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Evaluation of Alternative Sign-Lighting Systems To Reduce Operating and Maintenance Costs

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The study objective was to identify a sign-lighting system that has a lower electric power cost and reduced maintenance requirements and that provides adequately for the motorists' needs in terms of legibility and illumination level. Twenty-five candidate lighting systems were identified through a review of technical data and specifications for lamps and fixtures by an independent lighting expert. Photometric tests and computer analyses of sign illumination levels reduced the number of candidates to 10 alternative systems, which were then field tested. Each alternative lighting system was field tested for 10 to 14 months. Sign luminance was measured with a telephotometer. Power consumption was monitored. Maintenance requirements and lamp life were noted. A human factors study determined legibility distance and rated viewing comfort, lighting uniformity, and color rendition. An economic analysis was performed in which the initial cost of acquiring and installing the lighting systems and annual costs for electric power, washing, relamping, and ballast replacement were considered. A lighting system using the high-pressure sodium light source was recommended. Compared with the existing com-

monly used fluorescent system, it uses one-third as much electric power and has about one-third of the annual owning and operating costs. The recommended system has a satisfactory illumination level and provides the best legibility distance of the 10 systems tested.

During the past 5 years interest has been increasing nationwide in overhead guide-sign lighting because of the increasing cost of the energy to provide illumination. In California, for example, the annual cost of electric power to illuminate overhead signs on the freeway system increased from \$993,000 in FY 1977-1978 to \$2,200,000 in FY 1982-1983 (W.A.J. Hoverstern, California Department of Transportation, unpublished data, June 1985). The nationwide cost of power for overhead sign lighting (for all overhead signs on all roadway systems) was estimated to be about \$20 million annually in 1986.

In addition to the cost of electric power, highway agencies are also concerned about the maintenance costs and labor requirements for sign-lighting systems. California's annual maintenance cost for its overhead signs is \$800,000 per year

(W.A.J. Hoverstern, California Department of Transportation, unpublished data, June 1985). Resources are scarce and the monies and manpower available to highway agencies have been declining in real terms. Thus, with increasing operating and maintenance costs and limited resources there is a need to stretch dollars further and reduce manpower needs.

Although cost reduction is important, overhead sign-lighting systems must also serve the needs of the motorist. Signing must be sufficiently visible and allow the driver adequate time to respond. These factors led the Arizona Department of Transportation (ADOT) to initiate a research project designed to identify lighting systems that would be more power efficient, require less maintenance, and, at the same time, satisfy the needs of the motorist.

RESEARCH APPROACH

Introduction

The whole issue of overhead guide-sign visibility at night is quite complex. There are a tremendous number of variables that affect what the motorist sees:

The Sign

- Type of sign materials used for the legend and background and their luminance or reflectivity
- Contrast between the legend and the background
- Color of sign background
- Age of sign material (sign material deterioration)
- Dirt, dust, and road film accumulated on the sign
- Presence of rainwater, dew, or frost on the sign
- Size of letters in legend

Illumination

- Illuminated versus nonilluminated
- Type of light source
- Illuminance level
- Color rendition
- Presence of ambient lighting (surround luminance)
- Presence of glare sources behind sign or other competitive background lighting

Environmental Factors

- Snow, rain, fog, haze, blowing dust

The Vehicle

- Headlight characteristics (e.g., photometry, aim, clean or dirty, wet with rainwater)
- Windshield characteristics (e.g., tinted glass, clean or dirty, wet with rainwater)

Roadway Geometry

- Sign orientation (Perpendicular to road? Does road have horizontally or vertically curved alignment?)

The Motorist

- Observer visual characteristics (e.g., night vision, which is a function of age)

Other Factors

- Use of high-beam or low-beam headlamps
- Traffic volume (heavy stream of traffic provides more headlight illumination than a single vehicle)
- Vehicle position (lane position and distance from sign)
- Blockage of view by other vehicles (e.g., trucks)

There are additional factors that affect sign legibility requirements:

- Time required for the driver to recognize a sign, read it, and react to it;
- Length or complexity of the message on the sign;
- Vehicle speed (determines viewing time available); and
- Kind of response required of the motorist (immediate response or delayed reaction?).

These variables greatly complicate the task of quantifying the motorists' needs and complicate the development of a research approach to solve the sign-lighting problem.

To simplify the research problem and make the research project more manageable, two basic tenets were accepted:

1. The requirement in the *Manual on Uniform Traffic Control Devices* (MUTCD) (1) that overhead signs on freeways be illuminated or have a reflectorized background was accepted. The study was limited to illuminated signs.
2. Existing sign-lighting standards published by the Illuminating Engineering Society (IES) (2) and AASHTO (3) were accepted. A decision was made to develop lighting systems that met these standards.

An additional issue was color rendition. The MUTCD (1) requires that regulatory and warning signs show the same color by day and by night when illuminated. It does not require that guide signs have good color rendition. AASHTO's guide (3) states that "the light source . . . [should] . . . preserve the colors on the sign." Unlike the MUTCD, the AASHTO guide is only advisory; it is not a legal requirement.

The issue of color rendition is important because some light sources (high-pressure sodium, low-pressure sodium) do not provide good color rendition. Assessment of the need to see green at night is highly subjective and there is a great diversity of opinion. A decision was made to include light sources (high-pressure sodium and low-pressure sodium) that provide poor color rendition in the alternative lighting systems considered.

Study Objectives

The principal objective of the study was to identify a lighting system that has a lower power cost and reduced maintenance requirements compared with those of currently used lighting sources and that provides adequately for the motorists' needs in terms of color rendition and illuminance level.

Each of the light sources or lighting systems was evaluated on the following bases:

1. Illuminance level: compared with AASHTO and IES guides;
2. Economics: costs of lamps, fixtures, installation, electric power, and maintenance;
3. Maintenance required: person hours for installation, washing, cleaning, lamp replacement, and other maintenance;
4. Lamp life;
5. Legibility: the distance from which a sign is legible when illuminated;

6. Color rendition: a subjective assessment;
7. Light uniformity (whether the sign is uniformly lit): an assessment (a) in comparison with AASHTO and IES guides and (b) subjectively by human observers;
8. Viewing comfort: an assessment of glare or harshness due to brightness of a sign in a dark environment.

It was recognized at the beginning of the study that, potentially, there are a very large number of alternative sign-lighting systems. A system is composed of a light source, a lamp of a given size, a fixture, the ballast, and a specific number of lamps and fixtures. With approximately six principal light sources, roughly five lamp sizes for each source, several different fixtures on the market, and various numbers of lamps and fixtures that could be used to light one sign, the potential number of lighting systems available could easily be more than 100. A summary of the choices available follows.

Light Source

- Fluorescent (the standard light source now used by ADOT)
- Mercury vapor (available in a "clear" and a "deluxe" version)
- Metal halide (available in a "clear" and a "color-improved" version)
- High-pressure sodium (available in a "clear" and a "color-improved" version)
- Low-pressure sodium

Lamp Size

- Each light source is available in several sizes (wattages) and lamp configurations

Fixture

- Various manufacturers market a variety of fixtures. Design of the fixtures varies considerably. Design of the reflector (behind the lamp) and the refractor (the glass cover or lens in front of the lamp) can have a dramatic effect on the ability of the fixture to distribute light over a sign panel. One type of fixture is used for the long, narrow fluorescent lamp. A second type generally can be used for most high-intensity discharge (mercury vapor, metal halide, high-pressure sodium) lamps.

Ballast

- A variety of ballasts are available on the market for use with specific light sources and lamp sizes. The ballasts vary in efficiency.

Number of Lamps and Fixtures

- A given size of sign panel can be illuminated by using one, two, three, or more lamps and fixtures. The choice of number of lamps and fixtures affects the level of illuminance (footcandles), light uniformity, and economics of installation and operation.

The performance of an individual sign-lighting system is dependent on the choices made in the foregoing list. There were a very large number of possible combinations of light source, lamp size, fixture, ballast, and number of lamps and fixtures that could potentially serve in a sign-lighting system.

The challenge of the study was to weed out the lesser systems and identify the best one. This was done through a three-step process. Each succeeding step was more detailed and

rigorous than the previous step. The three steps were a preliminary evaluation, a laboratory evaluation, and field testing.

TESTING OF ALTERNATIVE LIGHTING SYSTEMS

Preliminary Evaluation

As noted, a large number of lighting systems were potentially available on the market. As a preliminary evaluation the whole range of alternatives was evaluated in terms of their ability to meet IES recommended illuminance levels for typical sign sizes, their ability to be competitive from the standpoint of power use, and their ability to be competitive from an overall economic standpoint. This evaluation was conducted by reviewing the technical data and specifications available for lamps and fixtures and through a subjective review. Contenders that did not meet the evaluation criteria were eliminated. This preliminary evaluation reduced the number of alternatives to 25.

Laboratory Evaluation

As a second step, each of the 25 systems underwent a laboratory evaluation. Photometric tests quantified the illuminance levels. Computer analysis of the photometric test results, using a program named SITESITE, predicted the illumination level that each alternative would provide on a typical sign face having dimensions of 8 ft high by 21 ft wide.

A review of the SITESITE computer analyses allowed a further reduction in alternatives. Alternatives were rejected if they did not provide illuminance levels as recommended by the IES, if they provided uneven light distribution, or if adequate illumination could be provided by a smaller-wattage lamp. The IES standards state that signs located in "medium" ambient light locations should have an average of 20 to 40 footcandles of illumination maintained. Alternatives were rejected if they did not provide an average of 20 footcandles of illumination maintained. In some instances it was apparent that a smaller-wattage lamp would provide adequate illumination. In these cases the smaller-wattage lamp was used in subsequent field testing.

As a result of the foregoing analysis, the number of alternatives for field testing was reduced to 10 (including the standard ADOT fluorescent lighting system). These 10 remaining alternatives were then subjected to field testing. A list of the 10 systems selected for field testing is given in Table 1.

Another element of the preliminary evaluation was an inventory of sign panel sizes. Sign panel dimensions are important in determining the performance of a sign-lighting system. A system that performs well on a small sign may perform poorly on a large sign. Conversely, a sign-lighting system that performs well on a large sign may provide illumination "overkill" and waste electric power on a small sign. For these reasons an inventory of existing sign panel sizes on the ADOT roadway network was compiled early in the study.

Great variability was discovered regarding sign dimensions. No standardization of sign panel sizes was discovered. In fact, the 355 sign panels measured represented 117 different sign panel sizes. The significant findings are as follows:

- Lengths varied from 6 to 28 ft,
- Heights varied from 5 to 14 ft,
- Length of 90 percent of all signs was between 8 and 21 ft, and
- Height of 94 percent of all signs was between 6 and 12 ft.

FIELD TESTING

Ten sites were selected for field testing on an 11-mile-long freeway segment in the Phoenix urban area. The sign sizes at each test site were representative of the total sign population and each was approximately 8 ft high and 20 ft wide. With one exception, all sites had porcelain enamel backgrounds [the tenth site (System 2) had a high-intensity reflective sheeting background]. The legends were all white porcelain enamel with reflector buttons. With one exception all signs were interchange sequence signs having three lines of legend. The lighting systems to be tested were installed, and wiring modifications were made to allow power consumption to be monitored during field testing. Following installation, each lighting system was field tested for a period of 10 to 14 months.

Sign Luminance

One aspect of field testing was the measurement of sign luminance. Photometric tests and the SITELITE computer program described previously were employed to predict sign illuminance (the amount of light shining onto the sign face). Sign luminance is the amount of light coming from the sign face. In general, luminance is related to illuminance but is also affected by the amount of light reflected by the sign material (dependent on color and surface characteristics), the angle of incidence of the illuminance on the sign face, and the position of the observer or measuring instrument with respect to the sign.

Sign luminance data were obtained for three purposes: to compare actual field performance with IES recommended luminance levels, to compare the actual performance of individual lighting systems with one another, and to compare actual performance (based on luminance) with predicted performance (based on illuminance) by the SITELITE program.

Luminance was measured by using a Spectra Pritchard photometer, Model 1980. The IES *Guide for Photometric Measurements of Roadway Sign Installations* (4) was followed. Measurements were recorded every 2 ft across the horizontal axis of the sign face, and every 1 ft on the vertical axis. Data were recorded on a segmented chart representing the sign face (see Table 3) for both the white legend and the green background.

Telephotometer readings were compared with IES standards. Each of the 10 lighting systems was designed, on the basis of SITELITE program evaluations, to provide an average of at least 20 footcandles of illuminance on an 8-ft-high by 20-ft-wide sign panel. The 20-footcandle value meets the IES standard for medium ambient lighting conditions. The IES standard also prescribes required luminance (reflected illumination) levels for the white legend. This value is 14 footlamberts and it assumes that white sign letters will reflect 70 percent of the illuminance. Therefore, field performance (telephotometer readings) was compared with the IES standard of 14 footlamberts.

Data on measured luminance for each of the 10 lighting systems are presented in Table 2. The values are estimates of the average luminance over the entire sign face based on telephotometer measurements of the legend. Measured luminance ranged from 10.6 footlamberts on System 5 to 20.9 footlamberts on System 7. If the IES luminance standard of 14.0 footlamberts is applied rigorously, three lighting systems fail to meet that standard. It is the opinion of the principal investigator that the IES standard is a broad guideline to be followed and that small deviations from that guideline have insignificant effects on visibility. As described later, two of the

TABLE 1 ALTERNATIVE SYSTEMS SELECTED FOR FIELD TESTING

System Number	Light Source	Lamp Size	Fixture (Manufacturer and Model)	Number of Fixtures	Predicted Average Footcandles *	Predicted Uniformity *
1	Fluorescent	800 milliwatt	Nu-Art NAFL	3 fixtures 6 lamps	20.1	4.1:1
2	Clear Metal Halide	175 watt	Holophane Expresslite	2	28.1	6.5:1
4	Clear High Pressure Sodium	70 watt	Guth Signlitter	2	33.7	7.3:1
5	Clear Metal Halide	175 watt	Guth Signlitter	2	47.6	7.5:1
6	Clear High Pressure Sodium	70 watt	General Electric Versaflood II	2	26.4	7.5:1
7	Clear Metal Halide	175 watt	General Electric Versaflood II	2	47.3	6.1:1
8	Low Pressure Sodium	35 watt	Holophane Expresslite	3	27.2	3.8:1
10	Clear High Pressure Sodium	150 watt	Holophane Panel-Vue	1	23.3	5.9:1
11	Clear Metal Halide	175 watt	Holophane Panel-Vue	1	22.1	
12	Clear Mercury Vapor	250 watt	Holophane Panel-Vue	1	22.3	

*The values given are the overall average footcandles of illumination and the uniformity ratio predicted by the SITELITE program for an 8 foot high by 20 foot wide sign. Uniformity ratio is based on the maximum and minimum foot-candle values for 1 foot squares.

TABLE 2 FIELD PERFORMANCE: LUMINANCE AND UNIFORMITY RATIO

Lighting System ¹	Predicted Luminance (Foot-Lamberts) ²	Measured Luminance (Foot-Lamberts) ³	Uniformity Ratio ⁴
1	14.0	18.8	3.3:1
2	19.7	approx. 12.	5.5:1
4	23.6	approx. 17.5	8.0:1
5	33.3	10.6	6.4:1
6	18.5	approx. 20.	3.4:1
7	33.1	20.9	5.9:1
8	20.5	20.6	6.0:1
10	16.3	11.9	3.3:1
11	15.5	14.0	5.0:1
12	15.6	16.7	4.3:1

¹See Table 1 for a description of each lighting system.

²Predicted Luminance is the predicted overall luminance for a white legend. It is based on the predicted overall illuminance level from the SITELITE program multiplied by 0.7.

³Estimated overall luminance based on telephotometer measurements of the legend.

⁴Uniformity Ratio is based on telephotometer readings. These are estimates only.

systems that had measured luminance of less than 14 footlamberts (Systems 2 and 10) had the best legibility distances in the observer study.

Luminance measurements were also used to determine the uniformity ratio for each sign-lighting system. The uniformity ratio is the ratio of the brightest luminance to the darkest luminance on the sign face. The IES standard states that this ratio should not exceed 6:1. In Table 2 estimated uniformity ratios based on telephotometer readings are presented. The best uniformity ratio was 3.3:1, and the worst was 8.0:1. Two lighting systems exceeded the 6:1 standard.

A comparison of actual performance in the field (based on luminance) to predicted performance (based on illuminance) by the SITELITE program shows mixed results. Comparisons were made of average luminance levels as shown in Table 2 and for individual points on the sign face as shown in Table 3. Some lighting systems showed good agreement between field performance and predicted performance. Lighting Systems 8, 11, and 12 are good examples. Other lighting systems showed poor agreement, notably Systems 2, 5, and 7.

Poor agreement could result from several factors: a higher-than-expected degradation in lamp light output, a greater-than-expected accumulation of dust and dirt on the fixtures, the possibility that lamps used in the laboratory photometric tests were not ordinary lamps, instrumentation errors, sign legend materials that reflect more than or less than 70 percent of the incident illuminance, the angle of incidence of the illuminance, and others. Although any of these factors could have resulted in poor agreement, none was identified as being a definite contributor.

Table 3 shows a comparison of the field performance and predicted performance for individual points on a sign face. The data presented are for System 1.

Telephotometer readings were used to determine one other parameter—the contrast between the white legend and the green background. Luminance of the white legend was generally 10 times the luminance of the green background.

Observer Studies

An important element of field testing was the evaluation of legibility distance, viewing comfort, lighting uniformity, and color rendition provided by each sign-lighting system. These four characteristics are defined as follows:

1. *Legibility distance*: the distance from which the sign can be read.

2. *Viewing comfort*: effect of brightness of the light source; discomfort in viewing may occur as the motorist approaches the sign, because of the bright light, or just after he has passed the sign, because of the sudden change from a brightly lit to a dark environment. An analogy would be the discomfort experienced when one drives out of a dark tunnel into bright sunlight or when one drives from bright sunlight into a dark tunnel.

3. *Lighting uniformity*: the range between bright spots and dark spots on the sign.

4. *Color rendition*: the presence or absence of color distortion. With certain light sources, notably, high-pressure sodium

TABLE 3 COMPARISON OF LUMINANCE MEASUREMENTS IN FIELD WITH SITELITE PREDICTION

COLUMN										
	1	2	3	4	5	6	7	8	9	10
1										
2	10.3	14.0	16.0	17.5	19.7				16.4	13.1
3	7.4	9.2	10.4	11.1	11.5				9.2	7.4
4										
5	13.1	16.7	19.7	23.0	25.0	27.0	27.0	26.0	25.0	12.3
6	11.6	14.8	16.5	17.4	17.9	17.9	17.4	16.5	14.8	11.6
7										
8	11.5	15.7	17.4	21.0	23.0				23.0	16.5
9	12.6	16.8	17.9	18.3	19.0				16.8	12.6
10										

Notes: The above matrix represents an 8 foot high by 20 foot wide sign

Each row is 1 foot high; each column is 2 feet wide.

Data are presented for Lighting System 1.

The value in the upper left of each cell is the luminance (in foot-lamberts) measured in the field for the white legend.

The value in the lower right of each cell is the predicted luminance (in foot-lamberts) for a white legend. It is based on the predicted illumination level from the SITELITE program multiplied by 0.7.

and low-pressure sodium, the sign colors appear much different in the nighttime than they do in the daytime.

The foregoing characteristics were evaluated with an observer study. Details of the methodology used in the observer study are not presented in this paper, for the purpose of brevity. The details are documented in the project final report (5). The major findings of the observer study are noted as follows.

Two different groups of observers were used. The first group was composed of hired observers, subdivided into two age groups—a group of young adults ranging in age from 18 to 33 and a group of senior citizens ranging in age from 61 to 86. The second group was composed of transportation professionals. Forty-three observers participated.

The average legibility distance for all hired observers for the 10 sign-lighting systems was 862 ft. The average legibility

TABLE 4 LEGIBILITY DISTANCE

Legibility Distance (Feet)				
Lighting System ¹	Young Adult Group		Senior Citizen Group	
	Standard		Standard	
	Mean	Deviation	Mean	Deviation
1	899	214	802	148
2	924	215	897	231
4	873	188	794	257
5	850	250	839	200
6	912	252	811	199
7	842	214	861	178
8	820	228	856	193
10	952	251	912	261
11	*		832	194
12	837	234	835	203

* System not operational during testing of this group

¹ See Table 1 for a description of lighting systems 1, 2, 4, 5, 6, 7, 8, 10, 11 and 12.

NOTE: Four different tests for statistical significance show that there is no statistically significant difference in legibility distance between any two lighting systems (95% level of confidence).

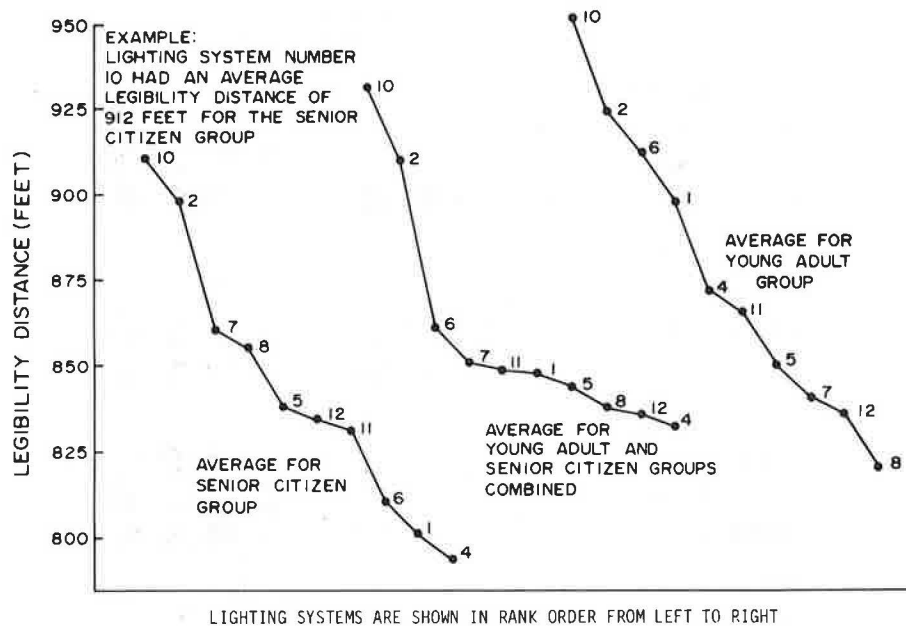


FIGURE 1 Legibility distances of lighting systems by group.

distance for the senior citizens was 844 ft; for the young adults it was 879 ft. In comparing the various lighting systems, the legibility distance ranged from a low of 794 ft for the senior citizens on System 4 to a high of 952 ft for the young adults on System 10 (see Table 4). The legibility distance of a specific lighting system generally tended to fluctuate greatly from observer to observer, as shown by the standard deviation.

As indicated in Figure 1, legibility distance varies little between lighting systems. Tests for statistical significance show that there is no statistically significant difference in legibility distance between any two lighting systems (95 percent level of confidence). The time span between the greatest and the shortest legibility distance is only 1.96 sec. Noteworthy, however, is that both Systems 10 and 2 consistently had noticeably greater legibility distances than the other lighting systems tested (1.03 sec and 0.61 sec, respectively) when compared with the standard fluorescent lighting system (System 1). System 10 had the greatest legibility distance, with an average of 932 ft.

All 10 lighting systems provided luminance levels within a relatively narrow range. Luminance levels generally meet the IES guidelines for medium ambient light conditions. Two systems with lower luminance levels were found to have the best legibility distance in the observer study. On the basis of these results, all 10 lighting systems provide satisfactory luminance levels.

For the characteristics of viewing comfort, lighting uniformity, and color rendition the observers rated individual signs as excellent, good, marginal, poor, and abysmal. These ratings were converted to a numerical scale (excellent = 5, abysmal = 1) so that a quantitative average score could be determined for each characteristic. Significant differences between lighting systems were found as shown in Figure 2.

Lamp Life

Lamp life is important because it determines how often maintenance is required. The costs of manpower and equipment

(trucks) to perform maintenance is significant; the longer the time interval between routine maintenance visits, the less the maintenance costs will be.

The 1-year field test period used in this study was not long enough to make conclusions about lamp life, because the life of all lamps tested exceeded 1 year. As a result, comparisons of lamp life can be based only on manufacturer claims. The values for lamps tested in this study are as follows:

Lamp	Size	Life (hr)
Fluorescent	800 mAmp	18,000
Clear mercury vapor	250 W	~28,000
Clear metal halide	175 W	10,000
Clear high-pressure sodium	70, 150 W	~28,000
Low-pressure sodium	35 W	18,000

The lamp-life values represent the average life for a random sample of lamps. Fifty percent will fail in less than the lamp-life values given.

ADOT's practice is to use a group replacement program with a replacement period short enough so that nearly all lamps are replaced before they fail. Sign-lighting lamps are lit for about 4,000 hr a year. ADOT uses a 2-year replacement period for fluorescent lamps, which results in an age of about 8,000 hr when lamps are replaced (compared with an 18,000-hr average life).

On the basis of the manufacturer claims of lamp life, the following intervals between group relamping were established for use in an economic analysis of each lighting system:

Lamp	Interval (years)
Fluorescent	2
Clear mercury vapor	3
Clear metal halide	1
Clear high-pressure sodium	3
Low-pressure sodium	2

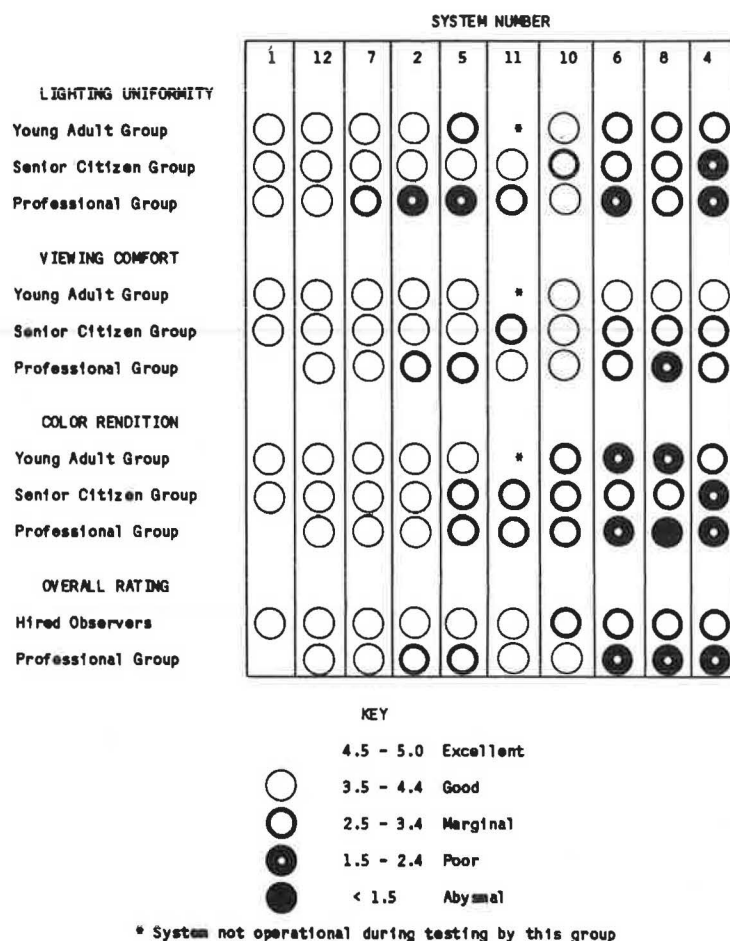


FIGURE 2 Observer ratings of lighting uniformity, viewing comfort, and color rendition.

Maintenance

During field testing ADOT's personnel kept detailed records of any maintenance required at the 10 field test sites. Maintenance was required at some test sites, but a careful review showed that, in each case, it was required by a malfunction external to the lighting system. All 10 systems performed equally well in that they did not require maintenance.

Power Consumption

During field testing, power consumption for each of the lighting systems was monitored monthly by using a wattmeter. The levels of energy consumption by the various lighting systems demonstrated little fluctuation over time. Although low-pressure sodium lamps are characterized by a gradual increase in power consumption over time, no trend was shown by the data.

Table 5 and Figure 3 present data on the power consumption by each lighting system. The current ADOT lighting system, which uses a fluorescent lamp, is represented as System 1. It had the highest level of energy consumption with an overall average of 531 W. This is in sharp contrast with the three most energy-efficient lighting systems (System 4, 183 W; System 10,

158 W; and System 6, 148 W). Each of these systems used a high-pressure sodium lamp.

ECONOMIC ANALYSIS

An economic analysis was performed to compare the 10 sign-lighting systems. The initial costs for fixtures and lamps and the labor and equipment for installation as well as the annual operating costs for electricity, washing, relamping, and ballast replacement were considered. The cost information used in the economic analysis is given in Table 6. The following points describe various inputs to the economic analysis.

- Prices for fixtures, lamps, and ballast replacement were obtained from local suppliers for purchases in both large and small quantities. (The values in Table 6 are for large quantities.)
- Installation cost was based on an ADOT estimate of the amount of time required to install fixtures. An ADOT labor rate of \$17.86/hr and an equipment rate (for a truck) of \$10.50/hr were used to calculate cost.
- A 10 percent interest rate was used.
- On the basis of ADOT experience with fluorescent lighting systems, all lighting systems were estimated to have a

TABLE 5 POWER CONSUMPTION

System Number	Light Source	Lamp Size	Fixture	Power Consumption (watts)	Power Consumption Compared to Standard Fluorescent System (Percent)
1	Fluorescent	800 milli-amp	Nu-Art NAFL	531	100
2	Clear Metal Halide	175 watt	Holophane Expresslite	385	73
4	Clear High Pressure Sodium	70 watt	Guth Sign-lite	183	35
5	Clear Metal Halide	175 watt	Guth Sign-lite	376	71
6	Clear High Pressure Sodium	70 watt	General Electric Versaflood II	148	28
7	Clear Metal Halide	175 watt	General Electric Versaflood II	432	81
8	Low Pressure Sodium	35 watt	Holophane Expresslite	289	54
10	Clear High Pressure Sodium	150 watt	Holophane Panel-Vue	158	30
11	Clear Metal Halide	175 watt	Holophane Panel-Vue	262	49
12	Clear Mercury Vapor	250 watt	Holophane Panel-Vue	282	53

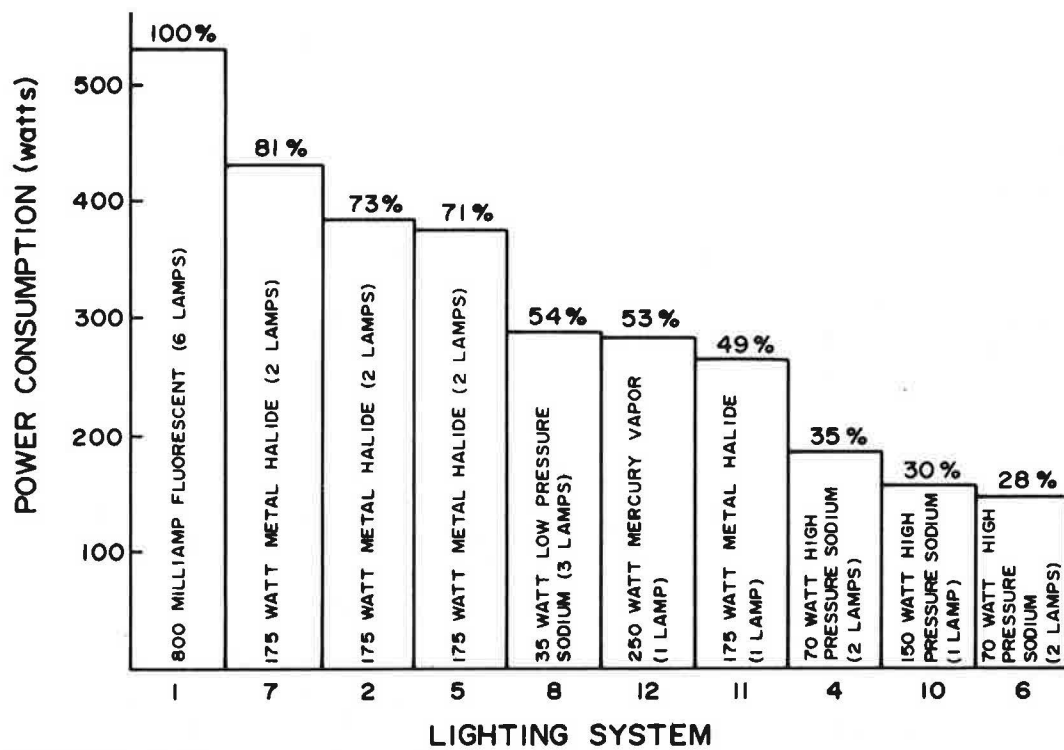


FIGURE 3 Relative power consumption.

TABLE 6 COST INFORMATION USED IN ECONOMIC ANALYSIS

System Number	10	12	11	6	4	8	5	2	7	1
Number of Fixtures	1	1	1	2	2	3	2	2	2	3
Cost per Fixture (includes ballast) (\$)	175.00	175.00	175.00	233.33	185.00	150.00	175.00	150.00	206.67	330.00
Installation Cost per Fixture (\$)	46.22	46.22	46.22	46.22	46.22	46.22	46.22	46.22	46.22	46.22
Number of Lamps per Fixture	1	1	1	1	1	1	1	1	1	2
Total Number of Lamps	1	1	1	2	2	3	2	2	2	6
Cost per Lamp (\$)	33.55	20.79	27.23	31.08	31.08	10.80	27.23	27.23	27.23	5.06
Interest Rate (%)	10.	10.	10.	10.	10.	10.	10.	10.	10.	10.
System Life (Years)	20	20	20	20	20	20	20	20	20	20
Salvage Value (% of Initial Cost)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Power Consumption (Watts per Fixture)	158.	282.	262.	74.	92.	96.	188.	193.	216.	177.
Annual Operating Hours	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Power Price per Kilowatt-Hour (¢)	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Energy Cost Escalator (percent per year)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Maintenance Labor Rate (\$ per Hour)	17.86	17.86	17.86	17.86	17.86	17.86	17.86	17.86	17.86	17.86
Time Required to Wash Lamp and Fixture or to Replace Lamp and Wash Fixture (Hours/Fixture)*	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Equipment Rate (Truck for Crew)(\$ per Hour)	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50
Time Between Washings (Years)	1.5	1.5	1.0	1.5	1.5	1.0	1.0	1.0	1.0	1.0
Time Between Group Relamping (Years)	3.0	3.0	1.0	3.0	3.0	2.0	1.0	1.0	1.0	2.0
Number of Ballasts per Fixture	1	1	1	1	1	1	1	1	1	2
Estimated Ballast Life (Years)	12	12	12	12	12	12	12	12	12	12
Ballast Material Replacement Cost (\$)	76.00	72.00	73.00	30.75	50.00	82.96	50.00	80.00	39.09	45.00
Time Required to Replace Ballast (Hours/Fixture)*	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

* 2 person crew for washing and relamping
1 person crew for ballast replacement

useful life of 20 years. The salvage value was assumed to be nil.

- Power consumption was based on actual experience during field testing. Annual operating time was 4,000 hr.

- ADOT currently purchases electric power at a weighted average cost of 8.5 cents/kW-hr.

- It was assumed that the cost of electric power would escalate no faster than the cost of labor and replacement parts.

- Current ADOT labor and equipment rates were also used for washing, relamping, and ballast replacement functions.

- The time required to wash fixtures and to relamp was estimated on the basis of ADOT's experience with fluorescent lighting systems.

- On the basis of ADOT's past practice of group relamping, this same practice was applied to all 10 lighting systems. The frequency of relamping was based on lamp life.

- The frequency of washing was based on the frequency of relamping and ADOT's past experience with dirt accumulation and washing needs.

- Based on manufacturer claims, a 12-year ballast life was

established for all systems. The time for ballast replacement was based on an ADOT estimate.

The computer program COSTLITE was used to calculate annual costs. The results for each of the 10 lighting systems are given in Table 7. COSTLITE calculates costs as follows:

Initial cost: Costs for a system's fixtures and lamps and their installation are determined.

Annual owning cost: A capital recovery factor for a 10 percent interest rate and a 20-year lifetime is applied to the initial cost.

Annual power cost: Power cost is based on consumption, hours of operation, and power price.

Annual washing cost: Washing cost is the time required multiplied by the labor and equipment rates and divided by the washing frequency.

Annual lamp replacement cost: Lamp replacement is lamp cost divided by the replacement period. Labor and equipment costs for lamp replacement are included in washing cost.

Annual ballast replacement cost: Ballast replacement is the time required multiplied by the labor and equipment rates. Ballast material replacement cost is added. The total is divided by the estimated ballast life.

Annual operating cost: Annual operating cost is the sum of the four preceding items. For none of these four items are increases in costs of labor, equipment, lamps, and ballast in future years considered. All annual costs are based on current prices.

Total annual owning and operating cost is the sum of *annual owning cost* and *annual operating cost*.

Review of Table 7 shows great differences in the annual costs of the 10 lighting systems (they are ranked in order of total annual costs). Total annual costs range from \$115 per year to \$423 per year. The following observations explain some of the dramatic differences in annual cost:

- Systems 10, 11, and 12 use only one fixture to illuminate a sign 8 ft high by 20 ft wide. Initial cost is considerably less than that for other systems. Conversely, System 1 requires three lighting fixtures and has a high initial cost.

- Systems 8, 5, 2, 7, and 1 have much higher annual operating costs. Four factors contribute to this: (a) these systems have higher power consumption, (b) they all require annual washing, (c) they have shorter lamp life than most of the other systems, and (d) the annual ballast replacement cost tends to be higher than that of the other systems.

It is emphasized that the cost information presented in Table 7 is for lighting a sign 20 ft wide. Systems 6, 4, 8, 5, 2, and 7 use two fixtures to light a sign of this width. For narrow signs these systems would be adequate with one fixture, and annual cost would be cut in half. For Systems 6 and 4 this would mean that the annual cost (approximately \$90) would be even less than that of System 10.

The discussion thus far has compared the annual cost of 10 different lighting systems for new installations. The existing fluorescent system is inferior to all of the other nine alternatives, but it is also important to evaluate the economics of allowing the existing fluorescent lighting systems to remain in place versus replacing them with a different system. The last column in Table 7 shows the annual cost of operating an

TABLE 7 INITIAL COST, ANNUAL OWNING COST, AND ANNUAL OPERATING COST FOR EACH LIGHTING SYSTEM

System Number	10	12	11	6	4	8	5	2	7	1	**
Initial Cost	\$254.77	\$242.01	\$248.45	\$621.26	\$524.60	\$621.06	\$496.90	\$446.90	\$560.24	\$1159.02	\$0.00
Annual Owning Cost	29.93	28.43	29.18	72.97	61.62	72.95	58.37	52.49	65.81	136.14	0.00
Annual Power Cost	50.56	90.24	83.84	47.36	58.88	92.16	120.32	123.52	138.24	169.92	169.92
Annual Washing Cost	15.13	15.13	22.69	30.25	30.25	68.06	45.38	45.38	45.38	68.06	68.06
Annual Lamp Replacement Cost	11.18	6.93	27.23	20.72	20.72	16.20	54.46	54.46	54.46	15.18	15.18
Annual Ballast Replacement Cost	8.22	7.89	7.97	8.91	12.11	26.41	12.11	17.11	10.30	33.84	40.61
Annual Operating Cost	85.09	120.19	141.73	107.24	121.97	202.84	232.27	240.47	248.37	287.01	293.78
Total Annual Owning and Operating Cost	\$115.02	\$148.61	\$170.91	\$180.21	\$183.58	\$275.79	\$290.64	\$292.96	\$314.18	\$423.15	\$293.78

The costs shown are those for illuminating an 8 foot high by 20 foot wide sign. Systems are ranked in order of Total Annual Owning and Operating Cost.

** See Text

existing fluorescent system. It treats the initial cost of the system as a sunk cost that has already been expended and for which there is no annual owning cost. On the basis of information provided by ADOT, an average age of 10 years and a remaining useful life of 10 years is assumed. An annual operating cost of \$294 is shown, a value nearly three times as large as the annual owning and operating cost of the most cost-effective system.

SELECTION OF A RECOMMENDED SIGN-LIGHTING SYSTEM

The rationale used to select a recommended sign-lighting system for use by ADOT is described. The various factors considered in the selection process are summarized in Table 8.

Many factors were evaluated in this study and considered in selecting a recommended system. Color rendition, lighting uniformity, and viewing comfort were evaluated by two observer groups. As shown in Table 8, three systems received overall ratings of marginal to poor by both the hired observers and the professional group. All other systems received an overall rating of either good or excellent from one or both of the two groups.

An important decision in the selection process is whether the high-pressure sodium light source has acceptable color rendition. In the observer study, a low relative importance was placed on color rendition. On the basis of the finding that lack of evidence that color rendition is important for overhead guide signs and the significant economic savings that can be achieved with high-pressure sodium, it was decided that this system does have acceptable color rendition. The research team also noted that four other states—Nebraska, Tennessee, Utah, and Virginia—are using high-pressure sodium for sign lighting.

All 10 lighting systems were about equal in legibility distance. Systems 2 and 10 had a slightly greater legibility distance. All 10 systems had satisfactory luminance levels.

Lamp life and maintenance requirements were considered as part of the economic analysis.

From an economic standpoint, it appeared that five systems should be considered—Systems 10, 12, 11, 6, and 4.

Considering all of the factors described earlier and summarized in Table 8, the following observations led to the selection of a recommended system:

- Systems 11 and 12 were very comparable in terms of observer group rating, legibility, and illumination level. System 12 was preferred due to its lower cost.

- Systems 4, 6, and 10 all use a high-pressure sodium lamp. Systems 4 and 6 have significantly higher annual costs than does System 10. They also received poorer ratings from the observer groups. Therefore, System 10 was preferred.

- A comparison of the two remaining systems showed that System 12 provided better color rendition and System 10 offered slightly more legibility distance. In view of the substantially lower annual cost, System 10 was selected as the preferred system.

Therefore, System 10 is recommended as the best overall lighting system.

ESTIMATED SAVINGS IN ARIZONA

It is estimated that the 699 existing illuminated signs (virtually all using fluorescent lighting) use 1,546 fluorescent fixtures. The annual operating cost for these 1,546 fixtures is \$151,400. If they were converted to the recommended lighting system, the annual owning and operating cost would be \$86,380. In addition to a lower annual cost, ADOT would have a lighting system in place with a 20-year life as compared with a remaining life of approximately 10 years for the fixtures now in place.

The initial investment for a conversion would be significant

TABLE 8 EVALUATION OF LIGHTING SYSTEMS

	LIGHTING SYSTEMS									
System Number	1	12	7	2	5	11	10	6	8	4
Overall Rating by Observer Groups										
Hired Observers	○	○	○	○	○	○	●	●	●	●
Professional Group		○	○	●	●	○	○	●	●	●
Legibility	○	○	○		○	○		○	○	○
Illumination Level	○	○	○	○	○	○	○	○	○	○
Total Annual Owning and Operating Cost		\$114,603**				\$128,353	\$86,380	\$120,477		\$122,723

**Total Annual Owning and Operating Cost is for the 699 signs currently illuminated on the ADOT system. Costs are shown only for the five less costly systems.

**System 12, as field tested, used a 250 watt lamp. For the 699 illuminated ADOT signs it was found that use of a 175 watt lamp would be more economical. This size lamp would still provide adequate sign luminance. For definitions of the symbols used in Table 8, see Figure 2.

Systems 2 and 10 had greater legibility distances

All systems had satisfactory illumination levels

but would result in a relatively short payback period. Initial cost for fixtures, lamps, and installation for 699 signs would be \$191,332. The annual savings in operating costs would be \$87,497. Thus, the investment would pay for itself in less than 2½ years.

CONCLUSIONS

The study conclusions are as follows:

- ADTO spends annually about \$87,500 in electric power costs, \$106,000 for washing, and \$23,500 for lamps for illuminating 699 overhead guide signs on freeways.
- There is no standard sign size on the Arizona freeway system. The great variety in sizes is a challenge in selecting the best sign-lighting system.
- All 10 sign-lighting systems tested provided satisfactory luminance. Only one of the systems had unsatisfactory lighting uniformity. All 10 systems had about the same legibility distance.
- Power consumption can be greatly reduced by using high-pressure sodium as a light source.
- All nine of the alternative lighting systems tested have substantially lower owning and operating costs than the standard fluorescent system.
- Conversion of existing sign-lighting systems from fluorescent lighting to System 10 would reduce annual operating cost from \$151,400 to \$63,903. The initial investment to conduct the conversion would be \$191,332.
- Use of the recommended lighting system on future installations would save an average of \$189 per sign in annual owning and operating costs for the state of Arizona.
- It should be noted that the results of this sign-lighting research were influenced by the needs and requirements of the state of Arizona and the particular methodology and techniques of this research. Other states and operating agencies may find different results if other requirements and research methodologies are selected.

ACKNOWLEDGMENT

This research was sponsored by the Arizona Department of Transportation in cooperation with FHWA. More detailed documentation on this research project may be found in the project final report (5).

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An integral part of the evaluation of lighting systems in this study was the assessment of lighting fixtures produced by various manufacturers. The results of this research would not be meaningful without reference to the manufacturer's name and the model of the fixtures evaluated. The trade names and manufacturer names herein are cited only because they are considered essential to the objectives of the paper. The U.S. government, the state of Arizona, Arizona State University, and the Transportation Research Board do not endorse products or manufacturers.

The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented here. The contents do not necessarily reflect the official views or policies of the Arizona Department of Transportation or FHWA. This paper does not constitute a standard, specification, or regulation.

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DISCUSSION

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This is a very interesting paper that combines a somewhat novel experimental test method with an economic analysis based on field data to determine a preferred lighting system for highway signs.

However, the results stated by the authors concerning their choice of "best" lighting system and their recommendations for its proposed use by Arizona and other states are, I believe, based on both insufficient evidence and potential problems in the experimental research.

My comments are primarily addressed to two aspects of the paper: (a) the economic analysis and (b) the field experiment.

The economic analysis, which is used to support the far-ranging recommendations, is based on test data from only one lighting system of each type, and furthermore, such lighting systems were only evaluated for one size sign.

The authors' measurements of power consumption differ from manufacturer's published specifications for many of the studied lamps. Are we to believe that one field measurement is more valid than extensive laboratory testing? Clearly, more field testing was required.

The number of lamps in each lighting system is the single most influential factor in defining the initial operating and maintenance costs of each system, but the number is dependent on the size of sign selected for study.

If a sign of a different size were studied, the costs would change radically. For example, a slightly larger sign would require two 150-W high-pressure sodium (HPS) lamps in the "best" lighting system, significantly increasing the costs of this system but having only a marginal effect on the costs of the system employing 35-W low-pressure sodium (LPS) lamps. Similarly, a smaller sign would still require one 150-W HPS lamp but fewer 35-W LPS lamps. Such changes would drastically alter the economic results and hence the choice of "best" system. To suggest that the 150-W HPS system is preferred for all applications is thus unsupported by the research, especially because the range of sign sizes in Arizona,

and most states, is quite large, and not limited to the size of sign selected for study.

The experimental design includes a number of facets that are either invalid or at least unexplained in both the paper and the referenced final report.

The 10 sign locations were not described, other than their location on the freeway. If the backgrounds against which the signs were viewed by the test subjects differed in visual complexity, the experimental results could have been confounded by these differences and this would invalidate the selection of "best" lighting system. The lack of significant differences in legibility distances reported by the authors could have resulted from this problem (and the ones discussed subsequently). If, for example, the LPS system—a poor performer—was viewed against a complex background and the 150-W HPS system—the "best"—was viewed against a simple background, the background itself could have dominated the subjective ratings of legibility.

The authors state that all lighting was evaluated in the preliminary studies against a "medium" ambient light background but were all field locations carefully checked for similarity? Can the authors support the necessary similarity of backgrounds in any objective manner?

The subjective, and subject-controlled, method of measuring legibility distances that the authors employed is somewhat novel and may have induced potential problems related to the accuracy and repeatability of the legibility distances. Classic sign legibility research by Forbes and others employed test methods that were quite different than the one reported here. Did the authors investigate alternative methods or attempt to test their methodology to determine its repeatability, accuracy, and validity? What led the authors to select such a method?

The test subjects all viewed the 10 signs in the same order of presentation, which could have resulted in a learning curve that biased the results. Counterbalancing the order of presentation would have been preferred.

The rating scale resulted in a narrow range of subjective ratings (e.g., as low as 2.8 to 4.4), indicating possible central tendency effects that might have been eliminated by better instructions (which were not described), a better rating scale, and other, better psychophysical testing procedures. No statistics are presented to support conclusions or indicate the significance of the differences in lighting system performance.

The authors state that field experiments began about 1/2 hr after sunset and continued thereafter. It is my experience—and published sky luminance values support it—that the sky on a clear day has considerable brightness at 1/2 hr after sunset, not reaching full darkness until at least 1 hr after sunset. Such sky luminance differences could have influenced the results.

Other comments include the lack of any descriptive material supporting the reduction in number from 100 to 25 lighting systems in the preliminary analysis; the lack of information describing Lewin's analysis methodology or the SITELITE results; the choice of only one ambient lighting background (medium) rather than many; the choice of only one sign size, resulting in the bias described previously; and the use of a lighting fixture not designed for the LPS lamp in a sign-lighting application.

In conclusion, it is my belief that the potential problems just described may have invalidated the results of this research, and

that the recommendation that Arizona and other states use such a sign-lighting system is unsupported.

Either the present paper should be rewritten to limit the results to those obtained under the exact study conditions (which still need better explanation) and should exclude the far-ranging recommendation for use of such a lighting system for all highway signs, or my comments should be included with the published paper to provide the prospective user of these results with a very different interpretation of the research and its implications.

AUTHORS' CLOSURE

The comments by Michael Janoff are greatly appreciated. His comments stimulate discussion on this important topic and offer the opportunity to present additional information on this research project.

Janoff notes that in the economic analysis, the cost data presented are based on only one lighting system of each type and implies that a larger sample size should have been used for determining system cost. Table 6 presents all the cost factors that went into the economic analysis. Of those several factors, the only one that would change if a larger number of lighting systems of a given type were evaluated is power consumption.

Janoff states that the measured power consumption differs from manufacturer's published specifications. There are differences between the measured power consumption and the rated lamp wattage. Considering ballast losses, however, only one system is substantially different. The power consumption for System 8 (low-pressure sodium) is much greater than expected and this discrepancy cannot be explained.

A sensitivity analysis shows that major changes in power consumption would be required to change the rank order of the 10 systems in the overall economic analysis. If the power consumption of the low-pressure sodium system is, in fact, about 135 W (approximately the expected value based on rated wattage), there would still be five other systems that had lower annual owning and operating costs.

We agree with Janoff's statement that there is great variety in sign sizes and this is supported by an inventory of sign sizes conducted in the study. As a part of the economic analysis, we did consider the fact that the lighting system that is most economical for a sign 20 ft wide would not necessarily be most economical for a different size of sign. Systems 4 and 6 would be more economical for a sign less than 10 ft wide because only one fixture would be required. The Arizona Department of Transportation preferred to use one lighting system for all signs to simplify parts inventory and maintenance. Based upon the mixture of sign sizes in Arizona, System 10 provided the lowest overall cost.

Janoff notes that differences in background complexity at the 10 test sites could have affected the evaluation of the systems by the observers. Every possible attempt was made in this study to have the 10 test sites identical in terms of approach geometry, mounting height, size of sign, amount of legend, and ambient illumination. We believed that the most important

characteristic was the size of the sign face. All other factors being equal, a change in the size of the sign face can result in significant changes in overall luminance levels and in lighting uniformity. We believed that it was desirable to have 10 test sites where the signs were close to the same size, where all signs had three lines of legend, where signs were mounted individually (rather than in pairs), and where test site locations were relatively close together for convenience in observer studies. Ambient illumination levels were comparable at all locations. Although it cannot be proven on an objective basis, backgrounds were similar at the 10 test sites.

The method of measuring legibility distances was selected for simplicity. The test method employed by Forbes (sign-

reading errors) may be more rigorous. One advantage of the method employed in this project is that the observers were approaching the signs at highway speed—a more realistic condition. The stopwatch method used in this study has also been used in similar signing studies conducted by the Texas Department of Highways and Public Transportation.

We agree that counterbalancing the order of presentation of the 10 test sites would have been a more rigorous approach.

It is our opinion that twilight sky luminance had no impact on the observer studies. All observations at actual test sites were made more than 1 hr after sunset. In the urban area test site environment skyglow caused by urban lighting overpowered any twilight sky luminance at 1 hr after sunset.

Evaluation of the Effectiveness of Crash Cushion Delineation

F. THOMAS CREASEY, CONRAD L. DUDEK, AND R. DALE HUCHINGSON

The objective of this study was to evaluate the effectiveness of a limited number of crash cushion delineation techniques in the field. Three candidate treatments were selected for field testing: (a) a yellow diamond-shaped object marker, (b) a yellow-and-black chevron-patterned nose panel, and (c) yellow-and-black chevron-patterned nose and back panels. Because accidents involving crash cushions are relatively rare events, it is difficult to make statistically valid comparisons. In this study vehicle encroachments into the gore area were considered to be indicators of the potential for accidents with crash cushions. Studies were conducted at three sites in El Paso, Texas. A low-light-level camera and time-lapse video recorder were used to collect continuous encroachment and traffic volume data at the sites. Three candidate delineation treatments and the existing delineation treatment were tested at each of the study sites. A classification system was developed to differentiate among the gore sites on the basis of the geometrics of the gore approach. Data were collected over a 3-day period for each of the candidate treatments and for the existing treatment at the three sites. Crossover rates were used to compare the effectiveness of the delineation treatments. Analysis of the data indicated no difference in crossover rates among the treatments. The results, based on a limited sample, suggest that added delineation did not reduce crossover rates at locations where sight distance

was not a critical factor and that accident problems at these sites may not be related to poor conspicuity alone, but instead may have also been influenced by informational deficiencies in signing and markings.

The use of crash cushions (impact attenuators) to protect vehicles from crashes with fixed objects in freeway gore areas has become a widespread practice. Use of crash cushions has been shown to reduce impact severity (1). However, crash cushions increase the frequency of accidents. This increase may result from reducing the area of the recovery zone, reducing decision or reaction time or both, or simply adding another fixed object in the roadway environment for vehicles to strike. Although crash cushions reduce fatalities and injury severity, collisions with crash cushions may lead to serious secondary accidents or disruptions in traffic flow. There is also a risk to maintenance personnel who are exposed to traffic during repair operations. Thus, the safety benefits derived from crash cushion use are offset to some degree by increased maintenance, labor, and operational costs.

A possible reason that some impact attenuators are more frequently struck than others may be a lack of conspicuity in gore areas. Drivers having to simultaneously process complex information inputs from geometric features, signing, and markings and from other vehicles in the traffic stream may fail to distinguish a gore area or crash cushion embedded in the visual

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