# Safety and Visibility Based Lighting Design

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# Introduction

A **large gap** (or disconnect) exists between traffic safety engineers and those designing street lighting.

Many safety-oriented studies simply define ***"improved lighting"*** in general as one of many safety improvements and assume just having any lighting is of high value

Can the way we design lighting impact safety to aid in meeting **Vision Zero?** ***YES!***

***All lighting is not equal. Products and designs vary***

***Glare, contrast, colour all impact visibility as much or more than light levels.***

Will focus on three (3) specific areas related to design and safety:

***Crosswalks and Intersections***

***Bike lanes***

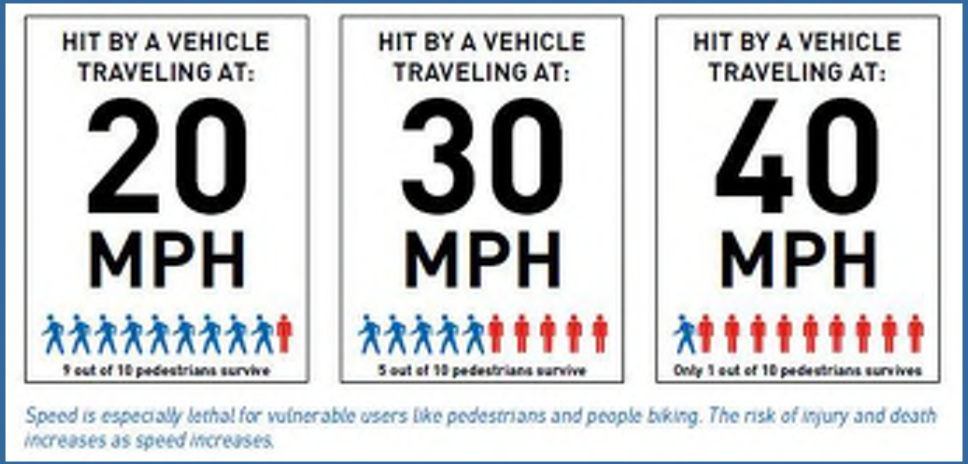
***Sidewalks and Security***

# Introduction

There should be a **balance** between safety for road users and impacts lighting has on humans, plants and wildlife off the roadway

This presentation is focused on **“safety”** however it is worth noting lighting design considerations should include:

- **Where and When to Light** - Light only where required
- **Glare reduction** - Shielding of bright sources off the roadway
- **Avoiding over lighting** – Brighter is not always better.
- **Spectrum impacts** – All lighting has impacts both positive and negative




# Vision Zero

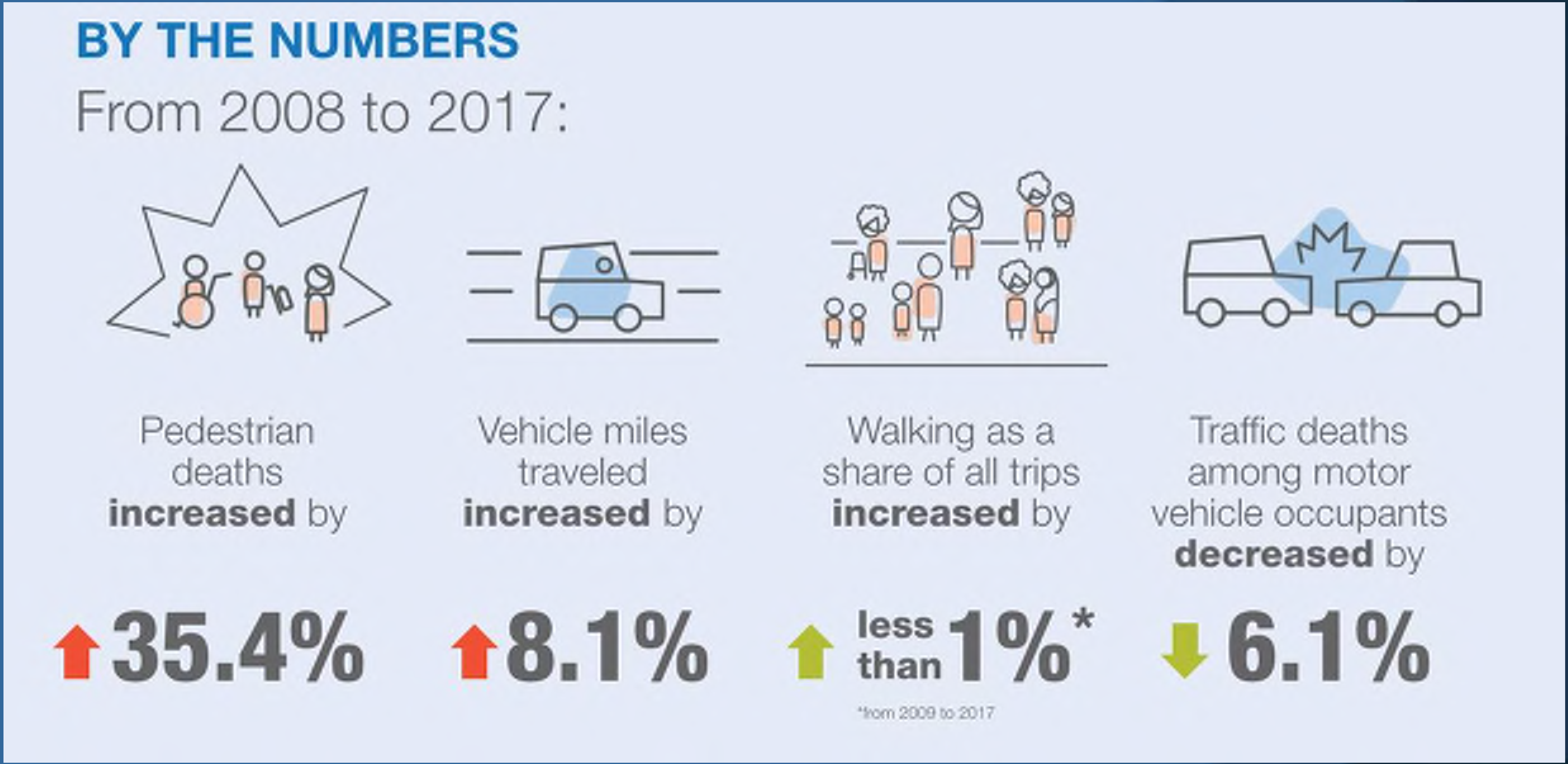


Source – Vision Zero web searches


# IES Vision Zero Task Group

Goal to provide info to Vision Zero regarding visibility based lighting design

Source – Vision Zero web searches



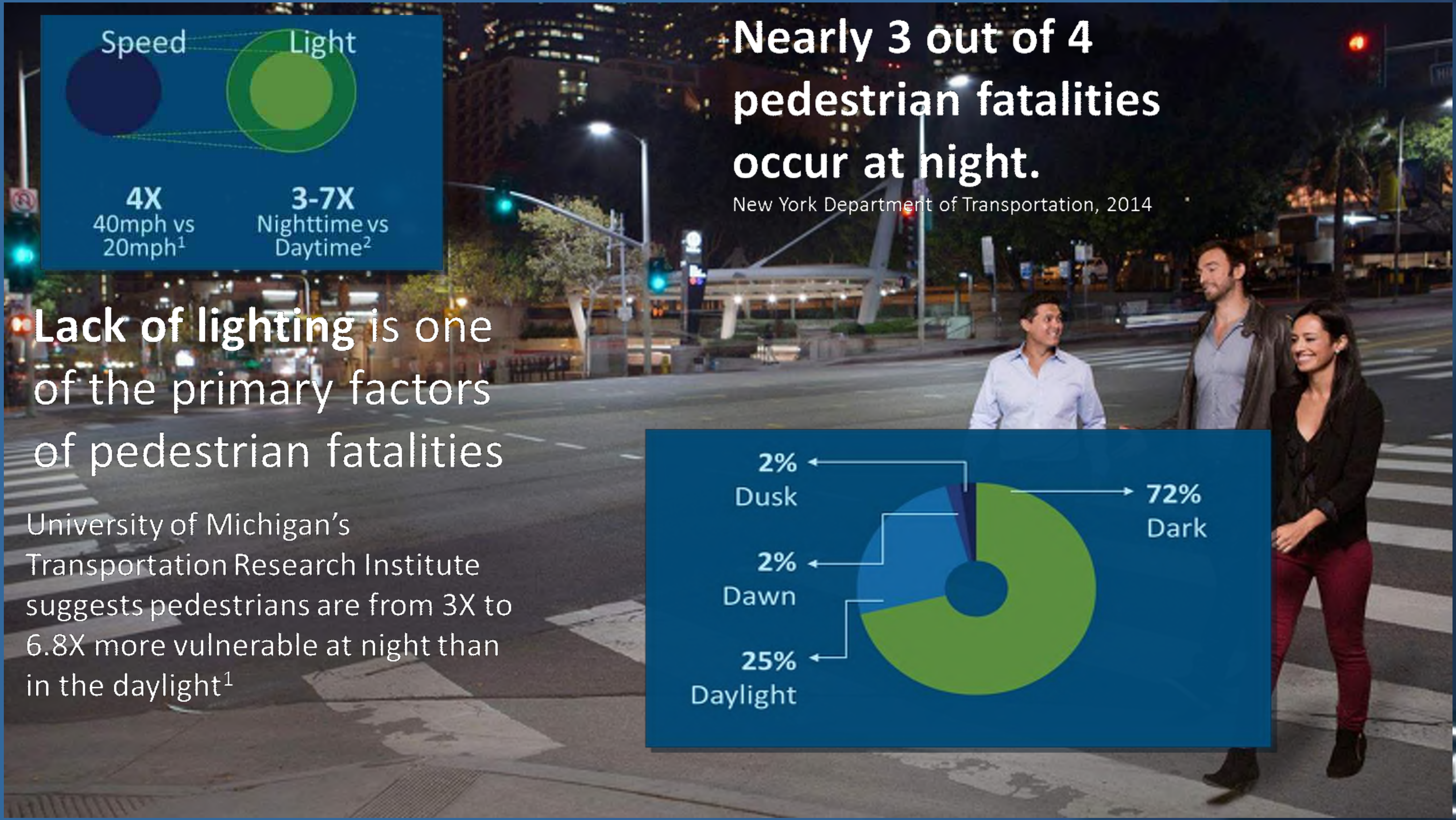

Source - 2019 Dangerous By Design Report

# Why Light

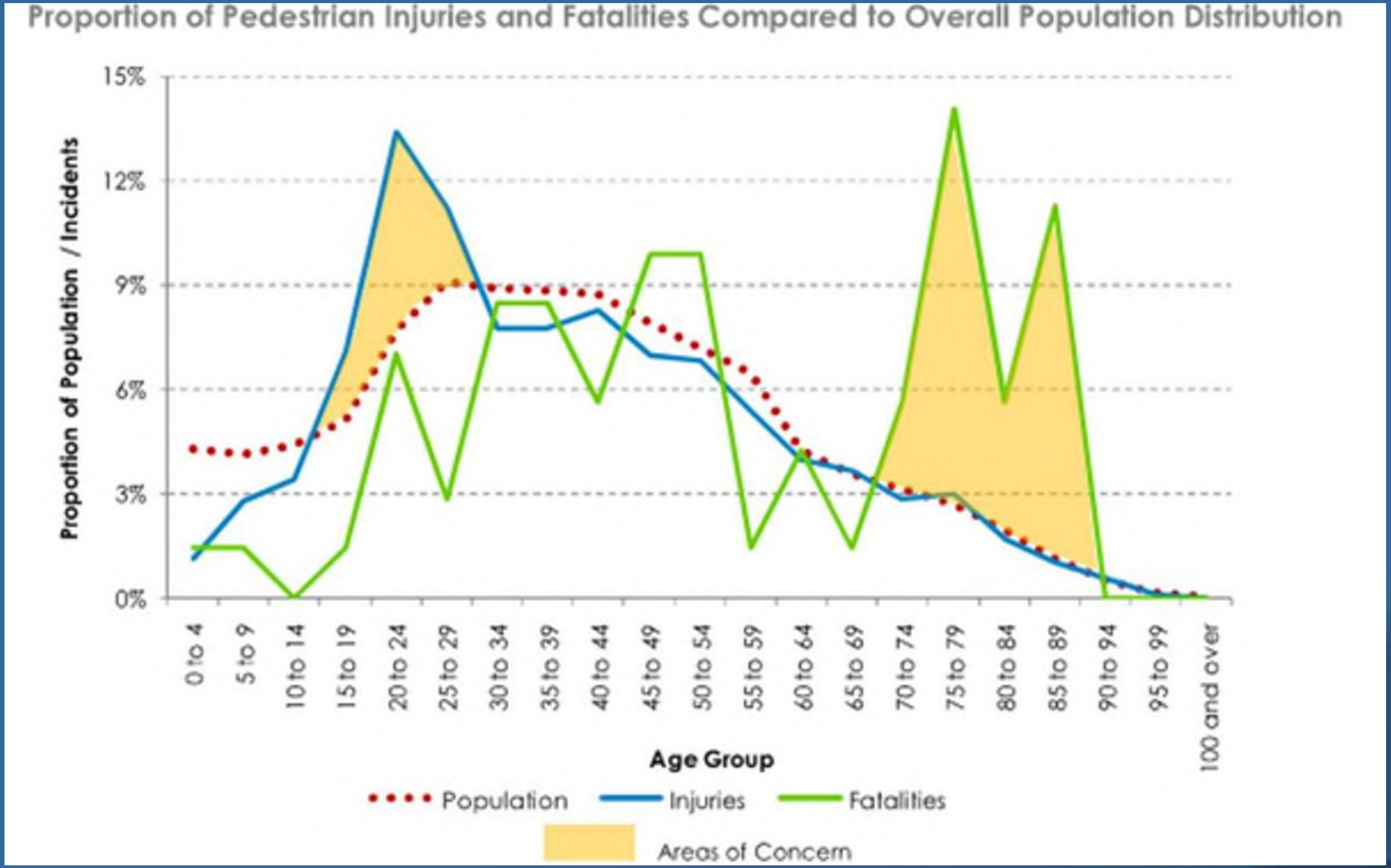
- ***Improves visibility for road users (drivers, pedestrians and cyclists) – Focus of this presentation***
- Reduces glare effects from oncoming vehicle headlamps
- Provides a level of comfort and feeling of security

ng.com

# Safety Issues – What We Know



# Age Factors




Source - City of Vancouver Pedestrian Safety Study - 2012

# Age – Key Visibility Factor

- % of older drivers is increasing. We are living longer!
- Age related changes in the eye can cause issues for the older driver.
- The yellowing of the lens can reduce visibility

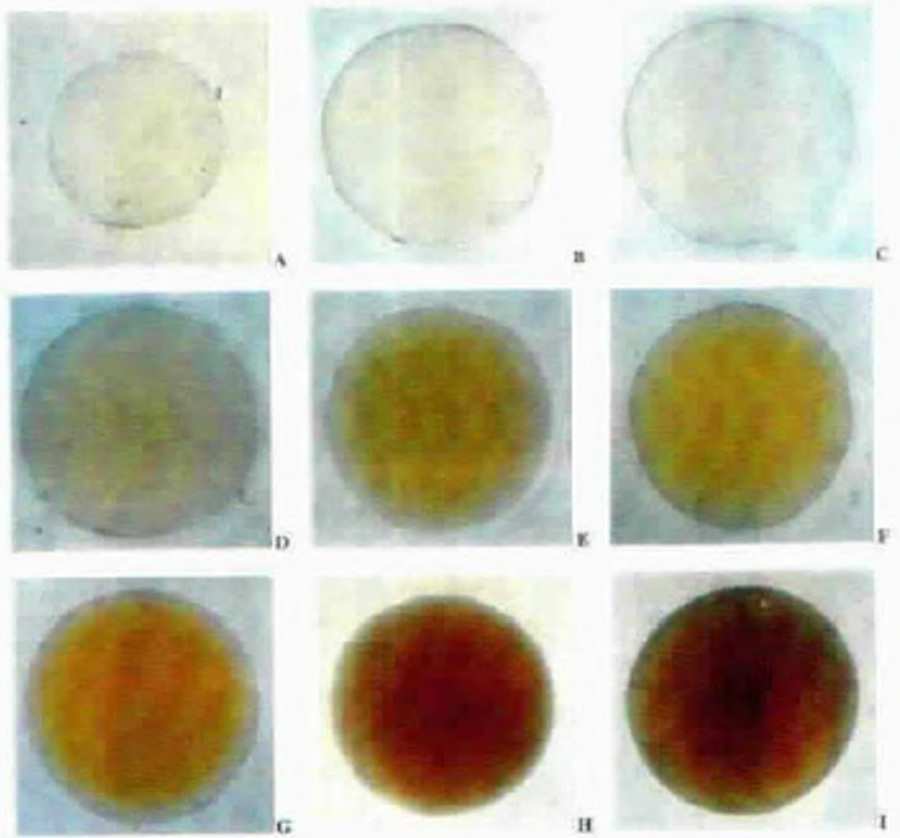


Fig. 3 Yellowing and transparency of the Human Lens from 6 month (A) to 8 years (B), 12 years (C), 25 years (D), 47 years (E), 60 years (F), 70 years (G), 82 years (H) and 91 years (I) of age.

Source – City of Edmonton Light Efficient Community Policy (2012)

# Stopping Sight Distances (SSD) – Key Factor

| Table 1: AASHTO Stopping Sight Distance (Wet Pavement) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Stopping Sight Distance M (Ft) by Percent Grade (%) | | | | | | | |
| | | Downgrade | | | Upgrade | | |
| Traffic Speed km/h (mph) | 0 | 3 | 6 | 9 | 3 | 6 | 9 |
| 35 (20) | 35 (115) | 35 (116) | 40 (120) | 40 (126) | 35 (109) | 35 (107) | 35 (104) |
| 40 (25) | 50 (155) | 50 (158) | 50 (165) | 55 (173) | 45 (147) | 45 (143) | 45 (140) |
| 50 (30) | 60 (200) | 65 (205) | 65 (215) | 70 (227) | 60 (200) | 60 (184) | 55 (179) |
| 60 (35) | 80 (250) | 80 (257) | 85 (271) | 90 (287) | 75 (237) | 70 (229) | 70 (222) |
| 65 (40) | 95 (305) | 95 (315) | 100 (333) | 110 (354) | 90 (289) | 85 (278) | 80 (269) |
| 75 (45) | 110 (360) | 115 (378) | 120 (400) | 130 (427) | 105 (344) | 100 (331) | 100 (320) |
| 80 (50) | 130 (425) | 135 (446) | 145 (474) | 155 (507) | 125 (405) | 120 (388) | 115 (375) |
| 90 (55) | 150 (495) | 160 (520) | 170 (553) | 180 (593) | 145 (469) | 140 (450) | 135 (433) |
| 100 (60) | 175 (570) | 185 (598) | 195 (638) | 210 (686) | 165 (538) | 160 (515) | 150 (495) |
| 105 (65) | 200 (645) | 210 (682) | 220 (728) | 240 (785) | 190 (612) | 180 (584) | 170 (561) |
| 115 (70) | 225 (730) | 235 (771) | 250 (825) | 275 (891) | 210 (690) | 200 (658) | 195 (631) |
| 120 (75) | 250 (920) | 265 (866) | 285 (927) | 305 (1003) | 235 (772) | 225 (736) | 215 (704) |

**Source:** A Policy on Geometric Design of Streets & Highways, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design.

The speed and distance columns only correspond to their metric or English equivalent, i.e., if determining the SSSD for a posted speed in kilometer per hour (km/h), use the value shown in m, if using miles per hour (mph), use the value shown for ft.

- SSD is the distance travelled to stop a vehicle.
- SSD used for tunnel lighting not for general roadway lighting
- Vehicle Headlamps may provide adequate illumination on straight roads with speeds of 50kph< (Source IES RP-8-18 Section 3.1.)
- The AASHTO Green Book suggests that with the assumed 24-inch height of headlamps, an object 16 inches above the roadway will be within the line of the headlamps at a distance equal to stopping sight distance.



AASHTO - American Association of State Highway and Transportation Officials

# Design Considerations

**Residential Streets 50 kph < (most are to lowest level 0.3 cd/m2)** – Consider Car headlamps and Driver Safe Stopping Distances and dim in off peak periods (say midnight to 5AM)

These roads comprise a significant inventory in a typical city. Lighting research focused on highways and freeways (FHWA)

Lighting is of value so turning lights off may diminish ones "feeling of security". Santa Rosa, California.

Consider 30-60% dimming off peak via adaptive system

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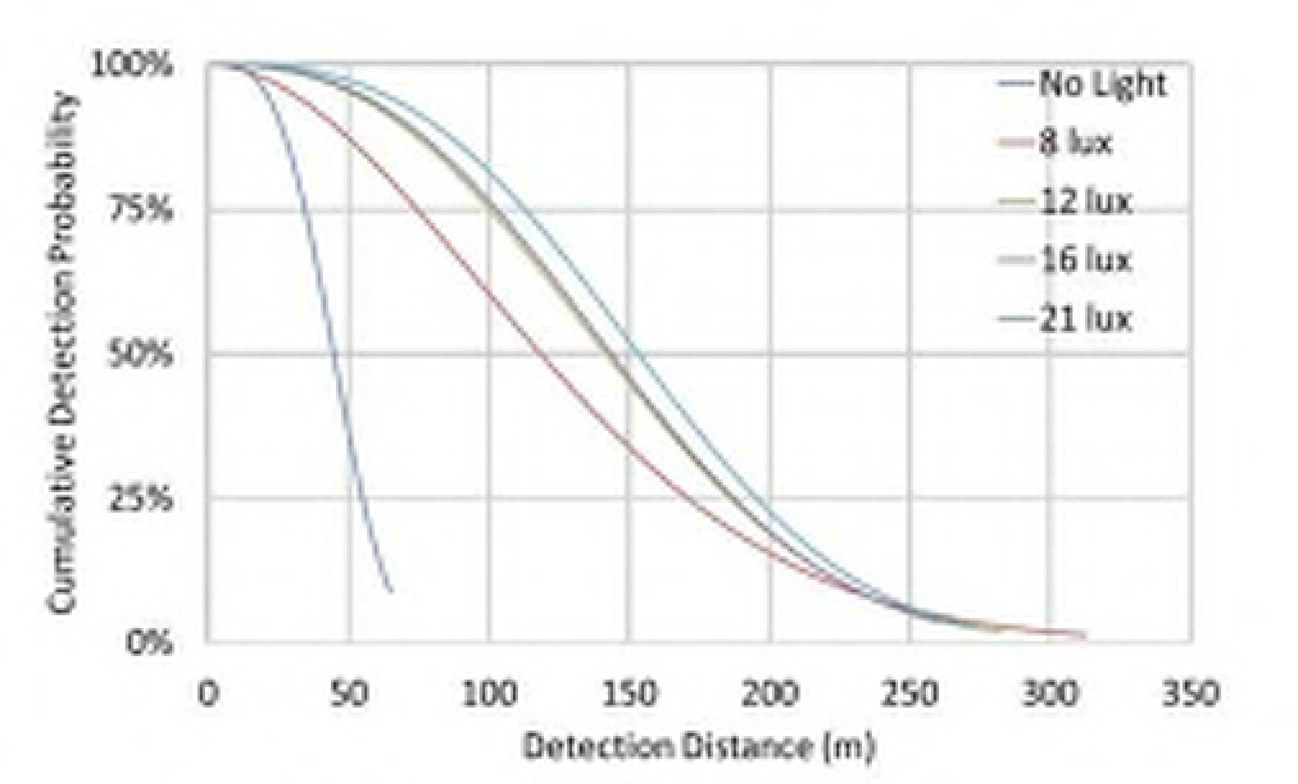
Source – TAC Roadway Lighting Efficiency and Power Reduction Guide (2012)

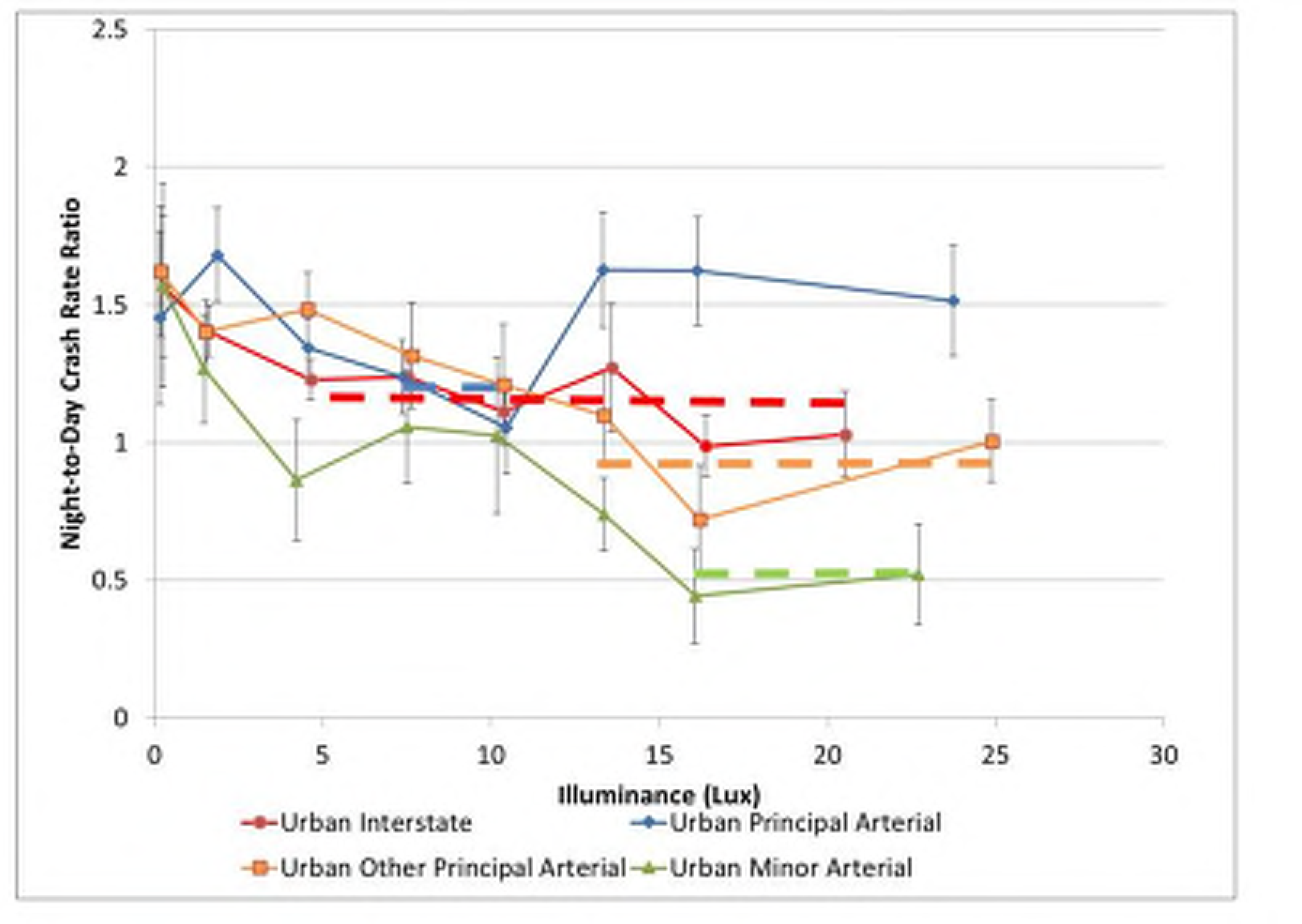
# Lighting Level and Detection Distances

- The human response to lighting is based on a rise and plateau relationship (Bhagavathula)
- Lighting has an impact up to a certain level
- Past that level there is no benefit of additional lighting




Source –Exploring the Relationship Between Street Lighting Levels and Physical Activity After Dark: Results of a Pilot Study - 2018

# Crash Data and Light Levels



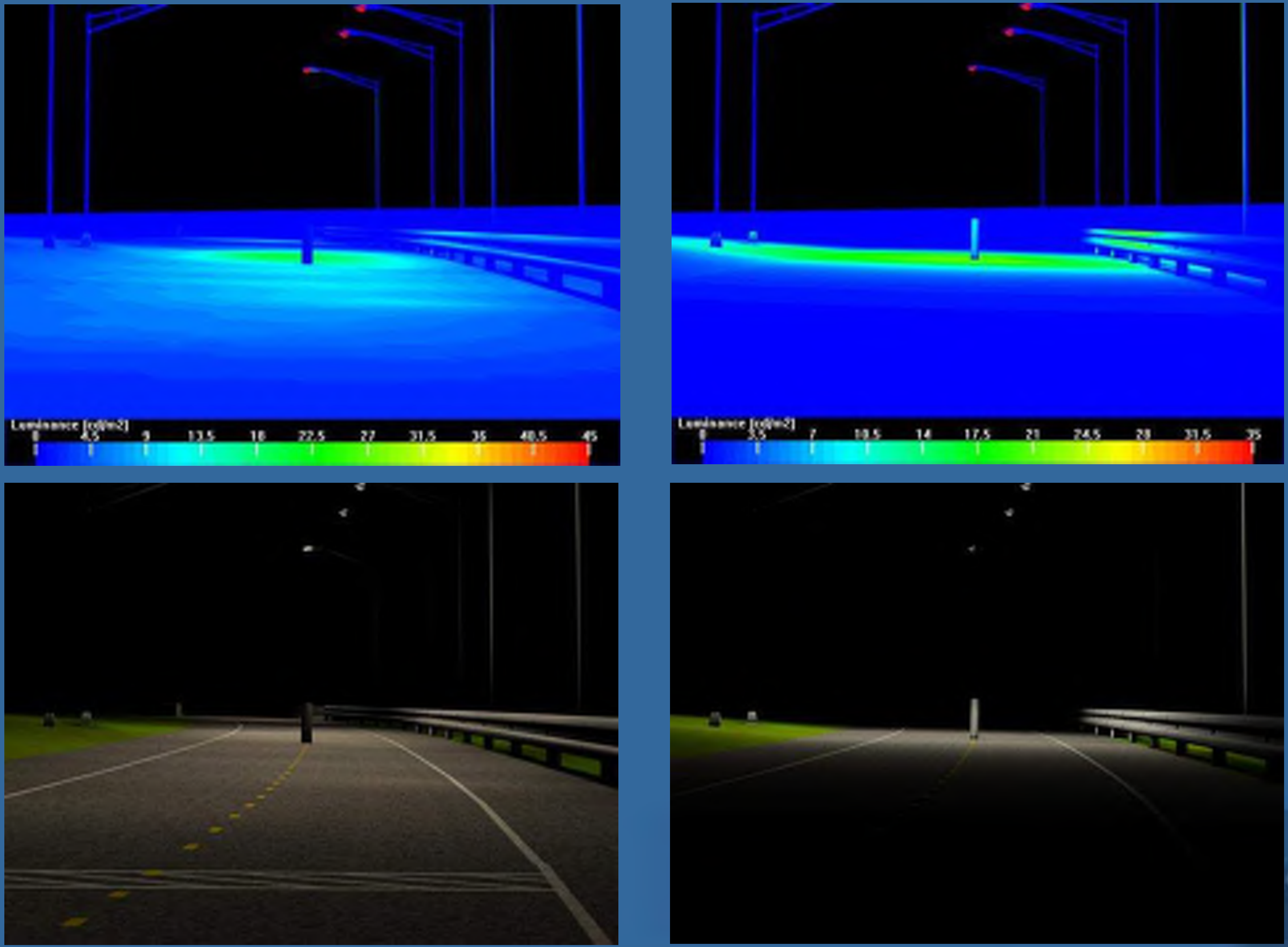

Source - Design Criteria for Adaptive Roadway Lighting PUBLICATION NO. FHWA-HRT-14-051

# Contrast – Key Visibility Element

We require contrast to detect objects


*Figure 2-14 – Examples of Negative and Postive Contrast.*

# Contrast



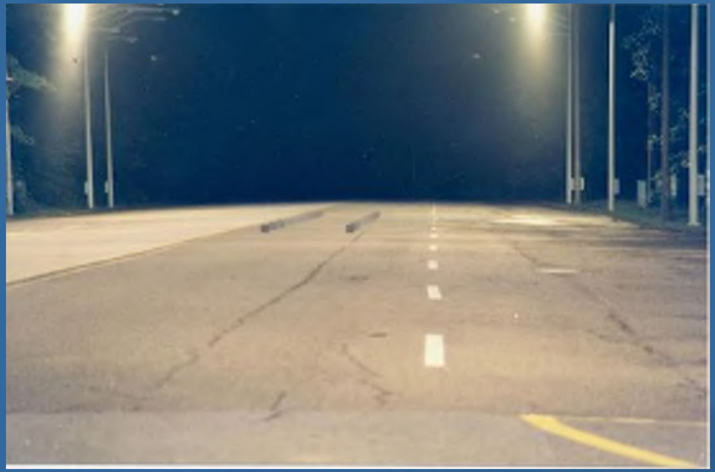

Images on the left are **negative contrast** and on the right are **positive contrast**

# Small Target Visibility (STV)

The STV value is a weighted average of the visibility level (VL) of these targets.  This method is a useful tool in comparing lighting designs.

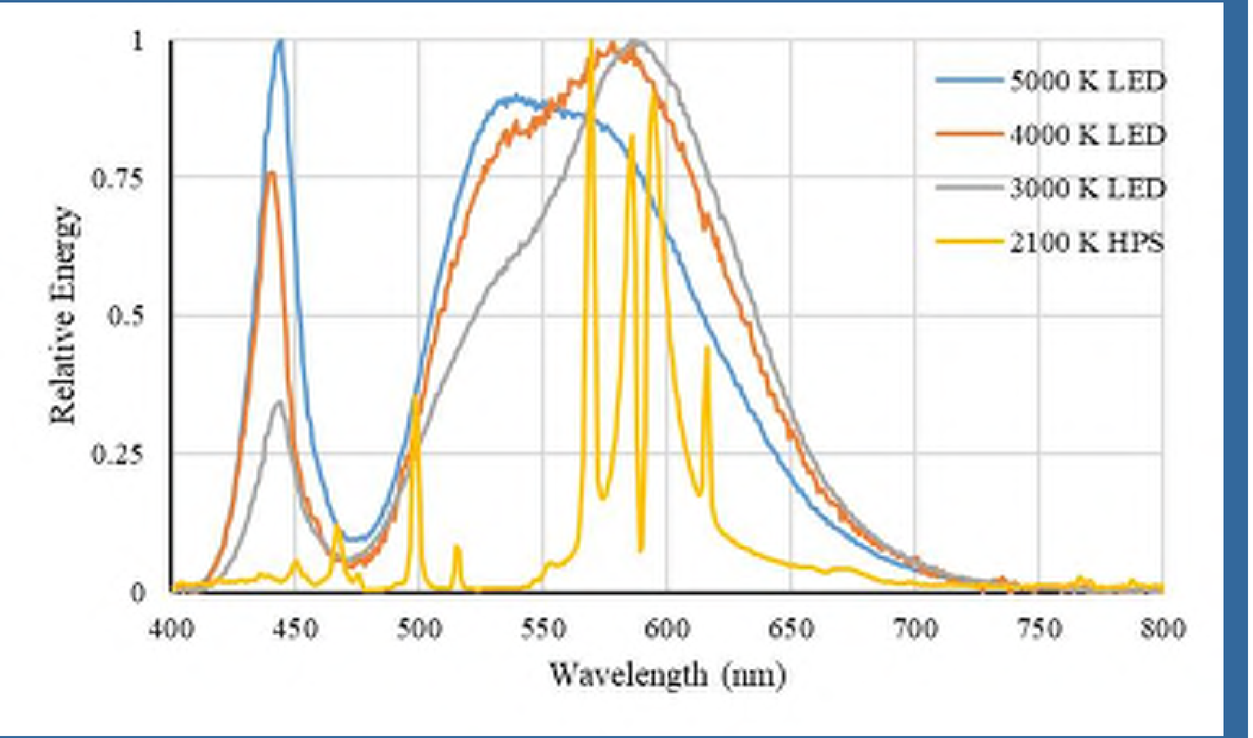
The figures below show similar luminance designs, but the higher STV value of the road on the left indicates better target visibility of rows of targets on the roadway.

Refer to IES RP-8-18

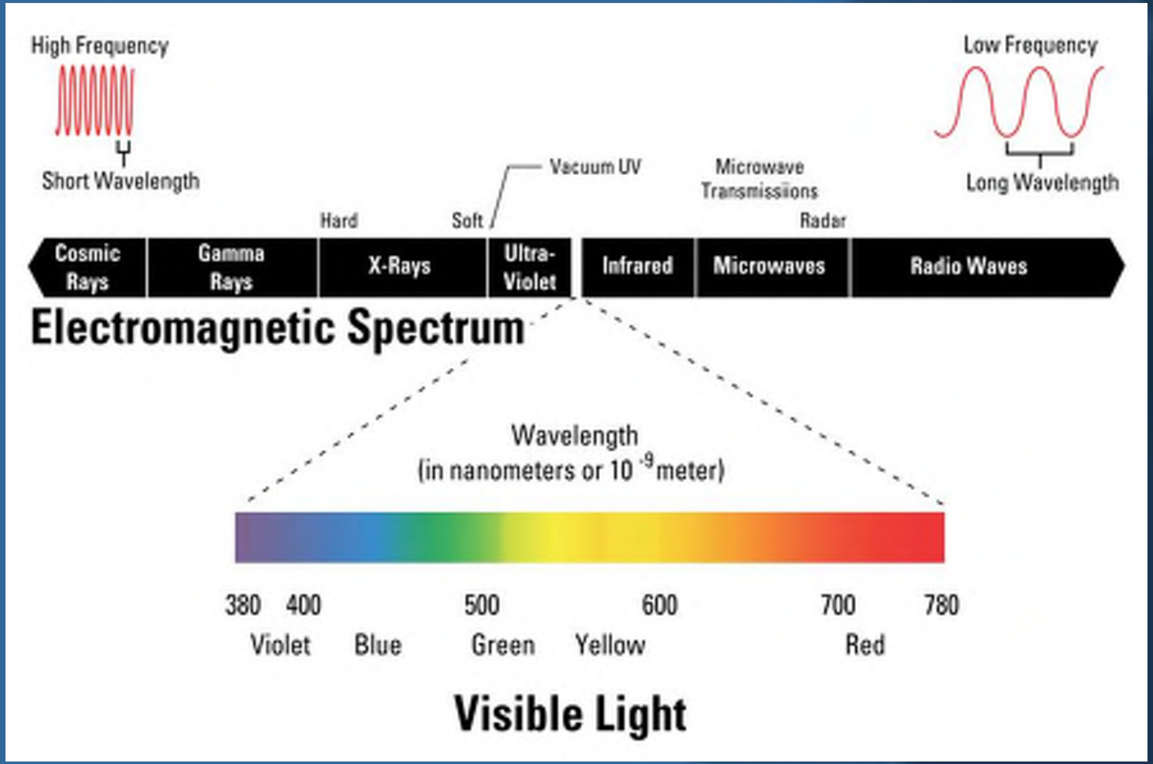


Source -  IES RP-8-18

# Spectral Power Distribution of Various Light Sources




Source - NCHRP 05-22 GUIDELINES FOR SOLID STATE ROADWAY LIGHTING (2019)




Source - TAC Roadway Lighting Design Guide (2006)

# Object Detection Distances under Various CCT's

| *Location* | *Luminaire Type* | *CCT & System Type* | *~Avg. Target Detection Distance (ft.)* |
|---|---|---|---|
| Anchorage, AK | LED | 4100 K | 213 |
| Anchorage, AK | LED | 4300 K | 210 |
| Anchorage, AK | Induction | 4000 K | 174 |
| Anchorage, AK | LED | 3500 K | 167 |
| Anchorage, AK | HPS | 2000 K | 141 |
| San Diego, CA | LED | 3500 K | 135 |
| San Diego, CA | Induction | 3000 K | 131 |
| San Diego, CA | HPS | 2100 K | 128 |
| San Diego, CA | Induction | 3000 K | 125 |
| San Diego, CA | LED | 3500 K | 105 |
| San Jose, CA | LED | 5000 K | 233 |
| San Jose, CA | LED | 4000 K | 223 |
| San Jose, CA | Induction | 4000 K | 197 |
| San Jose, CA | HPS | 2100 K | 193 |
| San Jose, CA | LPS | 1700 K | 190 |
| San Jose, CA | LED | 3500 K | 157 |
| Seattle, WA | LED | 4100 K | 145 |
| Seattle, WA | LED | 4000 K | 138 |
| Seattle, WA | LED | 5000 K | 122 |
| Seattle, WA | HPS | 2000 K | 103 |
| Seattle, WA | LED | 3500 K | 100 |
| Seattle, WA | HPS | 2000 K | 68 |

Sources - Advanced Street Lighting Technologies Assessment Project, City of San Jose, 2010; Advances Street Lighting Technologies Assessment Project - City of San Diego, 2010; Clanton, Gibbons, Garcia, & Barber, 2014; Street Lighting Survey for Commercial Areas in the Municipality of Anchorage, 2009).

# Object Detection Distance Studies

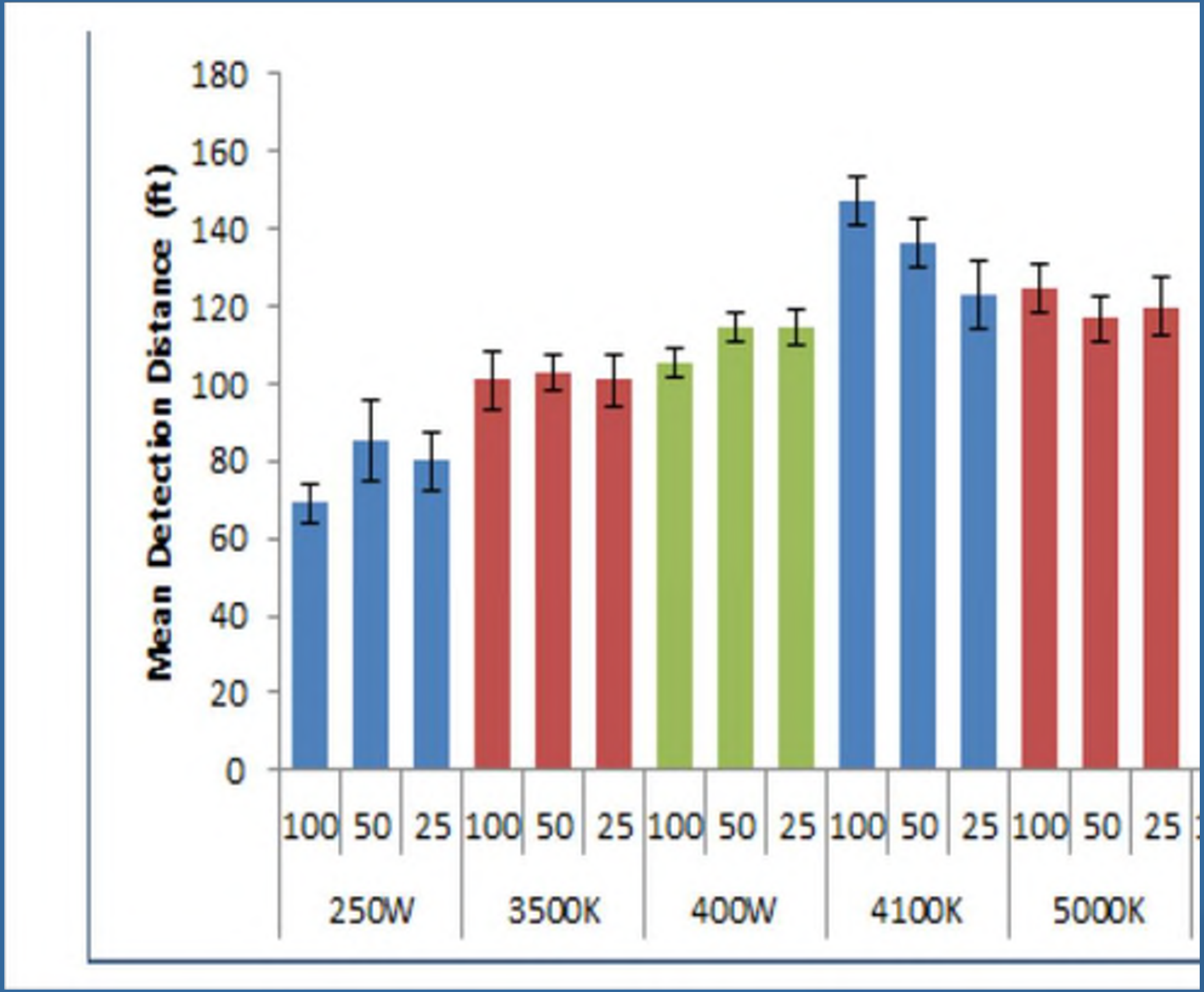
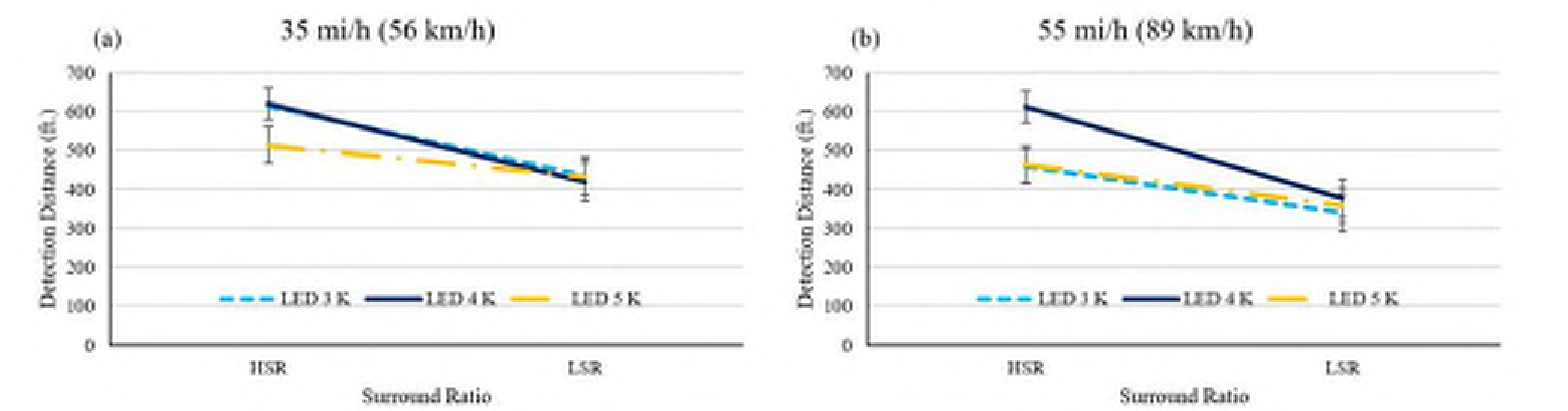



Diagram shows various light sources at mid block x-walk along with object detection distances (100-50-25 are % of full light output) - ***<u>Foveal</u>***

Source - 2014 REPORT #E14-286 Seattle LED Adaptive Lighting Study

# Object Detection Distance

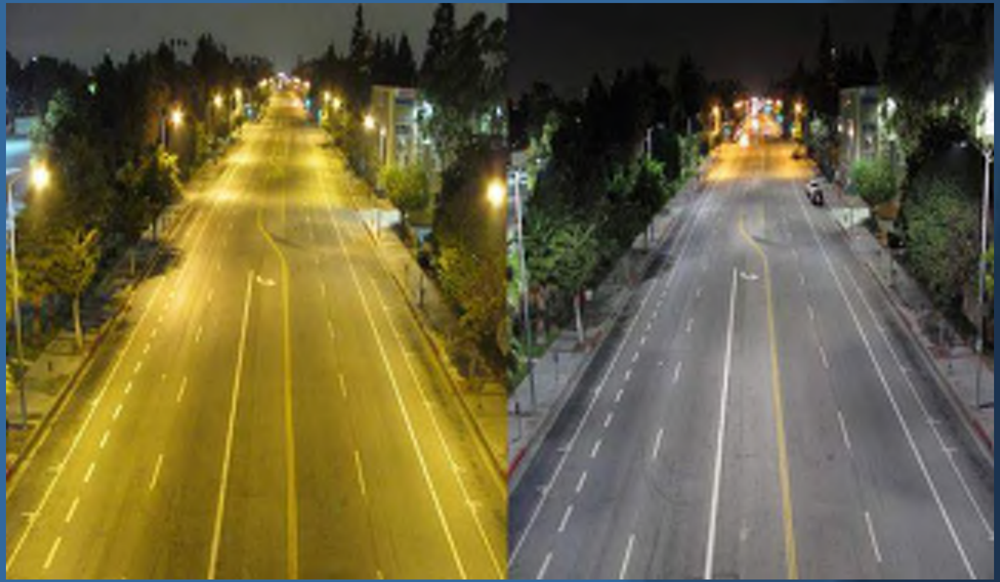



**Peripheral Vision**

SPD does not significantly influence driver visual performance at speeds less than 56 kph (<). At 89 kph(>) 4000K has benefits in Detection Distance

Source - NCHRP 05-22 GUIDELINES FOR SOLID STATE ROADWAY LIGHTING (2019)

# Correlated Colour Temperature (CCT)

Source - City of LA LED Conversion

# Contrast and Spectral Power Distribution (SPD)

**Colour can impact contrast – SPD of the lighting source is not factored into design and should be considered.**

# Turtle Friendly Streetlights

580-640 nm as “turtle friendly” and approved by the Sea Turtle conservation groups.

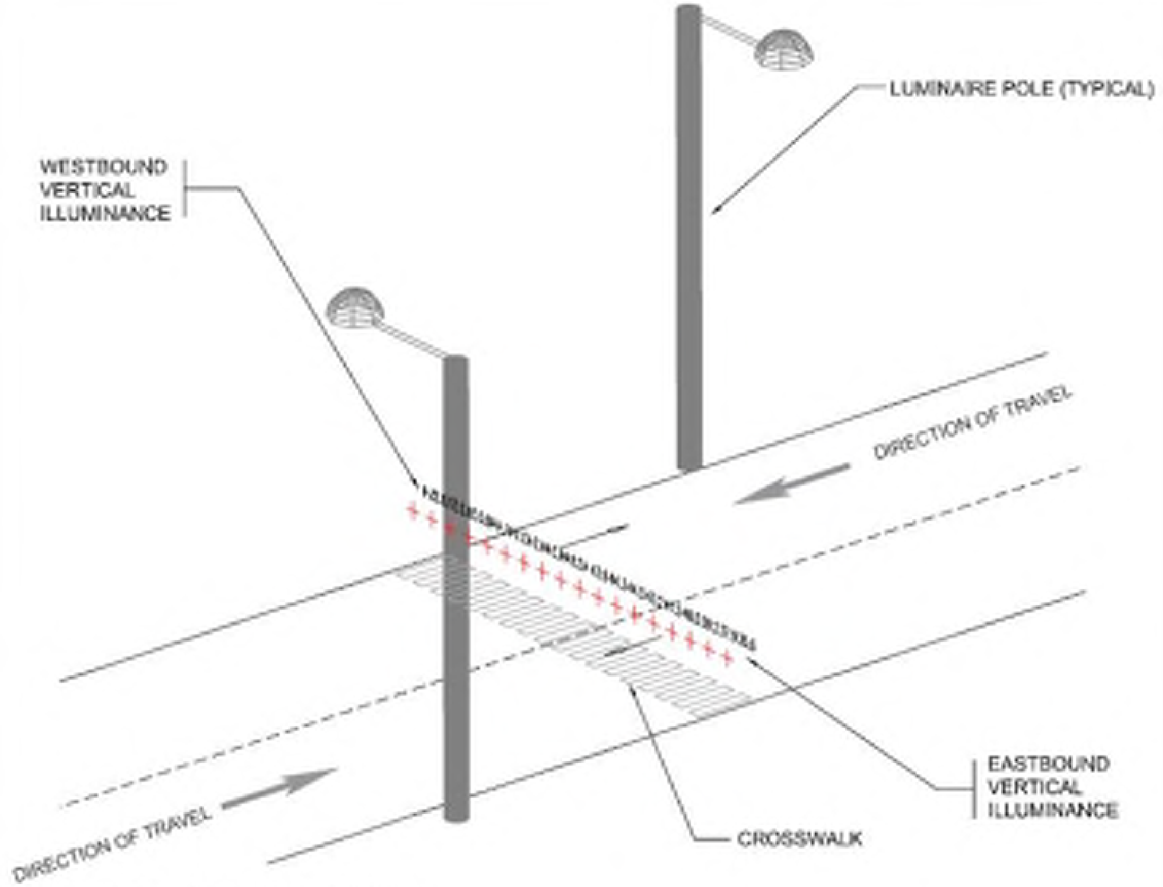
Source – Antigua LED Conversion

# Mid Block Crosswalk Lighting

- In Europe 40 Lux was used in all crosswalks which resulted a 66% reduction in pedestrian crashes (FHWA PL-01-034)
- Vertical illuminance levels of 20 Lux seems sufficient for crosswalks. Pole placement, mounting height and wattages are key to meet requirements

Source Informational Report on Lighting Design for Midblock Crosswalks Publication No. FHWA-HRT-08-053 April 2008

# Mid Block Crosswalk Lighting




Arrows indicate direction of measurements

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

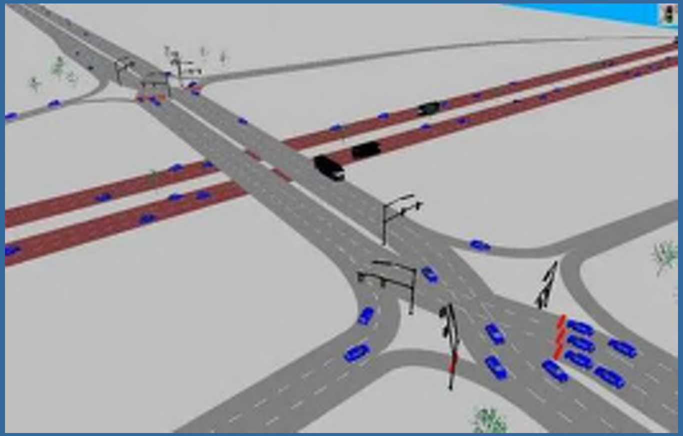
Source - TAC Guide for Design of Roadway Lighting (2006)

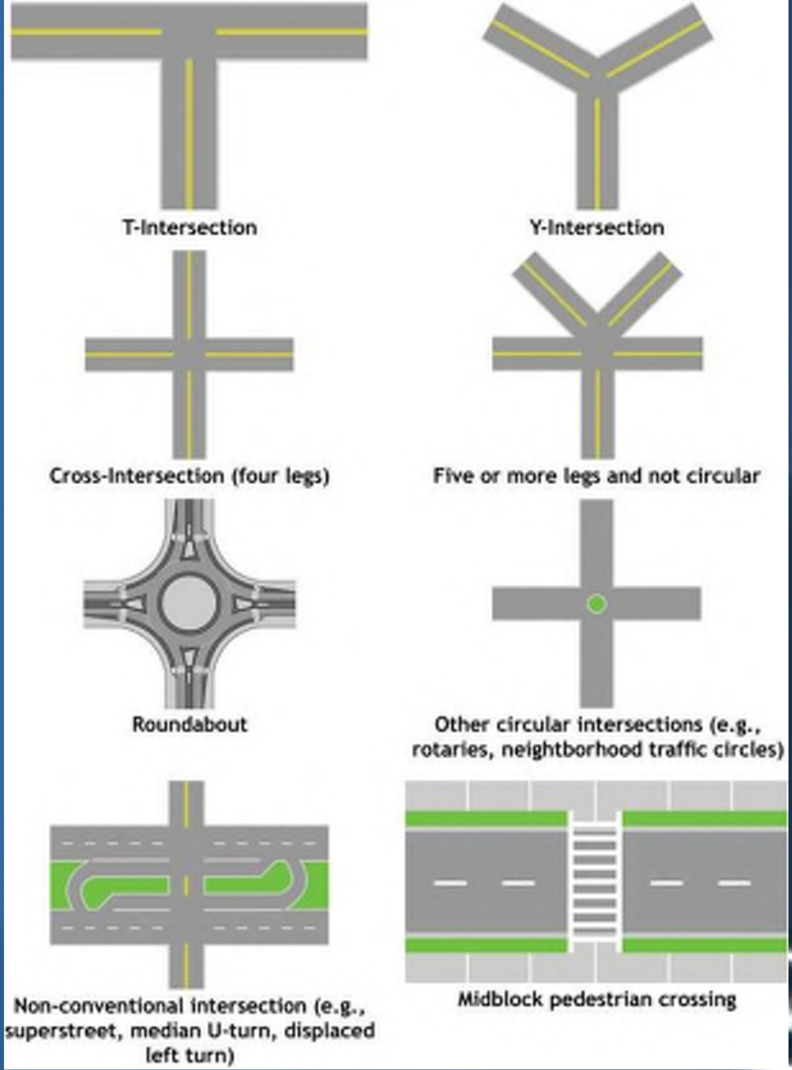
# Mid Block Crosswalks

Rectangular Rapid Flash Beacons (RRFB's)

Do we still light?

# Intersections



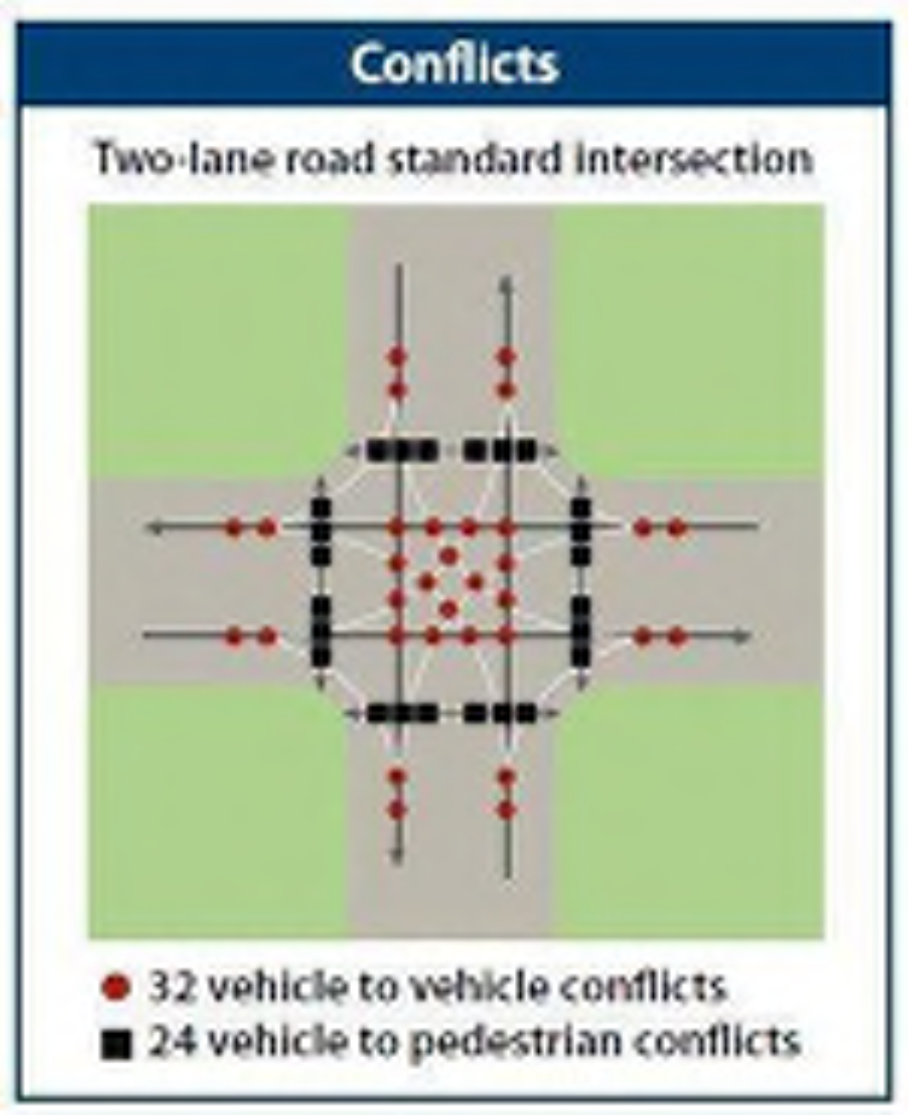



Source – Internet

# Intersection Conflict Points

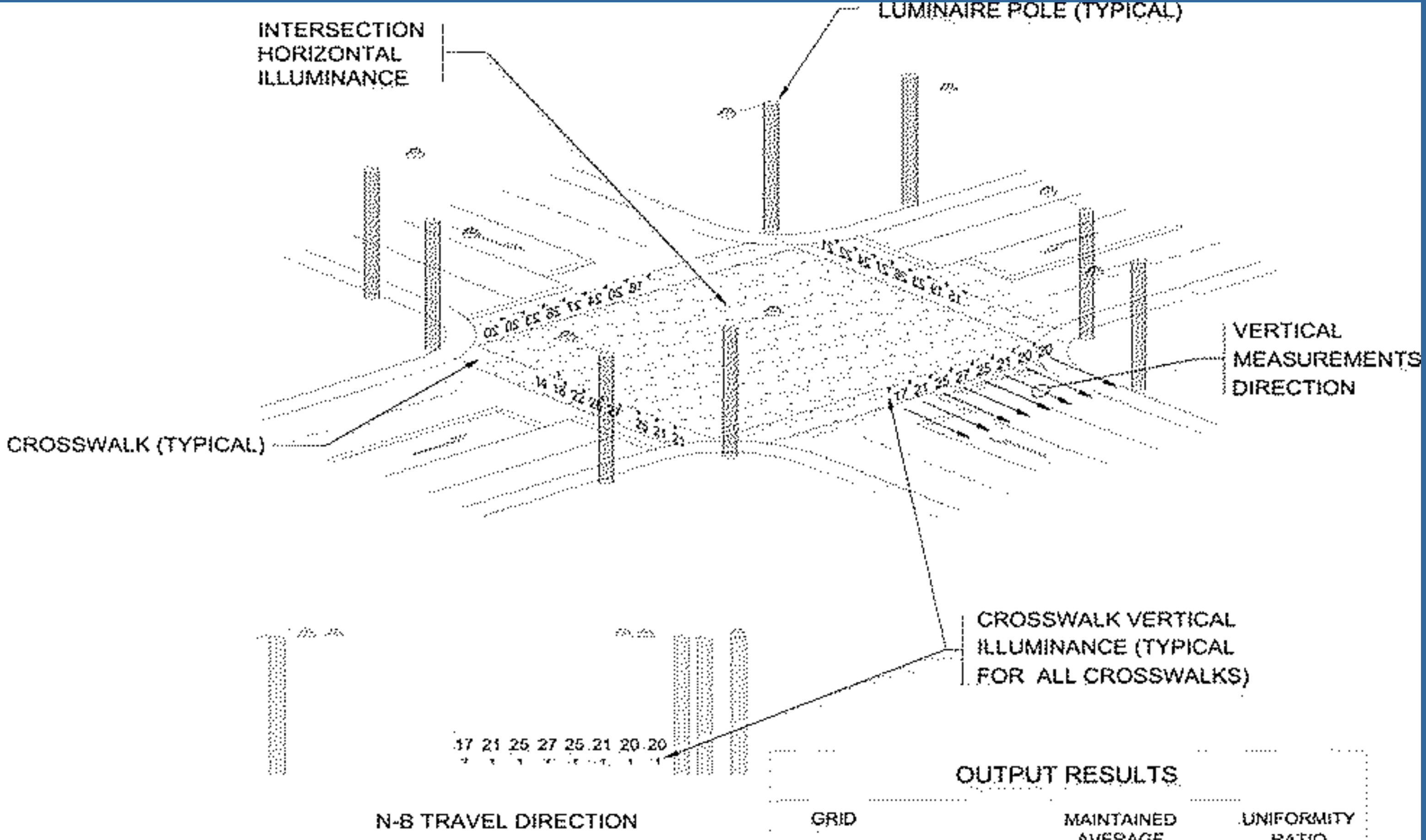
**Early Research Findings*** are showing – Typically Vehicle to Vehicle – Particularly rear end crashes are not impacted by lighting – It is all about the pedestrians – That is where lighting is effective

Source - Virginia Tech Transportation Institute




Source - Internet

# Intersection Lighting

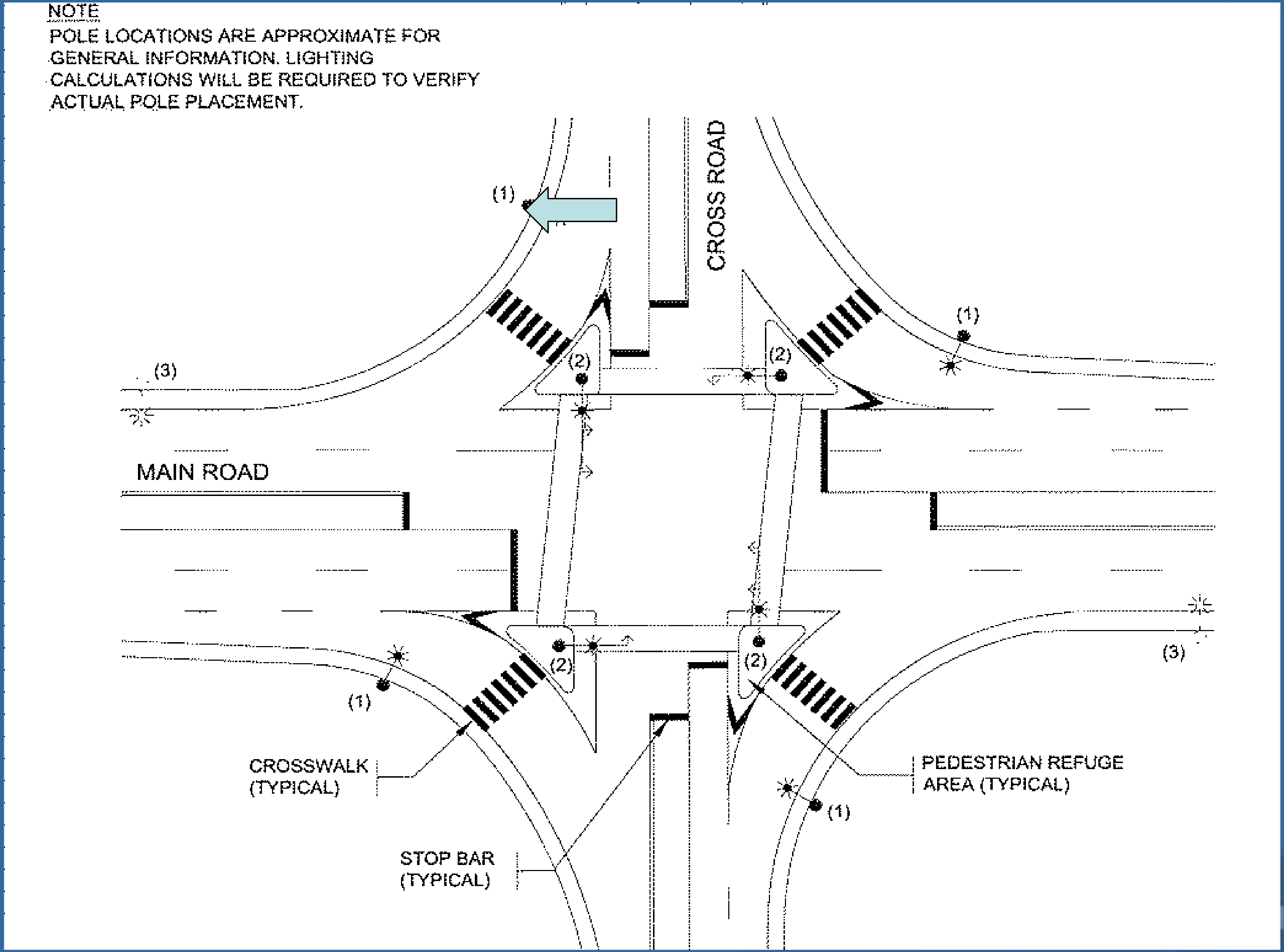



OUTPUT RESULTS

| 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 |

Source - TAC Guide for Design of Roadway Lighting (2006)

# Intersection Lighting RP-8-18



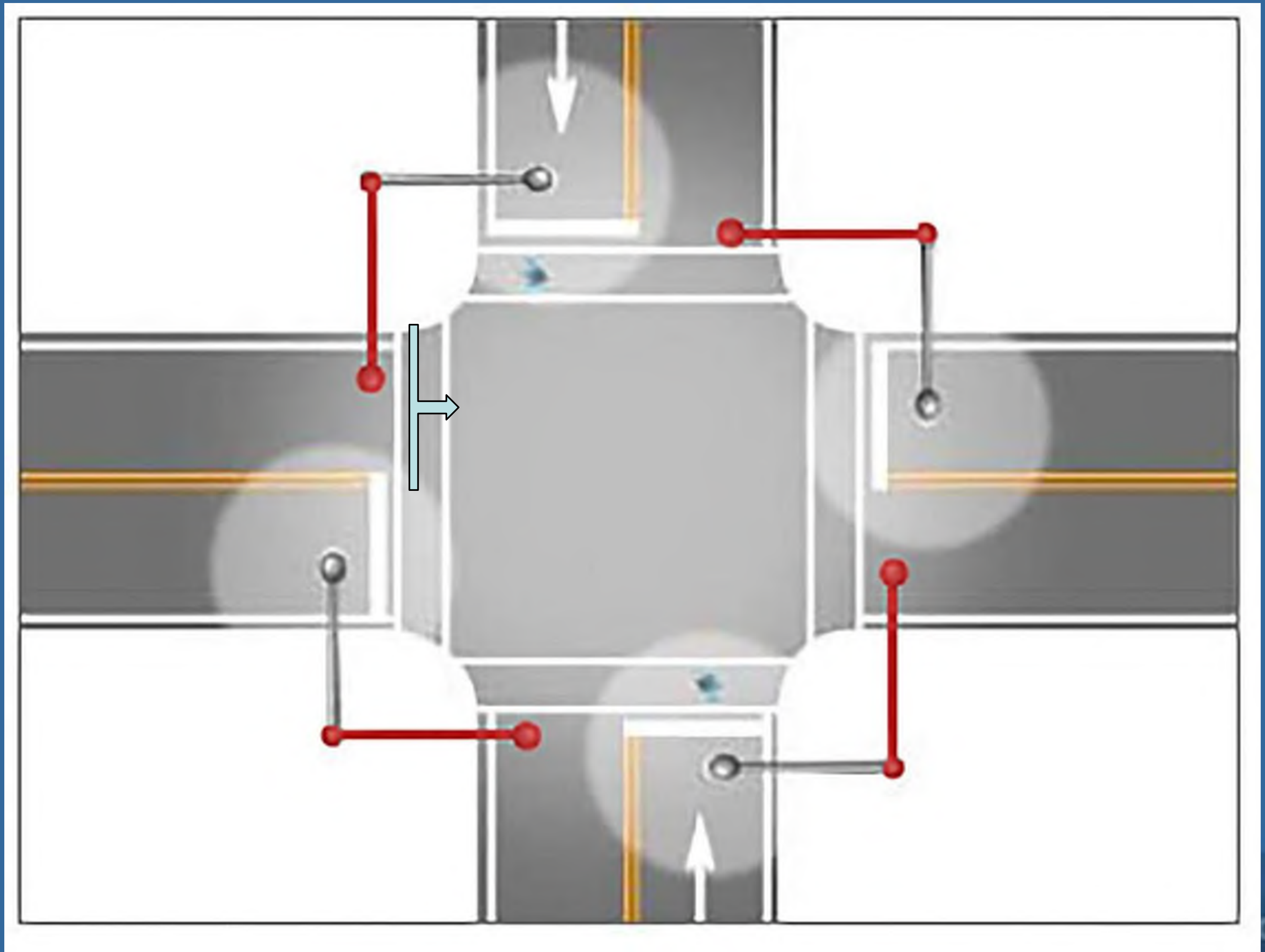

Source - TAC Guide for Design of Roadway Lighting (2006)

# Intersections - Signals


- Signal Operation – Protected Left or right Arrow and Permissive Green Ball Turning Movements. **Permissive left and right is high risk. Driver has allot to deal with**
- Car headlamp not effective as result of turning movement.
- Define conflict points and assess vertical levels.

Image Sources - Internet

# Intersection Lighting



Studying benefits of additional lighting on signal poles.

# Rural Intersection Safety Analysis

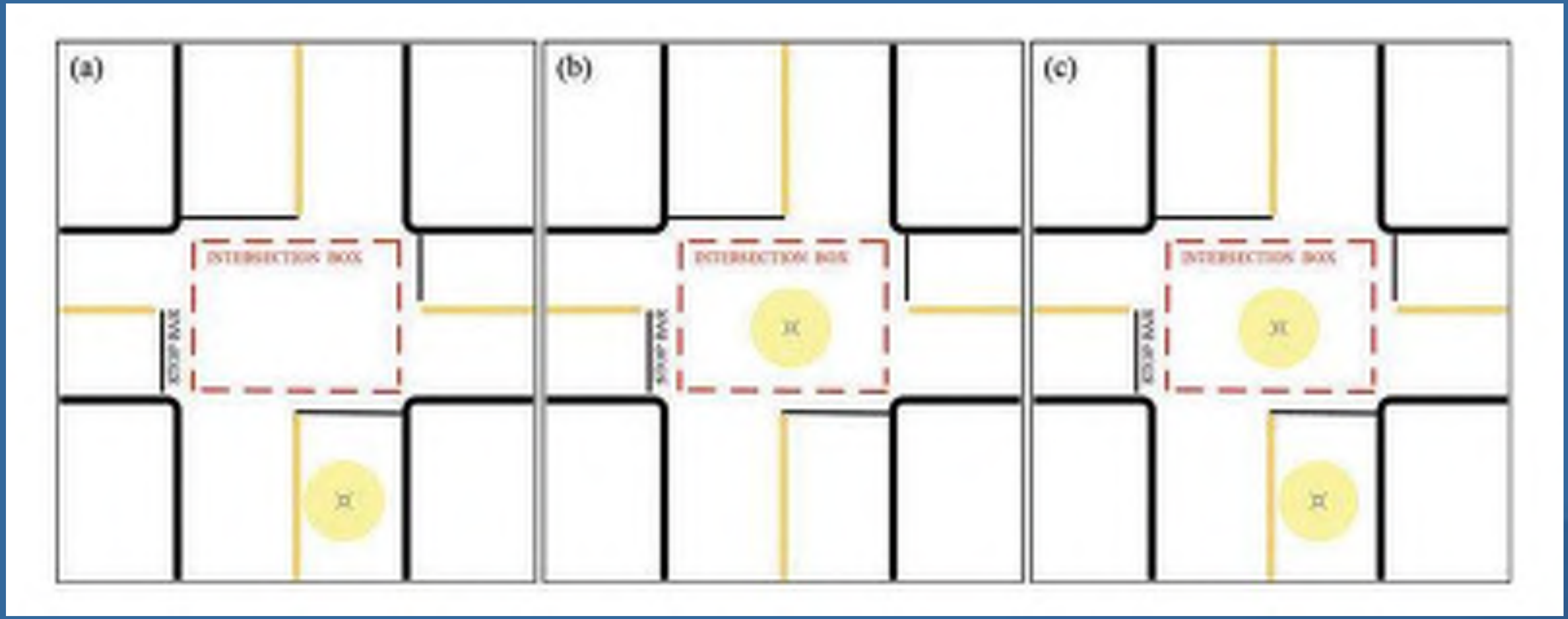
- Increasing illuminance at all the intersections by 1 lux average decreased the Night to Day (ND) crash ratio by 7% -9%.
- Stop-controlled intersections had higher ND crash ratios compared to signalized intersections.
- Speed was big factor in ND crash ratio (higher the speed the higher the values of lighting)
- Most lighting levels at the 130 rural intersections did not IES RP-8-18 requirementsRural Intersection Safety Analysis

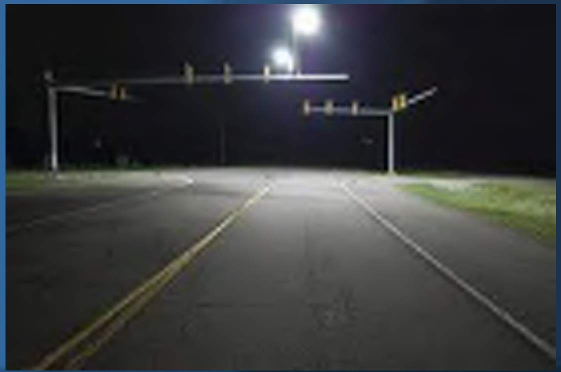
Source - Rural Intersection Safety Analysis (Report #17-UR-052)

# Effects of Intersection Lighting Design on Nighttime Visual Performance of Drivers (LUKOS)

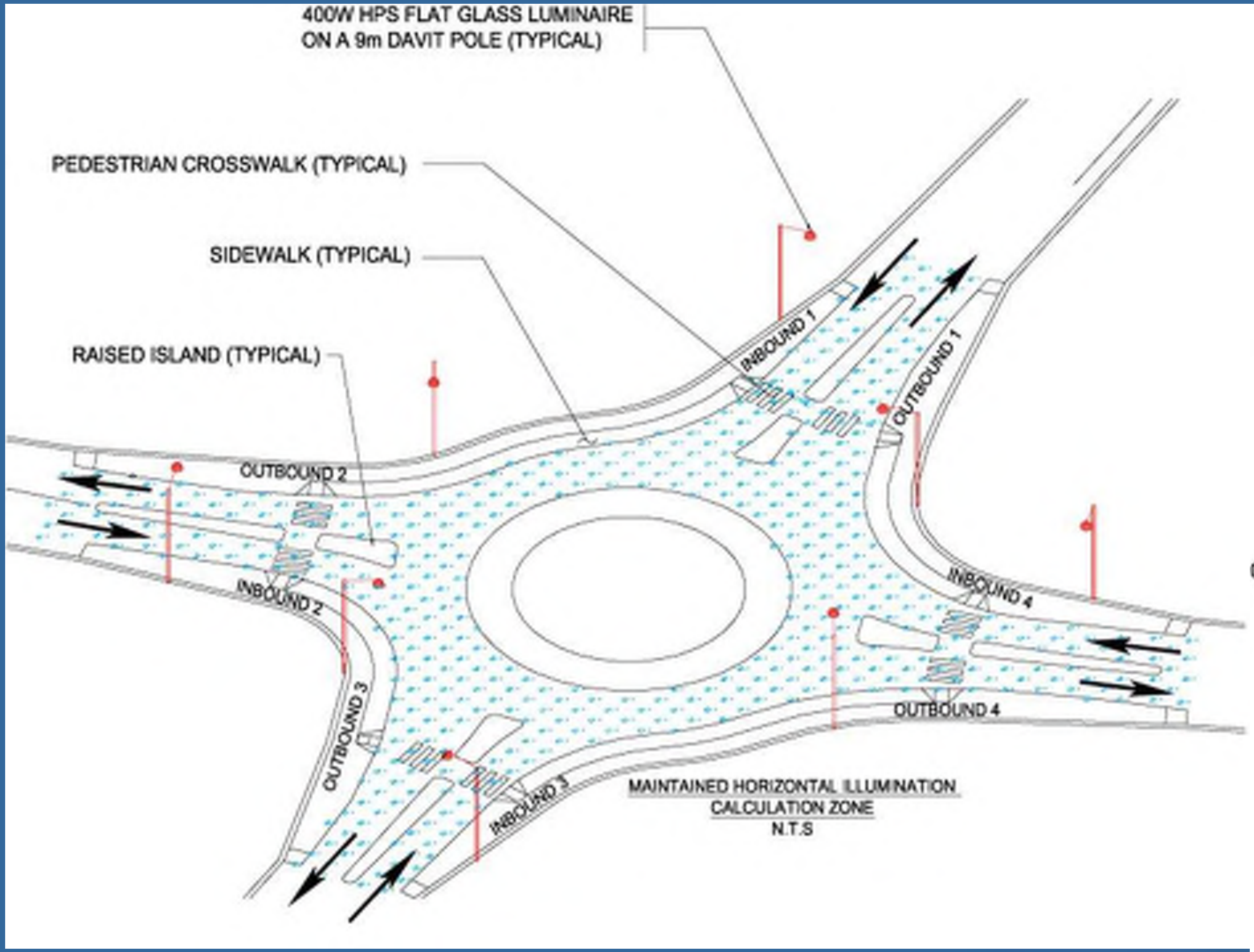
- Lighting in the box (b) had the best visual performance
- 7-10 Lux provided reasonable visual performance for younger drivers
- Older drivers benefited from higher levels (21 Lux>)

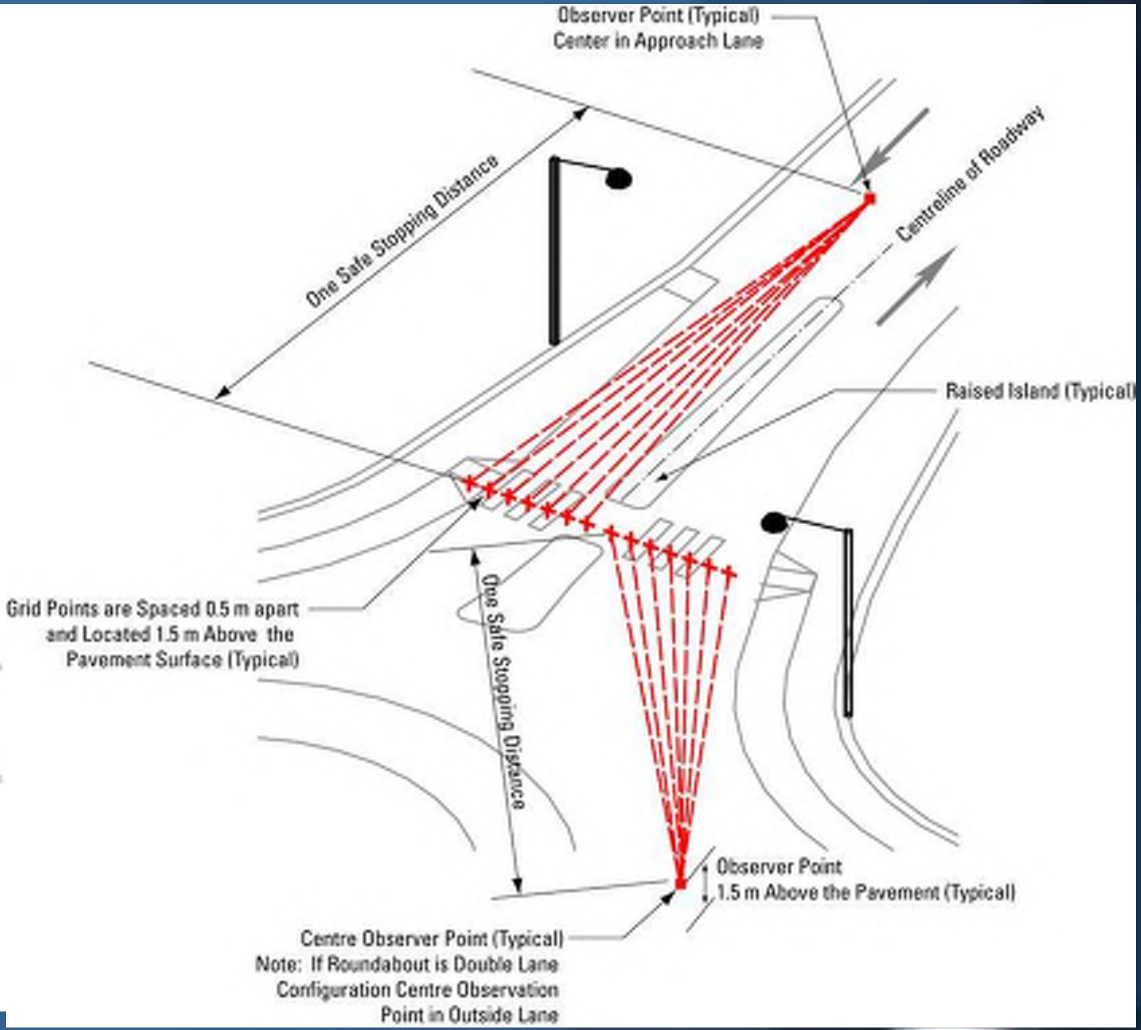
Source – IES LUKOS 2018 Article



# Roundabout Lighting RP-8-18



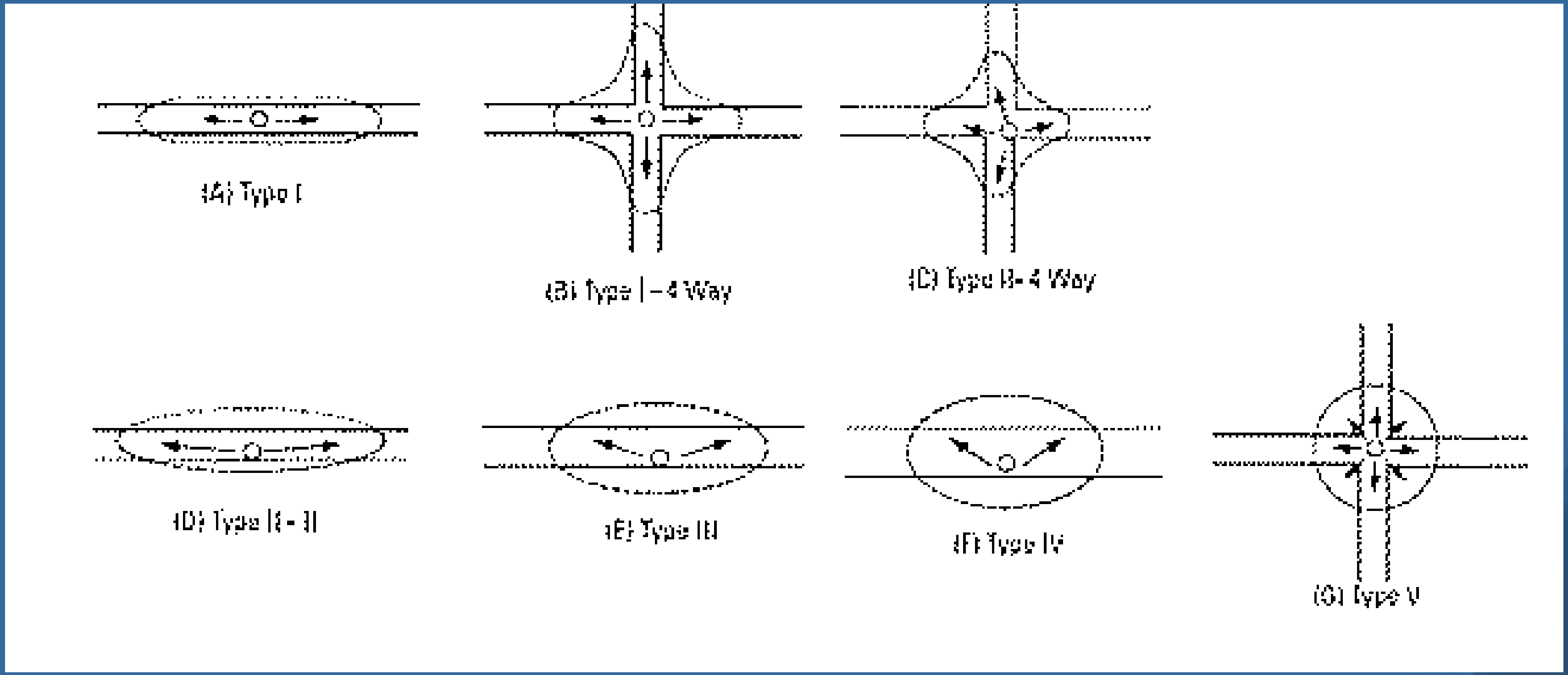




Source - TAC Guide for Design of Roadway Lighting (2006)

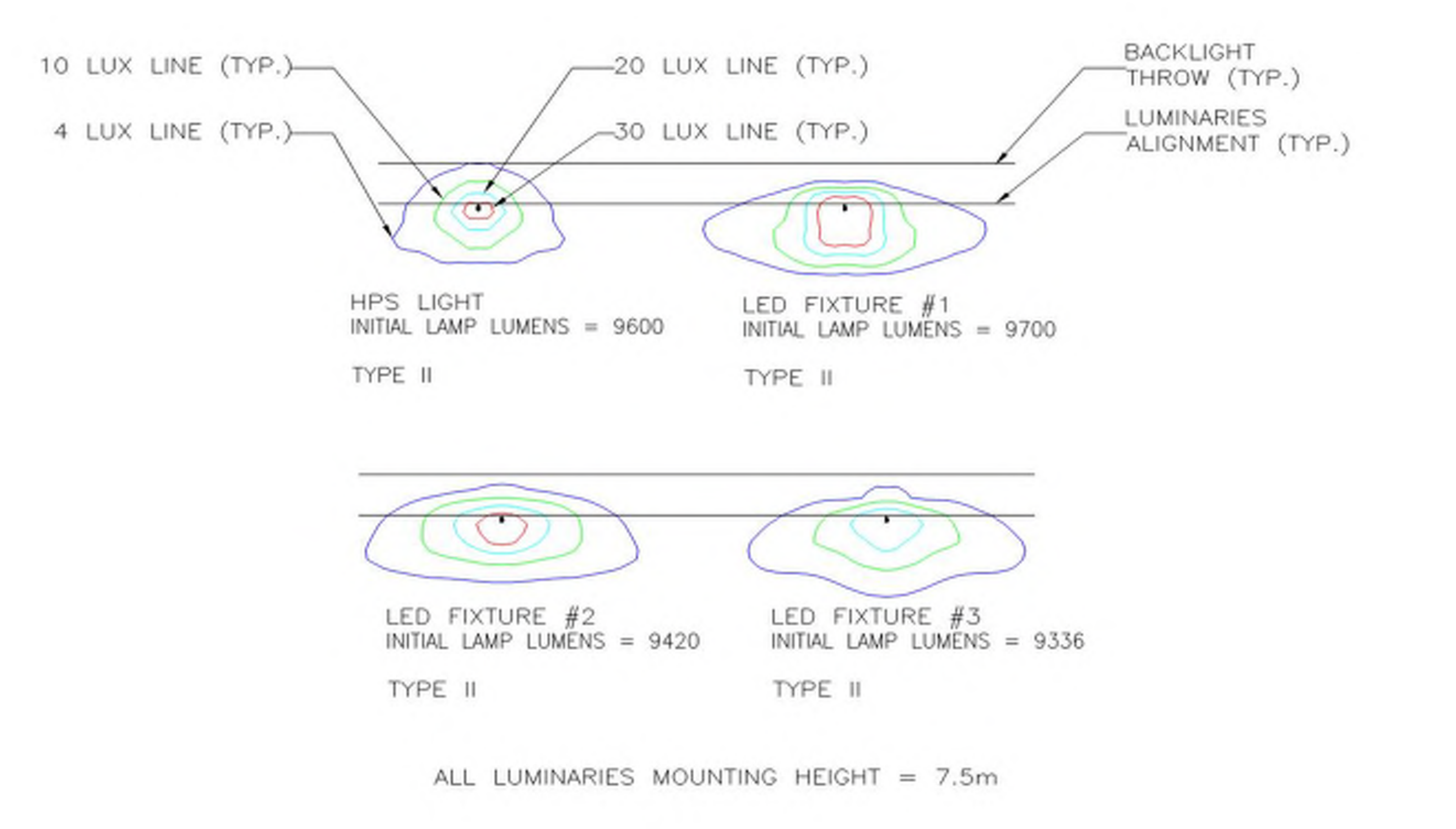
# Cyclists

- In US 900+ cyclist fatalities and 35,000+ serious cyclist injuries (requiring hospitalization). National Highway Traffic Safety Administration -2018
- Bike lanes and usages increasing. Marked bike lanes are relatively new.
- Lighting standards are currently very unclear and don't deal with conflict points.
- Apply vertical sidewalk levels whereas some simply apply horizontal roadway lighting levels to bike lanes?
- Vertical levels maybe of benefit – Expect IES RP-8-18 to be updated to better clarify and define requirements

# Distribution Classification



# Distribution Classifications

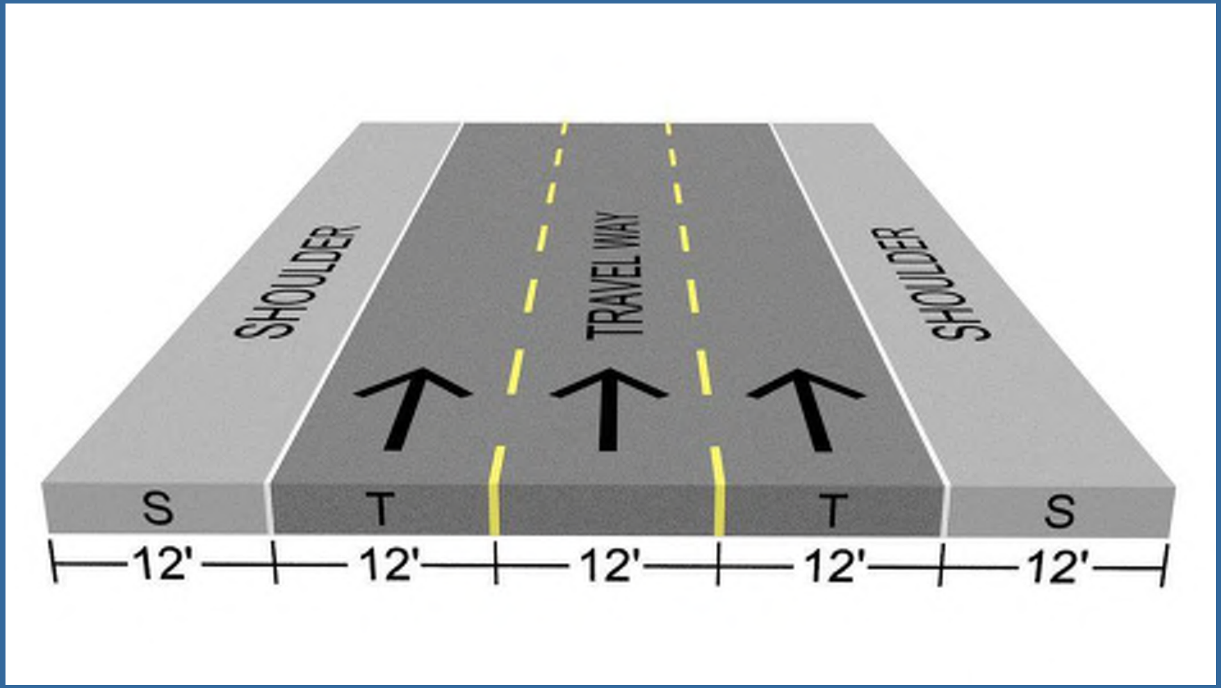


| Road Classifications-Pedestrian Activity | Local - Low | Local - Medium | Collector - High | Collector - Medium | Major - Medium | Major - High |
|---|---|---|---|---|---|---|
| Road Width (m) | 7 | 7 | 14 | 14 | 21 | 21 |
| Lanes | 2 | 2 | 4 | 4 | 6 | 6 |
| Mounted Height (m) | 9 | 9 | 9 | 9 | 11 | 11 |
| Pole Offset | 1.8 | 1.8 | 0.5 | 0.5 | 0.5 | 0.5 |
| Arrangement - Staggered (S), One Side (OS), Opposite (O) | OS | OS | S | S | O | O |
| **Pole Spacing Range (m)** | **64-85** | **45-79** | **66-94** | **69-112** | **48-108** | **53-89** |

# Surround Ratio

- Surround Ratio – A ratio of lighting level on roadway to the area off the roadway.
- Solid State Luminaires have focused on tight optical controls to reduce light spill off the roadway. This creates a dark surround (low ratio) which reduces visibility of objects off the roadway.
- Current IES standards do not define Surround Ratio.
- CIE 140:2000 and 115:2007 define a surround ratio of 0.5 to 1 or higher.
- Surface reflectance can also play a big factor

# Surround Ratio




NCHRP 05-22 GUIDELINES FOR SOLID STATE ROADWAY LIGHTING

*Using Surround Ratio in shoulder areas adjacent to the roadway increases the drivers' visual performance*

*RP-8-18 – Proposed 0.8:1 Ratio*

# Surround Ratio Testing

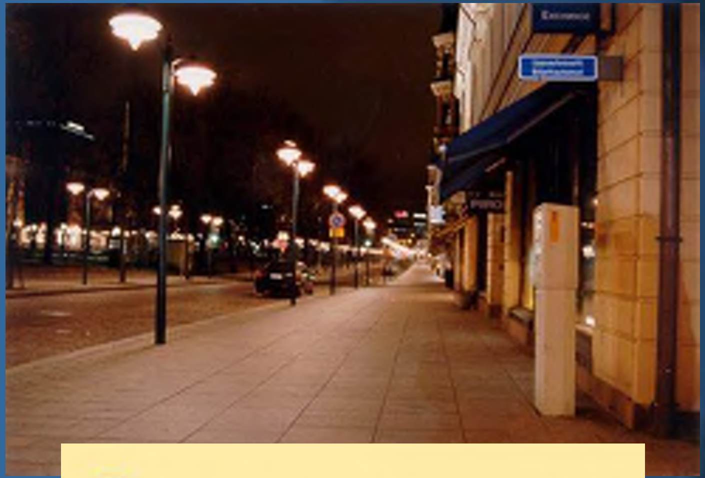
Table 3. Independent Variables and their Levels Used in the Study

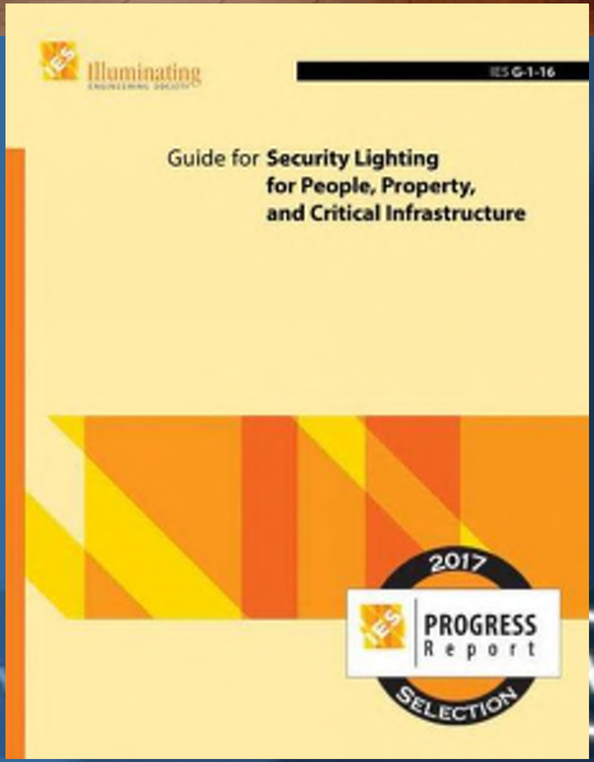
| Independent Variable | Level | Classification |
|---|---|---|
| Light Spectral Power Distribution | 3000K LED<br>4000K LED<br>5000K LED<br>HPS (only at medium light level) | Between-Subjects |
| Light Level | High (1.5 cd/m²)<br>Medium (1.0 cd/m²)<br>Low (0.7 cd/m²) | Within-Subjects |
| Surround Ratio (Avg. Shoulder Illuminance to Avg. Lane Illuminance) | High (0.8)<br>Low (0.45) | Between-Subjects |
| Uniformity Ratio (Avg. to Min Luminance) | High (1.8 to 3.5)<br>Low (1.3 to 1.4) | Between-Subjects |
| Speed | High (55 mi/h)<br>Low (35 mi/h) | Within-Subjects |
| Age | Old (65 and older)<br>Young (18 to 35 years) | Between-Subjects |

Source - NCHRP 05-22 GUIDELINES FOR SOLID STATE ROADWAY LIGHTING (2019)

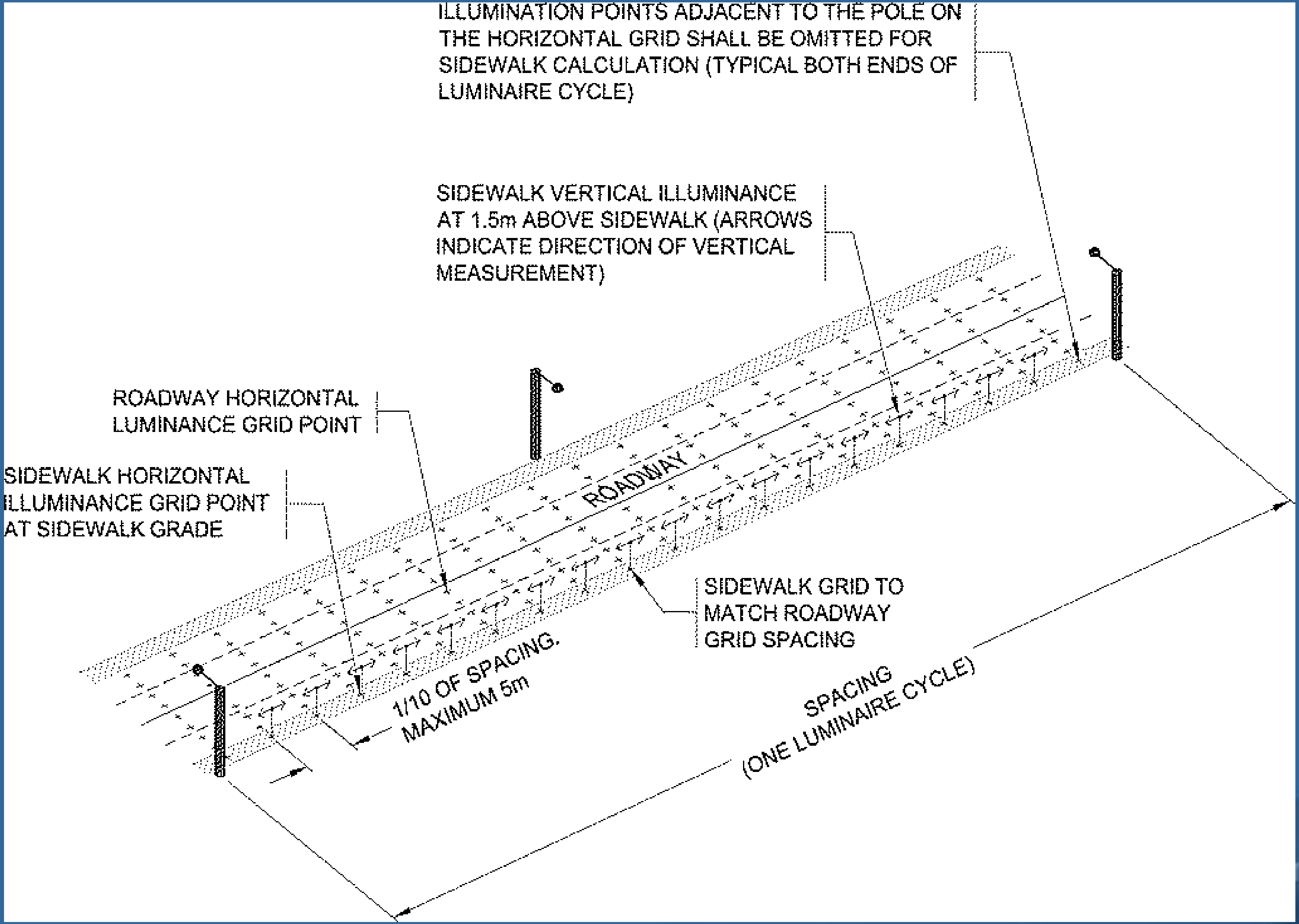
# Crime Prevention Thru Environmental Design (CEPTD)

- Vertical illuminance levels for security defined in IES G-1-16 (5-8 Lux).
- Natural surveillance key (park or lane vs street)
- Lighting can provide a feeling of safety and security
- Lighting can provide a false sense of security in isolated areas (ie; isolate lane or pathway).
- Fight or Flight (need visibility to make choice)
- Surround surface reflectance can impact visibility





# Sidewalk Lighting Calculation Grid




Source - TAC Guide for Design of Roadway Lighting (2006)

**Table 10-1. Lighting Design Criteria for Highways.**

| Road Classification | Average Luminance $L_{avg}$ (cd/m²) | 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

**Table 11-1. Lighting Design Criteria for Streets.**

| Street Classification | Pedestrian Activity Classification* | Average Luminance $L_{avg}$ (cd/m²) | 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

Source – IES RP-8-18

# Alternative Method of Defining Light Levels

**DESIGN CRITERIA FOR STREETS (S-CLASS)**

Base Value for Class: 6

**Table 23. Street design level selection criteria.**

| Parameter | Options | Criteria | Weighting Value |
|---|---|---|---|
| Speed | High | > 45 mi/h (70 km/h) | 1 |
| | Moderate | 35–45 mi/h (55–70 km/h) | 0.5 |
| | Low | < 35 mi/h (55 km/h) | 0 |
| Traffic Volume | High | > 15,000 ADT | 1 |
| | Moderate | 5,000–15,000 ADT | 0 |
| | Low | < 5,000 ADT | -1 |
| Median | No | No median | 1 |
| | Yes (or one-way) | Must be glare blocking | 0 |
| Intersection/Interchange Density | High | > 5 per 1 mi (1.6 km) | 1 |
| | Moderate | 1–5 per 1 mi (1.6 km) | 0 |
| | Low | < 1 per 1 mi (1.6 km) | -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 |
| Pedestrian/Bicycle Interaction | High | > 100 pedestrians per h | 2 |
| | Moderate | 10–100 pedestrians per h | 1 |
| | Low | < 10 pedestrians per h | 0 |
| Parked Vehicles | Yes | Parked vehicles present | 1 |
| | No | No parked vehicles present | 0 |

**Table 24. S-Class lighting design levels.**

| Class | Average Luminance (cd/m$^2$) | Max UR (avg/min) | Max UR (max/min) | Veiling Luminance Ratio |
|---|---|---|---|---|
| S1 | 1.2 | 3 | 5 | 0.3 |
| S2 | 0.9 | 3.5 | 6 | 0.4 |
| S3 | 0.6 | 4 | 6 | 0.4 |
| S4 | 0.4 | 6 | 8 | 0.4 |
| S5 | 0.3 | 6 | 10 | 0.4 |

1 cd/m$^2$ = 0.292 ft-lamberts

**DESIGN CRITERIA FOR ROADWAYS (H-CLASS)**

Base Value for Class: 5

**Table 21. Roadway design level selection criteria.**

| 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 | 1 |
| | Yes | Must be glare blocking | 0 |
| Intersection/Interchange Density | High | < 1.5 mi (2.5 km) between intersections | 1 |
| | Moderate | 1.5–4 mi (2.5 km–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 |

**Table 22. H-class lighting design levels.**

| Class | Average Luminance (cd/m$^2$) | Max UR (avg/min) | Max UR (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 |

1 cd/m$^2$ = 0.292 ft-lamberts

Source - Design Criteria for Adaptive Roadway Lighting PUBLICATION NO. FHWA-HRT-14-051 JULY 2014

# Research Projects

National Cooperative Highway Research Program (NCHRP)

- NCHRP-5-22 Guidelines for Solid-State Roadway Lighting
- NCHRP 5-22A - Gaps and Emerging Technologies in the Application of Solid-State Roadway Lighting
- NCHRP 5-23 Effects of LED Roadway Lighting on Driver Sleep Health and Alertness

http://www.trb.org/NCHRP/NCHRPProjects.aspx

# Information Sources

Virginia Tech Transportation Institute

Lighting Research Centre

Pacific Northwest National Laboratory

US Department of Energy (US DOE)

Natural Resources Canada (NRCAN)

US Federal Highway (FHWA)

Transportation Association of Canada (TAC)

Illuminating Engineering Society (IES – US/Canada)

American Association of State Highway and Transportation Officials (AASHTO- US)

International Commission on Illumination (CIE- Europe)

Institute of Lighting Professionals (England)