Value Metrics: Quantifying Lighting Benefits for Roadways

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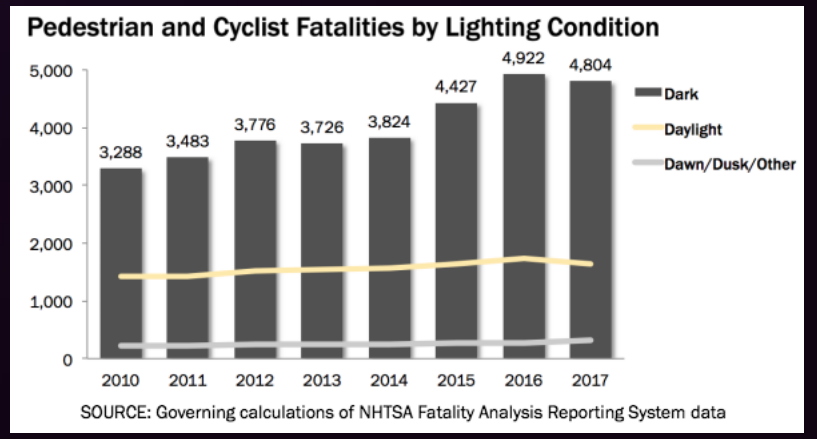
Effects of (or lack of) Roadway Lighting



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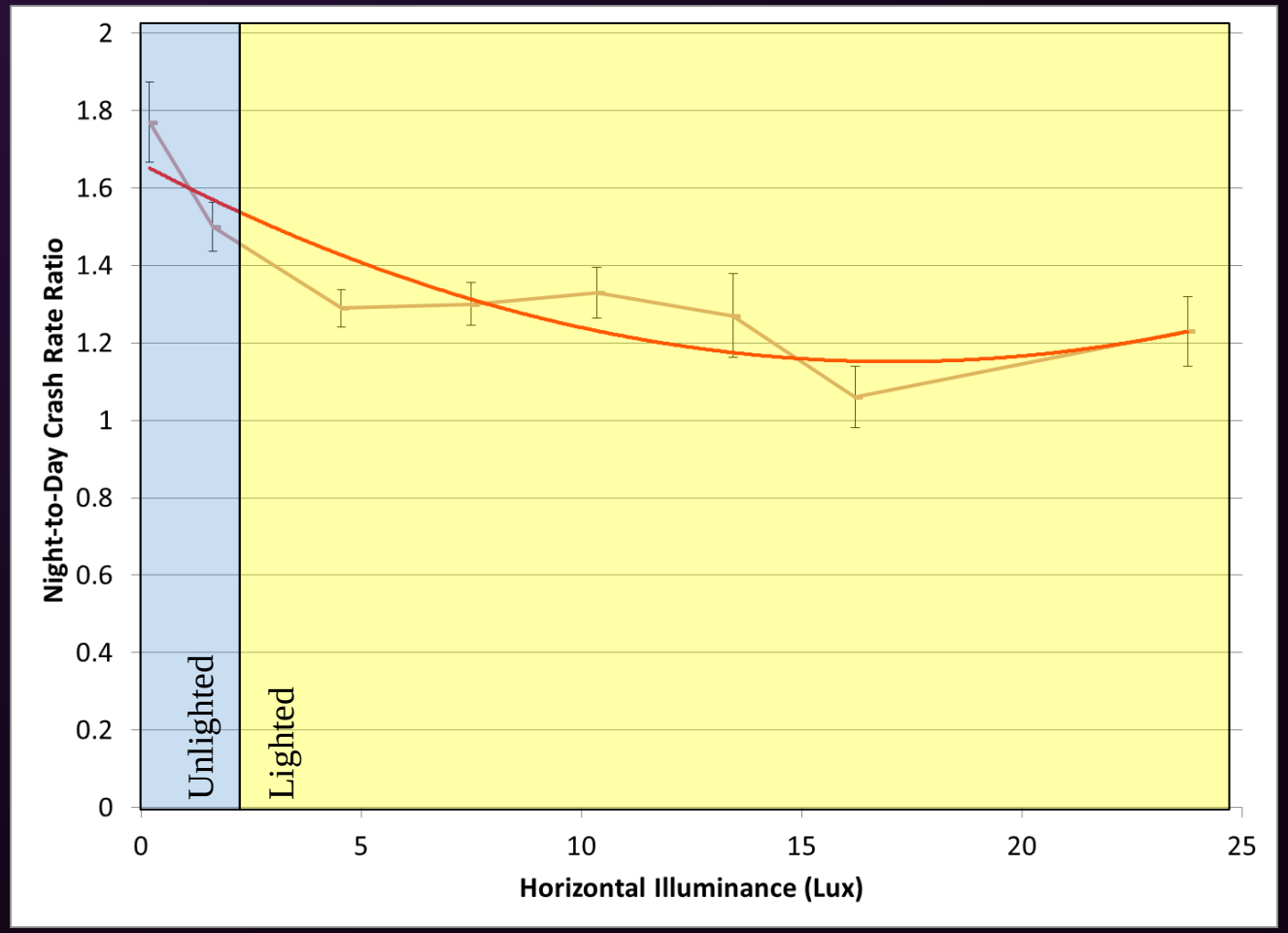
What metrics can be used to quantify roadway lighting?

- Crashes
- Light Distribution
- Color or Spectral Power Distribution
- Light Level

Standards and Specifications have lagged with advent of LED roadway lighting

Roadway Lighting and Traffic Safety – Decrease in Crash Metrics On Interstates



Gibbons, Ronald B., et al. *Guidelines for the Implementation of Reduced Lighting on Roadways*. No. FHWA-HRT-14-050. United States. Federal Highway Administration, 2014.

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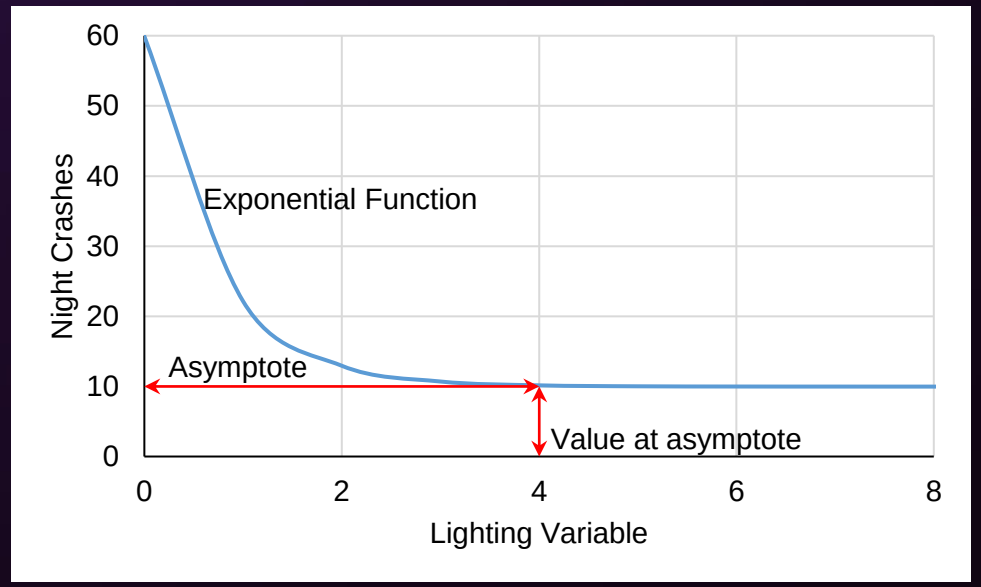
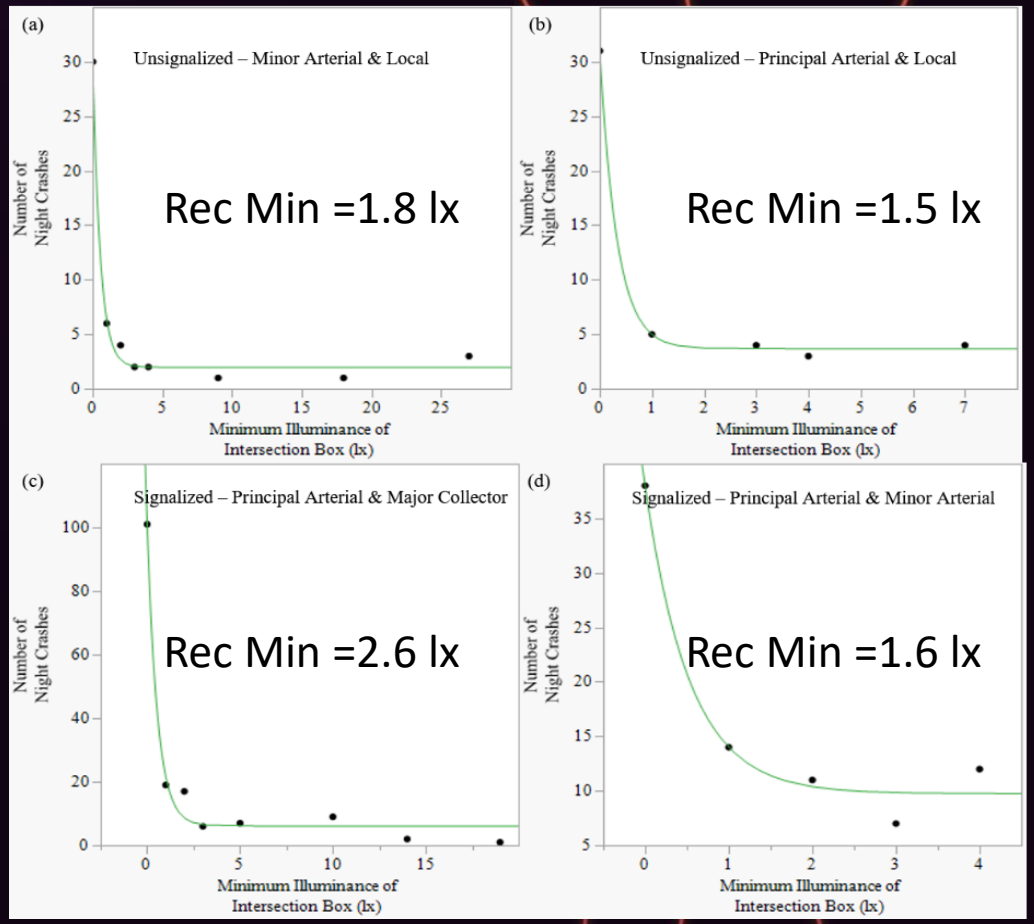
Roadway Lighting & Safety – Decrease in Crashes at Intersections

235 intersections in Virginia

Increase in light level by 1 Lux is associated with decrease in Night to Day Crash Ratio by 2.9 %





Li, Y. E., Bhagavathula, R., Terry, T. N., Gibbons, R. B., & Medina, A. (2020). *Safety Benefits and Best Practices for Intersection Lighting* (No. FHWA/VTRC 20-R31).

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Problems with using Crash Data

- Crashes are rare and extreme scenarios - 37000 traffic fatalities per 3.2 trillion miles travelled (2018)
  - 1 death per 86 million miles
  - 1 injury per 1.3 million miles
  - 1 crash per 508,000 miles
- Crashes are not a good metric to evaluate lighting
  - Multiple causal factors

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Crash Trifecta

Existing Unsafe Condition

+

Driver Behavior

+

Unexpected Event

Crash

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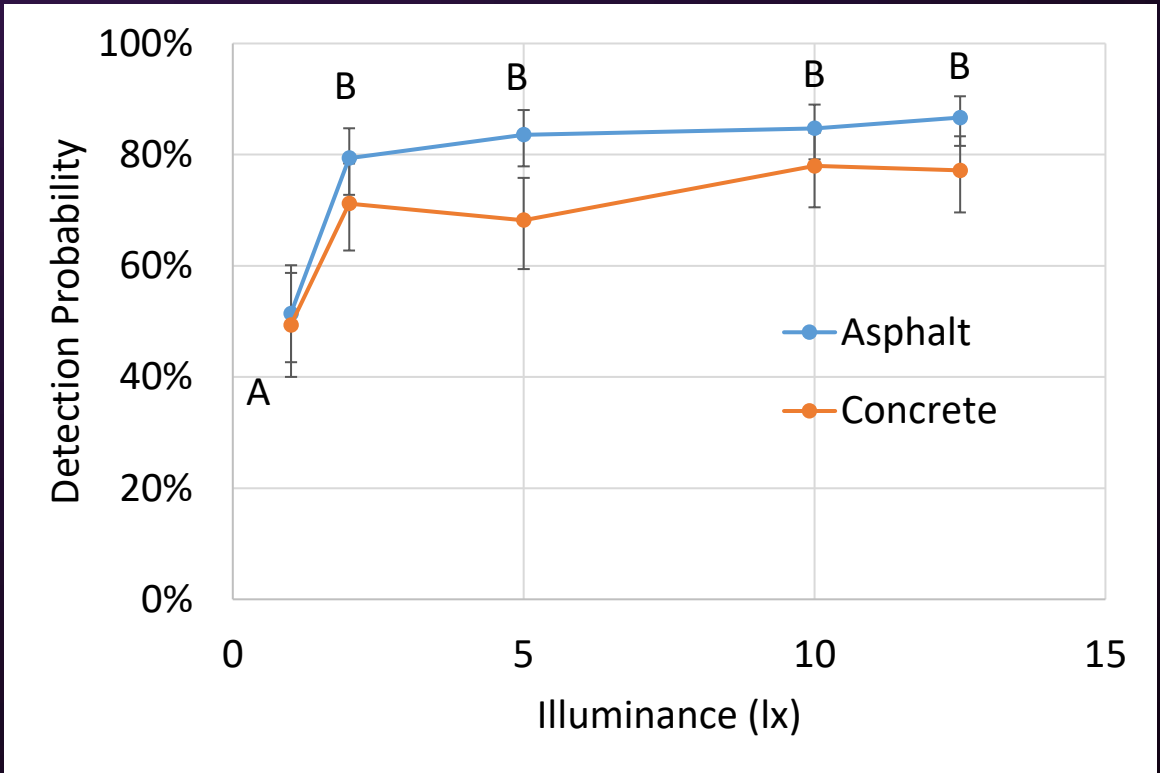
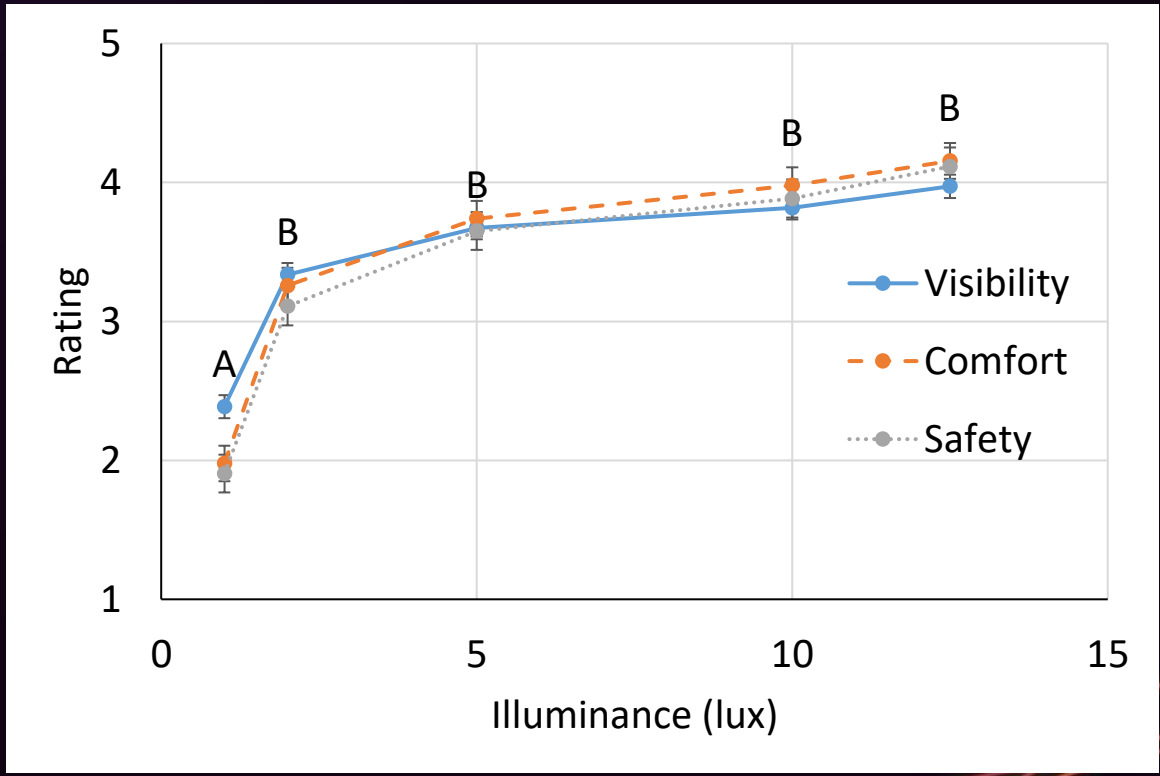
We cannot light our way to seeing better or feeling safer!

No increase beyond 2 lux





84% reduction in energy by dimming to 2 lux

Bhagavathula, R., & Gibbons, R. B. (2020). Light levels for parking facilities based on empirical evaluation of visual performance and user perceptions. *Leukos*, *16*(2), 115-136.

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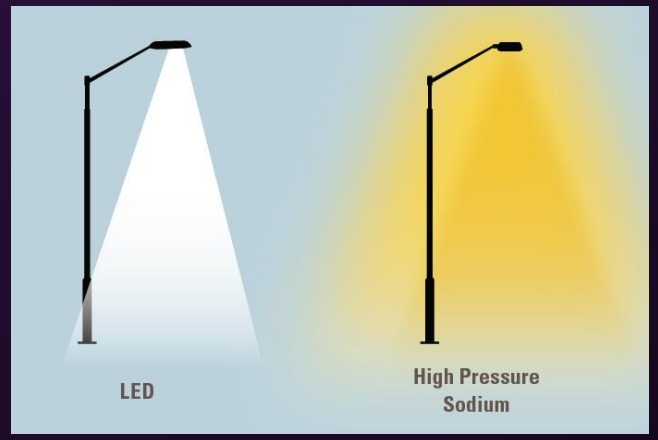
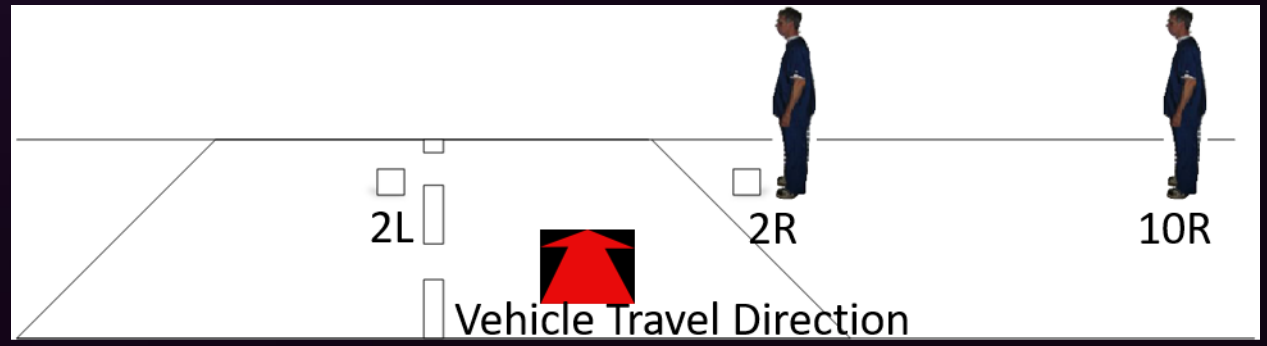
What areas should be illuminated by street lights?



Anchorage. Photo by Wayne Johnson, ML&P

High vs. Low Surround Ratio



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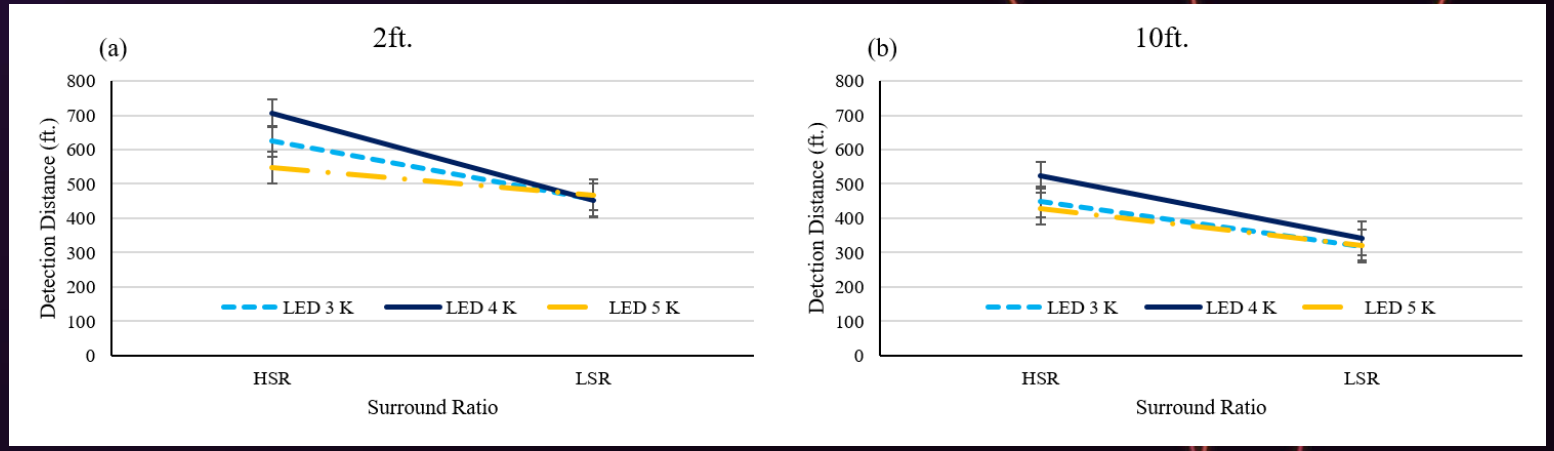
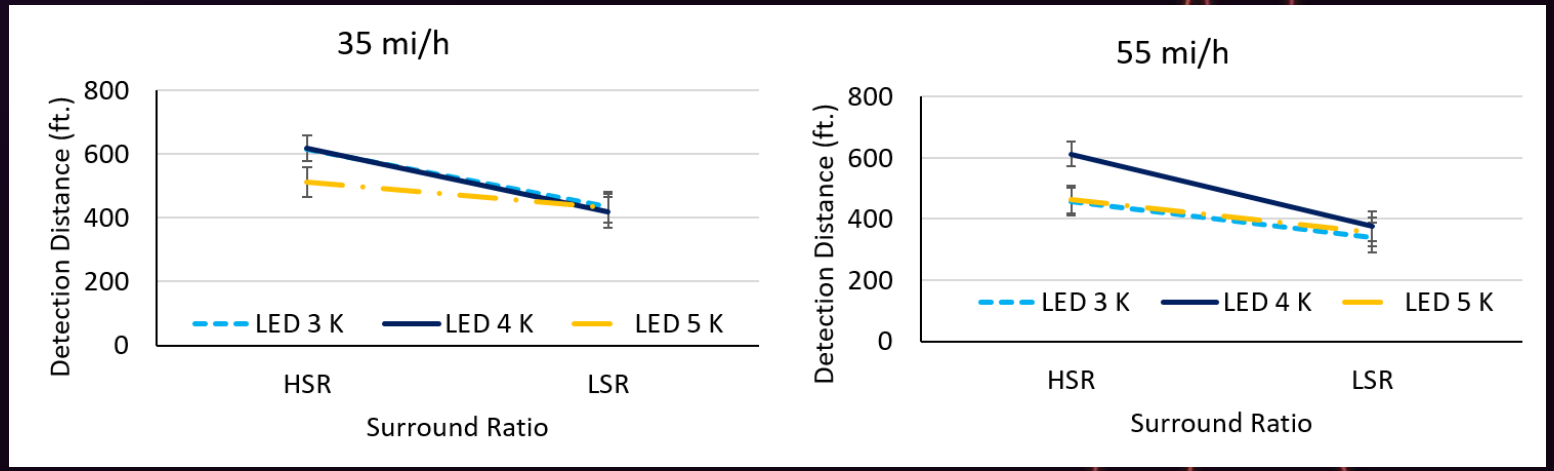
How does Surround Ratio affect Visual Performance

Offset Distance from Roadway



Speed



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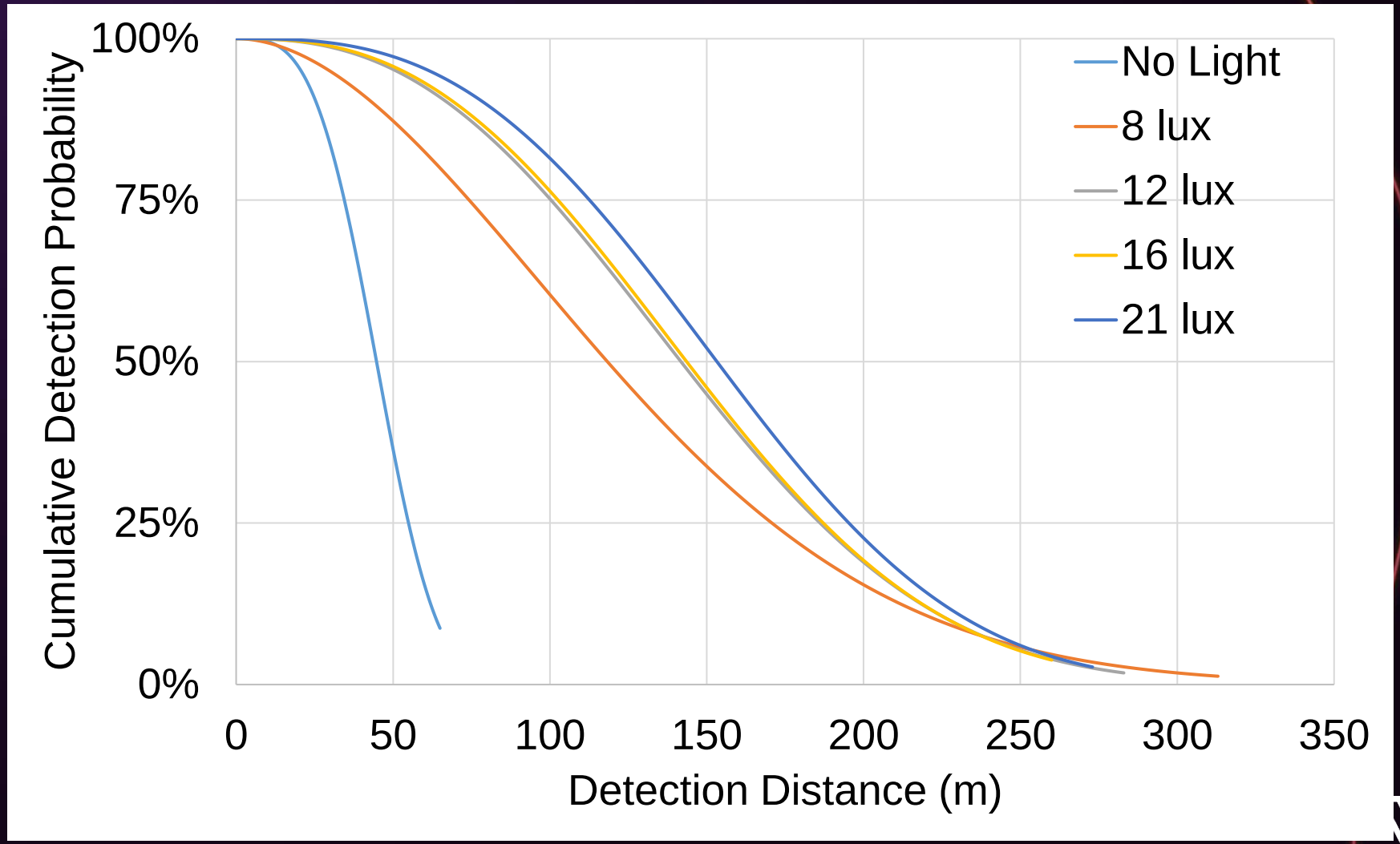
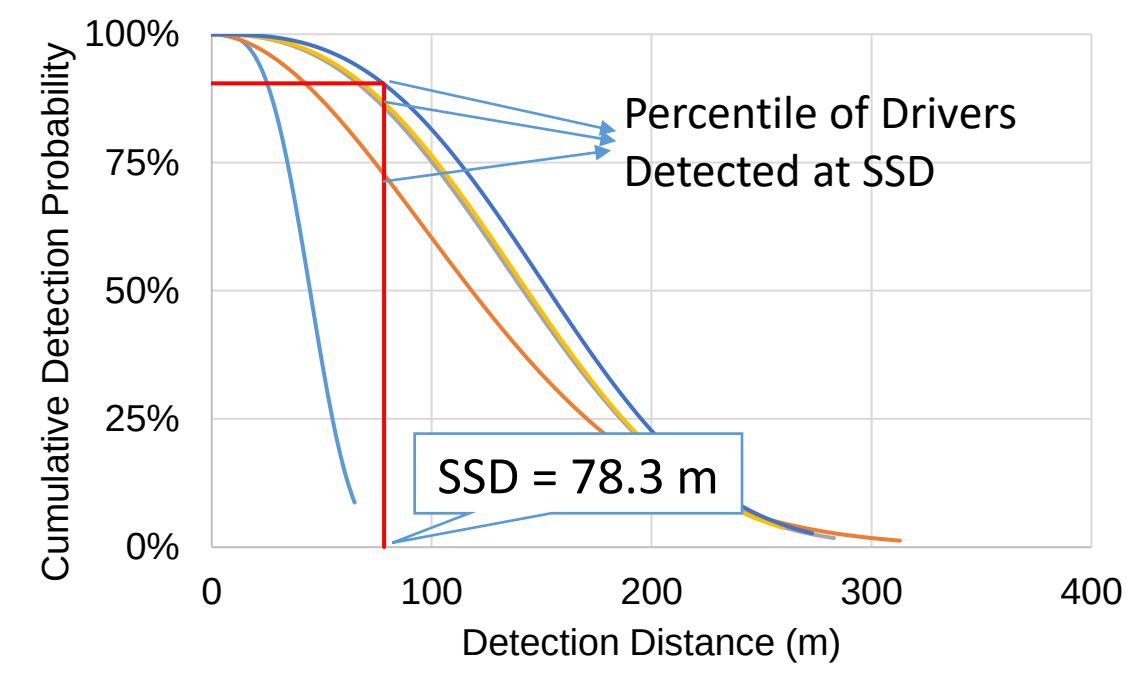
Future Directions to Evaluate Roadway Lighting

- Study probability distributions of detection in different light conditions
  - “How does the probability of detecting a hazard change with distance travelled?”
- Compare Detection distance to Stopping Sight Distance (SSD)
  - Easy for traffic engineers

Effect of Light Level on Probability Distribution



Comparison to Stopping Sight Distance



Light Level	Percentile of Drivers Detected at Distance Greater Than SSD
No Lighting	0
8 lux	73
12 lux	86
16 lux	88
21 lux	91

Can be used to identify how many drivers could have detected the hazard from a safe distance

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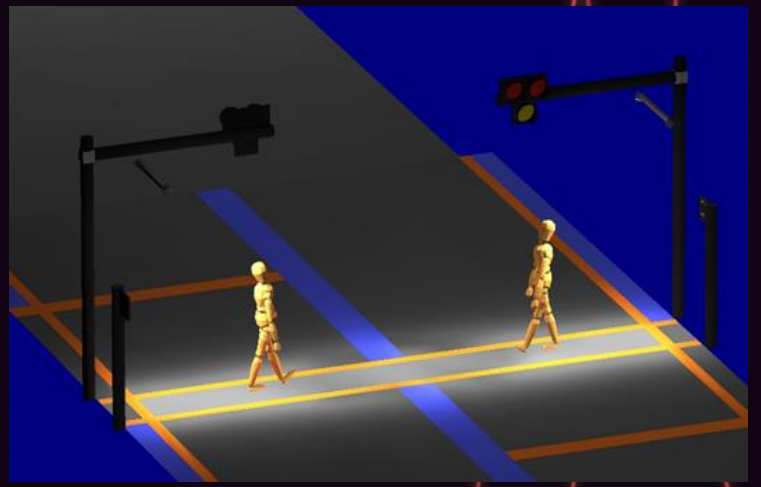
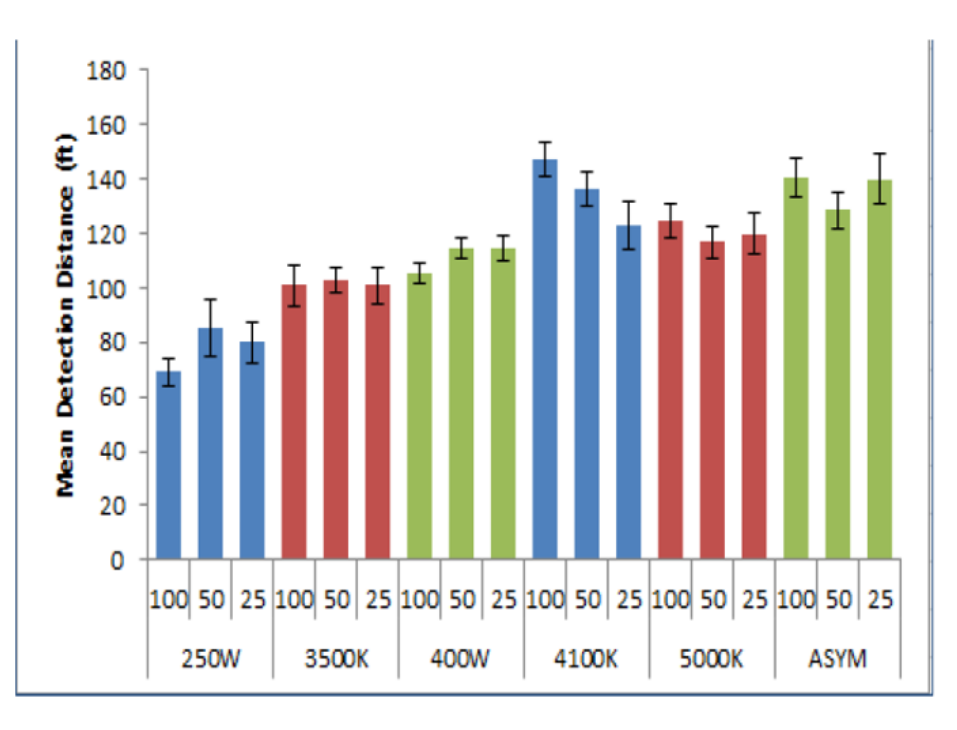
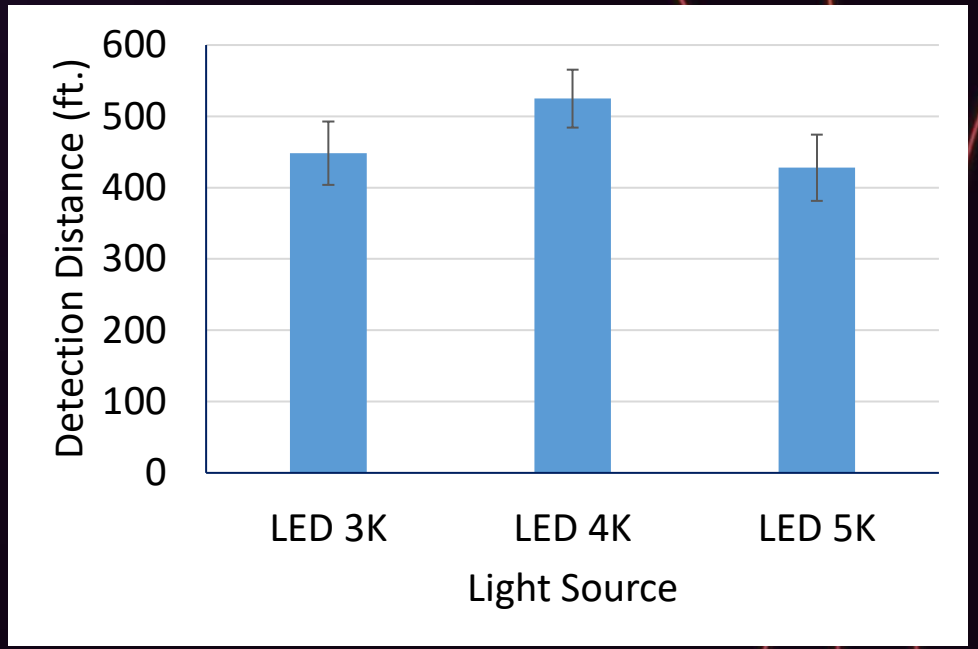
Comparison of lighting to other countermeasures

- Best combination to increase pedestrian safety at night – In progress



Driver visual performance under different light sources – Evidence of benefits of 4000 K LED



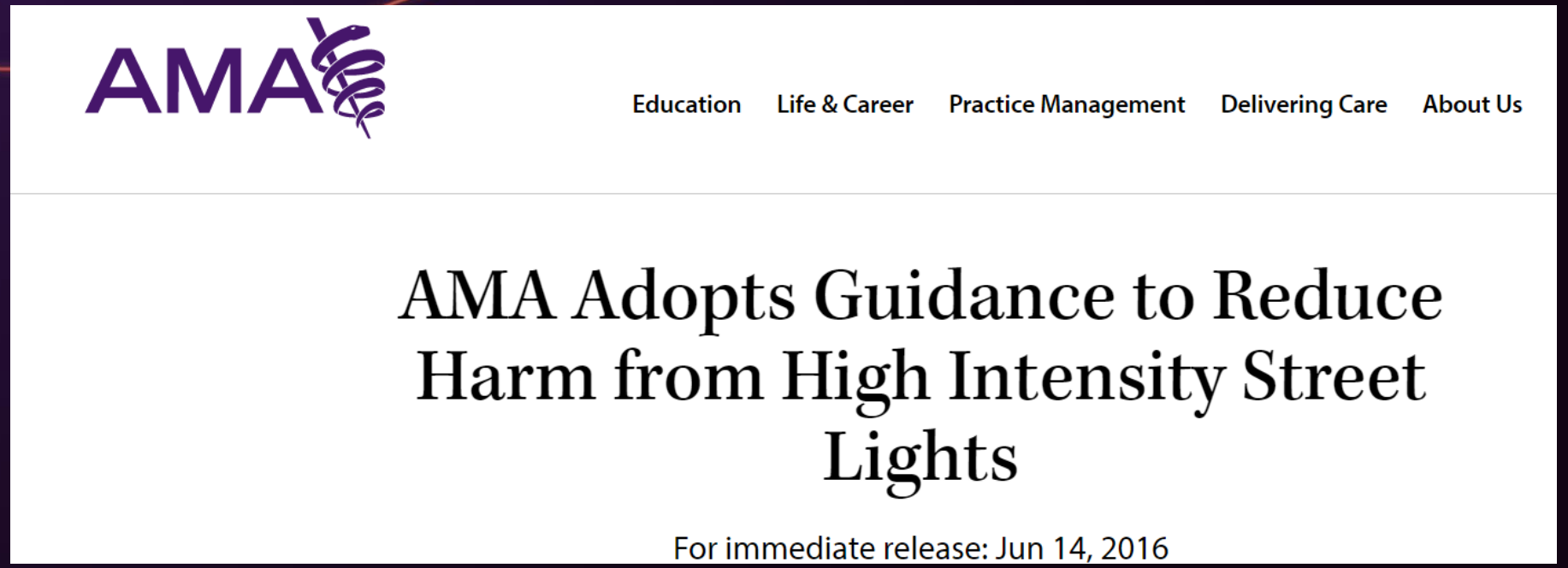


Replace a 4000 K with a 3000 K

- What is the increase in light level to match performance?
- Side effects of the increase

Clanton, N., Gibbons, R., Garcia, J., & Terry, T. (2014). Evaluation of Adaptive Lighting in the City of Seattle.

National Academies of Sciences, Engineering, and Medicine 2020. *Solid-State Roadway Lighting Design Guide: Volume 2: Research Overview*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25679.



Use 3000 K CCT

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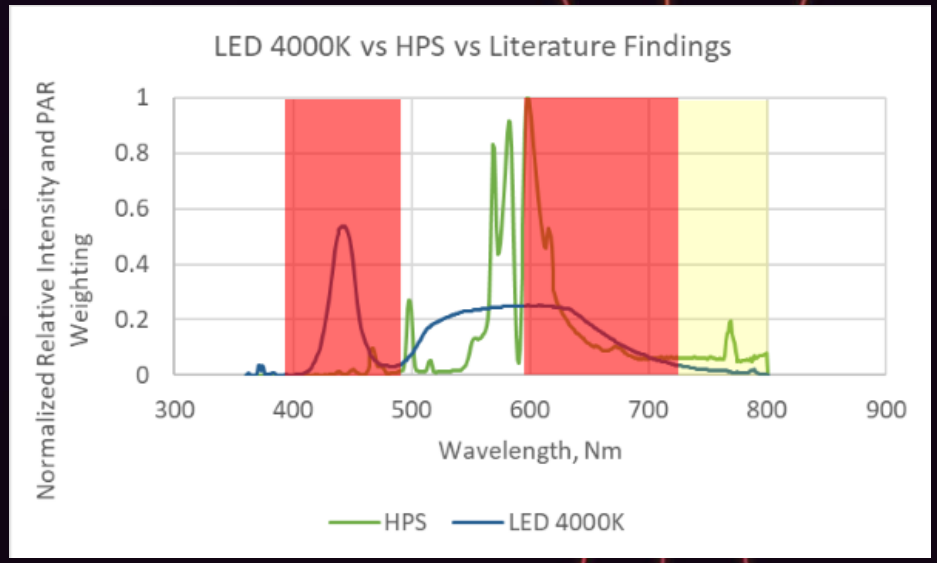
Roadway Light's Effect on Soybean Growth



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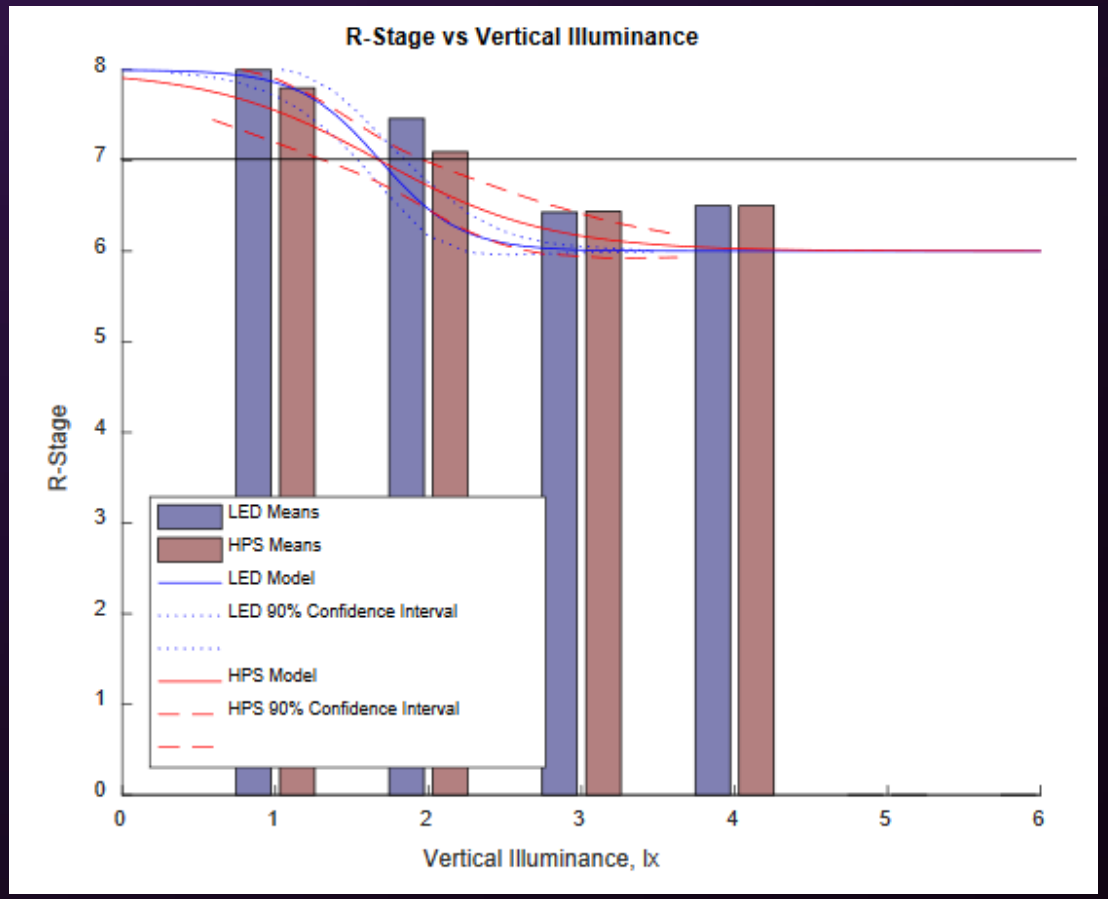
Effect of Roadway Light Level on Yield and R-Stage of Soybeans



Revised Trespass Illuminance Limits for the HPS and 4,000K LED Streetlights Used in This Study Continuous Nighttime Lighting

Illuminance	Maximum, lx
Horizontal	2.2
Vertical	1.8

Palmer, M., Gibbons, R., Bhagavathula, R., & Holshouser, D. (2018). *Roadway Lighting's Impact on Altering Soybean Growth–Volume 2: LED versus HPS Color Spectral Impact*. Illinois Center for Transportation/Illinois Department of Transportation.

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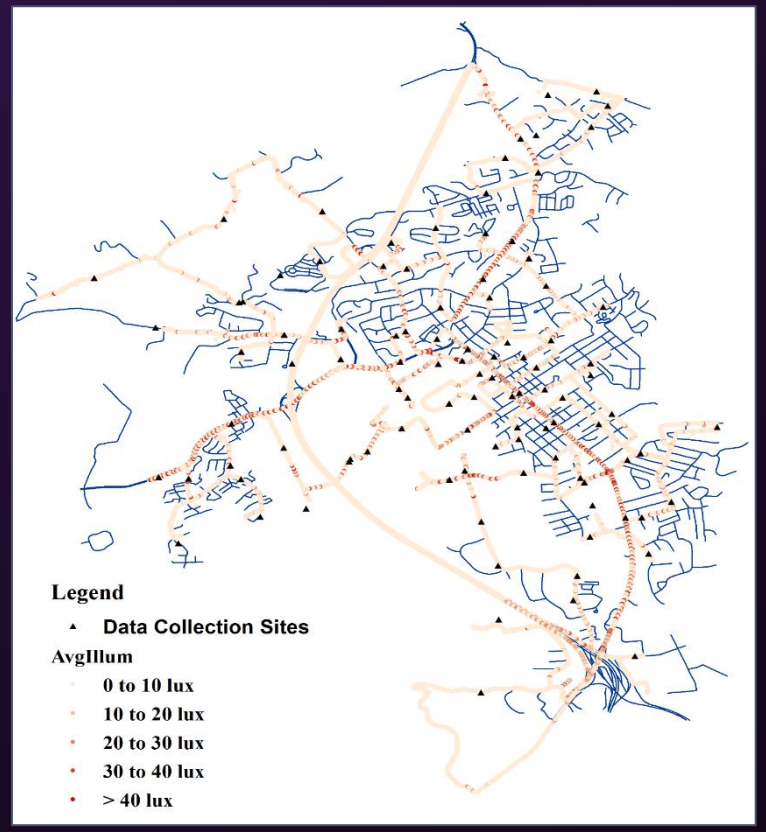
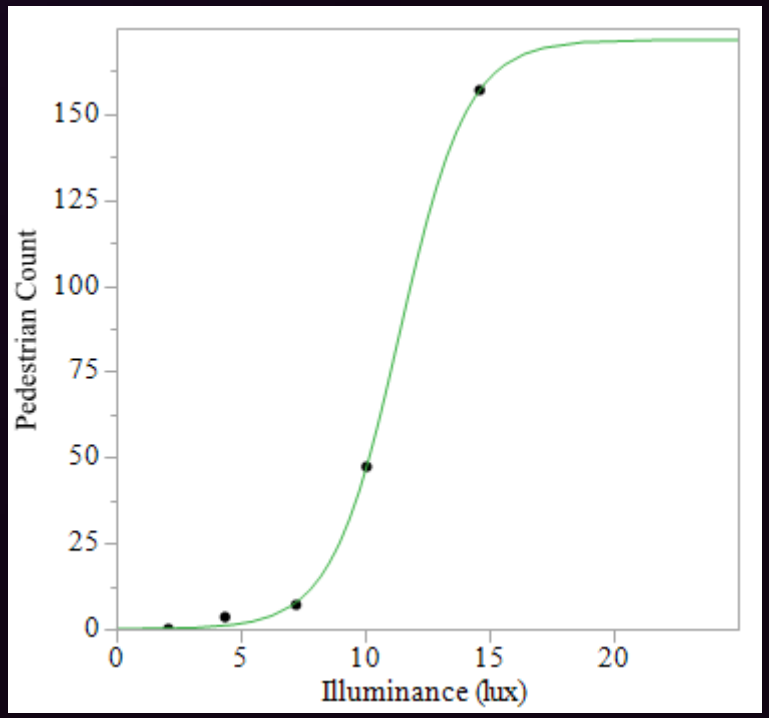
Does Roadway Lighting affect Facility Use or Physical Activity?





Increase in Average Illuminance by 1 lux → Increase in Night to Day Pedestrian Count Ratio by 11.8%

Inform the lighting design and guidelines for pedestrian walkways and bicycle lanes.

Roadway lighting and human health

- Lack of research on LED street lighting's effect on human sleep physiology and alertness
  - Light with a higher blue content (LEDs)
    - Affects sleep physiology by melatonin suppression
    - Contrastingly, also increases alertness (some evidence)
  - Studies in naturalistic roadway lighting exposures are in progress – almost done
- How much light do we get from street lights vs. other light exposures?
  - Indoor Light
  - Electronic Devices

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Roadway Lighting 2 hour exposure - Drivers

Light Condition	Road Luminance (cd/m²)	Total Dose (lux-s)	Avg. Corneal Illuminance per second (lux)
2200 K LED	0.8	9,448.00	1.3
3000 K LED	1	12,518.90	1.7
4000 K LED	1	12,663.00	1.8
5000 K LED	1	12,745.10	1.8
2100 K HPS	1	11,397.90	1.6
No Light	<0.05	6,150.00	0.9

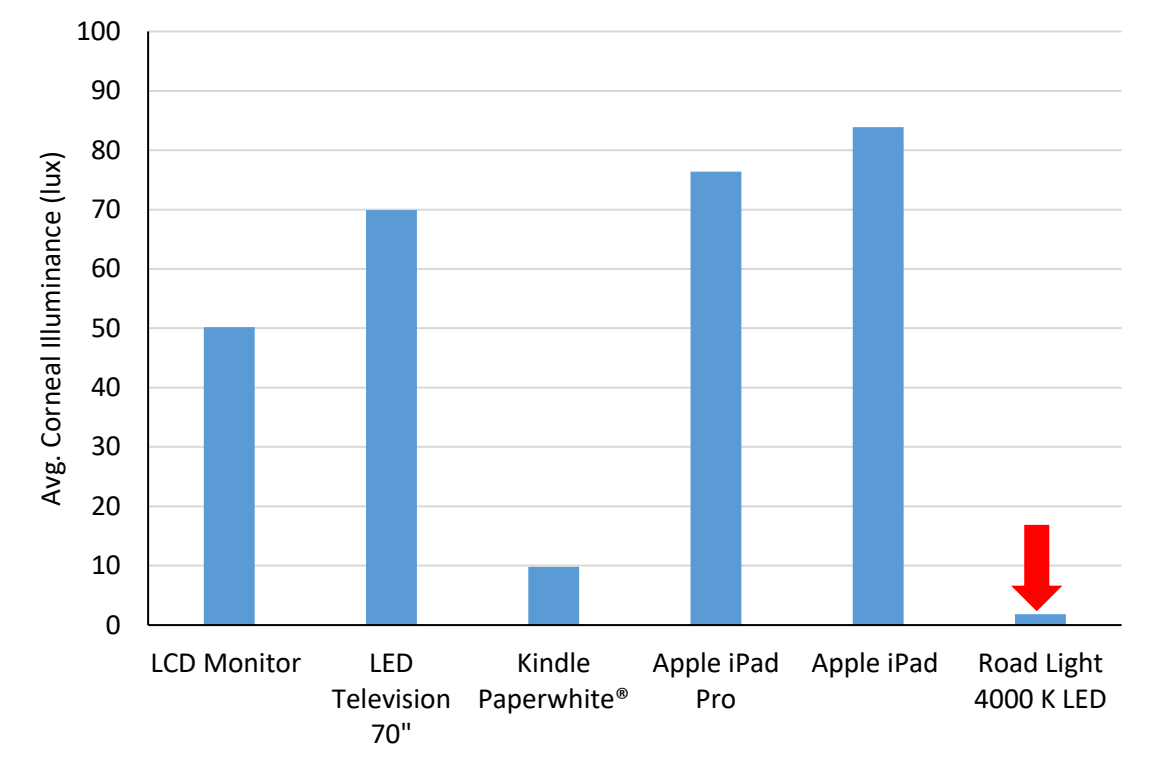
Photometric Measures with Calculated α-opic Lux Values

2018 CIE DS 026 Standard, CIE User Guide March 2020

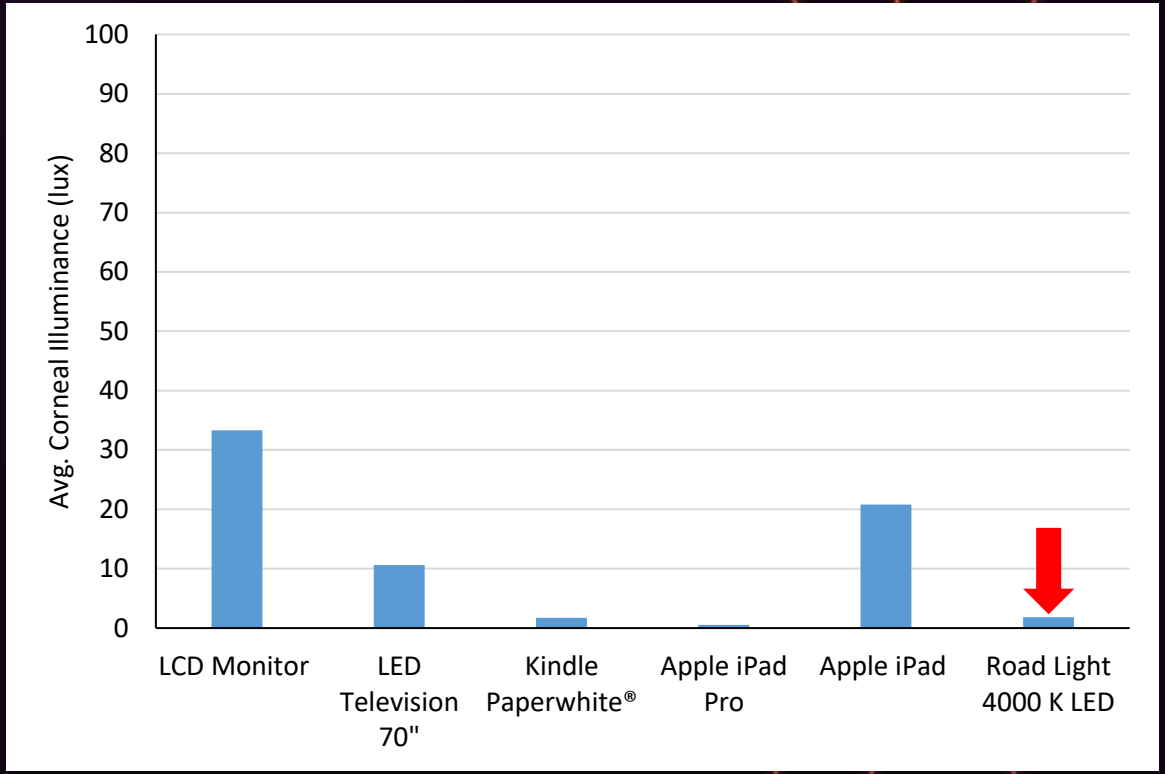
			α-opic equivalent daylight (D65) illuminance, lux				
Light Condition	Photopic Illuminance (lux)	Roadway Luminance (cd/m^2)	S-cone-opic	M-cone-opic	L-cone-opic	Rhodopic	Melanopic
Indoor Exposure	200 lux	--	66.4	173.0	194.5	112.4	87.1
2100 K HPS - HIGH	1.8 lux	1.5	0.3	1.2	1.9	0.5	0.3
4000 K LED - HIGH	1.9 lux	1.5	0.6	1.6	1.8	1.1	0.8
4000 K LED - MED	1.4 lux	1.0	0.5	1.2	1.4	0.8	0.6
4000 K LED - LOW	1.1 lux	0.7	0.4	1.0	1.1	0.6	0.5

Comparison of Consumer Electronic Devices to LED Road Lighting

Full Brightness



Dark Mode



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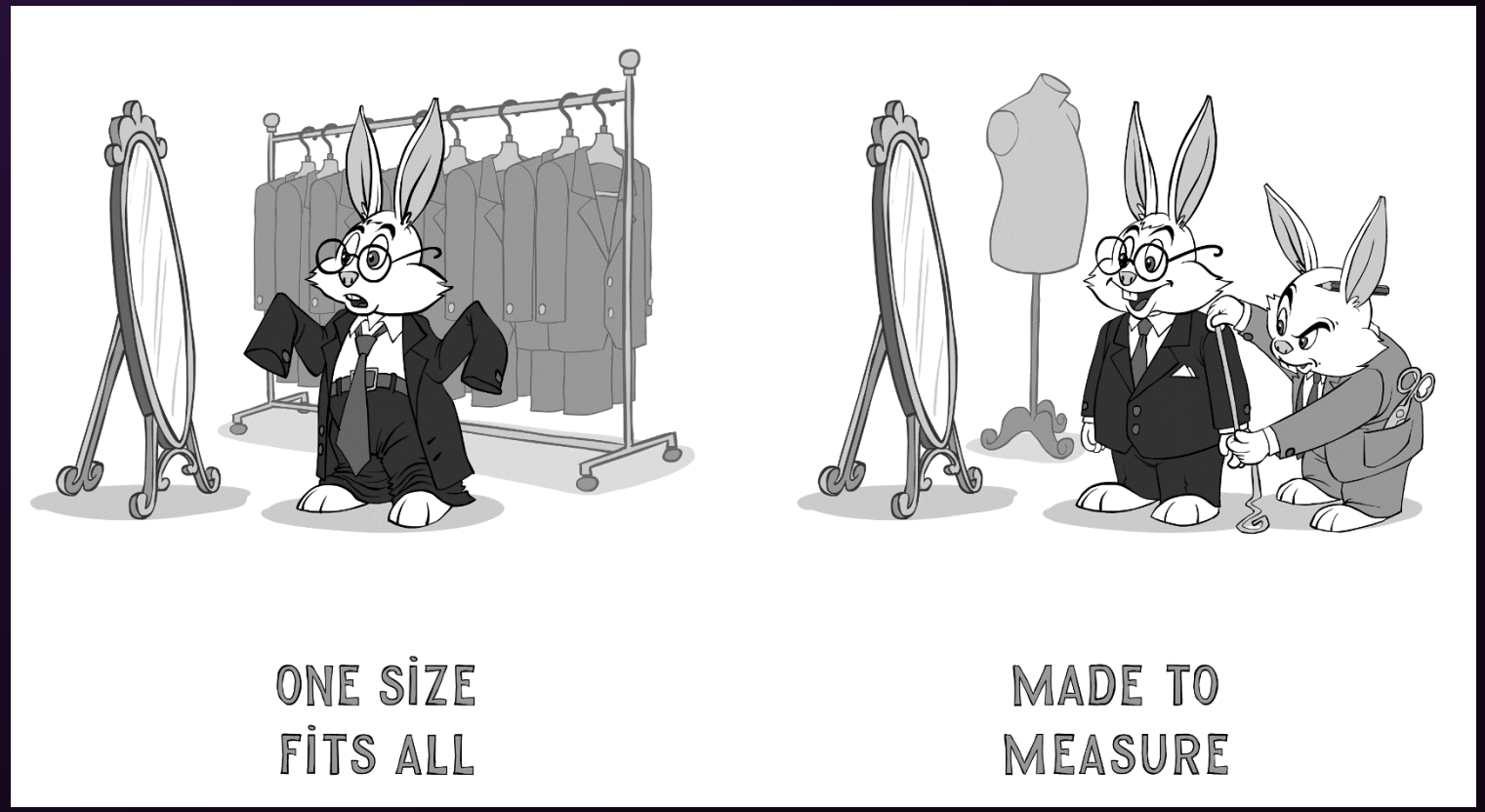
Integrating these value metrics into roadway lighting design

- Safety (Perceptions & Performance)
- Effects on Plants, Animals, & Insects
- Human Health
- Environmental Effects
- Energy Efficiency

Dimming or change in spectra or both

Evolution of Roadway Lighting Design



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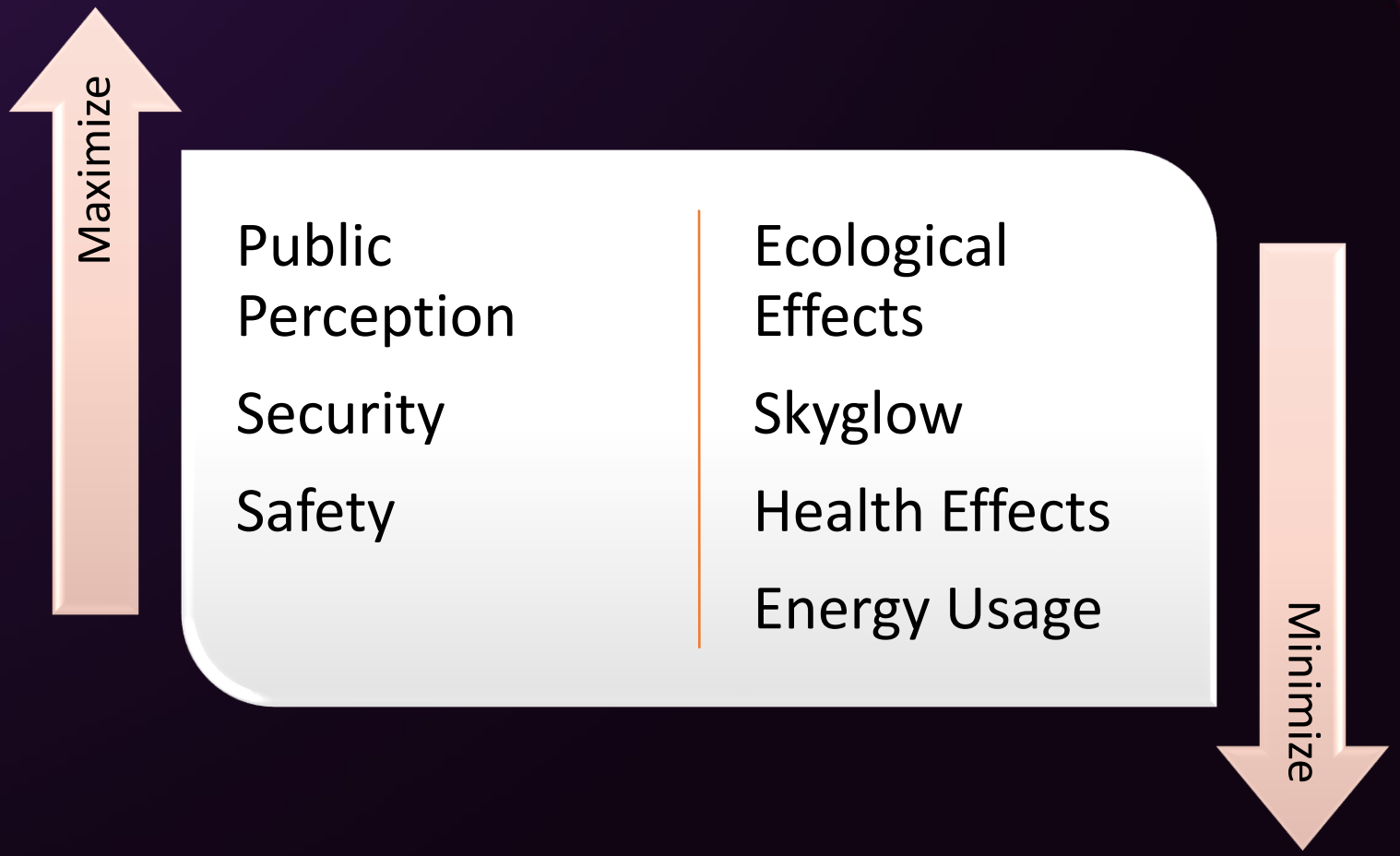
Good Roadway Lighting Design is a Balancing Act



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Consider Light as a Medicine

- Right Type
- Right Amount
- Right Time
- Right Location
- Adaptive Lighting
  - Dimming during periods of low use
  - Cambridge, MA
  - Tucson, AZ
  - San Jose, CA

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Value metrics for future

- How much light and what spectra are allowable
  - What are the thresholds for lighting impact
- What are the long term effects? How to quantify?

"To ask the right question is already half the solution of a problem."
— C.G. Jung

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Thank you

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