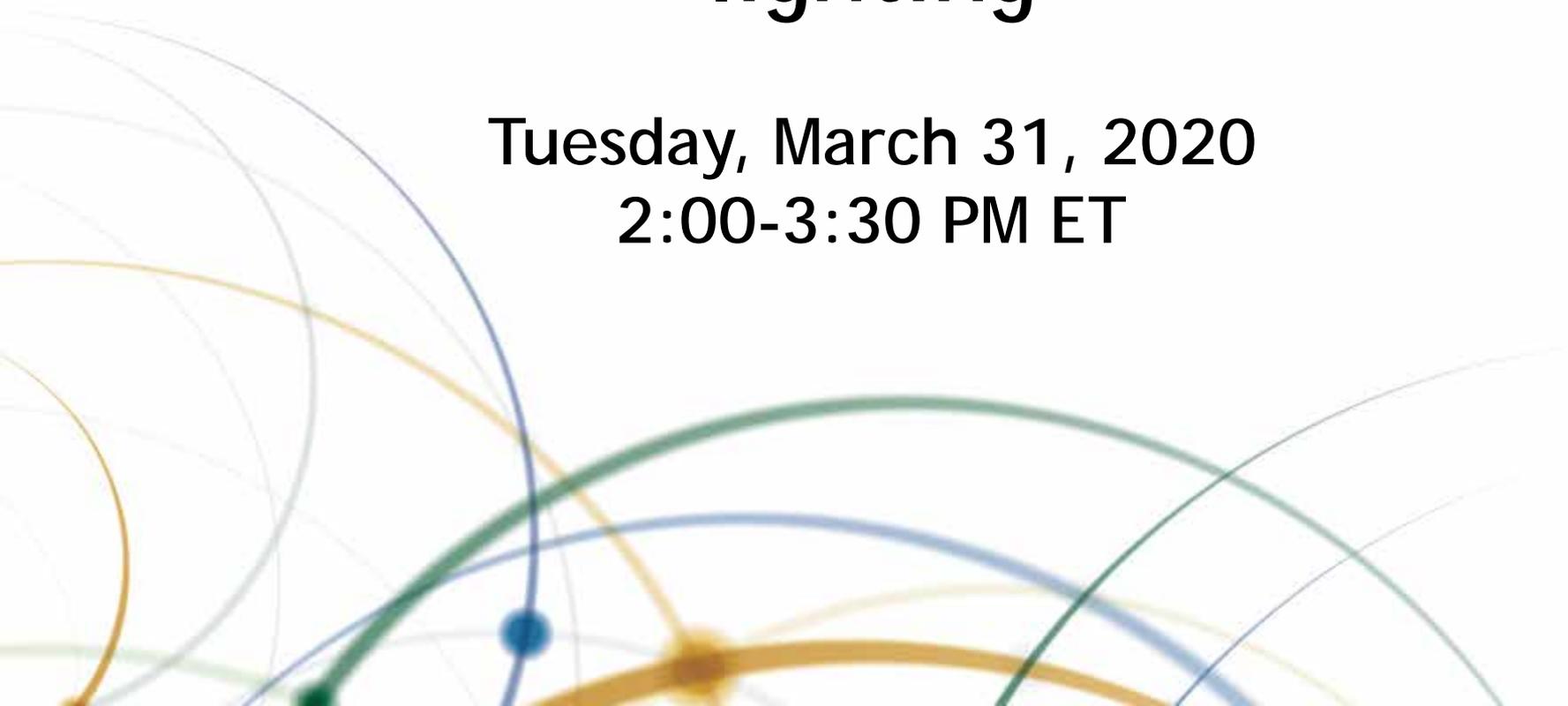


TRANSPORTATION RESEARCH BOARD

Designing solid-state roadway lighting

Tuesday, March 31, 2020
2:00-3:30 PM ET



The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.



REGISTERED CONTINUING EDUCATION PROGRAM



Learning Objectives

At the end of this webinar, you will be able to:

- Describe how to apply SSL to roadway environments
- Design SSL effectively



Introduction

Project No. NCHRP 05-22

GUIDELINES FOR SOLID STATE ROADWAY LIGHTING

FINAL REPORT

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
of
The National Academies of Sciences, Engineering and Medicine

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING AND MEDICINE

PRIVILEGED DOCUMENT

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August 2019

SOLID STATE LIGHTING GUIDE

Final – August 2019



AMERICAN ASSOCIATION
OF STATE HIGHWAY AND
TRANSPORTATION OFFICIALS
AASHTO

Supplemental Solid State Guide

- Chapter 1 – Introduction
- Chapter 2 – Master Lighting Plan
- Chapter 3 - Technique of Lighting Design
- Chapter 4 - Tunnels and Underpasses
- Chapter 5 - Work Zone Lighting and Temporary Roadway Lighting
- Chapter 6 – Roundabouts, Interchanges, and Intersections
- Chapter 7 – Electrical System Requirements
- Chapter 8 – Safety Rest Areas
- Chapter 9 – Roadway Sign Lighting
- Chapter 10 – Operation and Maintenance Considerations
- Chapter 11 – Potential Environmental Impacts
- Annex A – Design Examples
- Annex B – Solid State Lighting Sample Specifications



Roadway Lighting Design Guide

Seventh Edition * October 2018



Planning and Use of Solid State Lighting

Prior research, as well as research for this project, show differences in driver detection distances, with 4000K sources showing some advantages.

Key Differences Between Solid State and Traditional Light Sources

- Spectral content and effectiveness vary. CCT only partially describes LED source spectral content.
- Photometric distribution can greatly vary with HID sources as well as among LED products.
- Rated life of luminaires is based on different performance requirements.
- Solid state components require different considerations relating to electrical components and operations.
- Solid state luminaires allow for much greater flexibility regarding control, output, and optical distribution. These flexibilities offer potential benefits over HID and HPS.
- Solid state luminaires can create impacts relating to glare, environmental impacts, and subjective preferences which should be understood and mitigated.



Figure 14. Comparison of Different CCT Streets

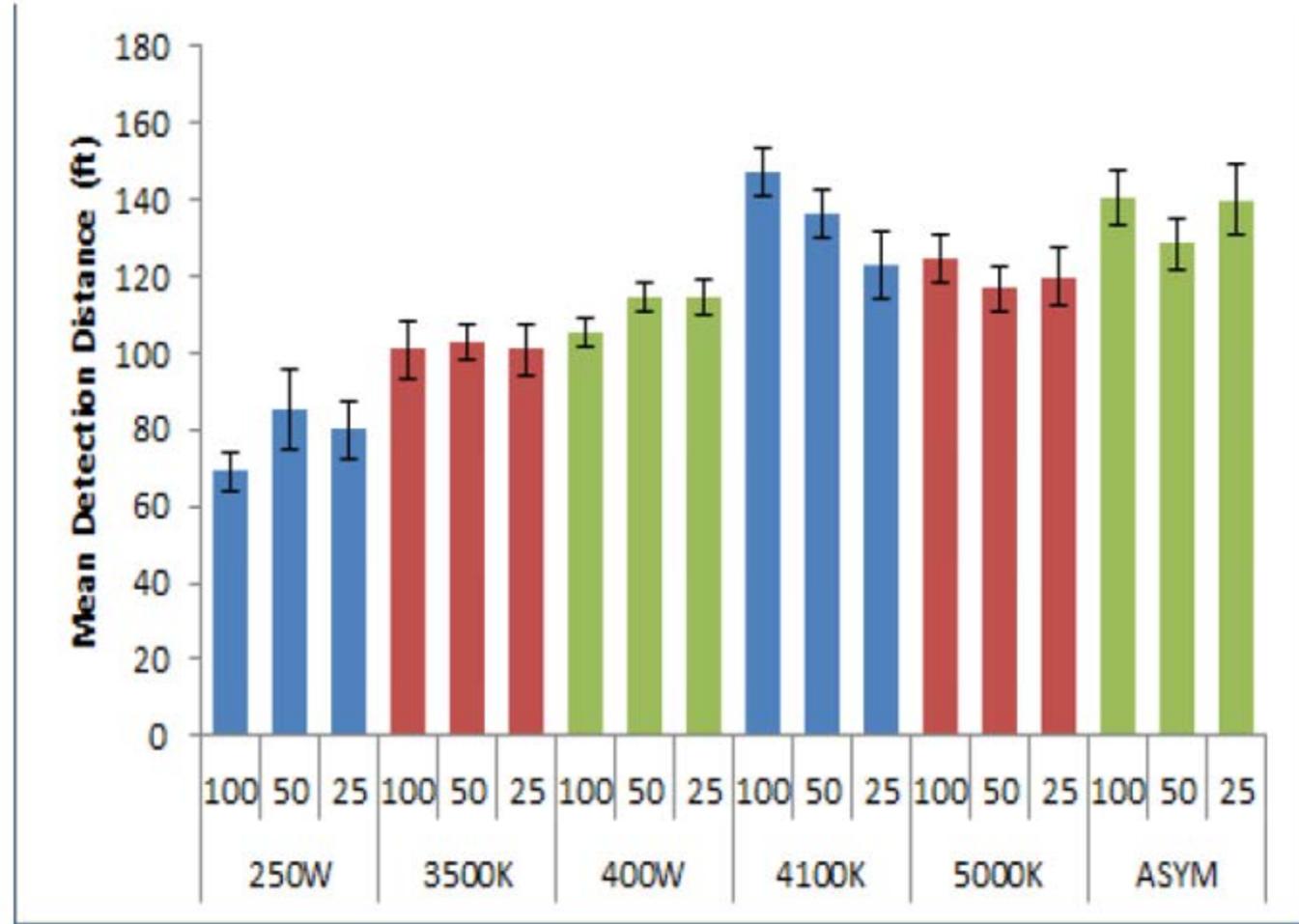


Figure 2. Mean Detection Distance Differences for Various Sources (Clanton & Associates Inc., 2014)

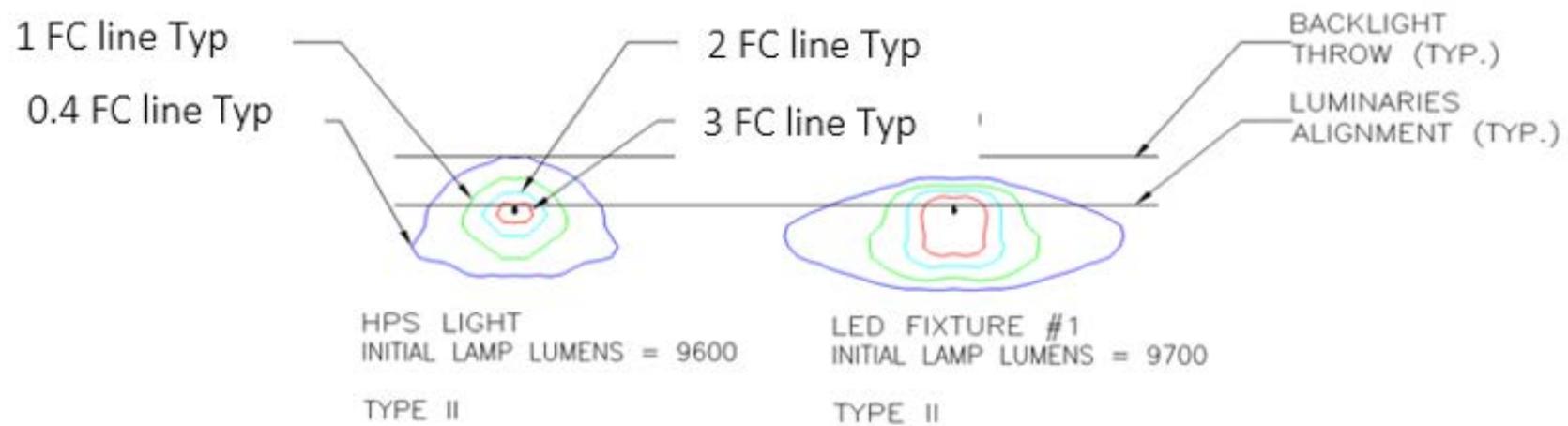


Figure 5. Comparisons of HPS and LED luminaires using Standardized Distribution Ratings

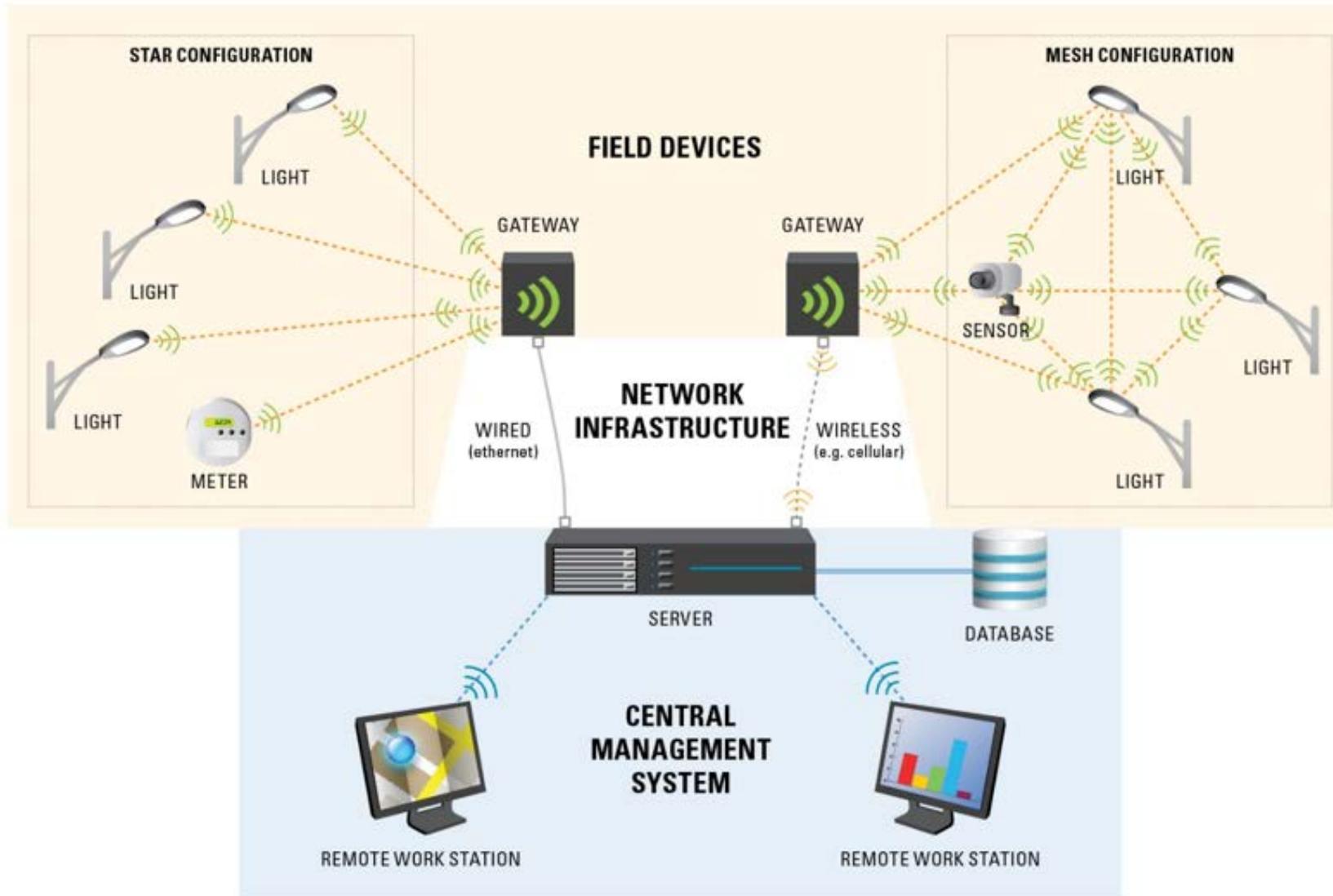


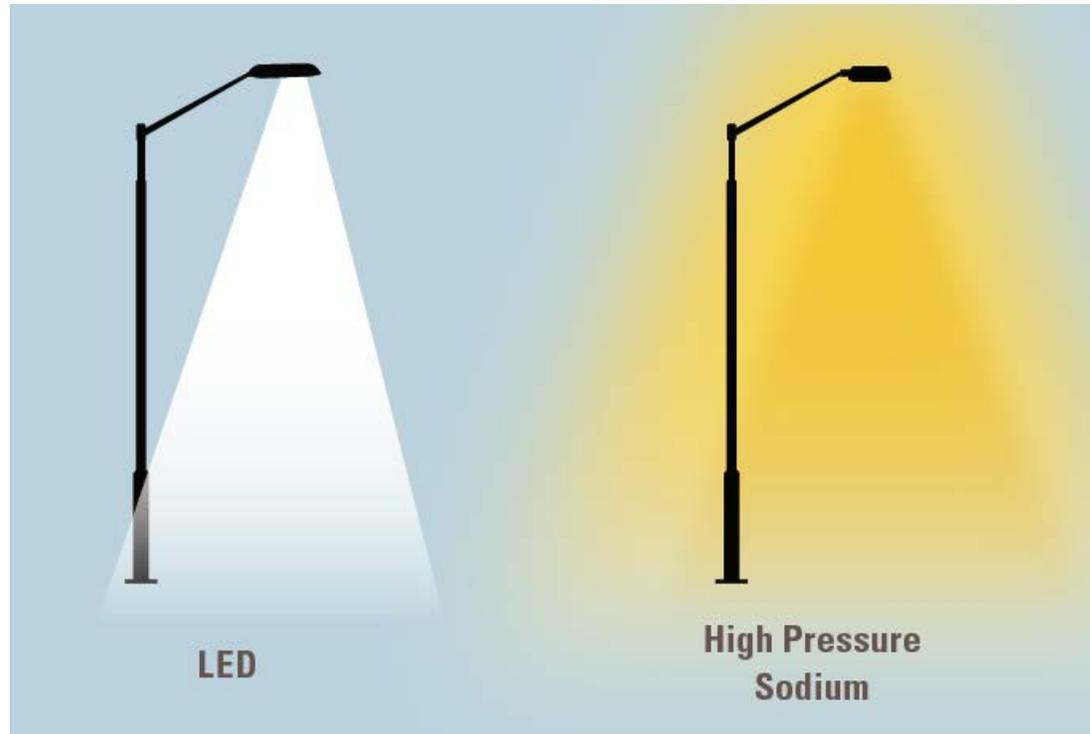
Figure 7. Major Components of a Wireless Outdoor Lighting Control

(Image Credit: California Lighting Technology Center, UC Davis)

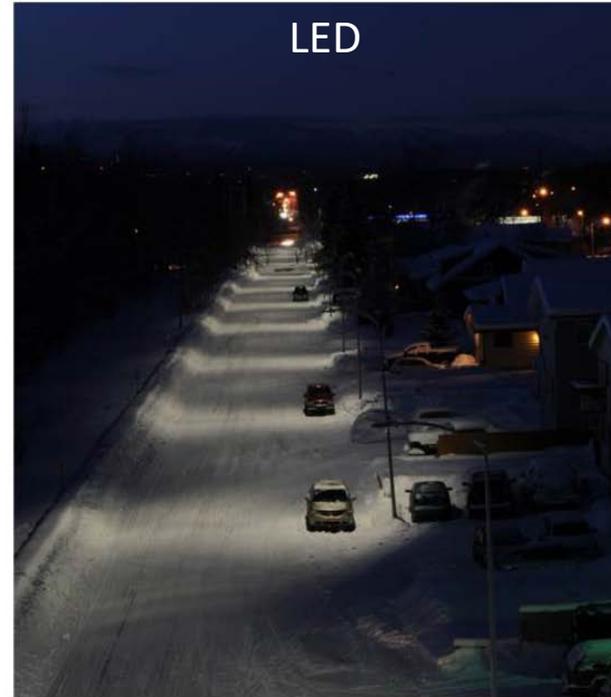
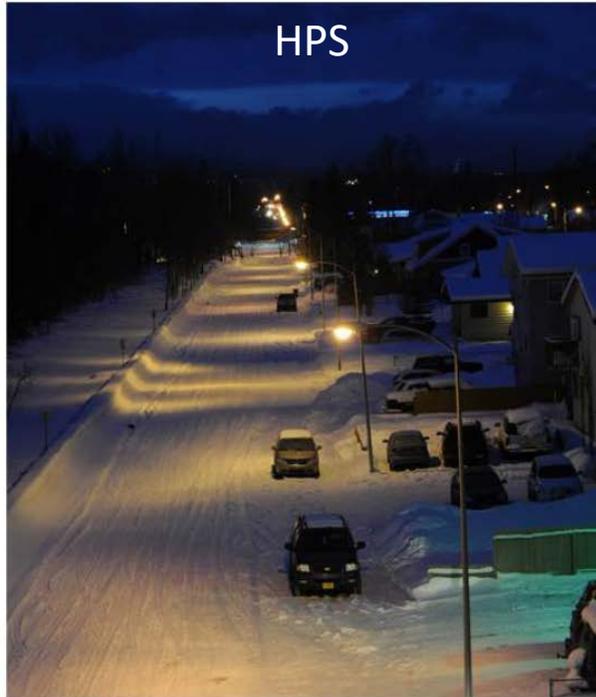
Criteria for Solid-State Roadway Lighting

Existing Recommendations for Light Levels on Roadways

- Based on legacy sources like HPS – Poor Optical Distribution Control



For HPS, light adjacent to the roadway could have been unintended safety benefit



Anchorage. Photo by Wayne Johnson, ML&P

How to deal with it in the age of LEDs

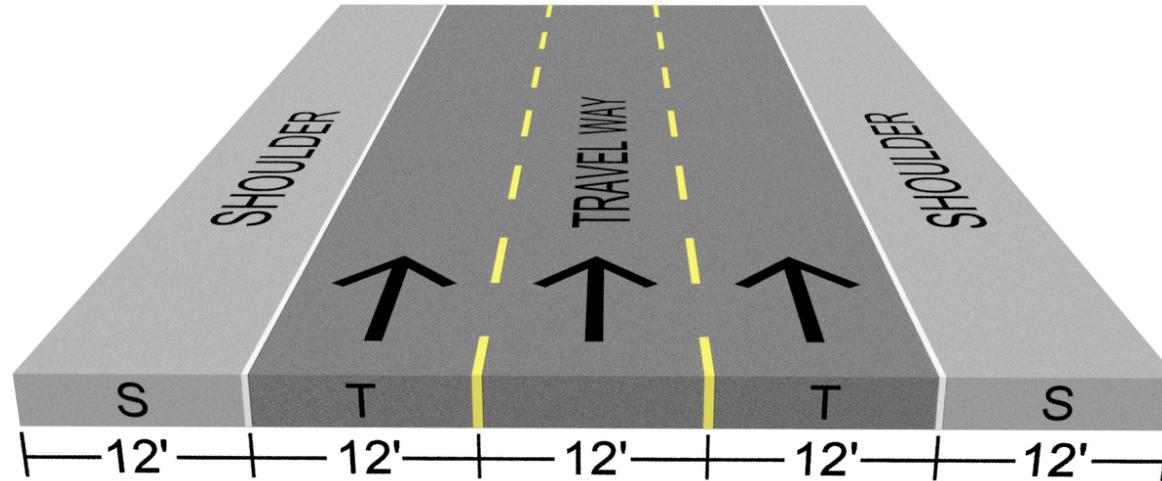
- Does additional lighting beyond the roadway help the drivers in seeing better?
- If yes..
 - How much light do we need?
 - How do we specify it?
 - Implications for sidewalks and bicycle paths
- This is the focus of NCHRP Project 5-22

What is Surround Ratio?

“Ratio of the average horizontal illuminance on the two longitudinal strips each adjacent to the two edges of the carriageway to the average horizontal illuminance on two longitudinal strips each adjacent to the two edges of the carriageway” - CIE 140: 2000

What is Surround Ratio?

$$\text{Surround Ratio} = \frac{\text{Edges}}{\text{Lanes}}$$



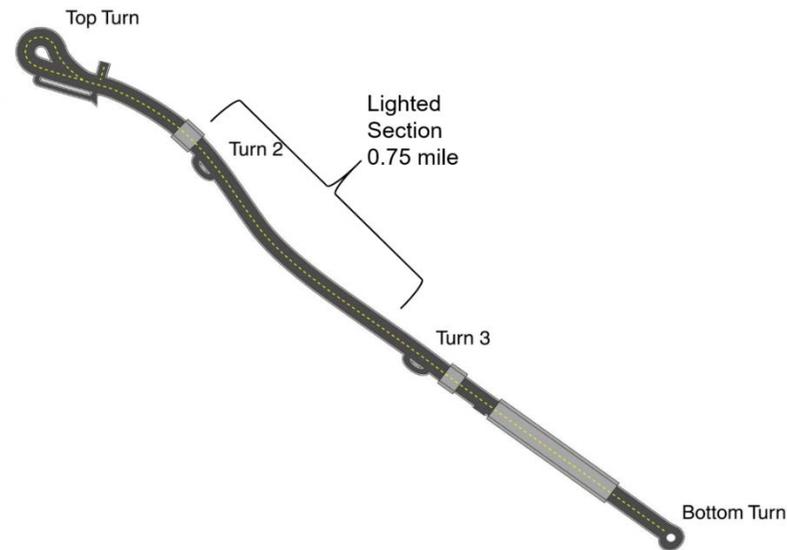
Objectives

How does changing the surround ratios affect driver visual performance?

- Pedestrian location on the roadway
- Speed
- Light level
- Uniformity

Experimental Procedure – Virginia Smart Road

- 60 Participants – Age and Gender Balanced
- Object detection task on the Virginia Smart Road
- Control system to dim
- 80 meter spacing
- 15 meter mounting height



Experimental Design – Independent Variables

Independent Variable	Level
Light Spectral Power Distribution	3000 K LED 4000 K LED 5000 K LED
Light Level (Avg. Luminance)	High: 1.5 cd/m ² Medium: 1.0 cd/m ² Low: 0.7 cd/m ²
Surround Ratio (Avg. Shoulder to Avg. Lane Luminance)	High (0.8) Low (0.45)
Uniformity Ratio (Avg. to Min Luminance)	High (1.8) Low (1.3 to 1.4)
Speed	High (55 mi/h) Low (35 mi/h)
Age	Old (65 and older) Young (18 to 35 years)

Surround and Uniformity Ratios



Dependent Measures – Detection Distances

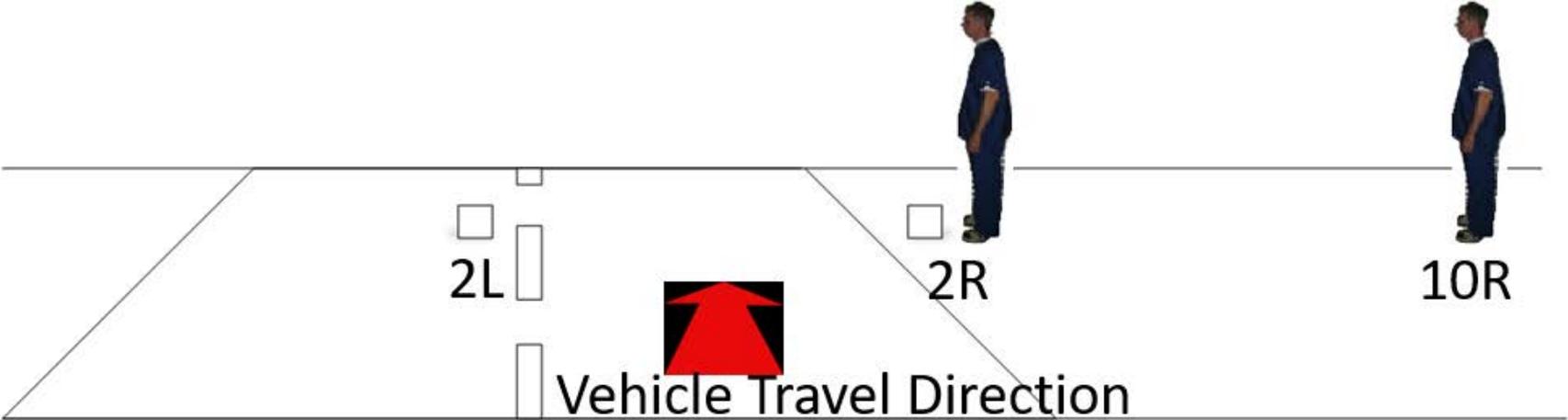
- **Targets (18 cm by 18 cm)**



- **Pedestrians**

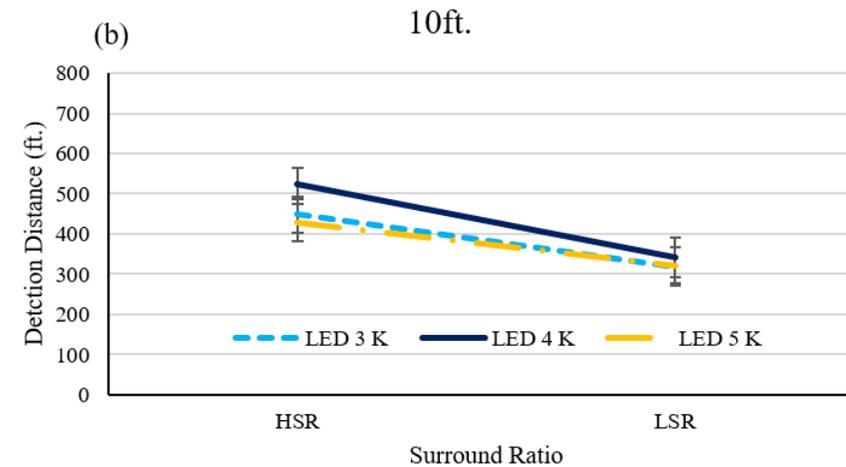
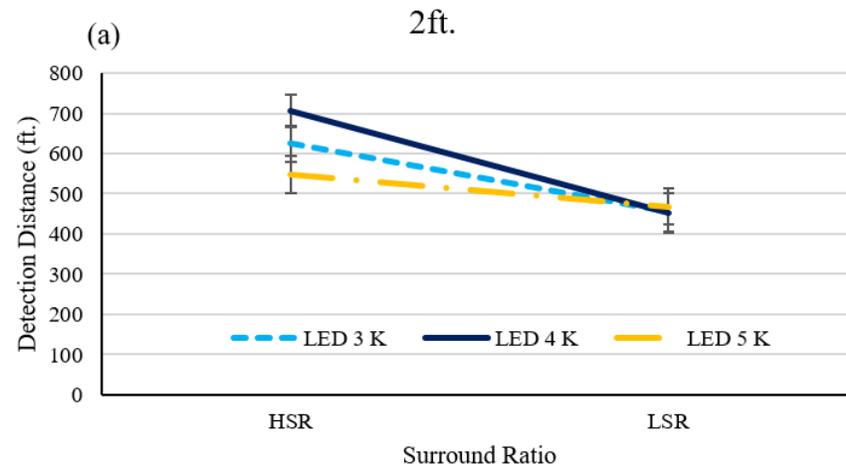


Object Locations – Detection Task

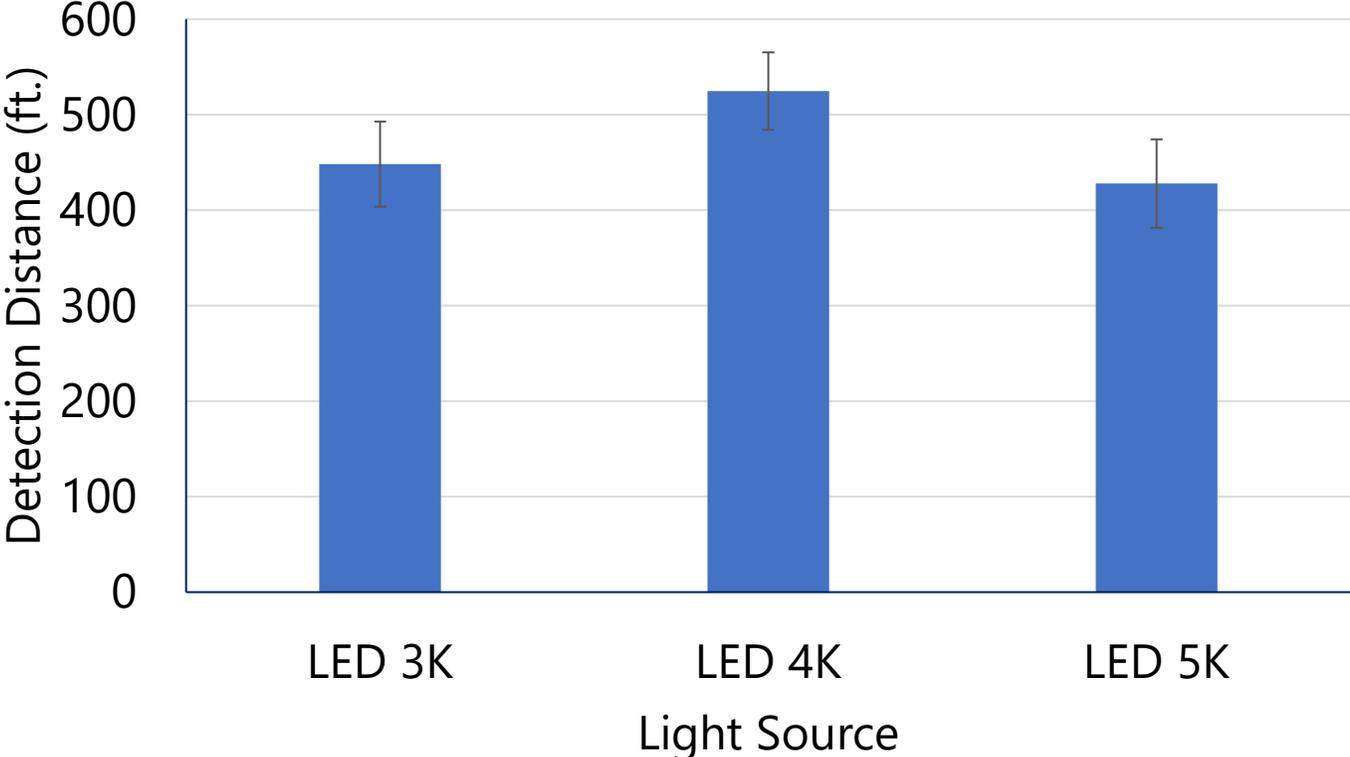


How does Surround Ratio affect Visual Performance Across LEDs and Offset Distances?

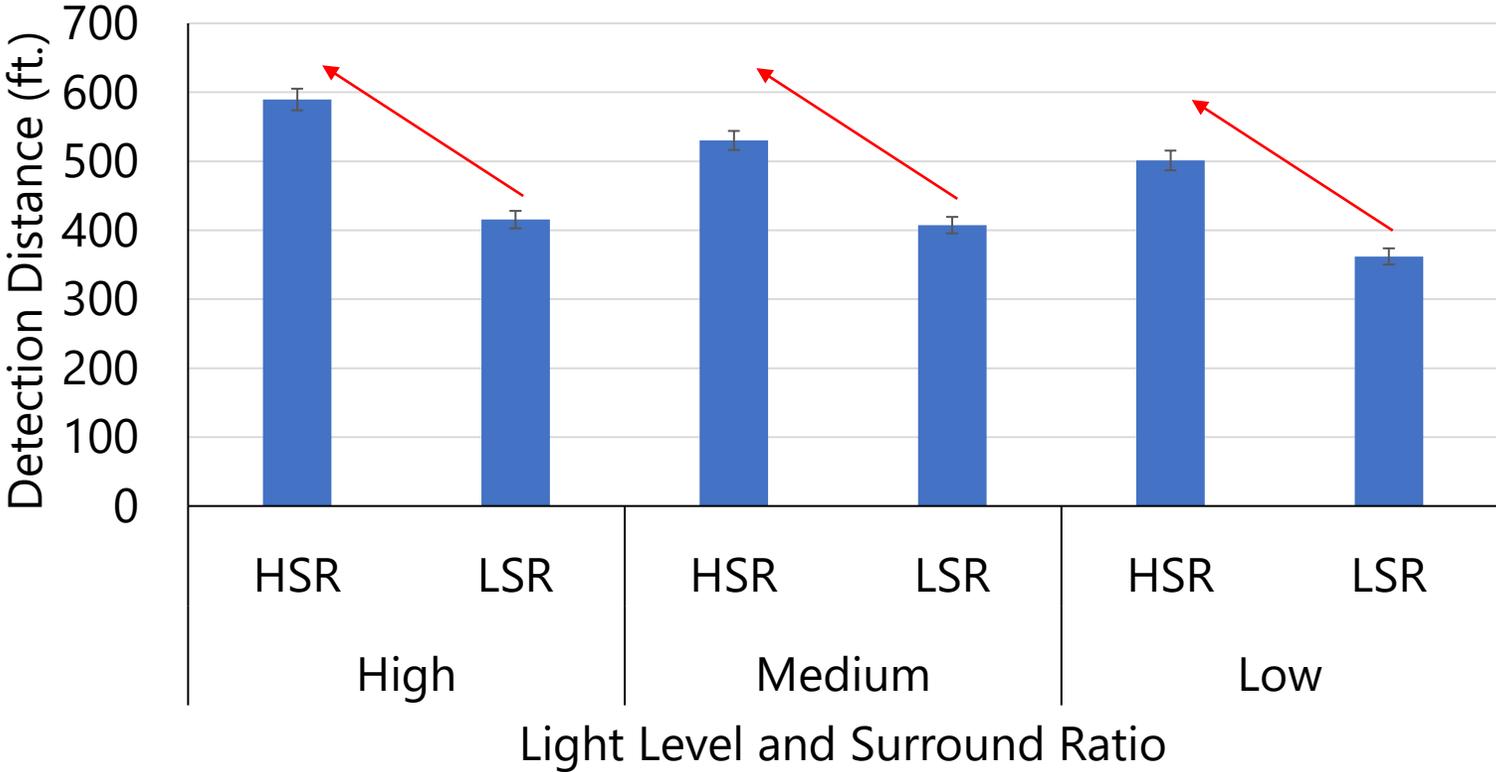
- Lower surround ratios had lower detection distances
 - Lowest at 10ft. offset
- Consistent across all LEDs



For Higher Surround Ratio, 4000 K LED increased detection distances for off-axis pedestrians



How does Surround Ratios affect visual performance across Light Levels?



Odds the driver can detect the pedestrian from a “safe” distance?

Independent Variable	Level	Reference Level	Odds Ratio	95% Confidence Limits	
Light Level	High	Low	1.7	1.3	2.3
	High	Medium	1.4	1.1	1.8
Surround Ratio	HSR	LSR	2.6	1.3	5.0
Uniformity Ratio	HUR	LUR	2.3	1.2	4.4
Age	Younger	Older	5.6	2.7	11.4
Clothing Color	Blue	Black	1.3	1.0	1.8
	Gray	Black	1.6	1.2	2.2
	Red	Black	3.3	2.4	4.6
Offset	2 ft.	10 ft.	3.4	2.7	4.3
Speed	35 mi/h	55 mi/h	37.7	27.8	51.1

Conclusions – Light Source Type

- No significant differences between LEDs and between LED and HPS
 - For Both Pedestrians and Targets
- 4000K typically had a higher response level
 - HPS had significantly higher uncertainty and higher non-uniformity
 - Higher speeds
- SPD of the light source might not majorly influence driver visual performance at speeds greater than 35 mi/h

Conclusions – Surround Ratio

- Higher Surround Ratios (SRs) increased visual performance (esp. for Pedestrians)
 - Longer detection distances
 - Higher odds of detection from safe distance
 - All offset distances
 - All light levels
 - All LEDs
- Higher SRs for 4000 K LEDs
 - only condition that had detection distance greater than SSD at 55 mph
 - longest detection distances for all offset distances
- Higher surround ratios increased off-axis visual performance
 - Increased light on the shoulder → more information for drivers
- A Surround Ratio of at least 0.8 will ensure good visual performance

Techniques for SSL Design

Key Issues During Lighting Design

- Consider an adaptive lighting system (or at least provide a controls-ready system) and establish light levels for dimming.
- Select CCT for the installation based on visibility differences for certain spectral content sources as well as preferences determined by the DOT or Authority. Generally, 4000K provides consistent results but consider other factors as discussed in other sections of this guide.
- Include the shoulders adjacent to the roadway in lighting design. When pedestrians and/or cyclists are present, consider the AASHTO recommendations for those areas as part of the design. For highways and freeways, adjacent areas should meet the SR levels discussed in this chapter.
- Consider warrants and other factors as part of the decision process for roadway safety improvements.
- Consider high-mast lighting, which can create more light trespass and perceived brightness issues from abutters, only for large area lighting or very wide roadway cross sections.
- Identify sensitive receptors and housing areas close to the roadway right-of-way early in design.
- Consider shielding in lighting system design.
- Because individual LED shields perform better than luminaire shields for high-mast lighting, carefully select shielding types.
- LED luminaires may help reduce structural requirements (fewer fixtures/weight/EPA) for poles.
- Consider longer periods between needed access to luminaires.

Adaptive Lighting Methods

Road Classification	Average Luminance L_{avg} (cd/m ²)	Average Uniformity Ratio L_{avg}/L_{min}	Maximum Uniformity Ratio L_{max}/L_{min}	Maximum Veiling Luminance Ratio $L_{v,max}/L_{avg}$
Freeway Class A	0.6	3.5	6.0	0.3
Freeway Class B	0.4	3.5	6.0	0.3
Expressway	1.0	3.0	5.0	0.3

Table Notes:

L_{avg} : Maintained average pavement luminance

L_{min} : Minimum pavement luminance

$L_{v,max}$: Maximum veiling luminance

Street Classification	Pedestrian Activity Classification*	Average Luminance L_{avg} (cd/m ²)	Average Uniformity Ratio L_{avg}/L_{min}	Maximum Uniformity Ratio L_{max}/L_{min}	Maximum Veiling Luminance Ratio $L_{v,max}/L_{avg}$
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

Table Notes:

* Pedestrian Activity Classifications are defined in Section 11.3.3.

L_{avg} : Maintained average pavement luminance

L_{min} : Minimum pavement luminance

$L_{v,max}$: Maximum veiling luminance

Figure 9. Excerpt from RP-8-18 showing Roadway and Street Lighting Levels

Adaptive Lighting Methods

Parameter	Options	Criteria	Weighting Value
Speed	Very High	> 60 mi/h (100 km/h)	1
	High	45–60 mi/h (75–100 km/h)	0.5
	Moderate	< 45 mi/h (75 km/h)	0
Traffic Volume	High	> 30,000 ADT	1
	Moderate	10,000–30,000 ADT	0
	Low	< 10,000 ADT	-1
Median	No	No median present	1
	Yes	Must be glare blocking	0
Intersection/ Interchange Density	High	< 1.5 mi between intersections (2.5 km)	1
	Moderate	1.5–4 mi (2.5–6.5 km) between intersections	0
	Low	> 4 mi (6.5 km) between intersections	-1
Ambient Luminance	High	LZ3 and LZ4	1
	Moderate	LZ2	0
	Low	LZ1	-1
Guidance	Good	> 100 mcd/m ² lx	0
	Poor	< 100 mcd/m ² lx	0.5

Class	Average Luminance (cd/m ²)	Maximum Uniformity Ratio (avg/min)	Maximum Uniformity Ratio (max/min)	Veiling Luminance Ratio
H1	1	3	5	0.3
H2	0.8	3.5	6	0.3
H3	0.6	3.5	6	0.3
H4	0.4	3.5	6	0.3

Figure 11. Excerpt from FHWA Adaptive Lighting Report - Classification Method for Highways (S class = 5- weighting factors)

Use of Surround Ratio

Research performed for this project shows that detection distances are increased when lighting is used in areas adjacent to the roadway. Therefore, consider SR as a criterion. The criteria for SR should be 0.8, higher than that used by CIE, and be the ratio of the average illuminance of an area adjacent to the travel way of 12 feet (ft) (3.6 meters [m]) and average illuminance of the lane of the travel way adjacent to it. For example, using the configuration shown in Figure 20, the average illumination of the area shown as shoulder divided by the average illumination of the adjacent lane should be 0.8 or greater.

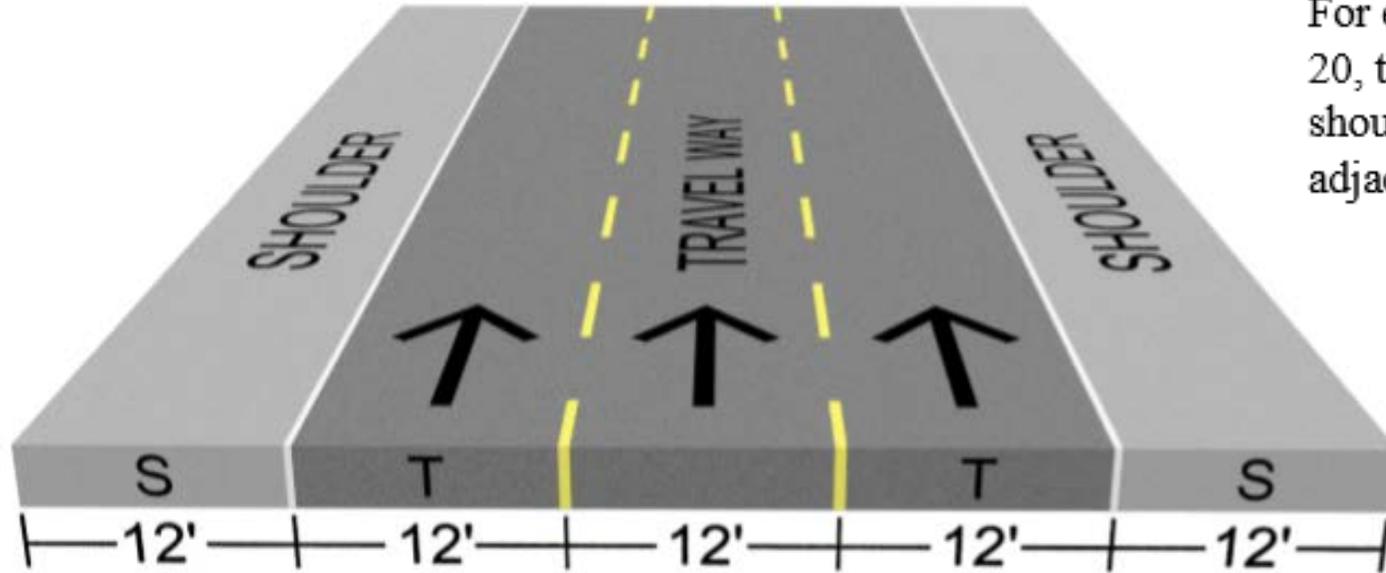
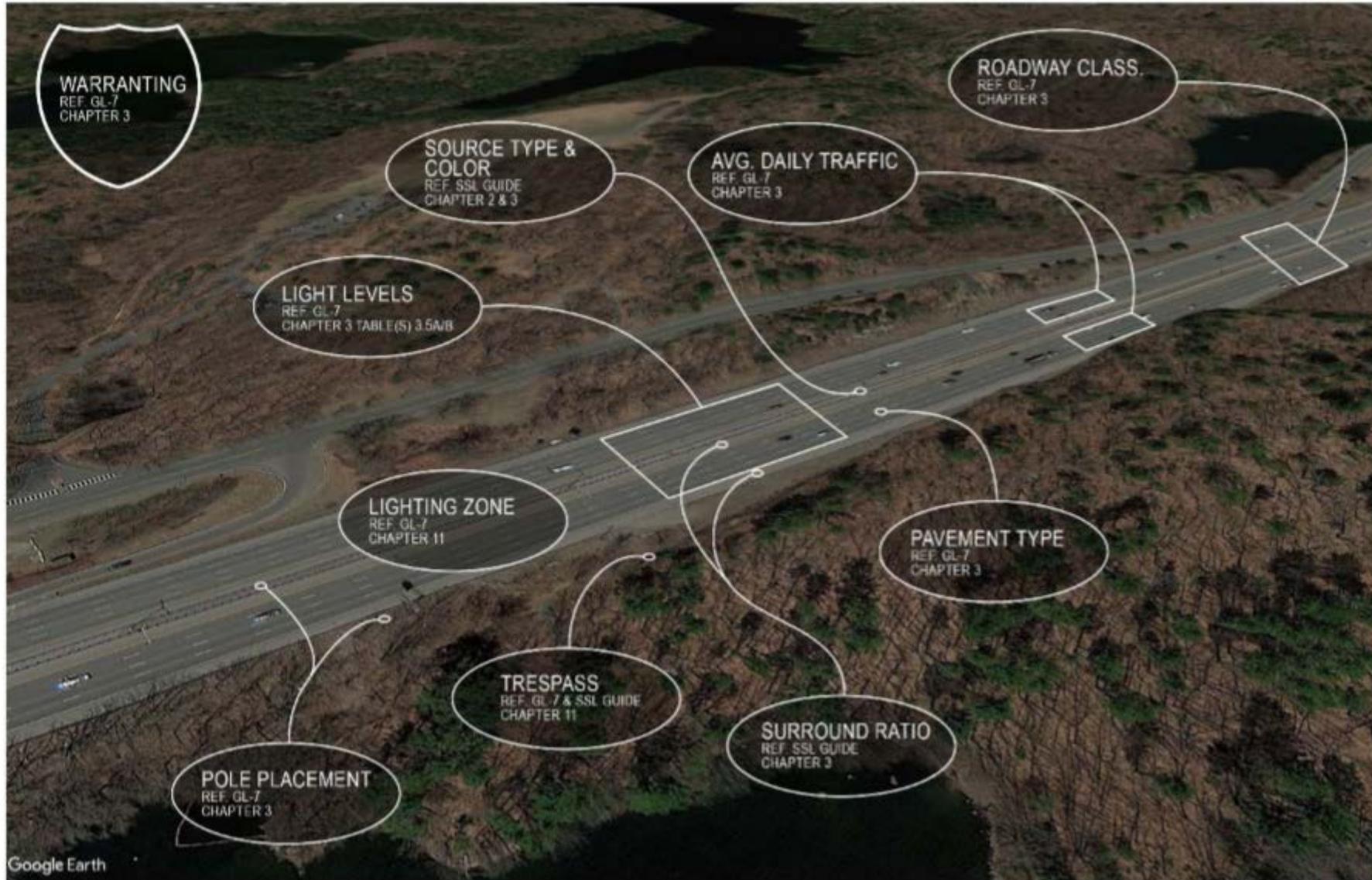


Figure 20. Example Diagram for Applying Surround Ratio (SR= Average Illumination in Shoulder Area S / Average illumination in Travel Way T)

Design Examples



Step 2a - Determine Illuminance or Luminance Design

Example Result: Both Illuminance and Luminance will be used for freeway calculations.

Step 2b – Determine the road surface classification to properly design a roadway lighting system.

Example Result: Asphalt, Class R3

Table 3-1. Road Surface Classifications

Class	Q_o^a	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 minimum 60 percent gravel [size greater than 0.4 in. (1 cm)]. 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

Example Result: Warranting condition, sections in and near cities where the current average daily traffic (ADT) is 30,000 or greater, CFL-1. Warranting conditions can also be applied from the SSL Guideline for crash modification factors. Lighting was decided to be added.

Case	Warranting Conditions
CFL-1	Sections in and near cities where the current average daily traffic (ADT) is 30,000 or greater.
CFL-2	Sections where three or more successive interchanges are located with an average spacing of 1.5 mi or less, and adjacent areas outside the right-of-way are substantially urban in character.
CFL-3	<p>Sections of two miles or more passing through a substantially developed suburban or urban area in which one or more of the following conditions exist:</p> <ul style="list-style-type: none"> a) local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the freeway b) the freeway passes through a series of developments—such as residential, commercial, industrial and civic areas, colleges, parks, terminals, etc. that include lighted roads, streets, parking areas, yards, etc.—that are lighted c) separate cross streets, both with and without connecting ramps, occur with an average spacing of 0.5 mi or less, some of which are lighted as part of the local street system d) the freeway cross section elements, such as median and borders, are substantially reduced in width below desirable sections used in relatively open country.
CFL-4	Sections where the ratio of nighttime to daytime crash rate is at least 2.0 times the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate. Where crash data are not available, rate comparison may be used as a general guideline for crash severity.

Example Result: Using Table 3-5a for Interstate and other freeways

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

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

^a See AASHTO's *A Policy on Geometric Design of Highways and Streets (1)* for roadway and walkway classifications.

^b Higher uniformity ratios are acceptable for elevated ramps near high-mast poles.

^c L_{max} refers to the maximum point along the pavement, not the maximum in lamp life. The Maintenance Factor applies to both the L_{avg} term and the L_{max} term.

^d Use 0.6 for R1 surface.

^e Assumes a separate facility. For Pedestrian Ways and Bicycle Ways adjacent to roadway, use roadway design values. Use R3 requirements for walkway or bikeway surface materials other than the pavement types shown. Other design guidelines such as IES or CIE may be used for pedestrian ways and bikeways when deemed appropriate.

Notes:

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

Step 2g - Consider SR as part of design

Example Results: Surround ratio will be included $SR = 0.8$

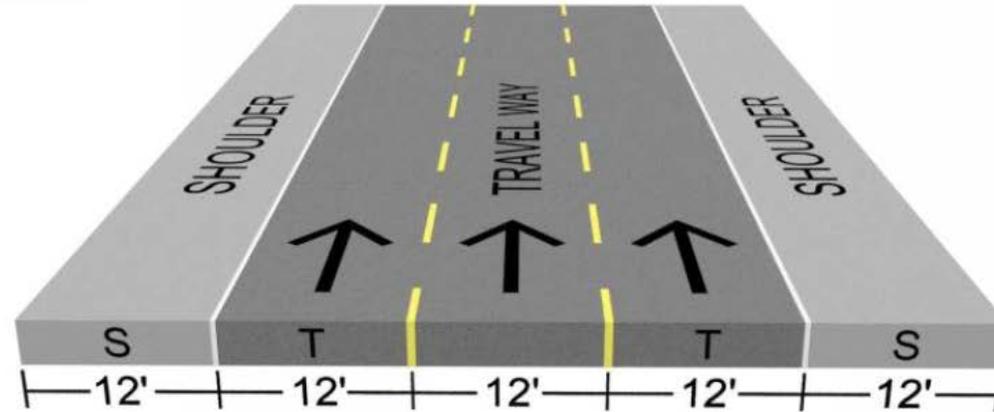


Figure 22 - Example Diagram for Applying Surround Ratio

Step 3 – Maintenance Considerations in Roadway Lighting Design

Step 3a – Select appropriate Maintenance Factors for Luminaire Dirt Depreciation, Lamp Lumen Depreciation, and Luminaire Ambient Temperature Factor to apply a total Light Loss Factor to the lighting design.

Example Results: SSL specific Maintenance Factors LDD: 0.9, LLD: 0.82, LATF:1 = LLF .738

Example Result: LZ2

LZ0: No ambient lighting—Areas where the natural environment will be seriously and adversely affected by lighting.

LZ1: Low ambient lighting—Areas where lighting might adversely affect flora and fauna or disturb the character of the area.

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, security, or convenience but is not necessarily uniform or continuous. After curfew, lighting may be extinguished or 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 is often uniform or continuous, or both. After curfew, lighting may be reduced as activity levels decline.

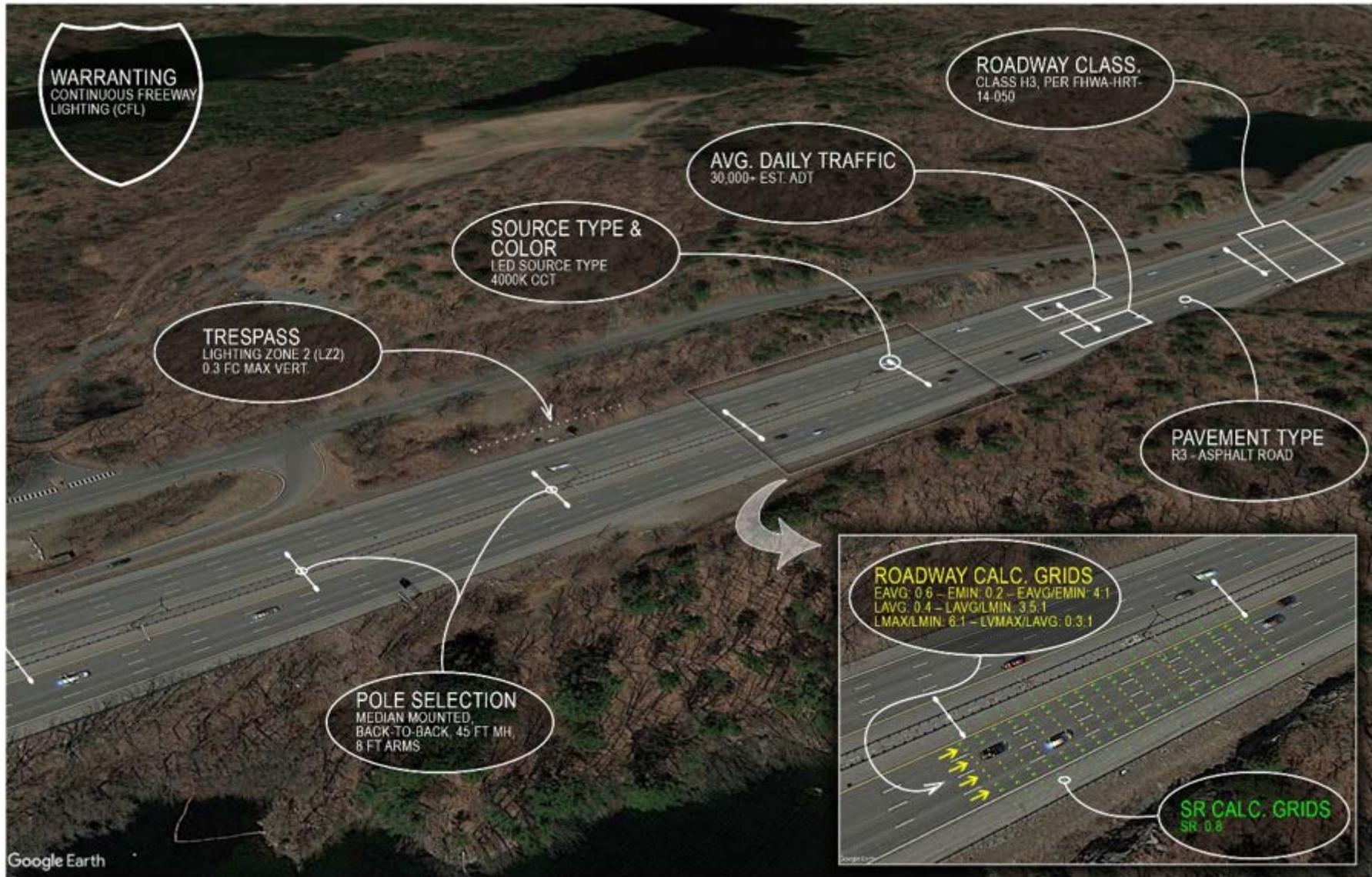
LZ4: High ambient lighting—Areas of human activity where the vision of human residents and users is adapted to high light levels. Lighting is generally considered necessary for safety, security, or convenience and is mostly uniform or continuous, or both. After curfew, lighting may be reduced in some areas as activity levels decline.

Step 4b - Determine mitigation of sky glow and trespass

Example Result: Maximum Illuminance 0.3 fc

Table 11-1. Maximum Values of Lighting Zones

Lighting Zone LZ0	Lighting Zone LZ1	Lighting Zone LZ2	Lighting Zone LZ3	Lighting Zone LZ4
0.05 fc (0.5 lux)	0.1 fc (1.0 lux)	0.3 fc (3.0 lux)	0.8 fc (8.0 lux)	1.5 fc (15.0 lux)



WARRANTING
CONTINUOUS FREEWAY
LIGHTING (CFL)

ROADWAY CLASS.
CLASS H3, PER FHWA-HRT-
14-050

AVG. DAILY TRAFFIC
30,000+ EST. ADT

**SOURCE TYPE &
COLOR**
LED SOURCE TYPE
4000K CCT

TRESPASS
LIGHTING ZONE 2 (LZ2)
0.3 FC MAX VERT.

PAVEMENT TYPE
R3 - ASPHALT ROAD

POLE SELECTION
MEDIAN MOUNTED,
BACK-TO-BACK, 45 FT MH,
8 FT ARMS

ROADWAY CALC. GRIDS
EAVG: 0.6 - EMIN: 0.2 - EAVG/EMIN: 4:1
LAVG: 0.4 - LAVG/LMIN: 3.5:1
LMAX/LMIN: 6:1 - LVMAX/LAVG: 0.3:1

SR CALC. GRIDS
SR 0.8



WARRANTING
REF. SSL GUIDE
CHAPTER 3

SOURCE TYPE & COLOR
REF. SSL GUIDE
CHAPTER 2 & 3

AVG. DAILY TRAFFIC
REF. GL-7
CHAPTER 3

ROADWAY CLASS
REF. GL-7
CHAPTER 3

LIGHT LEVELS
REF. GL-7
CHAPTER 3 TABLE(S) 3.5A/B

LIGHTING ZONE
REF. GL-7
CHAPTER 11

PAVEMENT TYPE
REF. GL-7
CHAPTER 3

TRESPASS
REF. GL-7 & SSL GUIDE
CHAPTER 11

POLE PLACEMENT
REF. GL-7
CHAPTER 3

SURROUND RATIO
REF. SSL GUIDE
CHAPTER 3

SIDEWALKS
REF. SSL GUIDE
CHAPTER 3



WARRANTING
CMF 0.72

ROADWAY CLASS
CLASS S3 PER FHWA-HRT-14-050

AVG. DAILY TRAFFIC
15,000+ EST. ADT

SOURCE TYPE & COLOR
LED SOURCE TYPE
4000K CCT

TRESPASS
LIGHTING ZONE 3 (LZ3)
0.8 FC MAX VERT.

PAVEMENT TYPE
R3 - ASPHALT ROAD

POLE SELECTION
SHOULDER MOUNTED
SINGLE ARRANGEMENT
35 FT MH, 6 FT ARMS

ROADWAY CALC. GRIDS
EAVG: 0.7 - EAVG/EMIN: 6:1
LAVG: 0.5 - LAVG/LMIN: 6:1
LMAX/LMIN: 10:1 - LVMAX/LAVG: 0.4:1

SIDEWALK GRIDS
EAVG: 0.8 - EAVG/EMIN: 4:1

SR ON S GRIDS
0.8

Tunnels and Underpasses

Key Issues for LED in Tunnels

- Use an adaptive control system with luminance sensors outside the tunnel for better control of required threshold and transition zone lighting.
- Evaluate source CCT and potential benefits.
- Evaluate tunnel luminaires and operating characteristics relating to temperature and expected environment of the installed luminaires.

Location Queen Creek Tunnel near Superior, Arizona (US 60, MP 228.4)

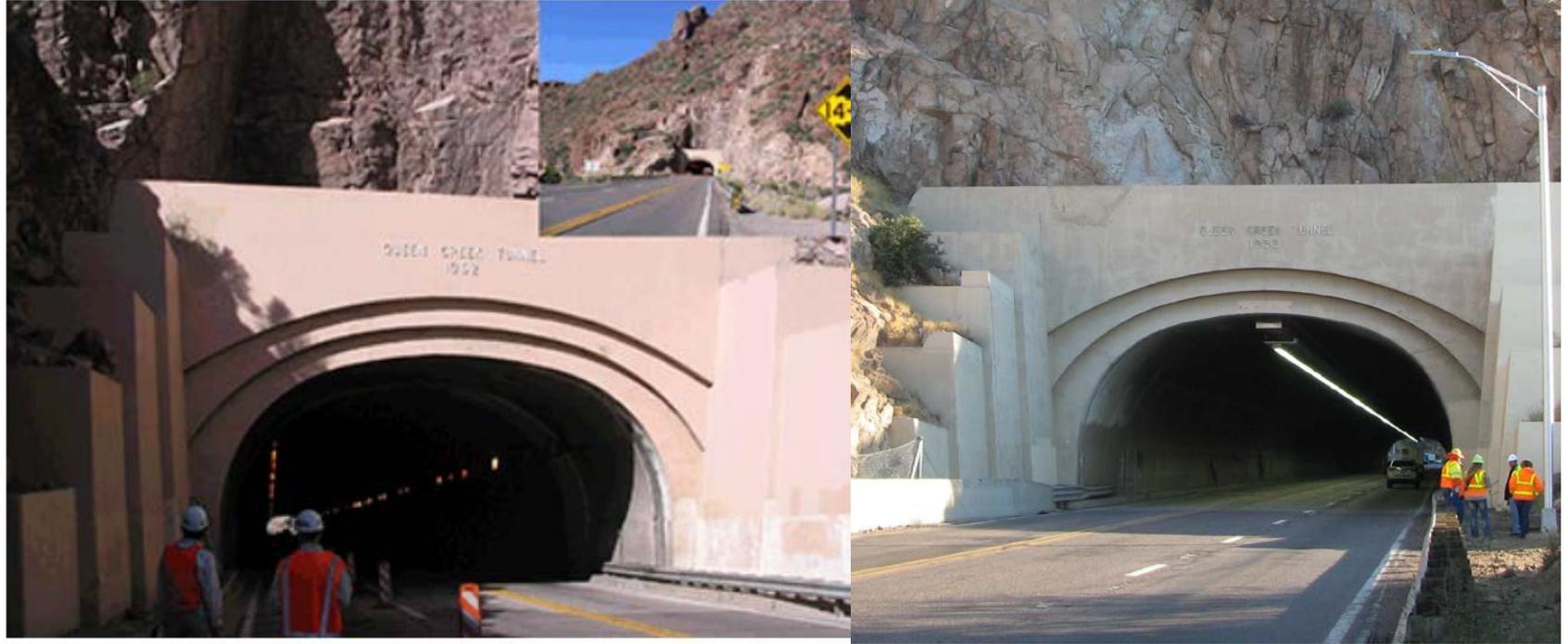
Award Recipient Arizona Department of Transportation

Innovation Light Emitting Diode (LED) Tunnel Lighting

Award Fiscal Year 2014

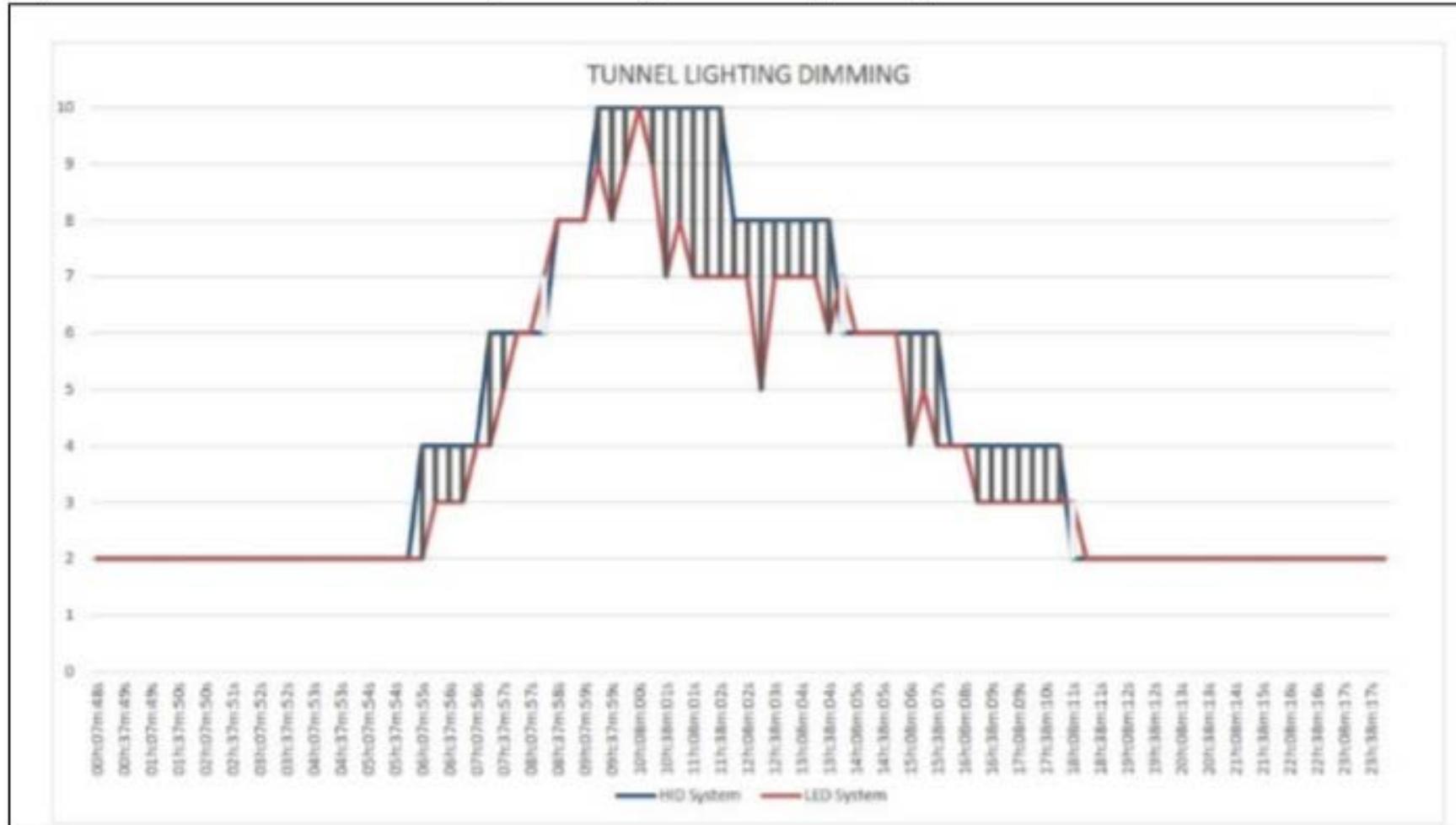
Project Aspect Construction

Description The Arizona DOT (ADOT) will install a new light-emitting diode (LED) lighting system in the Queen Creek Tunnel near Superior, Arizona to provide improved highway safety and efficiency along US 60. The adaptive control system will allow for status monitoring of luminaires, assisting in evaluating when and how much maintenance is necessary within the tunnel, saving time, money, and traffic disruptions.



Controls

Figure 26. Differences in Step Switching vs an Adaptive System

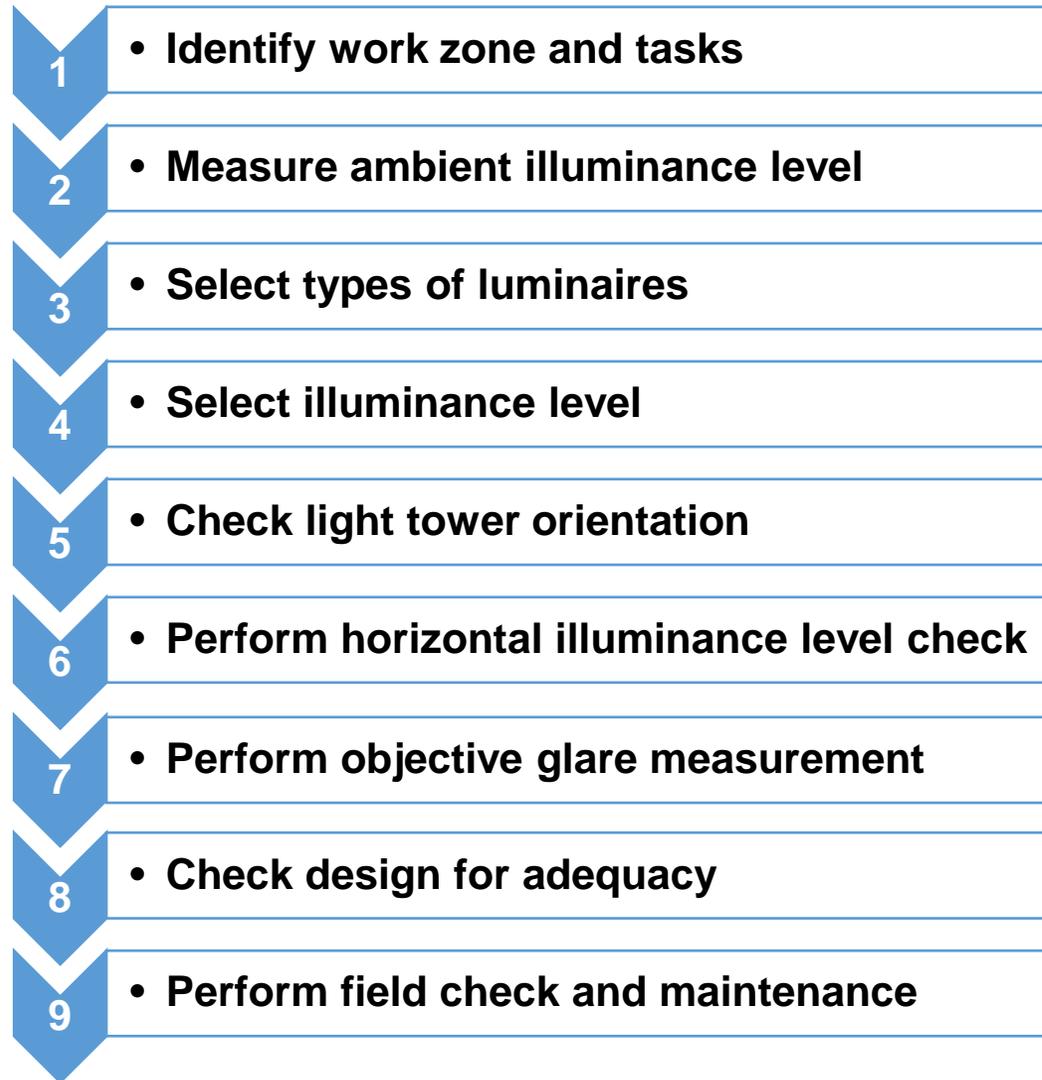


Work Zone and Temporary Lighting

Key Issues for Work Zone Lighting with LED Light Fixtures

- Base work zone lighting on the ambient environment in which it is used and illuminate the roadway in the work zone to AASHTO lighting requirements.
- Limit glare in work zones by proper selection of equipment and its use. Use the glare limits included in this document to assess when work zone glare would become an issue.

Work Zone Lighting Plan modified from ATSSA



Horizontal Light Levels in Work Zones – NCHRP 498

Category	Recommended for
Category I 54 lx (5-foot candles)	<ul style="list-style-type: none">• General illumination• Crew movement• Low accuracy tasks<ul style="list-style-type: none">• involving slow-moving equipment• large-sized objects to be seen.
Category II 108 lx (10-foot candles)	<ul style="list-style-type: none">• Illumination on and around construction equipment• Visual tasks associated<ul style="list-style-type: none">• equipment• resurfacing
Category III 216 lx (20-foot candles)	<ul style="list-style-type: none">• Tasks• Higher visual difficulty• Increased attention from the observer• Crack filling, critical connections, maintenance of electrical devices, or moving machinery.

Common Portable Light Tower Types



Metal Halide

- Widely Used
- Can be aimed
- Offers excellent visibility
- Could cause glare if aimed poorly



Light Emitting Diode

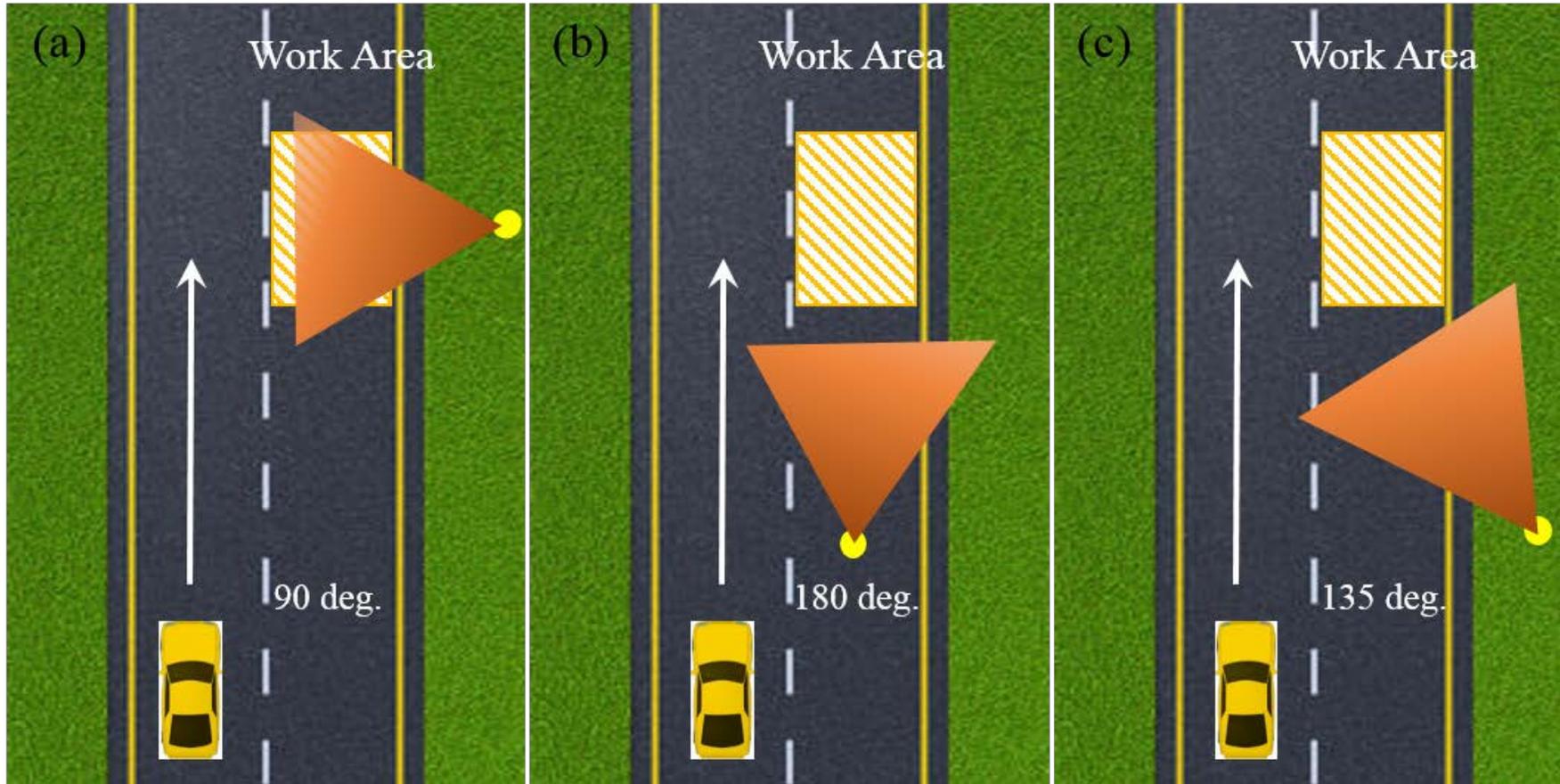
- New
- Can be aimed
- Potential to dim
- Could illuminate without light trespass
- Lowest glare
- Visibility lower than metal halide and balloon



Balloon

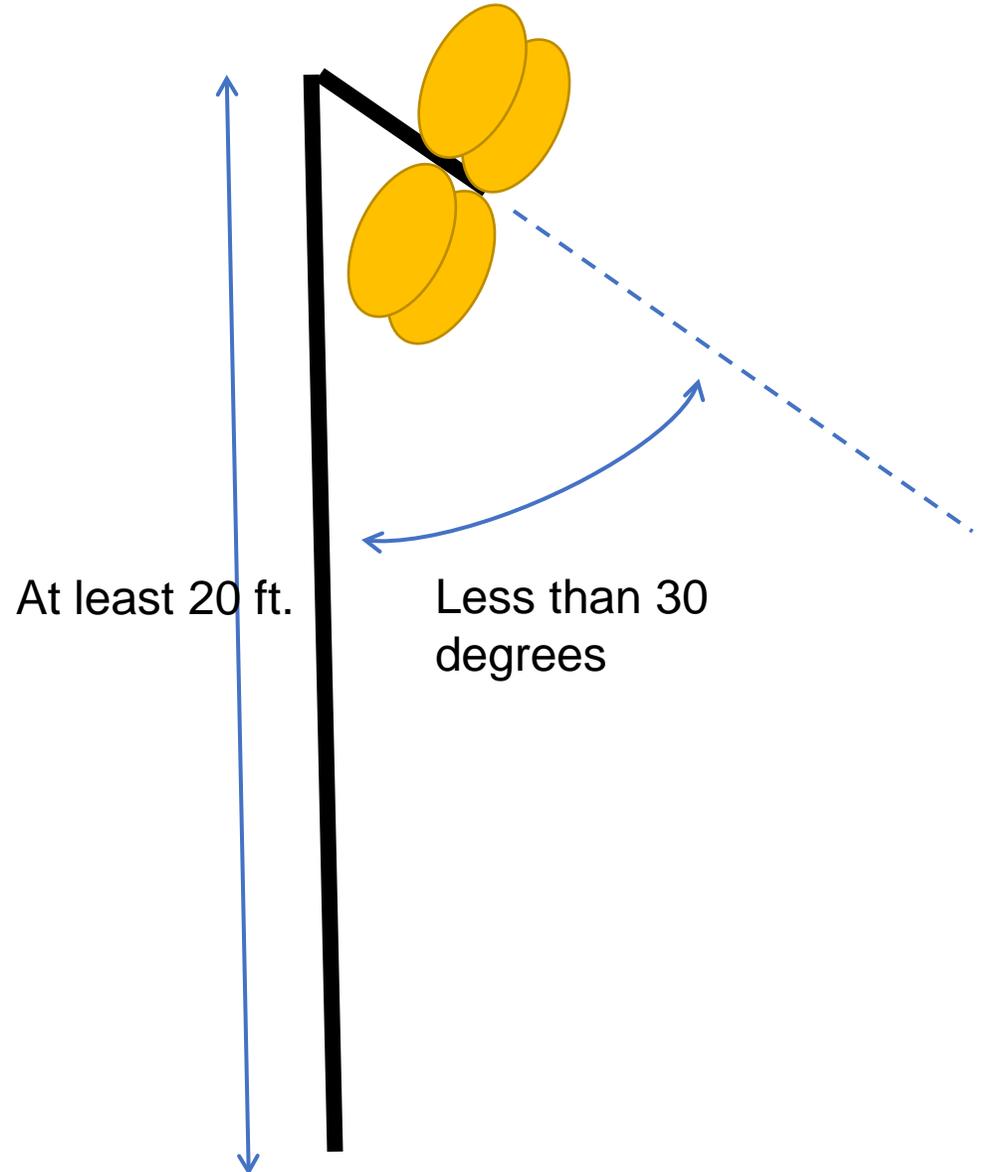
- New
- Aiming is not required
- Potential for lower glare
- Offers excellent visibility
- Could be susceptible to wind

Portable Light Towers Orientation

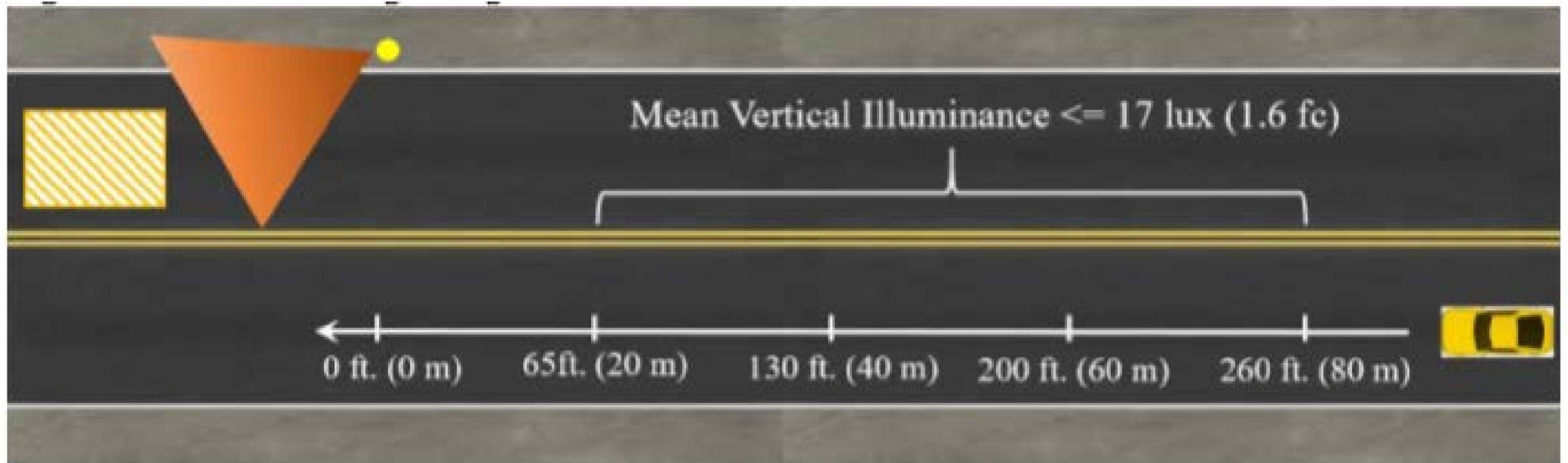
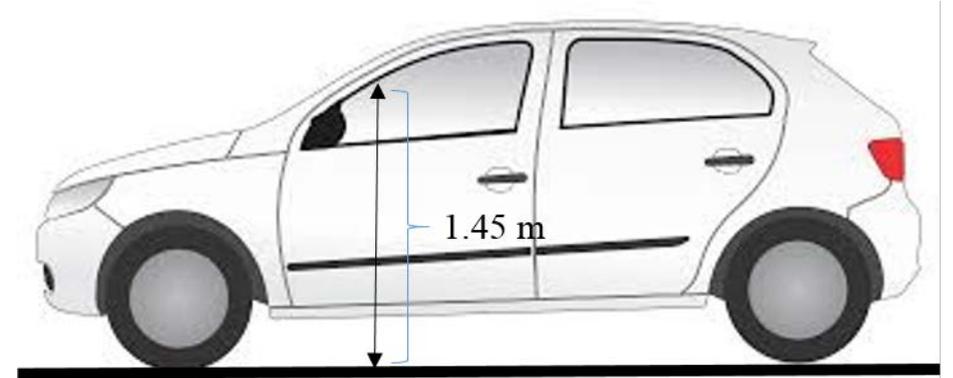


Mounting Heights

- Light Towers that cannot be aimed – Balloon Light Towers
 - At least 20 ft.
 - At distance of 10 ft. from roadway (in the shoulder or beyond the guardrail)
 - Increase offset distance if light output greater than 440000 lumens
- Light Towers that can be aimed
 - At least 20 ft.
 - Angle between beam axis and vertical is less than 30 degrees



Lighting Limits



Maximum vertical allowed in the critical range = 50 lux

Electrical System Considerations

Key Issues

- Assess inrush starting currents during design considering all expected overcurrent devices.
- Consider over-voltages for solid state components.
- Assess allowable voltage drop against local requirements and benefit/cost.
- Consider an adaptive control system to control and monitor electrical conditions of the lighting system.
- Consider adding a surge protection device in the pole handhole.
- Consider additional TVSS at the electrical service panels feeding the lighting system.

Inrush Current

- LED luminaires have a significant inrush current upon starting.
- Depending on the product, inrush current can be more than 100 times the luminaire input current for a very short duration.
- Consider slow blow fuses in pole handholes or time delay circuit breakers
- Obtain in-rush info from luminaire supplier and match breaker and /or fuse trip rating

Time in Seconds

Time Band Setting

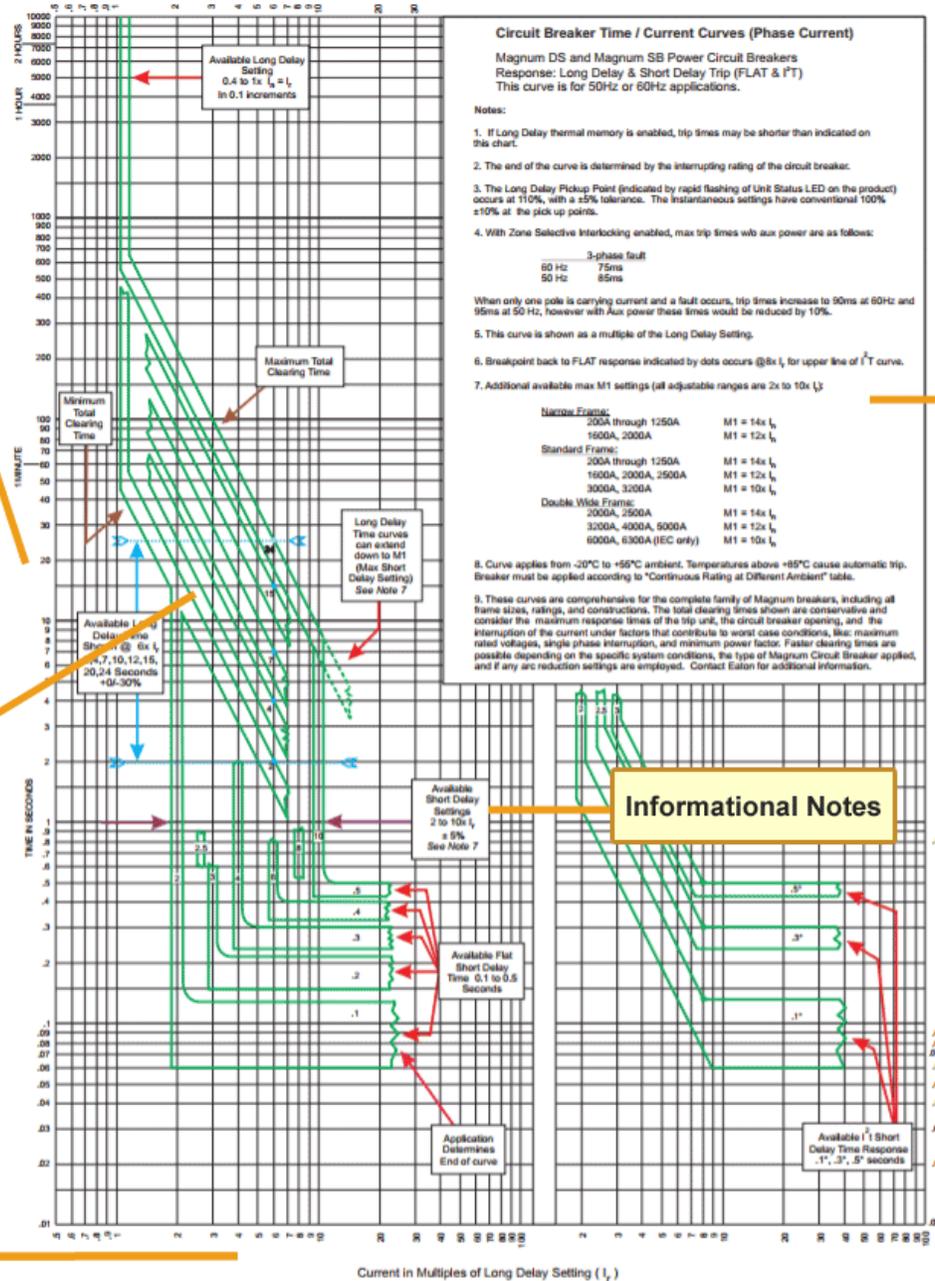
Current Multiple

Curve Type

Information Box

Informational Notes

Curve Number



Surge Protection

WHY?

- Protect critical and sensitive equipment (electronics)
- Increase equipment longevity
- Reduce downtime

HOW

This is achieved by diverting and limiting damaging transient voltages and currents

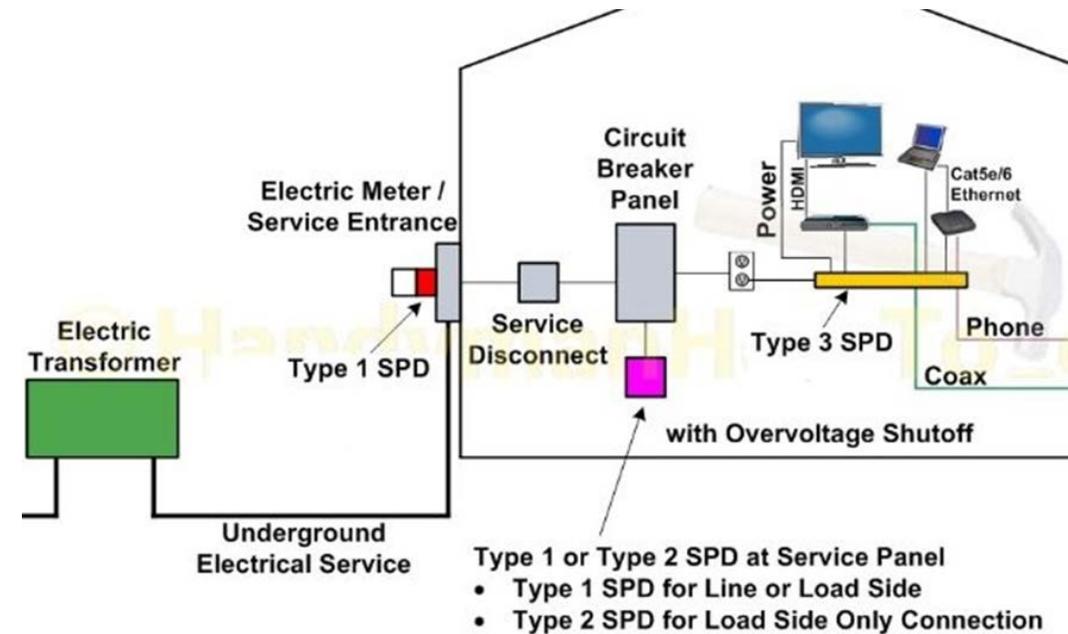


Surge Protection Devices (SPD)

- Such a device should be approved to:
 - *UL 96A, Standard for Installation Requirements for Lightning Protection Systems (see UL 1449, Standard for Surge Protective Devices, 4th Edition)*
 - *IEEE C62.45-2002, IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and less) AC Power Circuits Standards for Surge Protective Devices*
- Recommend a surge capacity of at least 50 kA with a short-circuit current rating of 200 kA.
- The surge protection device must be installed within 6 inches of the breakers within the panel, and wiring must run in straight paths with minimal bends.

UL1449

- The SPD type refers to the location where the SPD can be used
- *Type 1 – before the service disconnect overcurrent device*
- *Type 2 – after service disconnect overcurrent device*
- *Type 3 – a minimum 10m (30 ft) of conductor between service disconnect overcurrent device and SPD*



Operations and Maintenance

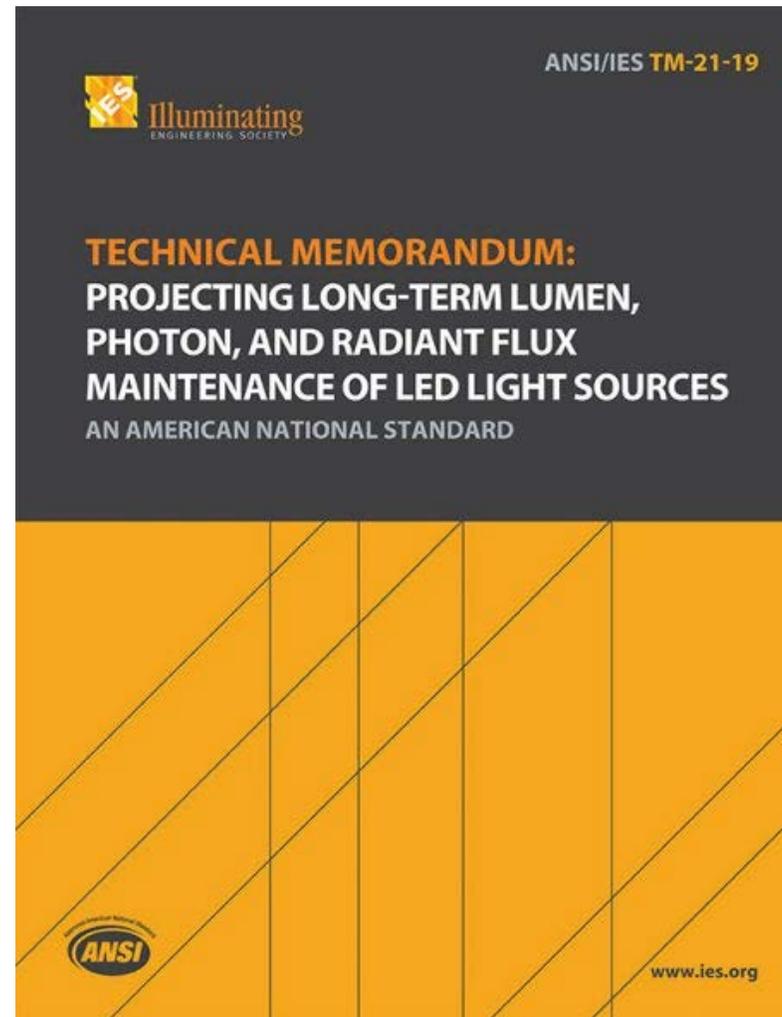
Key Issues

- Calculate light loss factors on a luminaire's expected service life determined by the DOT or agency installing the lighting system.
- Consider an adaptive lighting system as part of an overall control and operation and maintenance cost reduction tool as well as an asset management tool.
- Use benefit/cost analysis to help determine the best design approach for a proposed lighting system.

Light Loss Factor

- Because an LED luminaire degrades differently than a HID luminaire and the LED will likely continue operating but at a steadily decreasing lumen output, therefore a light loss factor light loss factor (LLF) is applied:
- $LLF = LLD \times LDD \times LATF$ where
 - *LLD = lamp lumen depreciation,*
 - *LDD = luminaire dirt depreciation, and*
 - *LATF = luminaire ambient temperature factor.*
- Design should be based end of life (say 20 years - 88,000 hours)

Lamp Lumen Depreciation (LLD) – IES TM-21



Luminaire Dirt Depreciation (LDD)

- IES RES-1-16 Measure and Report Luminaire Dirt Depreciation (LDD) in LED Luminaires for Street and Roadway Lighting Applications.
- This document is available as a free download from the IES at:
<http://media.ies.org/docs/research/IES-RES-1-16.pdf> .
- This report is the result of a project commissioned by the IES to quantify the impact of dirt accumulation on the light output of LED luminaires.
- Glass is easier to clean (example of optics which is harder clean on next side)

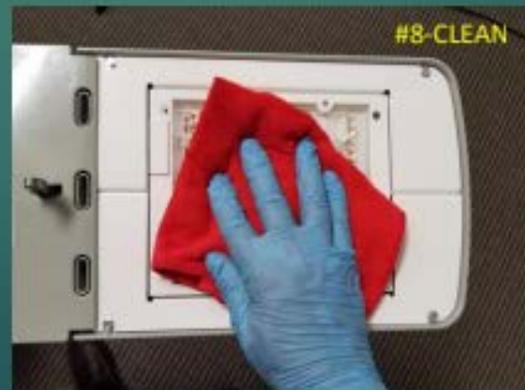
Luminaire Optical System	Dirt Depreciation Rate (per Year)	10-Year Cumulative Dirt Depreciation (LDD)	Impact to LLF
Flat Glass (protecting individual LED optics)	+1 %	10 %	
Exposed individual LED optics	+3 %	30 %	20% decrease



Cleaning Example

Steps for Cleaning Luminaire:

- ▶ Using a soft bristle brush, lightly brush away any debris that may be lying on the optic lens
- ▶ Spray the solution directly onto the scratch-free cloth while making sure the towel is damp.
- ▶ **Note:** Do not spray the solution directly onto the luminaire or lens at any time
- ▶ Using the damp towel, clean the exterior surface of the optic lens
- ▶ Use the soft brush in conjunction with the towel to clean the optic lens in detail



Luminaire Ambient Temperature Factor (LATF)

- The luminaire ambient temperature factor is based on the temperature testing of the luminaire at 25° C.
- Given average nighttime ambient temperatures vary a LATF can be applied.
- Typically allow 1% for every 5° C above or below 25° C.

LED Conversions – Lessons Learned

- Luminaire distribution and optical performance varies greatly from supplier to supplier.
- Product vary greatly in quality (you get what you pay for).
- Failure rates low - under 1% a year (service calls reduced). Most suppliers offer 10-year warranty. We request catastrophic failure requirement.
- Mass conversions typically have 5 to 8-year payback with a good return on investment (over say 20 years).
- Some conversions have resulted in public complaints (as result of luminaire brightness). Glare shields offered are typically of poor design.
- As result of optical control LED luminaires can create a tunnel of light on the roadway with reduced lighting off the roadway (poor surround ratio)

LED Conversions

- Most roads are well over-lit with high pressure sodium (HPS) luminaires. This is a result of HPS poor uniformity ratio. Some roads are underlit as result of pole spacing.
- LED's with improved optics can reduce over lighting and improve uniformity.
- Colour of the light source (CCT) can improve object detection distances (4000K vs 3000K).
- Simple wattage conversions (ie; 100W HPS for 50W LED) are not recommended. Best results obtained by reviewing GIS data and calculating lighting to ensure proper light levels are met. ***A conversion is huge cost investment so important to do the analysis!***

Potential Health and Environmental Impacts

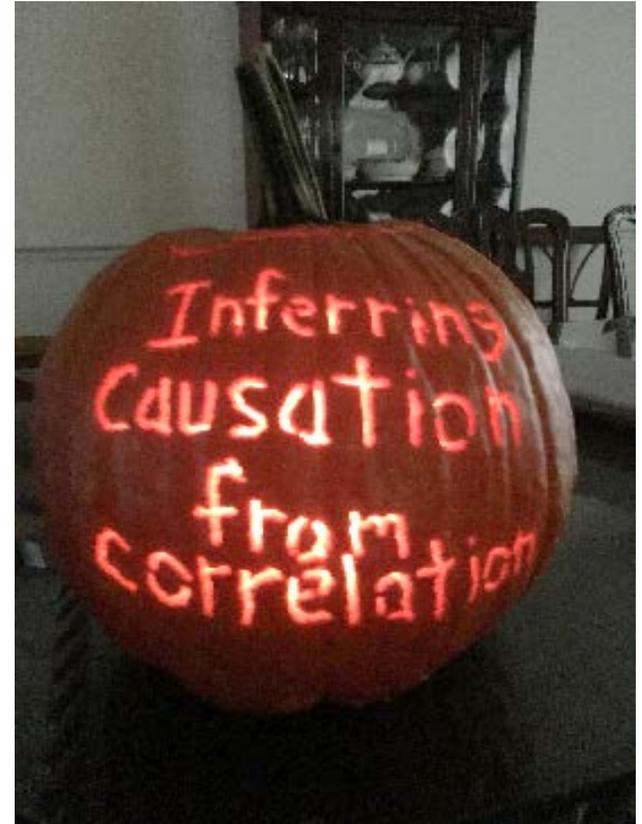
Key Issues

Much research has been done in the area of health and environmental impacts of lighting at night, and much more research continues. Although impacts and considerations may further develop as more data are analyzed, the following key items are recommended for design.

- Research does not show that a well-designed roadway lighting system using recommended light levels, meeting glare limits, and meeting light trespass values included in the AASHTO guide has any health effect using typical 3000K or 4000K LED sources.
- Although LED sources are likely to cause greater light scatter and sky glow, this is often offset by reduced total lumens and limited light trespass.
- Impacts on wildlife and plants vary by species. Research for some species is limited. For system design, lighting should be at the lowest level recommended, light trespass should be limited, and sensitive species in the area of the lighting system should be studied and mitigation, if any, should be documented if recommended (e.g., for turtle nesting grounds).

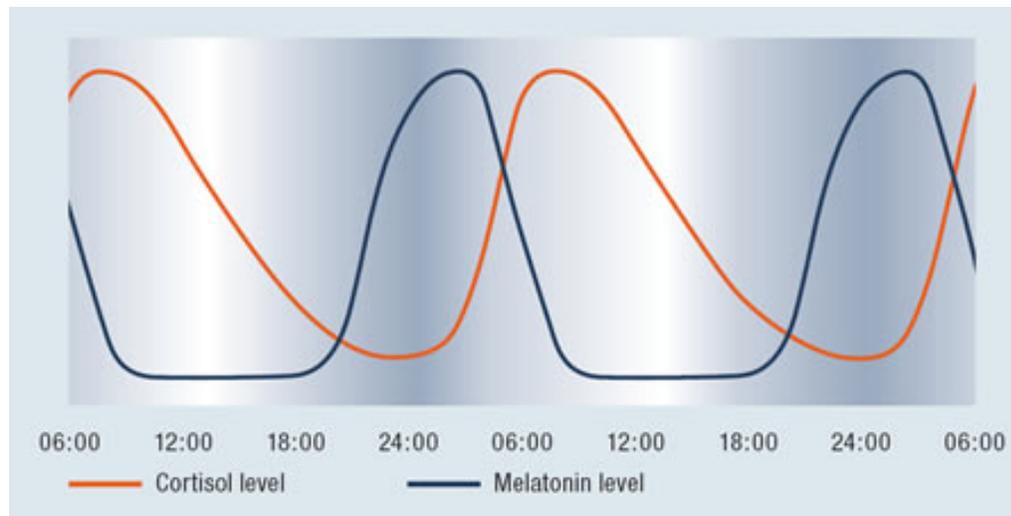
Consider the Negative Impacts of Roadway Lighting

- There is some evidence that Solid State Roadway lighting has:
 - Higher Health Impacts
 - Sleep and General Health
 - Sky glow
 - Impact on Flora and Fauna
 - Bugs, Buds, Bears and Bass



Health Impacts and Subjective Color

- Circadian rhythm, hormone secretion: The hormones responsible for the circadian rhythm in humans are melatonin, which is released in response to increasing levels of darkness and which promotes sleep, and cortisol, which is the biological opposite of melatonin and an indicator of the level of human activeness.

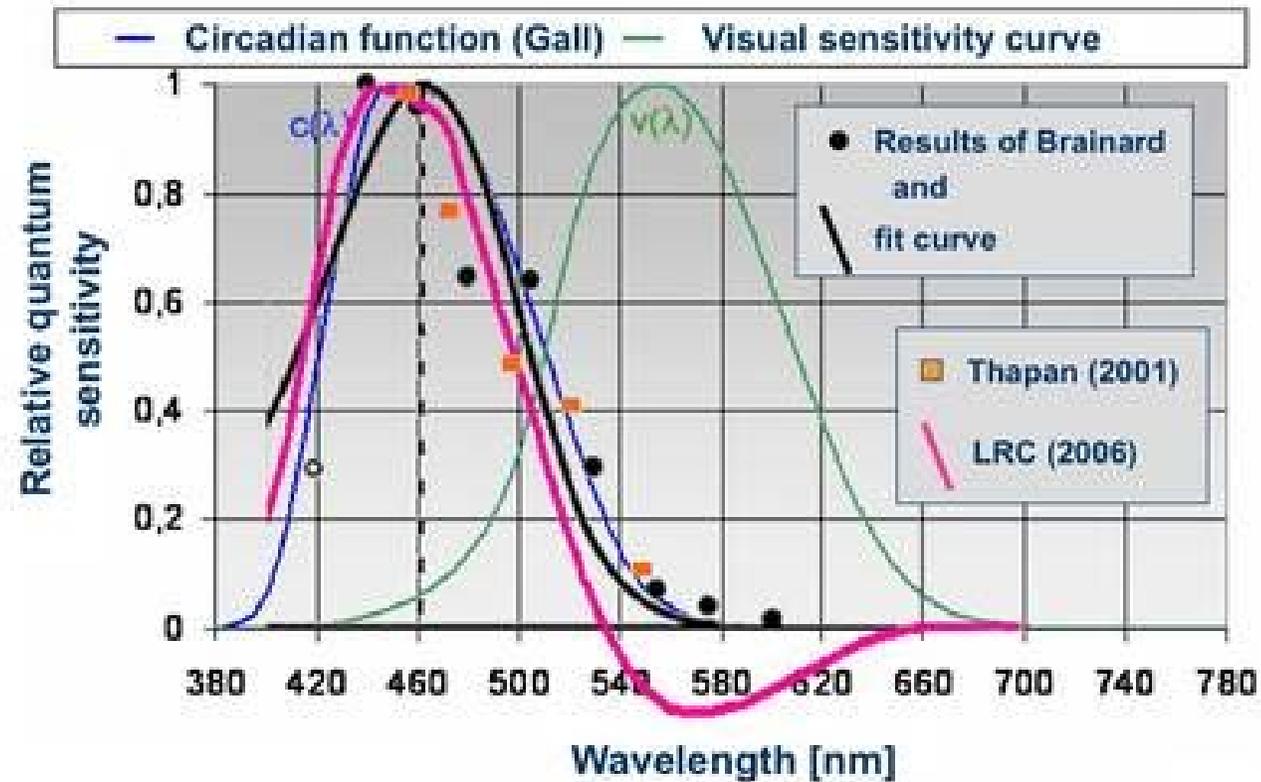


Light and Health

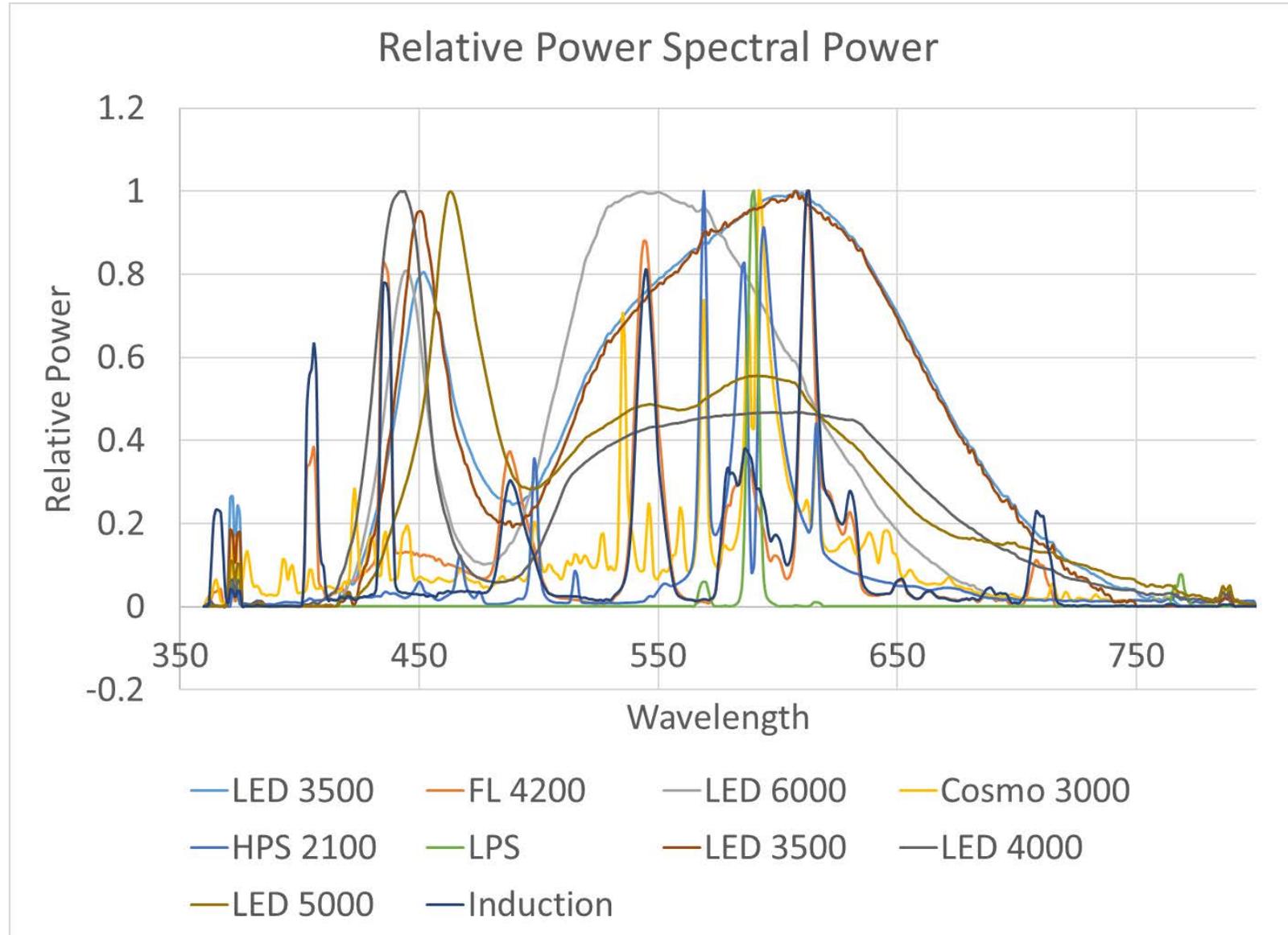
- Light Impacts the human
 - Melanopsin Response
 - Peaks around 480 nm
 - Impacts circadian rhythms, alertness
 - Sleeping etc.
 - Same in all mammals
- Interesting – Circadian Response
 - Light can keep you awake and alert
 - Is that good or bad for a driver?

Response to Spectral Content

Circadian action spectrum according to different sources



Comparison of SPDs





[Education](#) [Life & Career](#) [Practice Management](#) [Delivering Care](#) [About Us](#)

AMA Adopts Guidance to Reduce Harm from High Intensity Street Lights

For immediate release: Jun 14, 2016

AMA Report

- AMA has stated –
 - Use 3000k
 - Reduces Sky Glow
 - Reduces impact in Humans
 - Reduces impact on Migratory Animals
 - Reduces impact on Sea Turtles
 - Etc.
- Is it an unbiased recommendation?

Limitations in the Melanopic Research

- Performed at extremely high lighting levels as compared to roadways
- So what is the impact at street lighting levels?
 - The ratio would be the same
 - But does the magnitude make a difference?

Impacts (Dosage and Duration)

PNNL data

Combined subset* of readings taken by Naomi Miller, Bruce Kinzey, Rita Koltai, Terry McGowan, Derry Berrigan (*note: not all participants provided readings in every category; not all categories listed)	Reading (Lux)
Vert illuminance from window facing street light, if avail., interior lights off	
-- blinds open	≤0.1
-- blinds closed	0
Vert illuminance from window not facing street light	0-1
Kitchen	30-340
TV from 10 feet away, room light off	0-10
TV from 10 feet away, room light on	2-30
Phone/tablet at reading distance, other room lighting off	0-5
Phone/tablet at reading distance, room lighting on	15-45
Bedside lamp(s) reflecting on magazine/book page	35-350
Max horizontal illuminance at street light nadir - no vegetation interference	5-10
Max horizontal illuminance at street light nadir - some interference	0-5

Health Impacts and Subjective Color

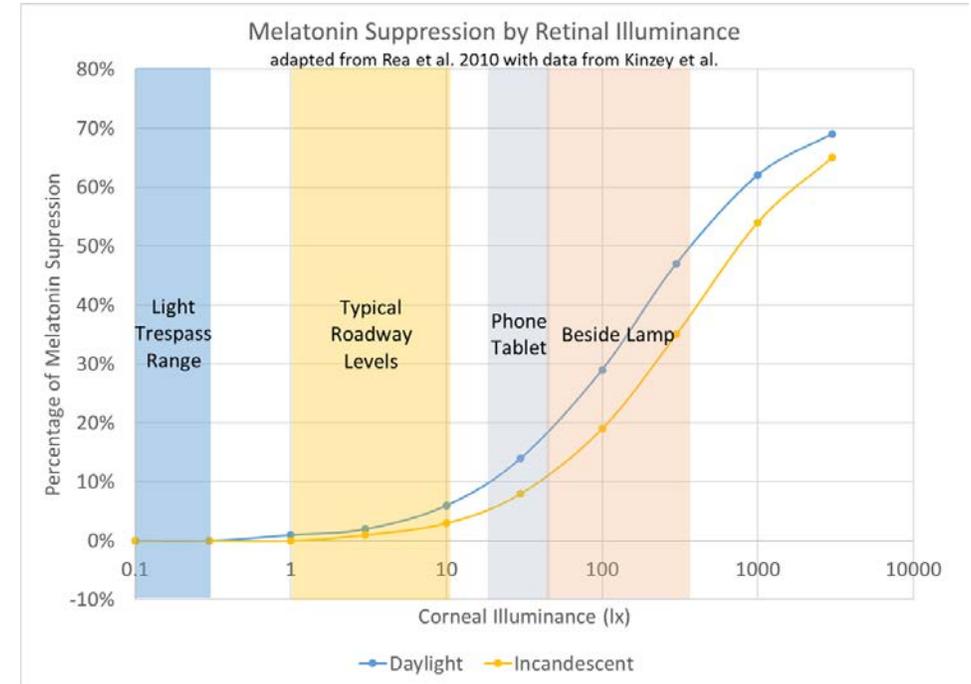
Table 2: Predicted Human Nocturnal Melatonin Suppression from Incandescent and Daylight Illumination [46] of Varying Corneal Illuminances and Durations, Based on Rea et al. [37]

<i>Incandescent</i>			
Illuminance (lx)	Melatonin suppression after 30 minutes	Melatonin suppression after 60 minutes	Melatonin suppression after 90 minutes
0.1	0%	0%	0%
0.3	0%	0%	0%
1	0%	1%	1%
3	1%	2%	2%
10	3%	5%	5%
30	8%	11%	13%
100	19%	25%	27%
300	35%	42%	45%
1000	54%	59%	60%
3000	65%	68%	69%

<i>Daylight</i>			
Illuminance (lx)	Melatonin suppression after 30 minutes	Melatonin suppression after 60 minutes	Melatonin suppression after 90 minutes
0.1	0%	0%	0%
0.3	0%	0%	1%
1	1%	1%	1%
3	2%	3%	4%
10	6%	9%	10%
30	14%	19%	20%
100	29%	36%	39%
300	47%	53%	55%
1000	62%	65%	66%
3000	69%	71%	71%

Potential Impact on Human Health

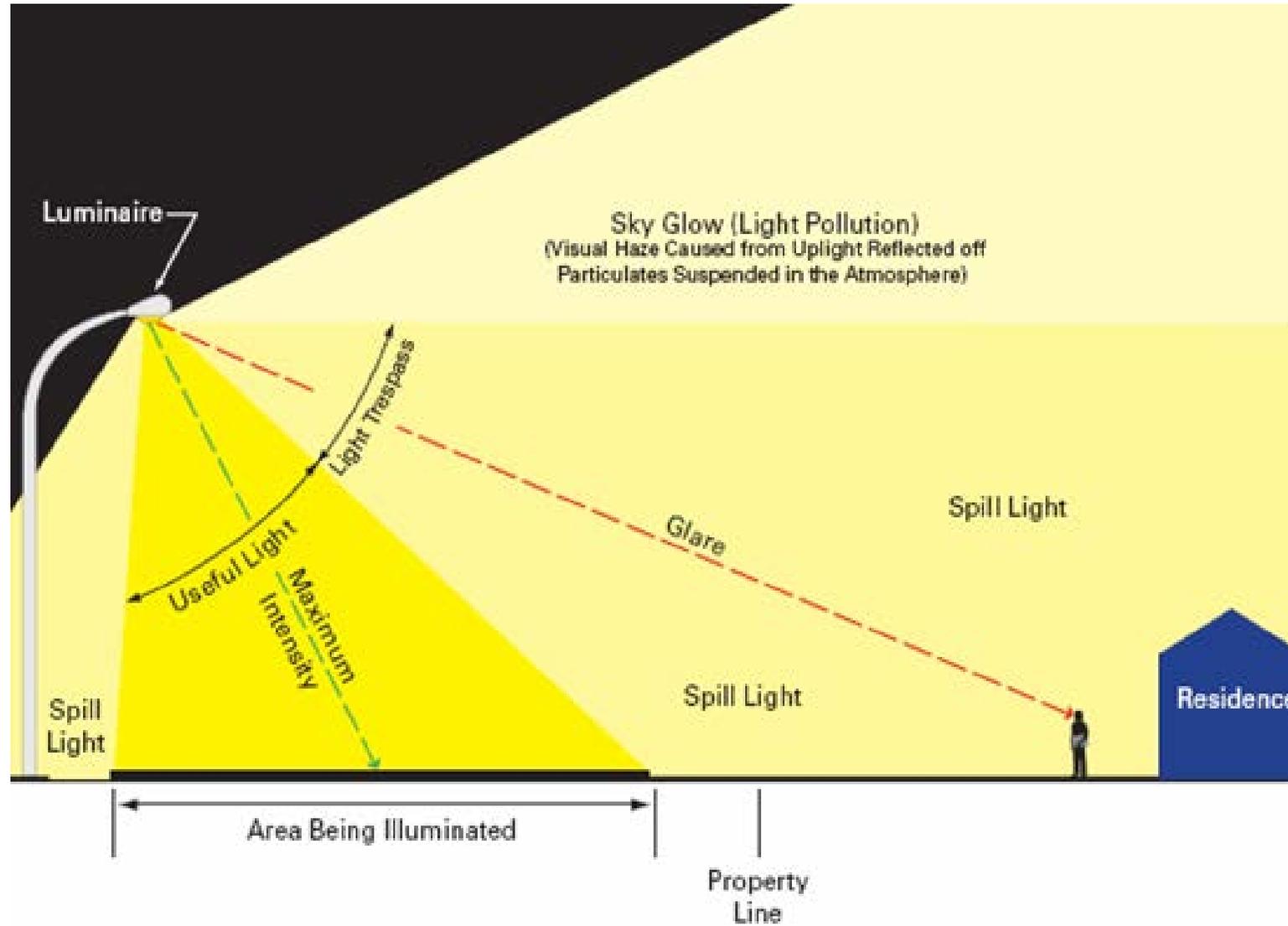
- Preliminary there may be an impact
 - Correlation but no causation
- Roadway Lighting Levels are below thresholds
 - Research is on-going



On-going Project

- DOE Sponsored project considering all roadway users
 - Pedestrians
 - Sleepers
 - Drivers
- Looking at the impact of lighting under 5 different light sources (5000K, 4000K, 3000K, 2200K, HPS) as compared to no lighting.
- Next Summer

Light Trespass



Sky Glow

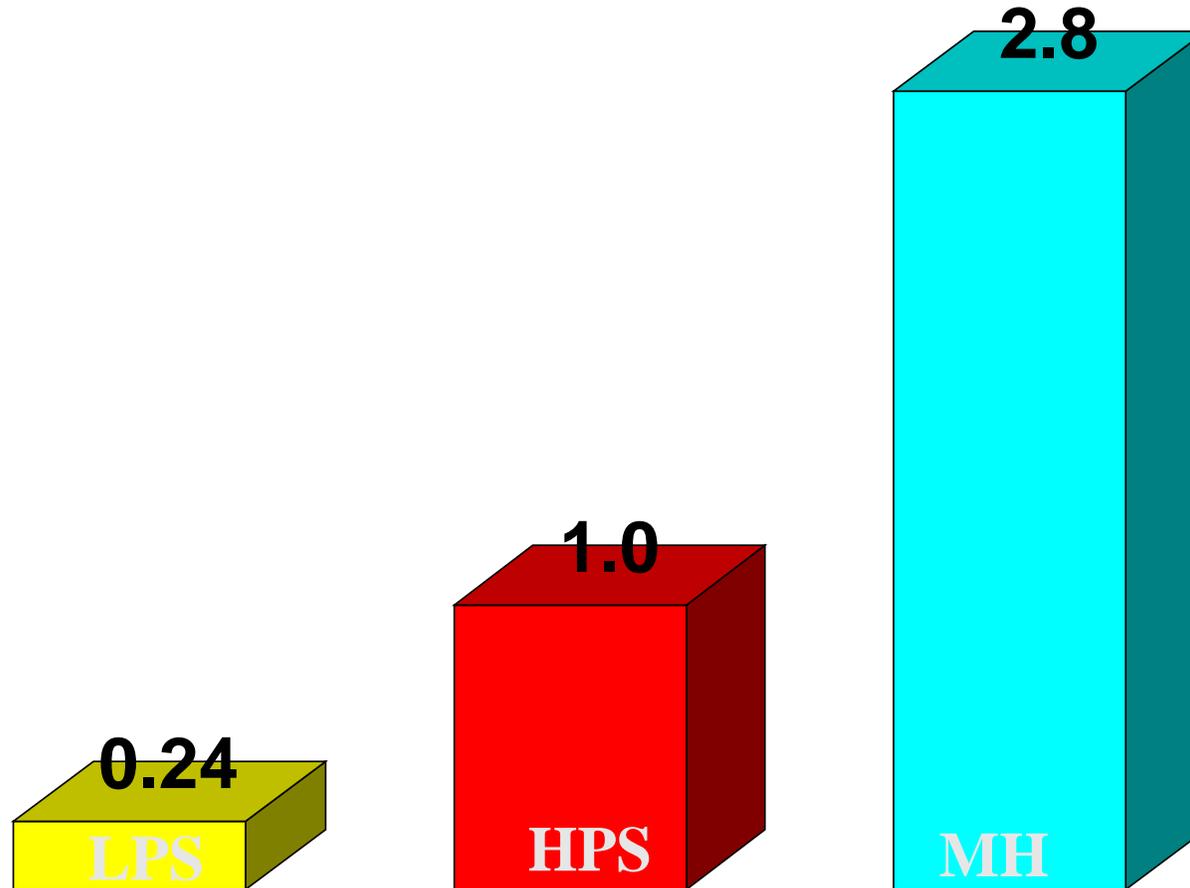
- Sky Glow
 - Blue Light Scatters more than amber light
- Rayleigh Scattering
 - Molecular Scattering – Molecules are about the same size as the wavelength for blue light
 - Blue Light Scatters more
 - Low angle blue content light is particularly bad
- Mie Scattering
 - Aerosol Scattering – Particles are much bigger than wavelength
 - Not Spectrally Selective

Sky Glow



View from Mt Wilson of light pollution in Los Angeles, before and after LED deployment

Relative Sky Glow

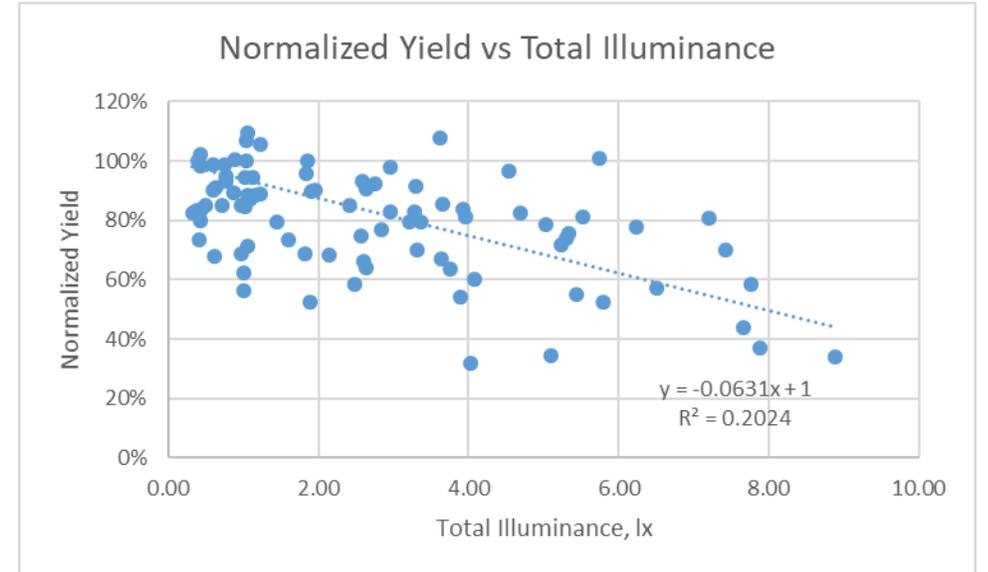
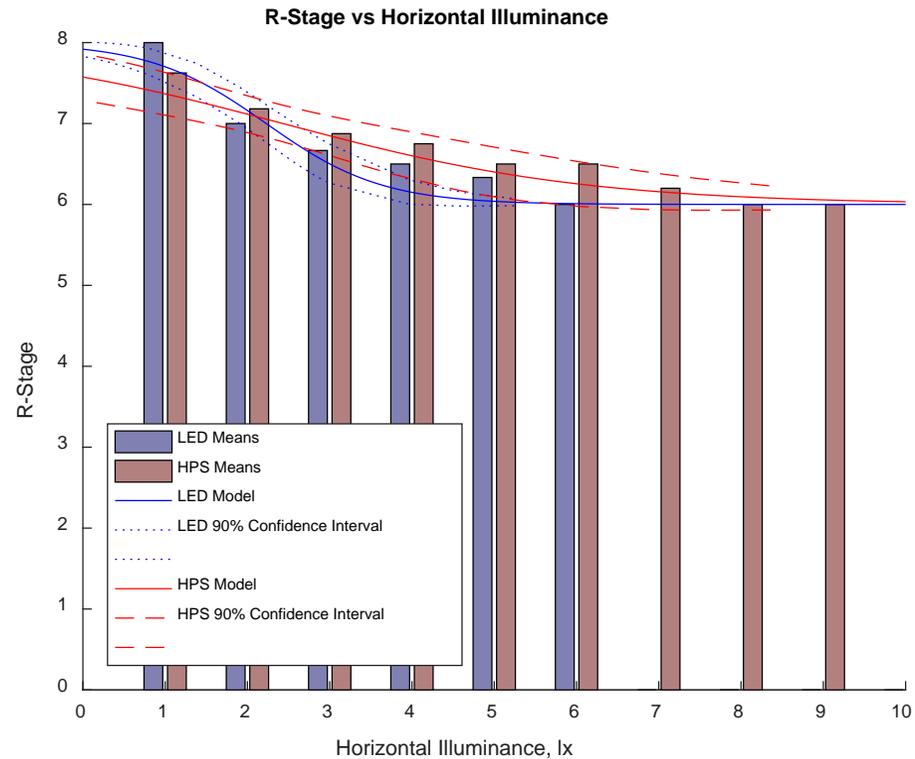


From CORM 2008, Luginbuhl, Keith & Knox

Impact on Soybean Growth

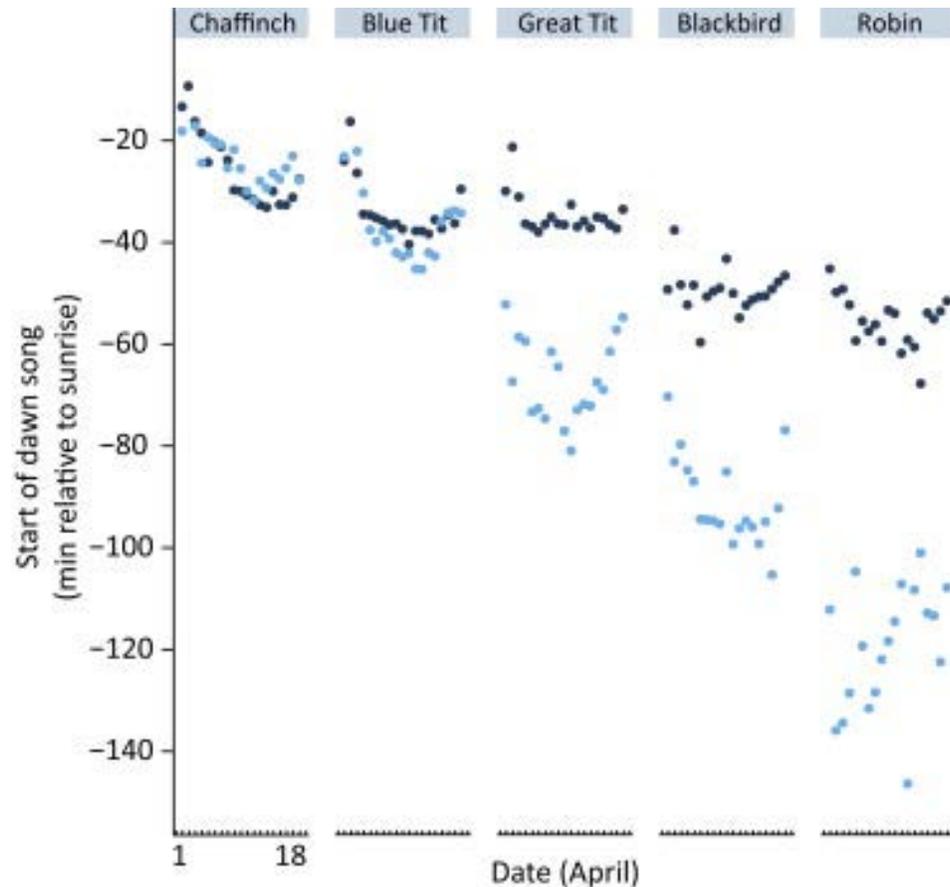


Yield and Moisture



Maximum Values	
Illuminance	Maximum, lx
Horizontal	2.2
Vertical	1.8

Birds, Bass, Bears and Bees

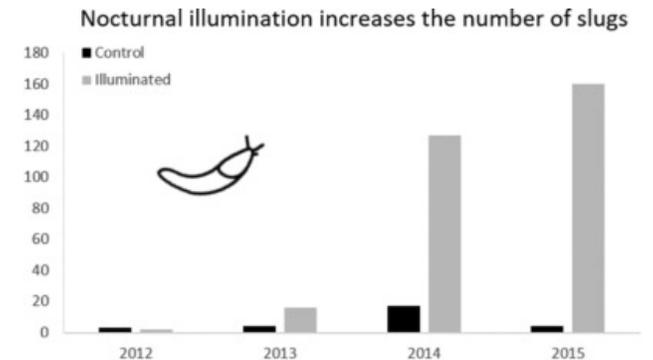
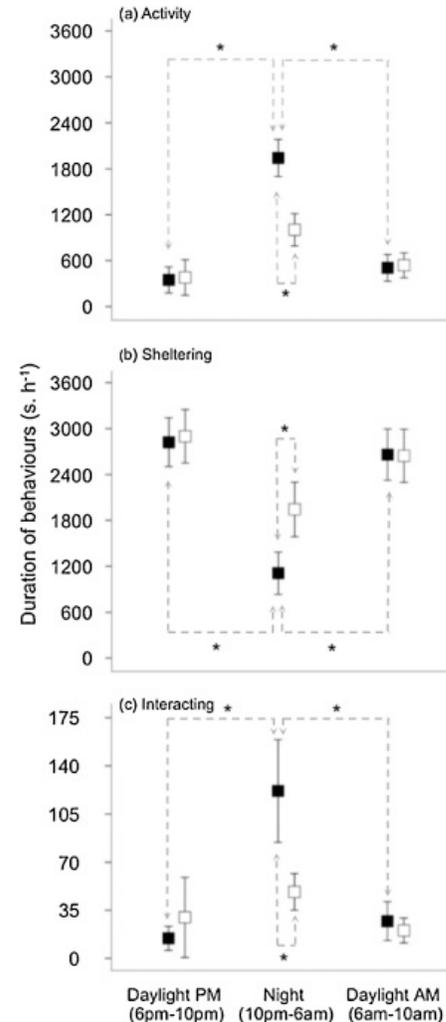
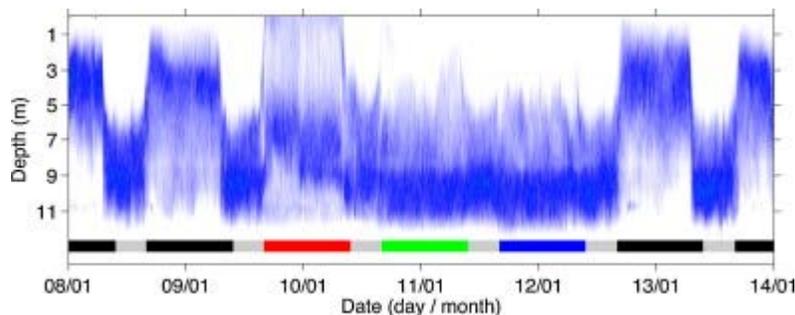


Lighting influences anything with eyes that are sensitive to visible light

- Eg. Robin Song will start as much as 2 hours early in areas adjacent to Roadways (Kempenaers et al, 2010)

We are changing the Ecology

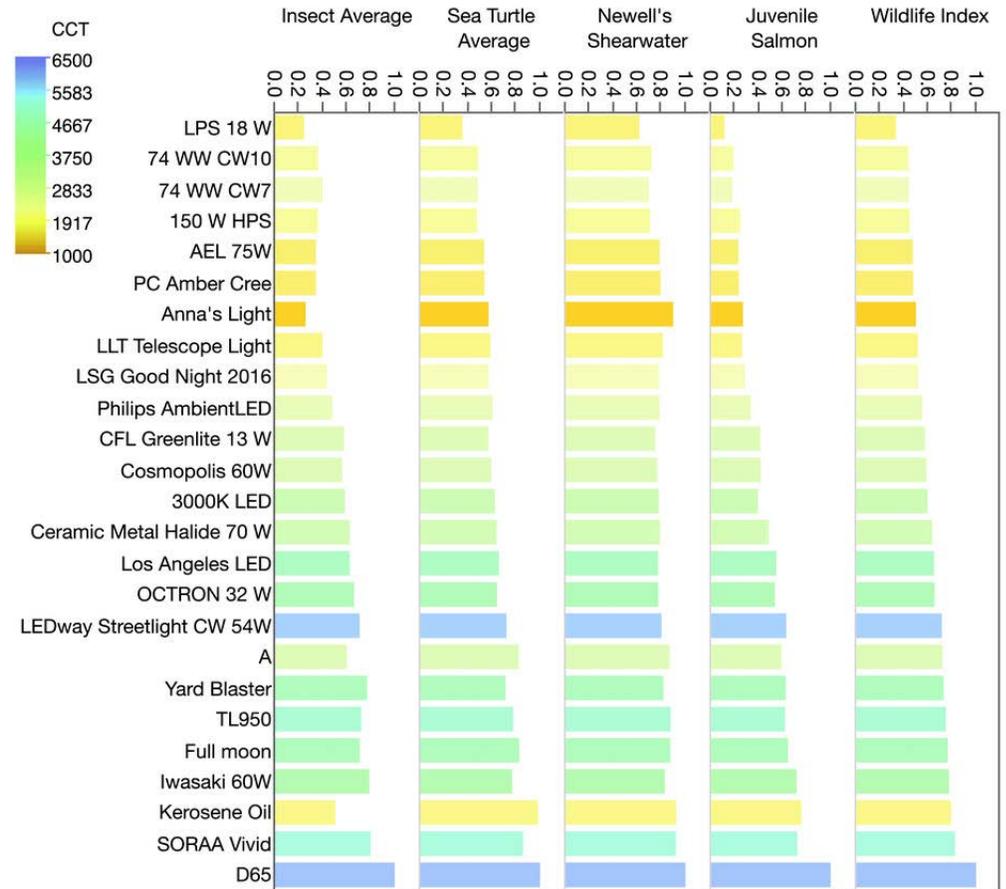
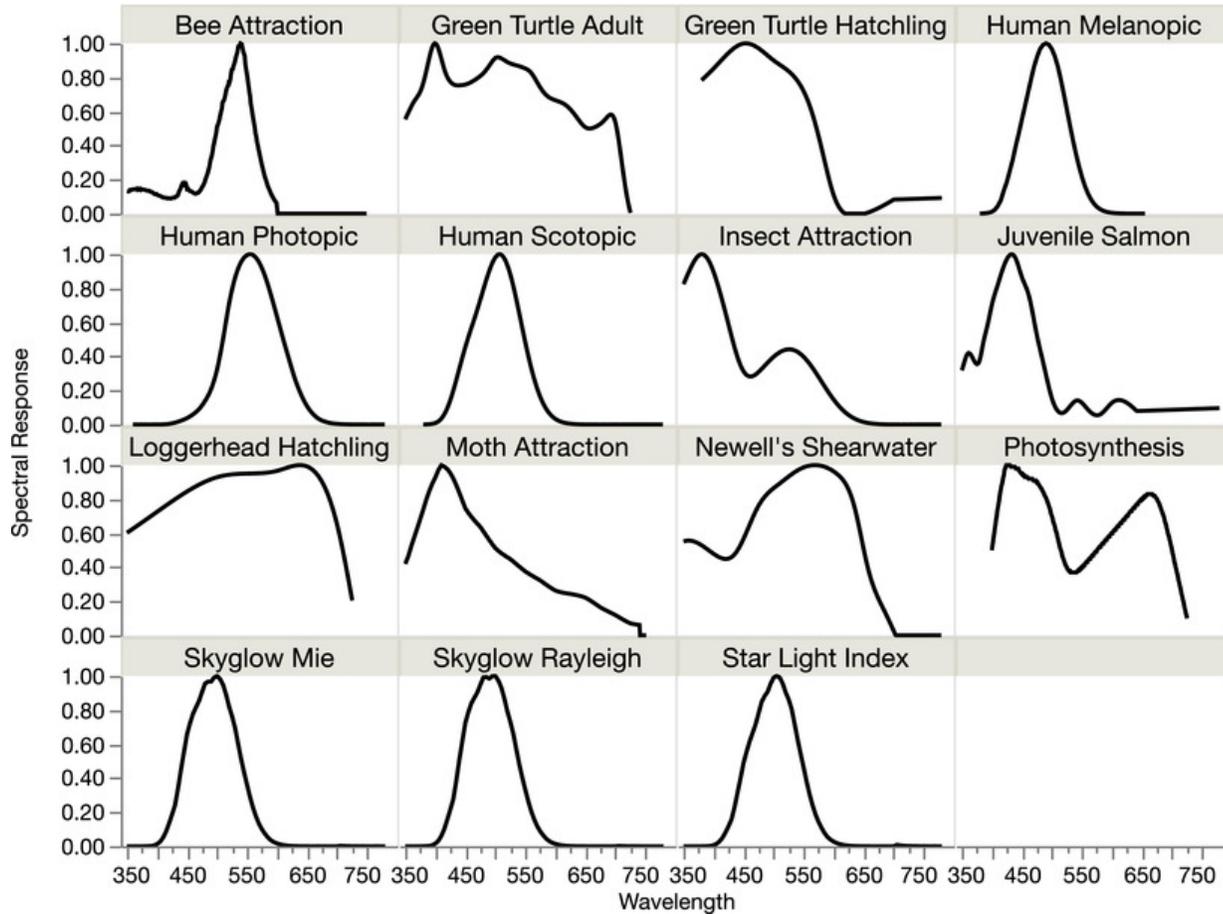
- Crayfish hide and do not interact as significantly under roadway lighting
- Bats now hunt under light fixtures
- Slugs are on the rise
- Salmon change their swimming depth



Bridges



Actinic Curves (Longcore et al)



$$E_{\text{eff}} = \int E_{\lambda} S_{\lambda}(\lambda) d\lambda$$

$$E_{\text{lux}} = \frac{\int E_{\lambda} S_{\lambda}(\lambda) d\lambda}{\int E_{\lambda} V(\lambda) d\lambda}$$

The approach to dealing with the drug varies:

Issue	Solution
Roadway User Safety	Depends
Energy Consumption	Lower Light Levels and use Solid State
Public Perception and Acceptance	Depends
Environmental Impact	Reduce or Remove Lighting
Impact on Surrounding Areas	Control Lighting, Reduce or Remove Lighting
Impact on user health	Use Warmer Colors / Reduce Lighting

New Standards for Safety

- We are getting much closer to understanding the issues of a safe roadway:
 - Trying to control driver behavior and the components of the crash trifecta
 - Likely not a broad brush approach to lighting
 - Lighting requirements may be segment based
 - Lower levels on tangents
 - Higher levels at conflict points
- Issues for agencies:
 - Huge inventory?
 - Changing needs?

Evolution of Roadway Lighting Design

Move from This



To This



Our approach is to slather light around the roadway

We now need to use fine brush strokes to put light when and where we need it

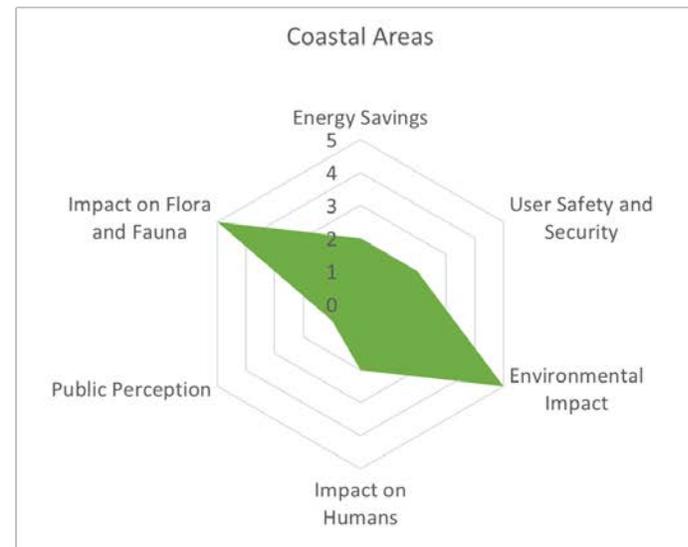
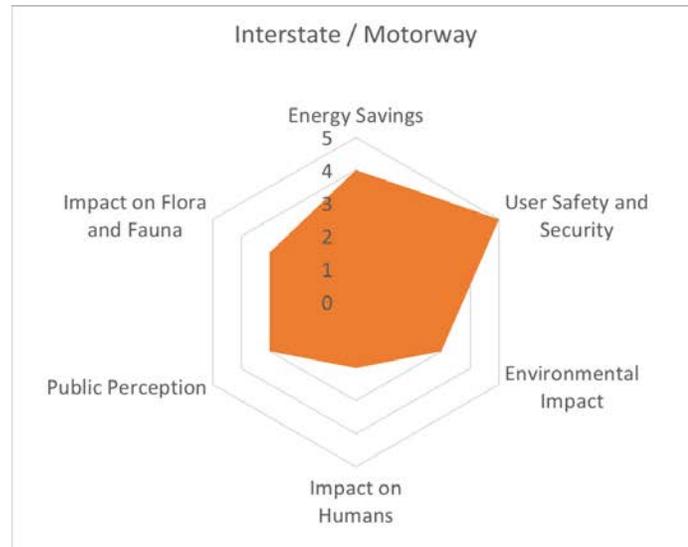
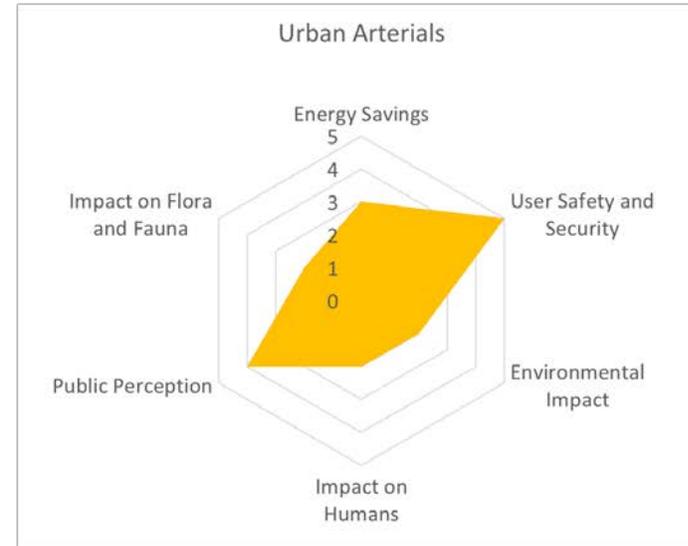
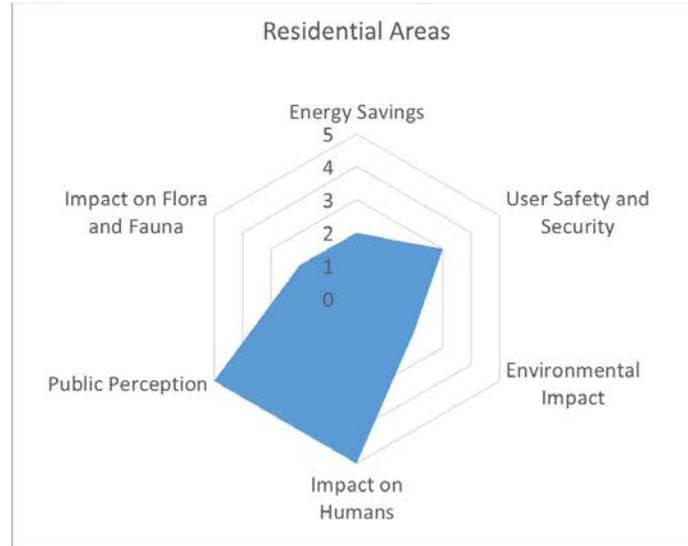
Looking for “Just right” in Lighting

- So what is “Just Right”?
- We judge this by a variety of Dimensions
 - Roadway User Safety
 - Energy Consumption
 - Public Perception and Acceptance
 - Environmental Impact
 - Impact on Surrounding Areas
 - Impact on user health
- Our current approach is Adaptive Lighting

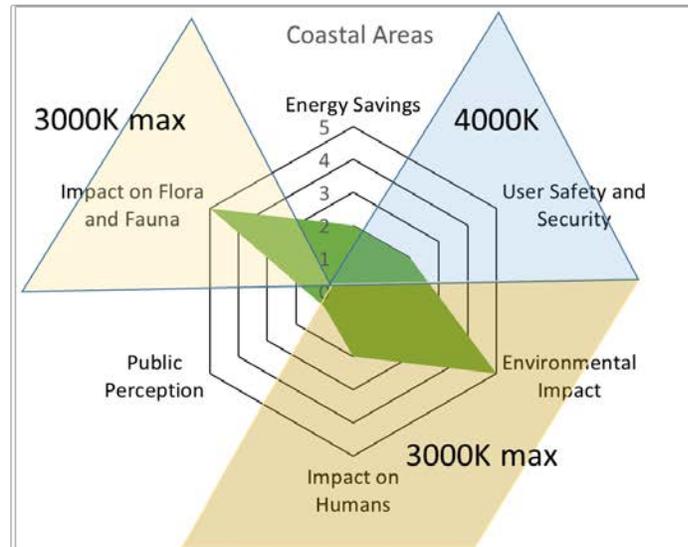
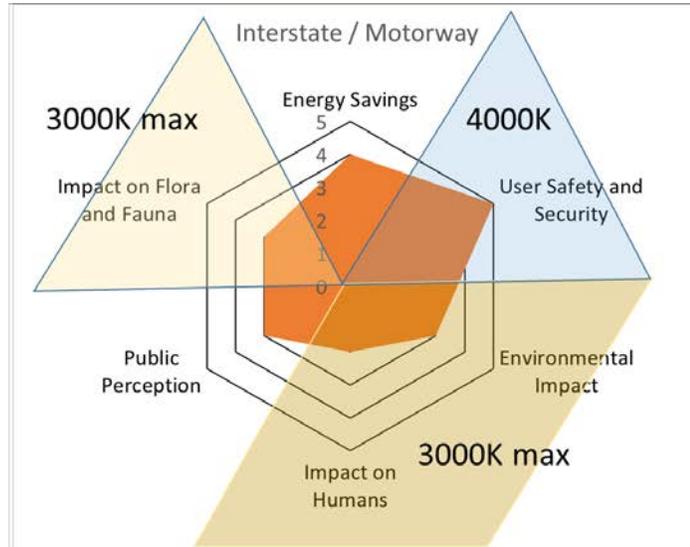
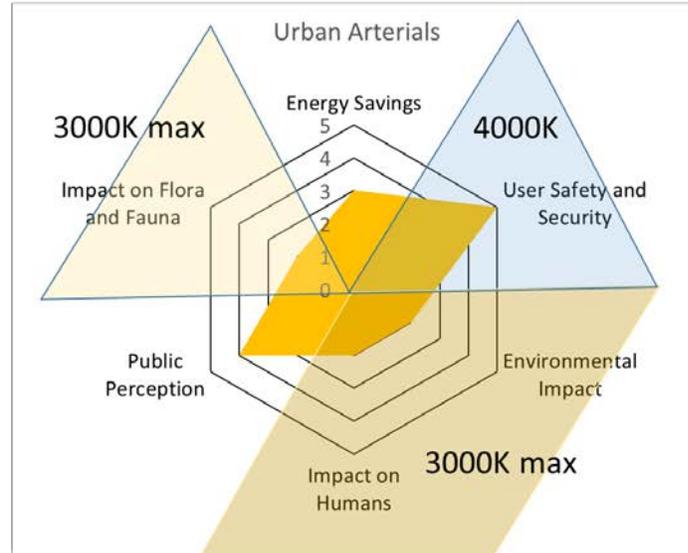
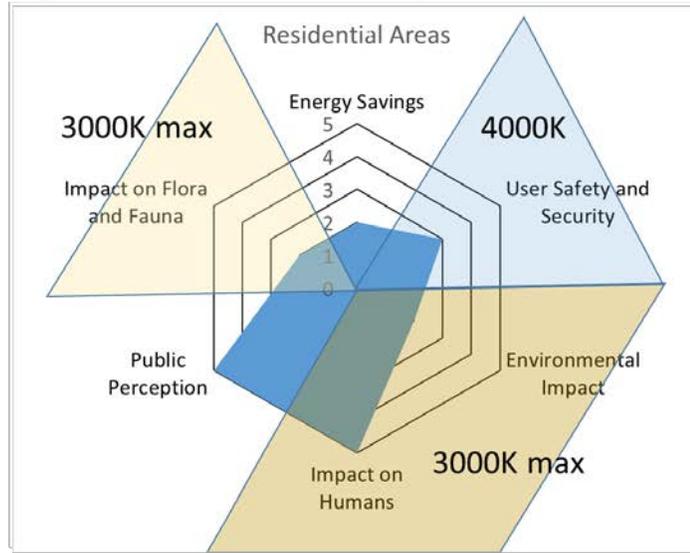
Light Source Selection Criteria

- Each of lighting valuation criteria can be weighted to provide guidance on how to approach the light source and lighting level selection.

Weighing the Impacts



Weighing the Impacts



Today's Panelists

- Paul Lutkevich,
paul.lutkevich@wsp.com
 - Don McLean, don@dmdeng.com
 - Ron Gibbons,
rgibbons@VTTI.VT.edu
 - Rajaram Bhagavathula,
RBhagavathula@vtti.vt.edu
- 

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 - Update your profile



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