SIZE VERSUS INTENSITY AS AIDS TO SIGNAL CONSPICUITY

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Providing the motorist with more effective traffic control devices has been the objective of constant efforts by the traffic engineering community, aided by professionals from other disciplines who share their interest in traffic safety. In recent years, an increasing amount of research has been devoted to improving the conspicuity of traffic control devices by manipulating parameters such as size, shape, color, brightness, location, number and so on.

Among the results of this research are the not-so-surprising findings that within limits, the conspicuity of traffic signals can be improved by increasing their intensity, as well as by increasing their size. Of these two improvements, increased intensity would appear to be the simpler alternative, since (in effect) all that is required is a brighter bulb, although there has been increasing use of larger signal heads at "problem" intersections.

In the past few years, however, restrictions in available funds have increased the need to assess the "cost-effectiveness", if possible, of every proposed improvement in the highway system. In addition, growing concern for present and future energy supplies, which may pose an even more pressing constraint than fund restrictions, has injected a new set of values in the cost-effectiveness evaluations, resulting in changes in the "trade-offs" that can be considered "acceptable".

One such trade-off relating to traffic signals has to do with size versus intensity as a means for making the signal more conspicuous and, hence, more effective. This paper describes research that produced findings which may be of value in resolving this issue.

OVERALL METHODOLOGY

The research described below was conducted as part of a larger study directed toward developing more effective warning devices for highway-rail grade crossings. This rather complex project, involving indoor and outdoor laboratory studies as well as the collection of field data, is described in detail in a report by Ruden, et al. (1).

The indoor laboratory study phase of the total project was conducted in the Federal Aviation Administration's Low Visibility Facility at the University of California's Richmond (California) Field Station. This facility consists of a building 1000 feet (305 m) long and 33 feet (10.1 m) wide, with 28 feet (8.5 m) of paved roadway along its length. It is 36 feet (11 m) high at the high end, tapering down to a height of 11 feet (3.4 m) for the last 500 feet (152.5 m). Translucent panels allow natural light to enter the facility, permitting observations to be made under daylight, as well as nighttime conditions. The facility also incorporates equipment for generating artificial fog of controlled density.

The indoor laboratory tests concentrated on determining the conspicuity of pairs of flashing lights, although retroreflectors and stop signs also were studied as add-ons to gate arms. Both incandescent bulbs and xenon flash tubes (strobe lights) were used as light sources, and included among the incandescent light units tested were standard 8-inch (20.3 cm) and 12-inch (30.5 cm) traffic signal heads. The primary variables investigated for the traffic signal heads were

1. COLOR: Red, blue, red and blue, orange, and amber flashing light pairs were tested.
2. FLASHRATE: Tested flashrates ranged from 40 to 120 cycles/minute, with a 50 percent duty cycle, for pairs of lights.
3. BRIGHTNESS: Luminance (brightness) levels used ranged from 275 to 1240 footlamberts (fL). This brightness range, below what one normally sees in steady-burning traffic signal lights, was necessary in order to test blue-filtered incandescent lights at a luminance level equivalent to that of amber-, orange- and red-filtered lights. That is, an incandescent bulb, rich in red wave lengths, is unable to transmit higher energy levels through blue lenses. The luminance values chosen were based on the recommendations of Fisher and Cole (2), as cited in Lunenfeld (3), as to the minimum luminance levels required for daytime viewing.
4. SIZE: Lights with 8-inch (20.3 cm) and 12-inch (30.5 cm) diameter lenses were compared. The lights in a pair were always of the same size.
5. PLACEMENT: Signal conspicuity at three positions was evaluated: "High Center" (17 feet (5.2 m) high, centered over the roadway), "High Right" (equally high, on the "right shoulder") and "Low Right" (9 feet (2.7 m) high, on the "right shoulder"). "Low Left" (on the "left shoulder") and "Low Center" positions also were used, but only as decoys. The various flashing light pairs were presented to the subjects in all positions during the course of the testing.

Some 150 drivers of both sexes and all ages served as subjects in the indoor laboratory tests. Nine subjects were tested per day, from 3PM to 11PM, and each viewed from 100 to 180 "displays". A "display" normally consisted of six "elements" - three pairs of flashing lights with each pair mounted on a separate post (left, center and right), and with a standard reflectorized highway sign mounted on each post below the flashing lights. No signs were used with the flashing lights when they were high mounted, because neither a high-mounted sign nor a large gap between the sign and the flashing light pair would have been appropriate.

In each display, only one pair of flashing lights was considered the primary target and the other two flashing light pairs and any post-mounted signs present served as "decoys". (The subjects were unaware of all this, of course.) Each day, nine subjects (plus two experimenters) were seated in a movable cabin structure, 8 x 16 feet (2.4 x 4.9 m) in size, that approached the display at a speed of approximately 5 mph (8 kph). When the subjects were approximately 450 feet (137 m) from the display, a shutter curtain automatically opened and closed, revealing the display to the subjects for a short time interval, which was varied from 1½ to 4½ seconds during the course of the study. (Short exposure times were used to simulate the time-stressed nature of real-world perception.) For each display presentation, each subject was instructed to record the single element of the display that most attracted or held his attention. This subjective judgement of conspicuity, or target value, then, was the dependent variable. Tests were conducted under daytime, nighttime and 475-foot (145 m) daytime fog conditions. For the nighttime tests, low-beam automobile headlights affixed to the subject cabin were turned on. In all instances, displays were viewed against either a noncompetitive rural or highly competitive urban background, the latter including a variety of lights, signs and/

opposing vehicle headlights (when appropriate). In the daytime fog tests, the flashing light pairs were not accompanied by reflectorized signs on the same posts, since these signs could not be seen at all at the distances at which they were viewed.

OVERALL RESULTS

Before discussing the experimental results specific to the size/intensity issue, it may be of value to understand some of the overall findings of the indoor laboratory tests. In brief, these results may be summarized as follows:

1. COLOR: Excluding white or clear unfiltered light, and with equal luminance for all colored lights, red is the most conspicuous daytime color and blue is the best nighttime color. Amber and orange are slightly better colors in daytime fog. These results are consistent with findings reported by Rumar (4).

2. FLASHRATE: Flashrates of 70 to 90 cycles/minute for alternately-flashing incandescent lights generally lead to greater conspicuity than either higher or lower flashrates.

3. BRIGHTNESS: Brightness increase yielded somewhat greater conspicuity during the daytime and in daytime fog conditions. At night, however, little difference in conspicuity was found, suggesting that even the lowest luminance level tested (275 fL) was more than adequate for detection and recognition.

4. SIZE: Increasing lens size from 8 inches (20.3 cm) to 12 inches (30.5 cm) increased conspicuity dramatically under all conditions, far more, proportionately, than did increasing the brightness (This is discussed in detail below.) When viewed at a distance of 450 feet (137 m), the size difference between the 8-inch (20.3 cm) and 12-inch (30.5 cm) signals was dramatic.

5. PLACEMENT: The "High Center" and "Low Right" positions were more conspicuous than the "High Right" position for all viewing conditions. "Low Right" placement was best for daytime fog conditions. (It should be mentioned that in the real-world situation, the "High Center" - i.e., cantilevered-position sometimes presents a difficult viewing situation to the motorist when the signal aligns with a row of streetlights in the distance.)

SIZE VERSUS LUMINANCE COMPARISONS

The overall indoor laboratory findings described above suggested the influence that size and luminance independently have on the conspicuity of flashing lights. However, they did not reveal the significant interaction that exists between these two critical variables, an interaction that has important implications for signal brightness standards and, ultimately, energy consumption. These implications go far beyond the findings given above, and in order to explore them further, separate indoor laboratory tests were conducted to study the interactive effects of light size and luminance.

Methodology

The conspicuity of pairs of alternatively-flashing red traffic signal lights was tested by comparing them with each other and with decoy targets (described above). Each pair of red lights was either 8 inches (20.3 cm) or 12 inches (30.5 cm) in diameter. Incandescent bulbs were used as light sources, and two luminance levels were used for each size: 620 fL or 1240 fL for the 8-inch (20.3 cm) and 275 fL or 550 fL for the 12-inch (30.5 cm) Each light pair was flashed at a rate of 55 cycles/minute (in keeping with current practice), with a 50 percent duty cycle. Three positions were used for placement of the light pairs: "Low Left", "Low Center" and "Low Right". Observations were made by 81 subjects, all of whom viewed the lights under daytime, nighttime and 475-foot (145 m) daytime fog conditions. Each display was revealed to the subjects for 3½ seconds, utilizing the same test procedure and apparatus as described above.

Results

Based on the frequency with which test subjects selected the target pair of flashing red lights as being the most attention-getting (and attention-holding) element of a display, the following results regarding the relative importance of luminance and size to target value were obtained:

1. Some increase in conspicuity resulted from doubling the luminance of the 12-inch (30.5 cm) heads from 275 fL to 550 fL under all three visibility conditions; however, this increase was not statistically significant (Chi-Square test).

2. A slight increase in conspicuity resulted from doubling the luminance of the 8-inch (20.3 cm) heads from 620 fL to 1240 fL under daytime and nighttime conditions, but once again, this increase was not statistically significant. There was, however, a significant increase in conspicuity (p=0.001) (the probability that the obtained difference in conspicuity occurred as a result of chance is less than one in a thousand) resulting from doubling the luminance of these smaller heads under daytime fog conditions.

3. Comparing the two signal sizes under different visibility conditions, as shown in Table 1, the results were quite consistent.

a. When viewed at night, the larger head had significantly higher target value than the smaller head regardless of their relative luminance levels. This was true even when the larger head, with 2.25 times the area of the smaller head, had only about 22 percent of the brightness (275 fL versus 1240 fL).

b. In daytime fog, the larger head at 275 fL and the smaller head at 1240 fL had approximately equivalent target value, with both targets being significantly more conspicuous than the smaller head at 620 fL. The larger head at 550 fL was significantly better than the smaller head at 620 fL, and slightly better than the smaller head at 1240 fL, but not significantly so.

c. Daytime results showed that conspicuity increased in the order: 8-inch (20.3 cm) at 620 fL, 8-inch (20.3 cm) at 1240 fL, 12-inch (30.5 cm) at 275 fL and 12-inch (30.5 cm) at 550 fL, although the differences between the two head sizes were not statistically significant for two of the comparisons.

Discussion of Results

It should be pointed out that in the daytime tests, the primary and decoy targets were viewed against a moderate-contrast background, without backplates, and although the "order of finish" of the four size/luminance combinations was the same as in the nighttime tests, the amplitude of the differences was much less in the daytime results. Although higher luminance levels were not tested, post project analysis of the data suggests that had higher luminance levels for both head sizes been used in the daytime tests, the results might well have been identical in significance to those obtained in the nighttime tests, since target lum-

TABLE 1: Traffic Signal Conspicuity as Related to Size, Intensity and Viewing Environment

SIZE/INTENSITY COMPARISONS	VIEWING ENVIRONMENT		
	NIGHTTIME	DAYTIME FOG	DAYTIME
8-inch (20.3 cm) @ 620 fL v. 12-inch (30.5 cm) @ 275 fL	12" better ($p \leq .02$)	12" better ($p \leq .004$)	12" better ($p \leq .10$)
8-inch @ 1240 fL v. 12-inch @ 275 fL	12" better ($p \leq .05$)	Both about the same	12" slightly better, but not signif.
8-inch @ 620 fL v. 12-inch @ 550 fL	12" better ($p \leq .005$)	12" better ($p \leq .001$)	12" better ($p \leq .05$)
8-inch @ 1240 fL v. 12-inch @ 550 fL	12" better ($p \leq .008$)	12" better, but not significant	12" slightly better, but not signif.

inance would have been further into the supra-threshold range, where the effects of size can more readily be isolated. Outdoor daytime testing with high background luminance levels in all likelihood would require even higher target brightness, plus the use of backplates, to produce results similar to those seen in nighttime viewing. It should be pointed out that the luminance levels used in the study were far below those recommended by the Institute of Traffic Engineers (5), and adopted by reference in the Manual on Uniform Traffic Control Devices (MUTCD) (6). The ITE standards call for 1411 fL for 8-inch (20.3 cm) and 1596 fL for 12-inch (30.5 cm) red signals. (These standards are given by ITE in candelas, but have been converted here to footlamberts, the measure of luminance used by most simple light-measuring devices.)

The results obtained in the study indicate that for daytime and nighttime there exist (different) supra-detection threshold values for the contrast between the light source and the "near" background such that any small increase in the luminance of the light source (such as doubling or tripling) will result in neglible improvement in the target value of the light source. Once the contrast exceeds this supra-detection threshold, increasing signal size is far more effective than increasing signal brightness as a means for improving target value. The nighttime data show that this contrast value was exceeded, while daytime results indicate that, without backplates, it was not. Daytime fog test results suggest that size, while more critical to target value than luminance, is, however, not completely dominant, as evidenced by the significant increase in target value resulting from doubling the luminance of the smaller, 8-inch (20.3 cm) head.

IMPLICATIONS OF THE FINDINGS

In recent years, the concept of dimming traffic signals as a means for conserving energy and reducing unwanted glare during hours of darkness has been given increasing consideration. For example, in 1974 Labrum (7) proposed replacing 8-inch (20.3 cm) signal heads with 12-inch (30.5 cm) heads for increased effectiveness, but suggested reducing bulb size in the 12-inch (30.5 cm) heads from the standard 150 watts to 100 watts, to save energy. (He recommended doing this for the yellow and green indications only, not for the red, because of the differential color sensitivity of the eye.)

Lunenfeld (3) suggested that while there are few instances in which the standard 8-inch (20.3 cm) signals should be dimmed at night, there are many more situations in which the 12-inch (30.5 cm) signal brightness can be reduced to the level of the smaller head without loss of an adequate margin of safety. He states that these decisions must be made on a location by location basis, taking into account such factors as background luminance and competition, geometric design and signal placement relative to the driver's line of sight. King (8) also feels strongly about signal placement, stating that it is the major element in signal effectiveness. This suggests that improved signal placement can be used together with signal dimming to reduce energy consumption without loss of signal effectiveness.

Fausch and Apeldorn (9) addressed the issue of glare, and recommended that all signal systems incorporate equipment that automatically adjusts signal brightness as a function of background luminance. A variety of such devices have been marketed for several years, and have been used by various governmental entities for dimming signal indications, despite the fact that the MUTCD provides no clear-cut authority for this and that criteria have yet to be developed that establish minimum signal luminance levels based on driver (and pedestrian) needs.

What has resulted is inconsistent, non-uniform application of a principle which appears sound, and in recognition of this, in 1978 the Federal Highway Administration indicated its desire to fund research in this area (RFP 413-8), citing the shortage and cost of energy and the possibility of glare from traffic signals at night, as well as the non-uniform application of signal-dimming techniques throughout the U.S., among the reasons why such research was needed. The FHWA project initially is to deal with driver/pedestrian requirements for the conspicuity, detection and recognition of signals in terms of their color, contrast, size and position in the visual field, and then is to concentrate on signal intensity using both 8-inch (20.3 cm) and 12-inch (30.5 cm) signal heads.

The FHWA research has not yet been accomplished; however, a significant headstart toward answering some of the critical questions addressed by the FHWA has been made by the study described in this paper, as well as by some of the other relevant research efforts completed to date. It would appear reasonable to make the following inferences from the research findings currently available:

1. As presently designed, once a supra-threshold contrast value has been attained, far greater conspicuity can be achieved by using 12-inch (30.5 cm) instead of 8-inch (20.3 cm) signal heads for the same or less expenditure of energy. This does not mean that the larger heads should automatically be used in all situations since, as King (8) suggests, it may be advisable to have a mix of signal head sizes, reserving the larger head sizes for the red indication, where more impact is desired.

2. If we can assume that the results of the present study, which used flashing lights, can be extended to steady-burning traffic signals, then there is no question but that the standard 150-watt bulb used in 12-inch (30.5 cm) signal heads is consuming excessive electrical energy during hours of darkness, with miniscule target value advantage over the same head in a dimmed operation. There is some question as to the value to conspicuity of powering 12-inch (30.5 cm) signal heads with 150-watt bulbs at any time; that is, if they are needed for driver detection in bright daylight, then clearly the standard 8-inch (20.3 cm), 60-watt head has to be seriously deficient in the same application.

3. Signal dimming is feasible; signals at night are often too bright, but additional research is needed to establish the exact values for required luminance in daytime in relation to size, and the degree of dimming permissible at night.

4. It is likely that energy savings can be accomplished along with both an increase in conspicuity and a decrease in glare, by manipulating size, intensity and placement of signal heads. However, it will be necessary to study each case individually, and take into account background, highway geometry and other factors.

5. It is likely that the costs associated with conversion to the larger head sizes will, in the long run, be more than offset by energy cost savings (let alone the absolute reduction in energy consumption as a social goal). This cannot be confirmed, of course, without a cost-benefit evaluation; however, if energy costs continue to rise and energy supplies become more critical, whether or not the conversion to larger head sizes will "pay for itself" may become immaterial.

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