Advancements in Roadway Lighting – IESNA BC Chapter – Feb 19, 2009

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Today's Presentation

- Review Upcoming Changes to IESNA RP-8
- Review Spectral Effects
- Review CSA C653
- Review LCS
- Review LLF
- Review Design Criteria
- Review New Technologies

RP-8-2010

RP-8-2010

Overview of changes:

- Value of roadway lighting added
- Roadway lighting is for highways and freeways and Street lighting is for local, collector and arterial roads
- Luminance will be the primary calc method
- Luminaire Classification System (LCS) will Replace Cut-off Classifications
- Highmast added
- No lumen multipliers for white light
- Crosswalks lighting (vertical Illuminance)
- Adaptive Lighting
- Application where lighting may not be required
- Info on impacts of trees

Reference Documents

Useful Documents / Status:

- MLO – 60% out for public review
- RP-33 Outdoor Lighting – Being Revised
- DG-22 Residential Lighting – Published soon
- DG-19 Roundabouts for purchase
- TM-15 Luminaire Classification System
- CSA C653 Luminaire Performance for purchase
- TAC Roadway Lighting Design Guide - available for sale
- IMSA Level II Roadway Lighting Certification - available

Spectral Effects

Basic Principals of Vision

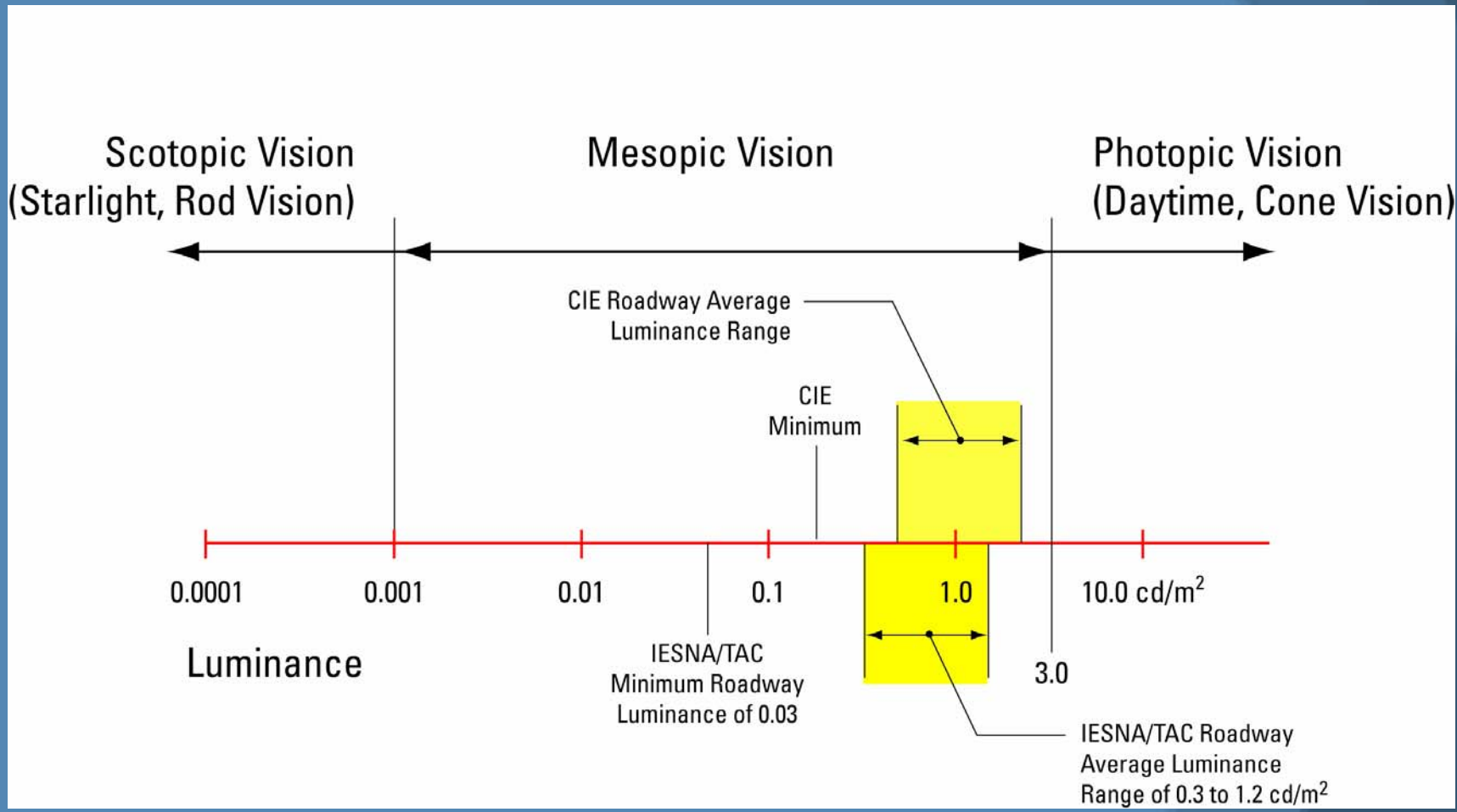
Rods and Cones

- Cones - are sensitive to color and operate at high light levels
- Rods – are insensitive to color and operate at low light levels

Adaptation - It is the process in the Retina where the eye adapts to varying brightness

- Photopic Vision - High light levels using cones
- Mesopic Vision - Intermediate level using rods and cones
- Scopotic Vision – Low light levels on using rods

Scotopic, Mesopic and Photopic



From Draft RP-8-2010

"there is no solid basis for the reduction in the lighting level recommendations for different source types. The recommendation given in the recommended practice should be applied consistently for any type of source including LED, metal halide, inductively coupled sources, high pressure sodium, fluorescent, or any other source."

HPS vs Metal Halide

High Pressure Sodium

Object Detection

Metal Halide

Visual Clarity

Metal Halide vs HPS

- Recent research by Dr. Werner Adrian (University of Waterloo) show that HPS reflects of pavement approx 21% to 25% better than MH

- Other research show MH to more effective with respect to ones peripheral vision. Recent research by Dr Ian Lewin show improvements in reaction time with metal halide

The debate lives on

CSA C653

CSA C653

- CSA C653 establishes a method to assess luminaire efficiency. Current system is not effective.
- New system will be based on luminance and unit power density. Unity power density is “watts per area (m2)”
- It is joint effort between suppliers and designers.
- Will list luminaires which meet requirements.
- C653 will apply to “cobra head” luminaires

CSA C653 - Calcs

Road	Pedestrian Conflict Area	Overhang in meters	Pole Height in meters				
			1 lane one side	2 lanes one side	3 lanes one side	4 lanes opposite	5 lanes opposite
Freeway Class A		-1.5	12	12	12	15	15
Freeway Class B		-1.5	12	12	12	15	15
Express Way	High	-1.5		12	12	12	12
	Medium	-1.5		12	12	12	12
	Low	-1.5		12	12	12	12
Major	High	-1.5		12	12	12	12
	Medium	1		12	12	12	12
	Low	1		12	12	12	12
Collector	High	1		10	10	10	12
	Medium	1		10	10	10	12
	Low	1		10	10	10	12
Local	High	1	7	7	10		
	Medium	1	7	7	10		
	Low	1	7	7	10		

CSA C653 - UPD

UPD is mathematically expressed as:

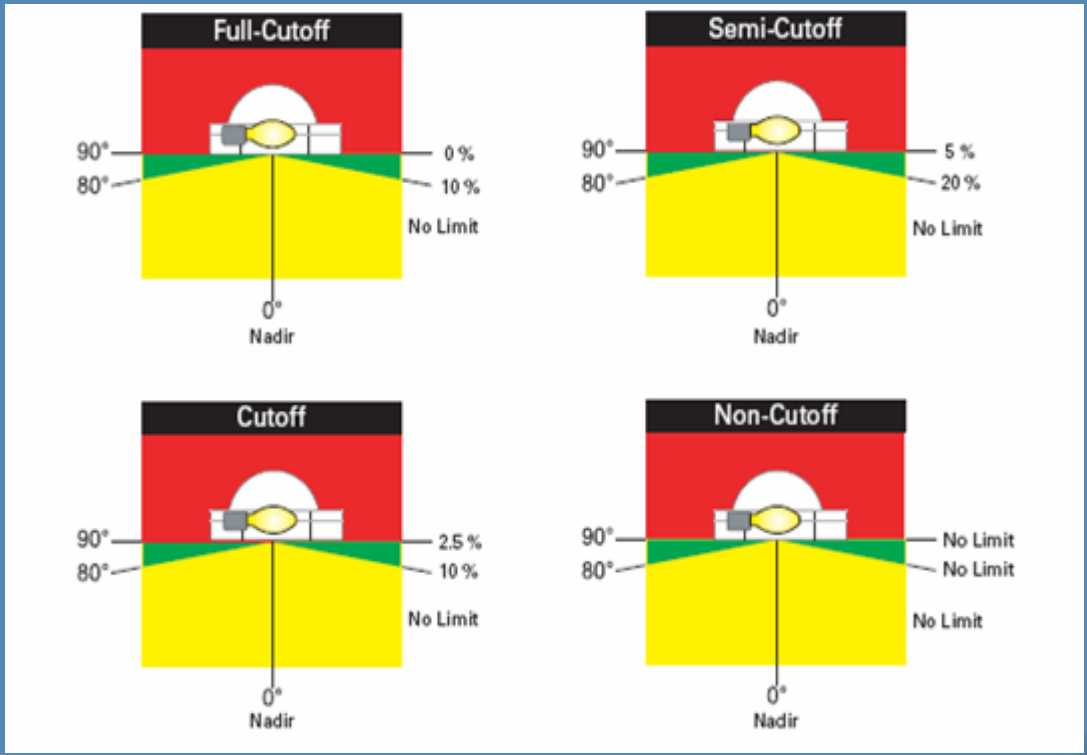
$$\frac{W}{m^2} = \frac{Rated\ Lamp\ Watts}{Roadway\ Width\ x\ Luminaire\ Spacing}$$

Roadway Classification		1 lane		2 lanes		3 lanes		4 lanes		5 lanes	
Road	Pedestrian Conflict Area	Full cutoff	Semi-cutoff	Full cutoff	Semi-cutoff	Full cutoff	Semi-cutoff	Full cutoff	Semi-cutoff	Full cutoff	Semi-cutoff
Freeway Class A		0.65	0.65	0.50	0.45	0.35	0.40	0.35	0.35	0.30	0.30
Freeway Class B		0.50	0.40			0.25	0.20	0.25	0.25	0.25	0.20
Express Way	High					0.45	0.55	0.50	0.45	0.55	0.45
	Medium					0.35	0.55	0.45	0.45	0.40	0.35
	Low					0.35	0.35	0.40	0.35	0.35	0.30
Major	High			0.75	0.70	0.60	0.55	0.55	0.55	0.55	0.45
	Medium			0.50	0.45	0.40	0.45	0.40	0.40	0.35	0.35
	Low			0.35	0.35	0.35	0.30	0.30	0.30	0.35	0.25
Collector	High			0.40	0.50	0.50	0.40	0.35	0.30	0.35	0.30
	Medium			0.35	0.35	0.40	0.25	0.30	0.25	0.25	0.25
	Low			0.30	0.25	0.25	0.20	0.30	0.20	0.20	0.20
Local	High	0.60	0.50	0.30	0.30	0.25	0.25				
	Medium	0.50	0.45	0.30	0.25	0.25	0.20				
	Low	0.40	0.30	0.30	0.20	0.15	0.15				

www.csa-intl.org/onlinestore/GetCatalogItemDetails.asp?mat=2419512

LCS

Current System



Luminaire Classification System

- New method which will replace traditional cutoff classification system (ie; full, semi, non, etc)
- Defined in IESNA TM-15 (new document)
- Will be valuable design tool

Luminaire Classification System

LCS defines the standard solid angles for evaluation and comparison of outdoor luminaires.

It provides a basic model from which limits for lumens within the solid angles by lighting zone and application type will be defined.

LCS utilizes existing photometric test data and can be easily reported by manufacturers or incorporated into software tools.

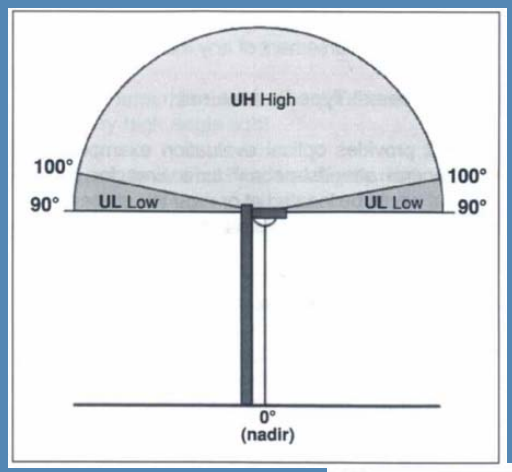
LCS enables designers to evaluate and compare the distribution of lumens for various types of luminaire optics, thus assisting in the selection of the luminaire most appropriate for the application.

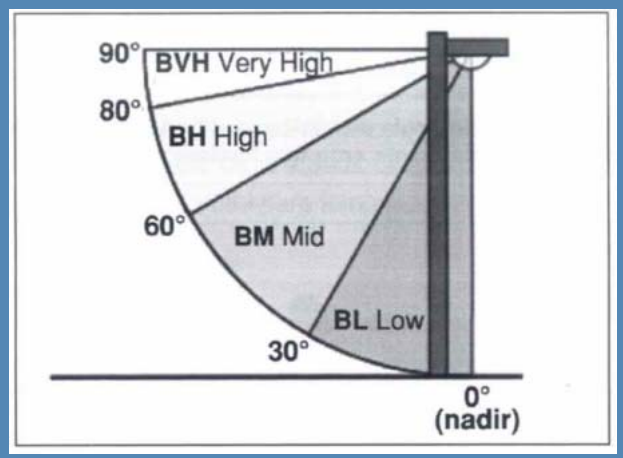
As illustrated, the primary solid angles defined by the LCS are:

- Forward Light
- Back Light
- Uplight

The sum of percentages of lamp lumens within these three primary solid angles is equal to the photometric luminaire efficiency.

Luminaire Classification System





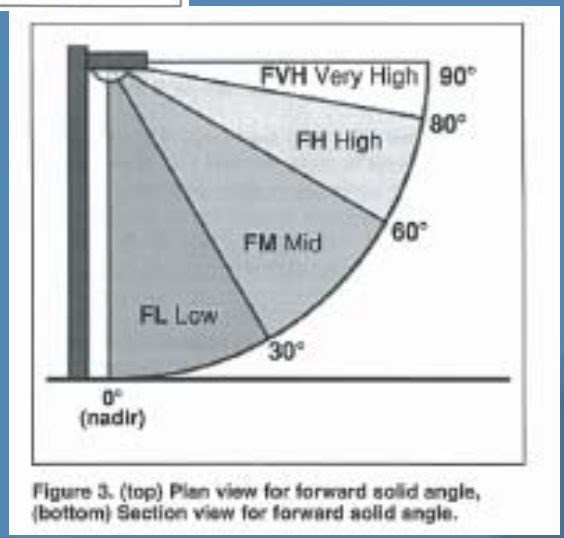


Figure 3. (top) Plan view for forward solid angle, (bottom) Section view for forward solid angle.

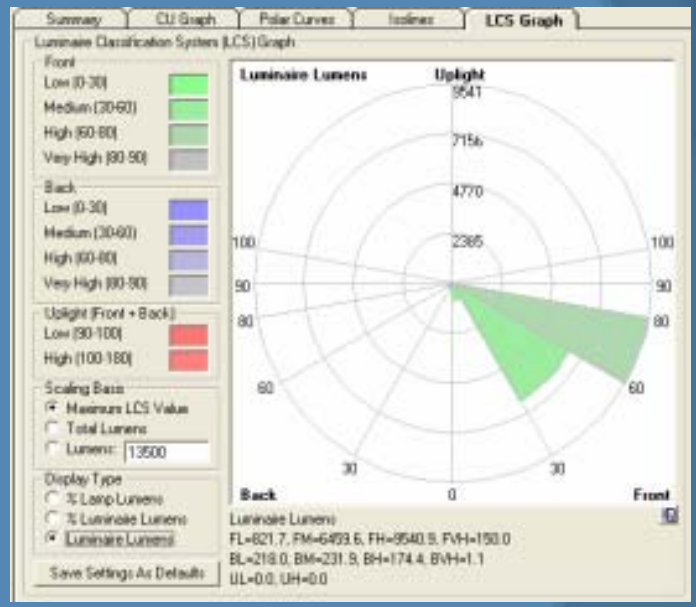
Luminaire Classification System

HPS Type II	 100 Watt	 150 Watt	 150 Watt
Forward Light			
Luminaire Lumens	5,365	8,589	9,188
% Lamp Lumens	56.5%	53.7%	57.4%
FL (0°-30°)	6.8%	5.0%	11.5%
FM (30°-60°)	24.5%	27.3%	27.6%
FH (60°-80°)	24.8%	20.6%	17.1%
FVH (80°-90°)	0.4%	0.8%	1.3%
Back Light			
Luminaire Lumens	1,965	3,447	3,832
% Lamp Lumens	20.9%	21.5%	24.0%
BL (0°-30°)	4.2%	4.1%	5.2%
BM (30°-60°)	10.7%	12.3%	11.8%
BH (60°-80°)	5.7%	4.4%	6.0%
BVH (80°-90°)	0.3%	0.8%	0.9%
Uplight			
Luminaire Lumens	42	0	390
% Lamp Lumens	0.4%	0.0%	2.4%
UL (90°-100°)	0.2%	0.0%	1.1%
UH (100°-180°)	0.2%	0.0%	1.3%

Luminaire Classification System

Use Photometric Toolbox – Professional Edition

www.agi32.com/products.htm



Lighting Zones (LZ's)

LZ0: No ambient lighting

- Areas where the natural environment will be seriously and adversely affected by lighting. Impacts include disturbing the biological cycles of flora and fauna and/or detracting from human enjoyment and appreciation of the natural environment. Human activity is subordinate in importance to nature. The vision of human residents and users is adapted to the total darkness, and they expect to see little or no lighting. When not needed, lighting should be extinguished.

LZ1: Low ambient lighting

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

LZ2: Moderate ambient lighting

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

LZ3: Moderately high ambient lighting

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

LZ4: High ambient lighting

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

BUG

A luminaire classification system that is used in the prescriptive method for evaluating optical distribution of outdoor luminaires that denotes levels of backlight (B), uplight (U) and glare (G).

	Lighting Zone 0	Lighting Zone 1	Lighting Zone 2	Lighting Zone 3	Lighting Zone 4
Allowed Backlight Rating					
>2 mounting heights from property line	B0	B1	B2	B3	B4
1 to 2 mounting heights from property line and properly oriented*	B0	B1	B2	B3	B3
0.5 to 1 mounting height to property line and properly oriented*	B0	B0	B1	B2	B2
<0.5 mounting height to property line adjacent to a street and properly oriented*	B0	B0	B1	B2	B2
<0.5 mounting height to property line and properly oriented*	B0	B0	B0	B1	B2
Allowed Uplight Rating	U0	U1	U2	U3	U4
Allowed Glare Rating	G0	G1	G2	G3	G4

LLF

Light Loss Factor (LLF)

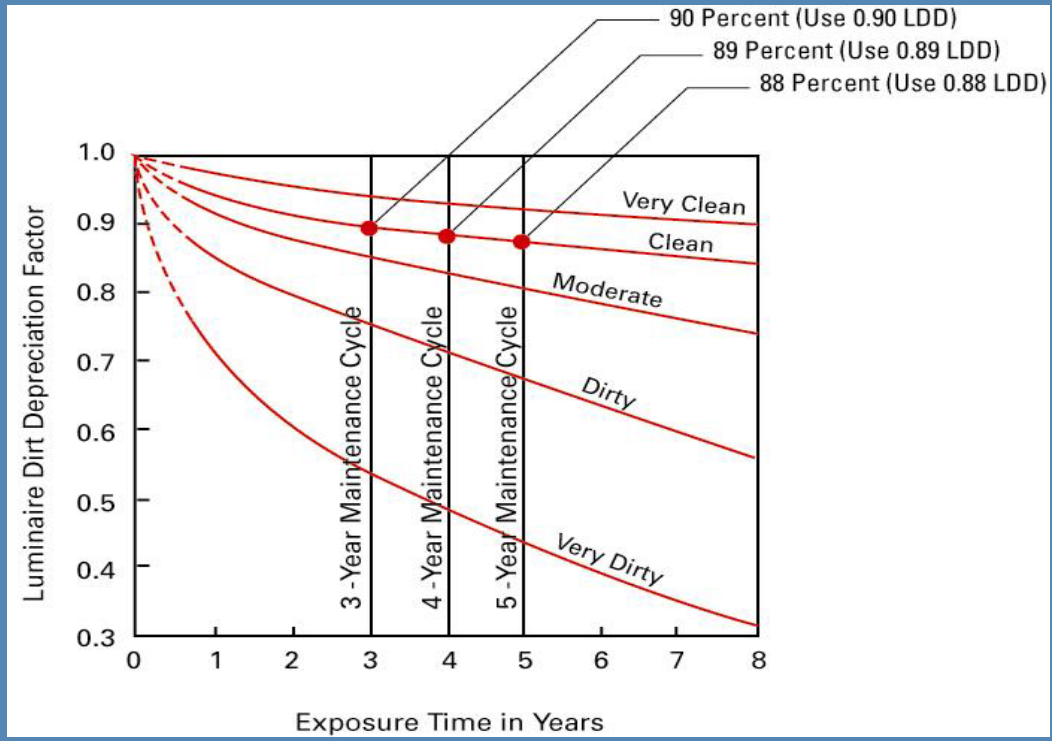
LLF is a factor applied to lighting design to compensate for depreciations over time:

Based on:

- *Lamp Lumen Depreciation (LLD)*
- *Luminaire Dirt Depreciation (LDD)*
- *Equipment Factor (EF) – Fixed number*

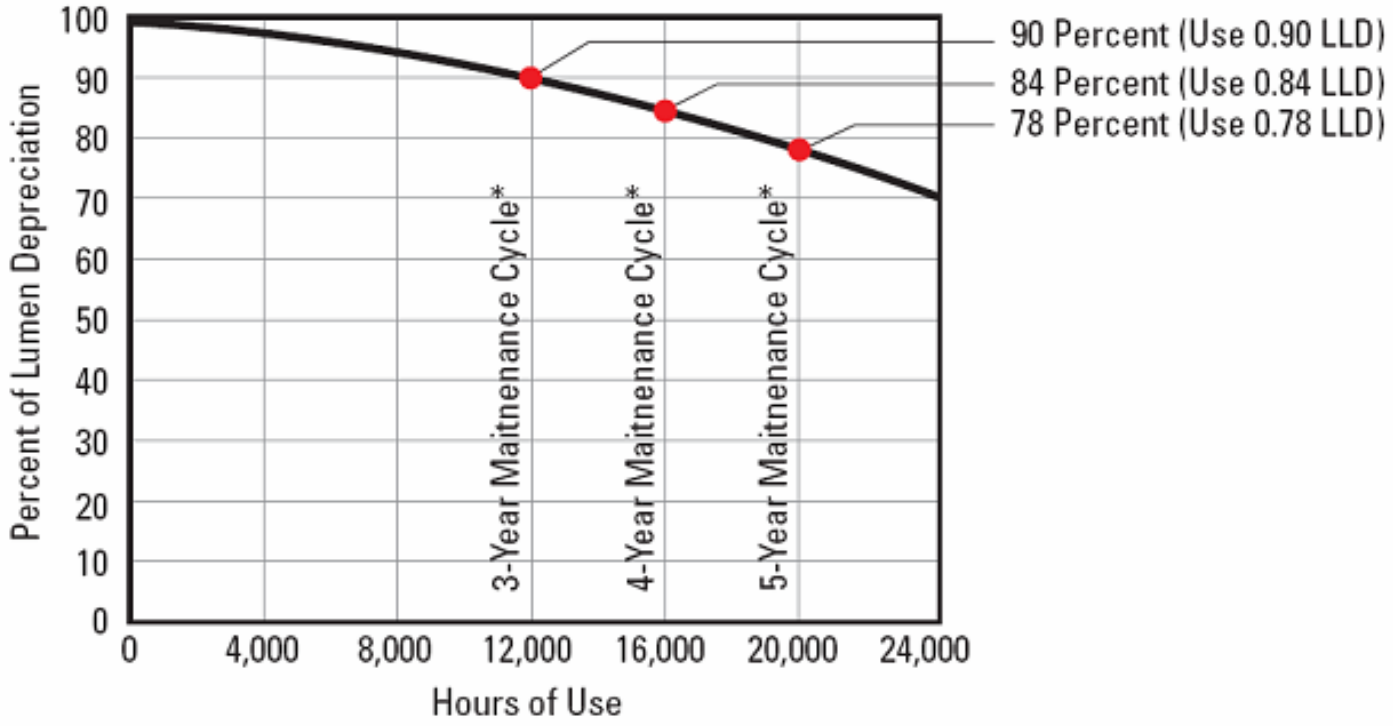
Important Consideration: Light loss factor should be based on end of lamp life at re-lamp ***not mean lumen value.***

Light Loss Factor (LDD)



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 m3.
Clean – No nearby smoke or dust generating activities and a low ambient contaminant level. Moderate to heavy traffic. The ambient particulate level is no more than 300 micrograms per m3.
Moderate – Moderate smoke or dust generating activities and a low ambient contaminant level. Moderate to heavy traffic. The ambient particulate level is no more than 600 micrograms per m3.
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.

Light Loss Factor (LLD)



* 4,000 hours of use is approximately one year

HPS Light Loss Factor Calculations

Three-Year Maintenance Cycle LLF Calculation:
0.77 (LLF) = 0.9 (LLD) x 0.9 (LDD) x 0.95 (EF)

Four-Year Maintenance Cycle LLF Calculation:
0.71 (LLF) = 0.84 (LLD) x 0.89 (LDD) x 0.95 (EF)

Five-Year Maintenance Cycle Calculation, or Maintenance by Spot Re-lamping LLF Calculation:
0.65 (LLF) = 0.78 (LLD) x 0.88 (LDD) x 0.95 (EF)

Additional Consideration - Lumen Depreciation Comparison

Typical High Pressure Sodium:

- 10% at 3 years
- 16% at 4 years
- 22% at 5 years

Typical Pulse Start Metal Halide

- 20% at 1 years
- 30% at 2 years
- 35% at 3 years

Typical Probe Start Metal Halide

- 40% at 1 years
- 53% at 2 years

LED's

LLD Diode factor		LDD Pollution factor based on a 5 years maintenance		DF Driver factor		EF Equipment factor		LLF
Life	Ratio	Condition	Ratio	Entry	Ratio	Life	Ratio	
15k hrs (3 years)	☐ 0.89	Very Clean	☑ 0.93	No Driver (direct)	☑ 1.00	3 years	☐ 0.99	0.722
20k hrs (5 years)	☐ 0.88	Clean	☐ 0.88	H.P.F. Electronic driver	☐ 0.90	5 years	☐ 0.99	
40k hrs (10 years)	☐ 0.84	Moderate	☐ 0.81	STD Electronic driver	☐ 0.85	10 years	☐ 0.98	
50k hrs (12 years)	☑ 0.80	Dirty	☐ 0.68	STD Driver	☐ 0.80	12 years	☑ 0.97	
60k hrs (15 years)	☐ 0.77	Very Dirty	☐ 0.43	Others	☐ -----	15 years	☐ 0.96	
80k hrs (20 years)	☐ 0.74					20 years	☐ 0.95	
100k hrs (25 years)	☐ 0.70					25 years	☐ 0.94	

Typical Case for 20 years

0.74 x 0.8* x 0.9 x 0.95 = 0.51 LLF

* Assumes 8 year cleaning

Lighting Design Criteria

Roadway Lighting

Road Area and Pedestrian Activity		Average Luminance cd/m^2	Average-to-Minimum Uniformity Ratio	Maximum-to-Minimum Uniformity Ratio	Maximum-to-Average Veiling Luminance Ratio
Road Type	Pedestrian Activity				
Freeway	--	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Partial Lighting of Interchange On-Ramps/ Off-Ramps	--	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Expressway-Highway	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
Arterial	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/Alleyway	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

Small Target Visibility (STV)

Higher STV is better

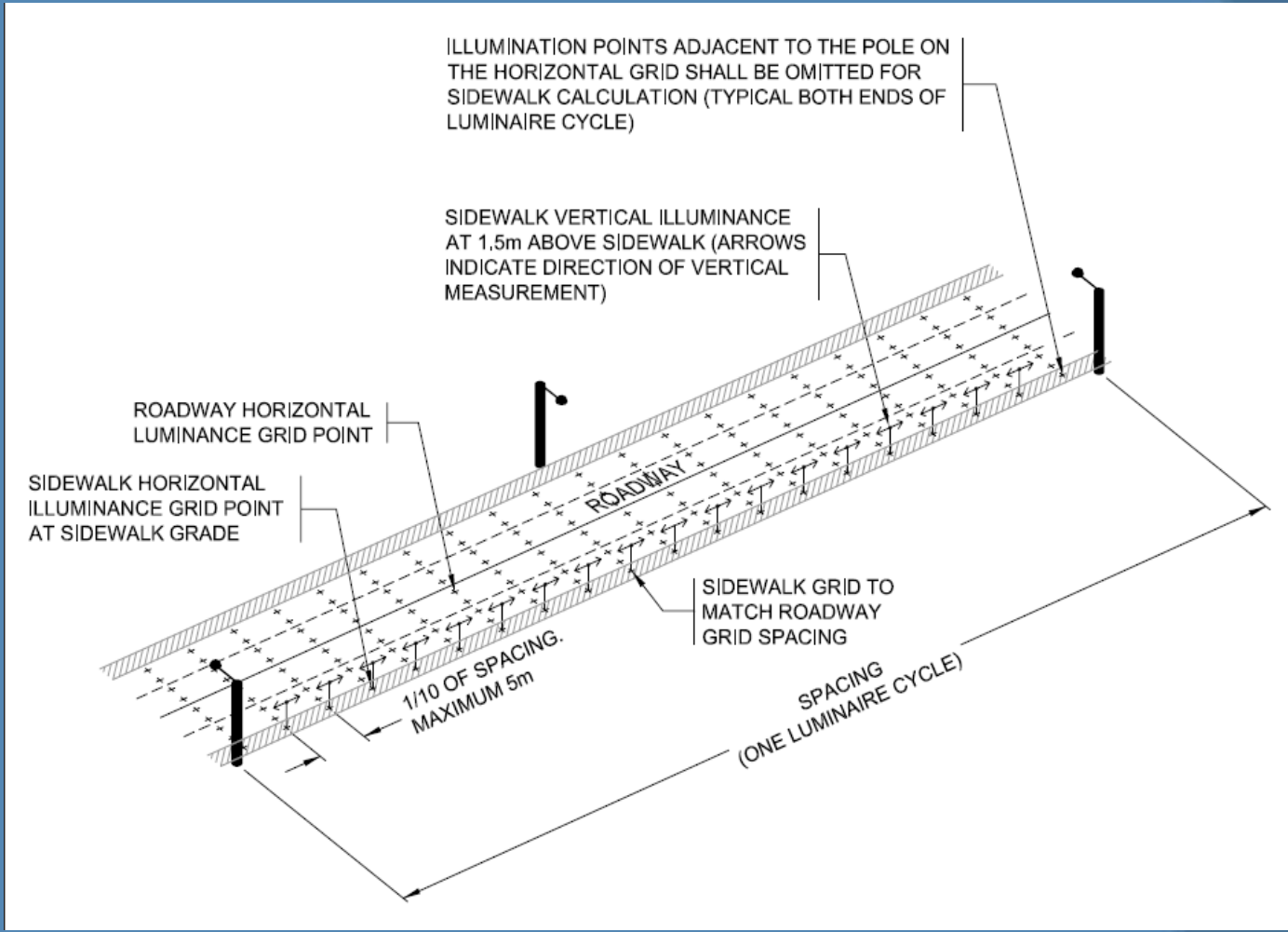
STV

Road Area and Pedestrian Activity		STV Criteria
Road Type	Pedestrian Activity	Weighted Average Visibility Level (VL)
Freeway	--	3.2
Expressway		3.8
Arterial	High	4.9
	Medium	4.0
	Low	3.2
Collector	High	3.8
	Medium	3.2
	Low	2.7
Local/Alleyway	High	2.7
	Medium	2.2
	Low	1.6

Sidewalk Lighting

Pedestrian Activity	Maintained Average Horizontal Illuminance (lux)	Average-to - Minimum Horizontal Uniformity Ratio	Minimum Maintained Vertical Illuminance (lux)
High	≧ 20.0	≦ 4.0	≧ 10.0
Medium	≧ 5.0	≦ 4.0	≧ 2.0
Low	≧ 3.0	≦ 6.0	≧ 0.8

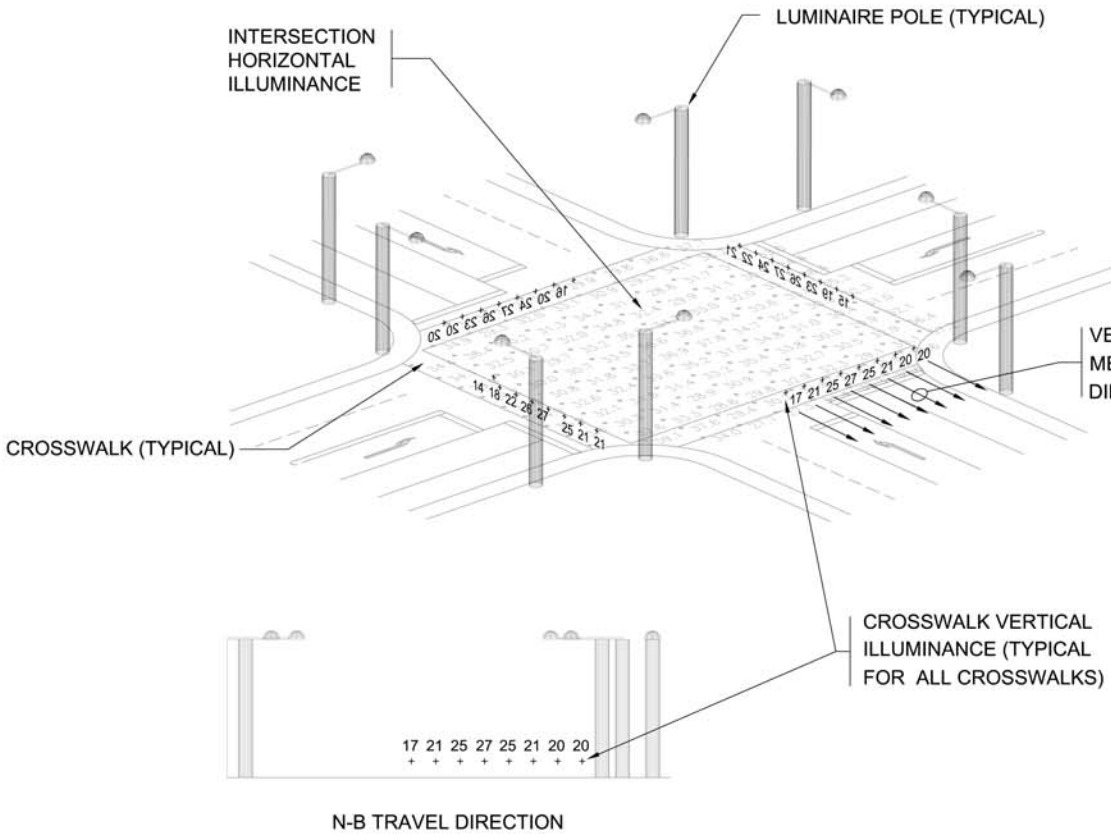
Roadway Calculation Grids



Intersection Lighting

Roadway Classification	Average Maintained Illuminance at Pavement by Pedestrian Conflict (lux)			Average-to-Minimum Uniformity Ratio
	High	Medium	Low	
Arterial/Arterial	34.0	26.0	18.0	≦ 3.0
Arterial/Collector	29.0	22.0	15.0	≦ 3.0
Arterial/Local	26.0	20.0	13.0	≦ 3.0
Expressway-Highway/Arterial	31.0	25.0	18.0	≦ 3.0
Expressway-Highway/ Expressway-Highway/	28.0	24.0	18.0	≦ 3.0
Expressway-Highway/Collector	26.0	21.0	15.0	≦ 3.0
Expressway-Highway/Local	23.0	19.0	13.0	≦ 3.0
Collector/Collector	24.0	18.0	12.0	≦ 4.0
Collector/Local	21.0	16.0	10.0	≦ 4.0
Local/Local	18.0	14.0	8.0	≦ 6.0

Intersection Calculation Example



OUTPUT RESULTS		
GRID	MAINTAINED AVERAGE	UNIFORMITY RATIO (AVG./MIN.)
INTERSECTION HORIZONTAL ILLUMINANCE	32.7 lux	1.2:1
W-B VERTICAL ILLUMINANCE ON CROSSWALK	22.0 lux	N/A
E-B VERTICAL ILLUMINANCE ON CROSSWALK	22.0 lux	N/A
N-B VERTICAL ILLUMINANCE ON CROSSWALK	22.2 lux	N/A
S-B VERTICAL ILLUMINANCE ON CROSSWALK	22.3 lux	N/A

Vertical Illumination

- It was found that in Switzerland, a level of 40 vertical lx was used in all crosswalks.
- This level reduced nighttime vehicle to pedestrian crashes by 66%.

Vertical Illumination – Smart Road

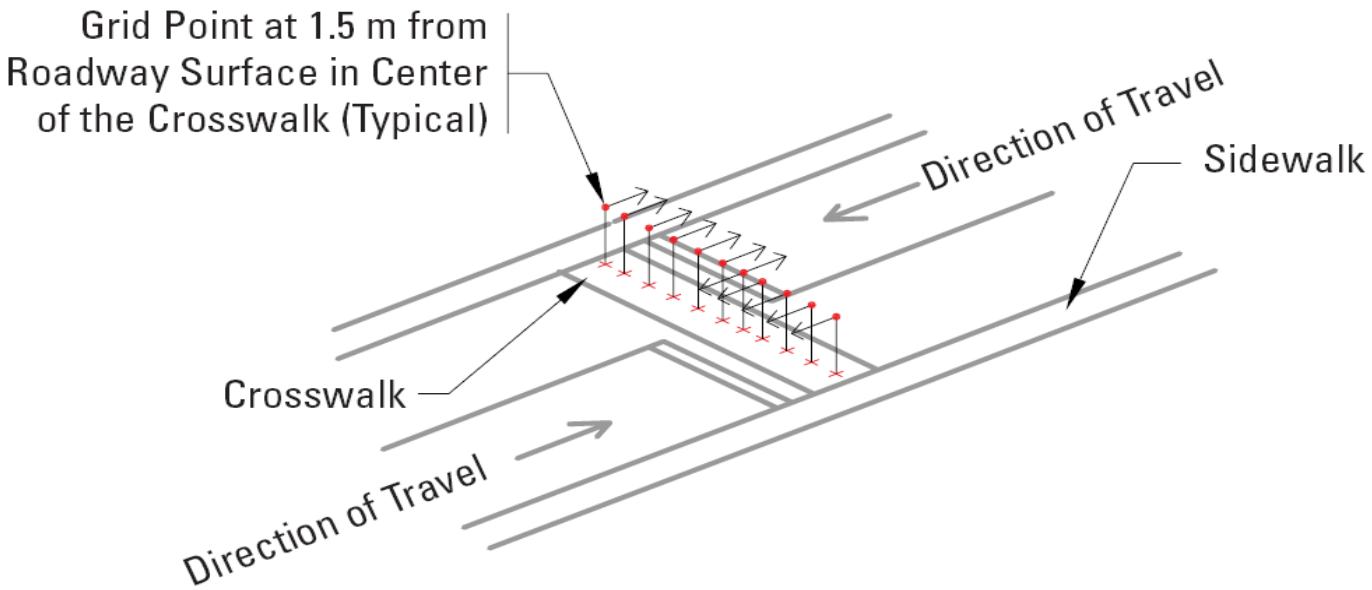
A lighting level of 20 vertical lux seems sufficient for crosswalks with the following limitations:

This is a static test, but dynamic testing may prove that this level needs to be higher.

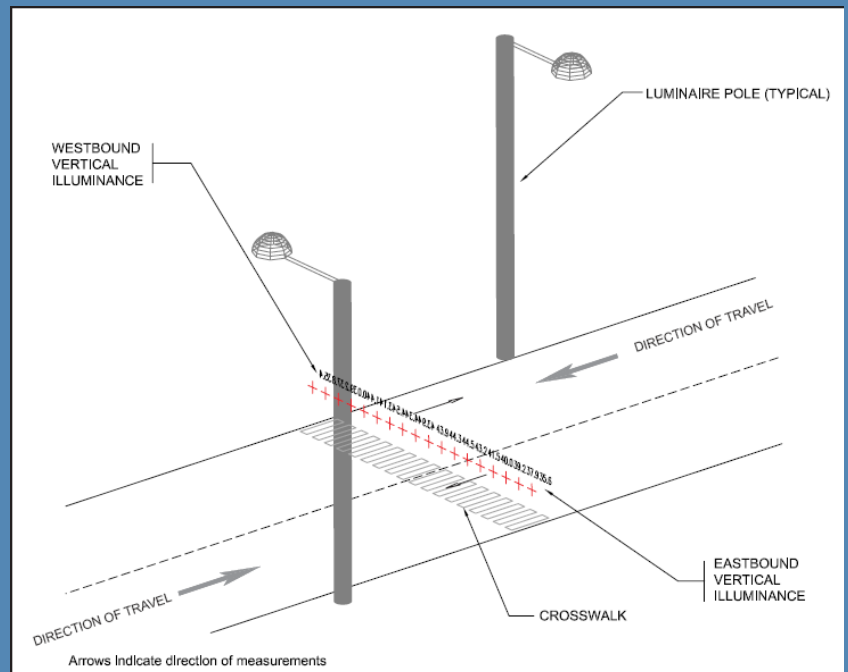
This was a rural road, but an urban area with a complex background may require a higher lighting level.

The addition of overhead lighting does not seem to mitigate the impact of glare.

Mid Block Crosswalk Lighting



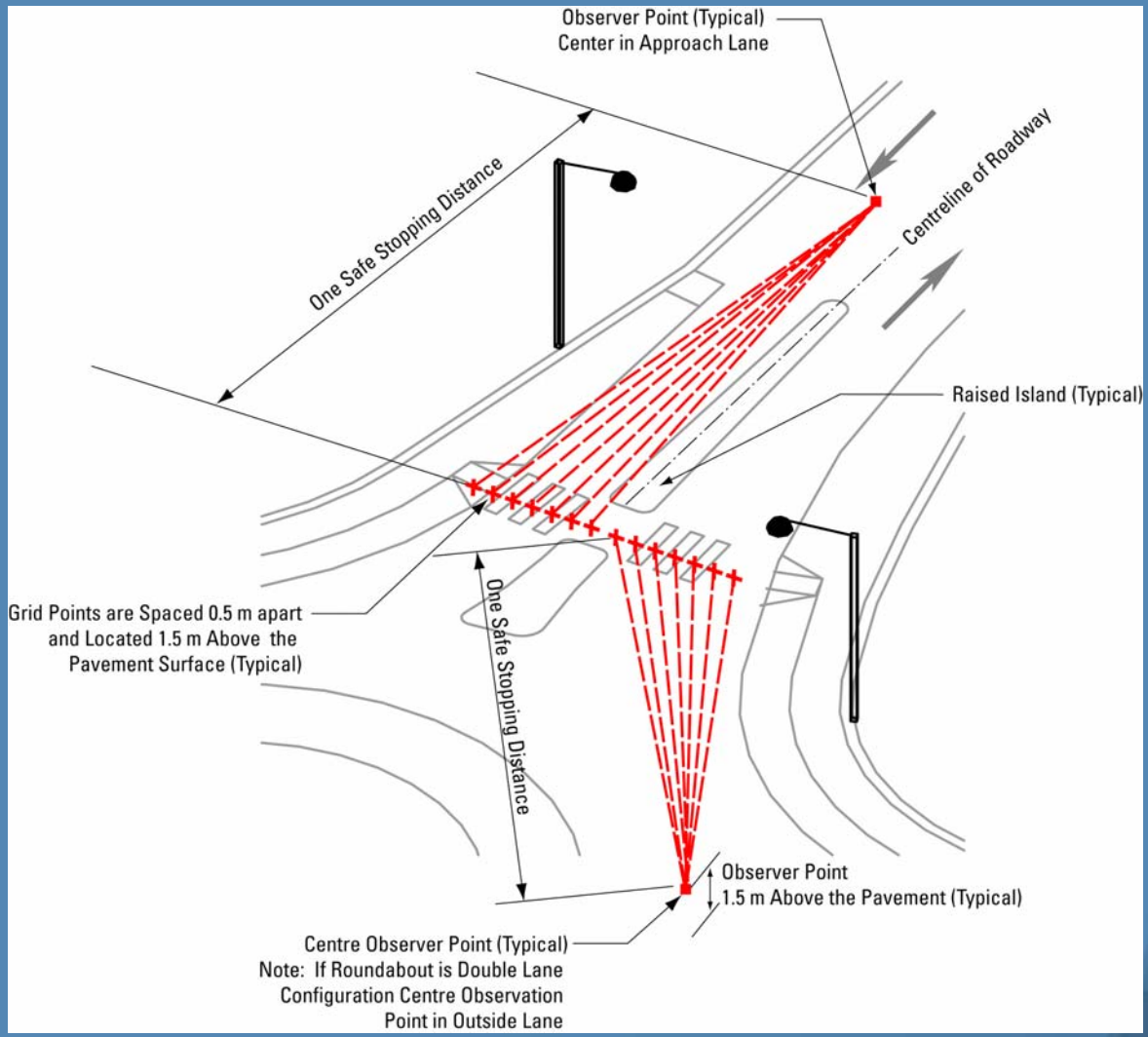
Mid Block Crosswalk Lighting



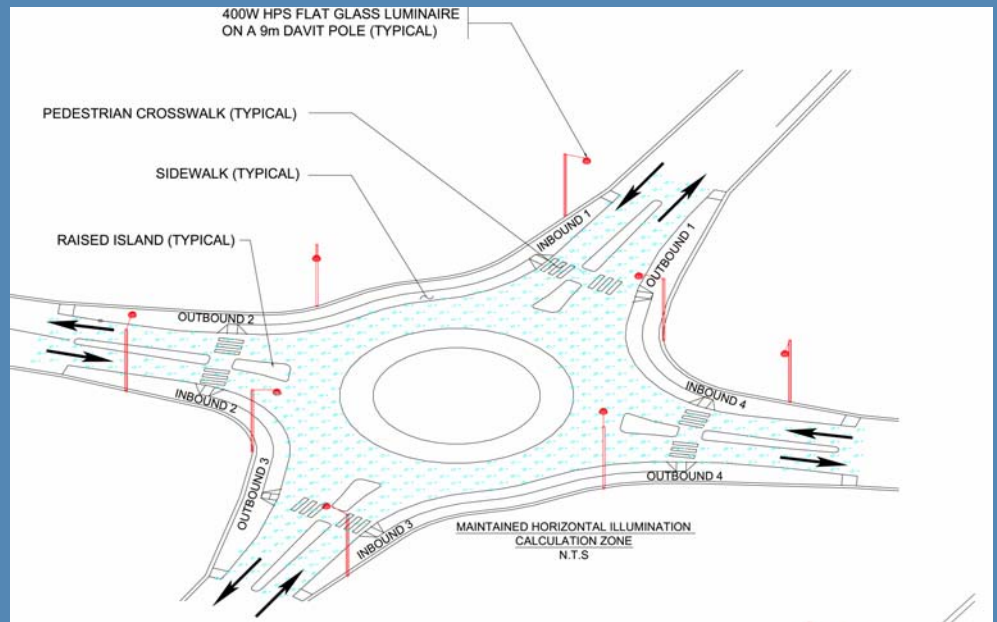
OUTPUT RESULTS	
GRID	MAINTAINED AVERAGE
W-B VERTICAL ILLUMINANCE	41.1 lux
E-B VERTICAL ILLUMINANCE	41.1 lux

Roundabouts

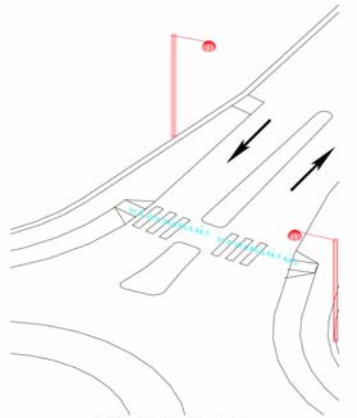
Roundabouts



Roundabouts



STATISTICS						
Description	Symbol	avg	Max	Min	Max/Min	Avg/Min
Inbound 1 (Vertical)	+	43 lux	47 lux	35 lux	1.3:1	1.2:1
Outbound 2 (Vertical)	+	41 lux	48 lux	32 lux	1.5:1	1.3:1
Inbound 2 (Vertical)	+	40 lux	45 lux	33 lux	1.4:1	1.2:1
Outbound 3 (Vertical)	+	41 lux	46 lux	33 lux	1.4:1	1.2:1
Outbound 1 (Vertical)	+	41 lux	47 lux	31 lux	1.5:1	1.3:1
Inbound 2 (Vertical)	+	41 lux	44 lux	34 lux	1.3:1	1.2:1
Outbound 4 (Vertical)	+	40 lux	46 lux	30 lux	1.5:1	1.3:1
Inbound 4 (Vertical)	+	40 lux	45 lux	34 lux	1.3:1	1.2:1
Roundabout (Horizontal)	+	42 lux	82 lux	14 lux	5.8:1	3.0:1



INBOUND1 AND OUTBOUND 1
MAINTAINED VERTICAL ILLUMINATION CALCULATION ZONES (TYPICAL)
N.T.S.

LED's

LED's

Fact

- Technology is evolving at a rapid pace
- High potential
- Suppliers are investing heavily

Unproven

- Technology is far more energy efficient
- Technology will be maintenance free
- Technology is more robust

LED's (barriers to market entry)

- Lack of industry roadway luminaire specifications.
- A low price based lighting market. In North America we are focused on low product cost. We must assess products by life cycle cost to truly get the best value for the dollar. The low cost product seldom has the best overall life cycle cost.
- Product over hype.
- Lack of knowledge.
- Lack of testing.

LED's (US DOE)

I-35W Bridge Lighting, Minneapolis

- 3 year demonstration project - MnDoT), FHWA, Beta LED (the supplier) and the Pacific Northwest National Laboratory (PNNL) on behalf of the US Department of Energy (DOE).
- 20 Beta LED fixtures mounted at 21.2m (40ft) and spaced at 45.7m (150ft) on a new bridge.
- The first phase completed in September 2008 involved selection, laboratory testing, installation and measurements following the installation.
- The second phase involves 3 years of field testing

Recent Comparison

Luminaire	Spacing (m)	UPD Required </=	UPD Achieved	Unit Cost	Power cost over 20 years	Maintenance Cost over 20 years	Total Life Cycle Cost
LED Street Light	61m	40	14	$1,200	$591	$200	$1,991
Cobra head Street light	50m	40	25	$200	$1,270	$500	$1,970

- Light loss factor of 0.61 for LED (0.74 diode factor, 0.88 dirt, 1.00 driver factor and 0.95 equipment factor. This will vary from supplier to supplier. Light loss factor of 0.72 used for HPS cobra heads
- Lighting criteria 2 lane local road as per CSA C-653. Local road with low pedestrian activity.
- Power Cost based 10.5 cents per kilowatt hour
- Maintenance assumes 4 year group re-lamp for HPS cobra head luminaires. Assume 10 year cleaning for LED luminaires
- Fixture input watts – 67W for LED and 144W for cobra head
- LED luminaire costs will vary. Costs are based on estimated costs for past projects and may vary greatly depending on quantity and supplier.

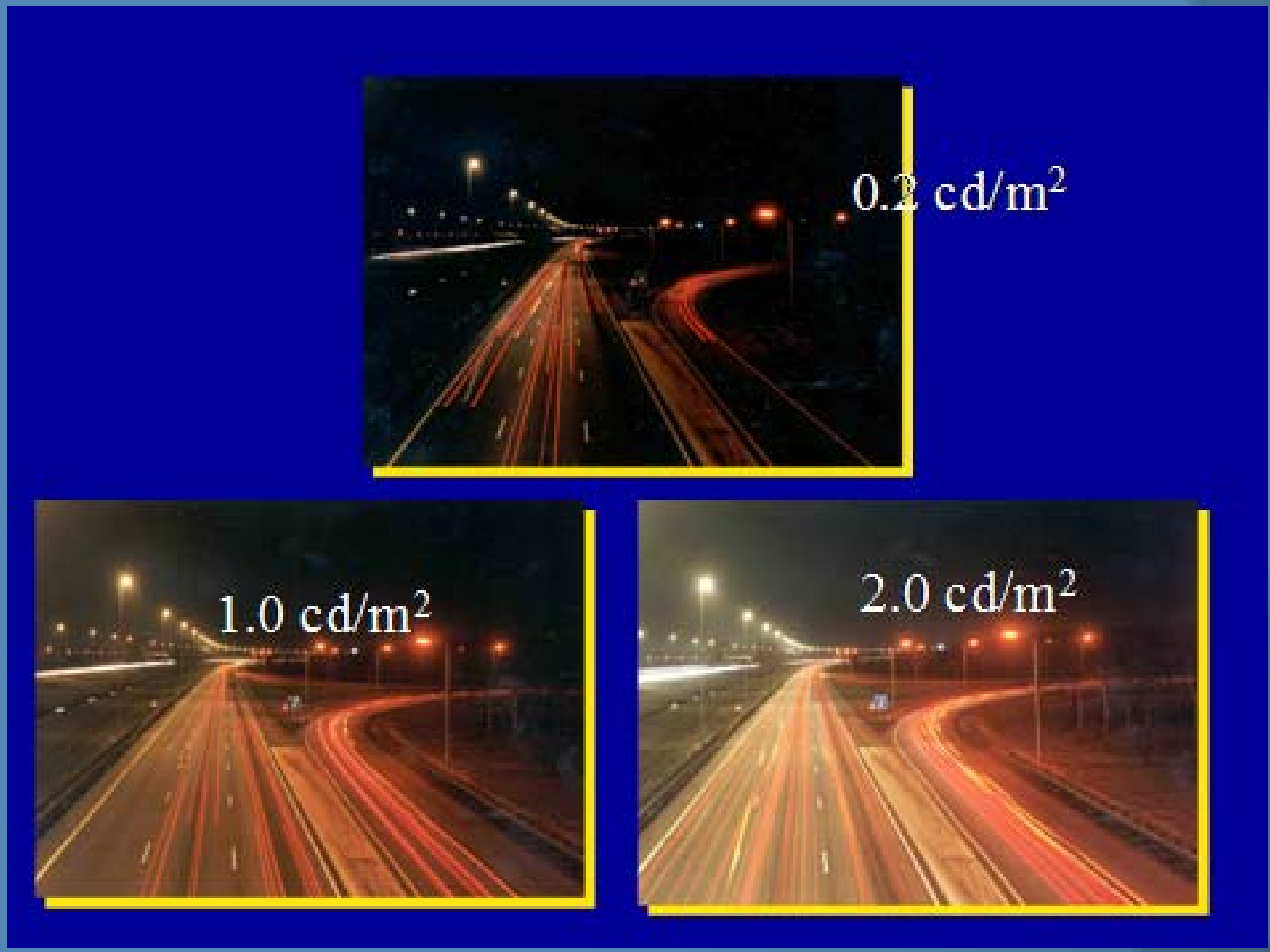
Adaptive Lighting

Adaptive Lighting (new term):

"The ability to vary lighting levels to suit activity levels."

Becoming accepted practice as it is (or will be) in many published documents (ie; TAC, CIE, IMSA, IESNA)

Adaptive Lighting (new term):



Potential Benefits of an Adaptive Street Lighting System:

- Reduced Energy Consumption
- Obtrusive Light Reduction
- Power Consumption Monitoring
- Streamlined Asset Management
- Alerts of wire theft

Adaptive Street Lighting System – Potential Energy Savings

Application		Advantages
1	Reduce Lumen Output of Lamps to Maintained Levels	• Energy Savings • Obtrusive Light Reduction
2	Reduce levels on over lighted roads to levels required	• Potential Energy Savings • Obtrusive Light Reduction
3	Match Lumen Output to Variable Pedestrian Activity Levels	• Significant Energy Savings • Obtrusive Light Reduction

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Questions and Answer