Countermeasure Strategies for Pedestrian Safety

Lighting Strategies

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Lee Engineering

December 15, 2015

Today's Presentation

- **Introduction and housekeeping**
- **Audio issues?**
  Dial into the phone line instead of using "mic & speakers"
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Countermeasure Strategies for Pedestrian Safety Webinar Series

Upcoming Webinars

Traffic Calming

Thursday, December 17 (1:00 – 2:30 PM Eastern Time)

Pedestrian Safety at Roundabouts

Wednesday, January 6 (1:00 – 2:30 PM Eastern Time)

Transit and Pedestrian Safety

Wednesday, January 20 (1:00 – 2:30 PM Eastern Time)

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PEDESTRIAN LIGHTING

Designing for Pedestrian Safety 201

CMF (CRF)

Intersection Illumination

- 38% CRF for all nighttime crashes
- 42% CRF for veh/ped nighttime crashes

CMF
CRASH MODIFICATION FACTORS CLEARINGHOUSE

Home » New Search Results

Countermeasure: Provide intersection illumination

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Area Type	Reference	Comments
0.62 [B]	38	★★★★☆	Nighttime	Serious Injury,Minor Injury	Not Specified	Elvik, R. and Vaa, T., 2004	Countermeasure name changed to match ... [*read more*]
0.58 [I]	42	★★★★☆	Nighttime,Vehicle/pedestrian	Serious Injury,Minor Injury	Not Specified	Elvik, R. and Vaa, T., 2004	Countermeasure name changed to match ... [*read more*]
0.41	59	★★★★☆	Vehicle/pedestrian	Serious injury,Minor injury	Not specified	Elvik, R. and Vaa, T., 2004	Countermeasure name has been slightly ... [*read more*]

Source: Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." Oxford, United Kingdom, Elsevier, (2004)

CMF (CRF)

Rural Intersection Illumination

- 44% CRF for veh/ped nighttime crashes

CRASH MODIFICATION FACTORS CLEARINGHOUSE

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Countermeasure: Provide intersection illumination

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Area Type	Reference	Comments
0.56	43.8	★★★☆☆	Vehicle/pedestrian	All	Rural	Ye et al., 2008	Countermeasure name has been slightly ... [*read more*]

Source: Ye, X., R.M. Pendyala, S.P. Washington, K. Konduri, and J. Oh (2008). A Simultaneous Equations Model of Crash Frequency By Collision Type for Rural Intersections, 87th Annual Meeting of the Transportation Research Board, TRB 2008 Annual Meeting CD-ROM

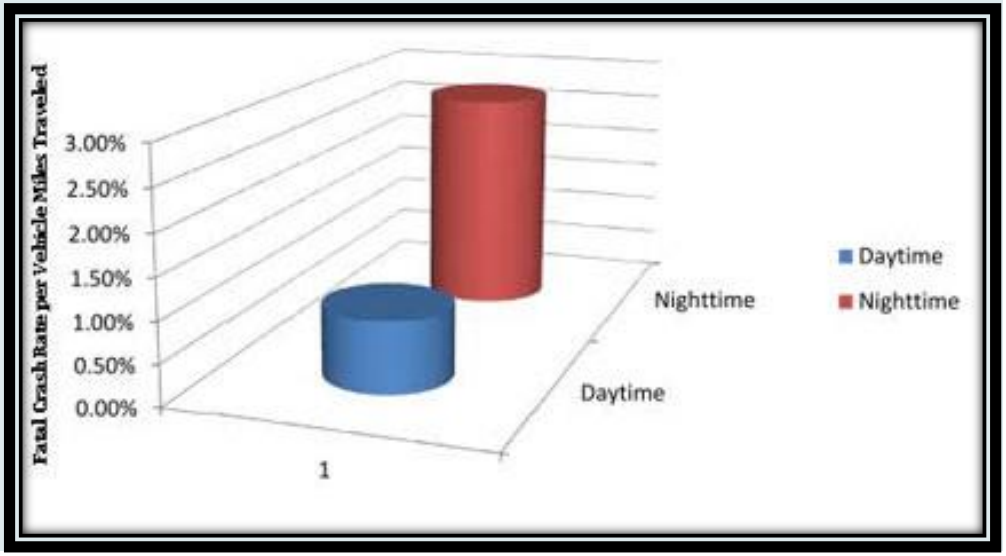
FHWA LIGHTING HANDBOOK - 2012

Guidance Document: supplement AASHTO, IES & CIE guides

- Policy and guidance
- Basic terms and concepts
- Warranting criteria
- Lighting impacts
- Application considerations
- Other systems and issues

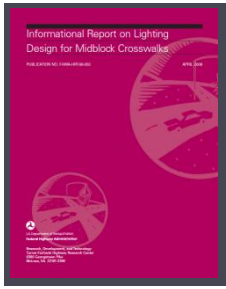
NIGHTTIME VS DAYTIME FATALITIES

- Driving or walking on, or across, a roadway is less safe in darkness than in a lighted area
- Fatal crash numbers in daylight are about the same as in darkness, but only 25 percent of vehicle-miles traveled occur at night
  - Nighttime fatality rate is three times the daytime rate
- Lighting for pedestrian safety can also benefit vehicle safety



ILLUMINANCE

- Amount of light that falls onto a surface
- Measured as the amount of lumens per unit area either in foot-candles (lumens/ft^2) or in lux (lumens/m^2)
- Variable by the square of the distance from the source
- Illuminance is simple to calculate and measure - Do not need to take reflective properties of the roadway surface into account & can use a fairly inexpensive illuminance meter for field verification
  - Drawback to this metric is that the amount of luminous flux reaching a surface is often not indicative of how bright a surface will be or how well a person can see



CONTRAST

- Contrast is the difference between the visual appearance of an object and the visual background against which that object is observed
- Crosswalk lighting should maximize the contrast between pedestrians on or near the crosswalk and the visual background behind those pedestrians from the perspective of approaching drivers

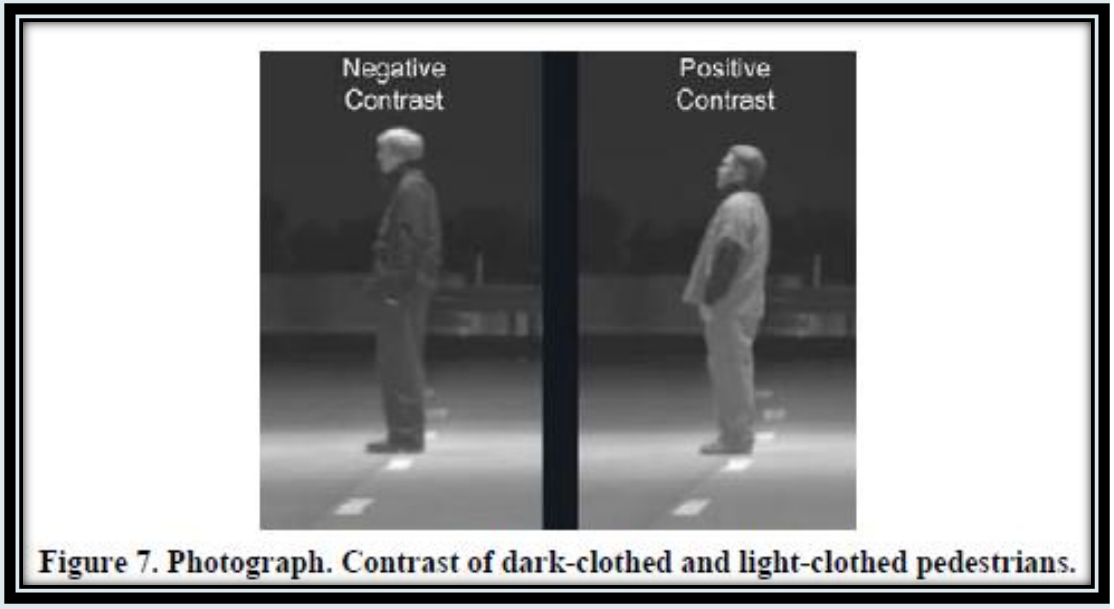
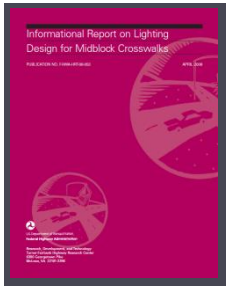


Figure 7. Photograph. Contrast of dark-clothed and light-clothed pedestrians.



CONTRAST

- Several factors affect the luminance contrast between pedestrians and their visual backgrounds:
  - Fixed roadway lighting
  - Headlamp lighting
  - Pedestrian clothing
  - Characteristics of visual background
- Designers can only control roadway lighting
- Lighting designers must react to but cannot change the other factors.

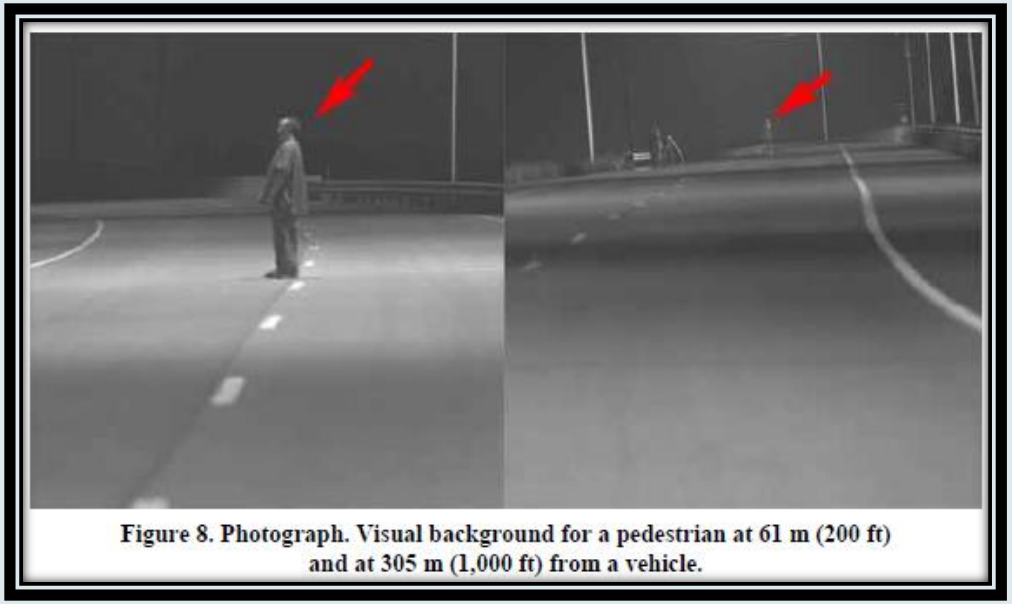
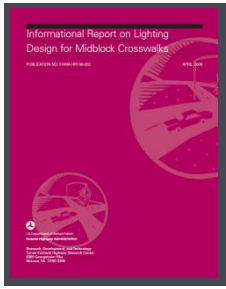
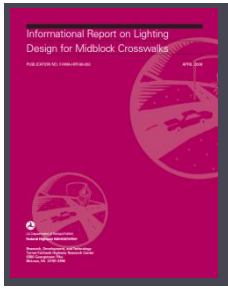


Figure 8. Photograph. Visual background for a pedestrian at 61 m (200 ft) and at 305 m (1,000 ft) from a vehicle.



CONTRAST

- Effectiveness of overhead lighting in increasing visibility distance—by increasing luminance contrast—is a function of:
  - Location and orientation of luminaire(s)
  - Intensity of emitted light
  - Color of light source



VERTICAL ILLUMINANCE

- E_{vert} defined as the illuminance on a vertical surface
- E_{vert} on pedestrian is luminous intensity emitted by a luminaire in the direction of the pedestrian times the cosine of the angle between the direction of propagation and a horizontal line parallel to the road surface divided by the distance between the luminaire and the pedestrian.

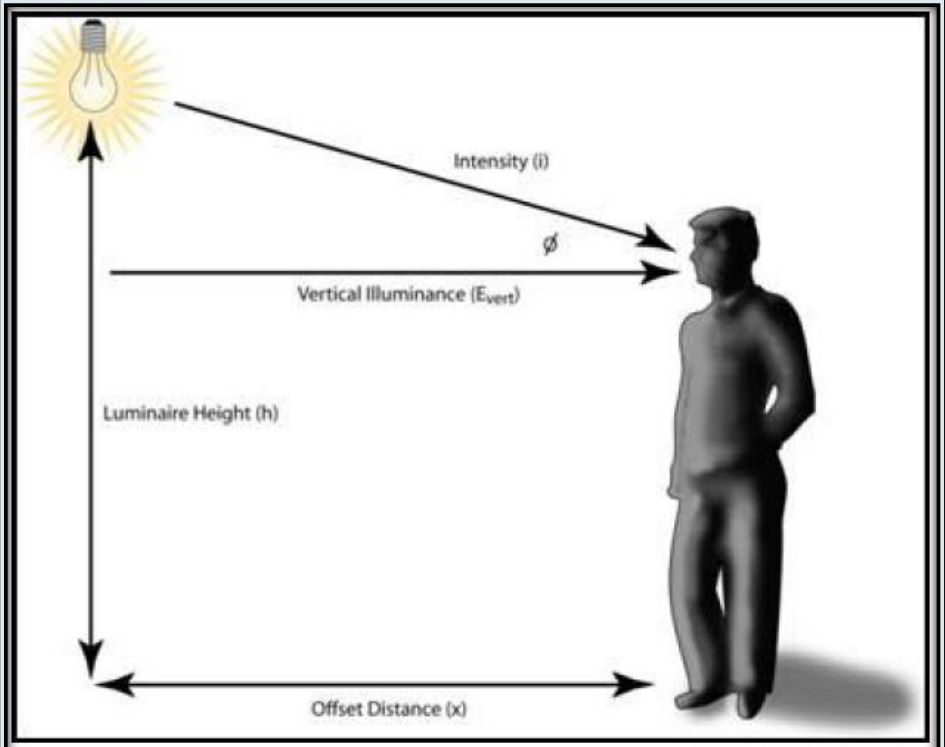
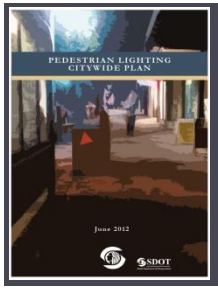


Figure 1. Drawing. Vertical illuminance components.

$$E_{Vert} = \frac{I\cos\phi}{D^2} = (I\cos\phi)\frac{\sin^2\phi}{(h-1.5)^2} = \frac{I\cos\phi\sin^2\phi}{(h-1.5)^2}$$

Figure 2. Equation. Vertical illuminance (E_{Vert}) at a height of 1.5 m (5 ft).

PEDESTRIAN LEVEL LIGHTING

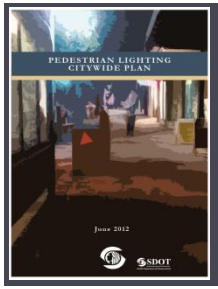


PEDESTRIAN-LEVEL LIGHTING

Purposes:

- Help pedestrians safely navigate sidewalks & pathways
- Provide for visibility & security at all hours
- Extend hours a business district is active
- Encourage walking as part of an active lifestyle
- Improve access to transit & other services at night/early morning

Pedestrian lights at 1st Ave and Yesler Way



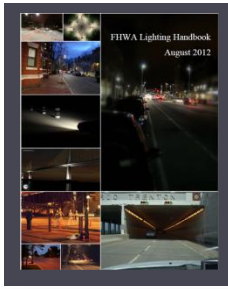
ROADWAY VS. PEDESTRIANWAY

- Roadway lighting typically 25 ft or higher
  - Overhead streetlights
  - Light source over roadway
- Road lighting may be sufficient for motorists to navigate & avoid obstacles
  - Often insufficient for specialized pedestrian needs
- Pedestrian-level lighting pedestrian needs typically 20 ft or less (18 ft on non-arterials) from the surface

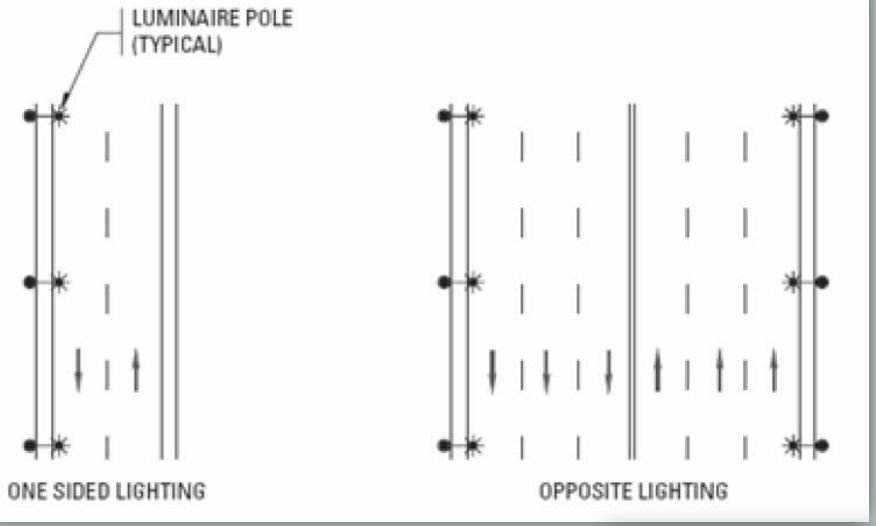
LED Streetlights on 10th Ave E

Pedestrian lighting in South Lake Union

ALONG THE ROAD LIGHTING

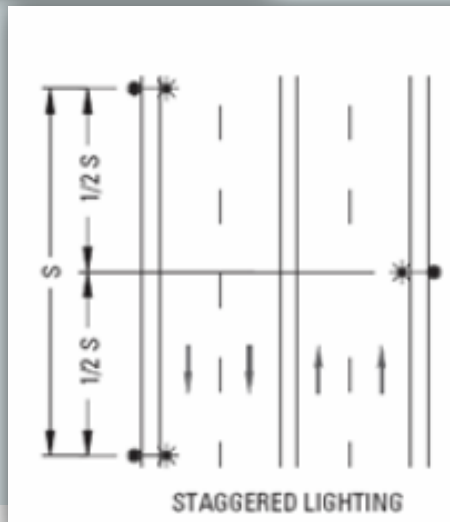


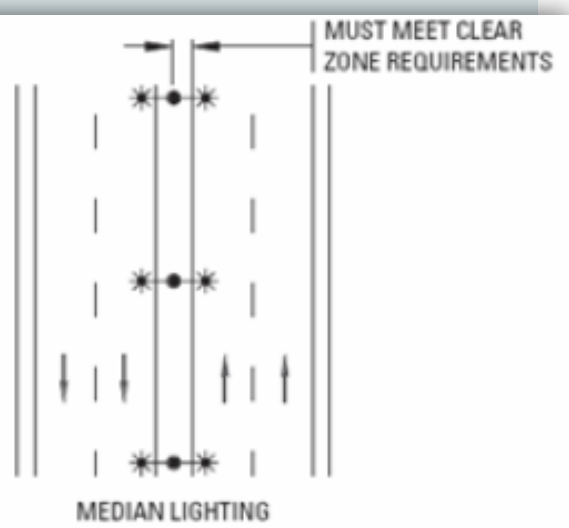
SYSTEM LAYOUT AND GEOMETRY

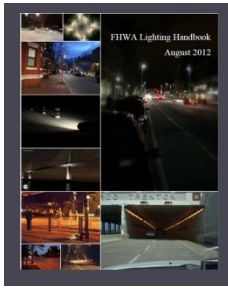


Standard pole spacing layout designations:

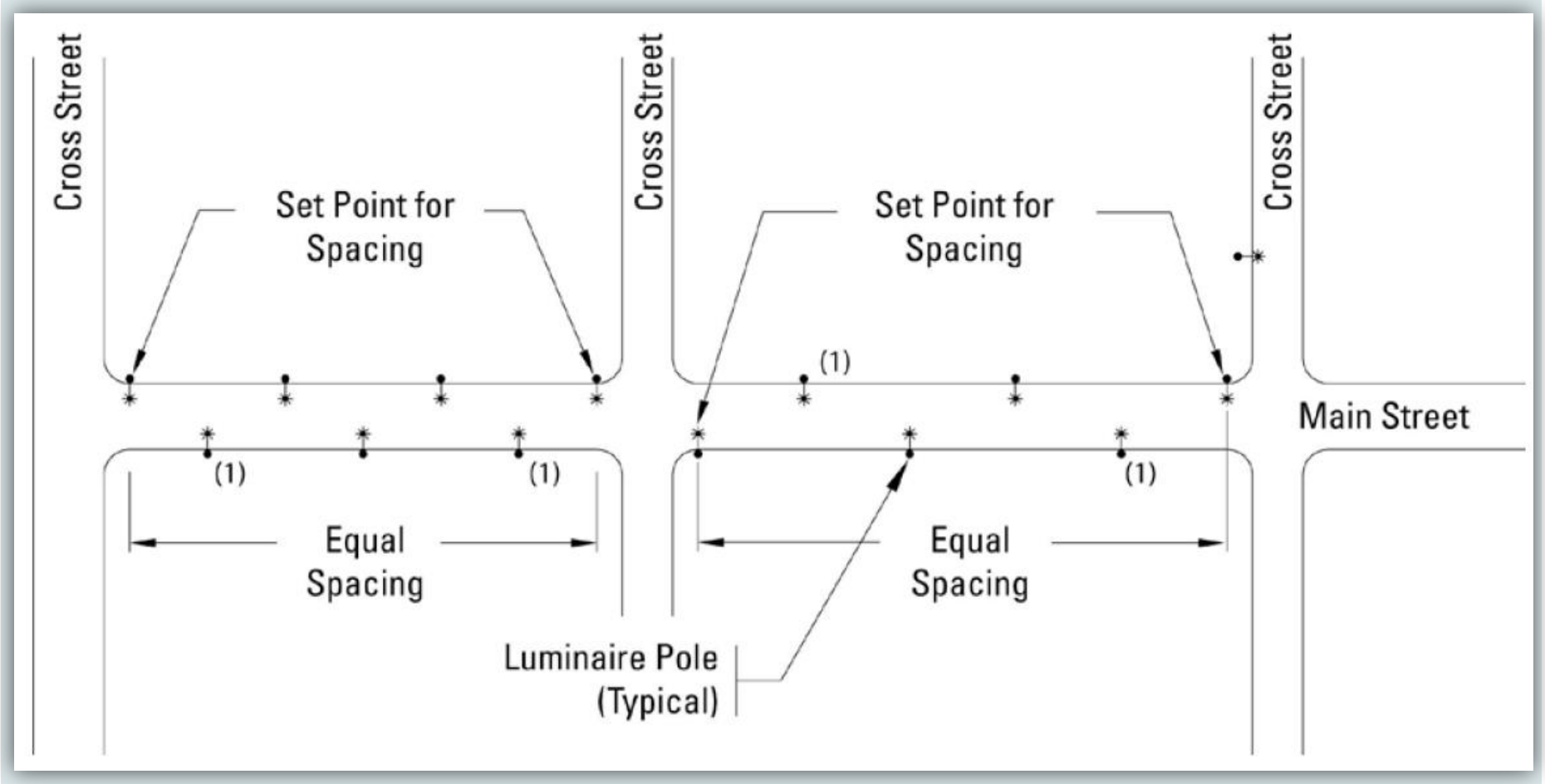
- one-sided lighting
- opposite lighting
- staggered lighting
- median lighting







POLE SPACING



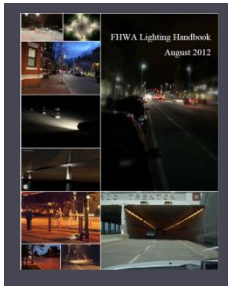
DESIGN LIGHTING POLE HEIGHT, TYPES & LUMINAIRE WATTAGE

Consider:

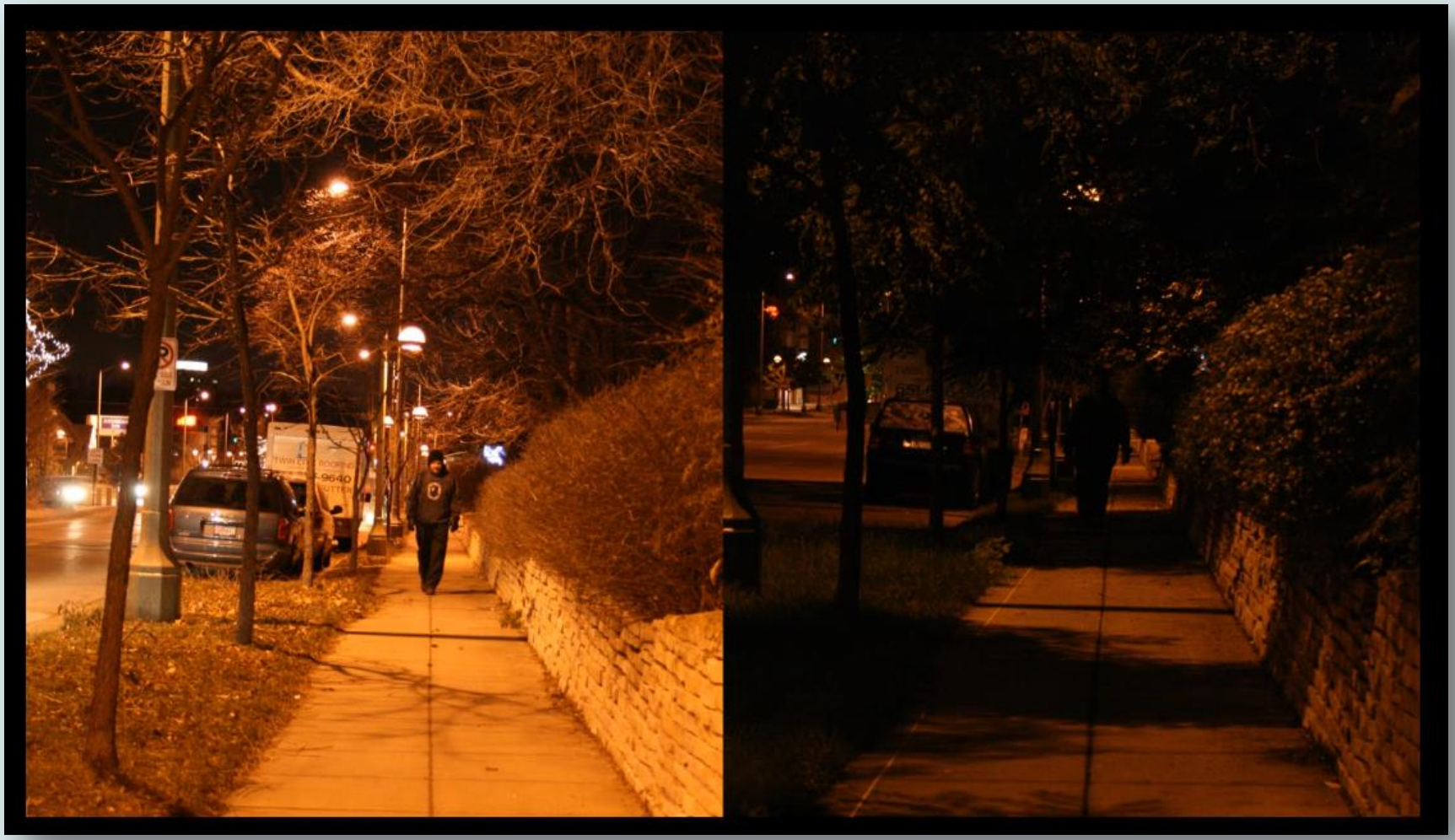
- Land use
- Road width

Other Factors:

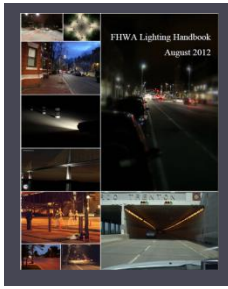
- Pole spacing and system layout
- Luminaire photometrics
- Wattage
- Road geometrics
- Power line conflicts
- Lighting levels and uniformity
- Aesthetics
- Obtrusive lighting issues



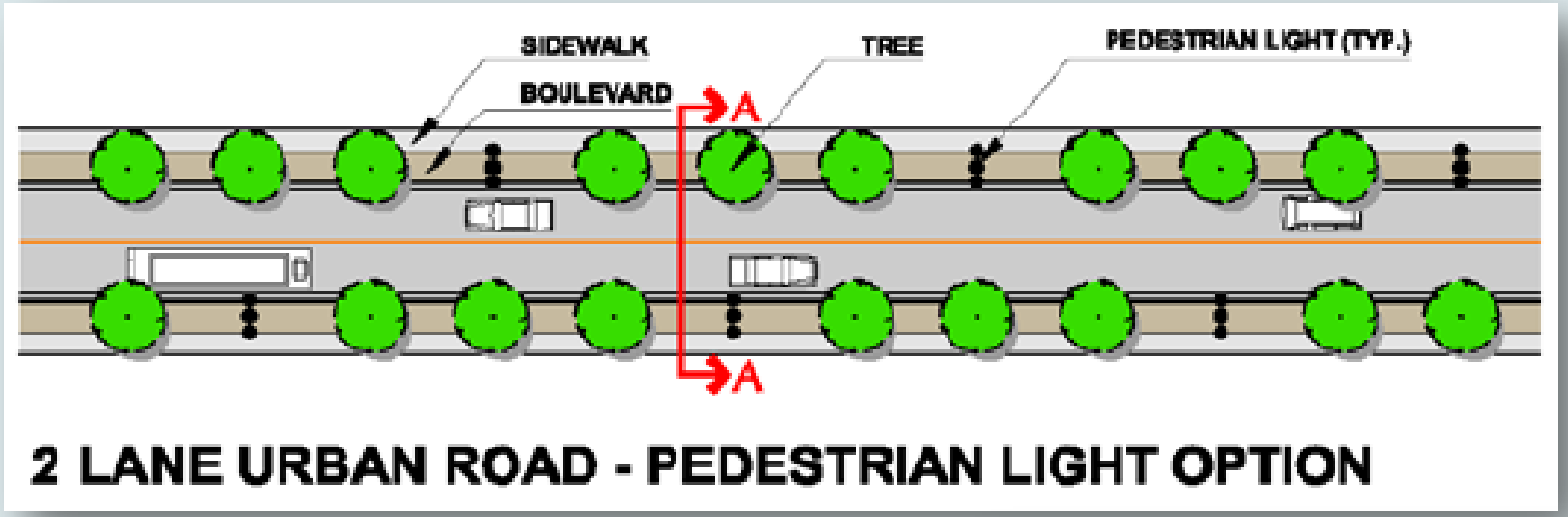
LIGHTING
CONSIDER TREE EFFECTS



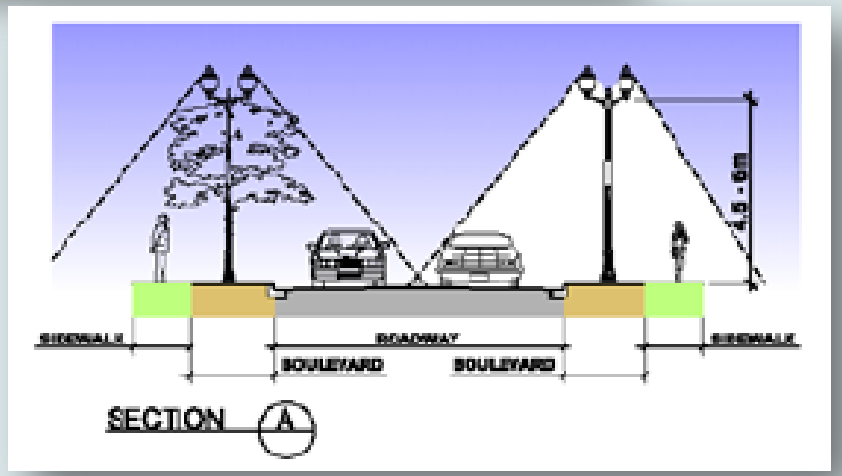
TRR 2120 - Trees, Lighting, and Safety in Context-Sensitive Solutions

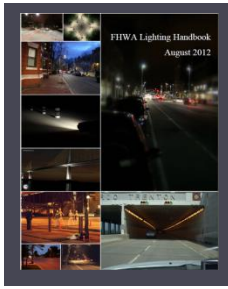


STREETSCAPE LIGHTING LAYOUTS

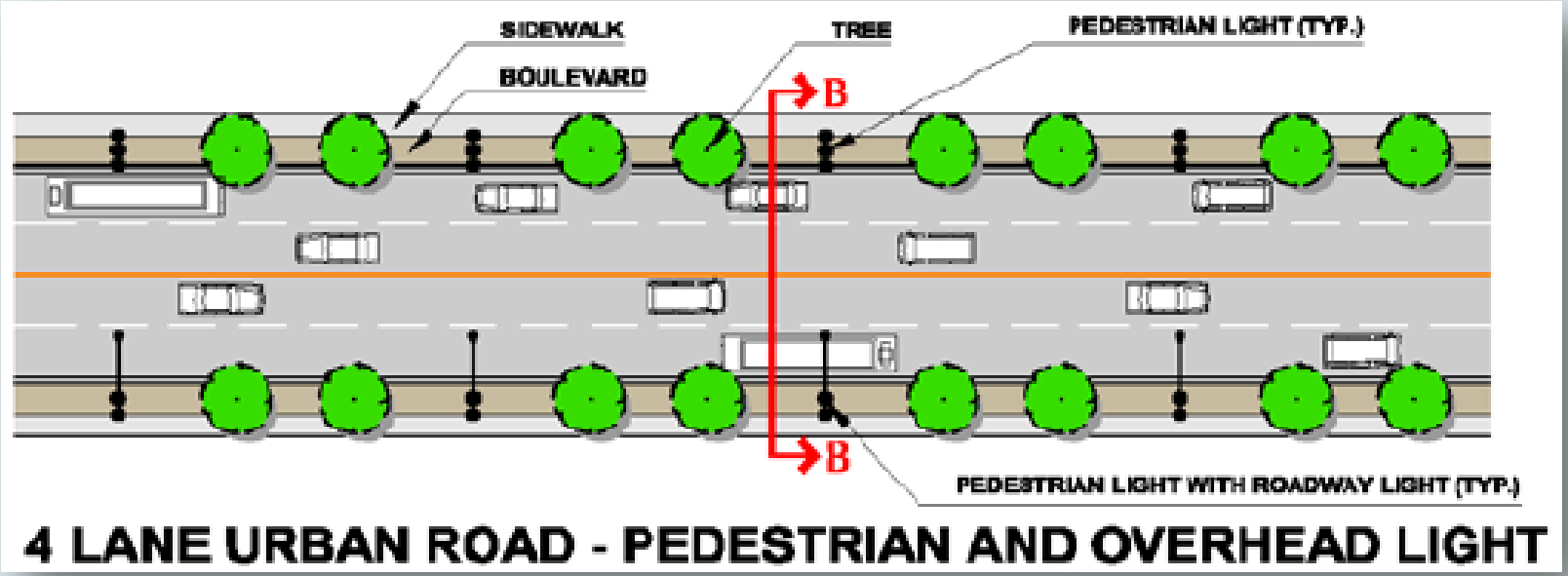


2 LANE URBAN ROAD - PEDESTRIAN LIGHT OPTION

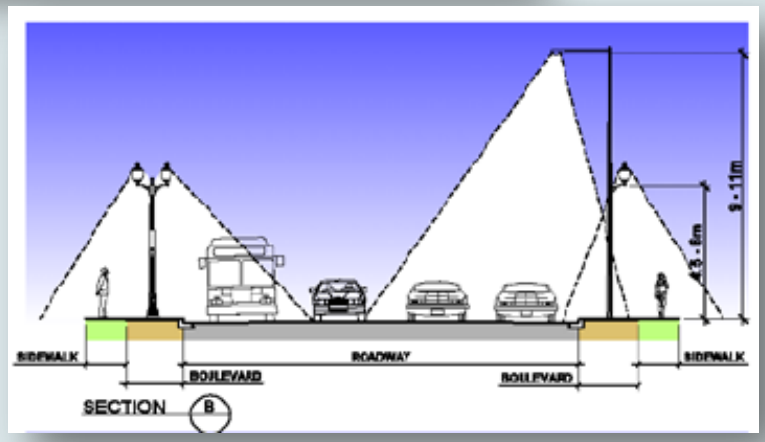


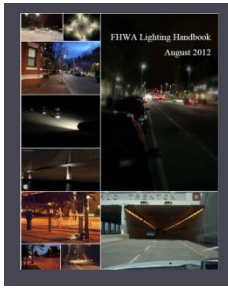


STREETSCAPE LIGHTING LAYOUTS

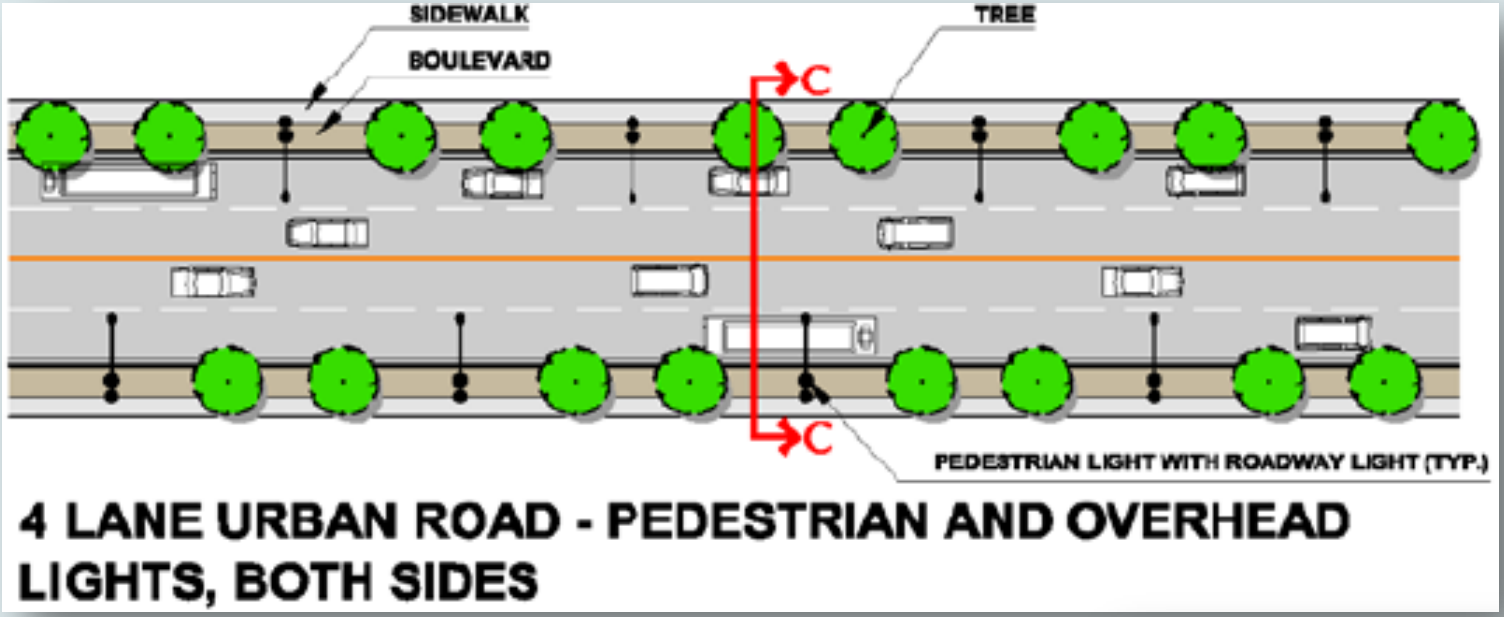


4 LANE URBAN ROAD - PEDESTRIAN AND OVERHEAD LIGHT

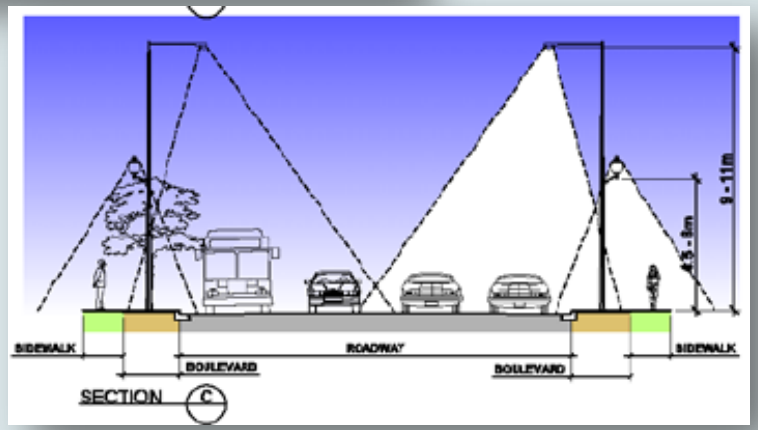


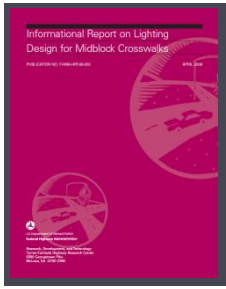


STREETSCAPE LIGHTING LAYOUTS



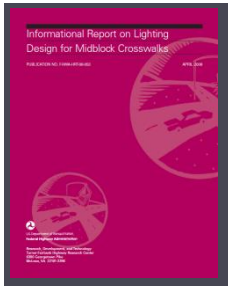
4 LANE URBAN ROAD - PEDESTRIAN AND OVERHEAD LIGHTS, BOTH SIDES





LAMP TYPE: HPS VS. MH

- High Pressure Sodium (HPS) and metal halide (MH) lamps most common sources for roadway lighting
- HPS produces amber light
- HPS used most because of its high efficiency and long life
- Same lighting level is recommended for MH and HPS
- A color difference between continuous roadway lighting and crosswalk lighting may highlight the presence of the crosswalk
- MH produces white or bluish-white light
- White light provides higher level of facial recognition & comfort
- There are claims that MH may provide a safety benefit because it improves driver peripheral vision
- Research did not show large differences in detection of a black-clothed pedestrian under HPS and MH lighting
- Pedestrians in denim detected at longer distances under MH lighting



LED STREET LIGHTS

Advantages

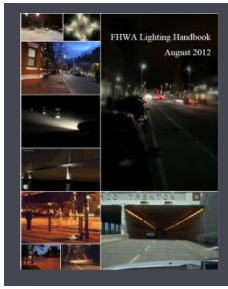
- Lower energy use
- Longer lamp life
- No warm-up time
- Good light quality
- Directional (less light pollution)
- Environmentally friendly

Disadvantages

- High initial cost
- Luminous efficacy
- Sensitive to heat
- Long-term performance issues

ADAPTIVE LIGHTING

- Lighting levels established based on road class (arterial, local, collector), pavement type, pedestrian activity/conflict level
  - For higher pedestrian conflicts, higher level of lighting recommended.
- Present design practice uses the highest pedestrian conflict/activity level for an area or segment of roadway to establish the minimum lighting levels for the portion of roadway under consideration
  - Once the minimum level of lighting is established, street lights have traditionally provided that level of lighting throughout the hours of darkness as adaptive technologies have been unavailable.

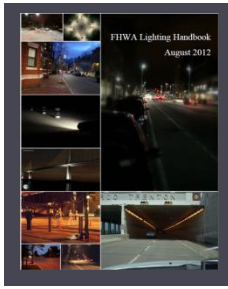


ADAPTIVE LIGHTING

- Pedestrian conflict levels do not necessarily remain constant throughout the hours of darkness
  - Pedestrians numbers will usually be reduced in the late night and early morning hours when businesses are closed
- Numbers of nighttime pedestrians may also be reduced based on the day of week, seasonal factors, and other dynamics
- During hours of reduced pedestrian conflict, the level of lighting provided can be reduced and while meeting recommended criteria for the actual level of pedestrians present

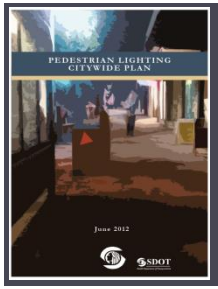
ADAPTIVE LIGHTING

- Energy saving depends on the variance of pedestrian conflict levels throughout the hours of darkness
- During hours of reduced pedestrian conflict/activity level of lighting provided could be reduced to recommended criteria for the actual level of pedestrians present
- Adaptive technology should not affect the distribution pattern of the luminaire, uniformity ratios are preserved, even with reductions in luminaire output



ADAPTIVE LIGHTING

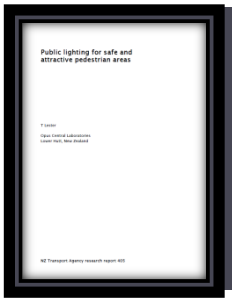
- Light output of luminaire and lamp depreciates over their useful life.
  - Designers provide initial level lighting higher than minimum maintained level
  - Compensation achieved by applying lighting loss factor
  - One component of light loss factor is lamp lumen depreciation
  - Factor is typically 10 percent to 30 percent depending on the lamp type
- Adaptive technology may allow street light to operate at its maintained level for the entire maintenance cycle
- One would not apply lumen depreciation to a lighting design



NIGHT-SKY LIGHT POLLUTION

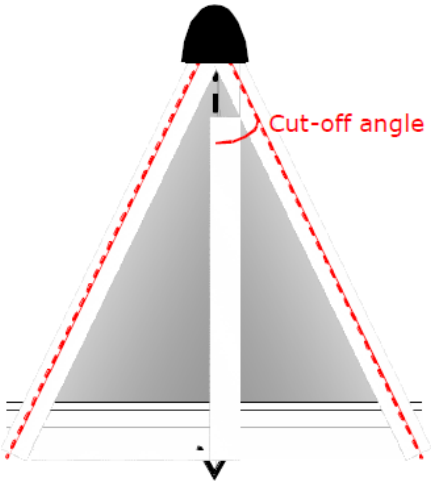
- Light pollution significant urban problem influencing many elements from astronomy to wildlife
- Flat lens luminaires and other minor adjustments can limit light pollution
- Restrictions may be placed on lumens above 90 degrees as a percentage of total lumens that can limit overall light levels

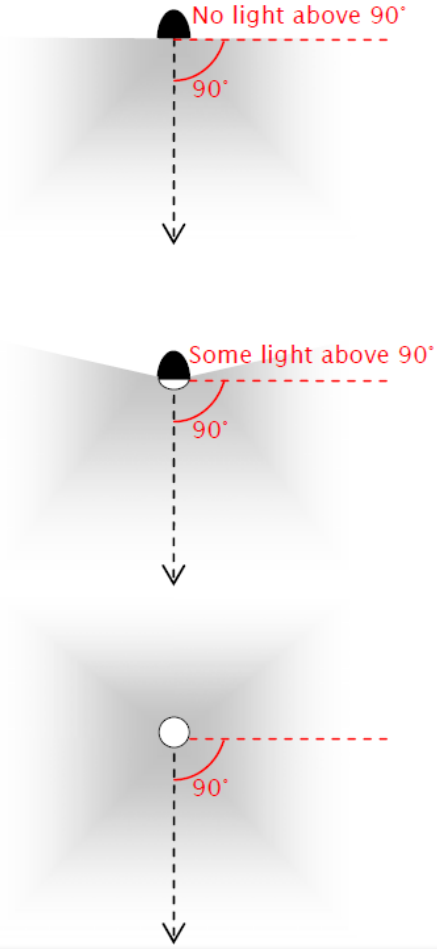

Light Pollution - Joe Mabel



NIGHT-SKY LIGHT POLLUTION

Figure 3.4 Luminaire fittings can be chosen to control the range of angles of illumination they provide





LIGHTING CROSWALKS

LUMINAIRE PLACEMENT

- Luminaire should be located 10 ft in front of crosswalk
- 20 vertical lux at crosswalk

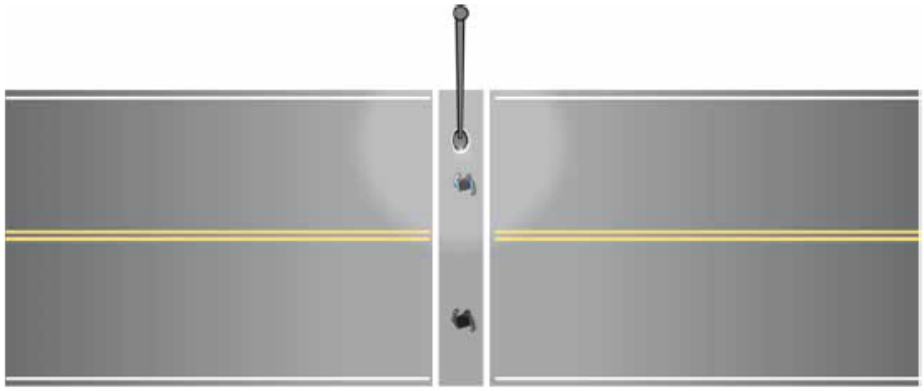


Figure 11. Drawing. Traditional midblock crosswalk lighting layout.

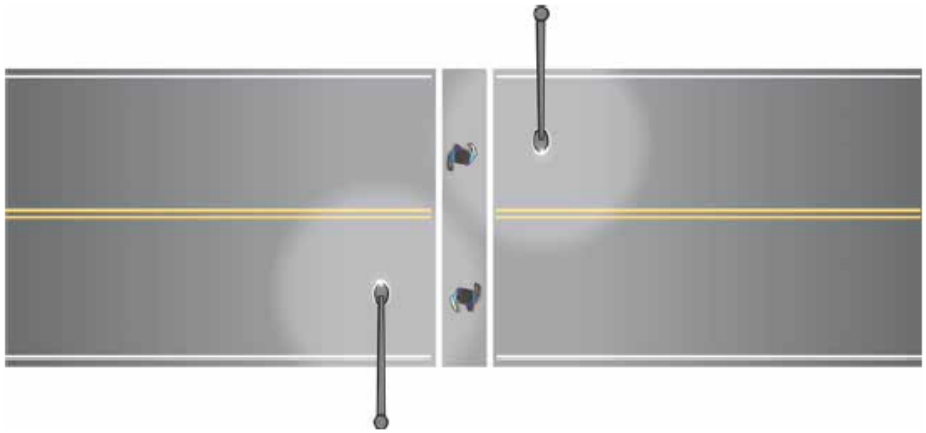
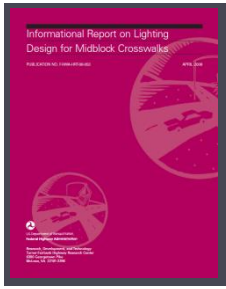
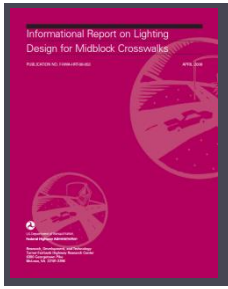


Figure 12. Drawing. New design for midblock crosswalk lighting layout.



LUMINAIRE SELECTION

- Luminaire type/level and height are critical
- If all light is directed downward, the vertical profile of pedestrians will not be adequately illuminated
- The luminous intensity distribution from the luminaire must be able to provide the required luminous intensity in the geometry required
- If the luminaire cannot produce the required intensity, it is not suitable for use in a crosswalk installation.



LUMINAIRE HEIGHT

- Suitability of a luminaire – use lighting design program.
- 250-W HPS mounted at height of 28 ft
- Two vertical lines indicate that the desired vertical illuminance of 20 lx may be found for a crosswalk located at a distance of 14–20 ft from the luminaire position.

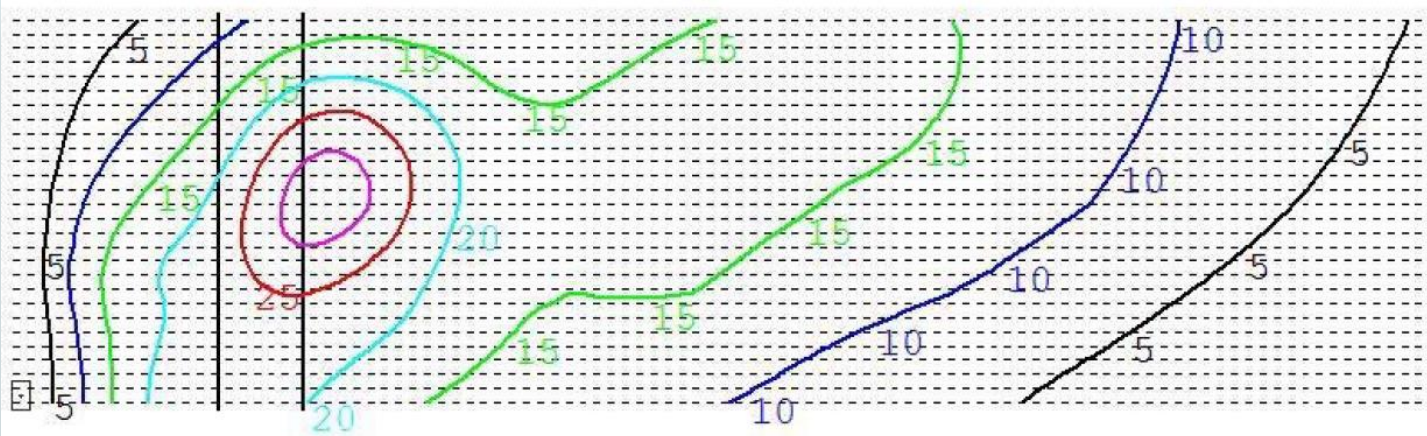
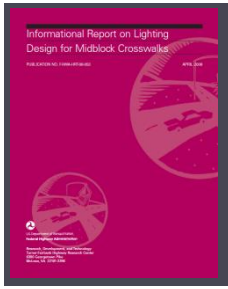


Figure 9. Plot. Vertical illuminance plot for a 250-W HPS flat lens cobra-head-style luminaire mounted at 8.5 m (28 ft).



LUMINAIRE HEIGHT

- Same luminaire at different height may not be suitable.
- 250-W HPS luminaire mounted at 33 ft from the road surface.
- Vertical illuminance levels do not reach desired level of 20 lx.

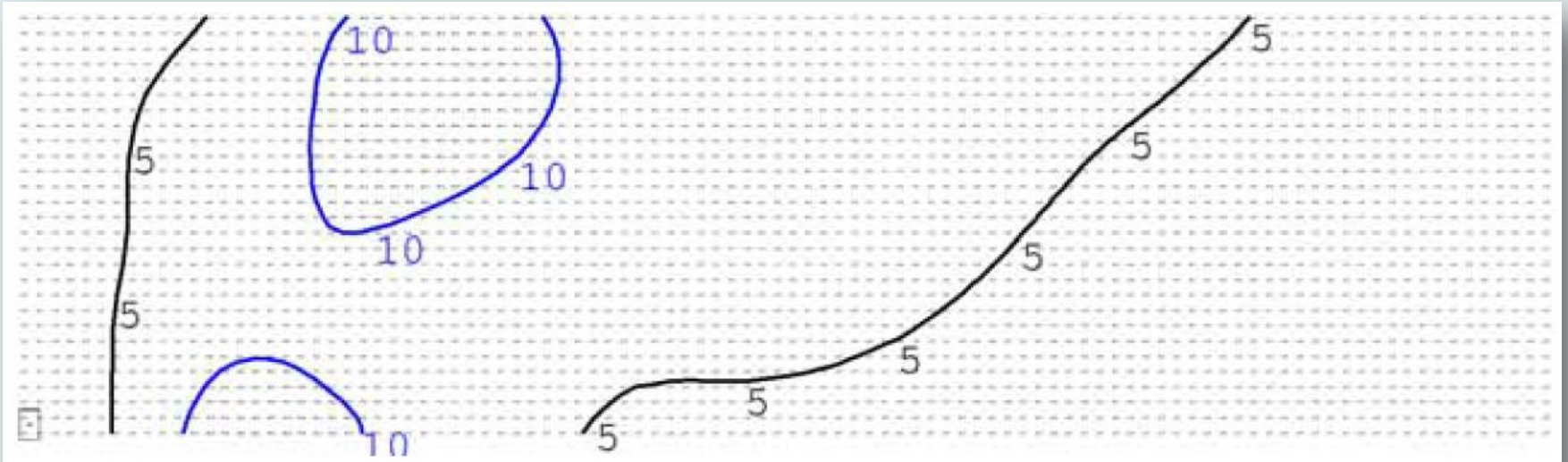


Figure 10. Plot. Vertical illuminance plot for a 250-W HPS flat lens cobra-head-style luminaire mounted at 10 m (33 ft).

CROSSWALKS AT INTERSECTIONS

- No specific research done to address higher background luminance typically found at intersections
- 30 vertical lux considered conservative estimate

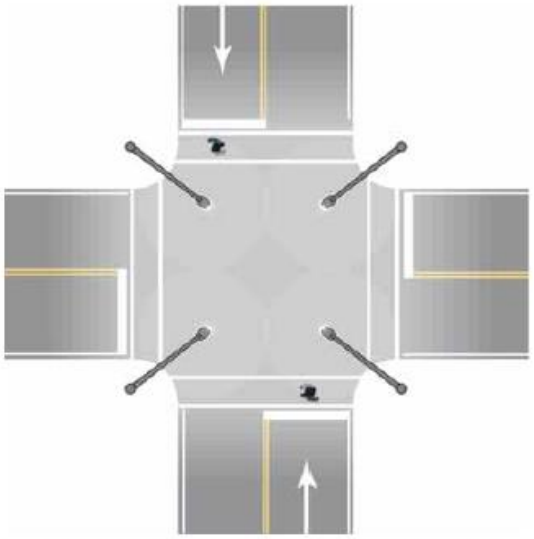


Figure 13. Drawing. Traditional intersection lighting layout.

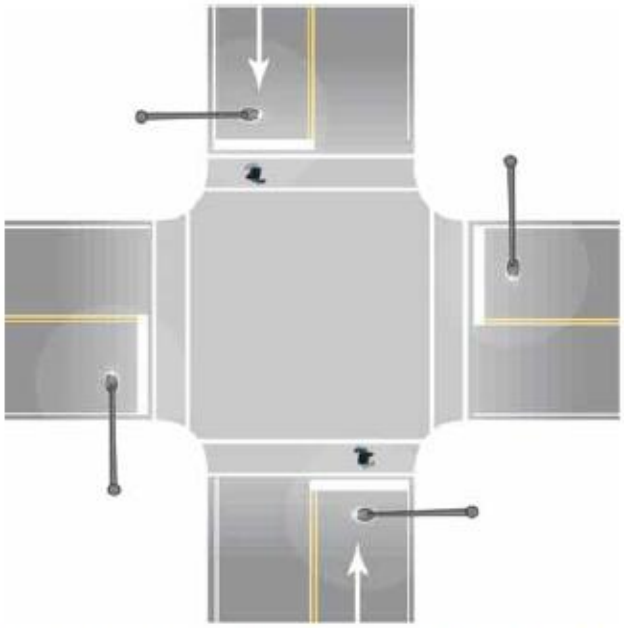


Figure 14. Drawing. New design for intersection lighting layout for crosswalks.

DESIGN & EVALUATION OF EFFECTIVE CROSSWALK ILLUMINATION REPORT

- Purpose: evaluate different approaches to lighting at pedestrian crosswalks to improve pedestrian visibility & detection
- Conducted series of photometrically accurate lighting simulations:
  - Assessed the visual conditions resulting from different lighting configurations
  - Assessed economics of each system
- Field tested most promising lighting configuration
- Results suggest bollard-based fluorescent lighting system mounted at the ends of a crosswalk and oriented to provide vertical illumination
- Results confirmed bollard-based solution was practical.
- Improvements: use louvers for glare control, coordinate light output level with the pedestrian signals, provide an alerting signal

BOLLARD-BASED FLUORESCENT LIGHTING SYSTEM

- New Jersey field test
  - Mounted at the ends of a crosswalk
  - Provides vertical illumination on pedestrians in crosswalk

Figure 23. a) View of crosswalk lighting while looking south; b) view of crosswalk lighting while looking north

BOLLARD-BASED LED LIGHTING SYSTEM

- Aspen, CO
- High contrast visibility with low glare

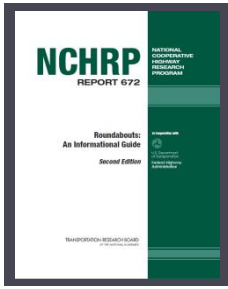
OTHER SITUATIONS

BUS STOP SHELTER LIGHTING DESIGN FACTORS

- The minimum level of lighting at shelter pavement should be 2.0 foot-candles
  - "over" lighting should be avoided.
- Transit stops should be located within 30-feet of an overhead light source
- Light patterns should concentrate light at the shelter while minimizing glare onto street.

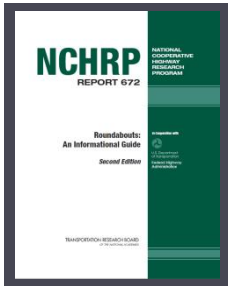
BUS STOP SHELTER LIGHTING POSSIBLE MATERIALS FOR USE

- Use vandal-resistant and durable fixtures.
- Lamp compartment and electrical access should be secured with a recessed hex head screw or equal means
- If possible, electrical services should be low voltage to reduce the risk of electrical shock
- Cutoff luminaries, low–reflectance surfaces, and low-angle spotlights can be employed to reduce light pollution
- Use solar lighting where there is no utility service until utilities can be established for the shelter or stop
  - Portable solar lighting may be used when transit service is detoured during construction projects



ROUNDABOUT LIGHTING

- The *Design Guide for Roundabout Lighting,* published by the Illuminating Engineering Society (IES), is the primary resource to consult for a roundabout lighting plan
- Lighting serves two main purposes:
  1. Provide visibility from a distance for users approaching the roundabout
  2. Provide visibility of the key conflict areas



ROUNDABOUT ILLUMINANCE

Functional Classification	Maintained Average Horizontal Illuminance on the Pavement Based on Pedestrian Area Classification			E_{avg}/E_{min}
	High	Medium	Low	
Major/Major	3.4 fc (34.0 lux)	2.6 fc (26.0 lux)	1.8 fc (18.0 lux)	3:1
Major/Collector	2.9 fc (29.0 lux)	2.2 fc (22.0 lux)	1.5 fc (15.0 lux)	3:1
Major/Local	2.6 fc (26.0 lux)	2.0 fc (20.0 lux)	1.3 fc (13.0 lux)	3:1
Collector/Collector	2.4 fc (24.0 lux)	1.8 fc (18.0 lux)	1.2 fc (12.0 lux)	4:1
Collector/Local	2.1 fc (21.0 lux)	1.6 fc (16.0 lux)	1.0 fc (10.0 lux)	4:1
Local/Local*	1.8 fc (18.0 lux)	1.4 fc (14.0 lux)	0.8 fc (8.0 lux)	6:1

Major = Roadway system that serves as the principal network for through traffic flow.
Collector = Roadway servicing traffic between major and local streets.
Local = Streets primarily for direct access to residential, commercial, industrial, and other abutting property.
High = Areas with significant numbers of pedestrians expected to be on the sidewalks or crossing the streets during the hours of darkness. Over 100 pedestrians during the average annual peak hour of darkness, typically 18:00 to 19:00 hours.
Medium = Areas where lesser numbers of pedestrians use the streets at night. Between 11 and 100 pedestrians during the average annual peak hour of darkness, typically 18:00 to 19:00 hours.
Low = Areas with low volumes of nighttime pedestrian usage. Less than 11 pedestrians during the average annual peak hour of darkness, typically 18:00 to 19:00 hours.

*Note: Use values for local/local functional classification if roundabout is located on roadway without continuous lighting.

Source: Adapted from IES *Design Guide for Roundabout Lighting* (*1*)

LIGHTING EQUIPMENT TYPE

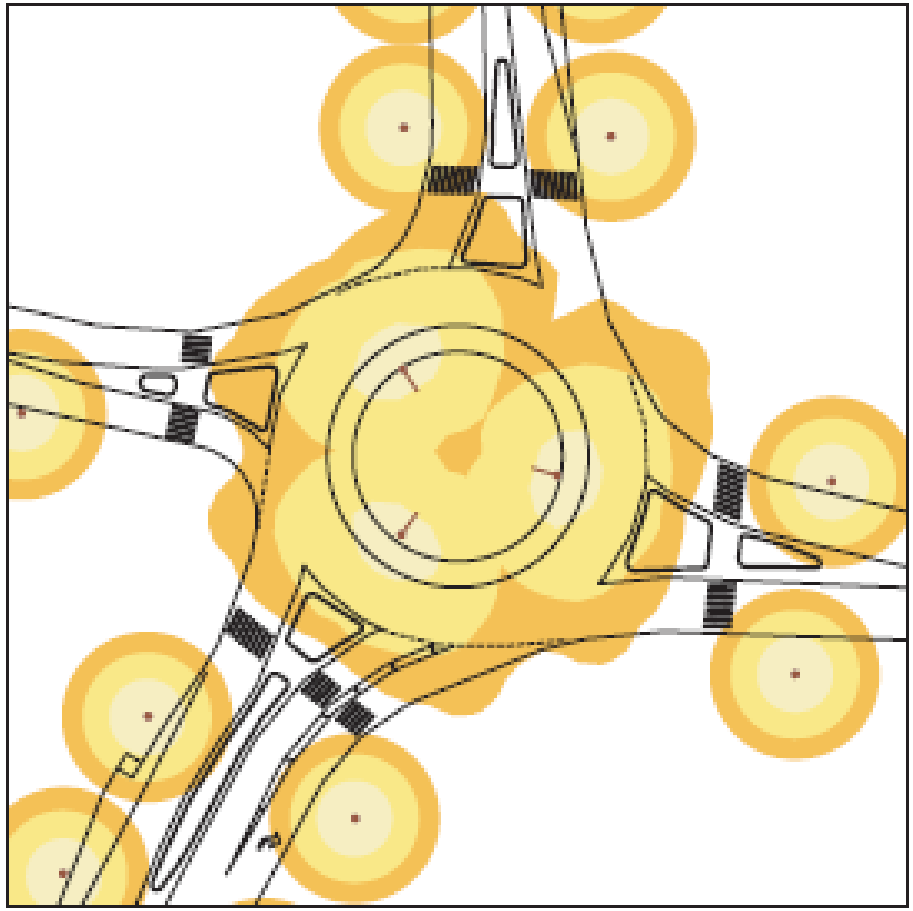
Type of Lighting Assembly	Typical Wattage	Typical Distribution	Common Mounting Height
Cobra-style	75 W–400 W HPS	Type II or III (full or semi cutoff)	30 to 50 ft (9 to 15 m)
Ornamental	75 W–200 W HPS	Type V (360° spread)	14 to 20 ft (4 to 6 m)
High-Mast	400 W–1,000 W HPS	Type V (360° spread)	50 to 100 ft (15 to 30 m)

W = watts; HPS = High Pressure Sodium
Source: Kansas Roundabout Guide (*9*)

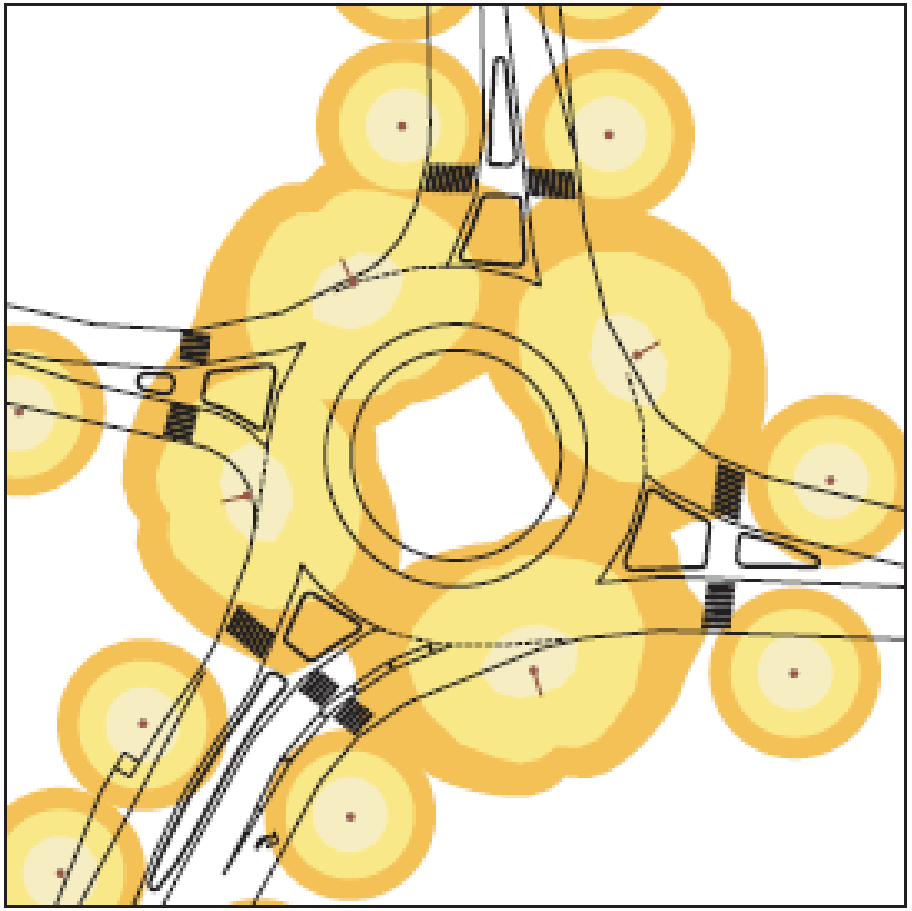
(a) Cobra-style (Loveland, Colorado)

(b) Mixed ornamental and cobra-style (Bend, Oregon)

CENTRAL VS PERIMETER LIGHTS



Central Illumination Design



Perimeter Illumination Design

ADVANTAGES & DISADVANTAGES FOR PERIMETER LIGHTING

Illumination Type	Advantages	Disadvantages
Perimeter illumination	• Illumination can be strongest around critical bicycle and pedestrian areas. • Continuity of poles and luminaires is maintained for the illumination of the lanes, as well as good visual guidance on the circulatory roadway. • Approach signs typically appear in positive contrast and thus are clearly visible. • Maintenance of luminaires is easier due to curbside location.	• Illumination is weakest in central island, which may limit visibility of roundabout from a distance. • More poles are required to achieve the same illumination level. • Poles may need to be located in critical conflict areas to achieve illumination levels and uniformity.

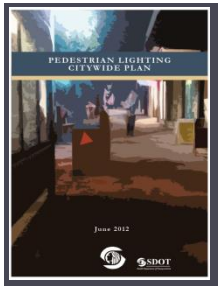
ADVANTAGES & DISADVANTAGES FOR CENTRAL LIGHTING

Illumination Type	Advantages	Disadvantages
Central illumination	• Perception of the roundabout is assisted at a distance by illuminating the central island. • Fewer poles are required to achieve the same illumination. • Pole in central island is clear of critical conflict areas for all but the smallest of roundabouts. • Exit guide signs on the periphery appear in positive contrast (front lit) and thus are clearly visible.	• Cannot achieve adequate vertical lighting levels without additional approach lighting. • Illumination is weakest in critical pedestrian and bicycle areas. • Signs on the approach are in negative contrast (back lit). • A path is needed to the base of the central pole for maintenance. • There is a greater risk of glare. • The central pole affects central island landscaping plan. • High mast lighting may be inappropriate in urban areas, especially residential areas.

Source: Adapted from Kansas Roundabout Guide (9)

SPECIALIZED FIXTURES

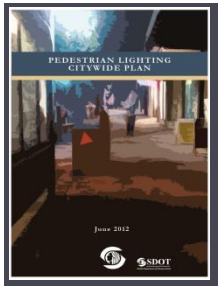
- Bollards
- Wall-mounted
- In-ground/on-ground
- Handrail



BOLLARDS

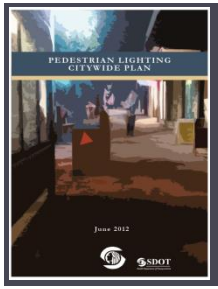
- When light needed at a lower level due to obstructions, tree canopies or nearby residential buildings where a pole-mounted light would be obtrusive
- When a need to restrict vehicle movements and access
- To delineate walkways in a curb-less environment

Bollard-style lights on Louisa walkway



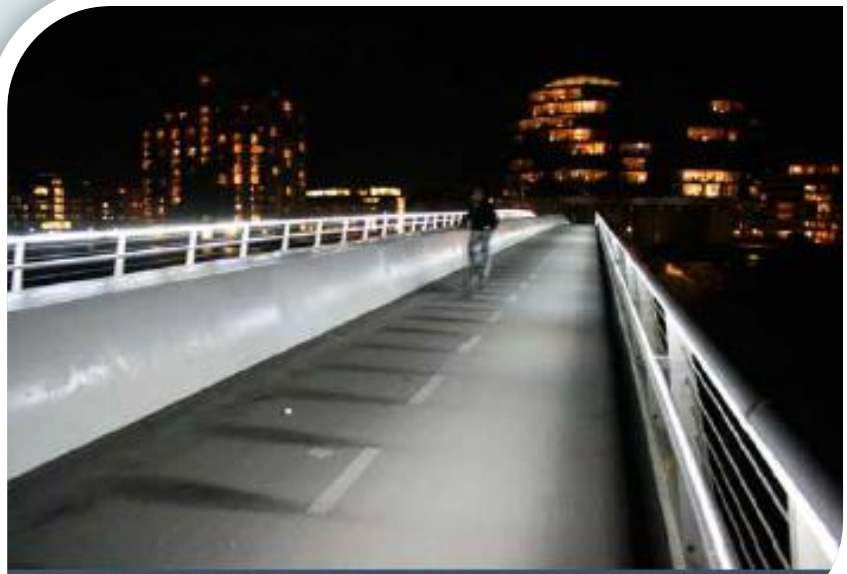
WALL-MOUNTED LIGHTS

- Useful in and around structures such as bridge over- and under-passes
- Used in conjunction with retaining walls and other structures as a cost effective alternative to pole-mounted lights

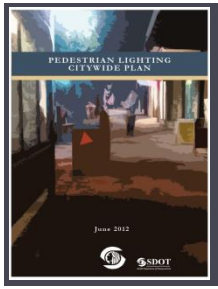


HANDRAIL

- Handrail lighting is a relatively new technology
- Provides a lighted strip integral to the underside of a handrail.
- Particularly effective on bridges and other structures to provide an alternative to pole mounted lights that can add weight and are more intrusive due to their mounting height



Lighted handrail on a bicycle/pedestrian bridge (Copenhagen)



IN-GROUND/ON-GROUND

- Used for up-lighting architectural and landscape features, designating edges of pathways or other elements, and for decorative effect
- Least supportive of dark-sky principles
  - should be used sparingly

Pedestrian lighting in McGraw Square near Westlake

QUESTIONS / RESOURCES

- FHWa Lighting Handbook – 2012
  - http://safety.fhwa.dot.gov/roadway_dept/night_visib/lighting_handbook/
- Informational Report lighting Design for Midblock Crosswalks
  - http://www.fhwa.dot.gov/publications/research/safety/08053/
- Pedestrian Lighting Citywide plan City of Seattle
  - http://www.seattle.gov/transportation/pedestrian_masterplan/docs/PedLightingFINAL.pdf
- NCHRP Report 672 Roundabouts: An Informational Guide Second Edition
  - http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_672.pdf
- Accessing Transit Design Handbook for Florida Bus Passenger Facilities
  - http://www.dot.state.fl.us/transit/Pages/AccessingTransitHandbook.pdf
- Public Lighting for Safe and Attractive Pedestrian Areas NZ Transport Agency Research Report 405
  - http://www.nzta.govt.nz/resources/research/reports/405/docs/405.pdf
- Design and Evaluation of Effective Crosswalk Illumination Final Report NJDOT
  - http://www.state.nj.us/transportation/refdata/research/reports/FHWA-NJ-2009-003.pdf

Thank You!

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