Optimizing Flashing Yellow Warning Lights for Safety

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Western States Highway Equipment Managers Association Conference
August 25, 2015

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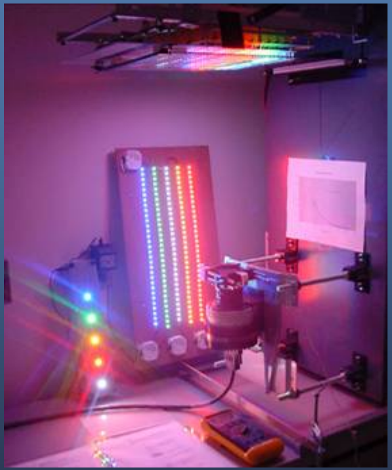
About the Lighting Research Center

Advancing the effective use of light, thereby creating a positive legacy for society and the environment.

NVLAP-accredited testing laboratory

30,000 sq. ft. near Rensselaer campus



40-60 concurrent projects in field and lab

~30 full-time faculty and staff

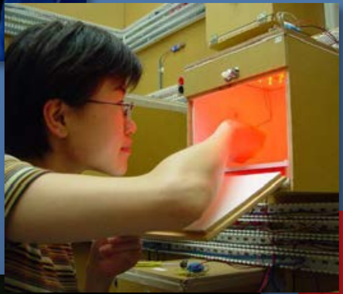
10-15 graduate students

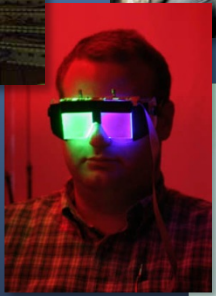
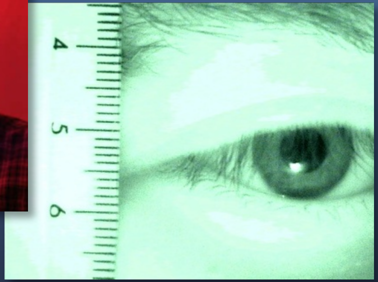
Focus areas

- Technologies
- Product testing
- Design
- Policy
- Health
- Transportation
- Demonstrations
- Technology transfer
- Education







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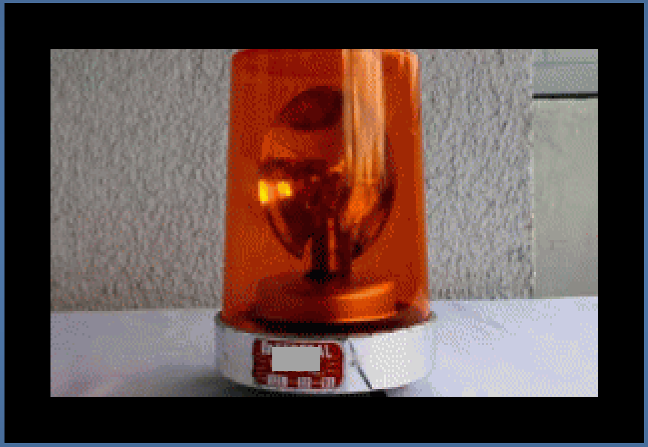
Presentation outline

- Purpose of warning lights
- Characteristics of warning lights
  - Peak intensity
  - Modulation
  - Spatial
  - “Special”
- Summary

Yellow flashing warning lights…

- …are a primary line of defense for the protection of front line service workers



- Used in work zones and on highway maintenance vehicles, tow trucks, utility trucks, and delivery vehicles

Why do we care about warning lights?

- Service workers in construction, transportation and utilities make up **13% of US work force but are involved of 36% of workplace fatalities** (NIOSH 2009)
  - Based on estimates (Cook 2000; US Census 2009) there are about 316,000 vehicle mounted warning lights in the US
  - Improved warning light design could help prevent 70 fatalities and 5200 injuries annually (Cook 2000) in the US

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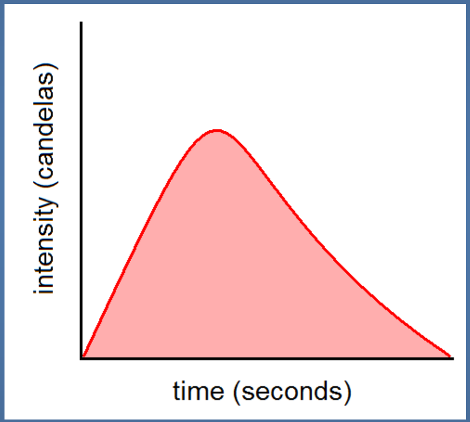
What are the requirements for warning lights?

- Vehicle-mounted warning light performance is specified by several standards from the **Society of Automotive Engineers** (SAE)
  - SAE J595: Flashing Warning Lamps for Authorized Emergency, Maintenance and Service Vehicles
    - Yellow: 1-2 flashes/second, peak intensity (when on) of 600 candelas; on-off flashing per SAE
  - SAE J845: Optical Warning Devices for Authorized Emergency, Maintenance and Service Vehicles and SAE J1318: Gaseous Discharge Warning Lamp for Authorized Emergency, Maintenance and Service Vehicles
    - Yellow: 1-4 flashes/second, peak flash energy of 90 candela·seconds (emergencies), 22 candela·seconds (warning), 10 candela·seconds (identification)



What is a candela·second?

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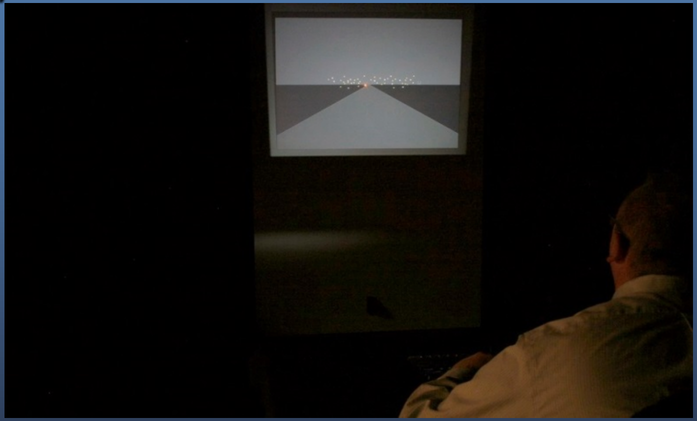
What properties of warning lights are important?

- Peak intensity
  - Warning lights need to be bright enough to be seen, during daytime and nighttime, but not so bright that they cause glare or distraction
  - Experiments were conducted to measure response times and subjective judgments for flashing warning lights and impacts on hazard visibility
  - Participants (n=26, <30 and >50 years old) viewed a target near or away from a simulated truck with a warning light with adjustable peak intensity (80-3100 candelas)

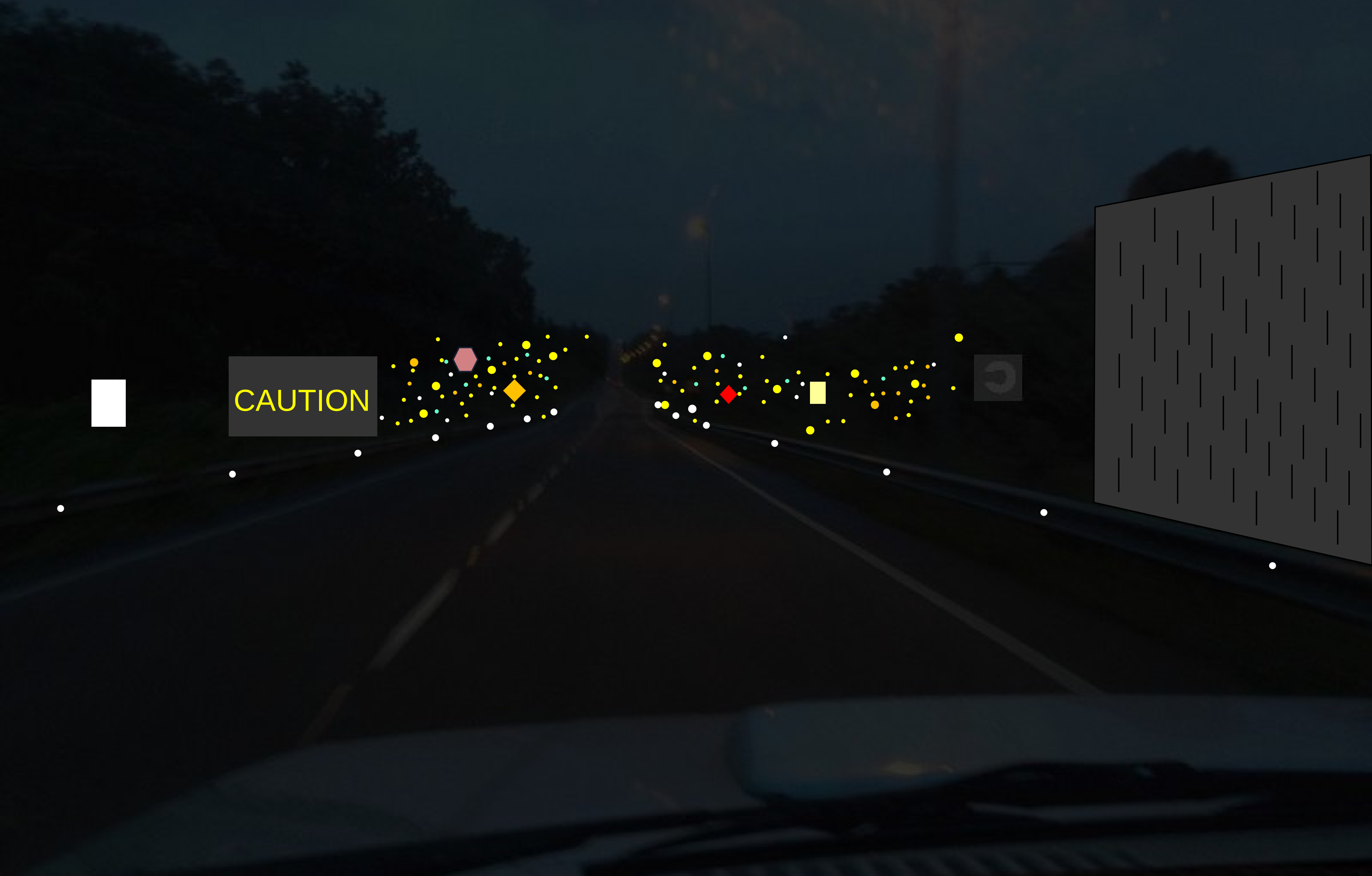


Sponsor: National Institute of Occupational Safety and Health (R01 OH0 10165)

On-Axis Warning Light, Daytime, No Clutter

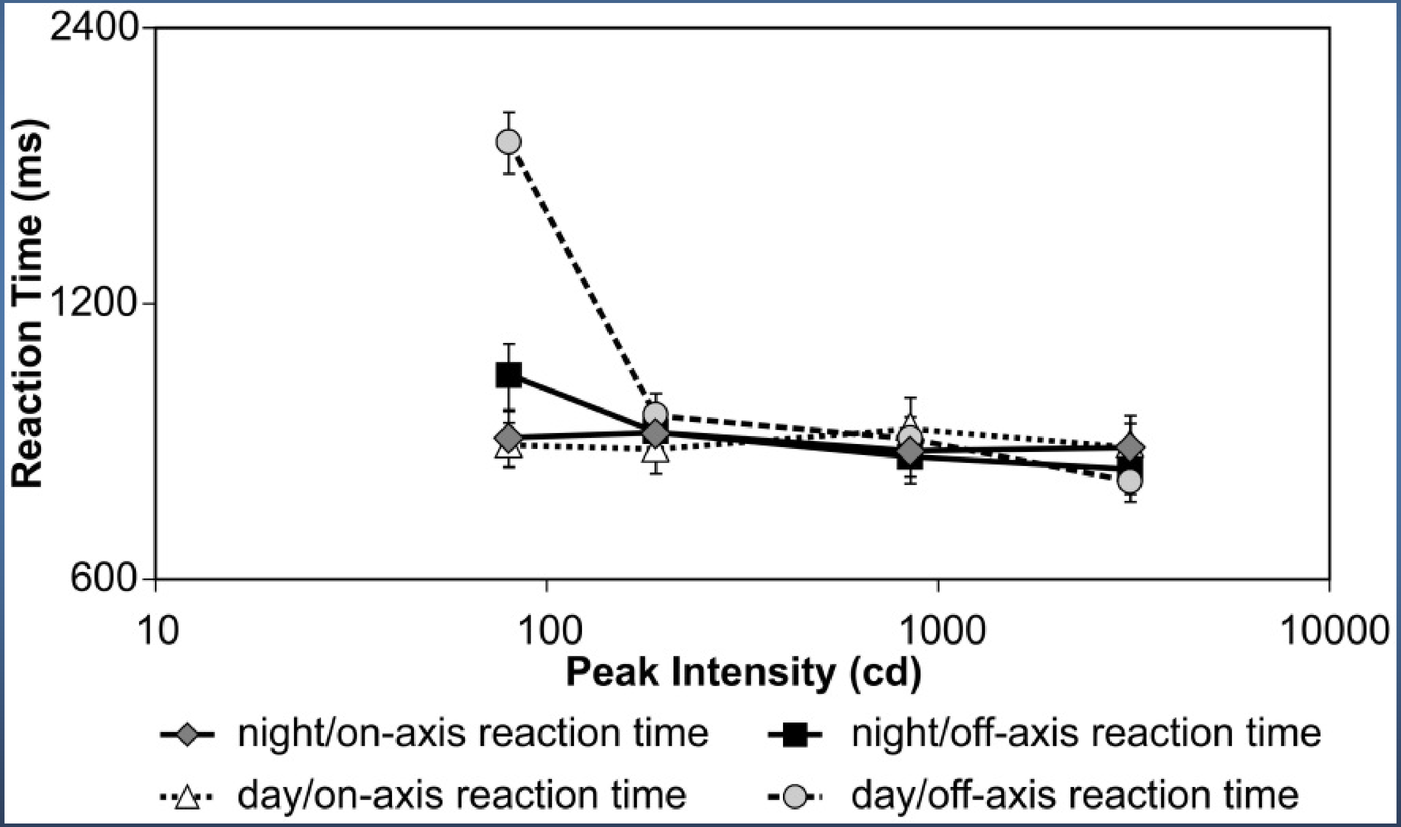
Off-Axis Warning Light, Nighttime, No Clutter

Off-Axis Warning Light, Nighttime, Clutter



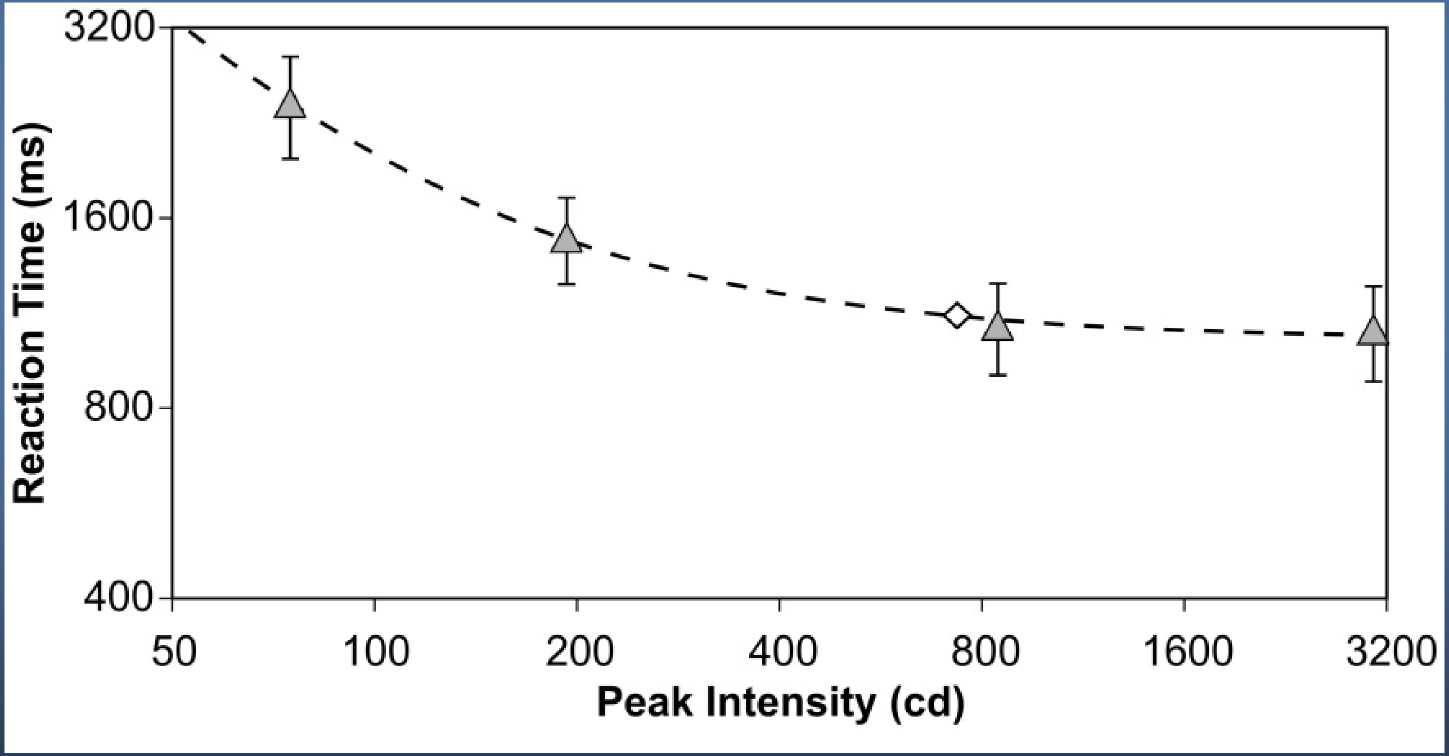
Response times vs. peak intensity

Response times exhibit asymptotic behavior



Toward a performance criterion based on response times

For older subjects under daytime, off-axis viewing conditions with clutter present, asymptotic response times required a peak intensity of 739 candelas (214 candelas at night)



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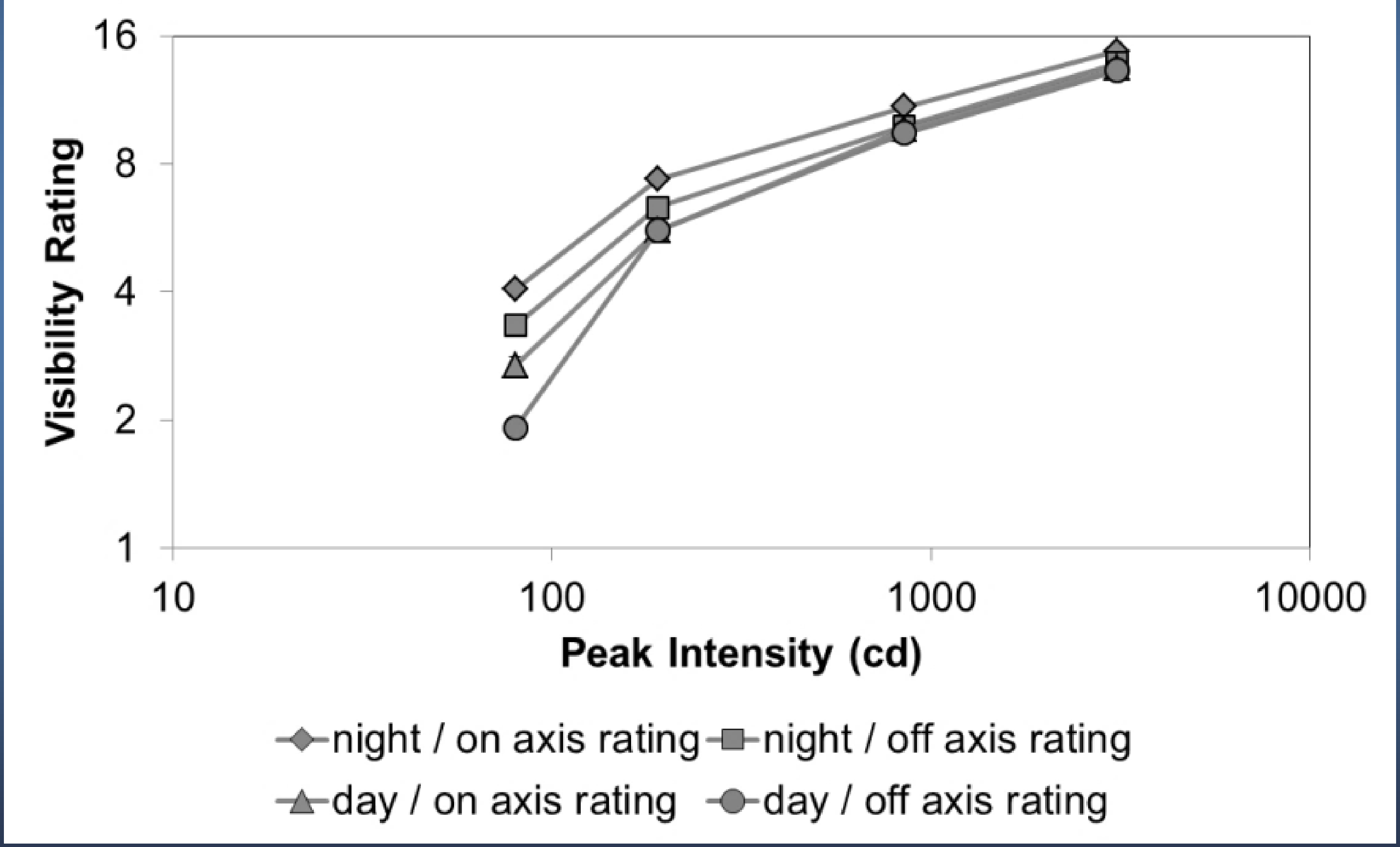
Subjective warning light visibility vs. peak intensity

Subjective warning light visibility ratings do not exhibit asymptotic behavior



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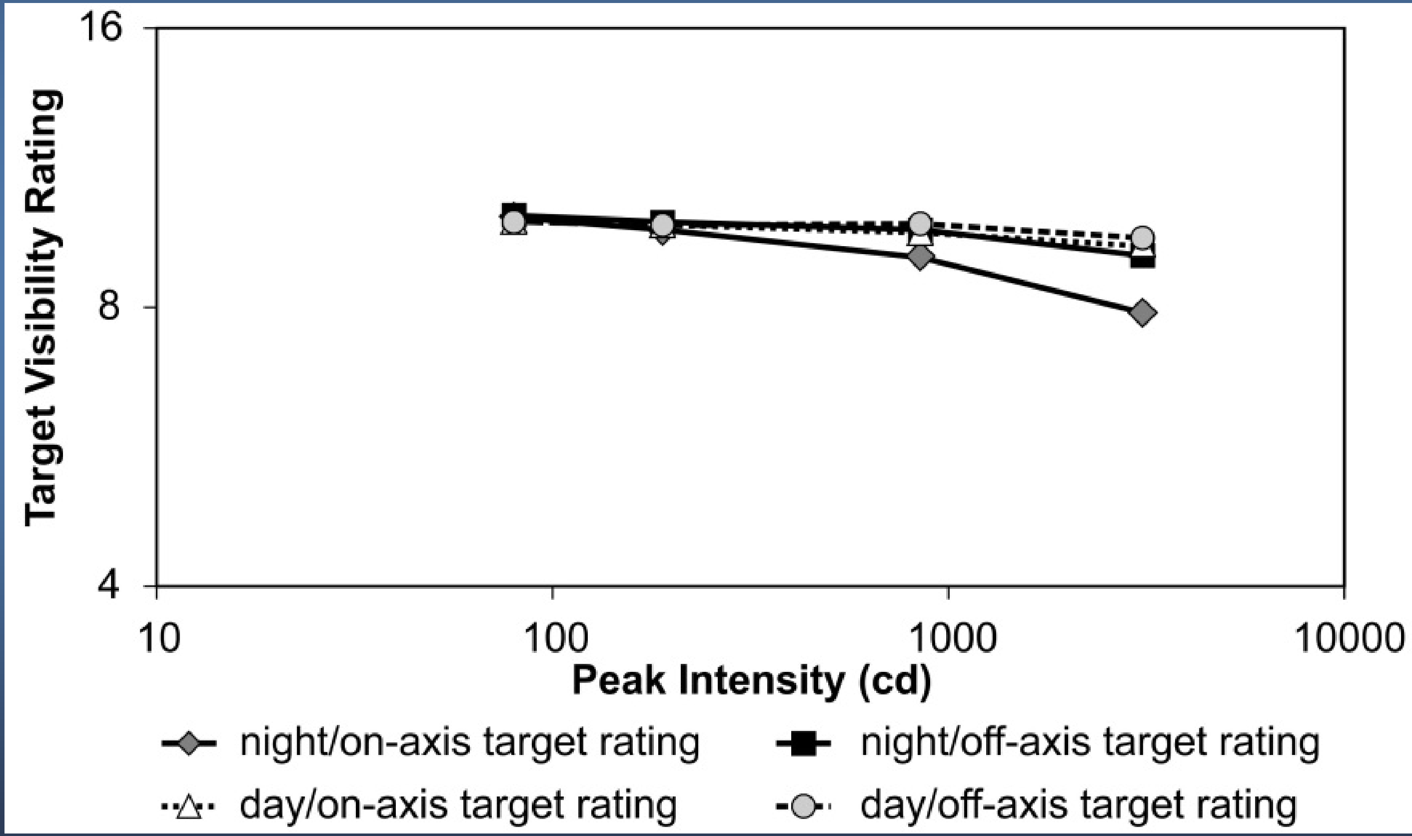
Subjective target visibility vs. peak intensity

Subjective target visibility ratings exhibit asymptotic behavior



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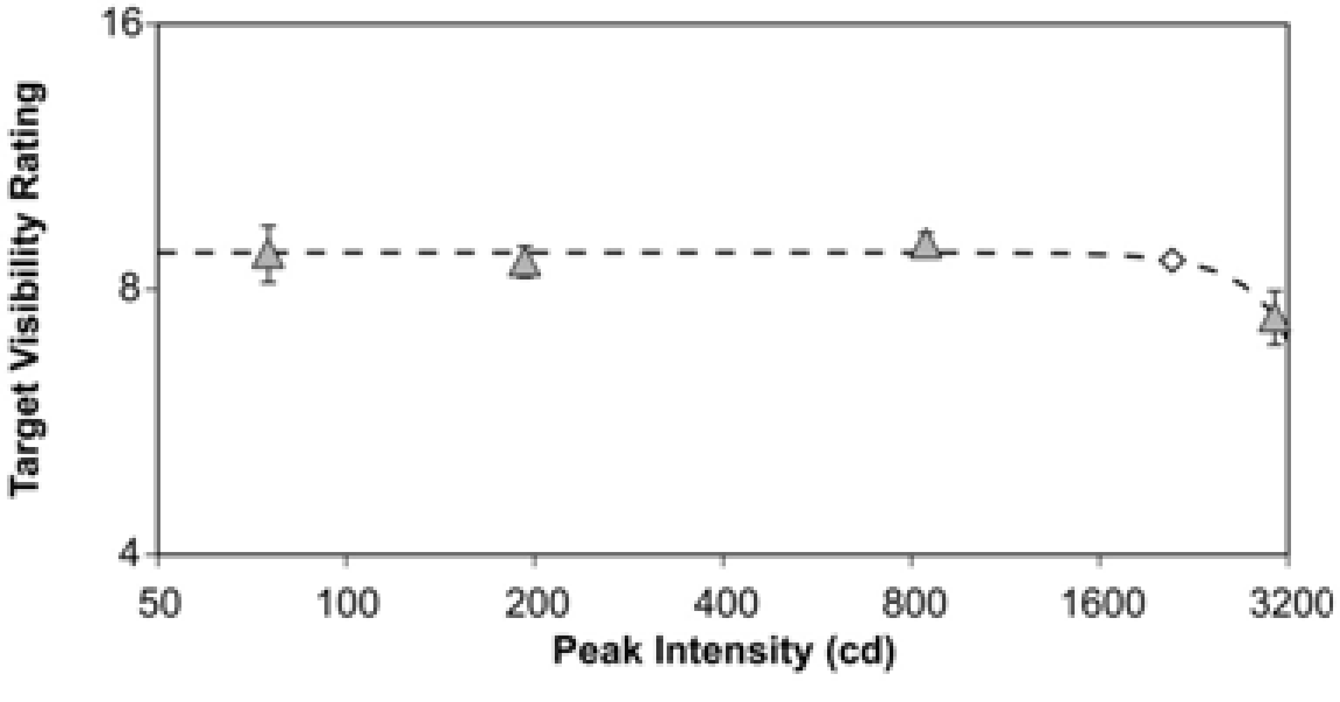
Toward a performance criterion based on judgments of target visibility

For older subjects under nighttime, on-axis viewing conditions with clutter present, asymptotic visibility ratings were achieved up to 2108 candelas



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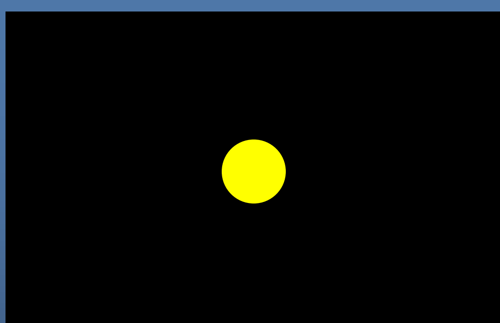
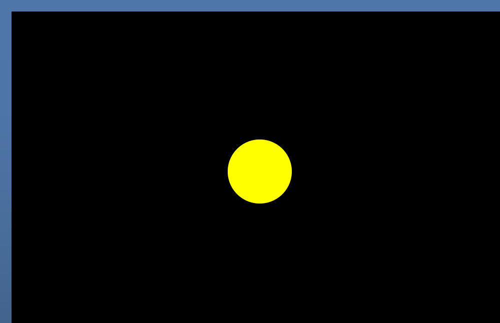
What properties of warning lights are important?

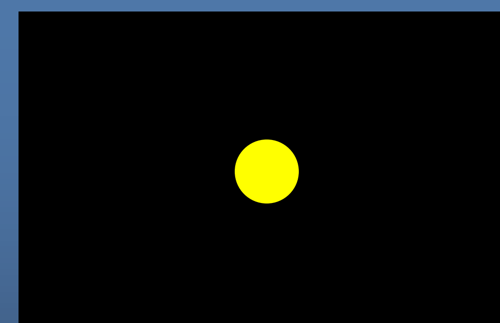
- Modulation
  - The amount of difference between the maximum and minimum intensity of a flashing light



100% modulation



50% modulation



0% modulation

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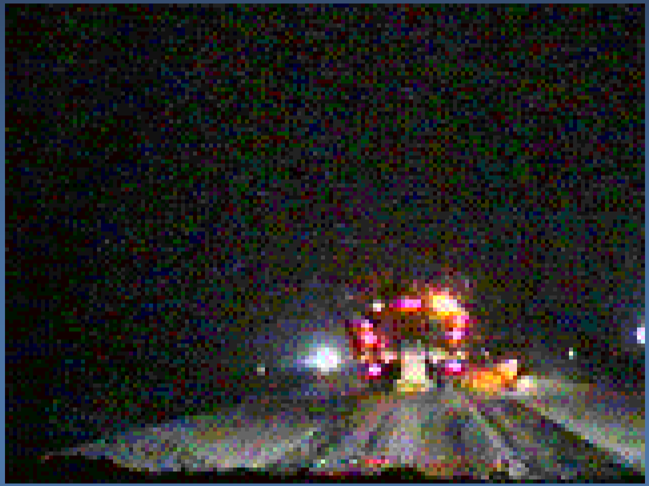
Why is modulation important?

- **70% of crashes involving vehicles such as snow plows are rear-end crashes** (Hale 1989; Stutzel et al. 1995)
- Flashing warning lights provide good attention-getting properties (Rabelo and Grusser 1961) but can make tracking judgments difficult (Croft 1971; Hanscom and Pain 1990)

Flashing versus steady-burning lights

(Sponsor: National Cooperative Highway Research Program)



- In Jefferson County, NY, drivers drove behind snow plows with conventional flashing yellow lights (100% modulation) and steady-burning light bars (0% modulation)
- They had to detect deceleration by the snow plow truck (without brake lights) as quickly as possible (Bullough et al. 2001)

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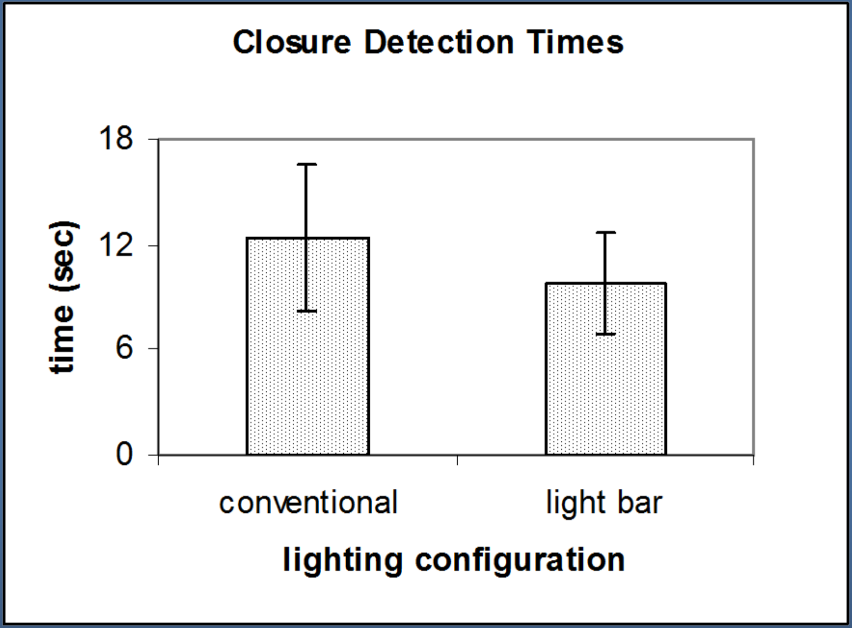
Closure detection results

- Drivers detected that they were approaching the snow plow sooner with the steady-burning lights than with the flashing lights
  - Difference in closure detection times was about **2.5 seconds**
- Reducing modulation by keeping a flashing light "on" at a reduced level may be beneficial for judging the relative speed and distance



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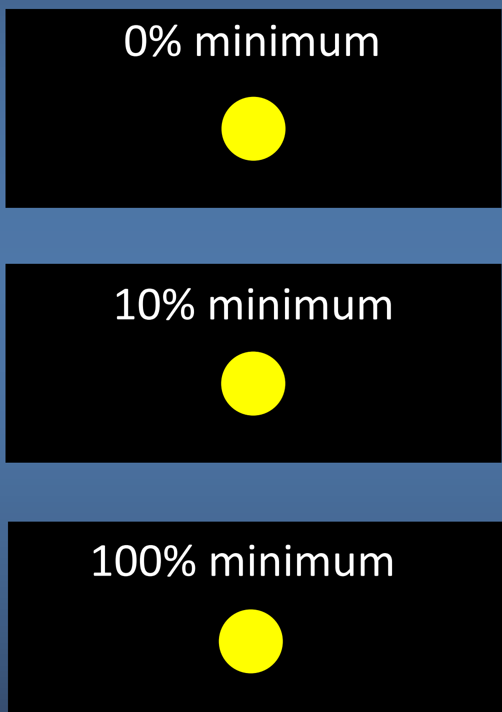
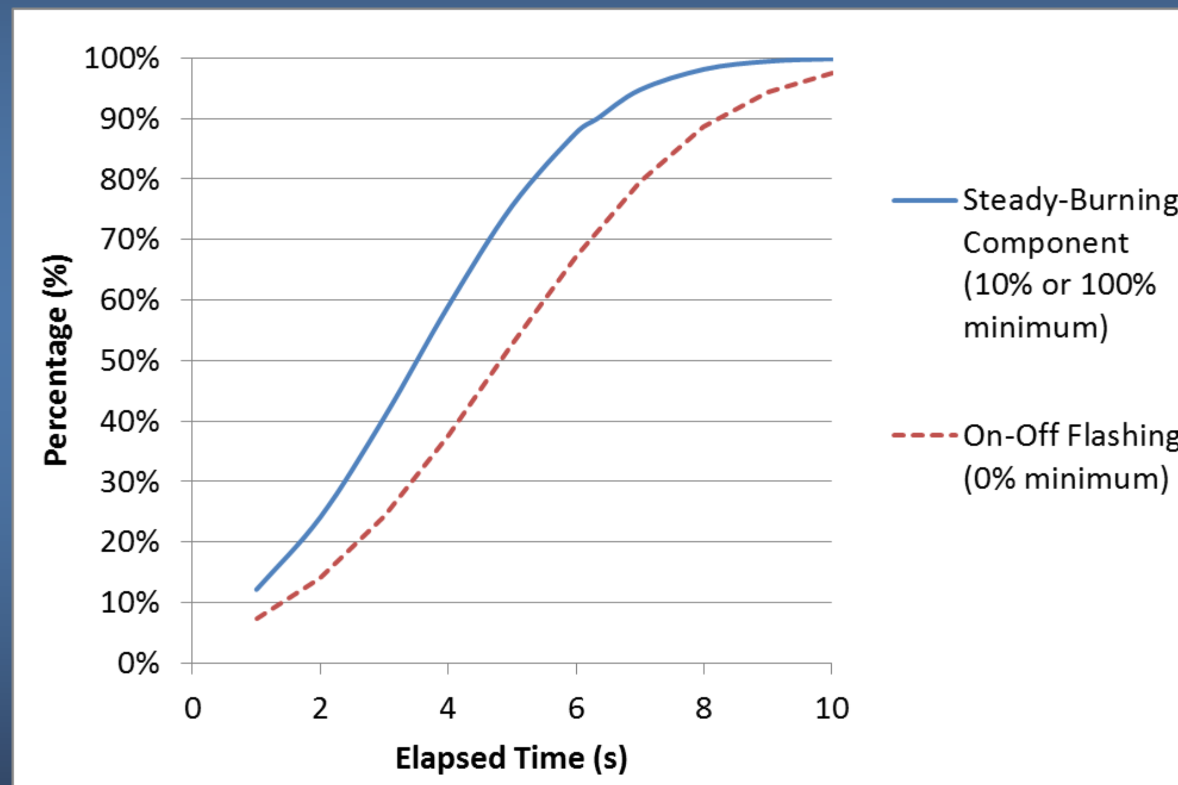
Amount of modulation

(Sponsor: National Institute of Occupational Safety and Health)

Closure detection is impacted by the amount of modulation





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What properties of warning lights are important?

- Spatial
  - Many but not all service vehicles have more than one warning light (or use a horizontal light bar)
  - In most cases, either configuration is detectable
  - Which is better for closure detection?

Single Incandescent Light

Pair of LED Lights

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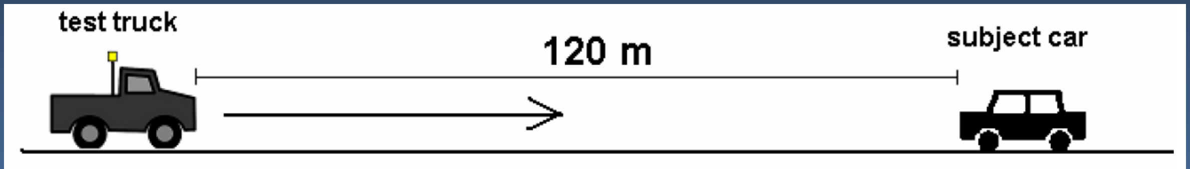
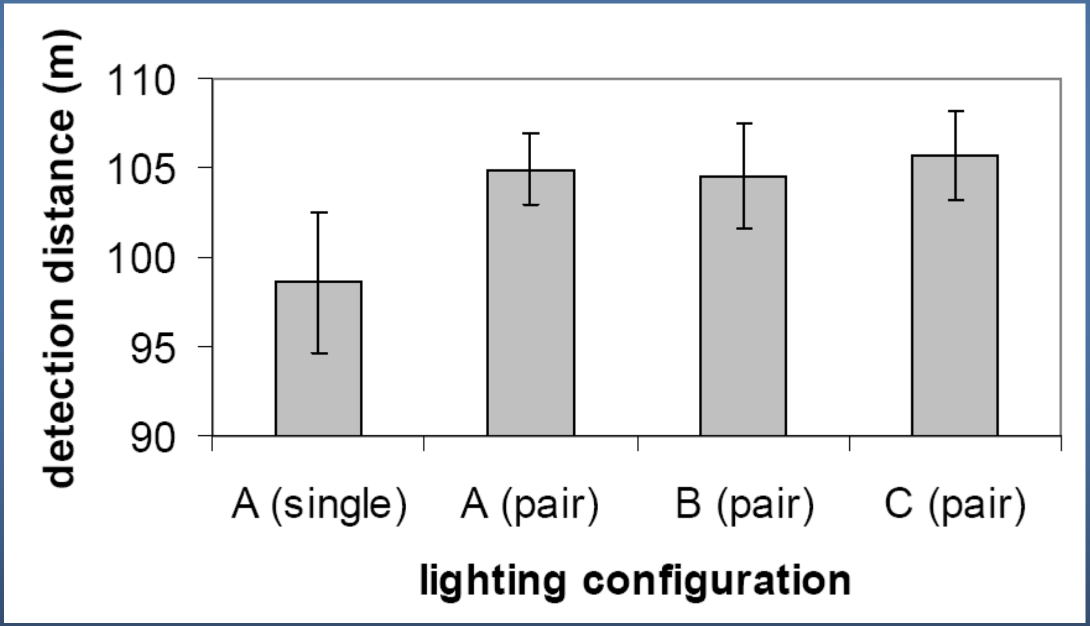
Additional closure detection results

(Sponsor: New York State Department of Transportation)



- In a field experiment, a truck was mounted with different incandescent or LED warning light configurations and driven toward an observer
- Statistically significant ($p<0.05$) differences **between single and paired** lights but not among paired lights



(Bullough and Skinner 2011)

What properties of warning beacons are important?

- “Special”
  - Most light signals used for warning are simple flashing units
  - Light source may be halogen, xenon strobe, or light emitting diode (LED)
    - Vehicle mounted LED warning lights use less power than halogen (6-16 watts versus 50-65 watts)
    - LED “matrix” design may permit new configurations such as animation

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Animated barricade lights

(Sponsor: University Transportation Research Center)

- Conventional barricade lights use a flashing yellow light
- New configurations were evaluated in a field test
  - Expanding: Size increases to provide added warning (“slow down,” “caution”)
  - Sweeping: Signal face illuminates from left to right or vice versa to indicate direction of lane shift (“turn/bear left,” “slow down”)

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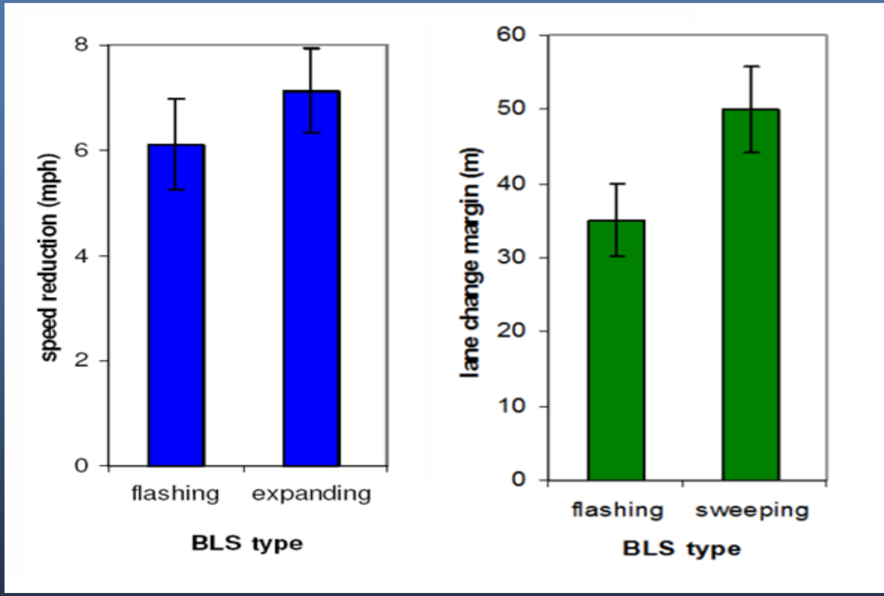
Field test

- Participants drove along a rural roadway where a simple simulated work zone was set up
  - Either with or without a necessary lane change to navigate through
- Barricade lights were either flashing, expanding or sweeping
- Test vehicle equipped with GPS sensor and data logger to record speed, lane position

Field test results

Compared to the conventional flashing light:

- Drivers **slowed down slightly more (by 1 mph)** in response to the expanding light
- Drivers **changed lanes sooner (by 15 meters)** in response to the sweeping light



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Summary

- Warning light performance depends upon several factors:
  - Intensity: Higher intensities are needed in daytime than nighttime; “too high” can result in reduced visibility at night
  - Modulation: Less than 100% modulation (“high-low” rather than “on-off”) could assist in closure detection

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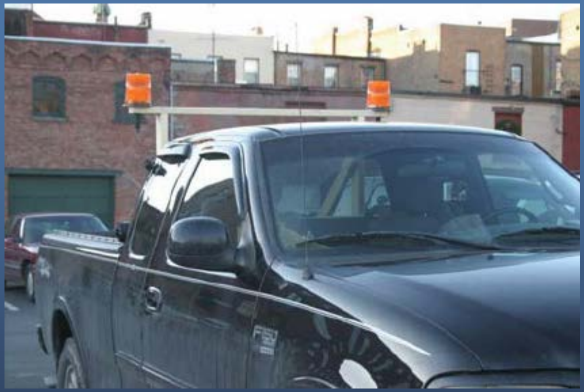
Summary (cont'd.)

- Warning light performance depends upon several factors:
  - Spatial: Two lights or an extended light bar will outperform a single point source for closure detection
  - "Special:" Animations, particularly sweeping motion, could provide cues to change lanes sooner



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Toward performance specifications*

Performance Characteristic	Preliminary Recommendation	Rationale
Maximum luminous intensity	**At least 750 cd (daytime)** **At least 215 cd (nighttime) and no more than 2000 cd**	Ensure optimal response times for day and night while preventing glare at night
Spatial distribution	Minimum of two beacons spaced separately or horizontal light bar	Provide angular separation for closure detection
Temporal modulation	10:1 maximum ratio for closure detection	Steady-burning lights outperform on-off flashing lights for closure detection; amount of modulation does not affect detection

*Preliminary, pending ongoing research activities.

Coordinating multiple warning lights

- Typically, when multiple warning lights are used they are not coordinated
- As part of a study for the New York State DOT the LRC compared random versus sequential and synchronized flashing lights for visual information

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Coordinating multiple warning lights

Clarity rating scale:

-2: very unclear

-1: somewhat unclear

0: neither clear nor unclear

+1: somewhat clear

+2: very clear

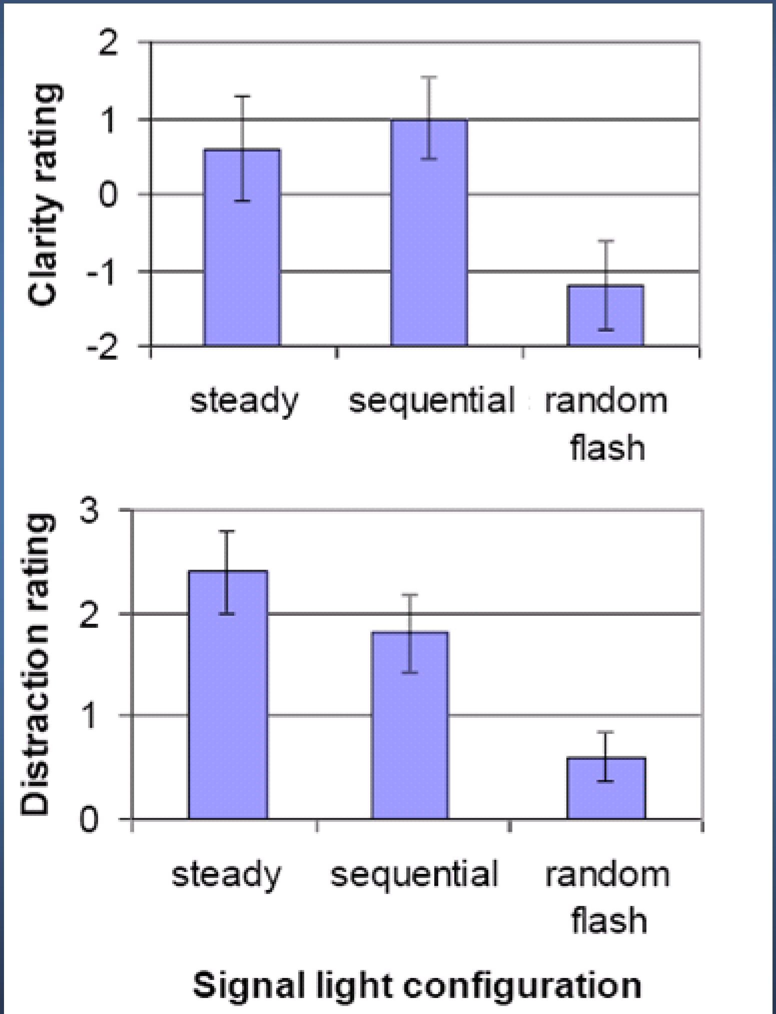
Distraction rating scale:

0: very distracting

1: somewhat distracting

2: slightly distracting

3: not at all distractingc



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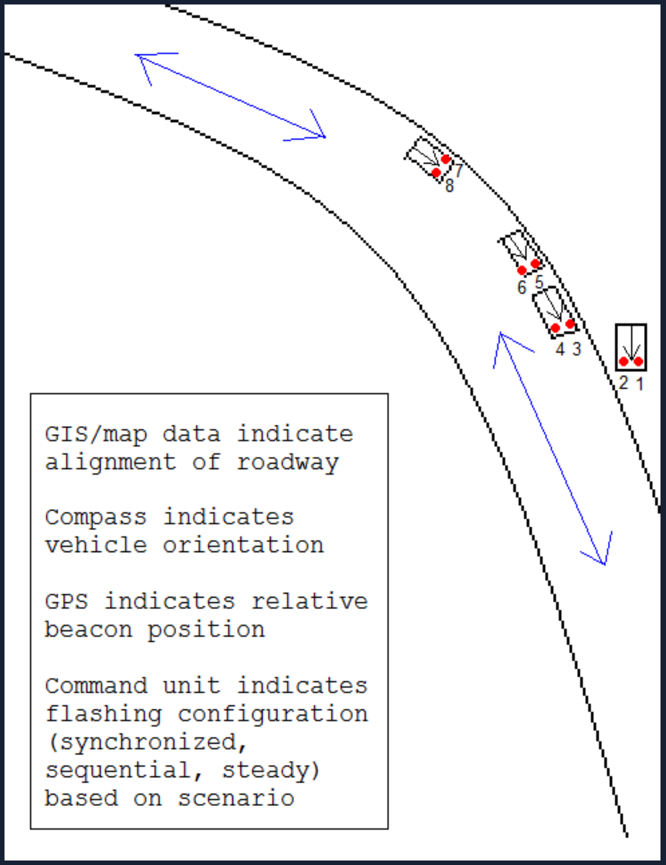
Toward the next generation of warning beacons

- The Lighting Research Center is developing intelligent functionality to provide visually effective guidance using warning lights, potentially including:
  - GPS and clock functionality for positioning and timing
  - Modified color and chromaticity
  - Intensity control based on ambient light level
  - Optical distributions to reduce visual noise in fog/snow
  - Polarization of light to control reflections from wet pavement

A roadway incident scene today

Making use of available data

- Ambient light sensor adjusts intensity based on day/night condition
- GPS/map data provide warning light positions relative to the roadway
- Master control unit sets flash configuration based on scenario



A roadway incident scene tomorrow?

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Planned field investigations

- Following human factors research to develop preliminary warning light specifications, prototype units will be field tested in collaboration with Pennsylvania State University

Acknowledgments

- Research sponsor organizations
  - NIOSH (Grant No. 1R01OH010165-01A1)
  - NYSDOT (SPR Project C-08-22) , (SPR Project C-08-14)
  - University Transportation Research Center
  - NCHRP (Project 6-12)
- Nicholas Skinner, Jeremy Snyder, Terry Klein, Hany Nakhla, Anna Lok, Richard Pysar (LRC); Thomas Spadaro, Rochelle Hosley, Janice Methe, Brian DeWald, John Cook (NYSDOT); Duane Amsler (AFM Engineering Services)

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