655
0.25	619	619	619	619	610	610	610	610	610	610	610	610	610	601	601	601	601	601	601	601
0.5	539	539	539	539	539	539	521	521	521	521	521	503	503	503	503	503	503	503	503	503
0.75	431	431	431	431	431	431	431	431	431	431	395	386	371	371	371	371	371	386	395	395
1	341	341	341	341	323	323	305	296	287	287	278	269	269	269	269	269	269	278	278	278
1.25	269	269	269	260	251	242	224	207	198	189	189	180	180	180	180	180	189	198	207	224
1.5	224	224	224	215	198	180	171	162	153	148	144	144	139	139	139	144	148	153	162	180
1.75	189	189	189	171	153	139	130	121	117	112	108	103	99	99	103	108	112	121	130	139
2	162	162	157	135	117	108	99	94	90	85	85	83	84	84	86	90	94	99	103	111
2.5	121	121	117	95	79	66	60	57	54	52	51	50	51	52	54	58	61	65	69	75
3	94	94	86	66	49	41	38	36	34	33	32	31	31	33	35	38	40	43	47	51
3.5	81	80	66	46	33	28	25	23	22	22	21	21	22	22	24	27	29	31	34	38
4	71	69	55	32	23	20	18	16	15	14	14	14	15	17	19	20	22	23	25	27
4.5	63	59	43	24	17	14	13	12	12	11	11	11	12	13	14	14	16	17	19	21
5	57	52	36	19	14	12	10	9.0	9.0	8.8	8.7	8.7	9.0	10	11	13	14	15	16	16
5.5	51	47	31	15	11	9.0	8.1	7.8	7.7	7.7										
6	47	42	25	12	8.5	7.2	6.5	6.3	6.2											
6.5	43	38	22	10	6.7	5.8	5.2	5.0												
7	40	34	18	8.1	5.6	4.8	4.4	4.2												
7.5	37	31	15	6.9	4.7	4.0	3.8													
8	35	28	14	5.7	4.0	3.6	3.2													
8.5	33	25	12	4.8	3.6	3.1	2.9													
9	31	23	10	4.1	3.2	2.8														
9.5	30	22	9.0	3.7	2.8	2.5														
10	29	20	8.2	3.2	2.4	2.2														
10.5	28	18	7.3	3.0	2.2	1.9														
11	27	16	6.6	2.7	1.9	1.7														
11.5	26	15	6.1	2.4	1.7															
12	25	14	5.6	2.2	1.6															

Q_o = 0.10; S1 = 0.25; S2 = 1.53

Table A3: r-Table for Standard Surface R3

6 tan γ	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294
0.25	326	326	321	321	317	312	308	308	303	298	294	280	271	262	258	253	249	244	240	240
0.5	344	344	339	339	326	317	308	298	289	276	262	235	217	204	199	199	199	199	194	194
0.75	357	353	353	339	321	303	285	267	244	222	204	176	158	149	149	149	145	136	136	140
1	362	362	352	326	276	249	226	204	181	158	140	118	104	100	100	100	100	100	100	100
1.25	357	357	348	298	244	208	176	154	136	118	104	83	73	70	71	74	77	77	77	78
1.5	353	348	326	267	217	176	145	117	100	86	78	72	60	57	58	60	60	60	61	62
1.75	339	335	303	231	172	127	104	89	79	70	62	51	45	44	45	46	45	45	46	47
2	326	321	280	190	136	100	82	71	62	54	48	39	34	34	34	35	36	36	37	38
2.5	289	280	222	127	86	65	54	44	38	34	25	23	22	23	24	24	24	24	24	25
3	253	235	163	85	53	38	31	25	23	20	18	15	15	14	15	15	16	16	17	17
3.5	217	194	122	60	35	25	22	19	16	15	13	9.9	9.0	9.0	9.9	11	11	12	12	13
4	190	163	90	43	26	20	16	14	12	9.9	9.0	7.4	7.0	7.1	7.5	8.3	8.7	9.0	9.0	9.9
4.5	163	136	73	31	20	15	12	9.9	9.0	8.3	7.7	5.4	4.8	4.9	5.4	6.1	7.0	7.7	8.3	8.5
5	145	109	60	24	16	12	9.0	8.2	7.7	6.8	6.1	4.3	3.2	3.3	3.7	4.3	5.2	6.5	6.9	7.1
5.5	127	94	47	18	14	9.9	7.7	6.9	6.1	5.7										
6	113	77	36	15	11	9.0	8.0	6.5	5.1											
6.5	104	68	30	11	8.3	6.4	5.1	4.3												
7	95	60	24	8.5	6.4	5.1	4.3	3.4												
7.5	87	53	21	7.1	5.3	4.4	3.6													
8	83	47	17	6.1	4.4	3.6	3.1													
8.5	78	42	15	5.2	3.7	3.1	2.6													
9	73	38	12	4.3	3.2	2.4														
9.5	69	34	9.9	3.8	3.5	2.2														
10	65	32	9.0	3.3	2.4	2.0														
10.5	62	29	8.0	3.0	2.1	1.9														
11	59	26	7.1	2.6	1.9	1.8														
11.5	56	24	6.3	2.4	1.8															
12	53	22	5.6	2.1	1.8															

Q_o = 0.07; S1 = 1.11; S2 = 2.38

Table A4: r-Table for Standard Surface R4

6 tan γ	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264
0.25	297	317	317	317	317	310	304	290	284	277	271	244	231	224	224	218	218	211	211	211
0.5	330	343	343	343	330	310	297	284	277	264	251	218	198	185	178	172	172	165	165	165
0.75	376	383	370	350	330	304	277	251	231	211	198	165	139	132	132	125	125	125	119	119
1	396	396	396	330	290	251	218	198	185	165	145	112	86	86	86	86	86	87	87	87
1.25	403	409	370	310	251	211	178	152	132	115	103	77	66	65	65	63	65	66	67	68
1.5	409	396	356	284	218	172	139	115	100	88	79	61	50	50	50	50	52	55	55	55
1.75	409	396	343	251	178	139	108	88	75	66	59	44	37	37	37	38	40	41	42	45
2	409	383	317	224	145	106	86	71	59	53	45	33	29	29	29	30	32	33	34	37
2.5	396	356	264	152	100	73	55	45	37	32	28	21	20	20	20	21	22	24	25	26
3	370	304	211	95	63	44	30	25	21	17	16	13	12	12	13	13	15	16	17	19
3.5	343	271	165	63	40	26	19	15	13	12	11	9.8	9.1	8.8	8.8	9.4	11	12	13	15
4	317	238	132	45	24	16	13	11	9.6	9.0	8.4	7.5	7.4	7.4	7.5	7.9	8.6	9.4	11	12
4.5	297	211	106	33	17	11	9.2	7.9	7.3	6.6	6.3	6.1	6.1	6.2	6.5	6.7	7.1	7.7	8.7	9.6
5	277	185	79	24	13	8.3	7.0	6.3	5.7	5.1	5.0	5.0	5.1	5.4	5.5	5.8	6.1	6.3	6.9	7.7
5.5	257	161	59	19	9.9	7.1	5.7	5.0	4.6	4.2										
6	244	140	46	13	7.7	5.7	4.8	4.1	3.8											
6.5	231	122	37	11	5.9	4.6	3.7	3.2												
7	218	106	32	9.0	5.0	3.8	3.2	2.6												
7.5	205	94	26	7.5	4.4	3.3	2.8													
8	193	82	22	6.3	3.7	2.9	2.4													
8.5	184	74	19	5.3	3.2	2.5	2.1													
9	174	66	16	4.6	2.8	2.1														
9.5	169	59	13	4.1	2.5	2.0														
10	164	53	12	3.7	2.2	1.7														
10.5	158	49	11	3.3	2.1	1.7														
11	153	45	9.5	3.0	2.0	1.7														
11.5	149	41	8.4	2.6	1.7															
12	145	37	7.7	2.5	1.7															

Q0 =$_o$ 0.08; S1 = 1.55; S2 = 3.03

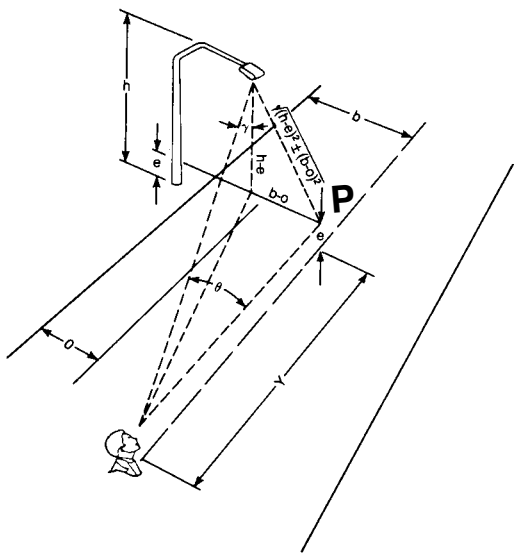


Figure A3. Orientation for veiling luminance. Downward viewing direction (α in Figure A2) is 1°.

Visibility Level (VL) for a target at a point for one viewing point and direction is the amount above the visibility threshold as seen by the observer. Visibility Level (VL) is a ratio and has no units.

To calculate STV for a grid of points and one direction of traffic flow, VL and Relative Weighted VL (RWVL) must be calculated for each point on the grid using steps one through ten.

The first step is to determine the target location at a grid point P and the viewing position and direction as viewed by an observer located as per **Section A2** at a distance of 83.07 meters. The observer is an adult (60 years) with normal eyesight whose fixation time is 0.2 second. The target is an 18 cm by 18 cm square flat surface perpendicular to the road surface and to a horizontal line from the observer's position. The target reflects light in a Lambertian manner with a reflectance of 0.50.

Target luminance (L_t) is calculated per **Section A5** for one point at the center of the target. Veiling Luminance (L_v) is calculated for the observer per **Section A7**.

Background luminance (L_{b1}) is calculated at a point on the pavement adjacent to the center of the bottom of the target, that is, the target's position on the roadway. Background luminance (L_{b2}) is calculated at a point on the pavement 11.77 meters beyond the target, at a point on a line projected from the observer's point of view through the point at the center of the top of the target. L_{b1} and L_{b2} are each calculated per **Section A4**, as if the observer were one degree above the plane of the roadway. Background luminance (L_b) for the target is calculated in this document as the average of L_{b1} and L_{b2}:

$$L_b = (L_{b1} + L_{b2}) / 2$$

The values L_t, L_b, and L_v are then used, together with constants for the target size, observer age, and fixation time, to calculate visibility level (VL) in steps two through nine.

The second step is the determination of the adaptation luminance (L_a), the Log_{10} of L_a (LL_a), and the visual angle (A) in minutes subtended by the target:

$$L_a = L_b + L_v$$

$$LL_a = Log_{10}(L_a)$$

$$A = \arctan(\text{Target size / Distance observer to target}) \times 60$$

For the standard Target Size of 0.18 meters on a side and Distance of Observer to Target of 83.07 meters, "A" is 7.45 minutes.

The third step is the determination of the sensitivity of the visual system as a function of adaptation luminance. This is done by using one of three equations depending on the value of L_a:

If $L_a = > 0.6$
then $F = [Log_{10}(4.2841 \times L_a^{0.1556}) + (0.1684 \times L_a^{0.5867})]^2$
and $L = (0.05946 \times L_a^{0.466})^2$

If $L_a > 0.00418$ and $L_a < 0.6$
then $F = 10^{\{2\times[(0.0866 \times LL_a^2) + (0.3372 \times LL_a) - 0.072]\}}$
and $L = 10^{[2\times(0.319 \times LL_a - 1.256)]}$

If $L_a < 0.00418$
then $F = 10^{(0.346 \times LL_a + 0.056)}$
and $L = 10^{[(0.0454 \times LL_a^2) + (1.055 \times LL_a) - 1.782]}$

The fourth step is to calculate a number of intermediate functions using the following equations:

$$B = Log_{10}(A) + 0.523$$
$$C = LL_a + 6$$
$$AA = 0.360 - \{(0.0972 \times B^2)/[B^2 - (2.513 \times B) + 2.789]\}$$
$$AL = 0.355 - \{0.1217 \times [C^2/(C^2 - (10.40 \times C) + 52.28)]\}$$

$$AZ = \sqrt{\frac{(AA)^2 + (AL)^2}{2.1}}$$

$$DL_1 = 2.6\left[\frac{\sqrt{F}}{A} + \sqrt{L}\right]^2$$

The fifth step is to calculate M by one of three equations depending on the value of LL_a and determine the value of a negative contrast adjustment factor (FCP). Note that FCP is not accurate when LL_a is less than

-2.4 (L_a, the adaptation luminance, less than 0.00418 cd/m^2). In practice such low levels of adaptation are never encountered with negative contrast:

If $LL_a > -2.4$ and < -1
then $M = 10^{-10^{-\{[0.075 \times (LL_a + 1)^2] + 0.0245\}}}$

If $LL_a > = -1$
then $M = 10^{-10^{-\{[0.125 \times (LL_a + 1)^2] + 0.0245\}}}$

If $LL_a <$ or $= -2.4$
then FCP = 0.5 (TGB and FCP need not be calculated)

$$TGB = -0.6(L_a)^{-0.1488}$$

$$FCP = 1 - \left[\frac{(M)(A)^{TGB}}{2.4\ (DL_1)\ (AZ + 2)/2}\right]$$

The sixth step is to adjust DL in accordance with the time of observation (T) which for this document is a constant 0.2 seconds:

$$DL_2 = DL_1 \times [(AZ + T)/T]$$

The seventh step is to calculate the adjustment (FA) for the age of the observer (TA) and then adjust DL accordingly. TA is 60 years in this document:

If age is < or = 64
then $FA = [(TA - 19)^2/2160] + 0.99$

If age is over 64
then $FA = [(TA - 56.5)^2/116.3] + 1.43$

$$DL_3 = DL_2 \times FA$$

The eighth step is to calculate the adjustment if the target is darker than the background (negative contrast):

If L_t is less than L_b
then $DL_4 = DL_3 \times FCP$
or else $DL_4 = DL_3$

The ninth step is to calculate VL:

$$VL = (L_t - L_b)/DL_4$$

The tenth step is to calculate the relative weighted visibility level RWVL.

Visibility Level values are typically both positive and negative over an area on the roadway. A magnitude less than 1.0 (positive or negative) indicates that the target is below threshold for a standard observer who is allowed a fixation time of 0.2 seconds. Very large VL values indicate that the target is easier to see or can be seen faster, but a VL of 9.5 at one point and a VL of 0.5 at another are not equivalent to two points with a VL of 5. Relative Weighted VL is used so that large VL values are not counted as heavily as small ones in the computation of the summary of target visibility (STV) values used in **Table 4** in the main document:

$$RWVL = 10^{[-0.1 \times ABS(VL)]}$$

Summary of Data, the Final Steps

After all RWVL values are calculated for all grid points, calculate the Average RWVL:

ARWVL = (Sum of all RWVL)/(Number of points in the grid)

Finally, calculate the Weighted Average VL, also known as Small Target Visibility or STV (see **Table 4** in the main document):

STV = Weighted Average VL = $-10 \times Log_{10}(ARWVL)$

A9 Selection of a Grid for Calculation or Measurement

Different procedures are required when selecting a grid for straight roadway sections, for curves, and for traffic conflict areas. While exact rules can not be specified for all situations this discussion is intended to illustrate the principles that should be followed in selecting grids for calculation or measurements.

A9.1 Straight Roadway Areas

The grid should be selected so that, for straight roadway sections between traffic conflict areas, the area of all grid cells is identical. A grid cell is defined as the area bounded by an imaginary line that is equidistant from all adjacent grid intersections and touches the edge of the pavement (**Figure A4**). There should be two grid lines per lane located on quarter (1/4) of the distance from the edge of each lane. In the event the roadway varies in number of lanes (left turn lanes added before intersections), the grid should be based on the number of lanes for the majority of the length of the roadway. In the event that the roadway width and number of lanes change, then a revised grid shall be used for the new width of roadway. In the longitudinal direction the distance between grid lines shall be one tenth (1/10) of the spacing between luminaires, or 5 meters, whichever is smaller. The starting point for grid lines should not be located directly under the luminaire, but the grid should start at a point one half (1/2) of the grid cell size from the luminaire. In the event that the luminaire location geometry is constant, the length of the gridded portion of the street need be no longer than the spacing between luminaires.

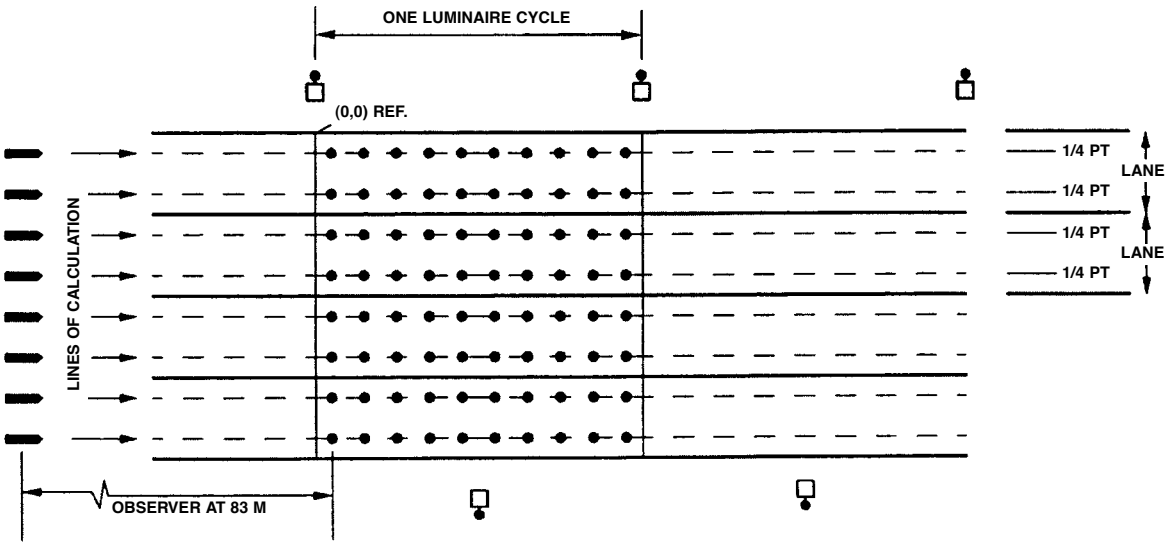


Figure A4. Location of test points for illuminance and luminance measurements on roadways. (a) Area and points are typical as shown: two transverse points per lane at each longitudinal point along one luminaire cycle. Maximum 5 meters between longitudinal points. (b) For illuminance measurements, the installation should include the contributions of at least three luminaire cycles: the cycle under test and one cycle on either side. (c) For luminance measurements: the observer moves with points parallel to the roadway [detector height = 1.45 meters; line of sight = 1 degree down over a longitudinal distance of 83 meters]. The installation should include a minimum of three luminaire cycles beyond the test area and one cycle in front of the test area.

Luminaire geometry refers to spacing, mounting height, overhang, tilt, and orientation of the luminaire. In the event that the luminaire geometry is not uniform along the length of the roadway, the gridded portion should continue until it has reached the point where the luminaire geometry remains constant for at least three luminaire locations.

A9.2 Curved Roadway Sections

The same principles should be followed for curved sections as for straight sections. There should be two grid lines per lane, located one quarter (1/4) the lane width from the edges of the lane. The longitudinal grid size should be determined along the roadway centerline with transverse grid lines appearing as radii from the center of curvature and longitudinal grid lines appearing as concentric circles about the center of curvature. The observer is located at a distance of 83 meters measured back along a chord from the grid point of calculation or measurement to the observers position.

A9.3 Traffic Conflict Areas

Traffic conflict areas can be divided into two types: areas where vehicles conflict with crossing vehicles and pedestrians, and areas where vehicular traffic must merge, diverge, or weave to reach either a through traffic lane or an exit lane. Where traffic conflict areas do not involve merging or diverging vehicle lanes, the normal grid should continue without change and any grid point falling within the defined traffic conflict area should meet the criteria for that area as defined in this Standard Practice. Where traffic conflict areas do involve merging, diverging or weaving there must be two grids superimposed on that area. Each grid should follow the rules for its lanes prior to entering the traffic conflict area. The grids can be separate or forced to coincide, depending upon the desire of the designer and the capability of the calculation program. In any event, the driver of a vehicle approaching the traffic conflict area should be considered as an observer and calculations made for the appropriate grid points that define the lane(s) that the driver might use to enter the traffic conflict area.

A10 Methods of Field Measurement

Field measurements can be made of both pavement luminance and visibility level of a target. The instrumentation is both expensive and time-consuming to use. Normally such instrumentation is used in research work or for validating calculation methods. However, there are other procedures that can be used to check equipment for proper manufacture and installation. These include photometering of random samples, checking geometry and leveling of random samples, and of comparing calculated and achieved illuminance measurements of an installation. It should be remembered that there are a great number of variables in terms of manufacturing, installation, electrical, pavement, and measuring instrument tolerances, which will cause variation between calculated and measured results. It can not be predicted which of these tolerances will cancel and which will have an additive effect. Illuminance field measurements are

described in IESNA Publication LM-50-99, *Photometric Measurements of Roadway Lighting Installations.*

A11 Light Loss Factor (LLF)

Those factors, which change with time after installation, may be combined into a single multiplying factor for inclusion in calculations. The LLF is composed of separate factors, each of which is controlled and evaluated separately. Many of these are controlled by the selection of equipment (Equipment Factor) and many others are controlled by planned maintenance operations (Maintenance Factor). A few are beyond the control of the lighting system owner or operator and depend upon actions of others, such as the system voltage regulation, or the control of emissions into the atmosphere. It is, however, the task of the system designer to determine and apply a realistic LLF factor to all design calculations.

A11.1 Maintenance Factor (MF)

The result of time-dependent depreciation effects must be considered in the initial design. Regular maintenance is particularly important with regard to energy conservation and these plans, once incorporated into the design, should be carried out or the system will not perform as expected.

A11.1.1 Lamp Lumen Depreciation (LLD). Information about the chosen lamp and its lumen depreciation and mortality are available from lamp manufacturers' tables and graphs. Rated average life should be determined for the specific hours per start. A typical roadway lighting system will be in operation about 4000 to 4300 hours per year. From these facts, a practical group relamping cycle should be established and then, based on the hours elapsed to lamp removal, the specific LLD factor can be determined. Consult manufacturers' data or the latest *IESNA Lighting Handbook* for LLD factors.

A11.1.2 Luminaire Dirt Depreciation (LDD). The accumulation of dirt on luminaires results in a loss in light output on the roadway. This loss is known as the LDD factor and is determined by estimating the dirt category (very clean, clean, moderate, dirty, or very dirty) from definitions given in **Figure A5**. From the appropriate dirt condition curve in **Figure A5** and the proper elapsed time in years of the assumed cleaning cycle, the LDD factor is then selected.

A11.1.3 Burnouts. Unreplaced burned-out lamps will vary in quantity, depending on the kinds of lamps and the relamping program used. Manufacturers' lamp mortality statistics should be consulted for the performance of each lamp type so that the number of burn-outs can be determined before the time of planned replacement is reached. For applications where maintained roadway illumination is critical, a periodic check of lamp performance is needed. This can be accomplished by a nighttime drive-by or other method of monitoring lamp and luminaire operation.

A11.2 Equipment Factor (EF)

Light loss factors, that are not dependent on time, relate mostly to the characteristics of the specific equipment selected. While some may not be correctable, it is possible that one or more may have an important effect upon the light level produced. Care should be taken in selecting equipment appropriate to the service conditions.

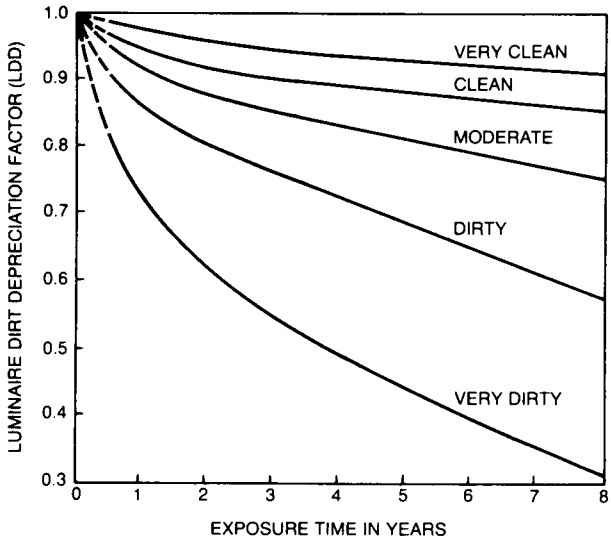
A11.2.1 Ambient Temperature. The effect of ambient temperature on the output of some lamps may be considerable. Each particular lamp-luminaire combination has its own distinctive characteristic of light output versus ambient temperature. To apply a factor for light loss due to ambient temperature, the designer must know the highest and lowest temperatures expected and to have data showing variation in light output with changes in ambient temperature for the specific lamp in the specific luminaire to be used.

A11.2.2 Voltage. In-service voltage is difficult to predict. However, if voltage fluctuations are expected then certain ballast types can be selected which compensate for voltage variations. Conductor size affects voltage drop and the trade-off between using smaller conductors and ballast types that compensate for voltage variations should be evaluated.

A11.2.3 Ballast and Lamp Factor. Information is available as to the relationship of the ballast circuit type, lamp type, and other factors to the rated versus actual light output of various lamps and ballasts. Certain circuits can minimize line voltage variation, others can minimize lamp tolerances while still others can compensate for lamp aging. Photometric data is based on rated lamp output under laboratory conditions. Under field conditions circuits and component tolerances in both the ballast and the lamp cause variations between any individual lamp ballast combination and rated output.

A11.2.4 Luminaire Component Depreciation. Surface depreciation results from adverse changes in metal, paint, plastic components, and gaskets, which reduce light output.

Because of the complex relationship between the light controlling elements of luminaires using more than one type of material, it is difficult to predict losses due to deterioration of materials. Also for various luminaire surfaces, the losses will be differentially affected by



SELECT THE APPROPRIATE CURVE IN ACCORDANCE WITH THE TYPE OF AMBIENT AS DESCRIBED BY THE FOLLOWING EXAMPLES:

VERY CLEAN—No nearby smoke or dust generating activities and a low ambient contaminant level. Light traffic. Generally limited to residential or rural areas. The ambient particulate level is no more than 150 micrograms per cubic meter.

CLEAN—No nearby smoke or dust generating activities. Moderate to heavy traffic. The ambient particulate level is no more than 300 micrograms per cubic meter.

MODERATE—Moderate smoke or dust generating activities nearby. The ambient particulate level is no more than 600 micrograms per cubic meter.

DIRTY—Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaires.

VERY DIRTY—As above but the luminaires are commonly enveloped by smoke or dust plumes.

Figure A5. Luminaire Dirt Depreciation (LDD) factors.

the type of atmosphere to which they are exposed. Lack of maintenance greatly impacts reflector deterioration. This effect can not be calculated at this time.

A11.2.5 Change in Physical Surroundings. The designer should know as much as possible about future changes that may affect roadway conditions. In the design process, it is desirable to know when the pavement is in poor condition and if it is likely to be resurfaced early in the useful life of the lighting system. Consideration may also be given as to whether trees or border areas will be added, or whether nearby buildings will be constructed or demolished.

A11.3 Total Light Loss Factor (LLF)

The total light loss factor is obtained by multiplying all the contributing factors described above. Where factors are not known, or believed to be reasonably small, they may be omitted. Otherwise, they are estimated based on past experience at similar locations. In all cases, a light loss factor should be used that at least considers the LLD and the LDD. At this point, if it is found that the total light loss factor is excessive it may be desirable to reselect the luminaire and/or lamp, or modify the cleaning and/or maintenance schedule.

A12 Determination of LLF for Existing Installation

From time to time it may be desirable to determine the LLF for an installation that has been in service for a number of years. The process is relatively simple and is made much more effective if a few randomly selected luminaires have been photometered prior to installation as per **Section A3**. A few randomly selected luminaires should be removed in the "as is" condition and photometered in that condition. Each luminaire should then be restored as closely as possible to its original condition in a step by step process, photometering the luminaire between each step. Such a procedure might be as follows: a) replace lamp, b) clean inside of luminaire, c) clean outside of luminaire, d) operate at rated voltage rather than field measured voltage, e) compare with photometered results when new. "Photometry" in the preceeding case could be as sophisticated as sending the luminaire to a commercial laboratory or as simple as measuring the nadir intensity with a photocell mounted in a baffled black box. By using such a procedure the validity of an assumed LLF may be checked and the slow permanent deterioration described in **Section A11.2.4** can be determined.

Annex B

Design Guides and Examples

(This Annex is not part of the *American National Standard Practice for Roadway Lighting*, RP-8-00, but is included for informational purposes only.)

Annex B – Design Guides and Examples

B1 Introduction

An examination of the equations for the visibility model, when compared with the equations of the calculation of pavement luminance, indicate that the two criteria respond in a completely different way to changes in the design. It is therefore probable that actions taken to improve one set of criteria will reduce the other. The recommended process for designing a lighting system to satisfy the criteria of horizontal luminance, pavement luminance or small target visibility (STV) is as follows:

1. Select a tentative luminaire and lamp
2. Select a tentative arrangement and spacing of luminaires
3. Evaluate the system in terms of horizontal illuminance, pavement luminance or STV
4. Make changes, intended to achieve the desired horizontal illuminance, pavement luminance or STV

The vast majority of the luminaires used for roadway lighting have light distributions symmetrical about an axis perpendicular to the centerline of the roadway and are intended to produce an identical candela distribution in each direction. When used in an opposite, staggered, or center-mounted arrangement, they provide equal luminance, horizontal illuminance and STV to the traffic in both directions. The discussion in this annex is limited to using this type of luminaire in such balanced arrangements.

B2 System Changes and Effect on Luminance and STV

Table B1 lists the common system changes and the effects these produce when conventional bidirectional luminaires are used.

B3 Modifications That Affect Pavement Luminance

Pavement reflectance characteristics are such that much better reflectance occurs when the pavement point is between the observer and the luminaire. The best reflectance occurs when the observer's line-of-sight runs directly under the luminaire ahead.

Average pavement luminance is directly proportional to the lumens per square meter provided the luminaire distribution and pavement type are not changed. Changes in average luminance as a result of changes in spacing can be accurately predicted using a pro-

Table B1: Common Lighting Systems Changes and The Effects Produced

System Change	Effect on Pavement Luminance	Effect on Small Target Visibility
Increase lamp output *	• Proportional increase • No change in uniformity	Small increase in average
Reduce spacing **	• Increase average • Improve Uniformity	Decrease average
Increase mounting height **	• Decrease average • Improve Uniformity	Decrease average
Increase overhang **	• Increase average • Uniformity change unpredictable	Slight decrease
Change from Staggered to Opposite ***	• No change in average • Improve Uniformity	Large increase
Change from Staggered to Center Mounting ***	• Small change in average • Degrade Uniformity	Large increase

* Assumes no change in luminaire distribution.
** Assumes no change in lamp output or distribution.
*** Assumes spacing is doubled with no change in lamp or luminaire.

portional ratio. Lowering the mounting height reduces spill light off the roadway and increases both the lumens per square meter and the average pavement luminance. The effect of lowering the mounting height cannot be predicted by a proportional ratio. Increasing the overhang will increase average pavement luminance as long as the increase in spill light on the far side of the pavement is less than the reduction of spill light behind the luminaire.

Improvement of uniformity of pavement luminance is more difficult to infer and can not be predicted by a ratio method. Decreasing spacing and increasing mounting height improve uniformity. It is desirable to examine a printout of the pavement luminance at each grid point to determine where the maximum and minimum occur. From this the effect of changes can be estimated. In general, if the low point occurs between luminaires it can be improved by selecting a luminaire with a higher vertical angle of maximum candlepower. If the low point occurs along the edge of the roadway, changing to a wider luminaire distribution, or changing the overhang may improve the situation. For an extremely wide roadway it is best to use an opposite arrangement, since pavement reflectance characteristics are poor for light at large angles to the line of the observer's sight.

B4 Modifications That Affect STV

Bidirectional luminaires normally used on streets with no median and two way traffic create small target visibility by both positive and negative contrast. Reversal of contrast normally occurs twice in the spacing cycle, on a line beneath the luminaire and again about one third of the distance between luminaires. With staggered arrangements the number of contrast reversals may increase. The number of times there is a reversal between positive and negative contrast should be minimized, and the reversal area should be small. In an area of positive contrast, the target face should be made as bright as possible and the pavement against which it is seen should be reasonably dark. In an area of negative contrast the reverse should be true.

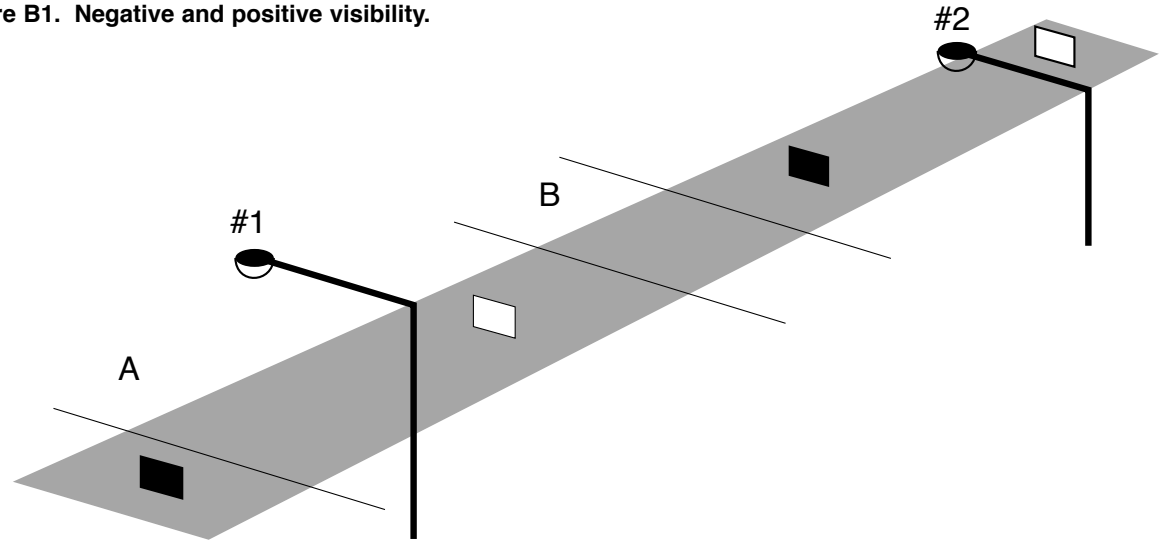
It is desirable therefore to achieve the desired average pavement luminance with luminance uniformity varying from close to the maximum permitted to the minimum permitted. The choice of the correct luminaire distribution and spacing is very critical to the achievement of high values of STV.

Contrast reversal under a bidirectional fixed lighting system occurs with all small objects viewed against the pavement as a background - unless they have near zero reflectance. The point where the target shifts from negative visibility to positive visibility will occur nearly under the luminaire, line "A" of **Figure B1**, and the band in which target visibility will be below threshold will be quite narrow. But it is important, to realize that such a band exists and that it is always present under luminaires with a bidirectional distribution.

Since the reversal of visibility from negative to positive also occurs under Luminaire #2, it follows that we must have another area of contrast reversal somewhere between Luminaires #1 and #2. This second area of contrast reversal "B" will also create a band where the target visibility is below threshold, and it may not be narrow and abrupt.

The goal, using bi-directional luminaire distributions, is to utilize luminaire arrangements and luminaire distributions that cause the lines of contrast reversal to be as infrequent and as short as possible, and cause the values of VL to be as high as possible.

Figure B1. Negative and positive visibility.



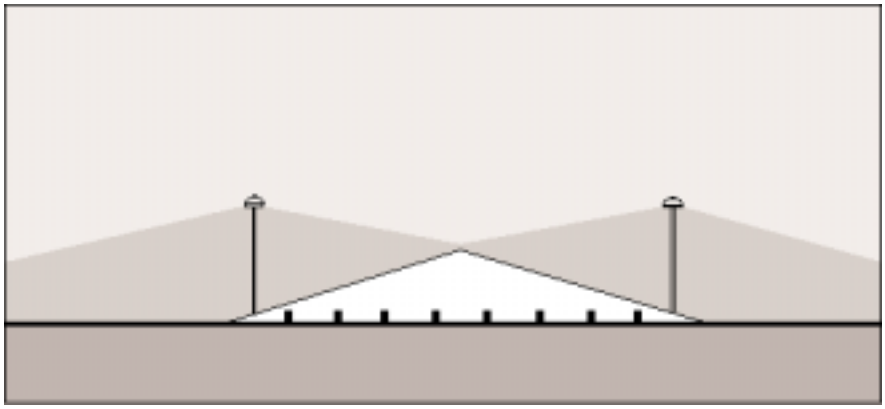


Figure B2. Example of luminaire overlap.

B4.1 Arrangements and Distributions That Maximize VL Values

For any given level of adaptation luminance there is a maximum VL for the negative contrast situation, but no maximum for the positive contrast situation. This occurs because the face of the target can become no darker than zero luminance, but under positive contrast the face of the target can, in theory, be made infinitely bright.

In order to maximize negative VL values, the pavement luminance should be increased and the luminance of the face of the target decreased. The opposite is true to maximize positive VL. This is done by reducing the overlap of the maximum 70 degrees candela values of the luminaires shown in **Figure B2**. There are two ways to do this; first by increasing the spacing to reduce overlap, and, second by choosing a luminaire distribution with a lower angle of maximum candlepower such as is shown in **Figure B3** while maintaining the same spacing. The use of luminaires with a very sharp cutoff will increase VL both by reducing disability glare and by narrowing the band of contrast reversal.

B5 Creating All Positive Contrast with Bidirectional Luminaires

It is possible to create designs with the target luminance of a 20 percent reflectance target always higher than the pavement luminance with either conventional bidirectional luminaires, or with luminaires having specialized distributions intended to be mounted with a negative overhang. This is done by reducing the spacing and moving the location of the luminaires behind the edge of the pavement (negative overhang). This causes the light reaching the pavement to be at an angle that is less effective in creating pavement luminance (background), while the angle to the target is still effective in producing target luminance. It is necessary to have the luminaires closely spaced so that the maximum beam candlepower reaches directly under the next luminaire.

This technique is frequently used to achieve the higher values of STV required by traffic conflict areas. Under such an arrangement there are no reversals of contrast in the traffic conflict area, contrast is always positive and, as noted above, higher positive contrasts can be achieved than negative contrasts. **Figure B4** and **Figure B5** show examples of traffic conflict areas with luminaire arrangements for all positive contrast.

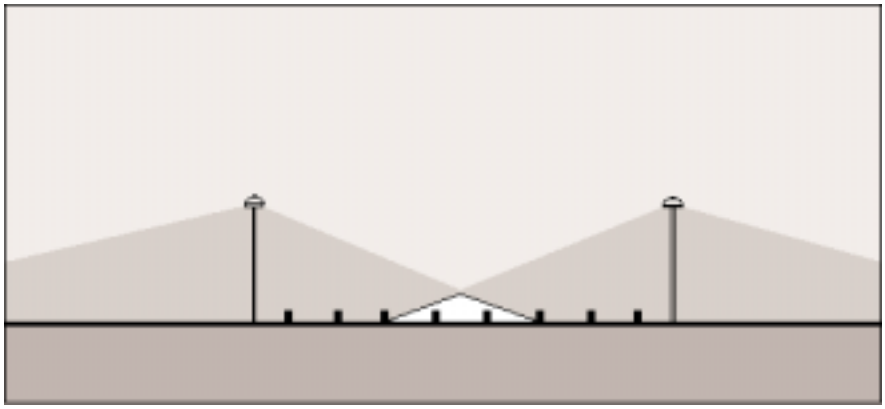


Figure B3. Example of reduced luminaire overlap.

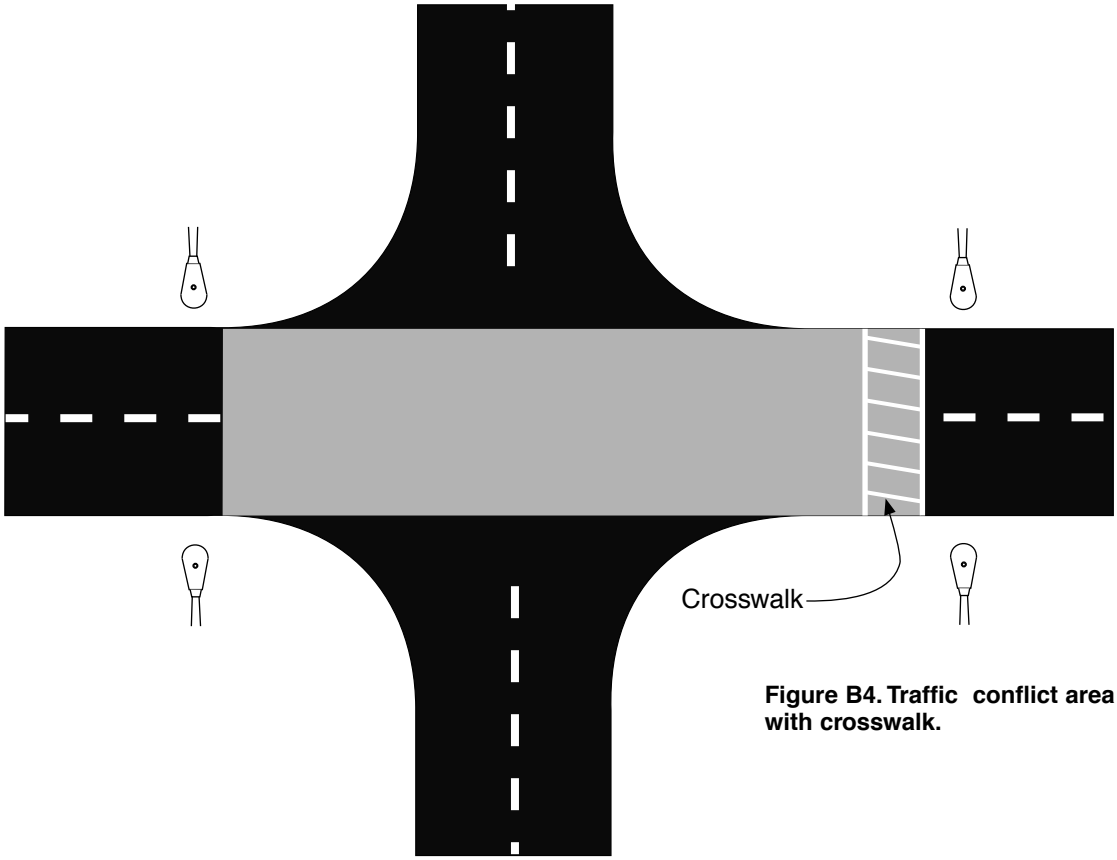
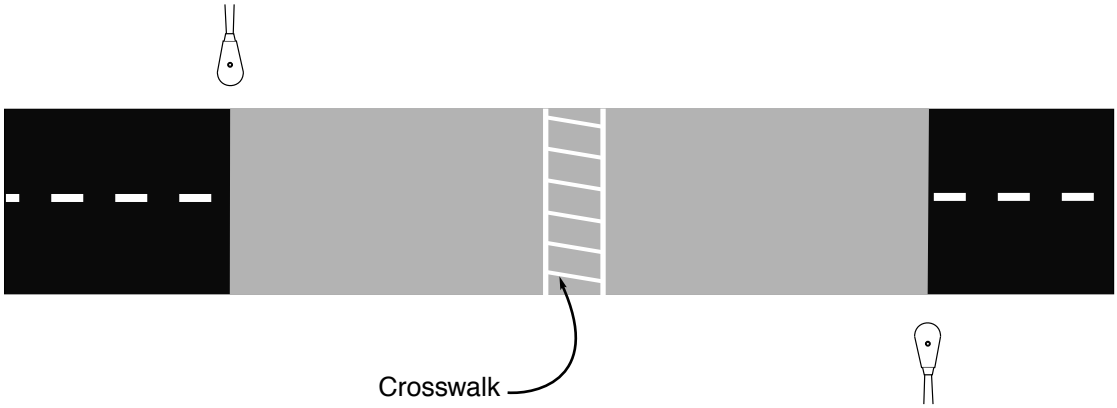


Figure B4. Traffic conflict area (grey) with crosswalk.

Figure B5. Traffic conflict area (grey) with crosswalk.



Annex C

Glare

(This Annex is not part of the *American National Standard Practice for Roadway Lighting*, RP-8-00, but is included for informational purposes only.)

Annex C – Glare

C1 Introduction

The common term "glare," as it affects human vision, is subdivided into two components, disability glare and discomfort glare. They are not completely indivisible but can be approached on a separate basis.

Disability glare is the glare that results in reduced visual performance and visibility. It often is accompanied by discomfort.

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

No lighting system, electric or daylighting, is ever "glare free," since the very light that produces the contrast borders essential to vision must enter the eye and as a result produces glare. In the roadway lighting situation, glare is produced by the lighting system, by the luminance of the pavement, and the luminance of objects in the surround. In this Standard Practice, the disability glare produced by the lighting system and the pavement luminance is included in the calculation of target visibility level (**Annex A**). Disability glare from the headlights of oncoming cars can be calculated and was considered in the recommendations for average pavement luminance and STV of **Table 4** (see also **Annex F**). Discomfort glare calculations and ratings are not a part of this Standard Practice but are being actively investigated.

Disability glare is considered in **Section C2**, and discomfort glare is discussed in **Section C3**.

C2 Disability Glare (Veiling Luminance)

For all roadway lighting situations, stray light produced within the eye by luminance sources (usually light sources) within the field of view, must be taken into consideration. Stray light within the eye produces a veiling luminance (L_v) which is superimposed upon the retinal image of the object to be seen. This alters the apparent brightness of any object within the visual field and the background against which it is viewed, thereby impairing the ability of the driver to perform visual tasks.

C2.1 Calculation of Veiling Luminance

The L_v (expressed in candelas per square meter) relative to the observers position and line of sight, can be calculated from the formula and relationships explained in **Annex A**. Veiling luminance changes with each observer position and with each change in line of sight as the observer moves along the roadway and glances at different objects. In order to simplify the situation for roadway calculations, the observers line of sight is assumed to be a line parallel to the centerline of the roadway but downward at a one degree angle with the observer at a height of 1.45 meters above the roadway surface.

C2.2 Field Measurements

The L_v can be measured at a particular location with a telephotometer equipped with a special lens which sums all the luminances in the field of view in accordance with the formula for calculating L_v as given in **Annex A**.

C2.3 Field of View

Luminaires shielded from the view of an observer do not contribute to glare. Pedestrians and cyclists with no helmets are shielded by their eyebrows from luminaires above 45 degrees above the direction of view. Unpublished studies (Adrian, et al) indicate that 75 percent of drivers of 1980's style autos are shielded by the windshield from luminaires above 20 degrees above horizontal.

No allowance is made for shielding in this standard and all luminaires are included in veiling luminance measurements and calculations. As a practical matter, since roadway luminaires do not generally put out maximum candlepower within 45 degrees of straight down, this has worked adequately.

C3 Discomfort Glare

Any source of luminance in the field of view, such as a streetlighting luminaire, the headlights of an oncoming vehicle, or off-roadway lighting sources, may cause both discomfort and disability glare. The calculation procedures are separated since the relative effect of changes in source size, luminance, displacement angle of the source, adaptation level, exposure time, and motion is different for the two types of glare. It is generally true that when disability glare is reduced, there will also be a reduction in discomfort glare, but not necessarily in the same amount. On the contrary, it is entirely possible to reduce the discomfort glare of a system but at the same time increase the disability glare.

Discomfort glare produces a sensation of ocular discomfort, which, in its milder form, often causes an increase in the blink rate of an individual and, in its extreme form, causes tears and pain. While discomfort glare does not reduce the ability to see an object as in the case of disability glare, it may cause fatigue, which results in driver error.

C3.1 Calculation of Discomfort Glare

Evaluations of discomfort glare from a single light source in the field of view have enabled researchers to determine the relative effect of changes in size, luminance, and angular displacement of sources. These may be related in terms of equations to predict subjective ratings, or a condition known as the borderline between comfort and discomfort (BCD). In general work done in Europe tends to evaluate subjective ratings and those in North America to evaluate BCD.

The discomfort glare effect from a number of sources in the field of view is more complex. In Europe the CIE committees for roadway lighting have developed a graphical method of combining the discomfort glare from a number of uniformly spaced streetlights, which results in a glare rating from 1 to 10 (10 the most comfortable). This is referred to as the "Glaremark System."[16]

In North America, research sponsored by the Lighting Research Institute, has resulted in a method of combining the discomfort glare from a number of sources into a single factor called Combined Brightness Effect (CBE).[17, 18, 19] The CBE of a lighting system can be calculated, using a computer program, for any number of observer positions as the observer moves through the lighting system.

C3.2 Field Measurements of Discomfort Glare

No instrumentation has been developed to measure the summation of the discomfort glare effect in the field. It may be possible to develop an instrument which will measure and combine luminances in the field into a CBE value.

Attempts have been made to correlate dynamic measurements of observer pupil size to the level of glare which observers subjectively have defined as BCD. As yet these have not been successful.

C4 Reduction of Discomfort Glare

Although no discomfort glare rating system has been adopted by the Illuminating Engineering Society of North America, the principles which should be used to reduce discomfort glare are well known. They are as follows:

1. Increase the angular displacement of light sources from the normal lines of sight.

2. Increase the size of the diffusing medium surrounding the light source.

3. Increase the adaptation level of the visual system.

Discomfort glare from oncoming vehicle headlights can be reduced by wider median strips between divided roadways, glare control panels erected in the median, or other methods which would eliminate oncoming headlights from the driver's field of view.

Annex D

Situations Requiring Special Consideration

(This Annex is not part of the *American National Standard Practice for Roadway Lighting*, RP-8-00, but is included for informational purposes only.)

Annex D – Situations Requiring Special Consideration

D1 Roadway Complexities

(1) The design data contained in this Standard Practice are for straight and level roadway areas and areas having minor curves and grades. Roadways, however, have many areas where the problems of vision and maneuvering of motor vehicles are much more complex, such as grade intersections, abrupt curves, underpasses, converging traffic lanes, diverging traffic lanes and various types of complicated traffic interchanges. The design of roadway lighting for these areas demands special consideration.

(2) When all of these areas are analyzed, it becomes apparent that there are the following three basic factors that are fundamentally different from those encountered on normal straight roadway areas:

(a) Motor vehicle operators are burdened with increased visual and mental tasks upon approaching and negotiating these areas.

(b) Silhouette seeing cannot be provided in many cases due to the vehicle locations, pedestrian locations, obstructions, and the general geometry of the roadways. Glare from oncoming headlights that sweep across the driver's line of sight is often a problem.

(c) Adequate vehicle headlighting often cannot be provided. This is due to the geometry of roadways, lack of stopping room within headlight distances at speeds above 55 kilometers per hour, and the fact that vehicle headlighting follows rather than leads the progress of a vehicle in negotiating turns.

(3) The lighting of such areas, at first glance, appears to be a very complicated problem. It becomes apparent upon analysis, however, that all such areas consist of several basic types of situations or a combination of these. The basic six situations are treated individually in the following sections.

D1.1 Grade Intersections (See **Figures D1** and **D3**)

(1) These intersections may have unrestricted traffic flow on both roadways, restriction by means of stop signs on one or both of the roadways, control by traffic signals, control by police officers or other means. Some are complicated by pedestrian as well as vehicular traffic. The lighting problem on all of these, however, is fundamentally the same. The lighting level in these areas should be higher than the level of either intersecting road.

(2) Luminaires should be located so that lighting will be provided on vehicles and pedestrians in the intersection area, on the pedestrian walkways, and on the adjacent roadway areas. Of particular importance is the creation of contrast between the object to be seen and the pavement against which it is seen.

(3) **Figure D1(b)** shows a larger, more complex intersection. The lighting problems and techniques are similar to the small intersections. The size, however, may require the use of more or higher-output luminaires.

D1.2 Curves and Hills (See **Figure D2**)

(1) The visual problems in driving increase on curves and hills. In general, gradual, large radius curves and gently sloping grades are lighted satisfactorily if treated as straight level roadway surfaces. Sharper radius curves and steeper grades, especially at the crest of hills, warrant closer spacing of luminaires in order to provide higher pavement luminance and improved uniformities (see **Figure D2** (**e**) and (**f**)).

(2) The geometry of abrupt curves, such as those found on traffic interchanges (see **Figure D1**) and many roadway areas, requires careful analysis. Headlighting is not effective in these situations and silhouette seeing cannot be provided in some instances. Luminaires should be located to provide ample light on vehicles, road curbings and berms, and guard rails. Poles should be located to provide adequate, safe clearance, behind guardrail or any natural barrier if such exists. There is some evidence that poles are more likely to be involved in accidents if placed on the outside of curves. Many vehicle operators may be unfamiliar with these areas and lighting the surroundings greatly helps their discernment of the roadway path (see **Figure D2** (**c**) and (**d**)).

(3) Proper horizontal orientation of luminaire supports and poles on curves is important to assure balanced distribution of the light flux on the pavement (see **Figure D2**(**a**)).

(4) When luminaires are located on grades, it is desirable to orient the luminaire so that the light beams strike the pavement equidistant from the luminaire. This assures maximum uniformity of light distribution and keeps glare to a minimum (see **Figure D2**(**b**)).

D1.3 Underpasses and Overpasses (see **Figure D1**)

(1) Short underpasses such as those encountered where a roadway goes beneath a two-or four-lane

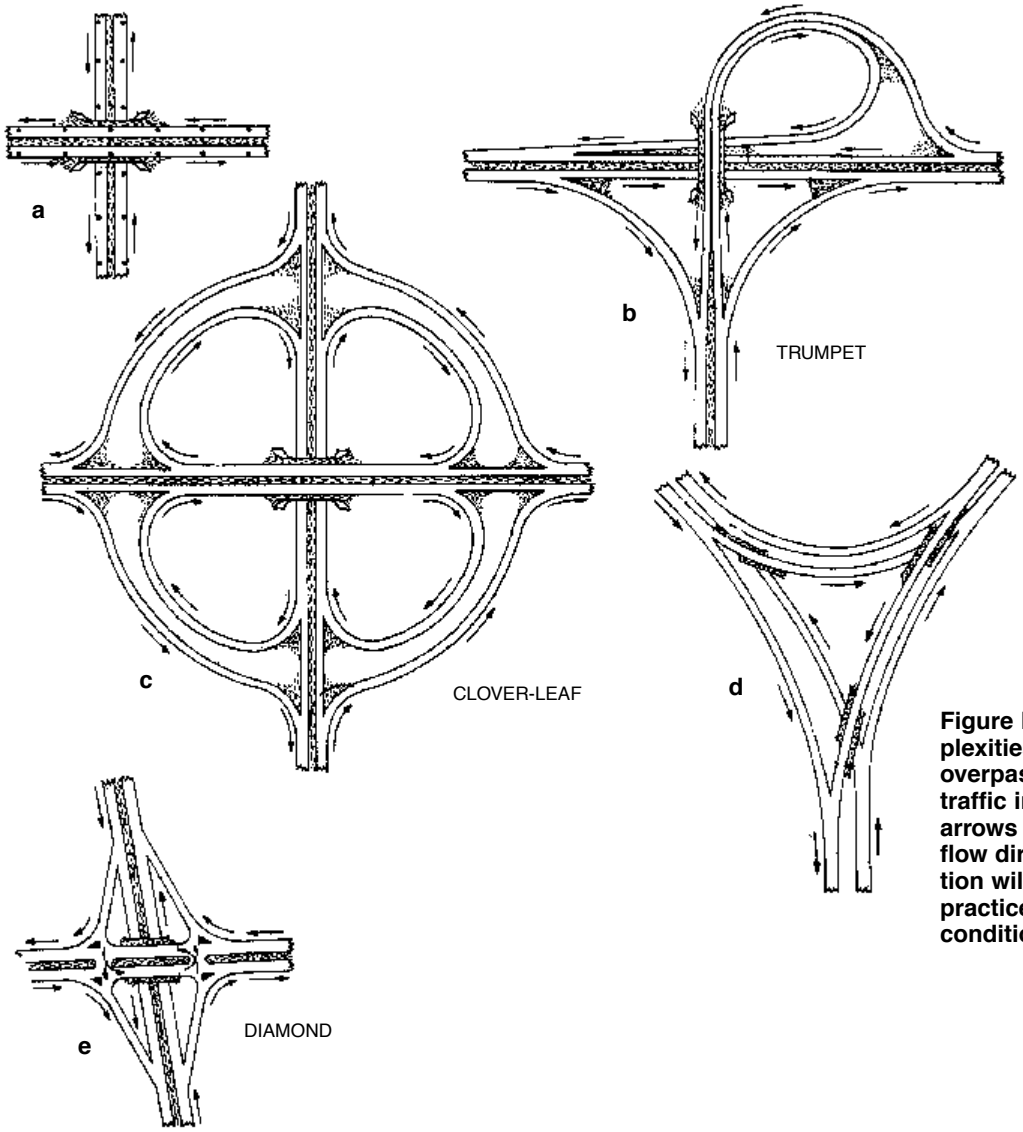


Figure D1. Roadway complexities: (a) underpass-overpass; and (b) to (e) traffic interchanges. *Note*: arrows indicate traffic flow directions. Pole location will depend on local practice and physical conditions of the area.

roadway can generally be lighted satisfactorily with standard luminaires if they are properly positioned. Luminaires on the lower roadway should be positioned so that there are not large discontinuities in the pavement lighting from that on either side of the overpass and so that the recommended levels are provided. Care should be taken so that the uniformity does not fall below the minimum values recommended in **Tables 2**, **3**, or **4**, depending upon selected method. These luminaires should also provide vertical illumination on the supporting structures.

(2) Long underpasses, where such overlapping of the lighting from the street luminaires cannot be accomplished, require special treatment. Long underpasses also greatly reduce the entrance of daylight, warranting lighting during the daytime. (See ANSI/IESNA RP-22-96, *Recommended Practice for Tunnel Lighting*.)

D1.4 Intersections of High-Speed, High-Traffic-Density Roadways (See **Figures D1** and **D3)**

(1) At first glance, interchanges appear to be complex lighting problems. However, analysis shows that they are comprised of one or more of the basic problems that are dealt with in previous paragraphs and may be treated accordingly.

(2) The regular roadway 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 lighted interchange with too few luminaires may lead to confusion for the driver, by giving misleading clues due to the random placement of the luminaires. (This does not apply to high mast lighting).

(3) When continuous lighting of the entire interchange area cannot be provided, it may be desirable to light intersections, points of access and egress,

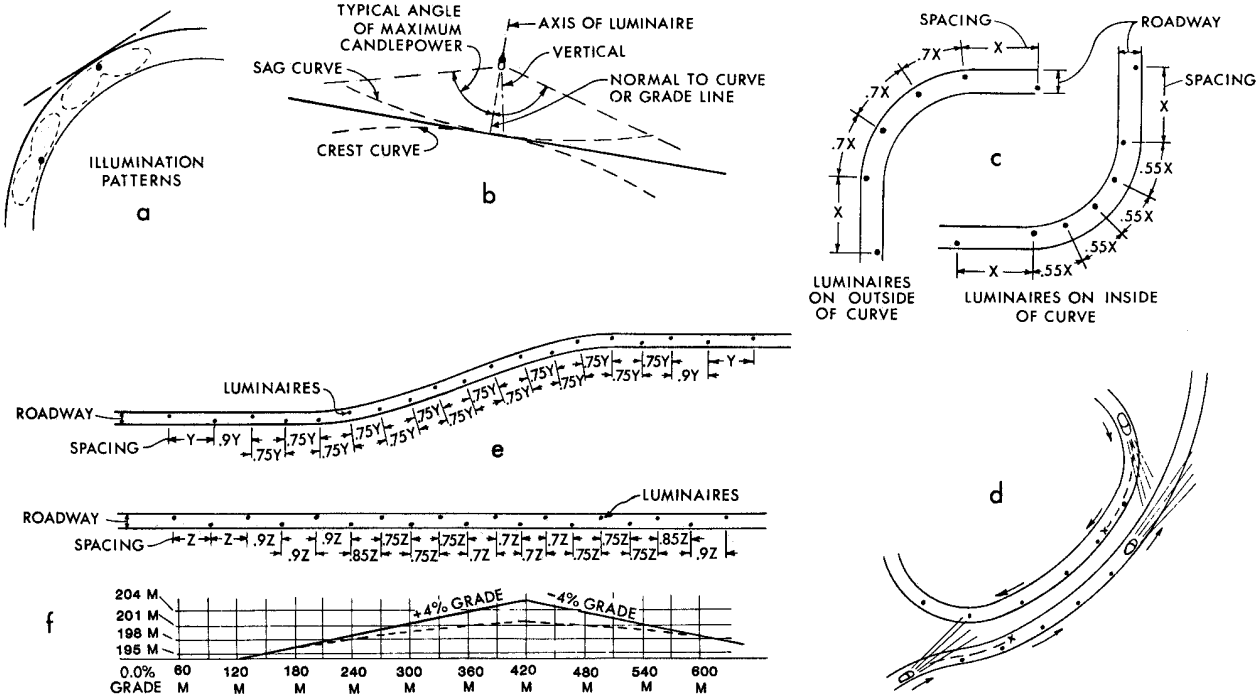


Figure D2. Typical lighting layouts for horizontal and vertical curves. (a) Luminaires oriented to place reference plane perpendicular to radius of curvature. (b) Luminaire mounting on hill (vertical curves and grade). (c) Short radius curves (horizontal). (d) Vehicle illumination limitations. (e) Horizontal curve, radius 305 meters, super elevation 6 percent. (f) 380-meter vertical curve with 4 percent grade and 230-meter sight distance.

curves, hills and similar areas of geometric and traffic complexity. In these cases, lighting should be extended beyond the critical areas. Two fundamental reasons for this are:

(a) The eyes of the driver, adapted to the level of the lighted area, need about one second to adjust to the changes in the illumination upon leaving the lighted area to maintain vision during the period of dark adaptation. Lighting transition, however, should be beyond the end of the maneuver area.

(b) 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.

(c) Diverging traffic lanes warrant extremely careful consideration because these are areas where motorists are most frequently confused. Luminaires should be placed to provide illumination on curbs, abutments, guard rails, and vehicles in the area of traffic divergence. Poles should be located to provide adequate safety clearance for vehicles that may cross the core area. Lighting should also be provided in the deceleration zone. Diverging roadways frequently have all the problems of abrupt curves and should be treated accordingly.

(4) The placement of luminaires should be carefully considered to minimize glare to the drivers and especially so as to not detract from sign legibility or to block the view of signs.

D1.5 Isolated Traffic Conflict Areas (Partial Intersection Lighting)

Partial intersection (non-continuous) lighting refers to lighting at an isolated intersection area, which has critical features such as curbed channelization and/or high vehicular volumes or pedestrian traffic.

The illumination of the intersection of a major street with a local street extending in only one direction (a T-type) is usually adequate if the major street luminaire is located opposite the intersecting street.

For the purposed of calculations in isolated traffic conflict areas, the conflict area is defined as the largest area within lines extended from (defined by):

- The face of the curb or the edge of the roadway
- The stop bars if present
- The crosswalks or the logical extension of the sidewalks, if used at night.

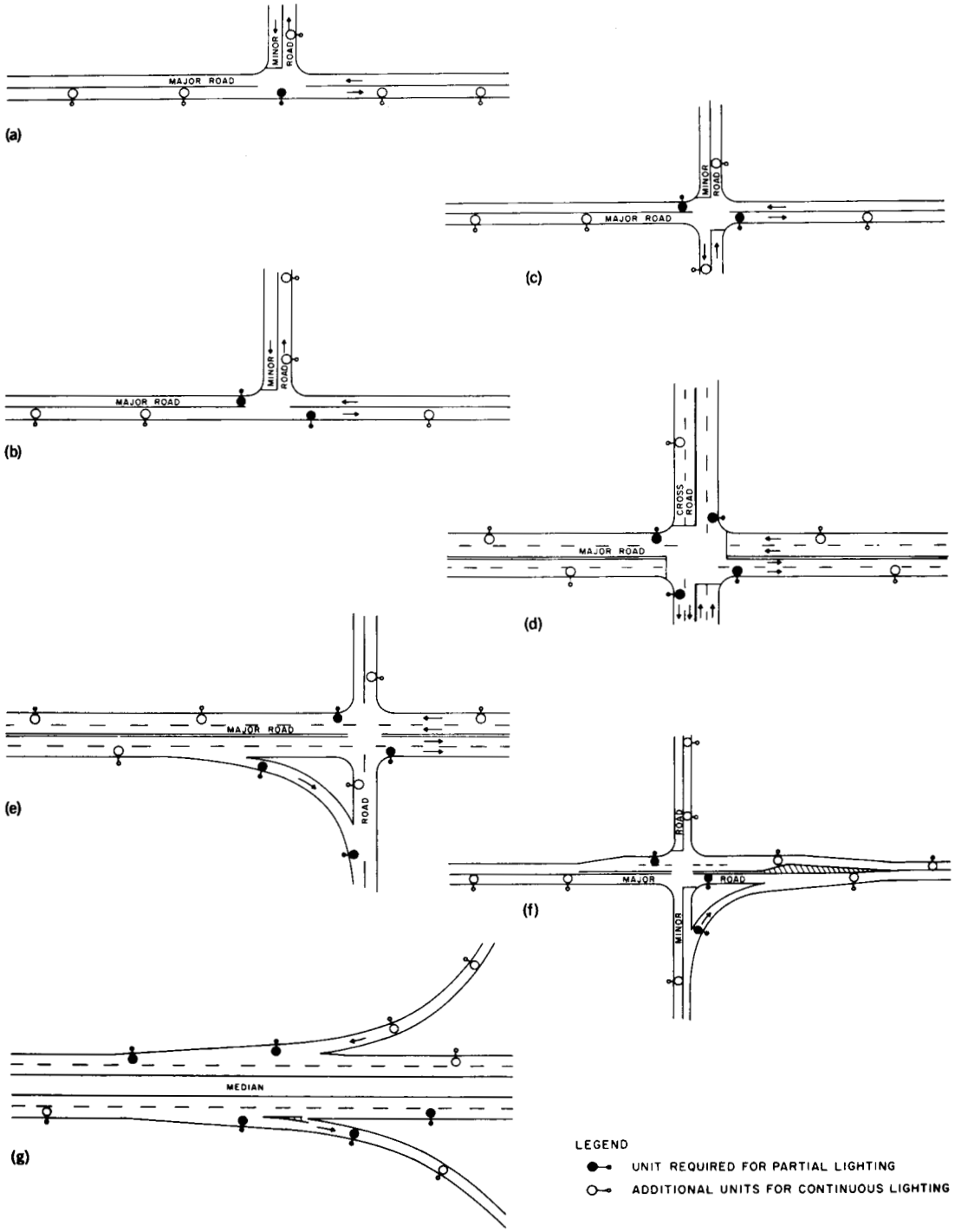


Figure D3. Examples of lighting configurations at intersections to provide illumination on vehicles and pedestrians in the intersection area, on the sidewalks, and on adjacent roadway areas for: (a) T-intersection; (b) T-intersection (alternate); (c) four-way intersection, two-lane road with two-lane sideroad; (d) signalized intersection, four-lane road with four-lane crossroad; (e) four-lane road with channelizing island; (f) intersection with channelizing island; and (g) typical acceleration and deceleration lanes at on and off ramps. *Note:* drawings are not to scale and the light locations shown are not to be considered complete in number or better than approximate in position.

For illuminance, the entire (more or less) rectangular area of the conflict area should be evaluated.

For roadway luminance and veiling luminance, each driving direction must be evaluated (separately).

For roadway luminance, the test points are along the quarter lane lines for all lanes in the chosen direction. Longitudinal spacing shall be:

- One tenth the longitudinal spacing but not more than 5 meters

Table D1: Illuminance Method - Recommended Maintained Values

Road Classification	Pavement Classification			Maximum Uniformity Ratio	Maximum Veiling Luminance Ratio
	R1 lux/fc	R2 & R3 lux/fc	R4 lux/fc	E_{avg}/E_{min}	L_{Vmax}/L_{avg}
Isolated Traffic Conflict Area	6.0/0.6	9.0/0.9	8.0/0.8	4.0	0.3

Table D2: Luminance Method - Recommended Maintained Values

Road Classification	Average Luminance	Maximum Uniformity Ratio	Maximum Uniformity Ratio	Maximum Veiling Luminance Ratio
	L_{avg} (cd/m^2)	L_{avg}/L_{min}	L_{max}/L_{min}	L_{Vmax}/L_{avg}
Isolated Traffic Conflict Area	0.6	3.5	6.0	0.3

Table D3: STV Method - Recommended Maintained Values

Road Classification	STV Criteria	Luminance Criteria		
	Weighted Average VL	L_{avg} cd/m^2 Median <7.3 m	L_{avg} cd/m^2 Median ≥7.3 m	Maximum Uniformity Ratio L_{max}/L_{min}
Isolated Traffic Conflict Area	2.6	0.5	0.4	6.0

- If two luminaires are present on opposite sides of the street, one tenth the longitudinal spacing but not more than 5 meters
- If a single luminaire is present, every 2 meters

The longitudinal grid points shall start at the first luminaire(s) and end one longitudinal grid point spacing before the next luminaire(s) cycle. The grid shall extend to cover the entire conflict area in the longitudinal direction of travel. The average roadway luminance (L_{avg}) shall include all lanes in the chosen direction.

For veiling luminance, the test points should be along the quarter lane lines in all lanes in the chosen direction. The grid should extend from one mounting height in front of the first luminaire encountered in the direction of travel to 45 meters before that point along the lane line. Grid increment should be 5 meters. The maximum veiling luminance (L_{vmax}) shall be the maximum L_{vmax} found in all lanes in the chosen direction.

In isolated traffic conflict areas, the ratio of maximum veiling luminance to average roadway luminance shall be limited to a maximum of 0.3.

D2 Railroad Grade Crossings

Railroad grade crossings shall be considered Isolated Traffic Conflict Areas with the following additions:

(1) At grade crossings where a substantial amount of railroad operation is conducted at night, particularly where train speeds are low, where crossings are blocked for long periods, or accident history indi-

cates that motorists experience difficulty in seeing trains or control devices during the hours of darkness, illumination 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.

(2) Proper illumination of a grade crossing will aid motorists in identifying the crossing, any irregularities in the pavement surface, the presence or absence of a train, a train approaching the crossing and allow recognition of unlighted objects or vehicles at or near the railroad crossing.

(3) Grade crossings are normally identified with railroad crossing “crossbuck” signs and pavement markings. The signs and the markings are reflectorized. Depending on its direction and level, grade crossing lighting could assist in the recognition of such signs and markings.

(4) General principles to be followed in selecting and locating lighting equipment are as follows:

(a) Lighting on roadway at track crossing area, starting 30 meters before the crossing and ending 30 meters beyond the crossing, should be in accordance with **Table D1** and **Table D2**, but never less than a luminance of 0.6 candela per square meter or an illuminance of 6 lux. Uniformity on roadway should meet **Tables D1** and **D2**.

(b) Pole and luminaire locations for providing vertical illuminance (minimum of 10 lux) on railroad cars are shown on **Figure D4** and should be located where railroad right-of-way crosses the public road right-or-way but never closer than 10 meters (consult luminaire photometric information to determine the most effective beam pattern).

(c) Vertical illumination of train cars in the crossing is most important, to provide adequate visibility. To maximize the night time visibility of trains approaching or in the crossing, lighting should extend along the railroad right-of-way at least 46 meters on each side of the crossing.

(d) Care should be taken in locating luminaires so as to (1) limit glare to vehicle drivers, bicyclists and pedestrians on the roadway approaches to the crossing and (2) limit glare that could interfere with the visibility of either railroad signal displays or the crossing by locomotive crews of trains approaching the crossing.

D3 Trees

(1) Both trees and roadway lighting are indispensable municipal assets. Through understanding and cooperation of those responsible, conflict between trees and roadway lighting can be reduced.

(2) Arborists should make tree selections based on those that will fit the available roadway space, with minimum conflict to utilities. Such selections may include upright, globular or ordinary tree shapes. In many cases, proper pruning of trees will solve any conflict between trees and roadway lighting.

(3) The presence of low overhanging foliage may seriously obstruct the light delivered to the pavement and sidewalk as well as impede truck movement. Judicious pruning can reduce or eliminate the screening effect. There are instances where pruning increased the average lighting effectiveness approximately one-third, and approximately doubled the lighting effectiveness in the critical areas of low visibility.

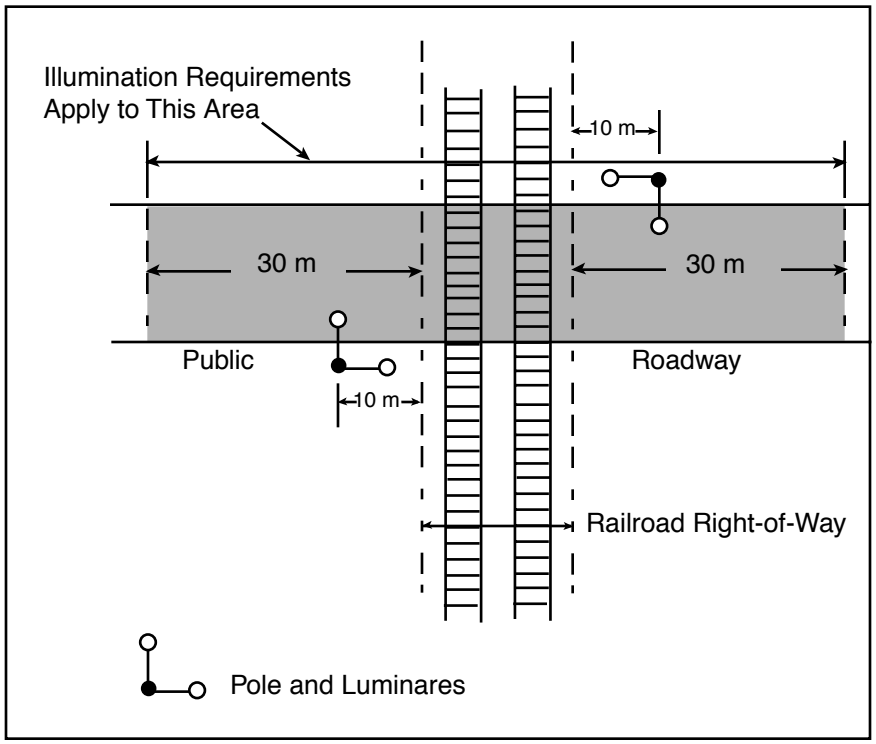


Figure D4. Pole and luminaire locations where a railroad right-of-way crosses a public roadway.

(4) It should be noted that even with high-mounted luminaires, it is not necessary to prune all trees to the height of the luminaire. It is necessary to prune only those branches that fall below the useful beam. (See **Figure D5**.) Foliage midway between luminaires and somewhat below lamp level helps to screen distant sources where silhouette lighting is intended; the attendant reduction in glare helps visibility and comfort of motorists and pedestrians. This gain is particularly important on local traffic and residential roadways where limited funds usually require relatively long spacings, with correspondingly high candlepower at angles near the horizontal.

(5) Another gain comes from reflection of upward light by the foliage, downward to the roadway and sidewalk. Although the amount is small, it adds to the low illuminance levels on local traffic roadways and increases the general adaptation level.

D3.1 Design Compromises

In order to minimize conflicts with trees, there are certain compromises that can be made in the lighting system. These compromises involve deviations from preferred system layouts with respect to luminaire spacing, mounting height, and transverse location. Such deviations usually should be accompanied by modifications in the light distribution provided by the luminaire. The amount of reduction in lighting effectiveness will vary depending upon the circumstances, type of modification and the extent of the deviation.

D3.2 Design Modifications

(1) As an example of modification, all luminaires may be mounted on longer mast arms. This generally increases construction costs to some extent, but the gain in lighting effectiveness may be substantial if foliage interference is reduced. Another modification is span-wire suspension of luminaires over the center of the street. Construction costs are substantially higher because two poles are required for each luminaire. Major disadvantages of span-wire suspension is that swaying and bobbing of luminaires in the wind nullifies to a great extent the effectiveness of the light control provided by modern luminaires, and the added pole and wiring may not be aesthetically pleasing.

(2) Still another modification is to reduce the luminaire mounting height with a corresponding reduction in spacing, use a lamp of lower lumen output, and lower the angle of maximum candlepower. This method materially increases the cost of roadway lighting.

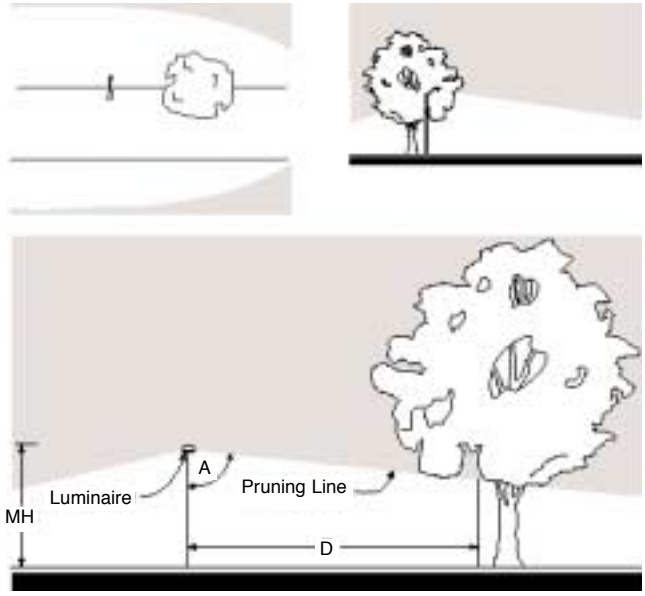


Figure D5. Pruning is needed only on branches falling below the useful beam.

(3) Only as a last resort, it might be expedient to increase lamp lumen output to compensate for reduction in illuminance levels caused by foliage interference. However, this has serious disadvantages because the impairment of light distribution, increased glare, and uniformity of illumination cannot be corrected by merely increasing lamp sizes. Also, cost will be increased considerably.

D3.3 Design Departures

(1) Where deviations in longitudinal spacing of luminaires are made to minimize conflicts with trees, generally a 10 percent deviation from average spacing will not seriously affect the uniformity of lighting. As a maximum compromise for certain types of luminaires, deviations up to 20 percent can be tolerated providing no two consecutive luminaire locations are involved. The variation in pavement luminance should be checked in the design process. When two or more consecutive locations necessitate deviations from the average spacing, then the resulting design should be re-analyzed and perhaps the transverse location or mounting height changed.

(2) Alignment of luminaires out over the street is important in respect to both visibility and appearance. Only where there is no other reasonable compromise would any transverse deviation of an individual luminaire be permitted. The length of the luminaire support should be selected which best meets the requirement of each particular street. It should be kept in mind that when using longer supports that approach the center of the street, pruning requirements become less, but structural costs of installation will increase and appearance is compromised.

D3.4 Design Data

(1) **Figures D6** and **D7** are intended to serve as a guide for determining proper overhang distances of luminaires for different heights of mounting and for different types of trees.

(2) Although foliage interference mostly affects the illuminance on the roadway pavement, the importance of adequate lighting for the sidewalks should not be overlooked. There may be instances on local traffic residential roadways where good sidewalk illumination is even more important than lighting of the roadway itself. Generally, this can be obtained either by altering the luminaire positions or by pruning, or a combination of both methods.

(3) The modern trend in roadway lighting practice is to use light sources of higher efficacy in luminaires having light distributions appropriate for the luminaire spacing, mounting height, and transverse positions, and for the roadway dimensions. Such proper lighting design is particularly important on residential and local streets. Also, it should be emphasized that, where we see by silhouette discernment, the high angle emission of light from the luminaire is very important. Obviously with longer spacings there are proportionately fewer luminaires which, in turn, reduce the requirements for pruning. This further contributes to lower combined maintenance cost of trees and lighting. Observations in different sizes of towns with properly designed roadway lighting indicate that as an average the number of actual conflicts between luminaires and foliage is in the order of 50 percent on the more heavily wooded roadways. It is quite probable that, of the total existing roadway system, the foliage interference is considerably less than 50 percent.

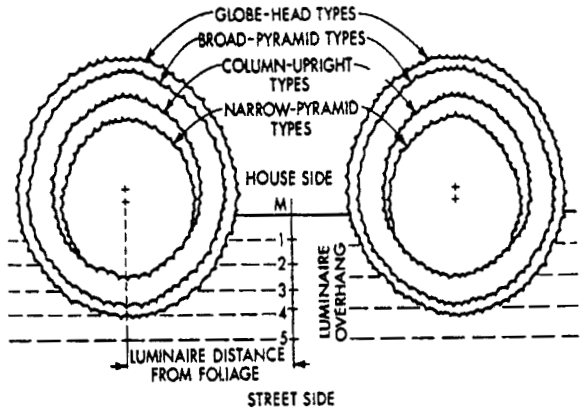


Figure D7. Longitudinal and transverse location of luminaires as related to different types of trees.

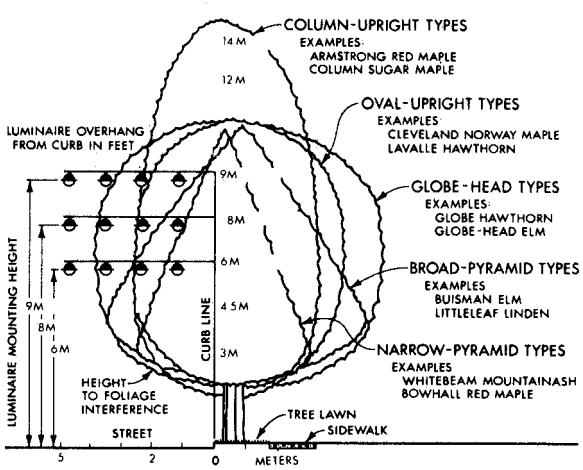


Figure D6. Determination of proper overhang distances.

Annex E

Light Sources

(This Annex is not part of the *American National Standard Practice for Roadway Lighting*, RP-8-00, but is included for informational purposes only.)

Annex E – Light Sources

E1 Introduction

Low pressure sodium and High Intensity Discharge (HID) light sources, commonly known as mercury, metal halide and high-pressure sodium (HPS), are most often used in today's roadway lighting systems. The lighting unit comprises the lamp, ballast, and luminaire. The following factors affect the selection of lighting units for roadway lighting:

- Lamp lumen output (lamp size)
- Lamp life
- Lamp lumen depreciation
- Ambient temperature range in the area
- Cost (lamp and luminaire)
- Lamp restrike time
- Luminaire light distribution
- Physical size (lamp and luminaire)
- Physical durability (lamp and luminaire)
- Lamp color

The advantages and disadvantages of the various viable lamp sources are discussed in the following sections.

E2 Low Pressure Sodium (LPS)

Low pressure sodium lamps have very high efficacy and find some application near observatories where sky glow is of concern. They are also used in some tunnel applications, see ANSI/IESNA RP-22-96, *Recommended Practice for Tunnel Lighting.*

The advantages include: (1) relatively short restrike in the event of momentary power interruption, (2) high efficacy, (3) monochromatic light emission; this single wavelength can be filtered out by observatories and (4) minimal or no lamp depreciation over life; this at the expense of increased power consumption over the same period.

The disadvantages include: (1) high lamp replacement cost, (2) large luminaire size, (3) shorter lamp life than HPS lamps, (4) minimal control of light utilization, and (5) no color rendering (monochromatic).

E3 High Pressure Sodium (HPS)

High pressure sodium lamps have a wide selection of lamp sizes, increased life ratings, compact size and are easily optically controlled.

The advantages include: (1) high lamp efficacy, (2) good luminaire light control, resulting in high luminaire effectiveness, (3) small luminaire size, (4) excellent lamp life and (5) minimal lumen depreciation.

The disadvantages include: (1) restrike time required in the event of momentary power interruption and (2) low CRI.

E4 Metal Halide (MH)

Metal halide lamps also have a wide selection of lamp sizes, good lamp life, compact size and are easily optically controlled.

The primary advantage of metal halide lamps is their color. Various lamp color temperatures are available with high color rendering index (CRI). At the time of the writing there is some evidence that the improved color offered by metal halide may positively influence the eye's performance for some tasks at the light levels used in roadway lighting.

Other advantages include: (1) high lamp efficacy, (2) good luminaire light control, resulting in high luminaire effectiveness and (3) small luminaire size.

The disadvantages include: (1) long restrike time in the event of momentary power interruption and (2) lamp life shorter than HPS (3) lumen depreciation worse than HPS and (4) a lower photopic efficiency than HPS.

E5 Mercury

Like metal halide, mercury lamps also have a wide selection of lamp sizes, very long life, and compact size.

The primary advantage of mercury is its exceedingly long life. Often such lamps are left to burn many hours beyond their useful life.

Other advantages include: (1) good luminaire light control, when a clear lamp is used and (2) small luminaire size.

The disadvantages include: (1) long restrike time in the event of a momentary power interruption, (2) lumen depreciation is worse than HPS or metal halide and (3) poor lamp efficacy.

E6 Other Light Sources

Other light sources are becoming available as manufacturers investigate and test new technologies such as sulfur lamps and electrodeless lamps. As the size of the sources are reduced and luminaires are designed to effectively distribute the light from such lamps, then options for roadway lighting may certainly expand.

Annex F

Description and Background of STV Method

(This Annex is not part of the *American National Standard Practice for Roadway Lighting*, RP-8-00, but is included for informational purposes only.)

Annex F – Description and Background of STV Method

F1 Introduction

This annex is intended to provide an understanding of the research basis that underlies the decision to include Small Target Visibility (STV) as a method for roadway lighting. It also explains the basis for the selection of levels of average pavement luminance used in **Table 4** of the Standard Practice.

In all editions of the Practice prior to ANSI/IESNA RP-8-83, the criteria for roadway lighting design was based on illuminance (horizontal footcandles) and the average to minimum ratio of illuminance. In the 1983 document alternative criteria were used, one in terms of illuminance (lux) and the other in terms of pavement luminance measured in candelas per square meter (cd/m^2).

RP-8-00 recognizes a new concept, that increased visibility results in both increased nighttime safety and improved nighttime driver performance. It also recognizes that not all roadway lighting is installed with the primary emphasis on traffic safety, and provides an alternative design criteria that may be used. This alternative set of criteria is based on the traditional concept of providing an adaptation level, on and adjacent to the roadway, that aids in recognition of low contrast objects.

F2 Visibility of Objects

The visibility of objects, including traffic signals and signs, is influenced by all four of the sources of illumination listed in **Section 1.4** of the Standard Practice. Usually one of the first three is the predominating factor affecting the visibility of an object - depending upon the object's location, size, and contrast. The visibility of a stationary object of a fixed size and uniform luminance is a function of:

(a) The contrast between the luminance of the object and its immediate visual background
(b) The general level of adaptation of that portion of the retina of the eye concerned with the object
(c) The amount of veiling luminance (disability glare) entering the eye
(d) The difference in eye adaptation between successive eye movements (transient adaptation)
(e) The size, shape and color of the object
(f) The background complexity and the dynamics of motion
(g) Visual capability of roadway users (see section 4.5 of reference 37)

The geometry of an installation and the relative positions of the driver-observer, light sources and object to be seen, affect contrast, adaptation level, and transient adaptation in a complex manner. The lighting flux, with lighting geometry constant, affects only the adaptation and veiling luminance level. In designing a fixed lighting system, the visibility level is often modified by changing the lighting geometry. This change in lighting geometry may either improve or degrade visibility. This publication stresses the need to consider the total effect of changes in lighting geometry when designing the fixed lighting system.

Visibility Level (VL) is a metric used to combine mathematically the varying effects of the several factors listed above on the visibility of a test object to a standard observer. VL as used in this publication is defined and explained in **Annex A**. Two equally important criteria are used in this publication. One is the level of VL as computed over the roadway area. The other is the adaptation level as measured by the average luminance.

In order to compute VL, a task must be specified. While the five general visual tasks of driving (**Section 1.3** of the Standard Practice) can be stated concisely, the specific driving tasks are widely varied and constantly changing. The VL in this publication is based on detection of a "Small Target" which is an 18 cm. flat square target of 50 percent diffuse reflectance. The target is perpendicular to the roadway surface and always located a fixed distance (83 meters) ahead of the observer with the observer to target sight line parallel to the centerline of the roadway. This convention maintains constant both target size and target-observer geometry . Observer height, observer age, and a line of sight to the center of the target are also constant (see **Annex A** for details). Small Target Visibility (STV) is the weighted average VL of an array of targets as calculated by the visibility model of **Annex A**.

Although a 20 percent target represents the reflectance of most objects commonly seen on roadways, 50 percent targets are used based on the findings of Keck who had reported that a design whose geometry is optimized for 50 percent targets yields higher weighted average VL values (STV) for all other target reflectances than does a design optimized for any other target reflectance.[20]

To calculate the STV of a lighting installation, the designer considers an array of small targets located at the intersections of grid lines that cover the roadway pavement. The VL of each target in the array is calculated and the system STV is determined by taking a weighted average of the absolute values of VL for all the targets in the array.

Research[21,22] has established a correlation between calculated VL and the detection and avoidance of a

small object on the roadway. Research has also established that a correlation exists between a visibility measure using small reference targets and the frequency of vehicular accidents at night[23] (the research was done at 50-60 km/h).

Research has established that adaptation level affects the ability of the human visual system in several ways. A higher adaptation level permits the detection of lower contrast objects, increases the speed of visual processing, and mitigates the adverse effect of both disability and discomfort glare.[24]

At night (with no fixed lighting), objects and pavement markings close to the vehicle are seen primarily with light from the vehicle headlights, while pavement markings and objects beyond the range of the headlights are either not seen, or seen with light from some other source. Traffic signals and vehicular signal lights are self illuminated, and most signs and markings are provided with retroreflective backgrounds and letters to increase their effective luminance from the vehicle headlights. The VL of a target array, defined and located as previously stated will depend upon the type of headlights in use, their aiming and condition as well as the presence of extraneous light affecting the background luminance.

Fixed lighting systems are intended to reveal objects beyond the range of the vehicle headlights and to provide for improved adaptation levels. At short distances headlighting and fixed lighting interact to affect the visibility of objects (or targets). The calculation of the STV as described here does not include the effect of vehicular lights or extraneous lights.

F3 Iterative Design Process

Using the appropriate recommended criteria from **Table 4**, the design process is an iterative one. A tentative design is conceived and then evaluated in terms of both the pavement luminance criteria and the STV. If the design, in terms of either criteria, is deficient then all or part of the design must be modified to correct the deficiencies. STV and average pavement luminances are minimums and both must be met or exceeded; exceeding one set of criteria does not permit reduction of the other. Pavement luminance uniformity should not be exceeded. If the design exceeds both the visibility and the pavement luminance criteria then the design may be modified (to reduce costs), or accepted depending on the judgment of the designer as to energy usage, aesthetics or other relevant consideration.

The criteria values of **Table 4** are recommended for both straight and curved portions of continuously (see **Annex A**) lighted Freeways and Expressways.

F4 Evaluation of Results.

Predictive calculations should be made at specific points in grids that include the usable paved traffic area.

Uniformity of pavement luminance is specified as the ratio of the maximum pavement luminance at any grid cell divided by the minimum pavement luminance at any other grid cell within the design area that is related to a specific road and area classification. Higher average levels of luminance, in any section of the design, are permissible as long as the uniformity ratio is maintained over that design section area.

The distance between grid points chosen by the designer or evaluator, should be small enough to reflect reasonable changes in criteria value and should reflect true averages. **Annex A** shows how the evaluation grids are determined.

F5 Calculation Techniques

Specific formulae and techniques for calculating pavement luminance and small target visibility are found in **Annex A**. Calculations for evaluation purposes may be performed either manually or by computer. Manual calculations are exceedingly time-consuming so computer calculations are recommended. Many computer programs are available, commercially and in the public domain, that calculate luminance, veiling luminance, and illuminance. Several are available to calculate STV at the time of this writing and more are anticipated with the adoption of this recommended practice. Like most software currently available calculations assume that the roadway is level, has no crown, and has uniform pavement texture and reflectance characteristics. Hills are assumed to be gentle in nature and no allowance is made for crests or dips. Curves are assumed to be circular sections and the grid points are continuations of the lines on straight sections with a variation in spacing as the radius changes. (See **Annex A** an for an example). These geometric variations should have little impact on the accuracy of calculations.

F6 The Iterative Design Procedure

The use of computer programs to quickly evaluate a tentative design makes the use of the iterative design procedure simple. Under this procedure the initial tentative design is based on experience or on an arbitrary assumption. It is then evaluated with a computer program and modified on the basis of the results. Changes are then made and the revised design reevaluated. This procedure is repeated until the design meets the requirements of **Table 4**.

After a design has been evaluated, and one or more areas are found to be either deficient or to exceed the criteria, changes should be made based on the factors impacting the lighting systems overall VL. A more detailed discussion of the effect of luminaire location geometry and luminaire distribution upon target visibility will be found in **Annex B**.

F7 Three Major Design Concepts

The visibility of real objects on the roadway, or targets used in calculating STV, may be enhanced by using one of the following major design concepts. It is important for the designer to select one of these, use luminaires that are intended to be used in that design concept, and not intermix luminaires intended for use in different design system concepts.

Alternating Contrast. In this concept the pavement luminance is deliberately made nonuniform, but not patchy or spotty. The luminance level should vary between the maximum level and the minimum level as determined in the criteria table. The luminaire distribution should produce high target luminance in the areas of low pavement luminance and low target luminance in the areas of high pavement luminance. Conventional bi-directional luminaires are suitable for use with this concept. In general, luminaires should be located over the pavement, using an opposite arrangement and long spacings, in order to achieve maximum VL values. The design method described in **Annex B** uses the Alternating Contrast concept.

All-Positive Contrast. In this concept, primarily for one-way roads, the pavement luminance level is kept as uniform as possible and the average luminance just above the luminance criteria level. The luminaire locations and the luminaire distribution are selected so as to produce relatively high vertical illumination on the face of the target. In the evaluation, the VL values will appear with a positive sign indicating that the target is lighter than the background.

All-Negative Contrast. In this concept, also primarily for one-way roads, the pavement luminance level is kept as uniform as possible. The luminaire locations and the luminaire distribution are selected so as to produce low levels of vertical illumination on the face of the target. In the evaluation, the VL values will appear with a negative sign indicating that the target is darker than the background.

Luminaire light distributions developed over the past decade reflect the desire of the luminaire manufacturers to produce an optimal level of horizontal illuminance with acceptable uniformity in accordance with past versions of the Standard Practice. Such luminaire light distributions yield reasonably good patterns of pavement luminance if used carefully, and produce alternating patterns of contrast when evaluated in terms of small target visibility. New optical designs will emerge as luminaire distributions are created to produce optimal designs for pavement luminance and small target visibility. One-way roads and streets can be expected to utilize either the all-positive or all-negative contrast concepts to achieve much higher levels of STV per watt of input energy than can be achieved using the alternating contrast concept.

F8 STV Questions and Answers

Q: STV as a visibility measure–what is it?

A: STV are the initials of “Small Target Visibility.” In order to take a lux reading, a meter must be placed at the measurement point. In order to take a measurement of pavement luminance, test personnel must get back and aim an optical imaging instrument with a small aperture at the measurement point. In order to take a visibility measurement, test personnel must put an object on the spot, then get back and make a measurement of its visibility. The object that is presently used for STV is an 18 cm by 18 cm target. The observer is located on a line parallel from the object to the centerline of the roadway at a distance of 83 meters. Visibility can be measured by using a contrast reducing meter or “visibility meter.” Visibility can also be calculated by measuring four values; 1) the luminance of the target, 2) the luminance of the immediate background, 3) the adaptation level of the adjacent surroundings, and 4) the disability glare present. Using these four measurements and a series of equations the visibility level (VL) of the target can be calculated. If the four factors can be predicted then the (VL) of the target can be predicted.

The visibility of a single target has little or no meaning. If the visibility of many targets symmetrically arranged over the roadway are calculated, their collective visibility has great importance. It becomes a visibility measure. In RP-8-00, a system of weighting the target VL is used, rather than a conventional average plus uniformity ratios, to ensure that the visibility over the entire roadway is taken into consideration. It does little good to provide very high target VL in a limited area, such as under a luminaire, since the importance decreases as the VL moves more and more above threshold. An analogy might be that if you can easily read the date on a coin, it does no good to double the visibility level. What is used is a grid of points, the visibility of a 50 percent reflectance target is calculated for each grid point, and then the weighted average VL is calculated. The weighted average is the STV. Do not consider that the targets are obstacles on the roadway which cause accidents–this is not the concept. The concept is that if the quality of the lighting design

produces an adequate STV, then the objects or markings needed for driver performance at night will be more visible than for a lighting design than produces a lower level of STV.

Q: What causes the STV to increase or decrease?

A: As just indicated, the VL of an individual target is a function of four measurements which are combined into three factors. As adaptation level (pavement luminance) increases, VL increases. As contrast between the target and its background increases, VL increases. As disability glare increases, VL decreases. VL increases at a more rapid rate when contrast increases than when adaptation level increases or glare decreases. When all four measures are increased in the same proportions, STV will always increase.

When the geometry of a lighting system, such as luminaire spacing, mounting height, or arrangement, is changed, the four measures do not change proportionally and STV may change radically. For example reducing the spacing may increase adaptation level and glare while decreasing contrast. Since contrast is the most sensitive factor, STV will decline even though the average light level is now higher.

For a driver in an "empty road" situation (an empty road being just one car on the roadway), a proper level of STV is all that is required. No level of pavement luminance needs to be specified since the STV calculation evaluates the relative contrast, adaptation level, and glare of the lighting system being evaluated, and determines the resultant visibility. An adequate level of STV can be achieved with vehicle headlights (high beam) alone. Headlights produce a very low level of pavement luminance at approximately 80 meters. An adequate level of STV can be achieved with fixed lighting, which also provides a much higher level of pavement luminance than do headlights alone. When the roadway is not "empty," a reasonably high level of pavement luminance is essential to reduce the adverse effect of glare from the headlights of oncoming vehicles with the exception of one way streets. The logic of RP-8-00 is that the pavement luminance (light level) for a high weighted average STV was not achieved in a manner that reduces contrast excessively.

Q: What is the research basis for the switch to STV?

A: Prior to the 1970s the accepted theory was that night accident rates would decrease and nighttime driver performance would increase with increasing light levels and improved uniformity. Such theory stands until it is confronted by facts that it can no longer explain, then it falls. The fall of one theory and the adoption of changes or an entirely new theory is an ongoing process in science. Theories do not fall quickly or without opposition, but over a period of time the weight of evidence that they cannot explain mounts, and eventually the new concepts become widely accepted. The research evidence in this case is summarized as follows:

- Finch[25] in a project sponsored by the Illuminating Engineering Research Institute (IERI) reported that non-uniformity was superior to uniform pavement luminance in revealing objects and pedestrians.

- Box[26] made a study of freeway accidents vs lighting levels which was sponsored by IERI and ASF, then later made a study of 105 miles of urban streets in Syracuse, NY[27] (for the city) and found that a plot of the night/day accident ratios vs horizontal footcandle level (HFC) produced a "U" shaped curve with its minimum occurring at different values on different streets. Box did not repudiate the accepted theory. Instead he concluded that it was possible to "underlight" and to "overlight" and that the optimum value of illuminance was a function of the street classification.

- Scott made a similar study in England using 89 sites, each over 1 km, and reported it to the CIE in 1979[28] using one statistical technique. Then he used a different technique[29] in his report published by the Transport and Road Research Laboratory (TRRL) who funded the project. Scott evaluated HFC, VFC, pavement luminance, surround luminance, uniformity, threshold increment, and glaremark. He found no correlation with threshold increment or glaremark, a negative correlation with HFC, VFC, pavement luminance, and surround luminance; and a positive correlation with uniformity. Scott did not find any trace of the "U" shaped curve but rather a continuous downward slope (negative) between light level and night/day accident ratios. Scott found no correlation between pedestrian accidents and light level, the correlation was only for vehicular accidents.

- There is no physiological research to support the optimum illuminance conclusion of Box, but there was quite a bit of research by Blackwell and others,[24] which indicated that the factors of contrast, adaptation level, and glare must be combined, each with its proper weight, to predict visibility. Gallagher[30] used a visibility measure "VI" to show an excellent correlation between driver performance and "VI" in the avoidance of gray traffic cones by naive drivers.

- FHWA then sponsored the study by Janoff et al[23] on night accident rates under various lighting condi-

tions in Philadelphia. The result was confirmation of the positive correlation between accidents and light level found by Box, and a negative correlation between accidents and "VI" using the bullet target. A positive correlation between population density and accidents was also reported. Janoff measured HFC, pavement luminance, uniformity, and VI.

- The number of studies which attempt to correlate different photometric measures to accident rates is very limited and most of the recent ones have just been listed. The majority of lighting vs accident studies are of the before and after type in which the accident record prior to making a change is compared to the accident record after making the change.

- A review of many such studies reveals many inconsistencies in the effect of lighting on night accident rates. In virtually all cases the change from no fixed lighting to recommended lighting levels results in some reduction in night accident rates. In those cases, however, where the lighting level is increased or decreased a substantial amount, the results are unpredictable. References 31 to 39 are a listing of such studies which may be examined more closely.

- The IESNA Roadway Lighting Committee's Task Force on Visibility has evaluated the visibility of targets and objects to validate the visibility models available. This has consisted of objective measurements of visibility, static subjective judgments of visibility, and dynamic subjective judgments of visibility. Much of this work has been reported by Janoff.[40, 41]

While the differences between the results of Box, Scott, and Janoff cannot be explained by the traditional correlation of light level to accident rates, those differences can be explained by the behavior of the visibility measure STV. The lighting installations examined by Box and Janoff were made in the USA during the period when the 400-watt mercury lamp was the predominant light source used for roadway lighting. Changes in light level were achieved by changing the spacing between luminaires. In the USA the common practice was to utilize a staggered arrangement since it yielded better pavement uniformity. Under such conditions, extremely long spacings, very low levels of light, yield low values of STV. But as spacings are reduced STV will increase and reach a maximum. But as spacings continue to decrease STV will now also decrease even though the light level is increasing and uniformity is nearly perfect. The lighting installations examined by Janoff did not include examples of extremely long spacings and so he found only half the curve, a set of data in which the accident rate increases as the light level increases.

In England there were two major differences in application techniques from those normally used in the USA. The luminaires used have much lower vertical angles of maximum candlepower which results in the frequent use of opposite arrangements rather than staggered (which can not span cross streets with short spacings) and they use a wider range of lamp wattages to achieve light level changes while keeping their spacings more constant. The result is that STV levels correlate more closely with light levels and tend to be higher since opposite arrangements of luminaires produce less frequent contrast reversals using bi-directional luminaires.

Q: What is the justification for lowering pavement luminance levels?

A: Pavement luminance levels recommended for use with the recommended STV criteria are substantially lower in RP-8-00 than in previous editions. As indicated earlier, in the "empty road" situation, the STV criteria alone will suffice and no minimum level of pavement luminance is required. However, on roadways carrying bi-directional traffic, the disability glare from the headlights of oncoming vehicles reduces visibility drastically if there is no median separation. Even with no change in headlight output the effect of the glare can be reduced by providing a median separation and/or by increasing the adaptation level.

The adaptation level for the visual system is set by the whole visual environment. Pavement luminance is an important factor but not the sole determinant of the adaptation level. In the "empty road" situation pavement luminance dominates. In crowded traffic little can be seen of the pavement and adaptation is dominated by the luminance of vertical surfaces of other vehicles and the off roadway surround.

In RP-8-00, the calculation of STV is based on the "empty road" situation and includes the glare of the fixed lighting system. Under light traffic conditions, the glare of the headlights of oncoming vehicles must be considered, since it can reduce the visibility of low contrast objects significantly. RP-8-00 responds by requiring a minimum average pavement luminance and uniformity requirement. The recommended level of average pavement luminance is determined by the width of separation between the closest adjacent lanes of traffic, and the number of lanes of oncoming traffic.

The recommended levels of average pavement luminance were calculated using the following technique.

1. Photometric data for 18 sets of low beam headlights, various types and manufacturers was obtained and an average data set selected.

2. Using a roadway with 3.66 meter lanes and no median the separation between the driver observer and the center of the oncoming vehicle will be 3 meters. The maximum veiling luminance (L_v) of an approaching car (two headlights) is calculated and will be 0.25 cd/m^2 with the approaching car 85 meters away.

3. Using an adaptation level for a rural country road of 0.034 cd/m^2, and a target contrast of 0.5, the target visibility will be reduced by 65 percent if the visibility is calculated with and without the veiling luminance of the oncoming headlights. This amount of visibility reduction when meeting another vehicle on an unlighted roadway is a frequent experience.

4. A curve, **Figure F1**, was prepared from a number of such calculations based on L_v of 0.5 cd/m^2 and with adaptation levels ranging from 0.05 to 2 cd/m^2. The "knee" of the curve occurs when adaptation is between 0.4 and 0.6 cd/m^2 with a visibility reduction of about 30 percent. For larger median separations the veiling luminance for direct line of sight for a single pair of headlights is considerably lower than 0.5 cd/m^2. However, because of lane changes, variations in road topography, and visual eye scanning behavior there is still a need for moderately large adaptation luminance to counter veiling luminance.

5. From the curves just discussed in item 4, values of adaptation levels, were selected appropriate to the roadway classifications of **Table 4** in the Standard Practice.

In general RP-8-00 adopts the position that the recommended average pavement luminance is adequate to compensate for oncoming headlight glare and that the need to discern low levels of contrast is minimized if the higher values of STV are achieved. In other words, if good luminaire selection and placement produces higher contrasts, then the need to see minimum contrasts is reduced. The overall energy needed to meet the requirements of the criteria of **Table 4** is less than was needed in prior editions of RP-8.

Q: What about high mast lighting?

A: The purpose of a fixed lighting installation, regardless of mounting height, is to make objects and markings on the roadway visible. With both very low mounting heights and high mounting heights it is difficult to confine the light to the paved roadway and to the driving lanes. The STV criteria evaluates the visibility produced, regardless of mounting height. For example, STV can be used if the mounting height is low (a vehicle headlight), medium (most fixed lighting systems), or high (30 meters or more).

Q: The lighting of adjacent areas––what is the basis?

A: The alternate criteria, referred to in **Section F1**, is based entirely on providing an adaptation level sufficient to see objects with low contrasts, which may or may not be located on the roadway. There is some research[26] that relates higher light levels in the surround to lower accident rates. Police and civilian patrols need to see what is happening off the roadway. Pedestrians on sidewalks near the roadway must evaluate the walkway ahead and other persons. A fixed lighting system normally provides some spill light onto the adjacent surround but prior editions of RP-8 have never recommended a specific amount of off roadway light. It would be very desirable to express this recommended surround light in luminance, however the directional reflectance of the materials is not known. RP-8-00 includes these recommendations, many of them are taken from CIE 92 - Urban Lighting.[42] No recommendations are made for any off roadway light to extend beyond the public right of way.

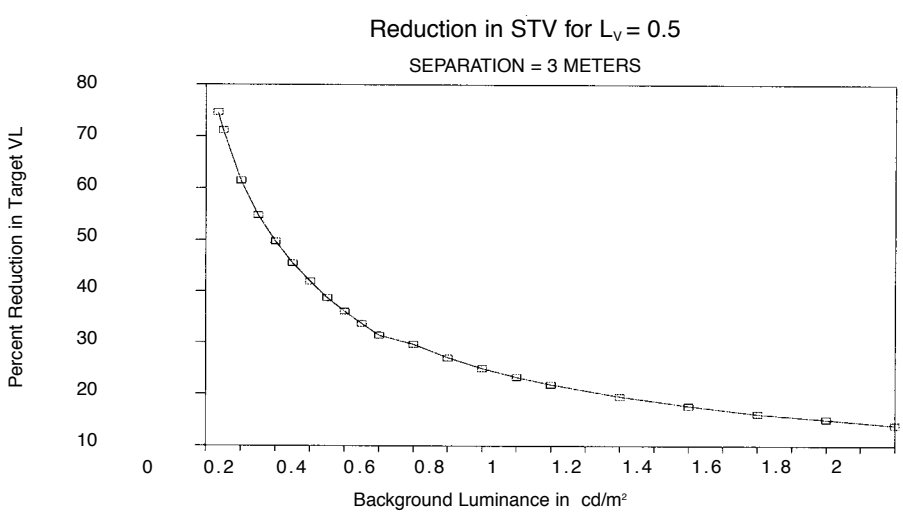


Figure F1. Impact of background luminance mitigating approaching headlights.

Annex G

Glossary

(This Annex is not part of the *American National Standard Practice for Roadway Lighting*, RP-8-00, but is included for informational purposes only.)

Annex G —- Glossary
(Other definitions may be found in ANSI/IESNA RP-16-96, *Nomenclature and Definitions for Illuminating Engineering*.)

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. (See **Figure G1**.)

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

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.

bracket (mast arm) an attachment, to a lamp post or pole, from which a luminaire is attached.

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 G2**.)

candela per square meter, Cd/m² 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.

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.

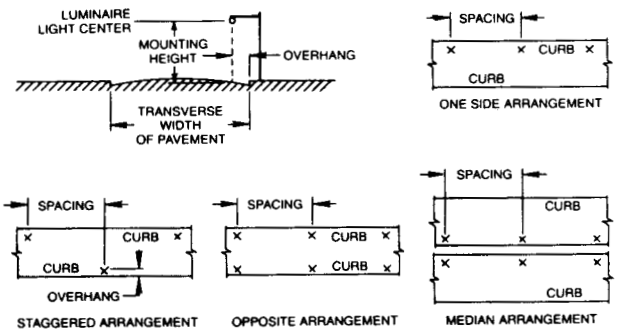


Figure G1. Terminology with respect to liuminaire arrangement and spacing.

footcandle, 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 lumi-

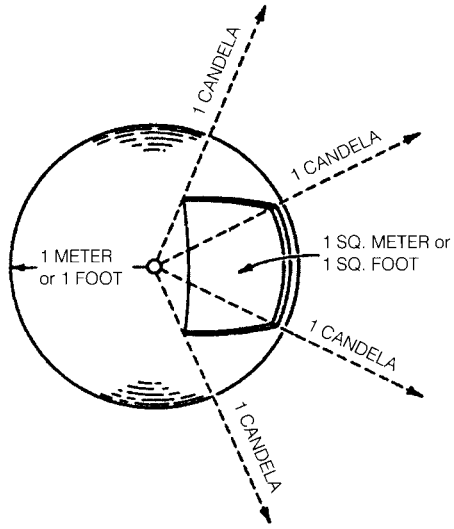


Figure G2. Relationship between candelas, lumens, lux, and footcandles: A uniform point source (luminous intensity or candlepower = one candela) is shown at the center of a sphere of unit radius whose surface has a reflectance of zero. The illuminance at any point on the sphere is one lux (one lumen per square meter) when the radius is one meter, or one footcandle (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 4π (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.

nance to which the eyes are adapted to cause annoyance, discomfort, or loss in visual performance and visibility. See **disability glare**, **discomfort glare**.

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 uniformily illuminated.

illuminance (lux or footcandle) 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 photodetector 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.

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

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.

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.

lamp restrike time the amount of time it takes for a hot lamp to re-establish the arc discharge.

light center (of a lamp) the center of the smallest sphere that would completely contain the light emitting element of the lamp.

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.

longitudinal roadway line, LRL may be any line along the roadway parallel to the roadway centerline.

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.

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.

orientation the angular position of the luminaire around an axis through the light center and along the 0-180 degree vertical angles. When the zero degree horizontal angle is directed north, orientation is zero degrees. Displacement of the zero degree horizontal end (street side) of the luminaire clockwise is a positive angle. See **roll**, **tilt**, and **Figure G3**.

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

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.

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.

reduced luminance coefficient, r the value at a point on the pavement defined by angles beta and gamma which, when multiplied by the appropriate luminous intensity from a luminaire and divided by the square of the mounting height, will yield the pavement luminance at that point produced by the luminaire.

reflectance of a surface or medium the ratio of the reflected flux to the incident flux. See also **directional reflectance**, **diffuse reflectance**, and **bidirectional reflectance-distribution function**.

roll the angular position of the luminaire around a axis through the light center that is an extension of the

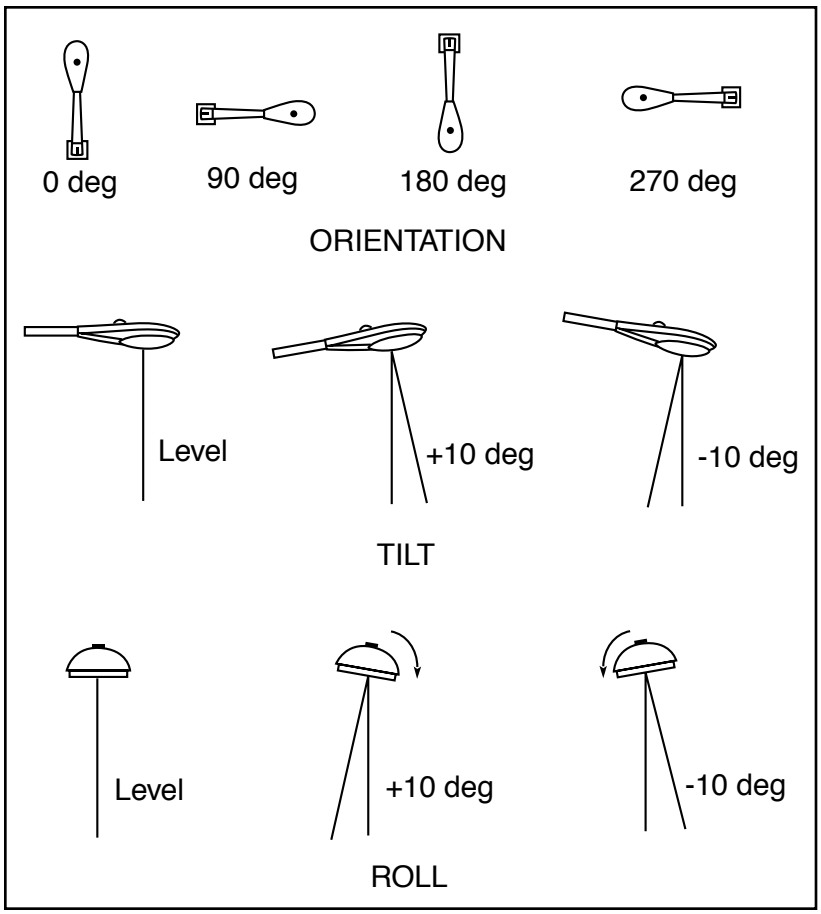


Figure G3. Luminiare orientation (top), tilt (center), and roll (bottom).

0-180 degree horizontal angle. When viewed from the 180 degree angle (mast arm end) rotation clockwise is a positive angle. See **tilt**, **orientation**, and **Figure G3**.

setback the lateral offset of the pole 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.

tilt the angular position of the luminaire around an axis through the light center and along the 90-270 degree horizontal angles. When the luminaire is level the tilt is zero degrees. Displacement of the zero degree horizontal end (street side) of the luminaire upward is a positive angle. See **roll**, **orientation**, and **Figure G3**.

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

transverse roadway line, TRL may be any line across the roadway that is perpendicular to the roadway center line.

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 outdoor 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.

visibility meter an instrument with a means of reducing the visibility of a scene, or part of a scene, to threshold without affecting the adaptation level of the 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.

Annex H

References

(This Annex is not part of the *American National Standard Practice for Roadway Lighting*, RP-8-00, but is included for informational purposes only.)

References

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