ROADWAY LIGHTING DESIGN UPDATE

Don McLean
DMD and Associates
May 5, 2021

PRESENTATION

- Focused on improving visibility (SAFETY) through lighting design
- Review current and upcoming research
- Environment

- DMD and Associates Electrical Consultants Ltd
- Consulting Engineers based in Surrey BC - Specializing in outdoor lighting design, traffic signals, ITS along with CEC

- WHY? – We are looking to become more active in Alberta long term.

- Q&A – What are your issues?

ORGANIZATIONS

- TAC – TRANSPORATION ASSOCIATION OF CANADA
- AASHT0 - American Association of State Highway and Transportation Officials
- NCHRP -National Cooperative Highway Research Program
- FHWA – US Federal Highway Association
- IES – Illuminating Engineering Society (mainly North America)
- CIE – International Commission on Illumination (mainly Europe)
- IDA – International Dark Sky Association (light pollution watch dog)

ENVIROMENTAL

https://www.ies.org/pressroom/reducing-light-pollution-and-its-negative-affects-ies-and-ida-new-collaboration/

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 important to consider the following 5 principals

REFERENCE AND EDUCATIONAL MATERIAL

- IES WEBSITE https://elearning.ies.org/roadway (2020)
- IES RP-8-18 – Being updated (2021)
- TAC Roadway Lighting Design Guide –Dated (2006)
- TAC Light Reduction and Energy Efficiency Guide (2012)
- FHWA Lighting Handbook – Being redeveloped (2022)
- FHWA Night-time Visibility Resources https://safety.fhwa.dot.gov/roadway_dept/night_visib/roadwayresources.cfm
- NCHRP 5-22A– Gaps and Emerging Technologies in the Application of Solid-State Roadway Lighting (2022)
- NCHRP Report 940 Solid State Lighting Design Guide (2019)
- AASHTO Roadside Design Guide (2019) – Clear Zone also ref TAC

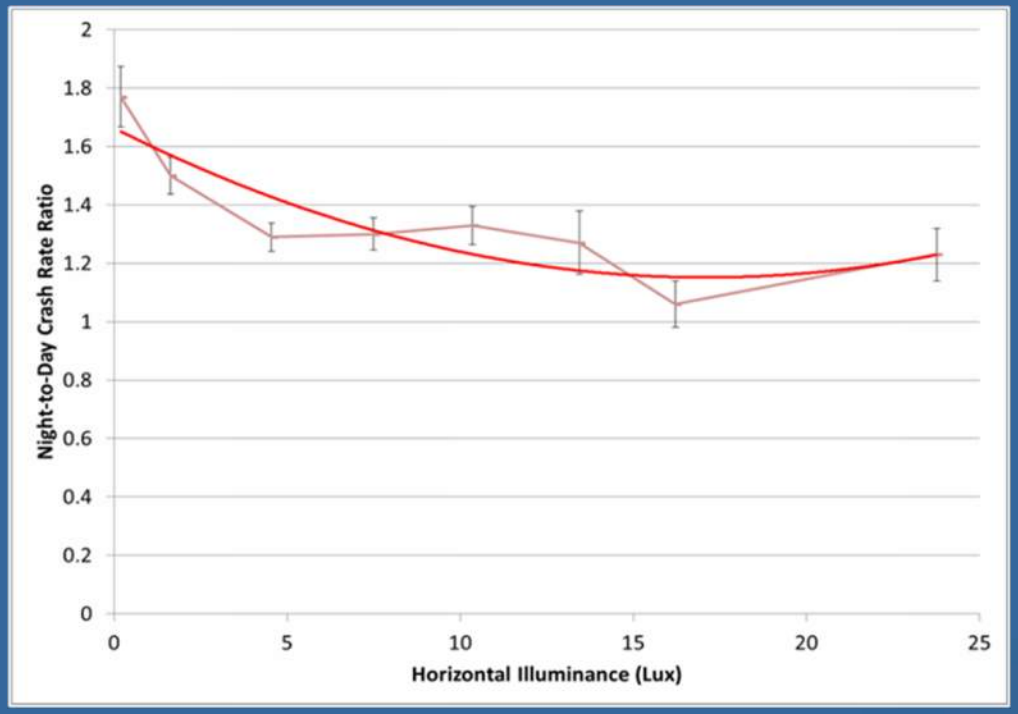
RP-8-18

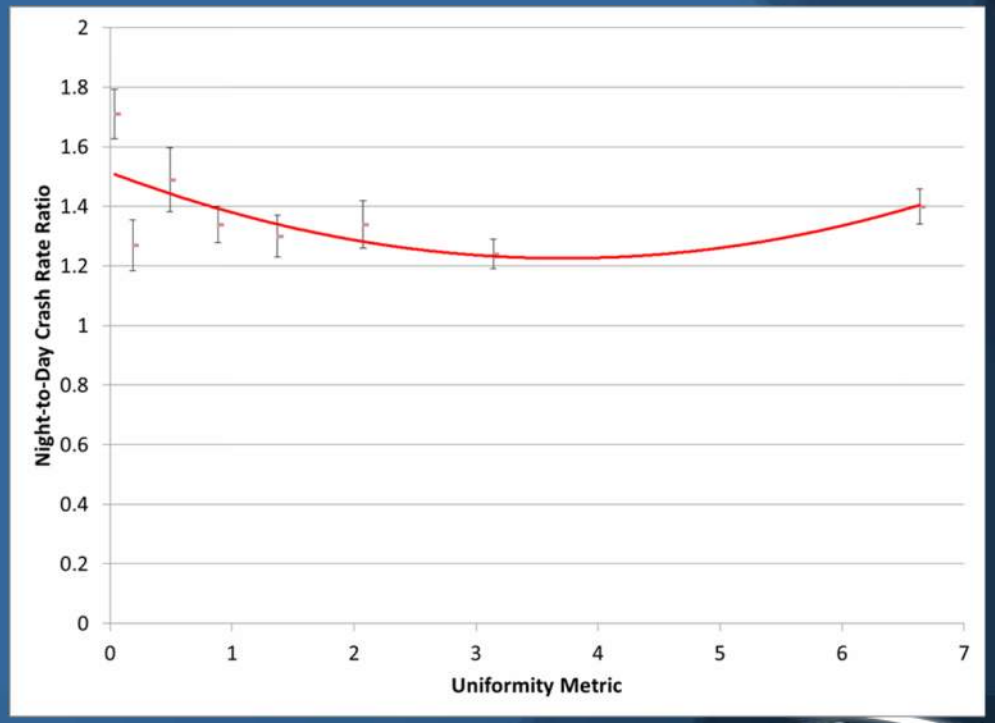
Anticipated Updates of Significance:

- Surround Ratio
- Minimum vertical levels for sidewalks changed from minimum to average
- Illuminance curve radius 600m (error notes 160m)
- Use of illuminance for closely spaced intersections
- Clarification of how to define valid values in R tables
- More focus on LED sources
- Delete redundancy and overlap for each Chapter (specifically Chapter 11)
- Extensive internal review as per ANSI process

RESEARCH

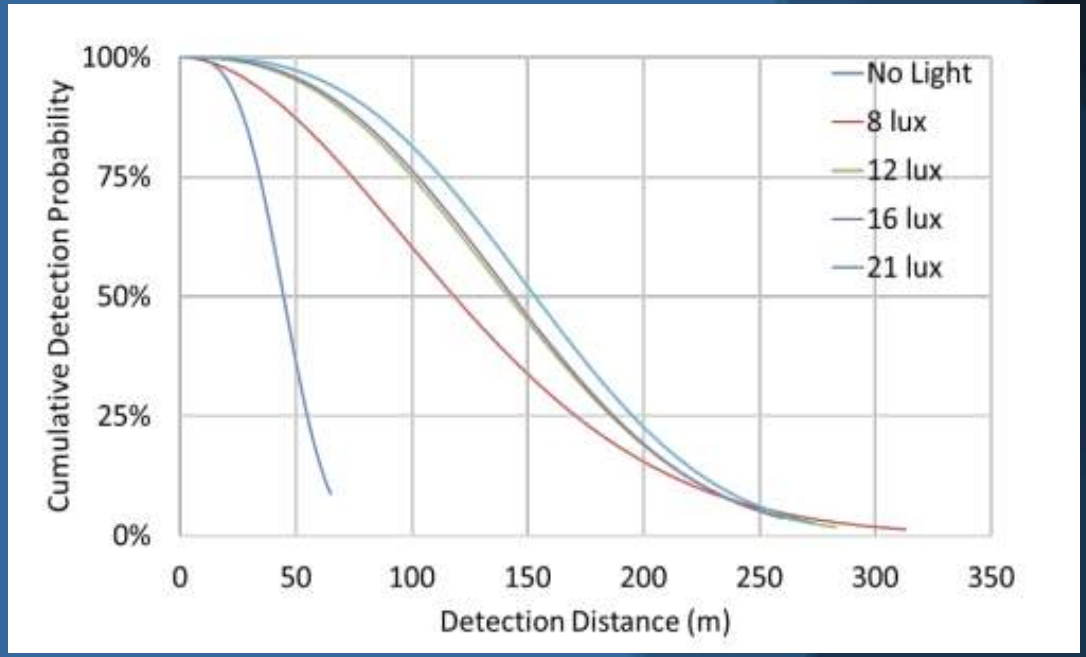
FHWA - Guidelines for the Implementation of Reduce Lighting on Roadways (2014)





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
- No benefit of additional lighting



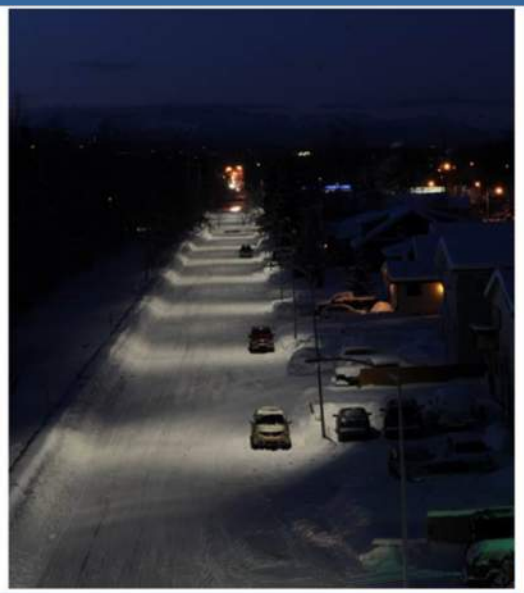
Source –Exploring the Relationship Between Street Lighting Levels and Physical Activity After Dark: Results of a Pilot Study - 2018

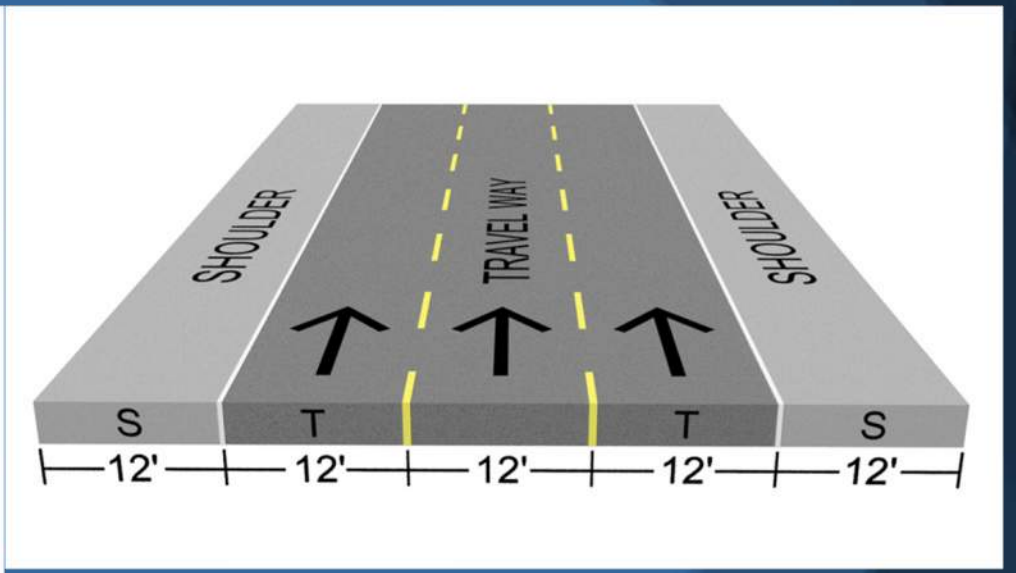
Surround Ratio

- 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 RP-18 does not define Surround Ratio (it is being added).
- CIE 140:2000 and 115:2007 define a surround ratio of 0.5 to 1 or higher.

NCHRP 05-22 GUIDELINES FOR SOLID STATE ROADWAY LIGHTING (REPORT 940)

Surround Ratio



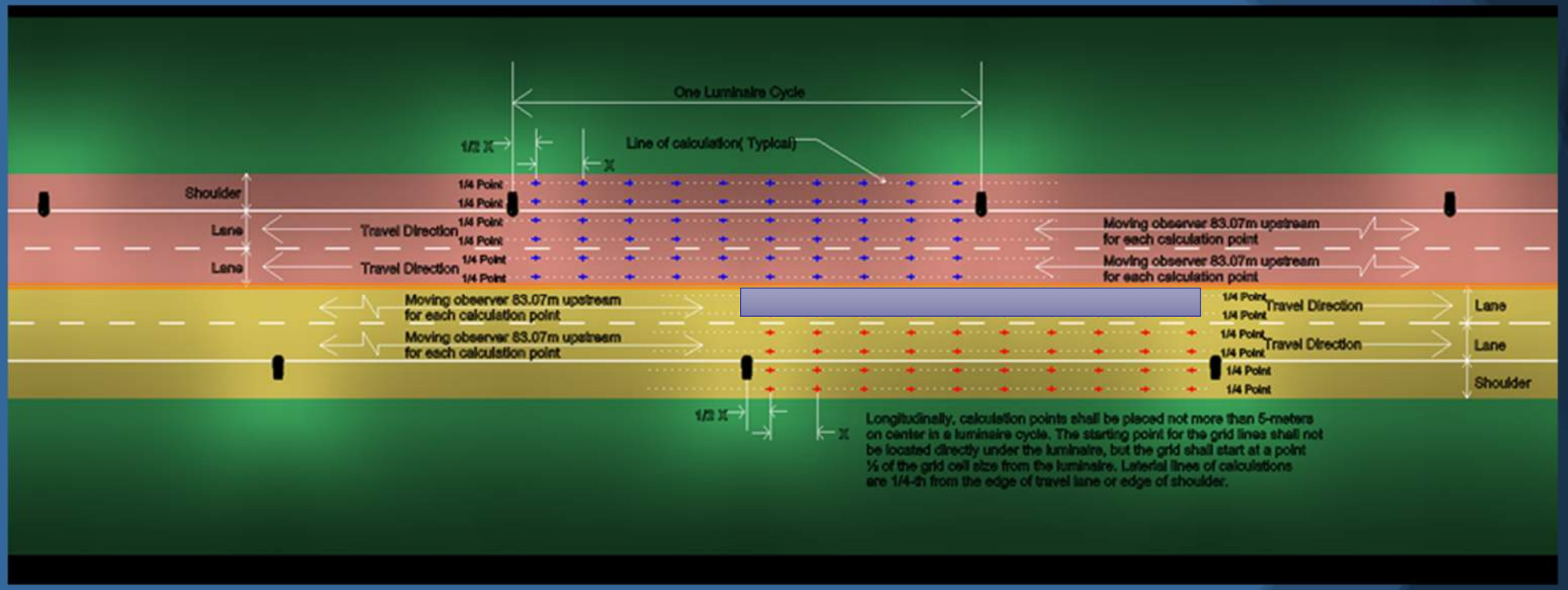


NCHRP 05-22 GUIDELINES FOR SOLID STATE ROADWAY LIGHTING

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 Calcs



Surround Ratio Testing

- Human Factors Testing
- At Virginia Tech Transportation Test 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

Surround Ratio Testing

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

Independent Variable	Level	Classification
Light Spectral Power Distribution	3000K LED 4000K LED 5000K LED HPS (only at medium light level)	Between-Subjects
Light Level	High (1.5 cd/m^2) Medium (1.0 cd/m^2) Low (0.7 cd/m^2)	Within-Subjects
Surround Ratio (Avg. Shoulder Illuminance to Avg. Lane Illuminance)	High (0.8) Low (0.45)	Between-Subjects
Uniformity Ratio (Avg. to Min Luminance)	High (1.8 to 3.5) Low (1.3 to 1.4)	Between-Subjects
Speed	High (55 mi/h) Low (35 mi/h)	Within-Subjects
Age	Old (65 and older) Young (18 to 35 years)	Between-Subjects

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

SURROUND RATIO

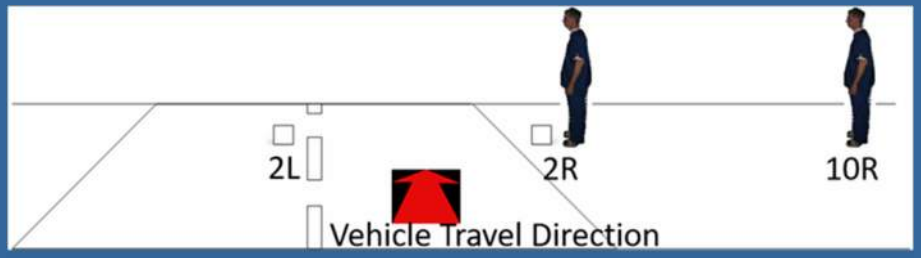
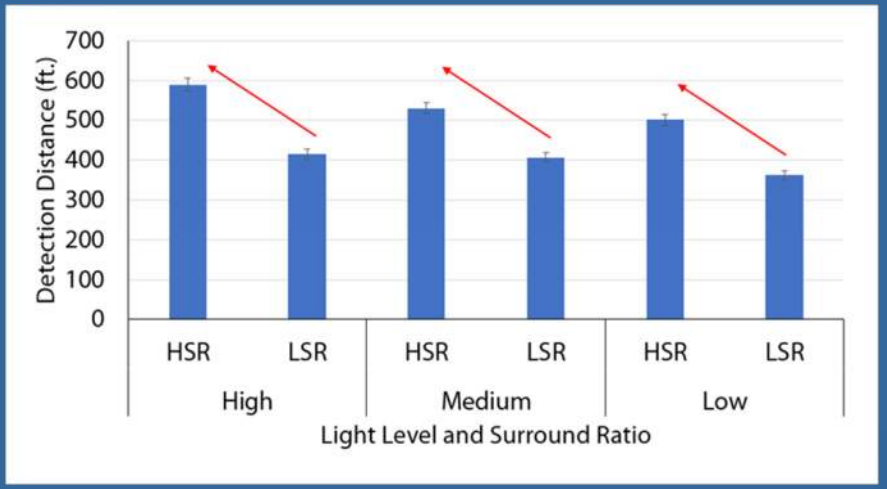


Figure 23. Pedestrians in Colored Scrubs



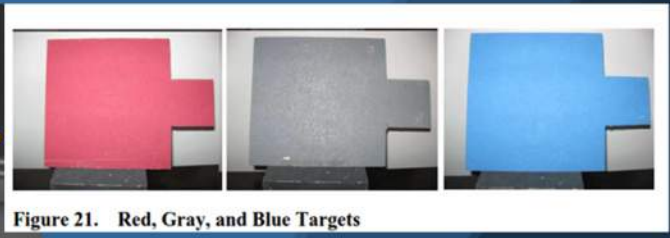
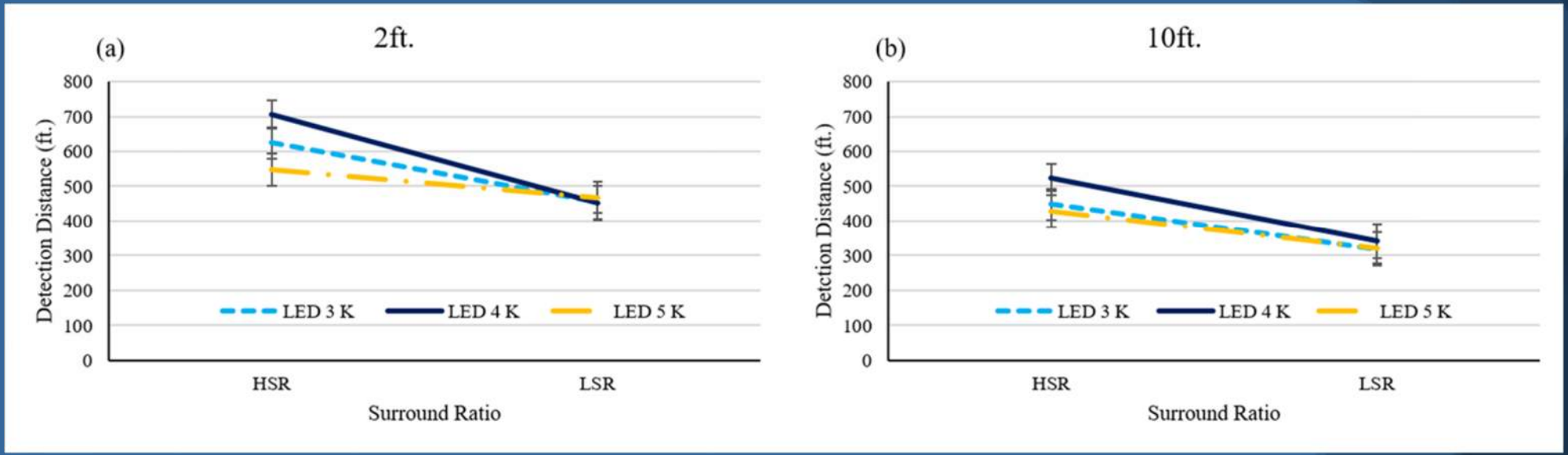


Figure 21. Red, Gray, and Blue Targets

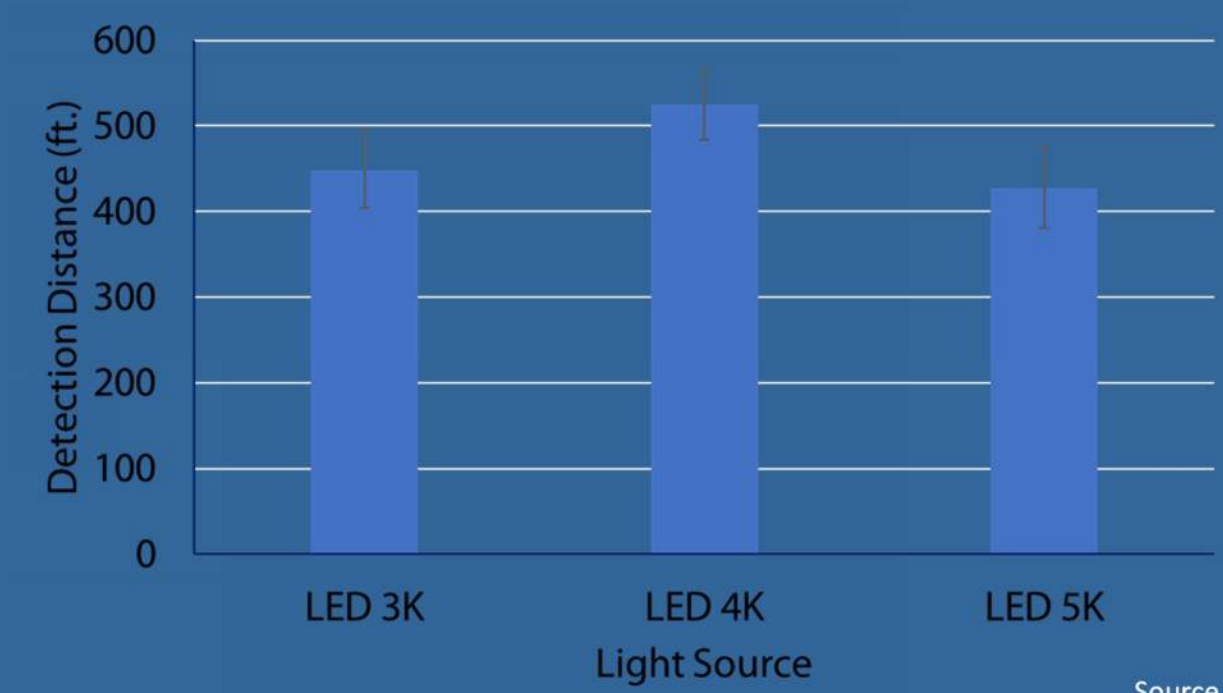
Surround Ratio Testing



Lower surround ratios had lower detection distances
Consistent across all CCT'S

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

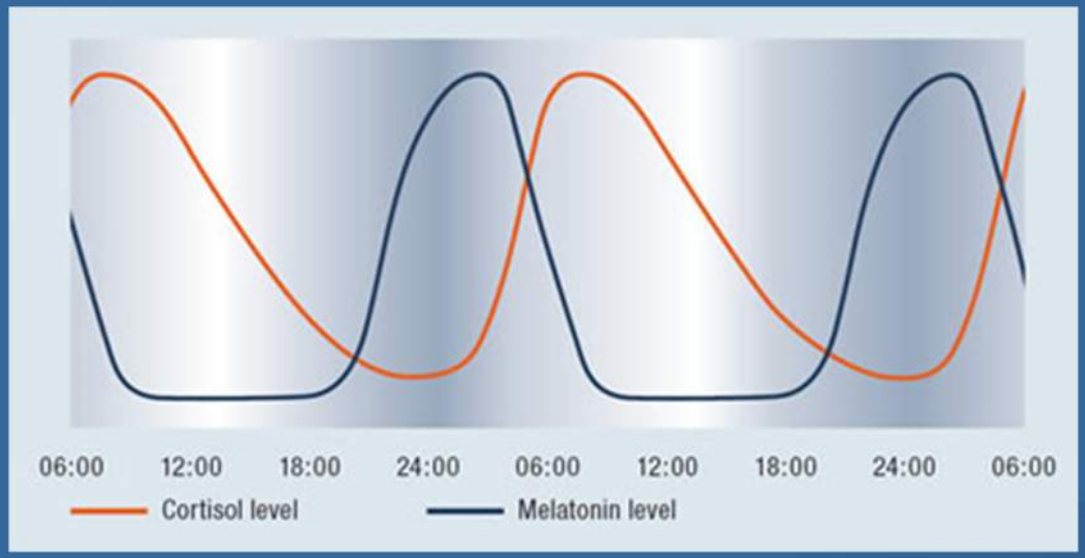
Surround Ratio Testing



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

CIRCADIAN RHYTHM

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.




AMA

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

MELATONIN SUPRESSION

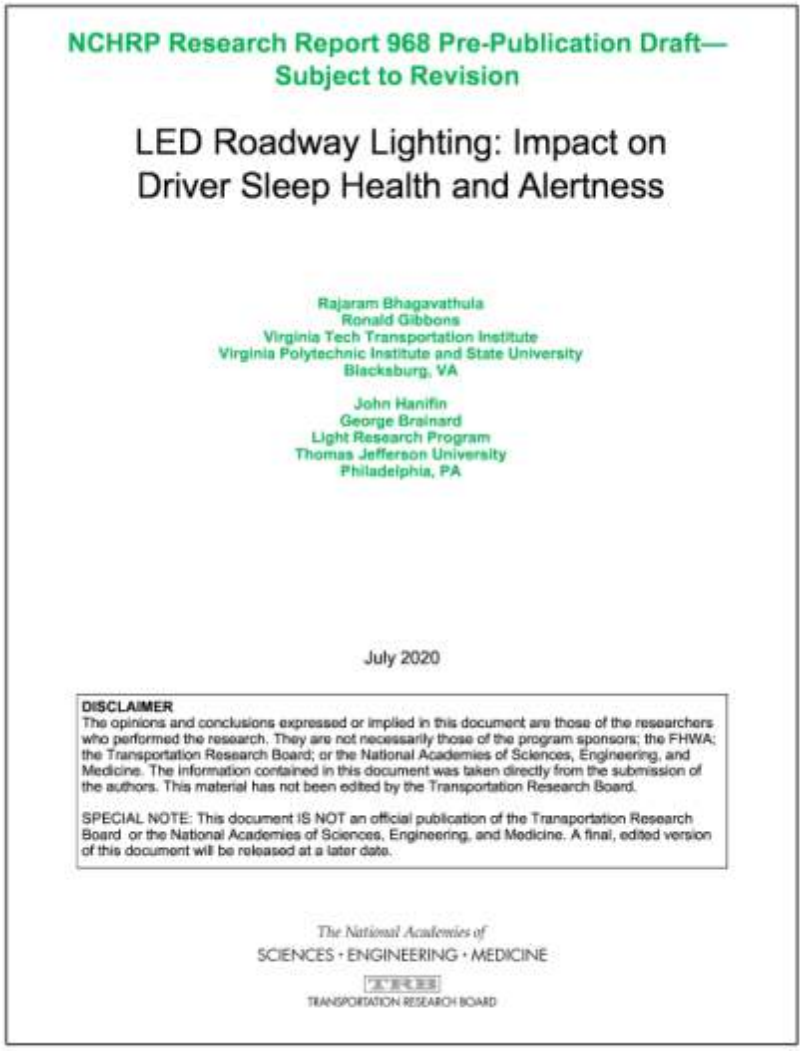
Table 2: Predicted Human Nocturnal Melatonin Suppression from Incandescent and Daylight Illumination [46] of Varying Corneal Illuminances and Durations, Based on Rea et al. [37]

Incandescent

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%

Daylight

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%



NCHRP Research Report 968 Pre-Publication Draft—
Subject to Revision

LED Roadway Lighting: Impact on
Driver Sleep Health and Alertness

Rajaram Bhagavathula
Ronald Gibbons
Virginia Tech Transportation Institute
Virginia Polytechnic Institute and State University
Blacksburg, VA

John Hanifin
George Brainard
Light Research Program
Thomas Jefferson University
Philadelphia, PA

July 2020

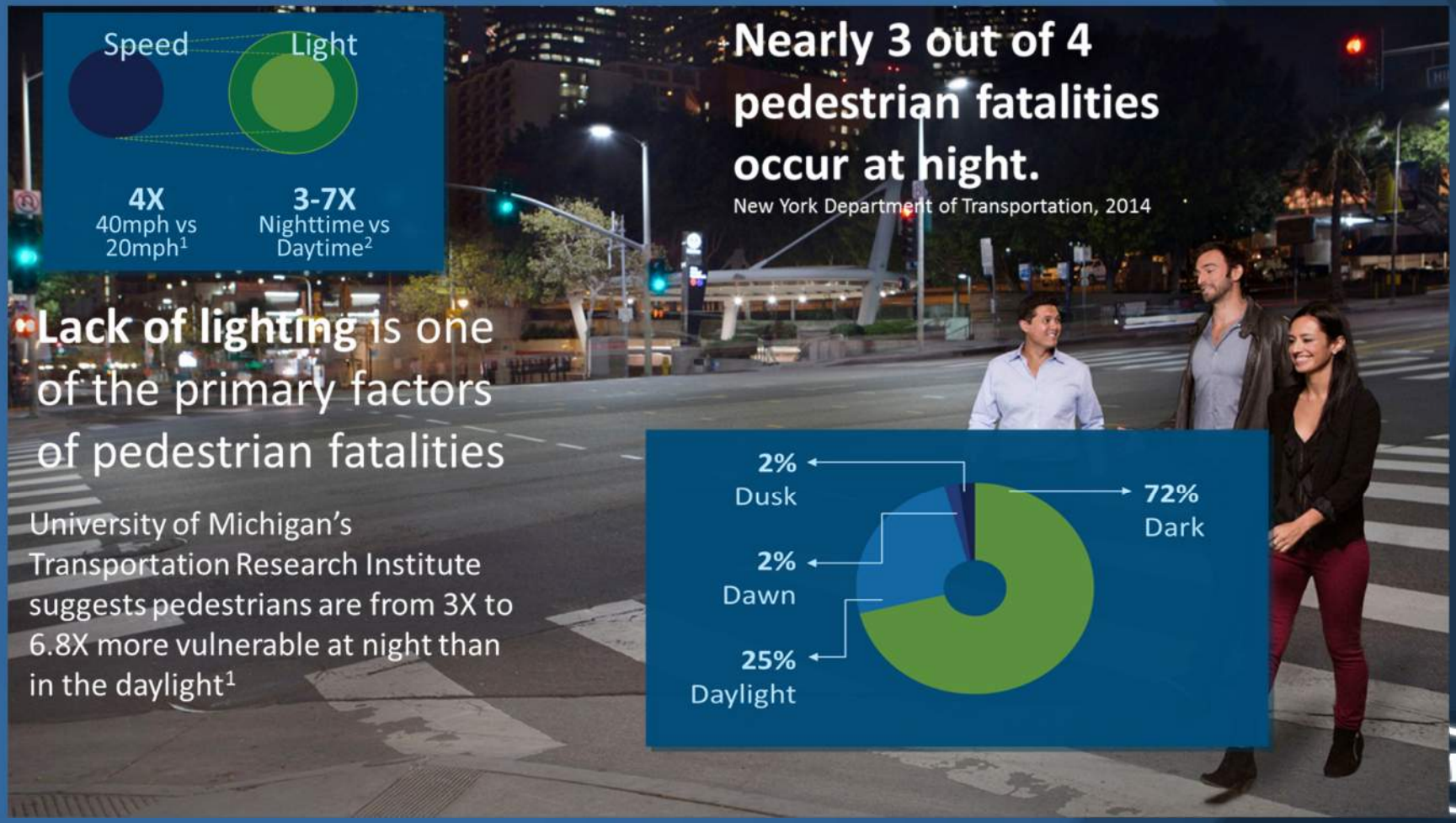
The National Academies of
SCIENCES • ENGINEERING • MEDICINE
TRANSPORTATION RESEARCH BOARD

Sleep health as measured by salivary melatonin suppression is not significantly affected by LED roadway lighting even at light levels that are higher than those specified in the IES RP-8-2018 (2100k TO 4000k STUDIED). **Refutes AMA data stating health issues where above 3000K CCT.**

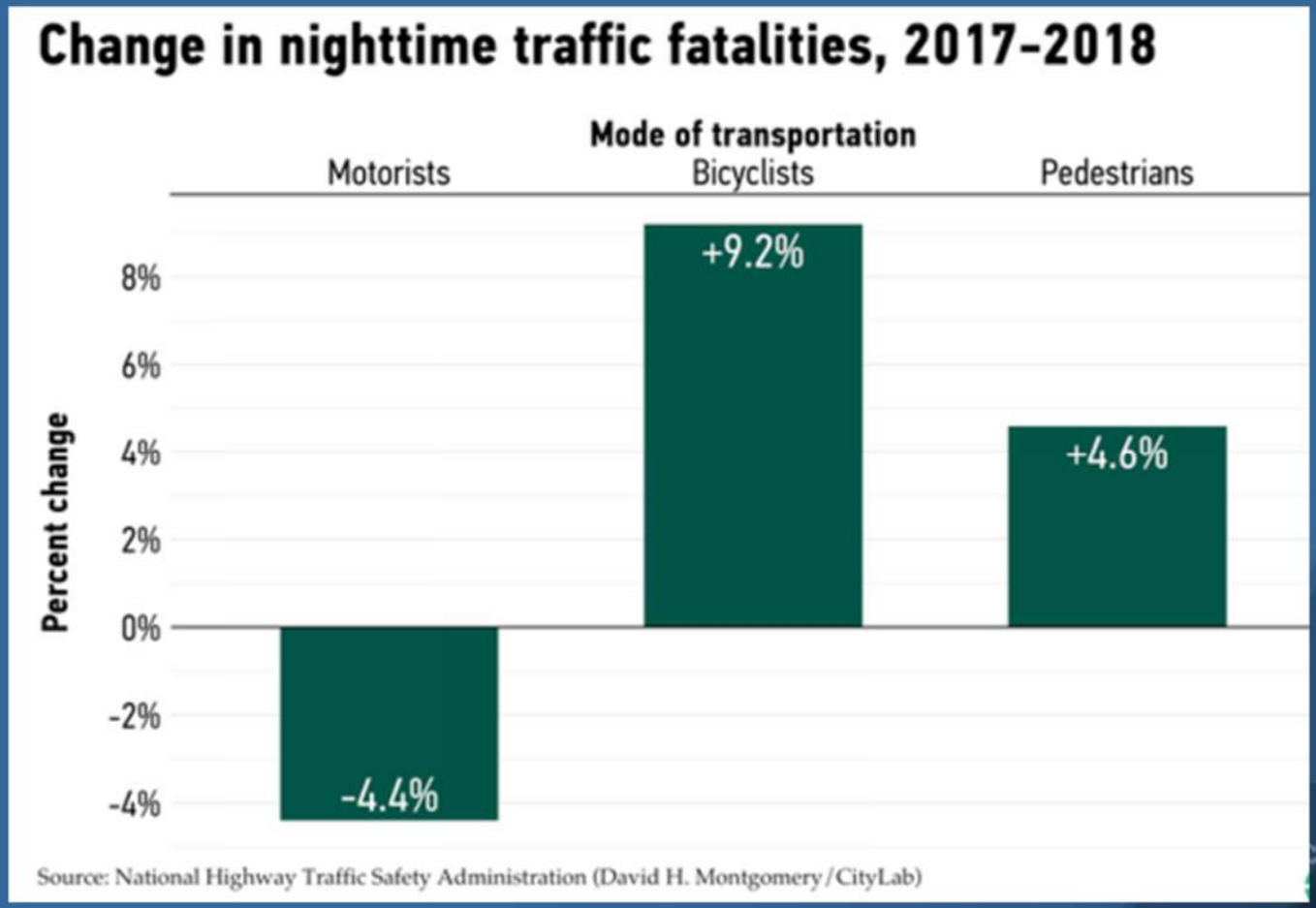
Illuminance dosages from the roadway lighting conditions (from both HPS and LED sources) are considerably lower than the illuminance dosages experienced from consumer electronic devices such as televisions and tablets.

Detection and color recognition distances for the HPS roadway lighting were also affected by exposure time, where increase in the exposure time resulted in a decrease in the detection and color recognition distances.

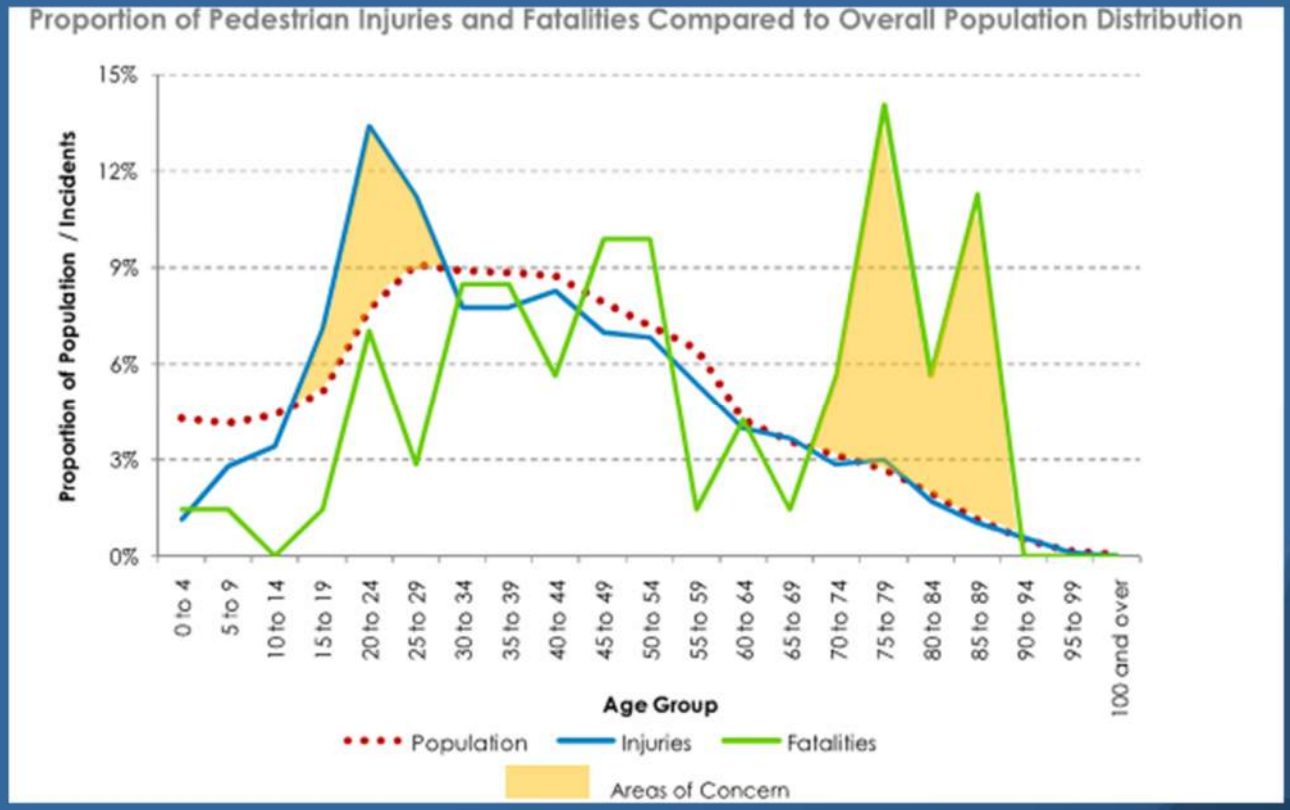
Safety Issues – What We Know



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

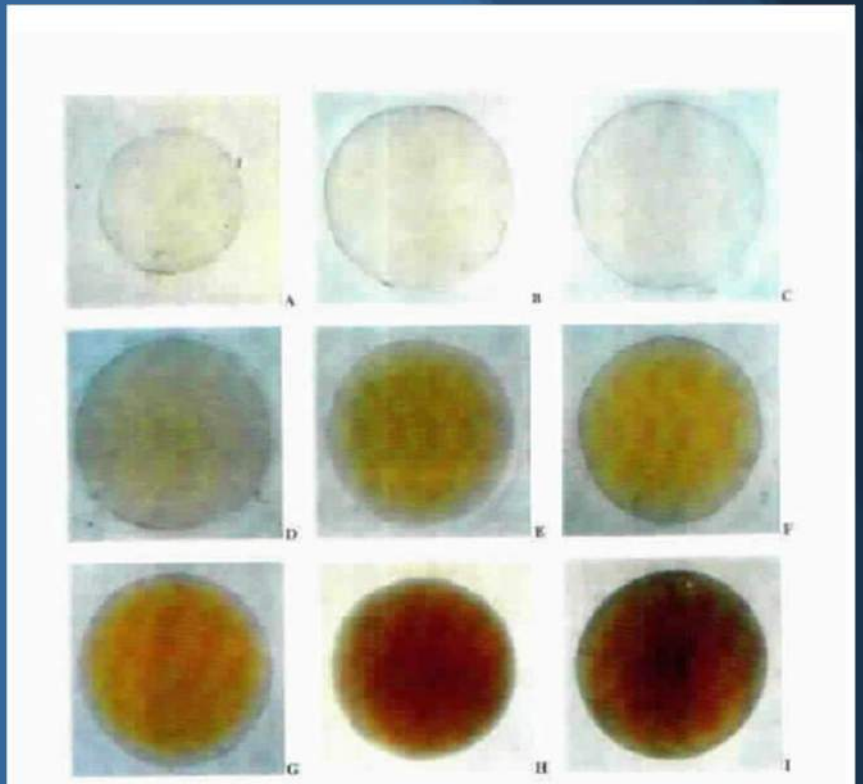


Fig. 3 Yellowing and transparency of the Human Lens from 6 month (A) to 8 years (B), 12 years (C), 25 years (D), 47 years (E), 60 years (F), 70 years (G), 82 years (H) and 91 years (I) of age.

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

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.

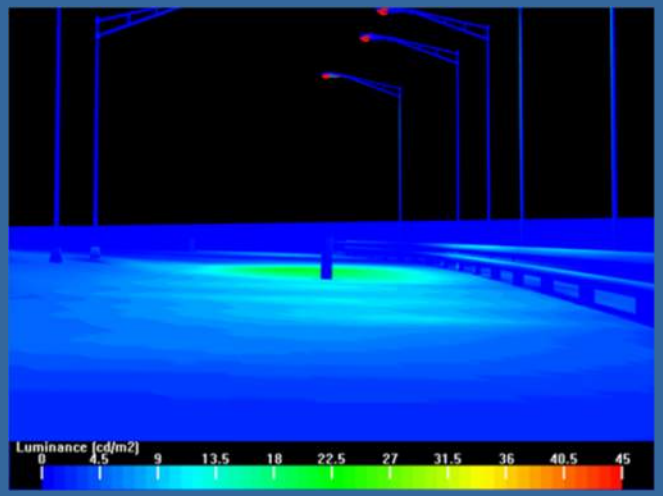
Source – TAC Roadway Lighting Efficiency and Power Reduction Guide (2012)

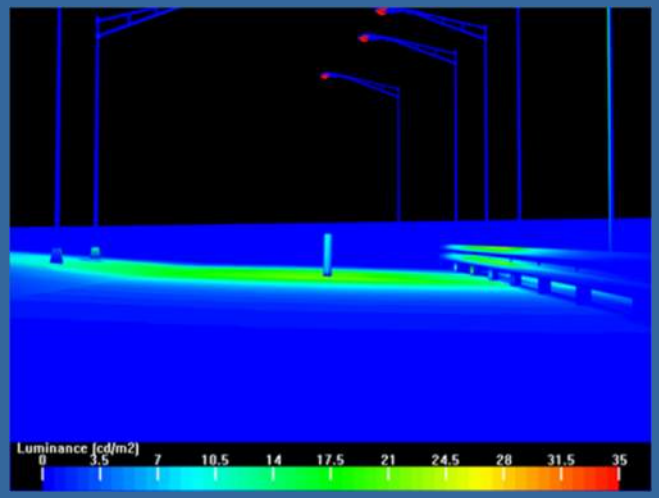
Contrast – Key Visibility Element

We require contrast to detect objects

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

Contrast



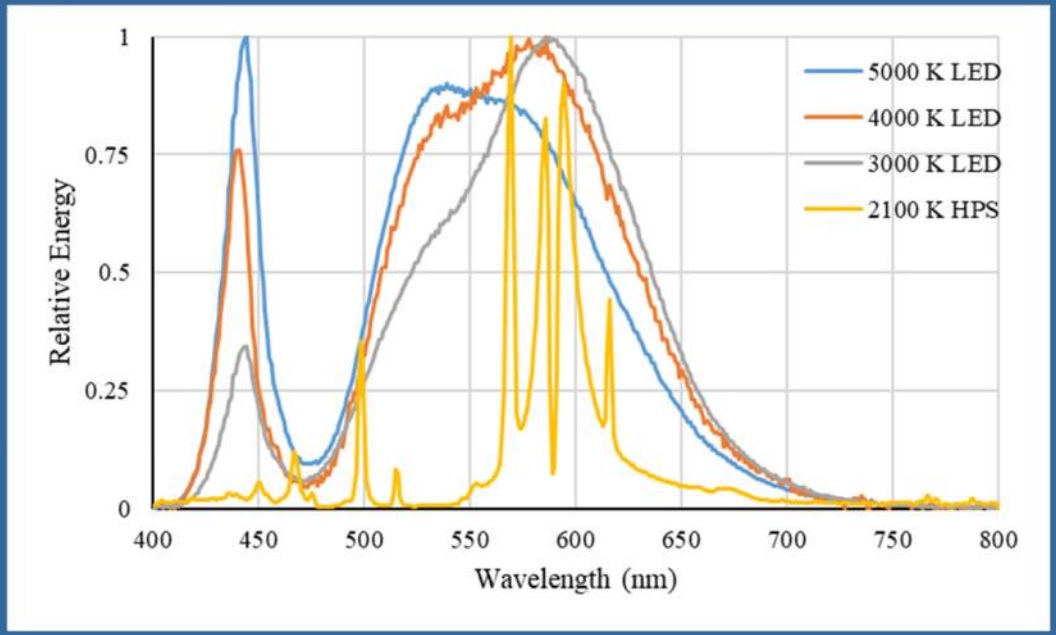


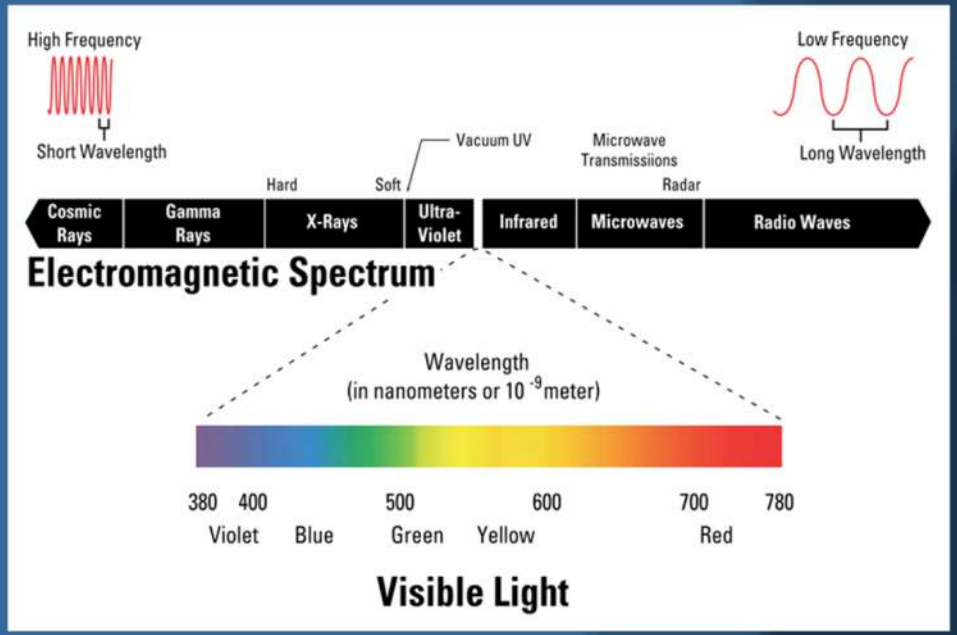
Images on the left are **negative contrast** and on the right are **positive contrast**

Contrast and Spectral Power Distribution (SPD)

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

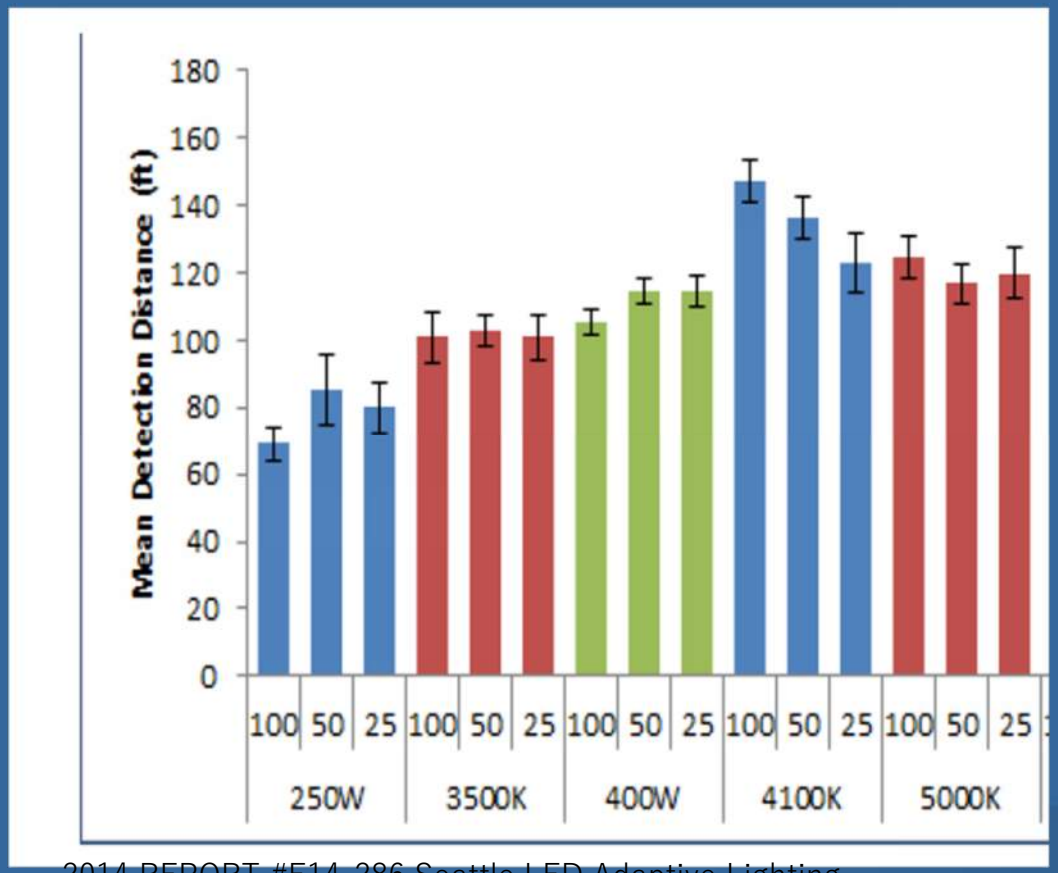
Spectral Power Distribution of Various Light Sources





*NCHRP 05-22 GUIDELINES FOR SOLID STATE ROADWAY LIGHTING

Object Detection Distance Studies



2014 REPORT #E14-286 Seattle LED Adaptive Lighting Study

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

NCHRP 5-22 - ***Peripheral*** SPD does not significantly influence driver visual performance at speeds greater than 35 mph.

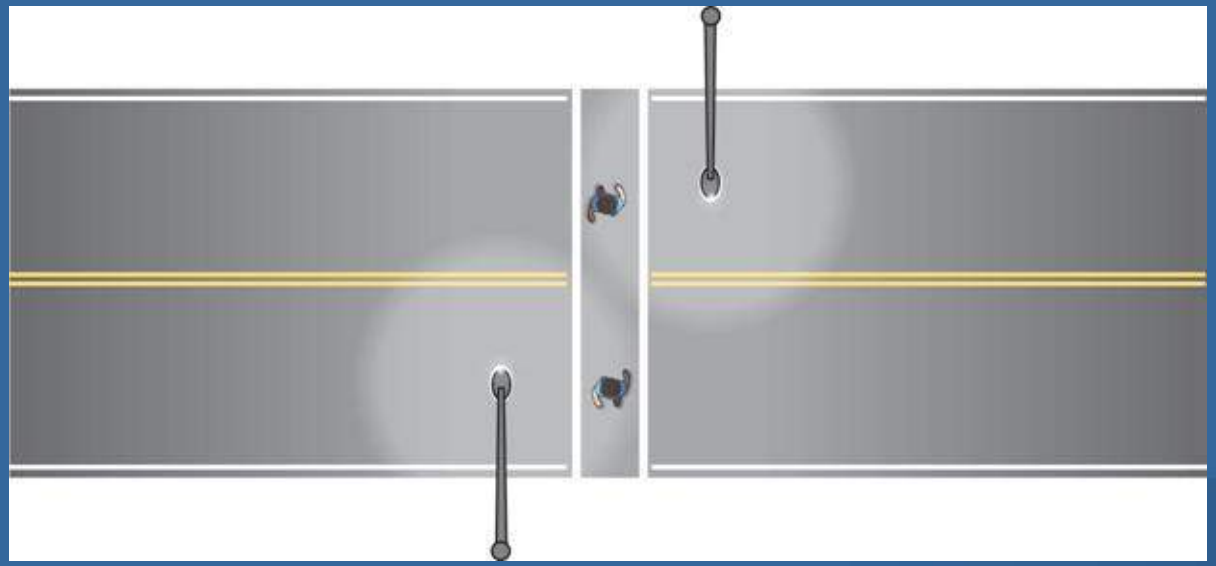
Object Detection Distances under Various CCT's

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).

Mid Block Crosswalk Lighting

- In Europe 4 vertical foot-candles (40 Lux) was used in all crosswalks which resulted a 66% reduction in pedestrian crashes (FHWA PL-01-034)
- Lighting level of 2 vertical foot-candles (20 Lux) lux seems sufficient for crosswalks (FHWA-HRT-08-053)



Mid Block Crosswalks

Rectangular Rapid Flash Beacons (RRFB's)

Do we still light?

Bike Lanes

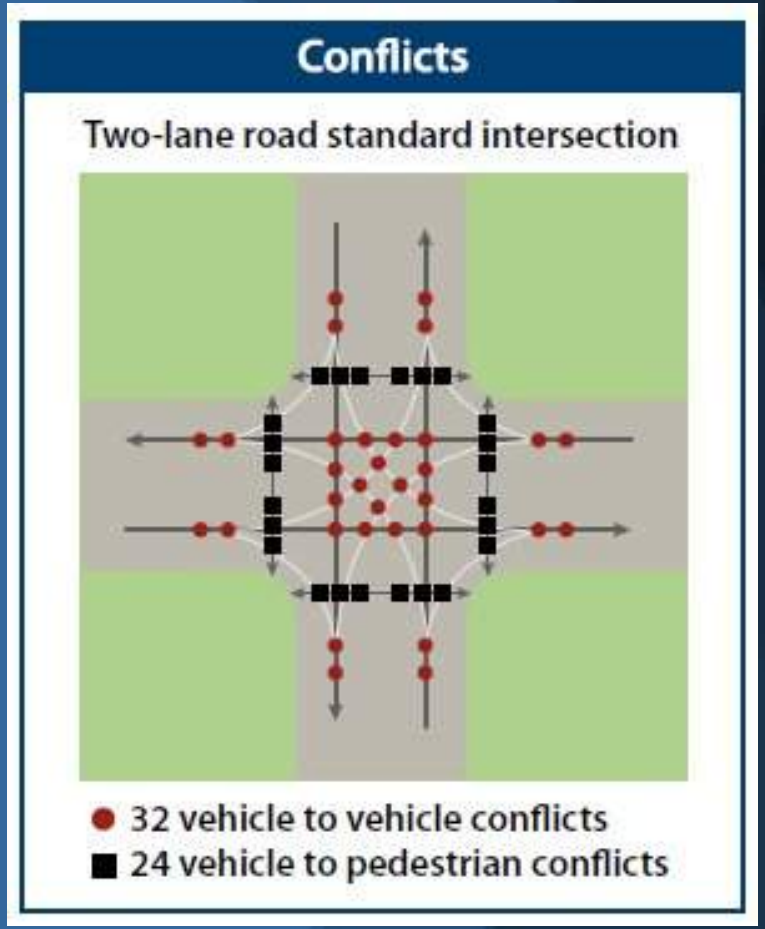
- In US 900+ cyclist fatalities and 35,000+ serious cyclist injuries (requiring hospitalization). National Highway Traffic Safety Administration -2018
- Bike lanes/cycle tracks and usages increasing. Marked bike lanes are relatively new.
- Lighting standards are currently very unclear and don't deal with conflict points.

LIGHTING OPTIONS

- Apply surround ratio (illuminance)
- Light bike lane as part of the roadway (luminance)
- Light bike lane as per sidewalk (consider vertical illuminance)

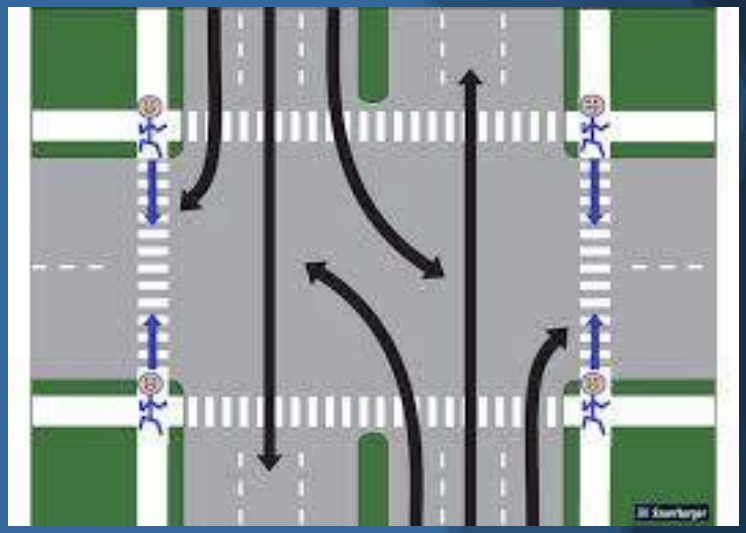
Intersection Conflict Points

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



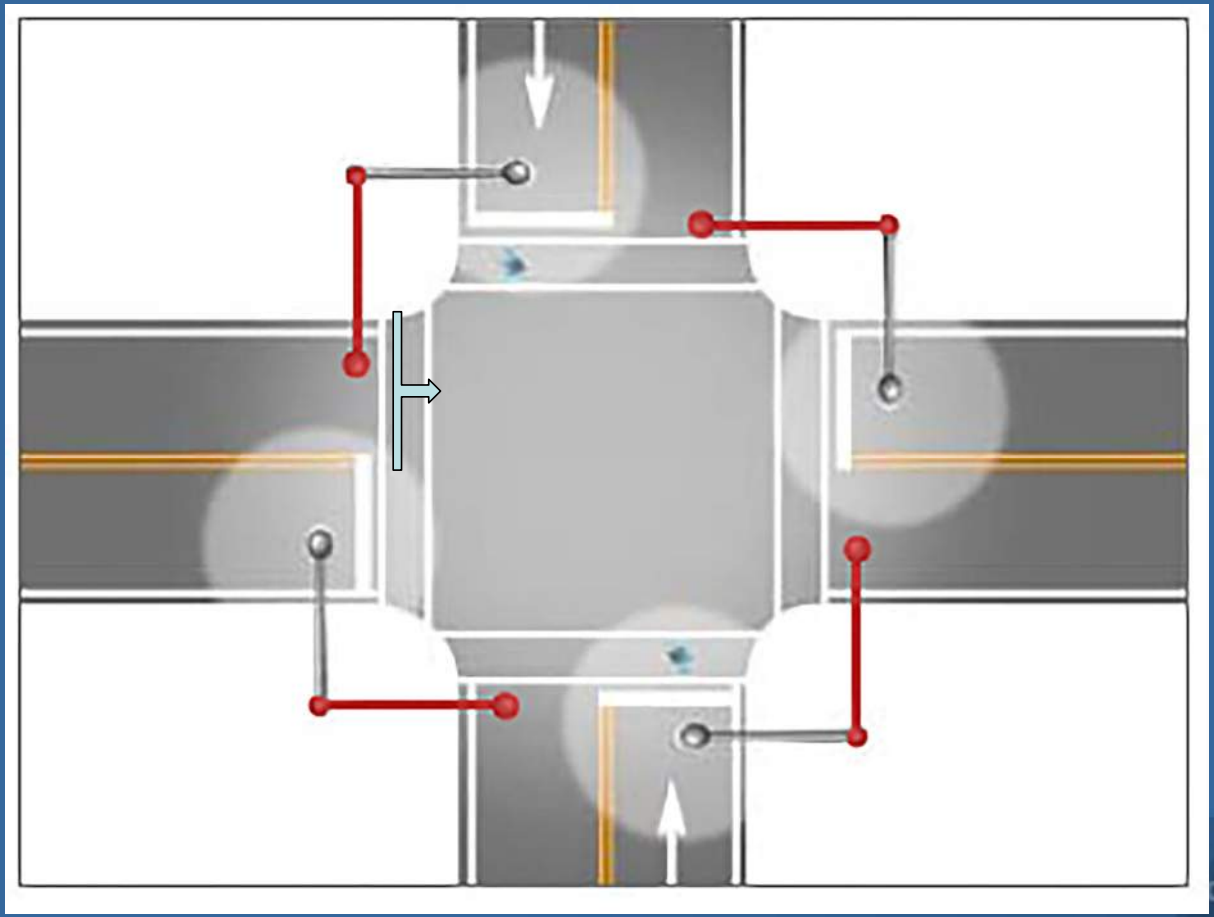
- * Virginia Tech Transportation Institute

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.

Intersection Lighting



Studying benefits of additional lighting on signal poles.