Alert, Inform, Manage:
Research-Based Suggestions for Warning Lights and Vehicle Markings

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Equipment Fleet Management 2024 National Conference

August 18-22, 2024 · Loveland, CO

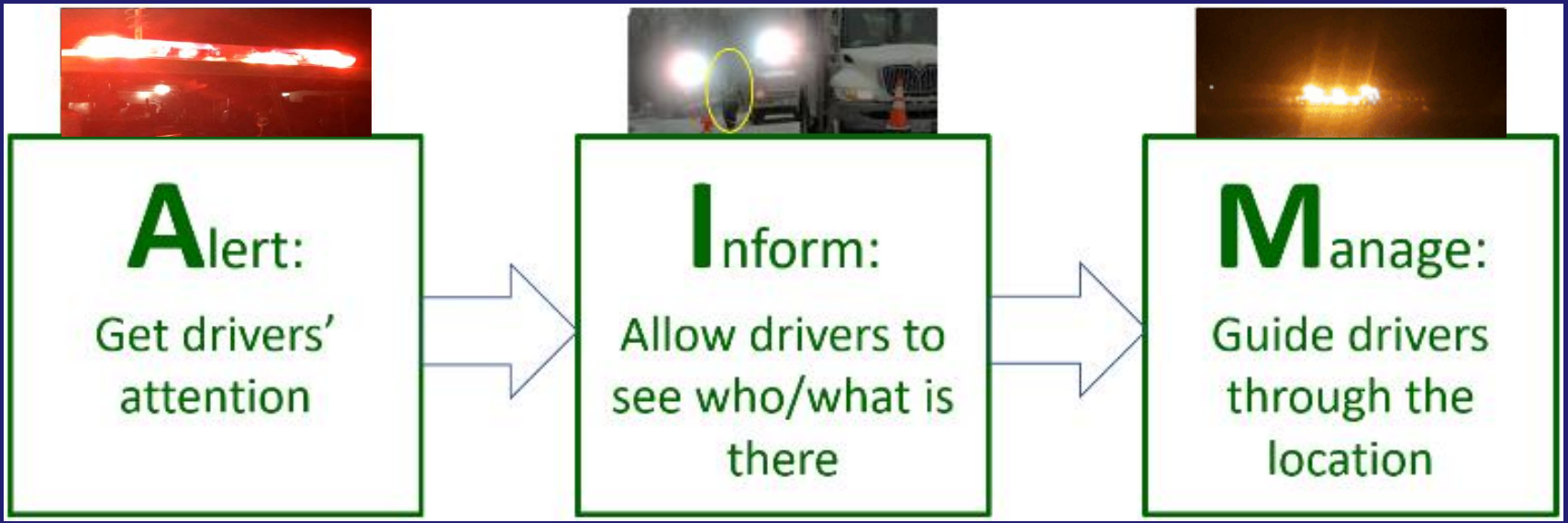
Icahn School of Medicine at Mount Sinai

Light and Health Research Center

Light and Health Research Center

- Part of the Department of Population Health Science and Policy in the Icahn School of Medicine at Mount Sinai
- Offices/laboratories in Albany, NY
- http://icahn.mssm.edu/LHRC
- Light for Transportation Safety Program
  - Vehicle lighting
  - Roadway and public lighting
  - Signage and signals, including warning and emergency lights

Flashing emergency lights serve multiple AIMs



(Bullough et al. 2022)

What are we trying to “fix”?

What properties of warning lights are important?

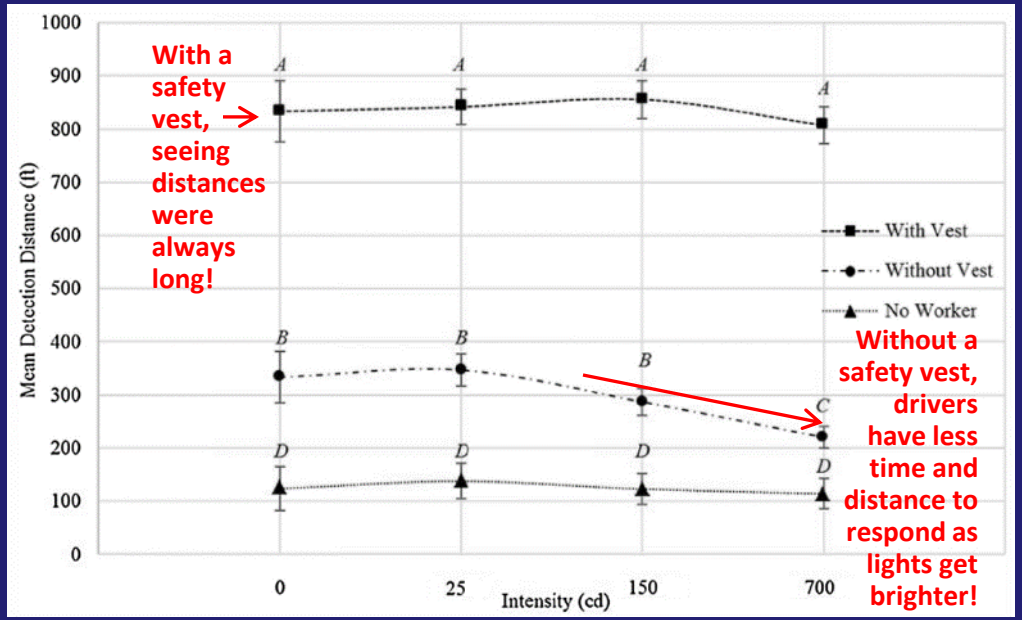
Intensity
- Society of Automotive Engineers (SAE) and National Fire Protection Association (NFPA) standards specify minimum intensities

Current field study:
- Different peak intensities
- Participants drove around a test track and recorded if/when they saw a simulated worker next to the truck
  - With or without a reflective safety vest
- Identification distances were recorded

(Kersavage et al. 2018)

How far away could workers be seen at night?

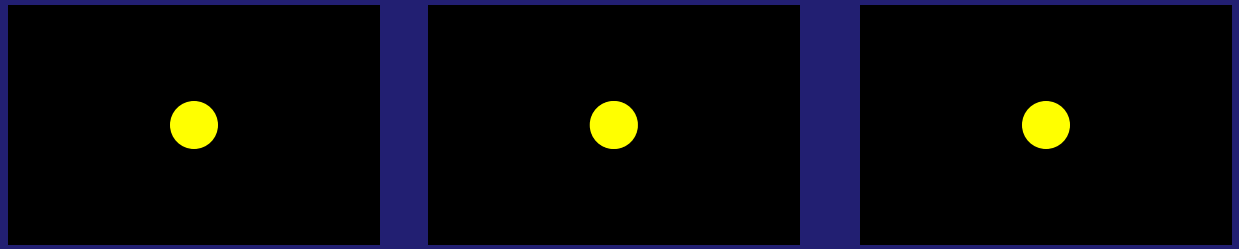
- Without a vest, large decreases in seeing distance occurred when the peak intensity was higher than 150 cd



(Kersavage et al. 2018)

What properties of warning lights are important?

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



100% modulation
(Most common!)

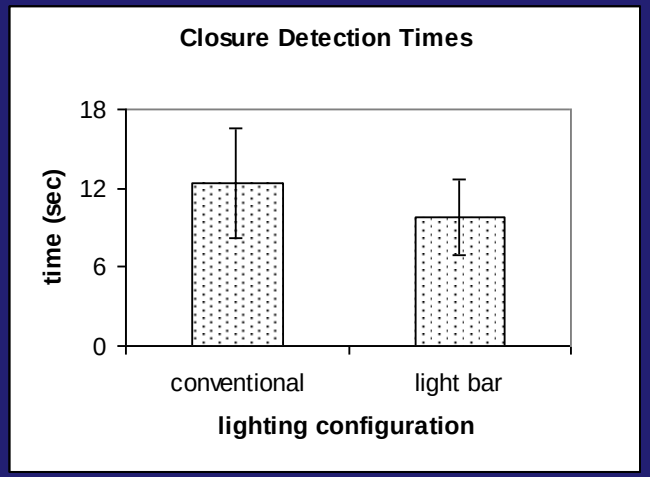
50% modulation

0% modulation
.

Flashing versus steady-burning lights

- Drivers rode behind snow plows with flashing yellow lights (~100% modulation) and steady-burning light bars (0% modulation)
- They had to detect when the snow plow slowed down (without brake lights) as quickly as possible

(Bullough et al. 2001)



What are we trying to “fix”?

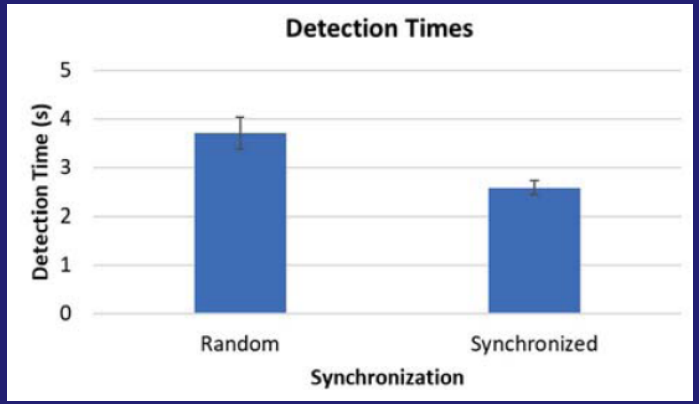
What have we “fixed” so far?

What properties of warning lights are important?

- Multiple-light flash patterns
  - Standards usually give requirements for flash rates of a single light or at a single location
  - “Random” flashing can still be confusing
  - What about **synchronizing** or **sequencing** flash patterns when multiple lights and vehicles are present?

Impact of flash pattern on ability to detect workers

- In a study of emergency vehicle lighting with randomized or synchronized flashing lights, participants reported the location of a police officer silhouette within the scene
- Drivers could identify the location of the police officer more quickly when the flashing lights were synchronized

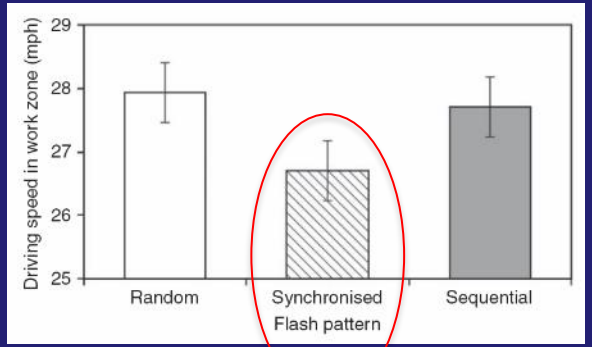


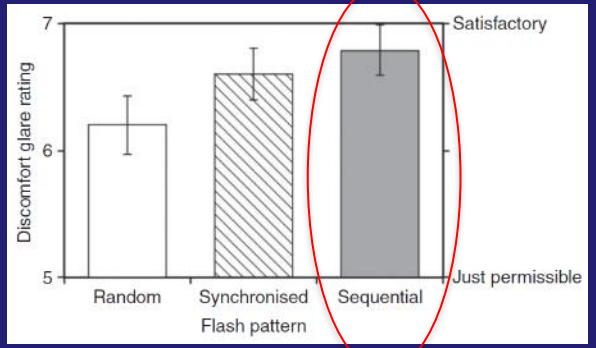
(Bullough et al. 2022)

Impacts of flash patterns

- Drivers slowed down more in response to synchronized barricade lights

- Drivers judged sequential lights as least glaring





(Rea et al. 2018)

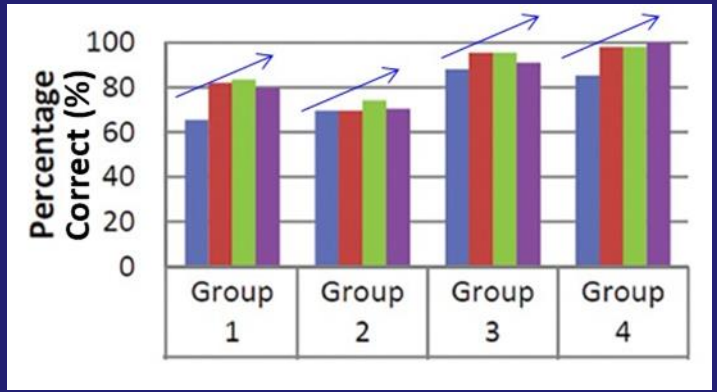
What are we trying to “fix”?

What have we “fixed” so far?

What properties of warning lights are important?

- Flash rate
  - People interpret “faster” flashing as more “urgent” and more “attention-getting”
  - They can “learn” that different flash rates mean different things and anticipate where vehicles might move
  - Possible application: “faster” flashing for vehicles making more dangerous maneuvers

Which direction will the truck move?



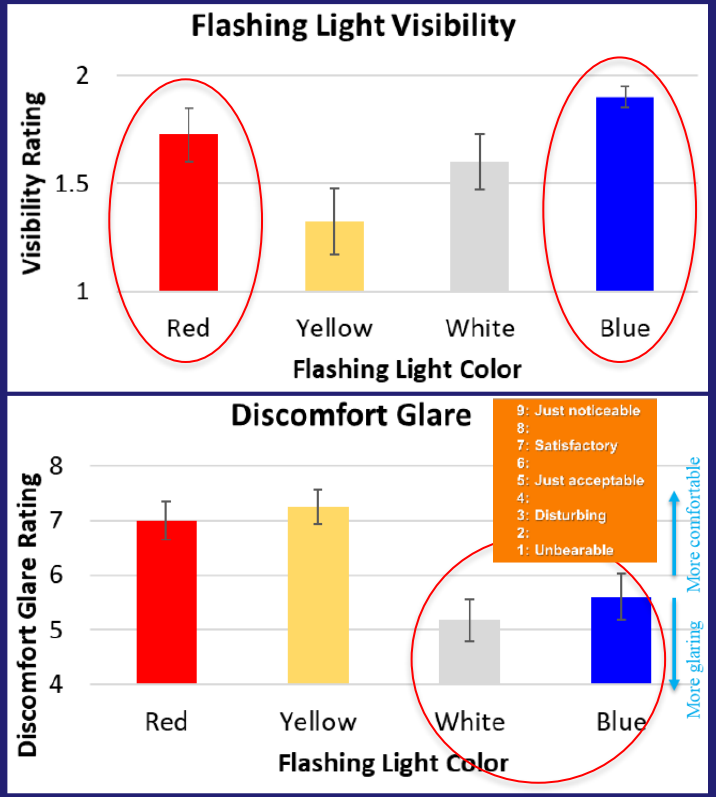
(Skinner et al. 2021)

What properties of warning lights are important?

- Color
  - How do different flashing light colors:
    - Affect how visible the lights appear?
    - Affect drivers' ratings of discomfort glare?

(Bullough et al. 2019, 2021)

Color: Visibility versus discomfort



- Red and blue lights (more saturated colors) were judged as more visible
- Blue and white lights (more short-wavelength/blue content) were rated as more glaring
- Flashing light color did not affect how visible the road scene was

(Bullough et al. 2021)

Importance of steady illumination at night

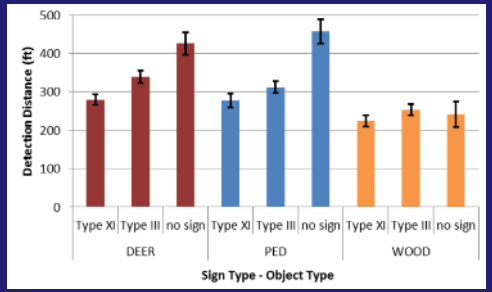
This officer is present in all four scenes!

(Bullough et al. 2019)

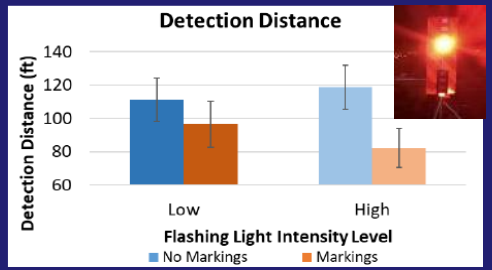
Impacts of vehicle markings

- Highway signs using highly reflective sheeting materials can reduce visibility of objects along the road (Carlson et al., 2014)

- The presence of reflective markings behind flashing lights resulted in shorter detection distances for a firefighter silhouette standing next to the flashing lights (Bullough et al., 2021)



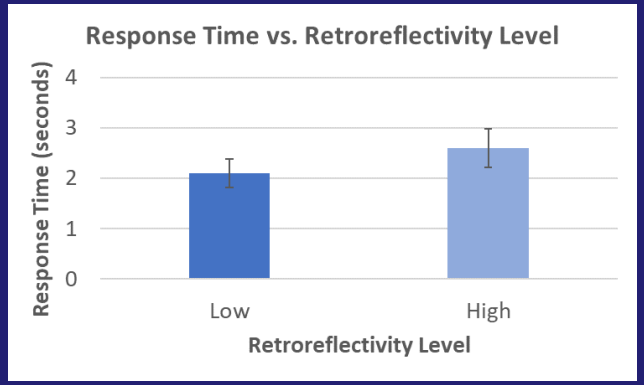
(Carlson et al., 2014)



(Bullough et al., 2021)

Impacts of vehicle markings (cont'd.)

- A follow-up study (presented at the 2024 TRB Annual Meeting) measured response times to identify the location of a mannequin wearing a firefighter uniform
- Response times were 0.5 s longer when a higher than minimum retroreflectivity level was used for the marking materials
- This corresponds to nearly 40 feet of stopping distance at 50 mph



Coordinating vehicle/color markings and flashing lights

- Vehicle colors can influence drivers' perceptions of what type of vehicle it is
- Red color is commonly used for fire apparatus and this color is associated with increased danger or urgency (Pravossoudovitch et al. 2012)
  - Lighter colors have been suggested for improving conspicuity (Solomon and King 1995) but red remains more familiar (FEMA 2009) and 85%+ of all fire trucks are red (MacPherson 2013)
- Colors of flashing lights differ across different U.S. states

Pilot study results (n=10): Which side is an emergency?

Experiment 1 (matching vehicle/light colors)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Ov.
Matching pairs			→		←						
Two red vs. two yellow vehicles											
Two red vs. yellow+red vehicles											
Two yellow vs. yellow+red vehicles											

Experiment 2 (different vehicle/light colors)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Ov.
Matching pairs			→		←						
Two red vs. two yellow vehicles											
Two red vs. yellow+red vehicles											
Two yellow vs. yellow+red vehicles											

Experiment 3 (reinforced vehicle/light colors)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Ov.
Matching pairs											
Two red vs. two yellow vehicles											
Two red vs. yellow+red vehicles											
Two yellow vs. yellow+red vehicles											

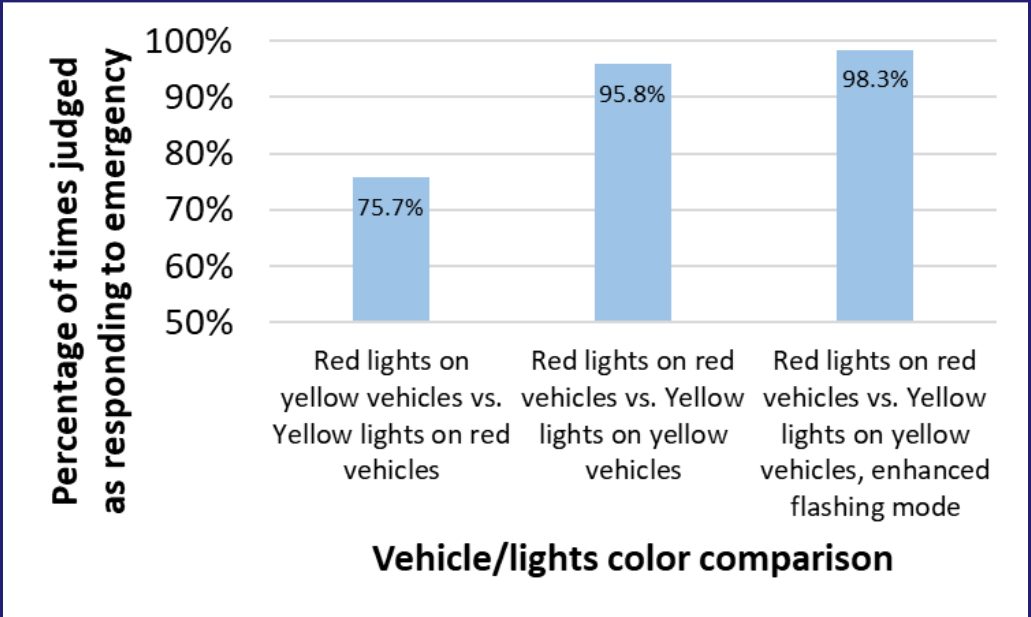
(Bullough et al., 2023)

Online survey questionnaire (n=118)

- Which side is an emergency situation?
- Red/yellow vehicle
- Red/yellow flashing lights
- Standard (1 Hz, equal intensity) or enhanced (1.5 Hz, brighter red and 0.5 Hz dimmer yellow) flashing

(Bullough and Rea, 2024)

Survey questionnaire results



(Bullough and Rea, 2024)

What leads to perception of an emergency?
(in order of importance)

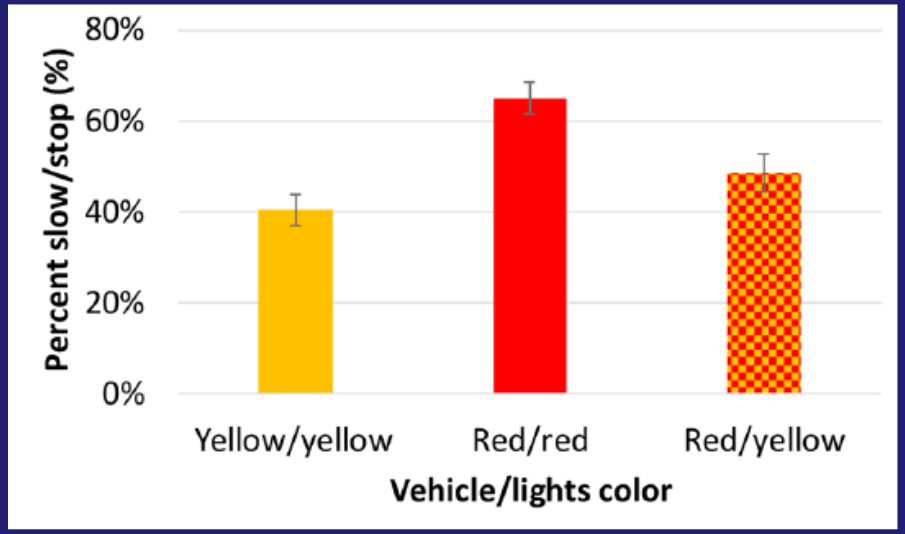
1. Red flashing lights
2. Red vehicle color
3. Enhanced flashing

Combinations of vehicle/marking colors, flashing light colors, and number of vehicles

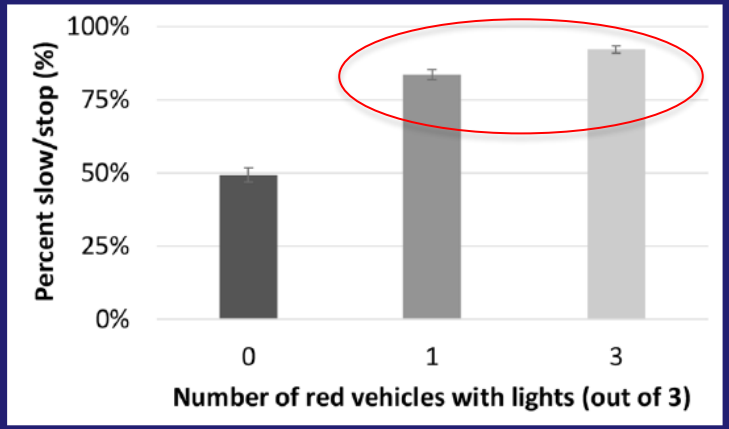
- Laboratory study to identify responses to different combinations
- Primary response:
  - Would you proceed, or prepare to slow down or stop?
- Secondary response:
  - Time to respond (indication of certainty/uncertainty?)

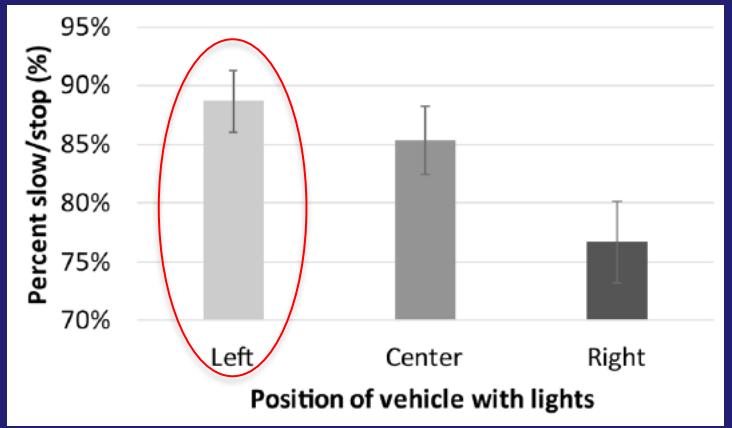
(Bullough et al., 2024)

Key results



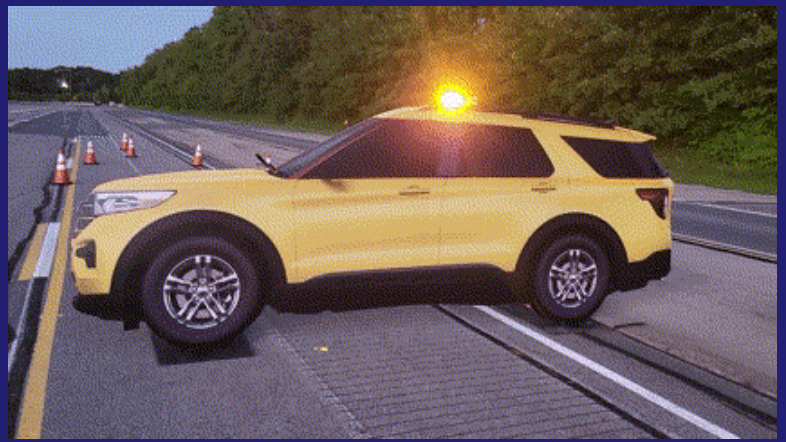
Response times were negatively correlated with percentage of slow/stop responses





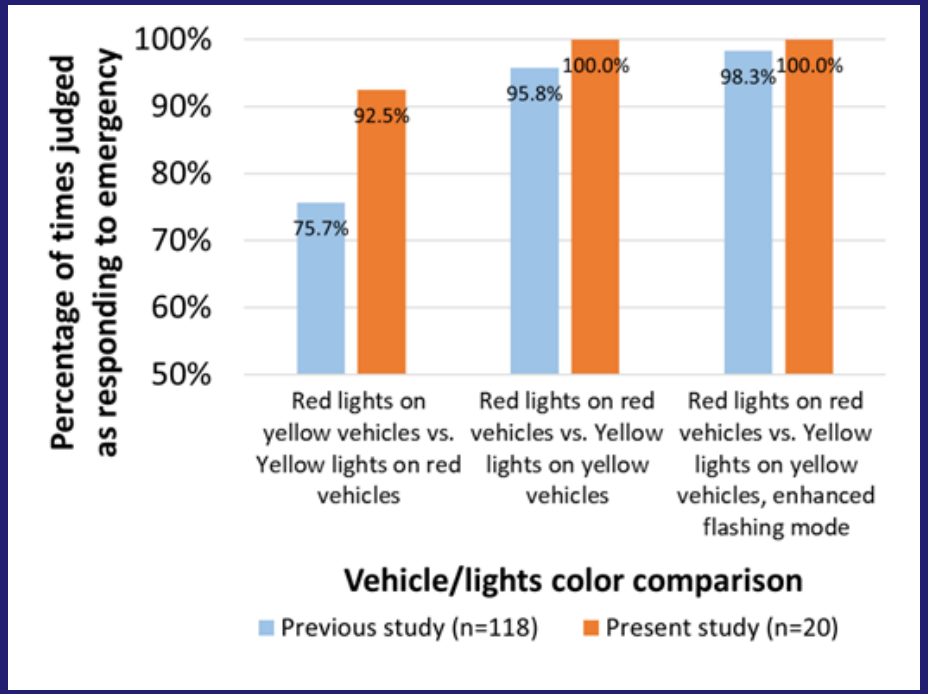
How will drivers respond to full-scale scenes?

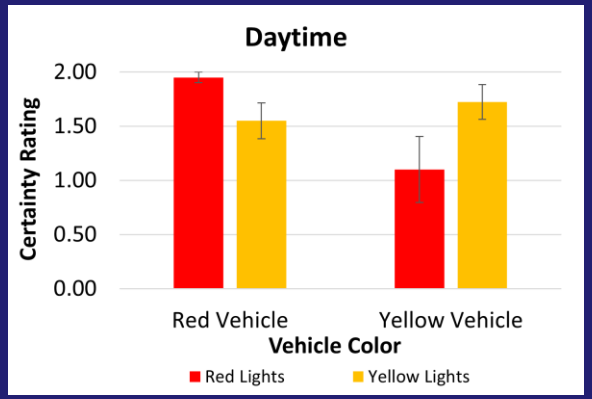
- Collaboration with Pennsylvania State University
- Combinations of vehicle/marking and flashing light colors

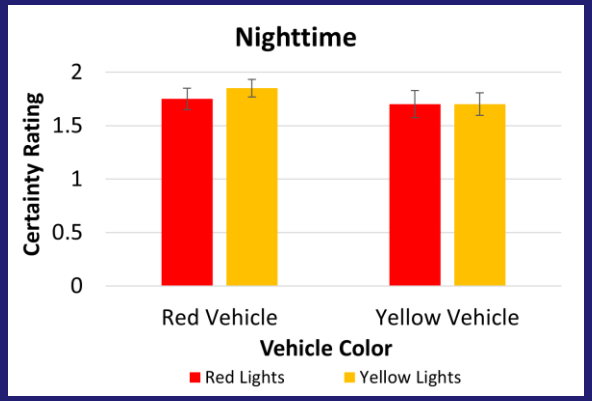


(Bullough et al., in press)

Field study results







Summary

- Reducing intensity at night will maintain *alerting* but allow responders to be seen more accurately (*informing* and *managing*)
  - Should we consider upper limits for nighttime intensity?
- “High/low” flashing is better than “On/off” flashing for closure detection
- Synchronized lights help reduce visual chaos, and sequential lights provide visual information
- Blue and red lights are rated most visible, blue and white lights most glaring
- Just a little steady illumination around the vehicle will make responders much easier to see
- Reflective vehicle markings can sometimes be “too bright,” making emergency responders more difficult to see at night
- Coordinating the colors of vehicle/markings, flashing lights and their flash rates will reinforce consistent understanding about roadside incidents

Acknowledgments

- National Equipment Management Conference organizers
- Research sponsor organizations:
  - NIOSH (Grants R01OH010165 and R21OH012465)
  - NCHRP (Project 6-12)
  - Emergency Responder Safety Institute (for U.S. Fire Administration)
  - SoundOff Signal
- Colleagues: Mark Rea, Nicholas Skinner (LHRC); Hany Nakhla, Richard Pysar (LRC/RPI); John Cook (NYSDOT); Duane Amsler (AFM Engineering Services); Jack Sullivan, Steve Austin, Todd Leiss (ERSI); Jim Stopa, Matt Kehoe (Whelen); Scott Parr, Emily Hiebner, Alec Sblendorio (Embry-Riddle); Bradley Miller, Douglas Baker (SoundOff Signal); Ilgin Guler, Adway Das, Kristin Kersavage, Philip Garvey, Eric Donnell (Penn State)

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