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Intelligent Warning Lights and Driving Safety

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John D. Bullough

Rensselaer Polytechnic Institute

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Abstract

Warning lights and beacons on service vehicles such as maintenance trucks, tow trucks, utility service vehicles and delivery vehicles are an important line of defense for the workers who operate them. These flashing lights can also contribute to visual chaos making it difficult to navigate through a work zone location. Research on the flashing configuration and spatial and temporal coordination of warning lights that could adapt to ambient conditions and situations is described, leading to recommendations for preliminary performance specifications

Introduction

U.S. workers in the construction, transportation and utilities sectors are over-represented in workplace fatalities [1]. Many of these workers perform their jobs in or adjacent to active rights-of-way where they are exposed to oncoming traffic. Among the primary lines of defense for these workers are warning beacons, flashing (or rotating) yellow lights that provide warning to other drivers that a utility truck, maintenance vehicle or other type of service vehicle is active.

At present, performance requirements for yellow warning beacons are specified by several standards published by the Society of Automotive Engineers (SAE) [2, 3, 4]. Flashing warning lamps must have a flash frequency from 1 to 2 Hz and the luminous intensity of the lamp in the on-axis direction should be at least 600 cd when the lamp is steady burning [2]. Optical warning devices have the same flash frequency requirements but the photometric performance is specified in terms of flash energy, defined as the integrated light-energy quantity in cd·s. For emergency situations, the minimum flash energy is 90 cd·s; for warnings the flash energy should be at least 22 cd·s and for identification, at least 10 cd·s [3]. Strobe-type beacons can also be used; these are required to have a flash frequency from 1 to 4 Hz and similar flash energy requirements as optical warning devices [4].

The applicable SAE standards [2, 3, 4] do not specify different levels of photometric performance based on ambient conditions (e.g., night versus day), nor are provisions made for any temporal coordination among multiple beacons used on a single vehicle. It is also assumed that the flash pattern for these devices is a simple on-off type of flash (even if it is generated using a rotating beacon, the resulting appearance is that of a flashing light).

In the present paper, several investigations of the characteristics of warning beacons are described, which can lead to new preliminary recommendations for performance specifications of these devices. A primary impetus of these investigations is a conclusion from Cook et al. [5] that suggests that warning beacon design plays a role in 20% of the 340 annual fatalities and 26,000 annual injuries in the U.S. [6] that involve vehicles with warning beacons.

Intensity Requirements

In order to evaluate the appropriateness of the SAE J595 intensity requirements for warning beacons, a laboratory study [7] was conducted under simulated daytime and nighttime conditions. Projected roadway scenes showing a scale model service truck equipped with a warning beacon and a low-contrast Landolt ring (C-shaped) target were used (Figure 1). The low-contrast targets served as visual fixation points and were located either directly adjacent to the truck or 5° to the right of the truck so that the warning beacon either appeared on- or off-axis to the observer's line of sight.

During experimental trials a simulated warning beacon created using a yellow light-emitting diode (LED; peak wavelength 590 nm, half-bandwidth 18 nm) was activated at a random time. The flash frequency of the beacon was 1 Hz, with a 50% duty cycle. The equivalent peak luminous intensity ranged from 80 to 530 cd as viewed from 100 m away. Response times to the onset of the beacon were measured by instructing subjects to press a button when they detected it. In addition, subjects were asked to rate the visibility of the low-contrast target while the beacon was flashing; its visibility when no beacon was present was defined at the start of each trial as a value of 10.

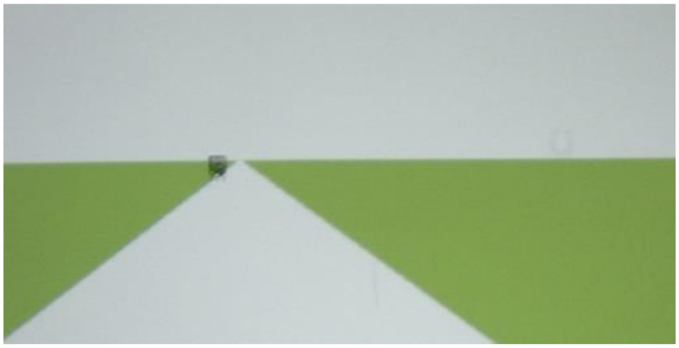

Figure 1. Portion of one of the projected daytime scenes used to investigate intensity requirements for warning beacons. A simulated truck is located along the left edge of the road.

When no visual clutter was present, response times to the warning beacons were always short and asymptotic (reached minimum values) when the beacon was viewed on-axis. Figure 2 shows the mean response times as a function of the peak luminous intensity of the beacon for both daytime and nighttime roadway scenes, when the beacon was located off-axis. Off-axis response times were longest for the lowest intensities for daytime viewing conditions; asymptotic response times occurred at a peak intensity of 530 cd. Asymptotic response times occurred for the nighttime viewing conditions across the range of peak intensities evaluated.

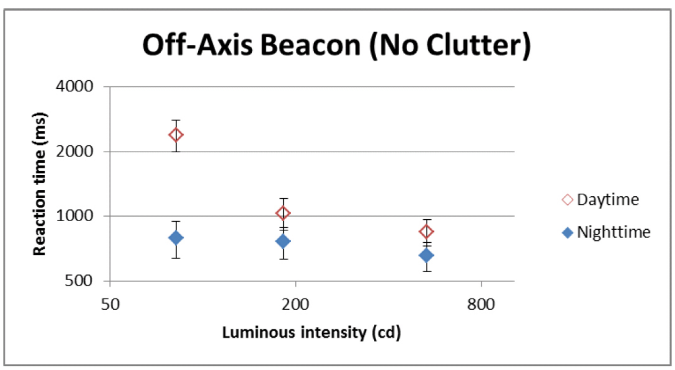

Figure 2. Response times to warning beacons viewed off-axis as a function of the maximum luminous intensity of the beacon, without visual clutter present.

Visibility ratings for the low-contrast targets when the beacons were located on-axis without visual clutter are shown in Figure 3. Target visibility was unaffected by the beacons in daytime conditions but were slightly lower when the peak intensity was highest. When the beacons were located off-axis, they did not affect the visibility of the targets under either daytime nor nighttime conditions.

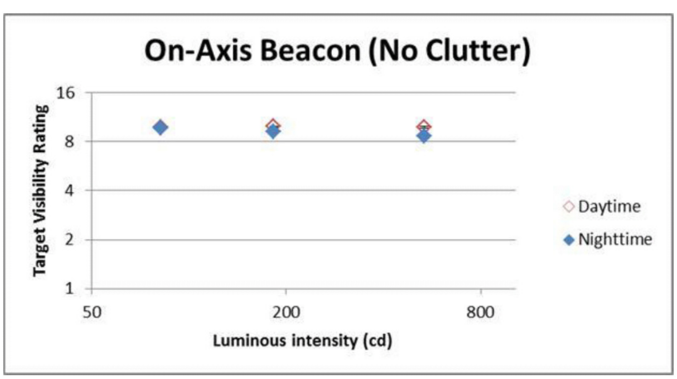

Figure 3. Target visibility ratings when the beacon was located on-axis, as a function of the peak intensity of the beacon.

When visual clutter was present, both on- and off-axis response times exhibited similar characteristics. Nighttime response times became asymptotic when the peak intensity reached 180 cd; daytime response times required higher peak intensities, of 530 cd, to reach asymptotic values (see Figure 4 for off-axis response times in the presence of visual clutter).

Interestingly, when visual clutter was present, ratings of low-contrast target visibility decreased for the both on-axis and off-axis beacon locations when the peak intensity was highest, during nighttime conditions.

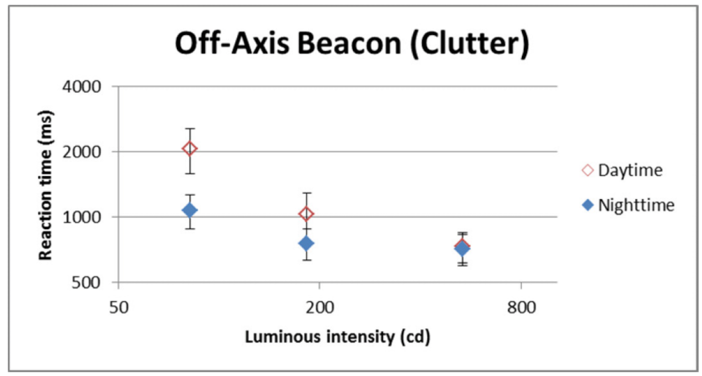

Figure 4. Response times to warning beacons viewed off-axis as a function of peak intensity of the beacon, when visual clutter was present.

Taken together the results of this investigation [7] suggest that a peak luminous intensity of 600 cd as specified by SAE [2] is appropriate for ensuring visual detection under daytime conditions, but would be excessive for nighttime conditions because it could begin to degrade the visibility of low-contrast objects.

Modulation Requirements

Flashing lights are inherently more conspicuous (attention-getting) than steady-burning lights, which is why they are often used in warning light applications. Typical on-off flashing has a modulation of 100%. However, there is some evidence that visual tracking of object motion is more difficult when flashing with 100% modulation is used [8]. A study of rear lighting on snow plows [9] used conventional flashing lights (100% modulation) in comparison with steady-burning LED light bars (0% modulation) mounted on the sides of the rear of the plow truck. Observers rode in a vehicle that maintained a constant distance behind the snow plow, and at random intervals, the plow truck decelerated (without using its brake lights). Observers were asked to indicate, as quickly as possible, when they noticed that their vehicle was approaching the snow plow.

Figure 5 shows the average closure detection distances; observers noted the change in distance about 2.5 s sooner with the steady-burning light bars than with the flashing lights, suggested that reductions in modulation are conducive to improved closure detection.

In a laboratory study [10], it was found that closure detection response times to a pair of flashing lights with 0% (steady-burning) or 90% (a 10:1 ratio between the maximum and minimum intensities) modulation were 1-2 s shorter than a pair of lights with 100% (on-off flashing) modulation.

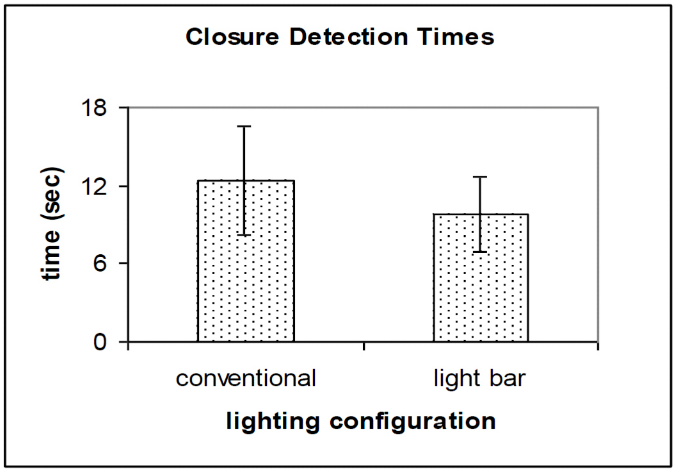

Figure 5. Closure detection times for a preceding snow plow truck equipped with conventional flashing lights or steady-burning light bars.

Spatial Characteristics

Many service vehicles are equipped with more than one warning beacon or with a light bar configuration that provides a relatively large spatial extent to an observer compared to a single warning beacon. Because the closure detection response is related to the change in angular size of an object in motion [11], it would be expected that it would be easier to detect a change in relative speed or direction when more than one warning beacon is used on a vehicle.

This expectation was tested in a study conducted to investigate the effectiveness of LED warning beacons in comparison to rotating incandescent beacons [12]. In some conditions a single beacon was installed on a test truck and in others a pair of beacons was installed. Subjects in a parked car 120 m in front of the test truck reported when they detected that the truck had begun moving slowly toward them. With one beacon, the truck had to be about 98 m away; for all pairs of beacons tested, the truck had to be about 105 m away (Figure 6), a difference of about 7 m.

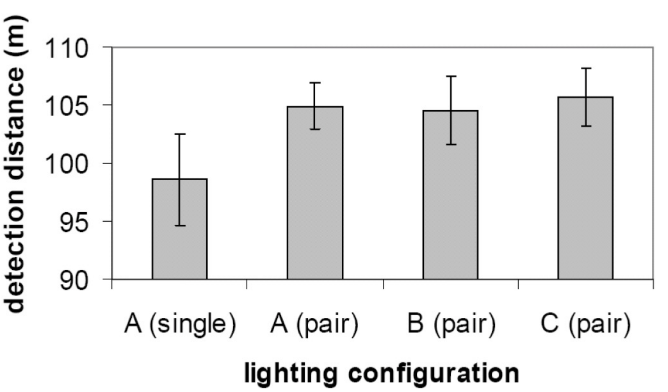

Figure 6. Mean closure detection distances to a test truck configured with one or two rotating incandescent beacons (A) or two flashing LED beacons (B, C).

Animation Characteristics

Many LED warning lights and similar products use an array of LED sources in a matrix configuration. Although many of these products simply flash all of the LEDs in unison to create a single flashing light appearance, the matrix configuration could, in principle, illuminate specific LEDs at different times to create an animated appearance.

As part of a study of yellow barricade lights used in delineating roadway work zones [13], conventional flashing barricade lights were compared to "sweeping" lights in which the signal module face illuminated starting with the leftmost (or rightmost) segments and then progressively illuminated adjacent sections toward the right (or left) until the entire signal face was illuminated.

Simulated lane changes were mocked up along a closed test roadway so that drivers would have to shift to the left in order to pass through. Participants in the study were asked to drive along the road safely and to heed any signs or warning lights that they approached. An instrumented vehicle with a GPS sensor that could record the vehicle's speed and acceleration was used.

As illustrated in Figure 7, vehicles changed lanes sooner, by about 15 m, when the barricade lights had a sweeping configuration than when they were simple flashing units. This result suggests that signal lights such as barricade lights or warning beacons can use animation to convey information about desired lane changes or other directional information effectively and without confusion.

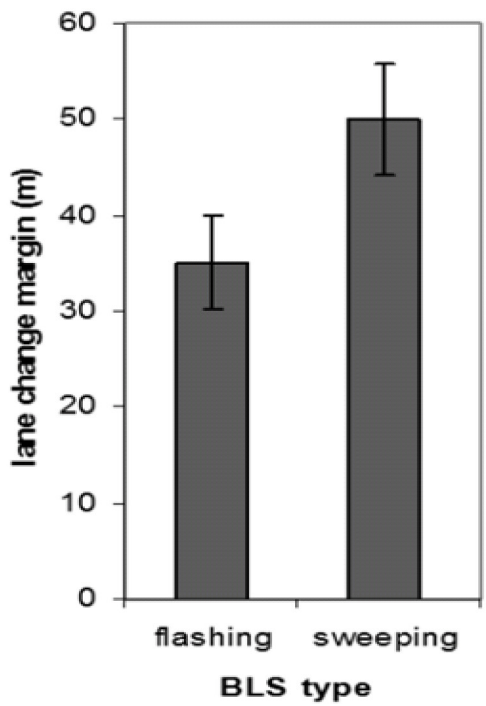

Figure 7. Lane change margins (defined as the distance ahead of a physical lane change that a vehicle actually changed to a different lane) in response to conventional flashing barricade lights and sweeping barricade lights.

Summary and Outlook

The research findings summarized in the present paper can be used to develop preliminary specifications for improved performance of warning beacons used on service vehicles that could be considered in the future:

Maximum luminous intensity:

- 530 cd minimum (daytime), 180 cd minimum (nighttime)
- Based on the laboratory study data summarized above [7], these values will ensure optimal response times for daytime and nighttime while preventing glare at night.

Modulation characteristics:

- 10:1 ratio between the maximum and minimum intensities while flashing
- Laboratory and field research [9, 10] data indicate that this ratio will provide improved closure detection over a source with on-off flashing.

Spatial extent:

- A minimum of two beacons should be used
- This will result in improved closure detection over a single warning beacon, based on field data [12]

In addition, when it is intended to convey a sense of direction similar to that in an arrow panel or to indicate a lane closure requiring drivers to change lanes, an animated “sweeping” signal face configuration will provide a meaningful cue that has been shown to result in earlier lane change maneuvers than conventional flashing lights [13]. This finding is also consistent with a recent study of vehicle turn signals using an animated configuration [14] in which long (>2.5 s) response times were reduced in frequency when an animated signal was used as a rear turn signal.

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Contact Information

John D. Bullough
Ph.D., Lighting Research Center, Rensselaer Polytechnic Institute
21 Union Street, Troy, NY 12180 USA
Tel.: +1.518.687.7100
Fax: +1.518.687.7120
bulloj@rpi.edu
www.lrc.rpi.edu/safety

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