Designing Lighting for Night Work Zones

Disclaimer

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Disclaimer

- Commercial products shown in this presentation are examples selected for instructional purposes, and do not indicate any endorsement, recommendation or favoring by FHWA, the authors, or the instructors.
- The introduction of LED lighting has led to rapid changes in the product offerings from major lighting manufacturers and many new products from start-up companies. Some luminaires shown in this presentation have been discontinued or replaced by newer models.

WHY IS ILLUMINATION DESIGN IMPORTANT?

Well-Designed Lighting

Source: Pavement Interactive

- Free of glare for all drivers
- Not distracting to drivers
- Bright enough to do high-quality work
- No harsh shadows on work surface
- Workers do not need to squint or use handheld lamps
- Supports worker productivity, does not worsen fatigue

Poorly Designed Lighting

Poorly Designed Lighting

When did you see the excavator?

Poorly Designed Lighting

The engineer who filmed this did not see it until she went back and watched the video.

Poorly Designed Lighting

Source: TOPS Lab

Poorly Designed Lighting

Source: TOPS Lab

Did you notice the concrete barrier with no end treatments?

More Bad Examples

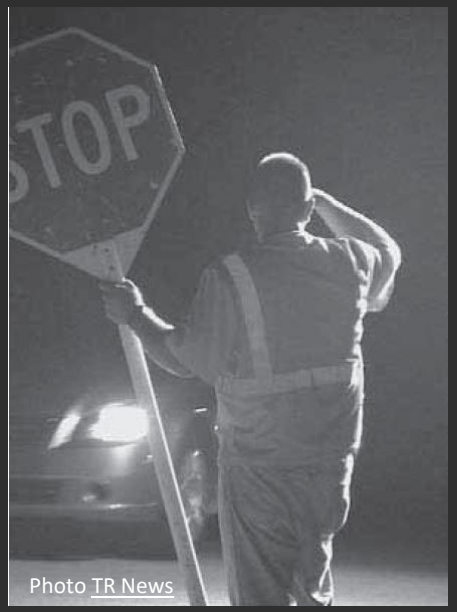


Photo TR News

Photo TR News

Flagger Can't See Traffic

Traffic Can't See Flagger

Photo ATSSA

Photo: National Cooperative Highway Research Program Report 476

Why?

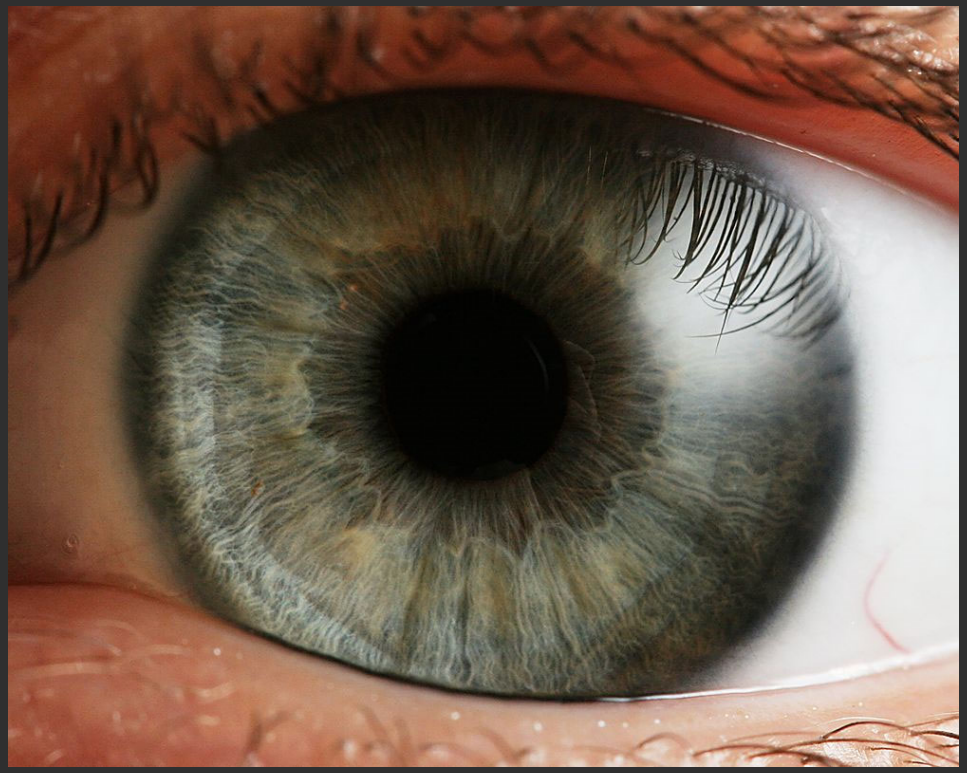


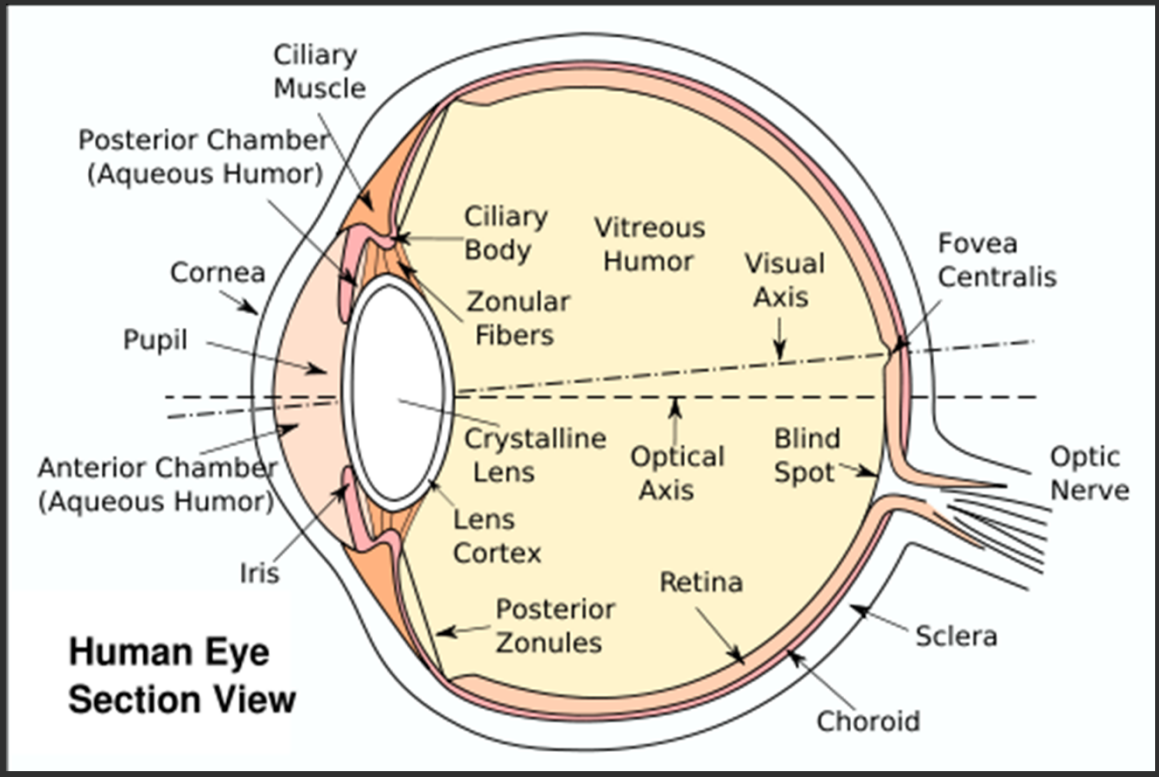
Photo: Petr Novák/WikiMedia Commons

- Human eyes cannot simultaneously adapt to bright and dim light.
- Dilation/contraction of the iris takes a few minutes.
- In the previous examples:
  - Light levels vary greatly in different parts of the work zone.
  - Light levels abruptly change from one second to the next.

Excessive Contrast = Glare

- Excessive light bounces around inside the vitreous humor
- In extreme cases, the observer is temporarily blinded

- Sensitivity to glare increases with age → elderly people most affected
- Wet surfaces and dirty windshields increase glare effects



Source: Zstardust /WikiMedia Commons

Reflexive Reactions To Glare

Photo: Matt Smith/WikiMedia Commons

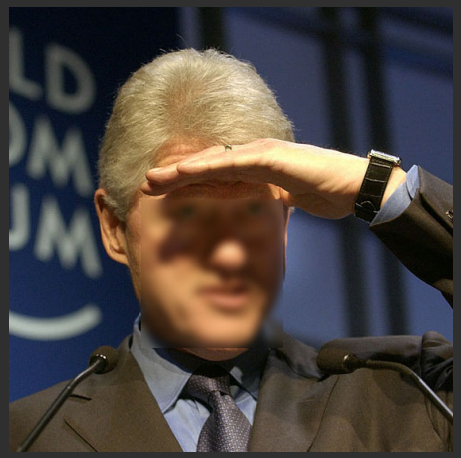


Photo: Remy Steinegger /WikiMedia Commons

Photo: Ahmedd /WikiMedia Commons

Photo: Paul Holcomb/US Air Force [WikiMedia **Commons]**

Mild to Moderate Glare

- Discomfort

Severe Glare

- Eye Shielding
- Squinting
- Looking Away

Extreme Glare

- Closing Eyes
- Temporary Blindness

All of these are undesirable while driving!

Effects of Poor Lighting on Workforce

- Increased risk of traffic crashes → Potential worker casualties
- Harsh shadows → Increased risk of trips, falls, etc.
- Squinting, eye strain & glare → Fatigue, reduced productivity
- Inability to see textures and details → Quality control issues
- Gloomy environment → Reduced morale, employee turnover

The cost of better lighting is probably offset by safety and efficiency benefits.

HOW MUCH LIGHT IS NEEDED?

https://www.youtube.com/watch?v=2D8wtLRGKYo

Measuring Luminance (L)

- Customary: Foot-Lamberts
- Metric: Candelas/Square Meter

- 1 cd/m^2 = 1 nit = 0.292 foot-lamberts

- Requires special photometer costing $750 to $2000
- Basis for some street lighting standards

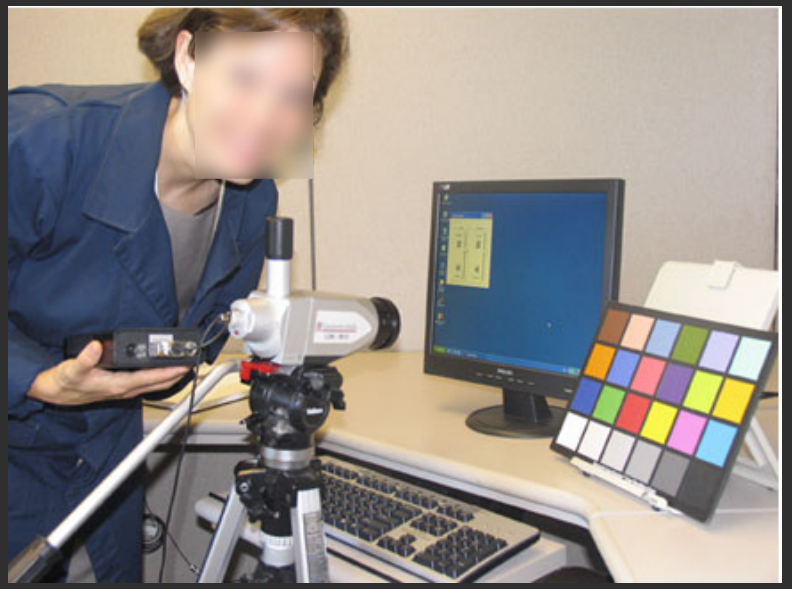


Photo: National Research Council of Canada

Measuring Illuminance (E) "E-Luminance"

- Customary: Foot-Candles
- Metric: Lux

- 1 fc = 10.76 lx

- Easy to measure with a meter costing $25 to $250
- Basis for most work zone lighting standards

Photo: Hankwang/Wikimedia Commons

Comparative Illuminance Levels

Situation	Illuminance (Foot-Candles)	Illuminance (lux)
Full Moon on Clear Night	0.025	0.27
Civil Twilight	0.3	3.4
Permanent Roadway Lighting	0.25 to 1.5	3 to 16
Residential Living Room	4.6	50
60 watt incandescent bulb 20 inches away	9 to 12	100 to 125
Office Interior	30	320
Sunrise on Clear Day	37	400
Hospital Operating Room	1675	18,000
Direct Sunlight	3,000 to 12,000	32,000 to 130,000

- Work zone lighting targets are typically 5 to 30 foot-candles.
- Permanent roadway lighting is seldom bright enough for work operations.

Recommended Illumination Levels
foot-candles (fc)

Work Type	**Minimum** Foot-Candles	**Target** Foot-Candles	**Maximum** Foot-Candles
General • Staking • Excavation • Pavement Rolling	4	5 to 10	25
Specialized • Milling • Paving • Pavement Marking	8	10 to 15	35
Precision • Joint Repair • Crack Filling • Electrical Work	15	20 to 30	45

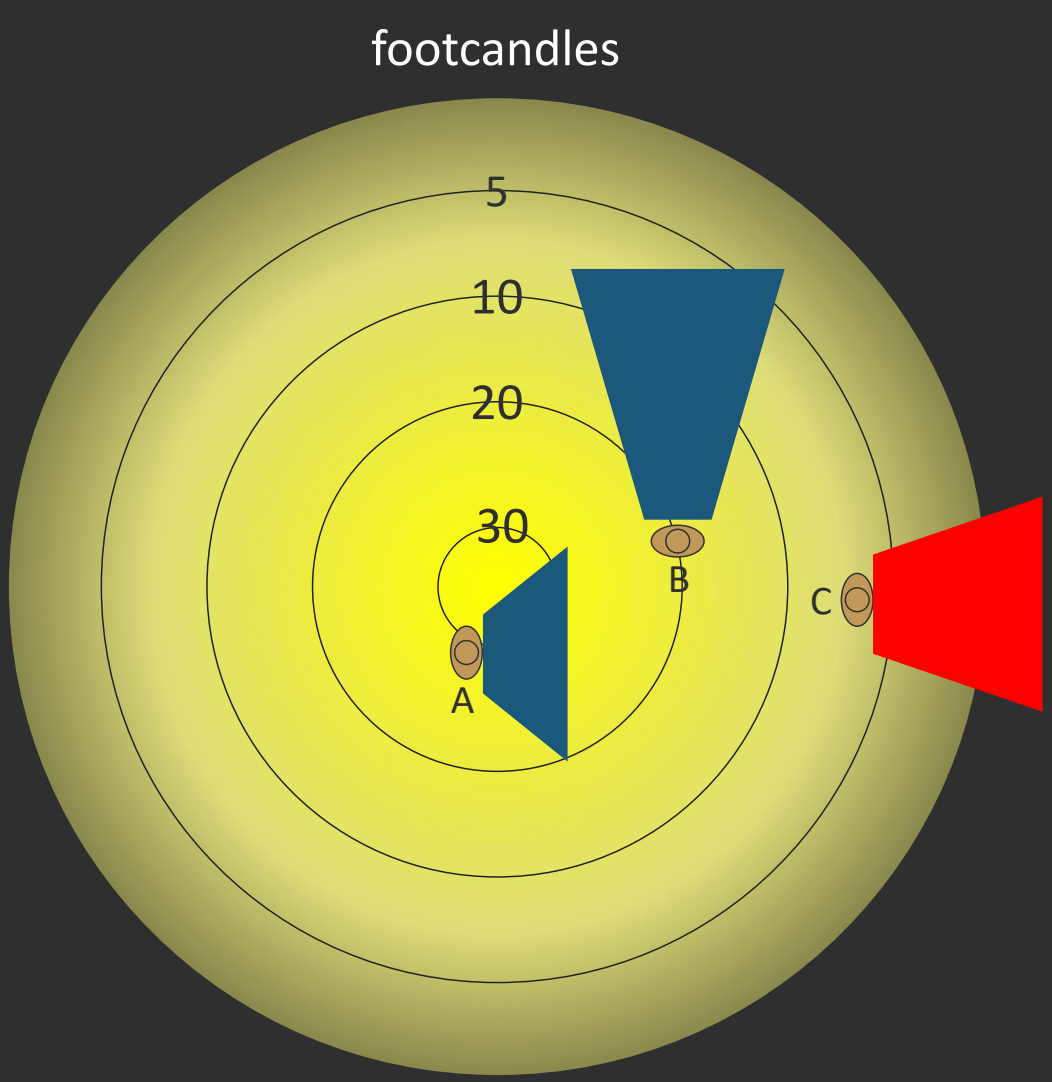
Recommended Illumination Levels

lux (lx)

Work Type	Minimum lux	Target lux	Maximum lux
General • Staking • Excavation • Pavement Rolling	40	55 to 110	270
Specialized • Milling • Paving • Pavement Marking	80	110 to 160	380
Precision • Joint Repair • Crack Filling • Electrical Work	160	220 to 320	480

1 foot-candle = 10.76 lux

Measuring Illumination Adequacy



General Construction
Minimum: 4 fc (40 lux)

Task area with adequate illumination

Task area with inadequate illumination

Portable Light Towers

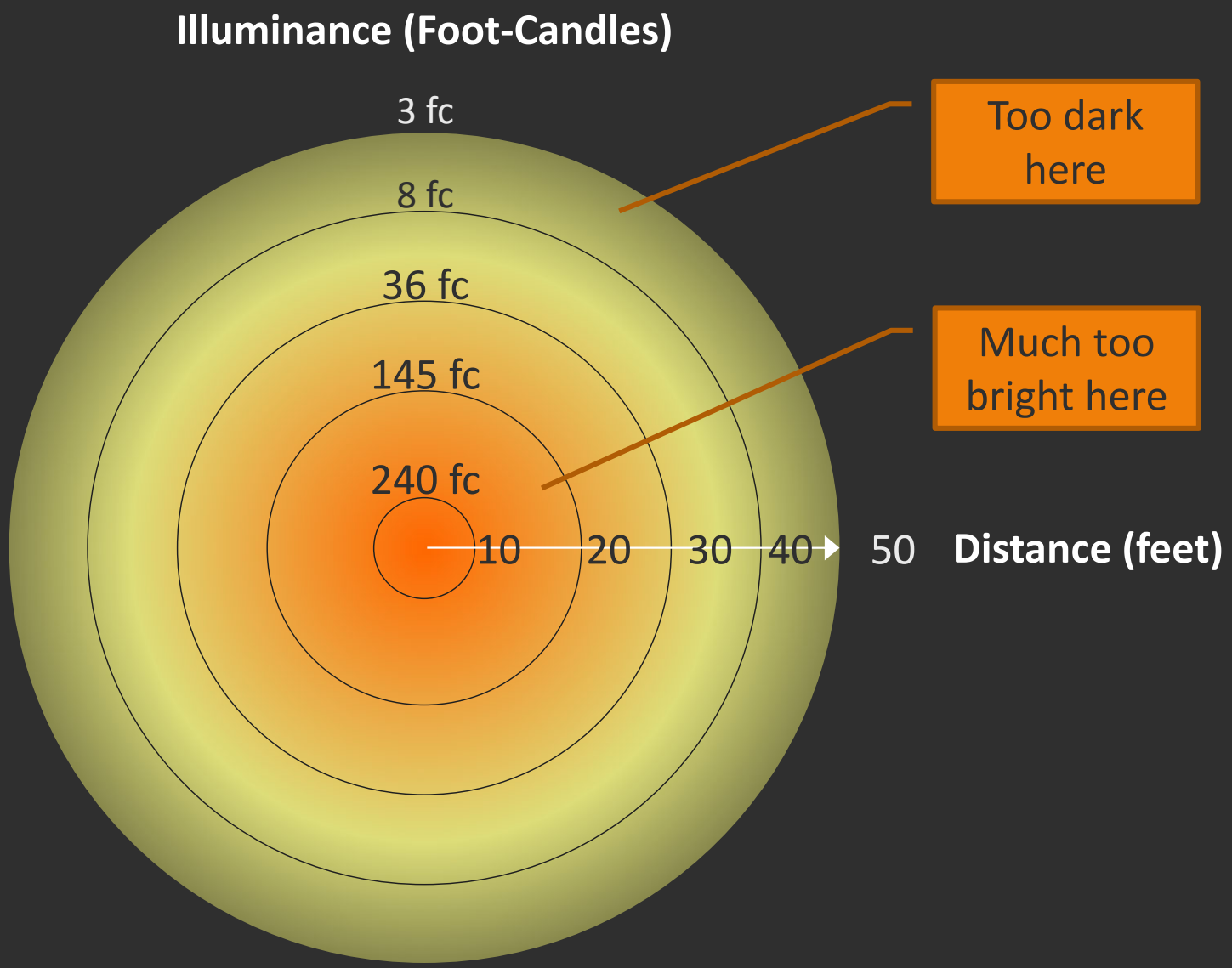
Photo: Shisheng Xuan / WikiMedia Commons

Photo: Pavement Interactive

- Currently the most widely-used method for lighting work zones
- Often a diesel generator with 4 x 1000 watt halogen lamps on 30 foot tower (some use LEDs)
- Typical light output of 400,000 to 500,000 lumens
- About 250 foot-candles at base of tower

Horizontal Illuminance

4 x 1000 Watt Halogen Light Tower Pointed Straight Down



Source: Tom Schuh, Moonglo Work Light, LLC

Effects of Using Only One Light

Photo: Simon Lee/WikiMedia Commons

Rivets on a Steel Girder

- Strong shadows
- Limited visibility in excavations
- Difficulty seeing surface textures
- Harsh reflections from wet/shiny surfaces

Multi-Point Lighting

Lessons Learned from Portrait Photography & Cinematography

Single Point Lighting:
Details Obscured

Three Point Lighting:
Details Clear

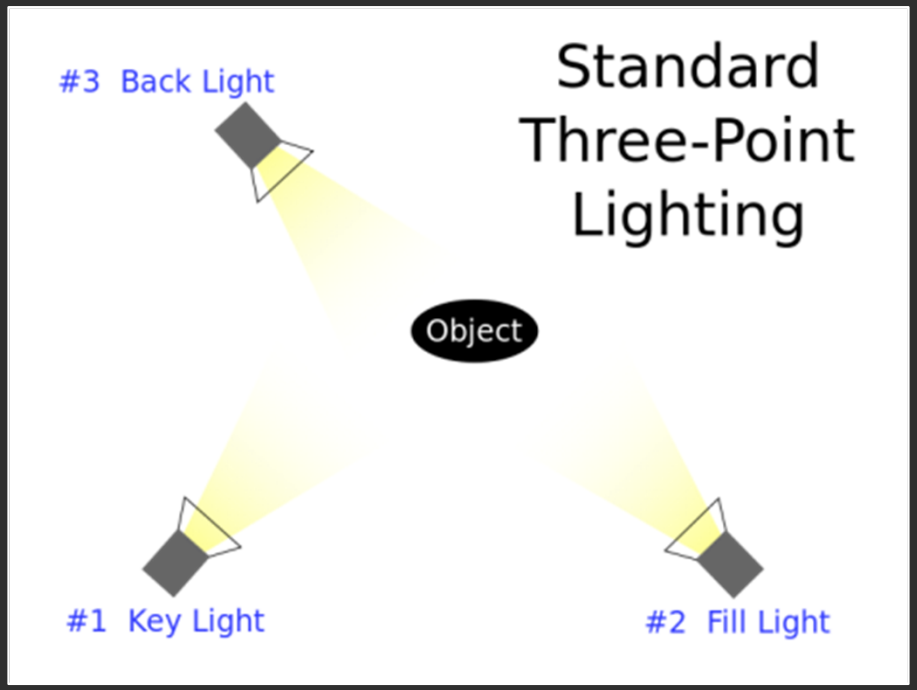


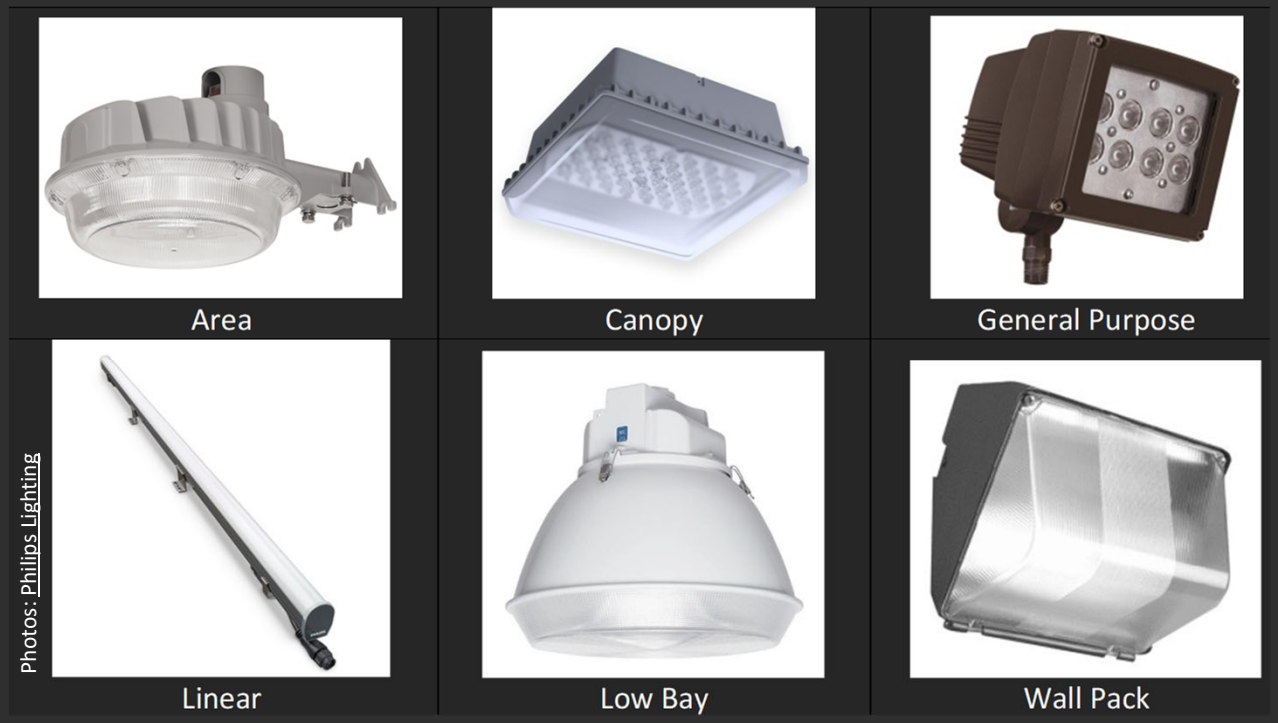
Image: Theonlysilentbob/WikiMediaCommons

Instead of one large light, use several smaller luminaires to reduce shadows and light the work zone more uniformly.

Left Photo: Warner Brothers/WikiMedia Commons (Public Domain)
Right Photo: Robert Judge/WikiMedia Commons

Alternatives to Light Towers

Photo: Thiemo Schuff/WikiMedia Commons



Photos: Philips Lighting

Balloon Lights

- Specialty item
- About $3000 per unit
- Four vendors in U.S.

Multi-Purpose Floodlights

- Widely used in commercial and industrial applications.
- $50 to $500 per unit.
- Available at hundreds of local suppliers and online.
- Some models available at home improvement stores.

2017 Outdoor Lighting Technologies

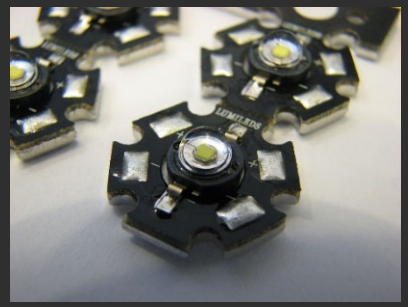


Photo: WikiMedia Commons/Gophi

Light-Emitting Diodes

- Pure white color
- No warm-up time
- 300 lumens per watt
- Vibration resistant
- RoHS compliant

Photo: WikiMedia Commons / JoeX

Metal Halide

- Acceptable color
- Long warm-up time
- 90 lumens per watt

Photo: WikiMedia Commons/Hundehalter

Tungsten Halogen

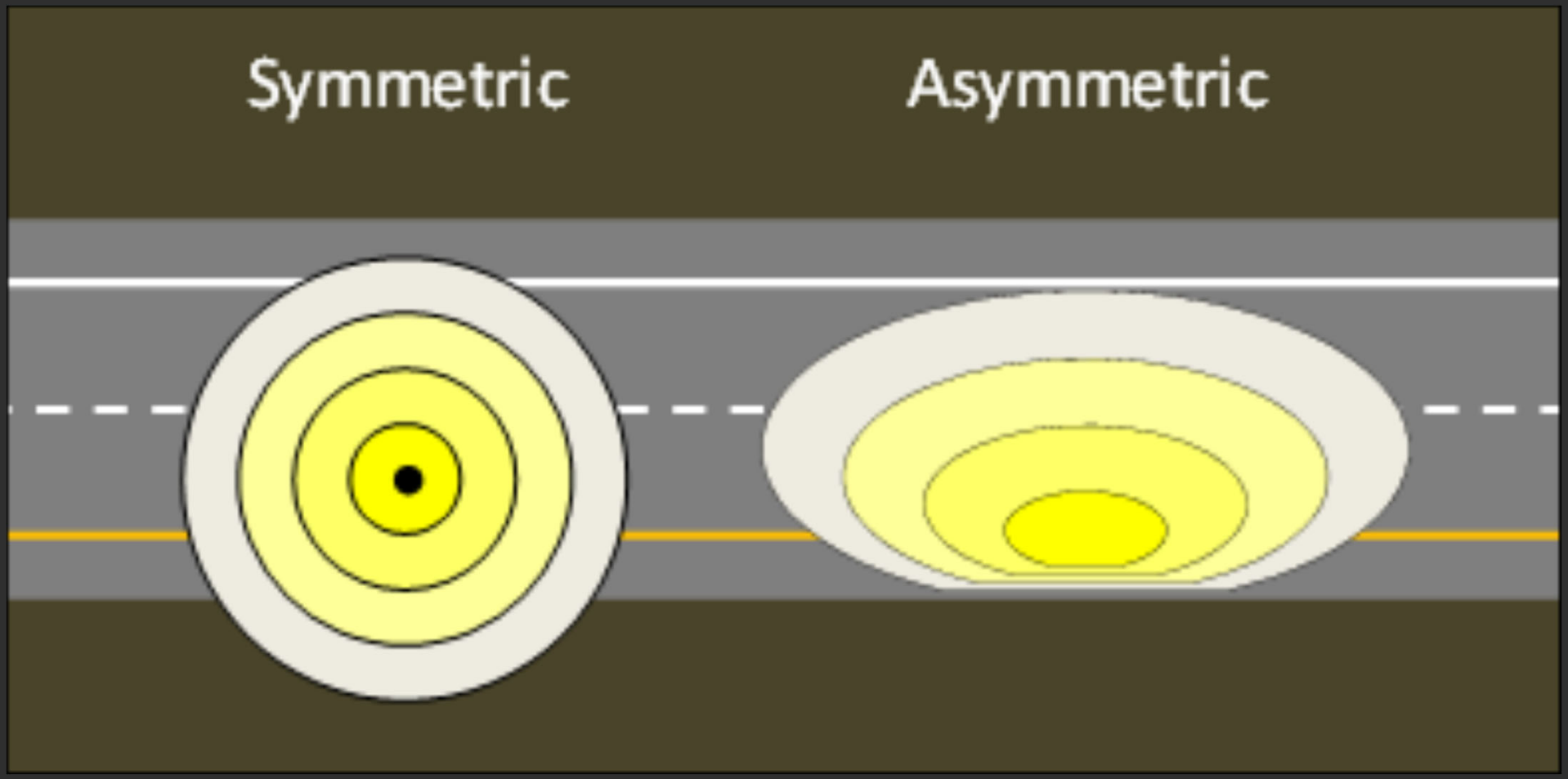
- Pure white color
- No warm-up time
- 22 lumens per watt
- Sensitive to vibration

Photo: WikiMedia Commons/Skatebiker

High Pressure Sodium

- Pinkish-orange color
- Long warm-up time
- 150 lumens per watt

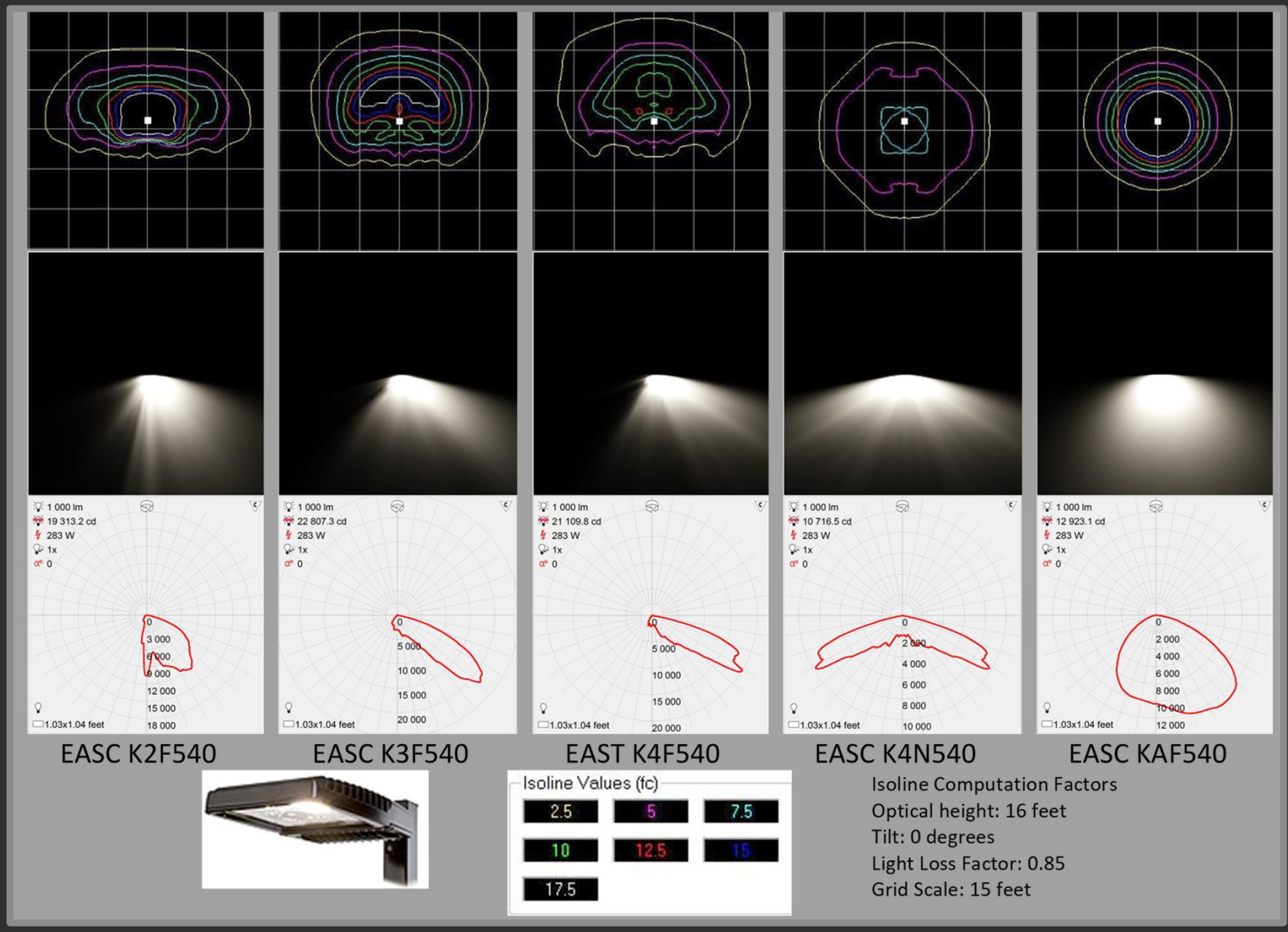
Symmetric vs Asymmetric Beam Patterns



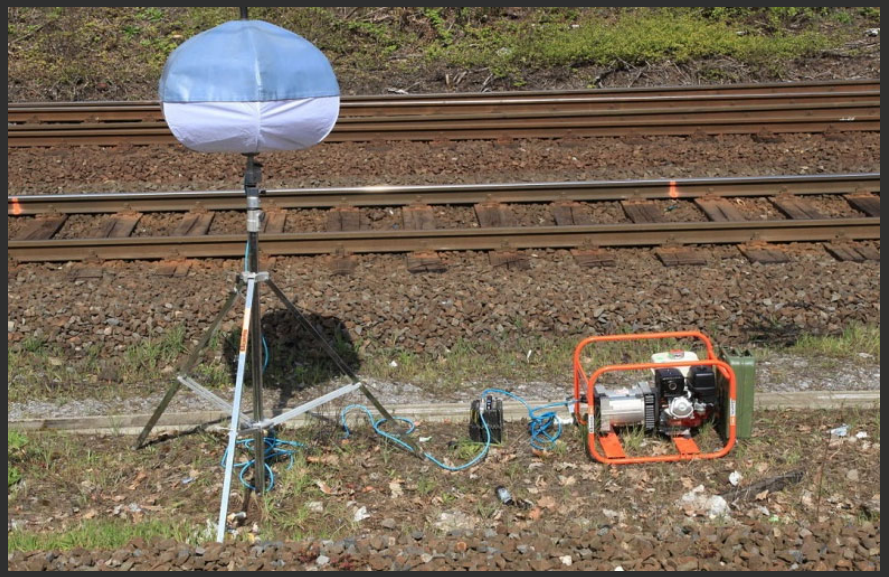
Asymmetric luminaires positioned on shoulder usually minimize conflict with work operations.

LED Luminaires

Not Limited to Oval Beam Patterns



Mounting Methods



Source: Frank Vincentz/WikiMedia Commons

Source: WikiMedia Commons/Ellin Beltz

Source: Airstar Safety

Source: AFRICAMAT

Source: WikiMedia Commons/Holger Ellgaard

Spillover Lighting

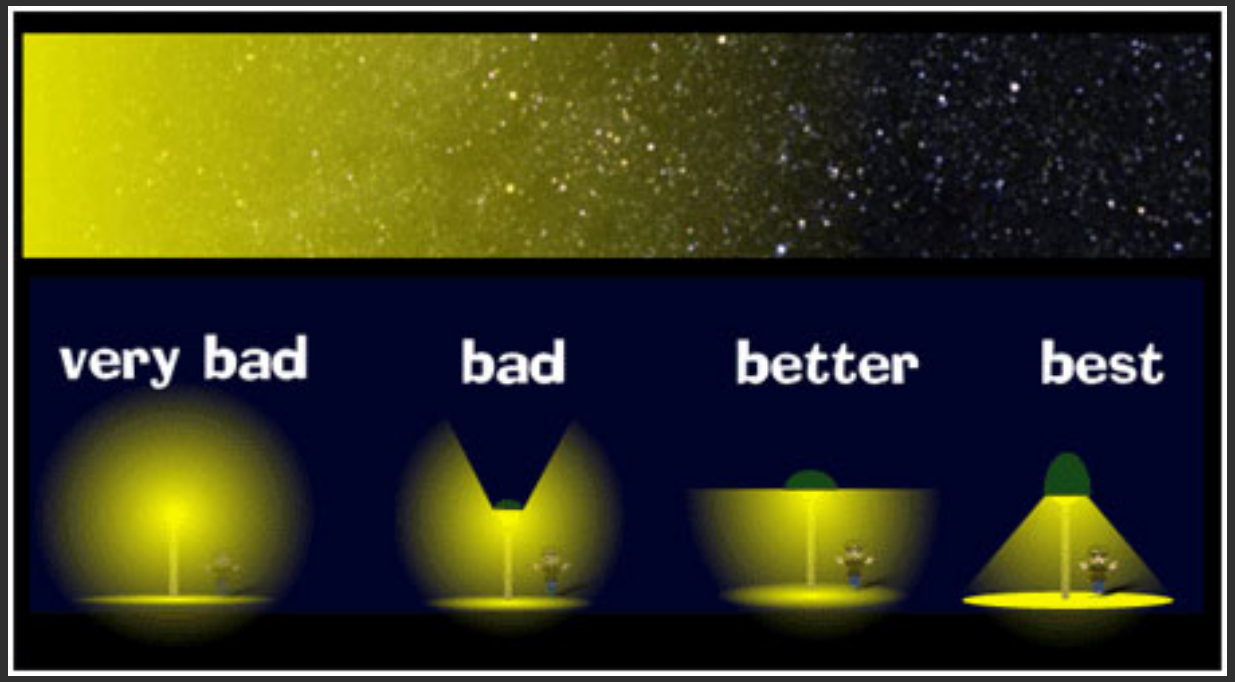


Image: University of Florida IFAS Extension

- Lighting the sky wastes energy
- Spillover beyond the right-of-way disturbs adjoining residents
- Well-designed systems direct light where it is useful
- Work in tunnels and under bridges sometimes requires uplighting

WHY NOT LEAVE IT UP TO THE FIELD ENGINEER?

Good Lighting Happens by Design

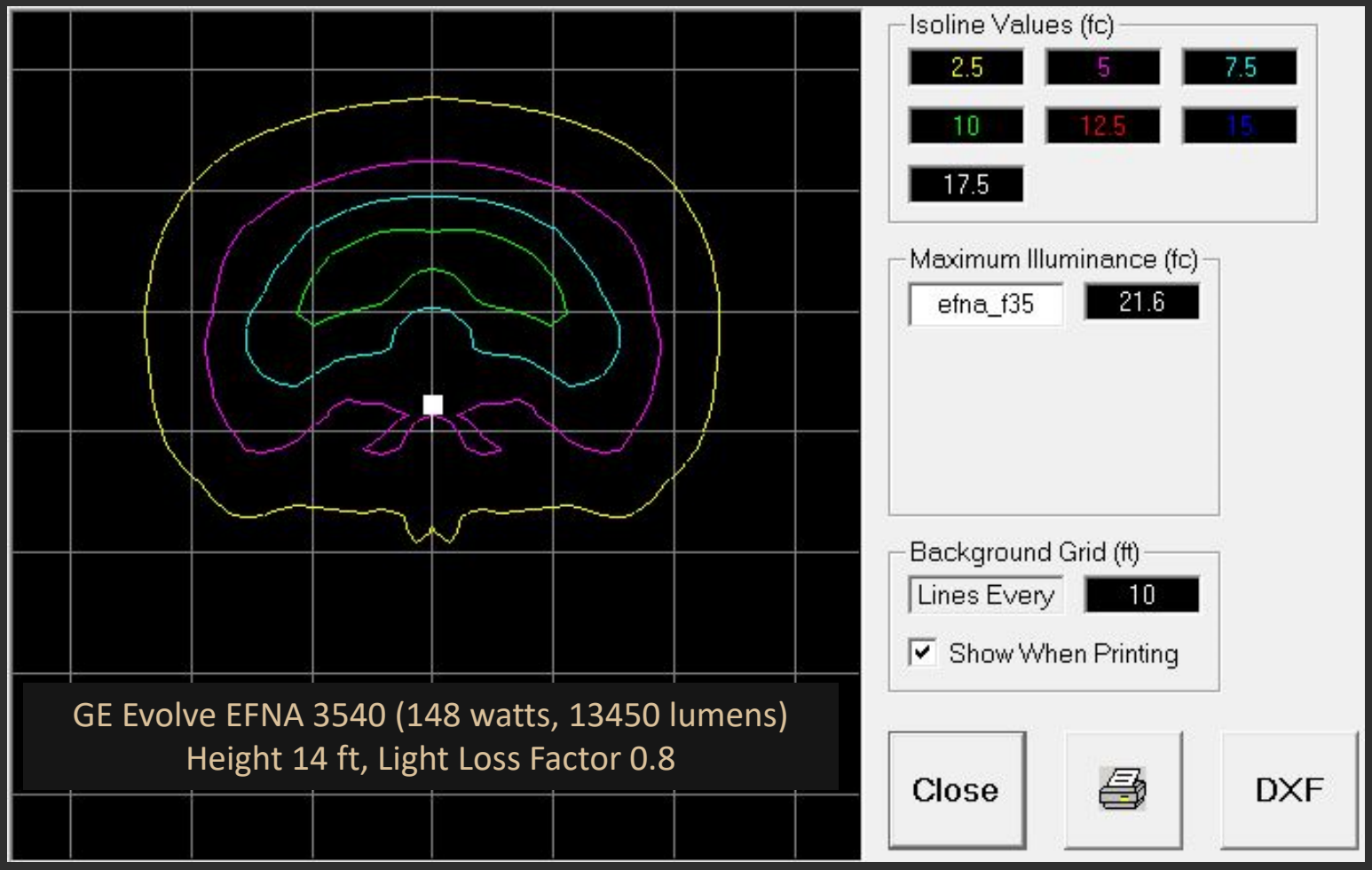
Photo: Diliff /WikiMedia Commons

It’s not a work zone, but…

- The complex shape of the Sydney Opera House made floodlight placement very complicated.
- The original 1968 exterior lighting design required months of hand calculations.
- Today, off-the-shelf software and fast computers make floodlighting design an efficient task for an engineer or engineering technician.

Photos:
Top: Jacques Greißmayer /WikiMedia Commons
Middle: Bkamprath /WikiMedia Commons
Bottom: Wj32/WikiMedia Commons

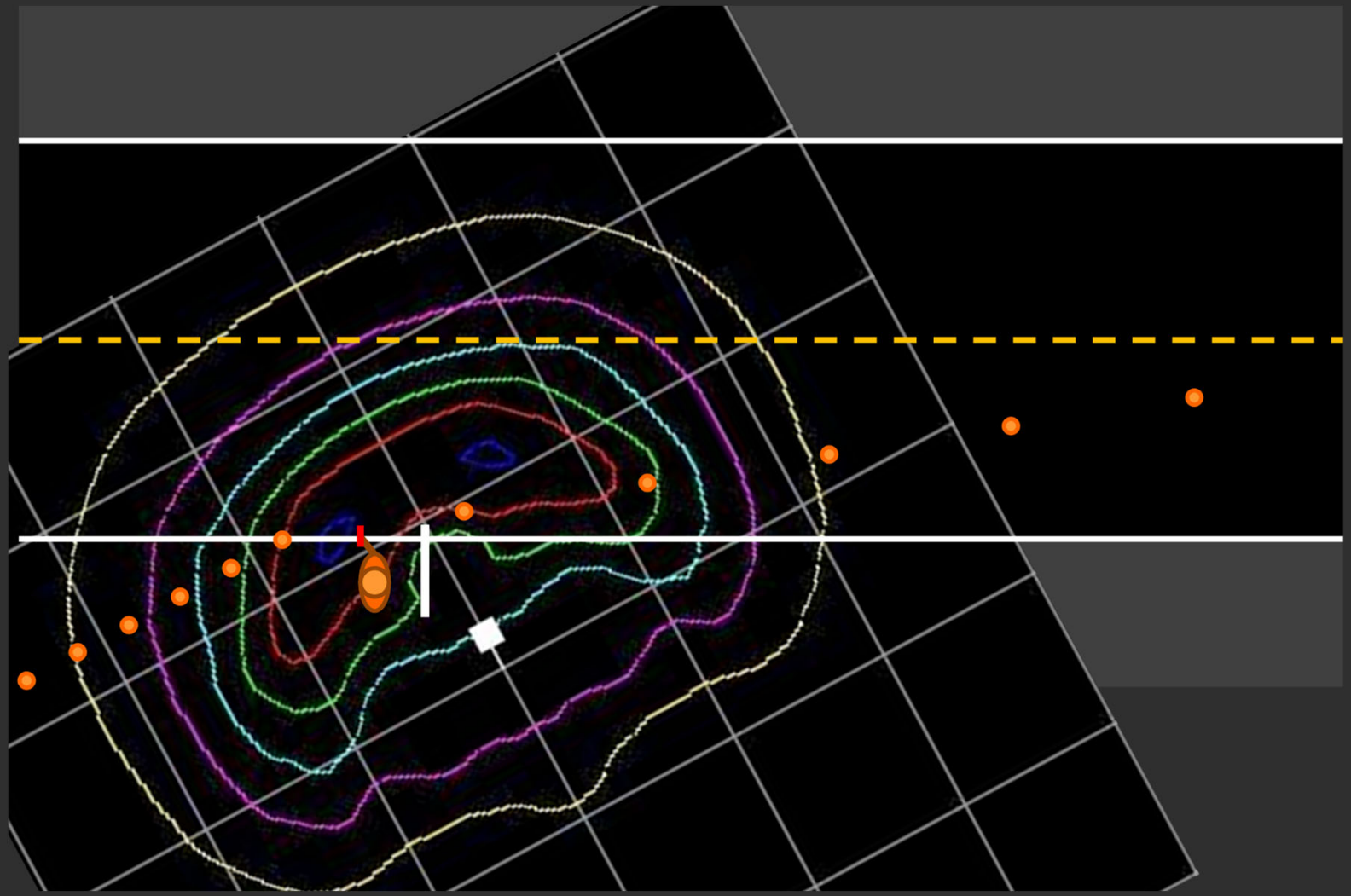
2D Software for Work Zone Lighting Design



Two-Dimensional Isoline Charts

Examples: Footprints, Photometric Toolbox

2D Software for Work Zone Lighting Design



Two-Dimensional

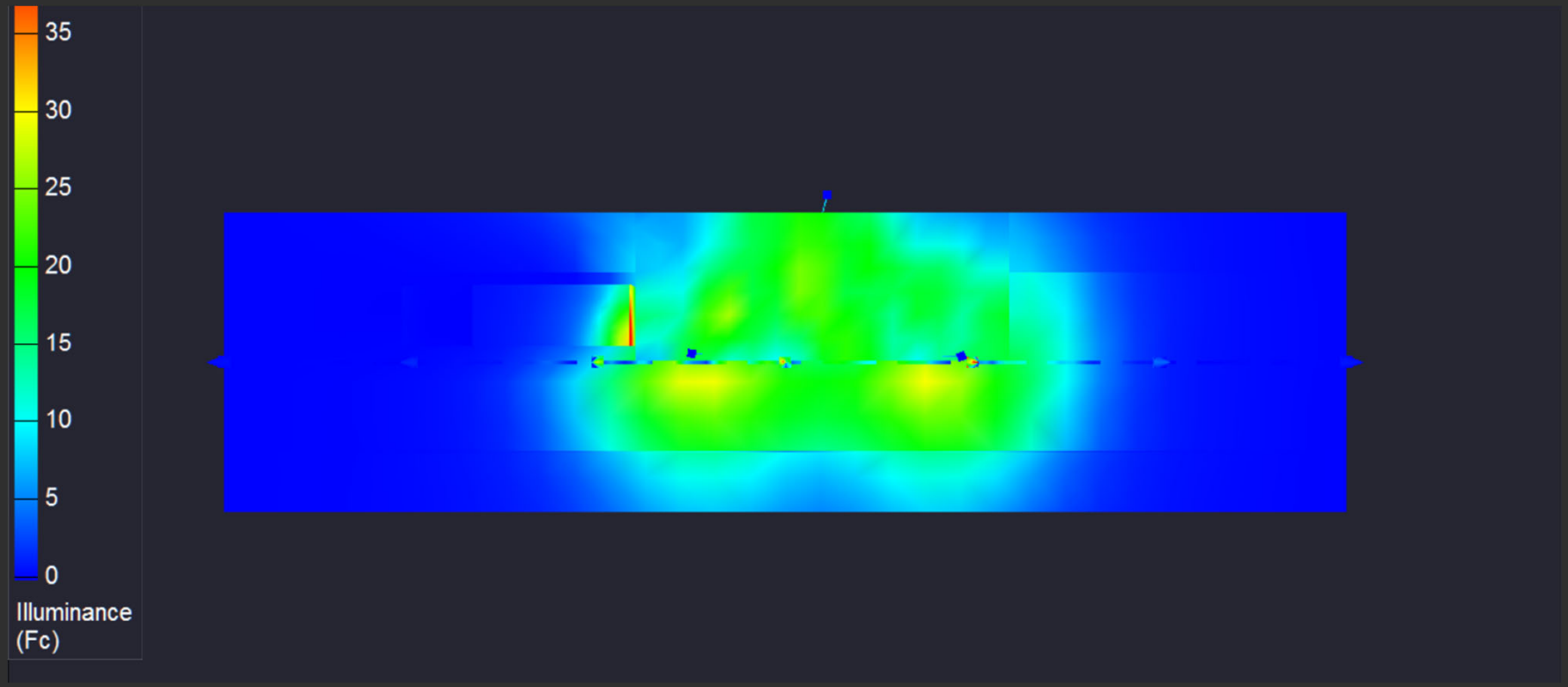
Isoline Chart with Site Sketch Overlay

3D Software for Work Zone Lighting Design

Three-Dimensional Rendering

Examples: AGi32, Relux, Radiance

Advantages of Using Software



- Predicts areas that will be too bright or too dim for worker efficiency.
- Allows evaluation of effect of rotating or repositioning luminaires.
- 3D software allows layout to be checked for excessive driver glare.
- Helps assure correct equipment is on-site before work begins.

Old Process

Design Engineer: “The project will be built at night.”

Construction Engineer: “The contractor is responsible for lighting.”

Foreman: “Do you guys rent lights?”

Equipment Rental Clerk: “We have a 4000 watt portable light tower in our yard.”

Worker: “I guess I just raise the mast and fire it up.”

Construction Engineer: “There is too much glare, but the job will be delayed if I make them fix it.”

New Process

Design Engineer: “Here is our Standard Detail Drawing for work area illumination.”

Construction Engineer: “Please install the lights in accordance with the Standard Detail on page 7 of the plan set.”

Foreman: “No problem, that’s the way we bid the job.”

Equipment Supplier: “The lights you ordered have arrived. Stop by and I’ll show you how to set them up.”

Worker: “I placed the lights as shown on the drawing. We can see well.”

Construction Engineer: “The lighting looks good. With a few minor adjustments, it will be perfect.”

USING SOFTWARE TO COMPARE LAYOUTS AND PRODUCTS

Work Zone Lighting Design Criteria

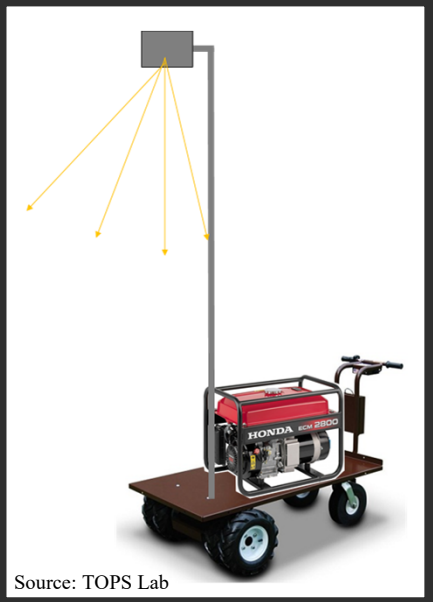
Priority	Design Consideration	Performance Measures and Criteria (See referenced sections for additional details)
1	Glare Control	Maximum Veiling Luminance Ratio less than 0.4 or Maximum Threshold Increment less than 15%.
2	Code Compliance	All system elements compliant with relevant state/local electrical codes.
3	Min and Max Intensity Levels	Horizontal illuminance measured at work surface 4 to 45 foot-candles depending on type of work.
4	Shadow Control	Task areas illuminated from at least two directions to avoid hard shadows that mask work details.
5	Spillover Control	Proper shielding and aiming to minimize lighting spillover into adjacent properties, especially residential areas.

Example: Flagger Station Lighting Analysis

Idea

Photo: Airstar Safety

Try…

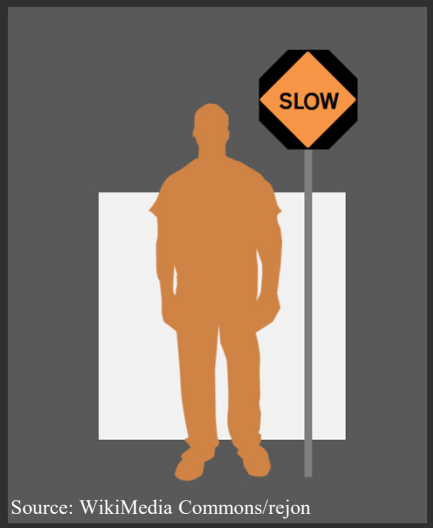


Source: TOPS Lab

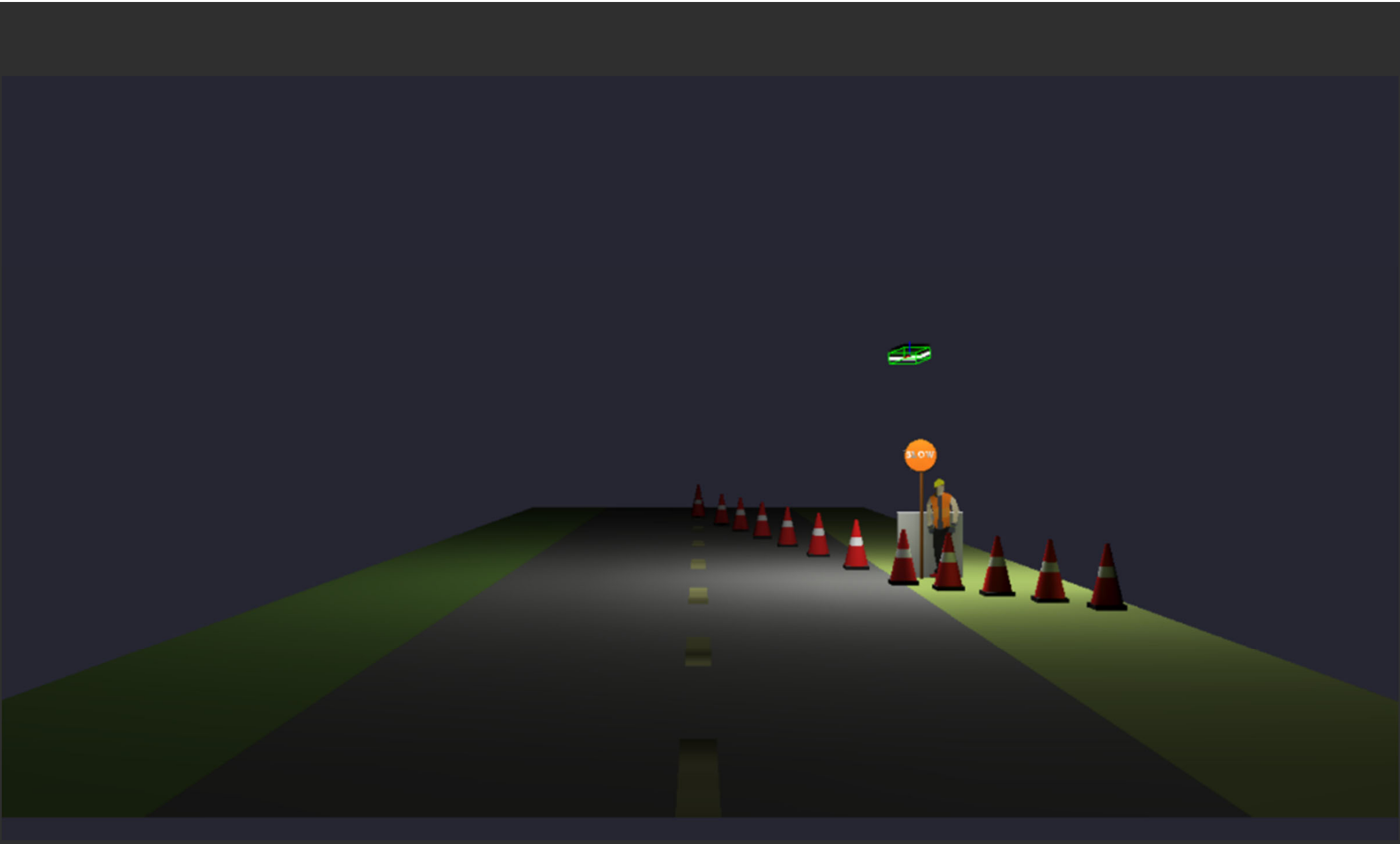
Problem

Photo: RVeCafe.com

Try…

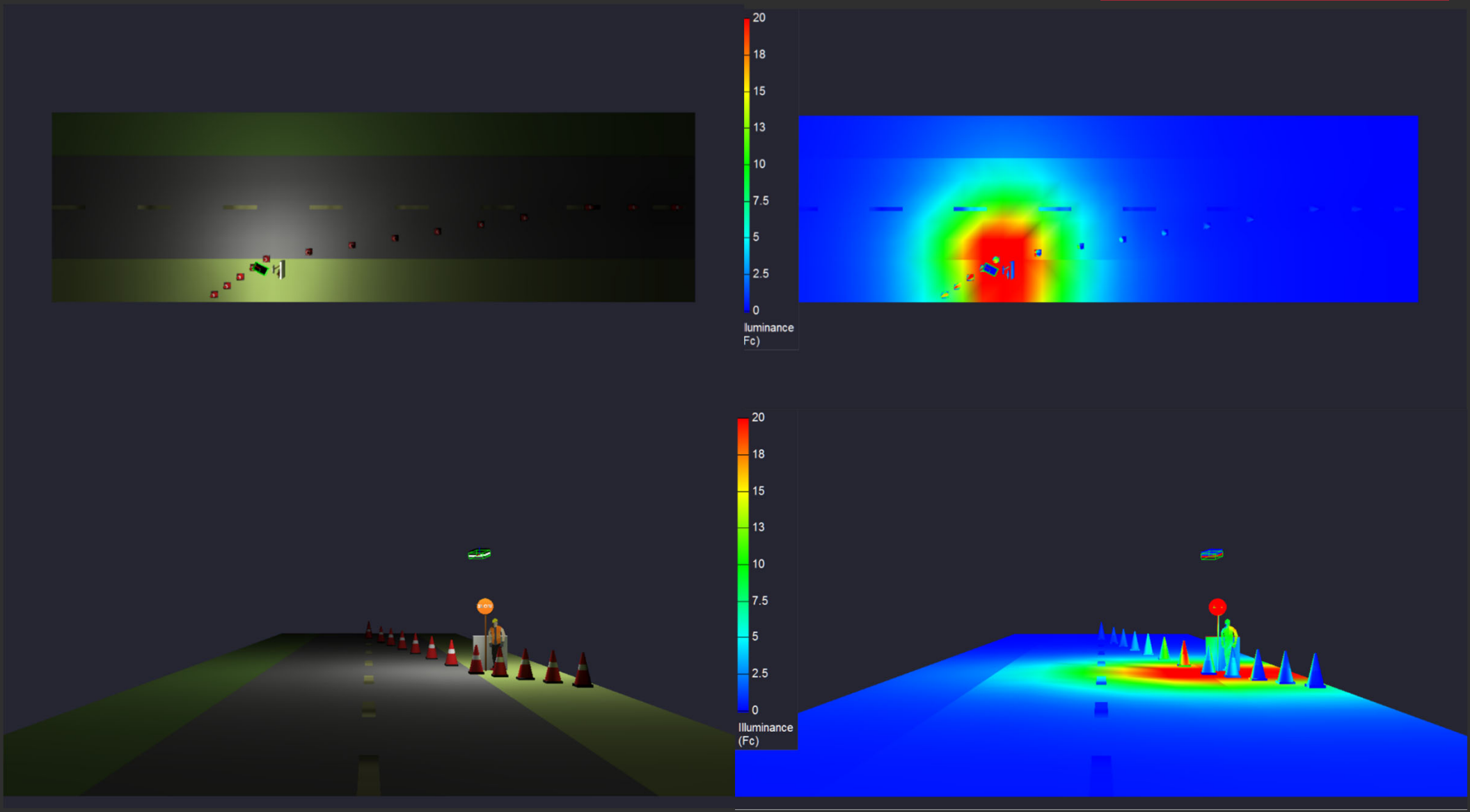


Source: WikiMedia Commons/rejon

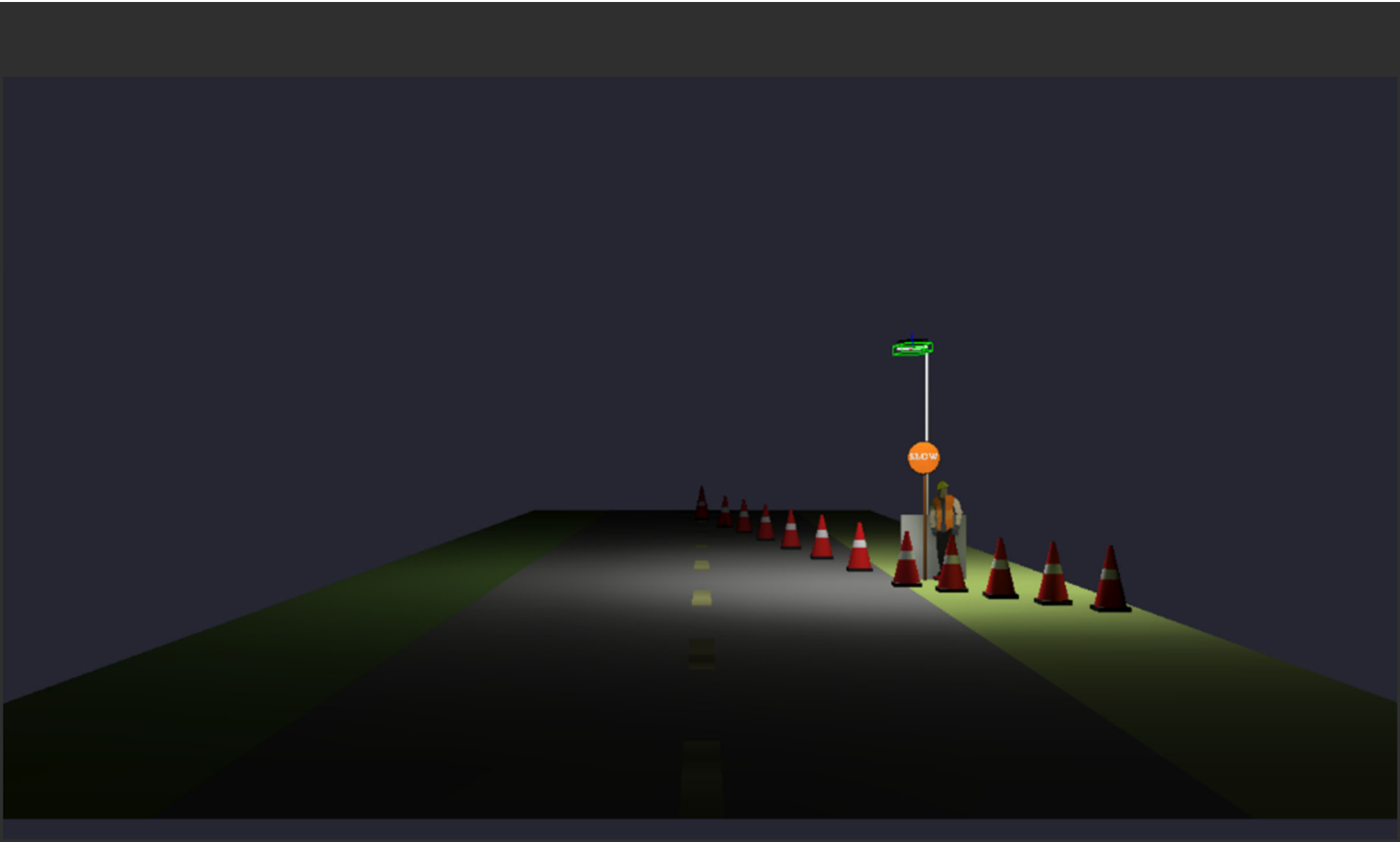


Flagger Station Alternative 1: Airstar Sirocco Balloon Light

Good, but expensive.

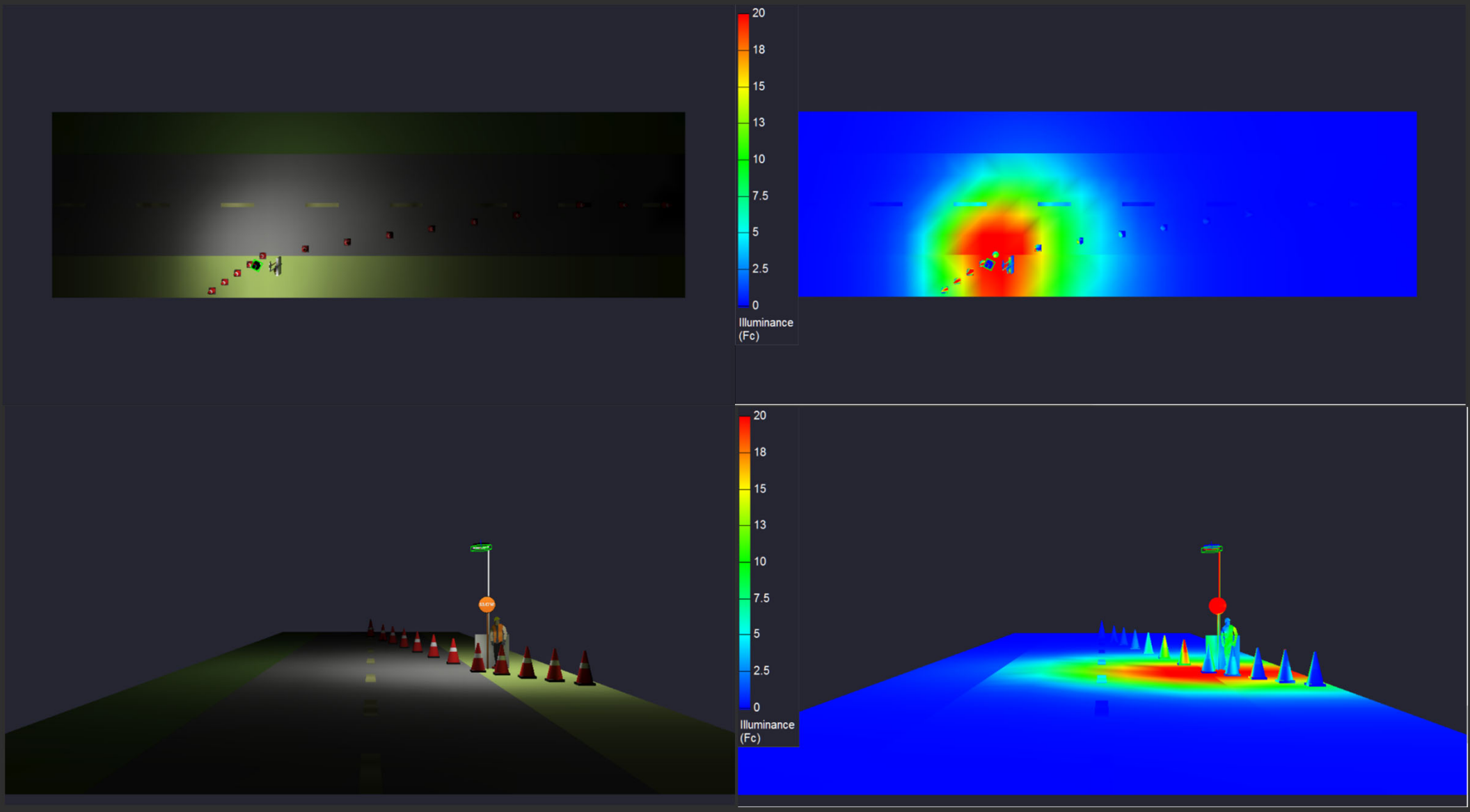


Flagger Station Alternative 1: Airstar Sirocco Balloon Light

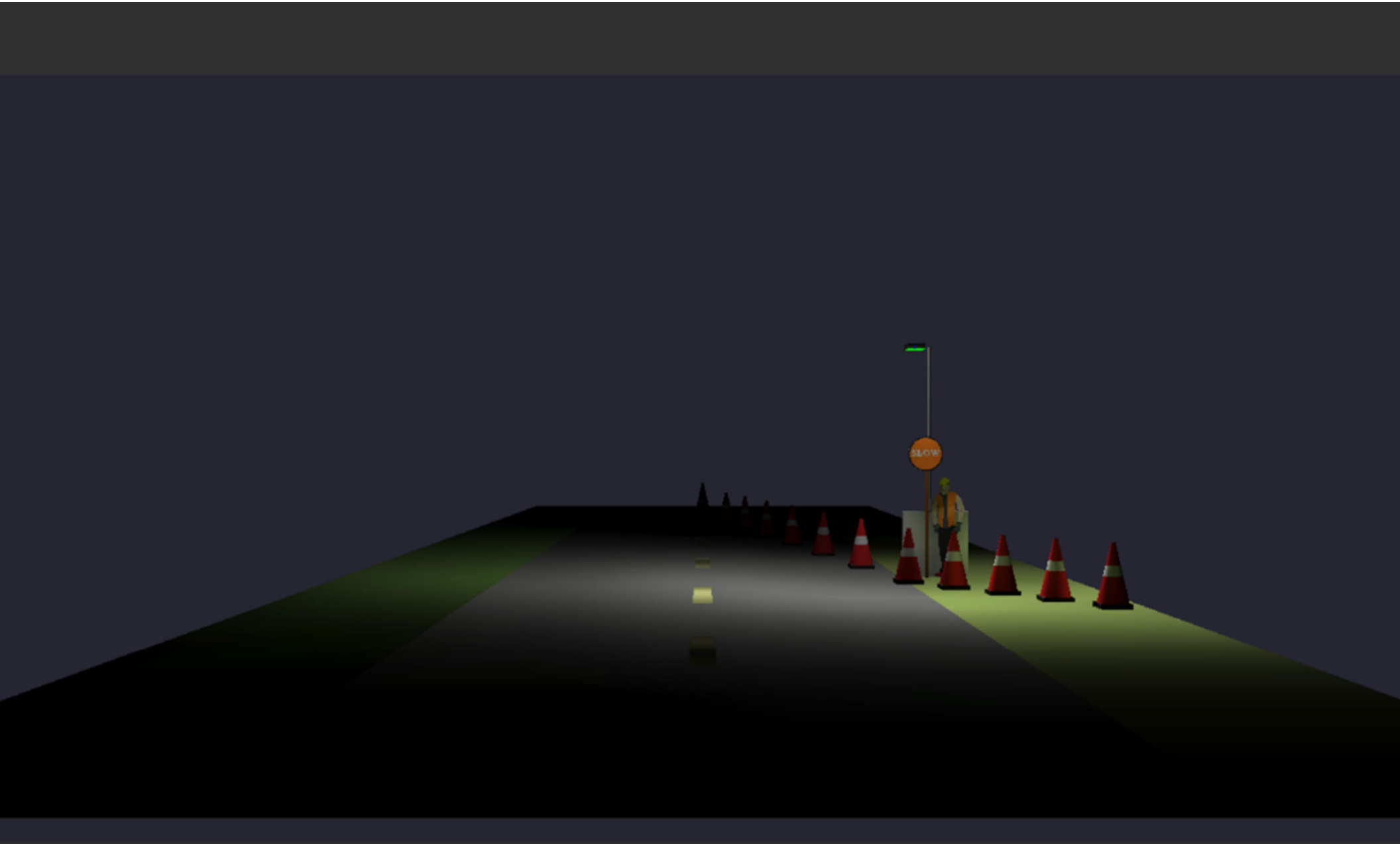


Flagger Station Alternative 2: Philips MILM400

Good, inexpensive.

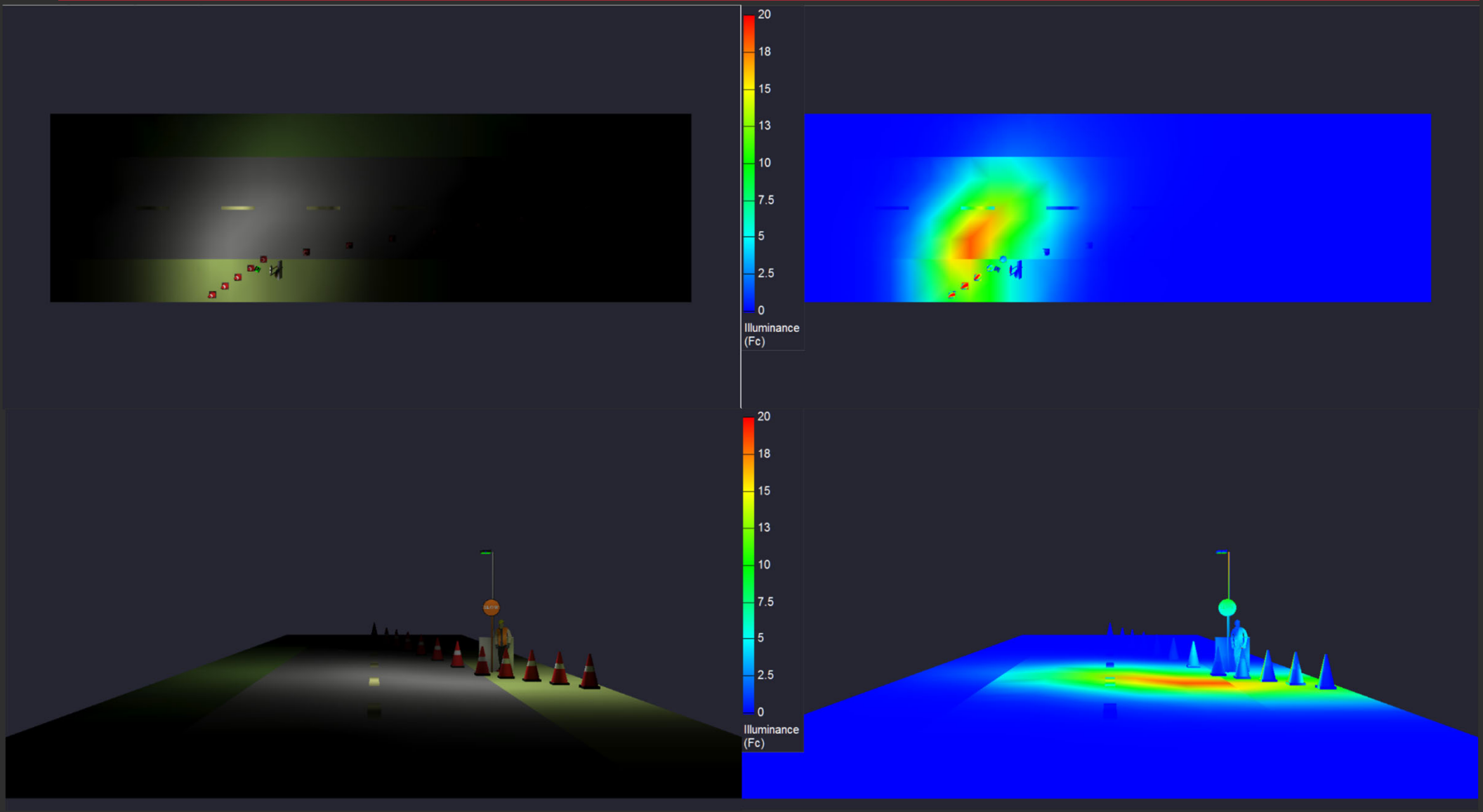


Flagger Station Alternative 2: Philips MILM400

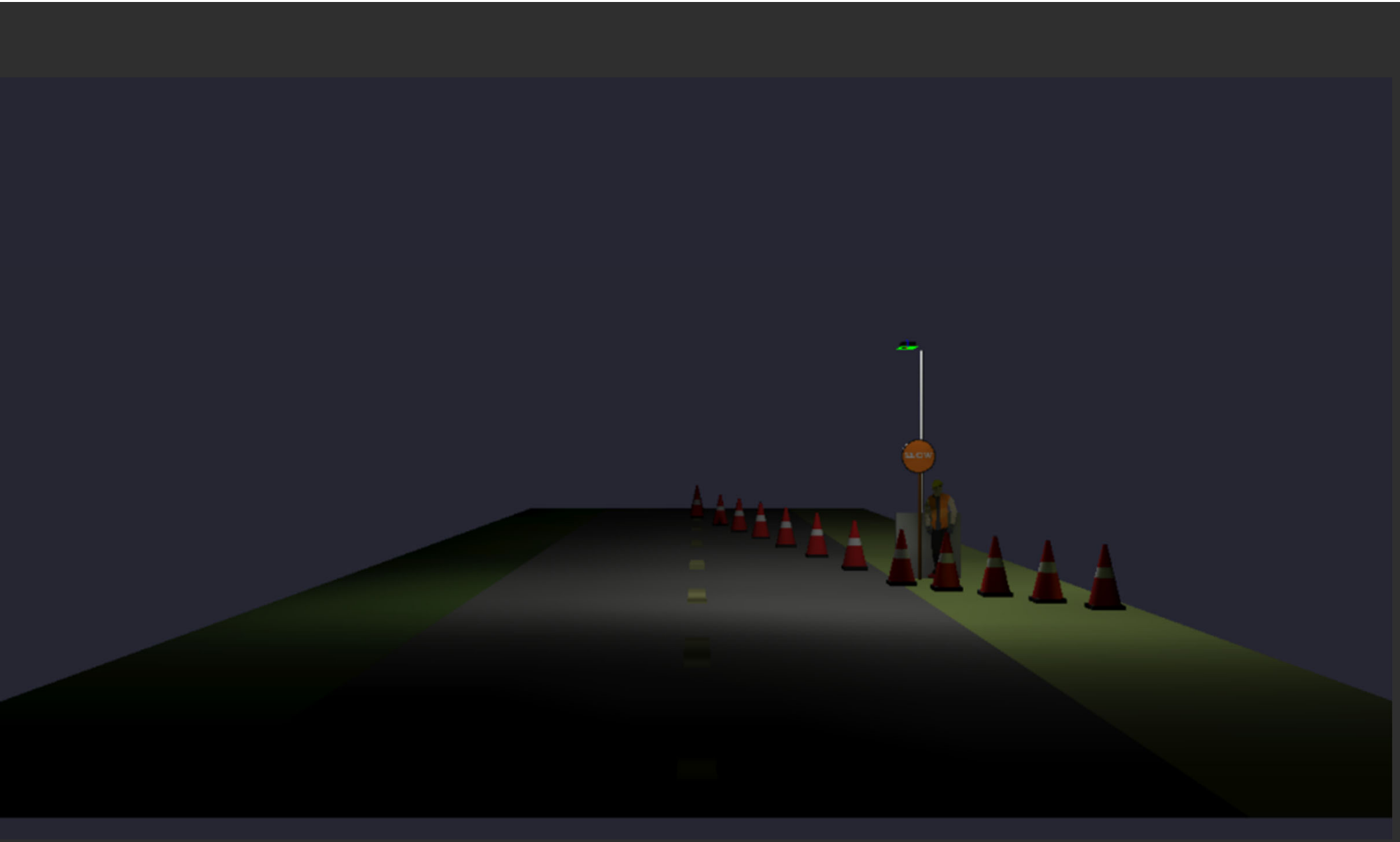


Flagger Station Alternative 3: GE EFNA

OK, but try rotating the luminaire clockwise about 20 degrees and moving it back a few feet.

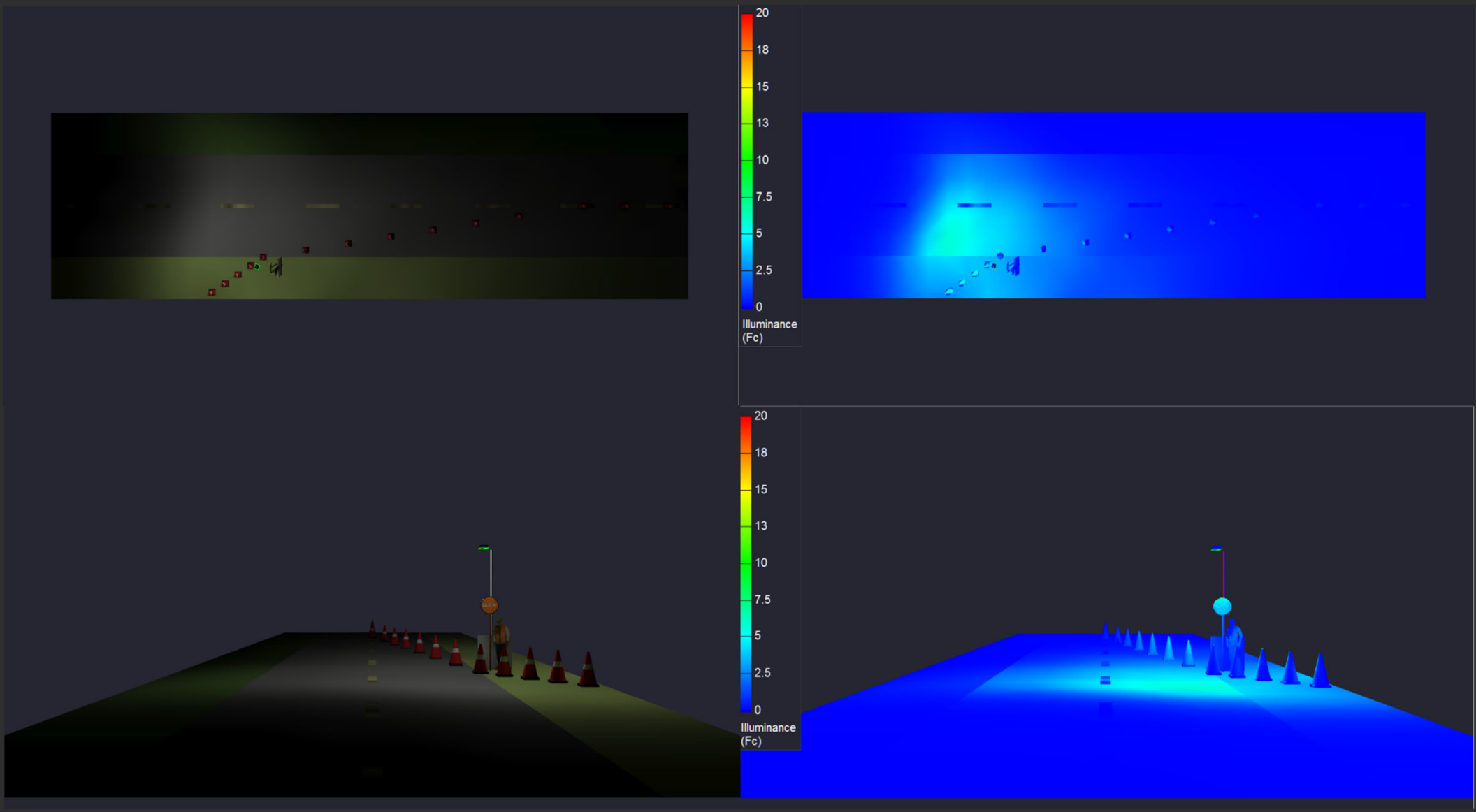


Flagger Station Alternative 3: GE EFNA



Flagger Station Alternative 4: Hubbell Kemlux III

Not enough vertical illuminance on flagger's face; try a brighter model.

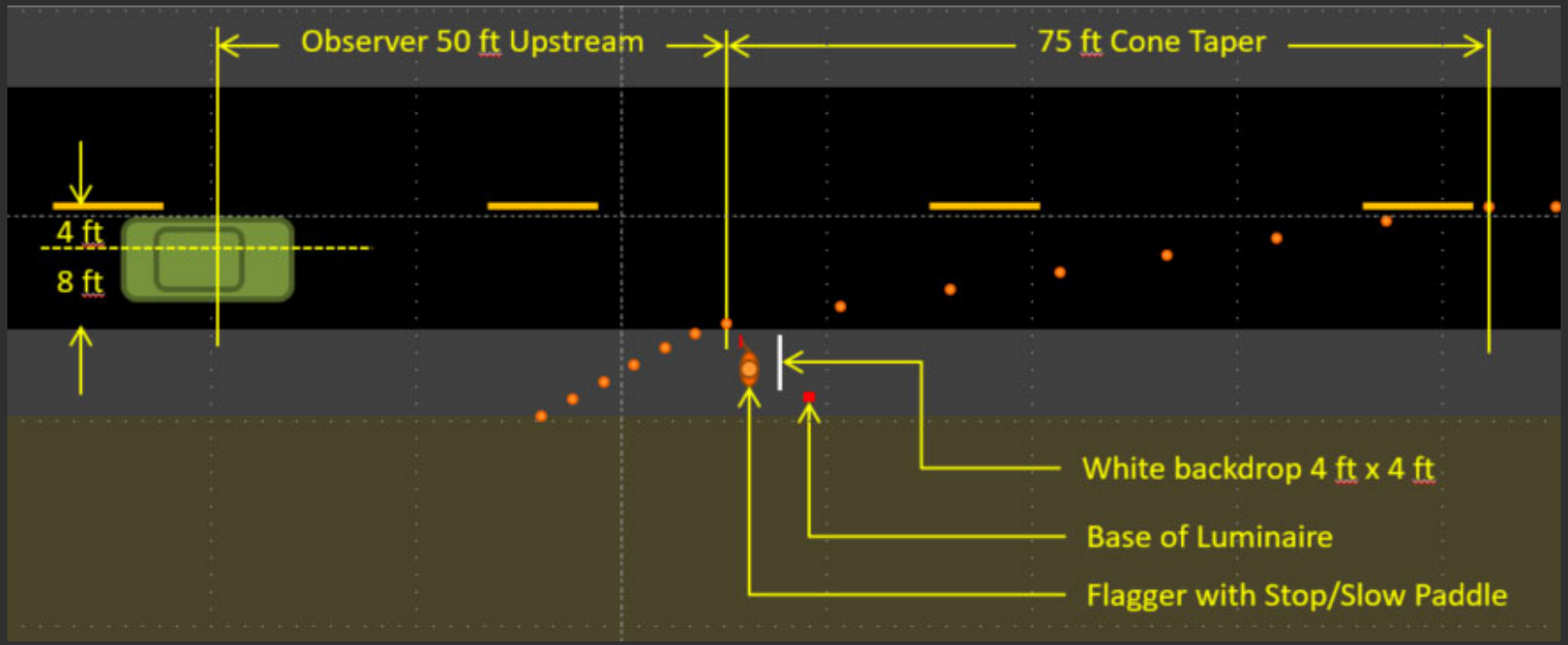


Flagger Station Alternative 4: Hubbell Kemlux III

ANALYSIS PROCESS

Example: 3D Rendering with AGi32

Step 1: Determine Typical Site Geometry



Step 2: Obtain Luminaire Data

```
IESNA:LM-63-2002
[TEST] 83020202 PUBLISHED CURVE CREATED
[TESTLAB] GE LIGHTING SOLUTIONS
[ISSUEDATE] 2/2/1983
[MANUFAC] GE LIGHTING SOLUTIONS
[MORE] www.gelightingsolutions.com
[_FILETYPE] RELATIVE
[SEARCH] INDOOR LOW BAY UM5
[LUMINAIRE] UNIMOUNT 400
[DISTRIBUTION] SC 1.9
[LUMCAT] UM5_40M__EAAA__
[LAMP] 1; 400W MH, CLEAR ED37, VBU
[LAMPCAT] GE MVR400/U
[BALLAST]
[BALLASTCAT]
[OTHER] HSNG: CAST HOUSING  FABRICATED SHEET DOOR/COVER
[MORE] REFL: SEMI-SPEC HYDROFRM ALUM
[MORE] ENCL: PRISMATIC MOLDED ACRYLIC
[MORE] ACSY:
[MORE] SOCKET POSITION: A
[MORE] COMMENT:
[_ABSOLUTELUMENS] NA
[_LCS]
[_BUG]
[_SUPPLYVOLTAGE]
[_AVERAGEDFILES]
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1 36000 3.6000 37 1 1 1 -2.5 0.0 0.3
1.0 1.0 459
 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170
175 180
 0
 1828 1852 1944 2054 2119 2087 1992 2140 2427 2412 2257 1839 1179 731 476 302 172 89 50 40 30 30 60 110 110 50 0 0 0 0
0 0 0 0 0 0
 0
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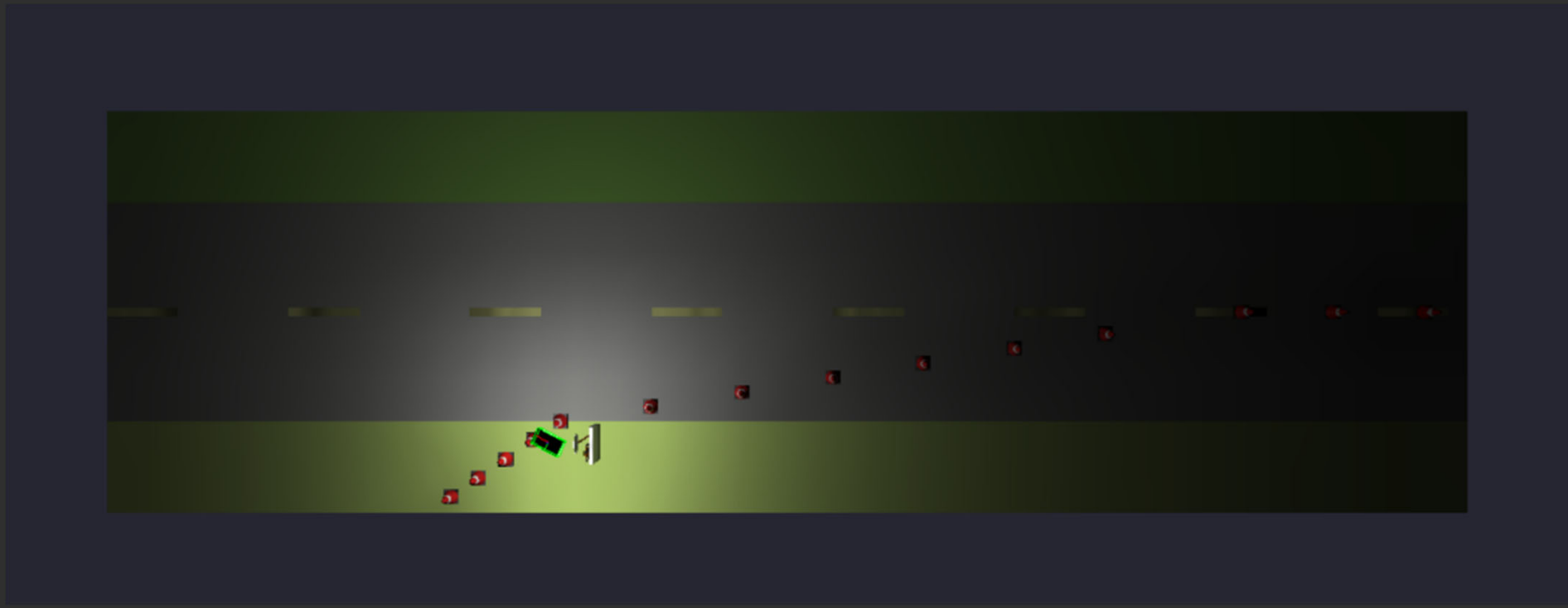
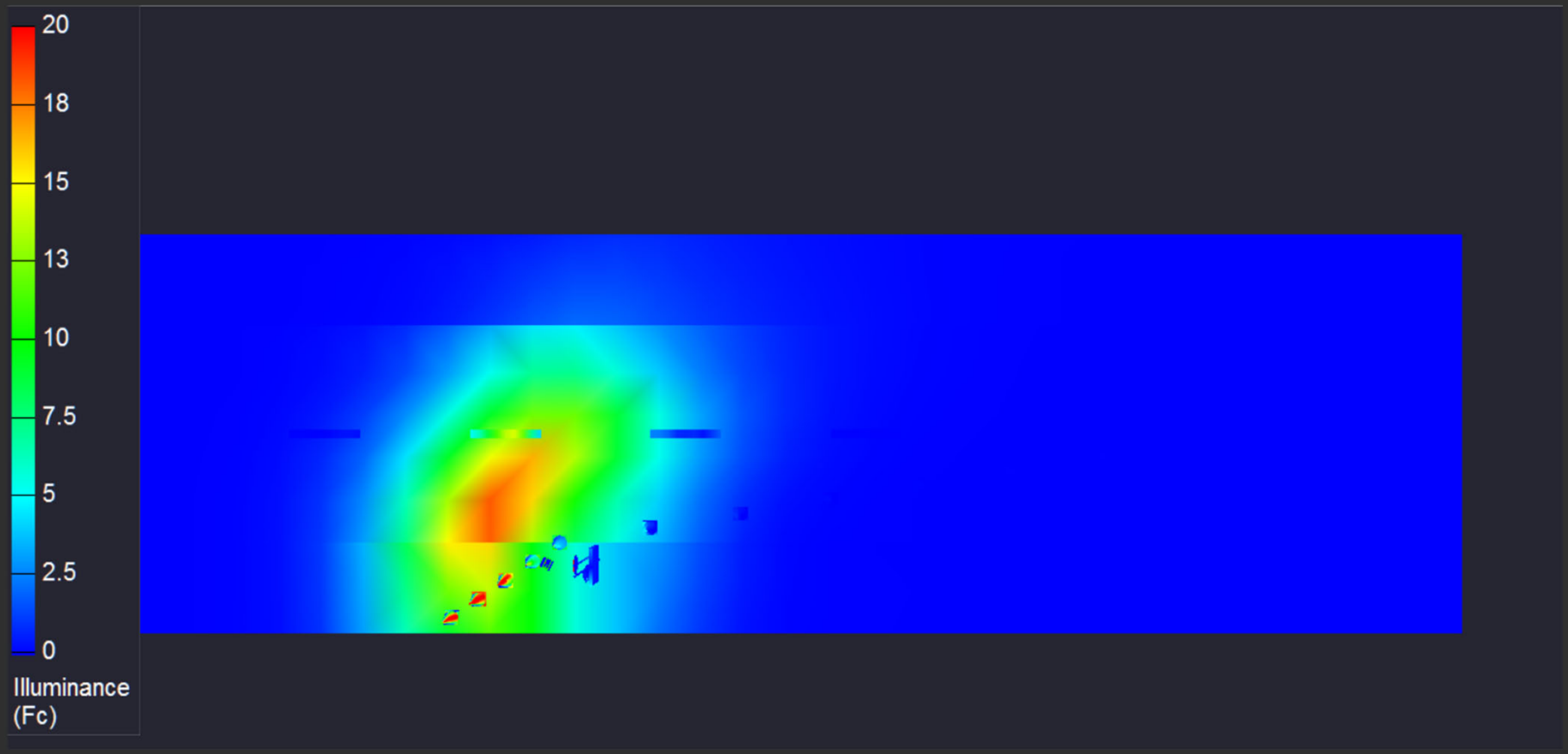
- Identify candidate luminaires
- Obtain IES files from manufacturer

Step 3: Prepare Site Model



- Several lighting analysis packages support import/export of CADD files.
- Some packages are plug-ins for popular CADD software.

Step 4: Prepare Renderings



- Use simplified object shapes for quick renderings.
- Adjust luminaire model, angle, and position as necessary.
- Final rendering using detailed 3D objects may require overnight software runs.

Step 5: Prepare Glare Analysis

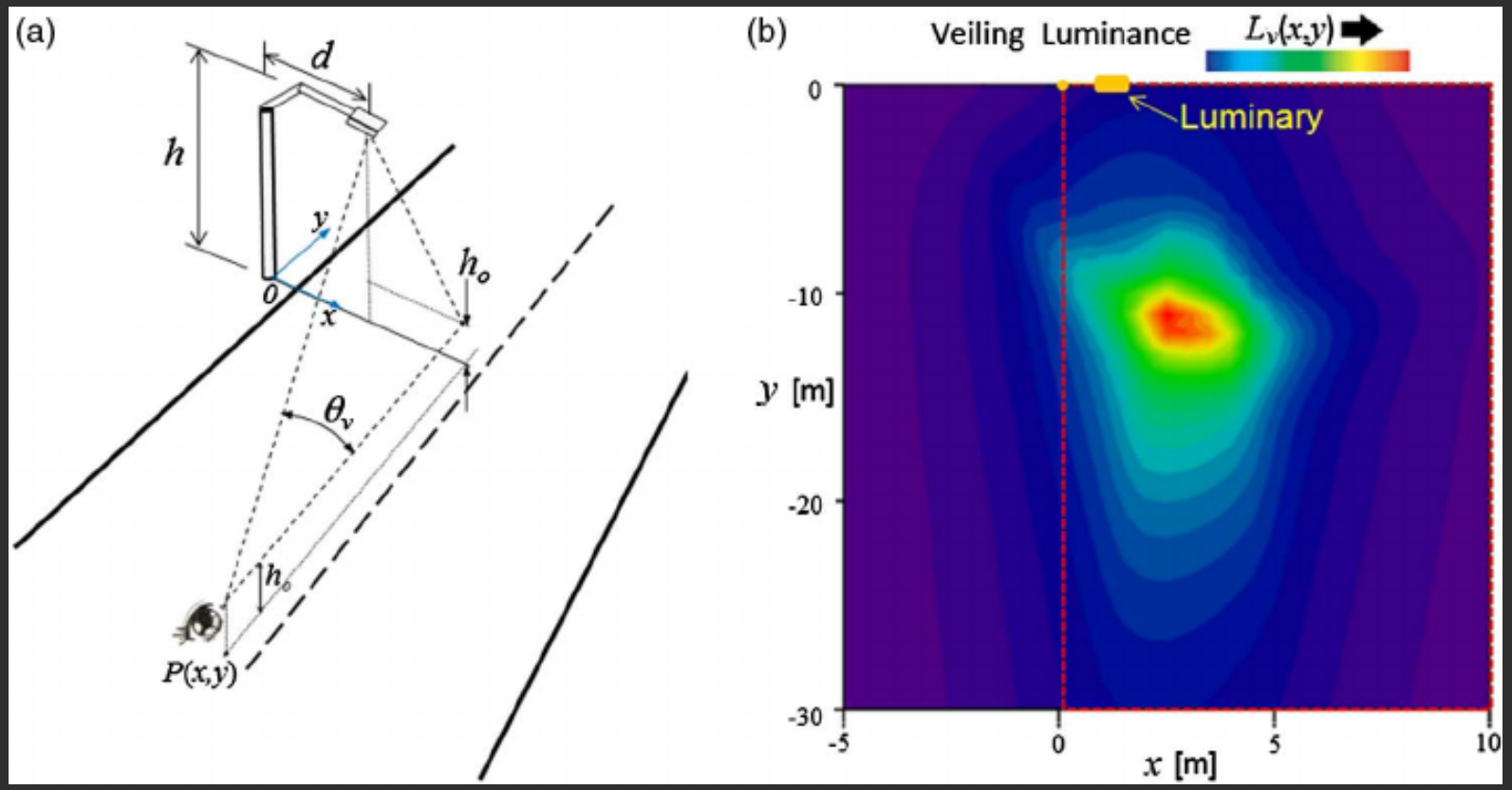


Image: Moreno et al

- Software can compute Veiling Luminance Ratio or Threshold Index for vehicles in lanes parallel to the work area.
- VL ratio > 0.4 or TI > 15% are potentially cause for concern.

Anticipated Work Process

- Agency provides Standard Detail Drawings for commonplace lighting scenarios
  - Flagger stations
  - Paving
  - Bridge deck repair
- Standard Details include options for various functionally-equivalent commercial lighting products
- If contractor wants to deviate from Standard Detail, submit:
  - Shop drawing showing proposed lighting layout
  - Renderings and analysis files from agency-accepted lighting software

Discussion

- Would the proposed process improve lighting in your work zones?
- What concerns do you anticipate from contractors? How can you minimize them?