ARIZONA DEPARTMENT OF TRANSPORTATION

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EVALUATION OF ALTERNATIVE LIGHTING SYSTEMS FOR GUIDE SIGN ILLUMINATION

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16. Abstract

The study objective was to identify a lighting system which has a lower power cost and reduced maintenance requirements and which 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 ten 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 which considered the initial cost of acquiring and installing the lighting systems and annual costs for electric power, washing, relamping, and ballast replacement.

A lighting system using the high pressure sodium light source was recommended. Compared to the existing commonly used fluorescent system, it uses one-third as much electric power and has about one-third of the annual owning and operating cost. The recommended system has a satisfactory illumination level and provides the best legibility distance of the ten systems tested.

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Throughout the conduct of the research, five organizations made significant contributions to the project. The project staff wishes to recognize the assistance of those organizations.

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- Office of Safety and Traffic Operations Research and Development
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- Psychology Department,
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- Lighting Sciences, Incorporated

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- Ms. Patricia Reichwein, Psychology Department, Arizona State University
- Dr. David Burstein, Physics Department, Arizona State University
- Dr. Ian Lewin, Lighting Sciences, Incorporated

SI (METRIC) UNIT CONVERSION FACTORS

The material contained in this report is presented in terms of English units. The following factors may be used to convert the measures used in this report to the International System of Units (SI):

1 mile per hour (mph) = 1.6093 kilometer per hour (km/h)

1 km/h = 0.6214 mph

1 inch = 2.54 centimeters

1 centimeter = 0.3937 inches

1 foot = 0.3048 meter

1 meter = 3.2808 feet

1 mile = 1.6093 kilometers

1 kilometer = 0.6214 miles

1 foot-candle = 10.76 lux

1 lux = 0.0929 foot-candle

1 foot-lambert = 3.426 candelas/square meter

1 candela/square meter = 0.2919 foot-lambert

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CHAPTER 1 - INTRODUCTION

During the past five years there has been an increasing interest nationwide in overhead guide sign lighting due to the increasing energy costs to provide illumination. In the state of California, for example, the annual cost of electric power to illuminate overhead signs on its freeway system increased from $993,000 in fiscal year 77-78 to $2,200,000 in fiscal year 1982-83. Arizona faces the same problem, and has a strong interest in solving it, although the costs are of smaller magnitude. It is estimated that the annual power cost for lighting the approximately 1500 sign lighting fixtures in the state is now $88,000.

In addition to the cost of electric power, highway agencies are also concerned about the maintenance costs and labor requirements for sign lighting systems. 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.

A further reason for Arizona to be interested in the efficiency of sign lighting systems is that a large number of them will be installed in the Phoenix urban area during the next 20 years. The existing Phoenix area freeway system has an average of 8.1 overhead signs per mile of freeway. At this density there will be 1871 new overhead signs installed on the 231 miles of freeway projected to be built in the next 20 years. Even if sign density is reduced by 50 percent, nearly 1000 new overhead signs may be installed. If a more efficient and economical sign lighting system can be designed, then monies will be more wisely spent as Arizona constructs and begins to operate the new freeway mileage.

While cost reduction is important, overhead sign lighting systems must also serve the needs of the motorist. Signing must be adequately visible and allow the driver adequate time to respond. Therefore, the basic problem addressed by this research project is to determine if alternate lighting systems can result in reductions in power consumption and maintenance requirements while still satisfying the needs of the motorist.

In preparing the proposal to conduct this research the principal investigator considered four possible ways of reducing power consumption:

1) simply turning off the lighting equipment;

2) turning off the lighting equipment and upgrading the sign materials (such as installing reflectorized backgrounds);

3) reducing the level of the illuminance, or

4) using more power efficient light sources.

A decision was made to focus this research effort on item 4) - using more power efficient light sources for the following reasons.

- From 1978 to 1988 the California Department of Transportation studied alternatives 1) and 2). Caltrans had proposed that many types of overhead guide signs not be illuminated and not have reflectorized backgrounds. This proposal violated the requirements of the Manual on Uniform Traffic Control Devices and had raised much controversy. Many professionals questioned whether a non-illuminated opaque background sign would adequately provide for the motorists' needs.

- Other agencies, notably Virginia, Pennsylvania and Ontario had conducted research to evaluate the effectiveness of overhead signs with reflectorized legend <u>and</u> background.
- Item 3) - "reducing the level of the illuminance" would violate existing standards for sign lighting illuminance levels. Any change in these standards would require a rigorous human factors type study to objectively determine if illuminance levels could be reduced and still provide for the needs of the motorist.

This project, therefore, was designed to identify lighting systems that would be more power efficient while at the same time satisfy the needs of the motorist.

SIGNIFICANCE OF WORK

The research results reported herein are significant because of the large sums of money spent on electricity and maintenance manpower for overhead guide signs each year. Arizona's cost of electricity for overhead sign lighting is estimated to be $88,000 per year and California's is $2,200,000 per year. California's maintenance costs are $800,000 per year. The nationwide power cost for overhead sign lighting (for all overhead signs on all roadway systems) is estimated to now be about $20 million annually. Maintonance costs further increase the annual expenditures.

DISCLAIMER

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 name and model of the fixtures evaluated. The trade names and manufacturer names which appear herein are cited only because they are considered to be essential to the objectives of the report. The U.S. Government, the State of Arizona, and Arizona State University do not endorse products or manufacturers.

The results of this study represent an evaluation of lighting system alternatives available in early 1984. Undoubtedly, products have been improved since that time and will continue to be improved. As time passes new products (lamps, fixtures, and ballasts) will become available in the marketplace. Some of them will be able to outperform the lighting systems tested in this study. The Arizona Department of Transportation should consider new products as they become available.

CHAPTER 2 - RESEARCH APPROACH

INTRODUCTION

The whole issue of overhead guide sign visibility at night is quite complex. There are a tremendous number of variables which affect what the motorist sees (see Table 1) as well as additional factors which affect sign legibility requirements (see Table 2). These greatly complicate the task of quantifying the motorists' needs and complicate the development of a research approach to solve the sign lighting problem.

Key questions to ask about overhead guide sign illumination are as follows.

1) Are the requirements for sign illumination given in the Manual on Uniform Traffic Control Devices justified?
2) If signs should be illuminated, what level of illuminance is required?
3) Is good color rendition required for overhead guide signs and which light sources provide adequate color rendition?
4) What light source can most economically provide the required level of illumination?

Several observations can be made regarding the four key questions.

1) The MUTCD requires that overhead guide signs on freeways either be illuminated or have reflectorized backgrounds. (The MUTCD requirements are listed in Appendix A). The requirement for illumination does not state what level of illuminance is required.
2) Two other documents provide some guidance as to what level of illumination is required. They are: AASHTO's "An Informational Guide for Roadway Lighting" (reproduced in Appendix B); and the

TABLE 1. FACTORS AFFECTING LEGIBILITY OF OVERHEAD GUIDE SIGNS

The Sign
- Type of sign materials used for the legend and background and their luminance or reflectivity
- The 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 Non-illuminated
- 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 (photometry, aim, clean or dirty, wet with rainwater)
- Windshield (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 (night vision -- this is a function of age)

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

TABLE 2. ADDITIONAL FACTORS WHICH AFFECT SIGN LEGIBILITY REQUIREMENTS

The 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)
The kind of response required of the motorist (Does it require immediate response or will the driver have a long time to react?)

Illuminating Engineering Society's "Recommended Practice for Roadway Sign Lighting." These recommendations are highly subjective. The AASHTO publication, for example, states that "Sign lighting is warranted where the sign will not be adequately visible at night." It then goes on to give specific illuminance levels which were subjectively determined. No rigorous work has been done to define what illuminance levels are required for the motorist. Despite the subjective development of these standards, the study team made the decision to accept the existing AASHTO and IES lighting standards and to develop lighting systems which met these standards.

3) The MUTCD requires that regulatory and warning signs show the same color by day and night when illuminated. It does not require that guide signs have good color rendition. AASHTO's "An Informational Guide for Roadway Lighting" 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. Some observers contend that the public has a strong preference to be able to see green at night. On the other hand, responses to a survey of 57 state and local jurisdictions by the Western Association of State Highway and Transportation Officials showed that 80 percent of the respondents (traffic engineering professionals) did not feel it was necessary to see background color on non-illuminated overhead guide signs at night.

No rigorous research has been done to evaluate the value of seeing green at night. Does green improve driver reaction? Does green provide a visual cue to the motorist which helps him assimilate information or which is essential to driver understanding? The research approach in this study was to include light sources with poor color rendition. Those individuals who were hired to observe test lighting systems were asked to evaluate color rendition and give their opinion on the importance of good color rendition.

With the foregoing factors in mind, the basic framework of the research approach included the following.

- o The concept of developing more power efficient lighting systems.
- o Acceptance of the MUTCD requirement that overhead signs be illuminated (if they do not have a reflectorized background).
- o Acceptance of the AASHTO and IES lighting standards.
- o Inclusion of light sources (high pressure sodium, low pressure sodium) which provide poor color rendition.

STUDY OBJECTIVES

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

Each of the light sources/lighting systems was evaluated on the following bases.

Illuminance level - compared to AASHTO and Illuminating Engineering Society guides.

Economics - costs of lamps, fixtures, installation, electric power, maintenance.

Maintenance required - person hours for installation, washing, cleaning, and lamp replacement, and other maintenance.

Lamp life

Legibility - the distance from which a sign is legible when illuminated.

Color rendition - a subjective assessment

Light uniformity (is the sign uniformly lit?) - a subjective assessment.

Viewing comfort - an assessment of glare or harshness due to brightness of a sign in a dark environment.

A further objective, for the lighting system which was determined to be best, was to estimate the cost of changing all signs in Arizona to the alternative lighting system and to estimate the annual savings in operating costs if a changeover were made.

STUDY TASKS

The remainder of this chapter presents a summary of the tasks undertaken to carry out the research project. This summary completes the description of the research approach used in the study.

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 which make up the lighting system. With approximately six principal light sources, roughly five lamp sizes for each source, several different fixtures on the market, and various number of lamps and fixtures which could be used to light one sign, the potential number of lighting systems available could easily be more than 100.

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 in evaluating alternative lighting systems. The three steps were: 1) a preliminary evaluation; 2) a laboratory evaluation, and 3) field testing.

Task I

Task I determined the universe of light sources, lamp sizes, and fixtures which were available on the market. As a preliminary evaluation the whole range of alternatives were evaluated in terms of their ability to meet Illuminating Engineering Society recommended illuminance levels for typical sign sizes, their ability to be competitive from a power usage standpoint, 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 by an independent lighting expert, Dr. Ian Lewin. Contenders that did not meet the evaluation criteria were eliminated. This preliminary evaluation reduced the number of alternatives to 25.

As a second step, each of the 25 contenders underwent a laboratory evaluation. Photometric tests quantified the illuminance levels provided by each of the 25 alternatives. Computer analysis of the photometric test results predicted the illumination level that each alternative would provide on a typical sign face. A review of the computer analysis allowed for further reduction of alternatives. Alternatives were rejected if they did not provide illuminance levels as recommended by the Illuminating Engineer Society, if they provided uneven light distribution, or if adequate illumination could be provided by a smaller wattage lamp. The result of the second step was a reduction in the number of alternatives to ten. (The ten alternatives included the standard ADOT fluorescent lighting system.) These ten alternatives were then subjected to the third step - field testing (described in Task V).

An additional activity in Task I was an inventory of the sizes and shapes of overhead sign panels in Arizona.

Task II

Other states and agencies were contacted to learn about their field experiences in using some of the more unusual light sources such as high pressure sodium and metal halide.

Task III

Sites were selected for field testing of the ten alternative lighting systems identified in Task I.

Task IV

The ten alternative lighting systems were installed for testing at the field sites.

Task V

Each lighting system was field tested for a period of 10 to 14 months. The following items were quantified or evaluated during field testing.

Luminance Levels

Power Consumption

Maintenance Requirements

Lamp Life

Legibility

Color Rendition

Light Uniformity

Viewing Comfort

<u>Task VI</u>

A task was included in the study to remove the lighting systems undergoing testing at the end of the field test period. The preliminary indication by the Arizona Department of Transportation is that they will allow the ten test systems to remain in the field.

<u>Task VII</u>

Each lighting system tested was evaluated based on the following criteria.

Luminance Level

Economics

Maintenance Requirements

Lamp Life

Legibility

Color Rendition

Light Uniformity

Viewing Comfort

The most economical lighting system which also provided satisfactory luminance levels, legibility, color rendition, light uniformity and viewing comfort was identified and selected as the recommended sign lighting system.

Task VIII

The annual savings which could be realized in Arizona if the recommended sign lighting system were utilized statewide were estimated.

CHAPTER 3 - TESTING OF ALTERNATIVE LIGHTING SYSTEMS - PROCEDURES USED AND RESULTS

PRELIMINARY INVESTIGATIONS

There were a very large number of potential sign lighting systems which could have been evaluated in this project. A sign lighting system is composed of a light source, a lamp of a given size, a fixture, a ballast, and a choice in the number of lamps and fixtures which make up the sign lighting system. A summary of the choices available is shown below.

- o Light source
  - Fluorescent (the standard light source now used by the Arizona Department of Transportation)
  - 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
- o Lamp Size
  - Each light source is available in several sizes (wattages) and lamp configurations
- o 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.

- o Ballast
  - A variety of ballasts are available on the market for use with specific light sources and lamp sizes. The ballasts vary in efficiency.
- o Number of Lamps and Fixtures
  - A given size sign panel can be illuminated using one, two, three or more lamps and fixtures. The choice of number of lamps and fixtures affects the level of illuminance (foot-candles), light uniformity, and economics of installation and operation.

The performance of an individual sign lighting system is dependent on the choices made in the above list. There were a very large number of possible combinations of light source, lamp size, fixture, ballast, and number of lamps and fixtures which potentially serve in a sign lighting system. (These combinations shall henceforth be described as "alternatives.") The number of possible alternatives were clearly too large for field testing all of them.

To reduce the number of alternatives to a manageable size for field testing, two steps were undertaken. First, the whole range of alternatives was evaluated in terms of their ability to meet Illuminating Engineering Society recommended illumination levels for typical sign sizes, their ability to be competitive from a power usage standpoint, 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 by a lighting expert, Dr. Ian Lewin. Contenders that clearly did not meet the evaluation criteria were eliminated. This review reduced the number of possible alternatives to 25.

Second, photometric tests of each of the 25 alternatives were conducted in a laboratory. The photometric testing was conducted by Lighting Sciences Incorporated. A list of the 25 alternative systems subjected to photometric testing is given in Table 3. The photometric testing quantified the illuminance levels provided by each of the 25 alternatives (a combination of lamp and fixture). The illumination levels were in terms of the light levels at approximately 2800 points on a hemisphere surrounding the fixture.

The photometric test results were utilized in a computer program named SITELITE to predict the illuminance levels that each sign lighting system would provide on a "standard" sign panel. Sign panel dimensions of 8 feet high and 21 feet wide were used for the "standard" sign panel. The location of the fixture with respect to the sign was based on typical ADOT design. The SITELITE program predicted: 1) illuminance on a one-foot grid on the sign face; 2) the overall average illuminance on the sign face; 3) a summary of the maximum and minimum foot-candle levels on the sign face; and 4) a lighting uniformity ratio. The output from a sample SITELITE run is shown in Table 4.

TABLE 3. LIGHTING SYSTEMS SUBJECTED TO PHOTOMETRIC TESTING

Light Source	Lamp Size	Fixture (Manufacturer and Model)
Fluorescent	430 milliamp, 40 watt	Nu-Art NAFL (Two 40 inch lamps)
Fluorescent	800 milliamp, 85 watt	Nu-Art NAFL (Two 72 inch lamps)
Clear Mercury Vapor	250 watt	General Electric Versaflood II
Clear Mercury Vapor	250 watt	Guth Signliter
Clear Mercury Vapor	250 watt	Holophane Expresslite
Clear Mercury Vapor	250 watt	Holophane Panel-Vue
Clear Mercury Vapor	250 watt	Nu-Art MVFL-R
Clear Metal Halide	250 watt	General Electric Versaflood II
Clear Metal Halide	250 watt	Guth Signliter
Clear Metal Halide	250 watt	Holophane Expresslite
Clear Metal Halide	250 watt	Holophane Panel-Vue
Clear Metal Halide	250 watt	Nu-Art MVFL-R
Clear Metal Halide	400 watt	Holophane Expresslite
Clear Super Metal Halide	400 watt	Holophane Expresslite
Clear High Pressure Sodium	100 watt	General Electric Versaflood II
Clear High Pressure Sodium	100 watt	Guth Signliter
Clear High Pressure Sodium	100 watt	Holophane Expresslite
Clear High Pressure Sodium	100 watt	Nu-Art MVFL-R
Clear High Pressure Sodium	250 watt	General Electric Versaflood II
Clear High Pressure Sodium	150 watt	Holophane Panel-Vue
Clear High Pressure Sodium	250 watt	Guth Signliter
Clear High Pressure Sodium	250 watt	Holophane Expresslite
Clear High Pressure Sodium	250 watt	Nu-Art MVFL-R
Low Pressure Sodium	35 watt	Holophane Expresslite
Low Pressure Sodium	180 watt	Prototype Fixture

Table 4. SAMPLE SITELITE OUTPUT

```
                       21 FT. LONG SIGN 8 FT. HIGH USING 1 LUMINARE@ .
                                   ILLUMINATION RUN@

              TABLE OF VERTICAL ILLUMINANCE LEVELS ON PLANE FACING SOUTH @
                           FOR POINTS AT Y =     0.00 FEET @
                             ALL VALUES IN FOOTCANDLES@

CO-ORD. (
FEET@

25.5 <    +    +    +    +    +    +    +    +    +    +@
     <  8.2 10.9 13.4 15.7 19.2 21.4 21.5 22.7 23.0 22.2 @
     <@
24.5 <    +    +    +    +    +    +    +    +    +    +@
     <  7.8 11.8 15.7 18.7 22.3 26.4 27.9 29.3 29.6 27.7 @
     <@
23.5 <    +    +    +    +    +    +    +    +    +    +@
     <  7.2 10.8 17.0 23.1 27.1 31.1 35.4 35.4 35.7 33.7 @
     <@
22.5 <    +    +    +    +    +    +    +    +    +    +@
     <  6.4  9.5 15.3 24.0 31.2 34.5 39.9 41.9 40.7 39.9 @
     <@
21.5 <    +    +    +    +    +    +    +    +    +    +@
     <  6.0  8.5 12.3 19.7 29.7 34.3 37.5 42.0 42.5 42.0 @
     <@
20.5 <    +    +    +    +    +    +    +    +    +    +@
     <  6.8  8.6 11.3 16.4 22.5 28.1 32.4 35.3 38.7 40.1 @
     <@
19.5 <    +    +    +    +    +    +    +    +    +    +@
     <  8.8 11.3 13.2 14.7 18.3 22.0 25.9 29.7 30.2 29.1 @
     <@
18.5 <    +    +    +    +    +    +    +    +    +    +@
     <  9.4 12.8 16.1 19.2 21.8 21.7 24.9 30.2 28.8 27.7 @
     <@
     ------------------------------------------------------ @
        1.0       3.0       5.0       7.0       9.0@
             2.0       4.0       6.0       8.0      10.0 @

                           X CO-ORDINATE - FEET@

 SCALE: 1 INCH =     2.0 FEET@

                        AVERAGE FOOTCANDLES =  23.33@

                        MAXIMUM FOOTCANDLES =  42.45@

                        MINIMUM FOOTCANDLES =   6.01@

                        MAX./MIN. RATIO =    7.1 : 1@

                        AVG./MIN. RATIO =    3.9 : 1@
```

A review of the SITELITE computer analyses allowed a further reduction in alternatives. Alternatives were rejected if they did not provide illuminance levels as recommended by the Illuminating Engineering Society, 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 foot-candles of illumination. Alternatives were rejected if they did not provide an average of 20 foot-candles of illumination. In some instances it was apparent that a smaller wattage lamp could be used in field testing and this was done.

As a result of the above analysis the number of alternatives for field testing was reduced to ten. These ten alternatives were then subjected to field testing. A list of the ten systems selected for field testing is given in Table 5.

In addition to predicting illuminance levels, the SITELITE program was also valuable in demonstrating the importance of fixture location and orientation. SITELITE results showed that distribution of light on the signface is very sensitive to the positioning of the fixture in front of the sign. When installed, it is <u>crucial</u> that fixtures be correctly positioned in relation to the sign face. Four dimensions are important:

A - The horizontal distance from the sign face to the fixture

B - The vertical distance between the bottom of the sign face and the fixture

C - The spacing of fixtures along the front of the sign face

TABLE 5. 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 milliamp	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 Signliter	2	33.7	7.3:1
5	Clear Metal Halide	175 watt	Guth Signliter	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 illuminance 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.

D - The tilt, or angle, which the fixture is rotated with respect to the sign.

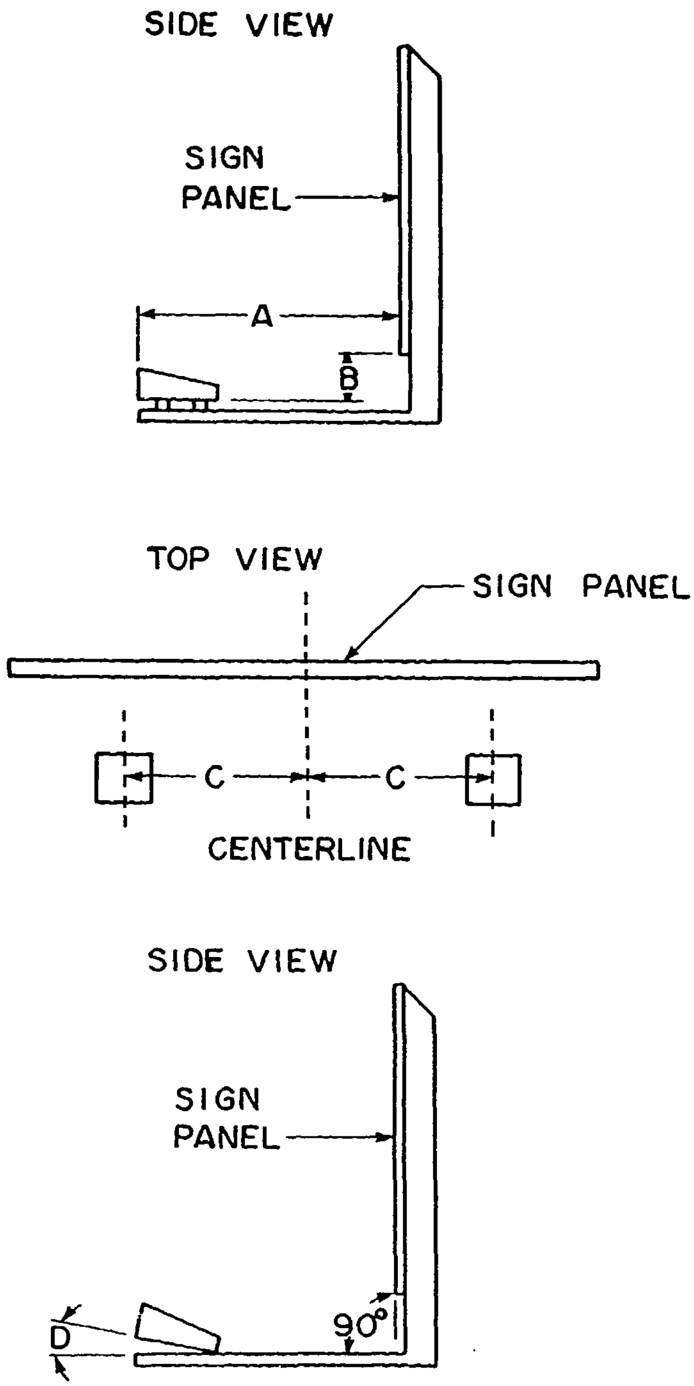
These dimensions are illustrated in Figure 1. Of these four dimensions, the most crucial is the tilt of the fixture with respect to the sign (dimension D). Small changes in tilt can have a dramatic effect on illuminance levels on the sign face. For example, SITELITE results showed that the average footcandles of illuminance on a sign can be increased from 45 to 60 percent for certain fixtures by tilting them 13 degrees toward the sign. Dark spots in the lower corners of a sign panel can also be dramatically improved.

Inventory of Sign Panel Sizes

Sign panel dimensions are important in determining the performance of a sign lighting system. A sign lighting system which performs well on a small sign may perform poorly on a large sign. Conversely, a sign lighting system which 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.

As-built plans were studied to determine sign panel dimensions. Currently within ADOT's inventory are approximately 699 illuminated sign panels. Exact dimensions were available from as-built plans for about half (355) of these signs. Given the large sample size, it was reasoned that this should be representative of the total sign panel population.

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 following summarizes the significant findings.



Note: See Table 7 for actual values of A, B, C, and D at each test site.

Figure 1. LOCATION OF FIXTURES WITH RESPECT TO SIGN

- o Lengths varied from 6 feet to 28 feet
- o Heights varied from 5 feet to 14 feet
- o 90 percent of all signs are between 8 feet and 21 feet in length
- o 94 percent of all signs are between 6 feet and 12 feet in height
- o Only 5 percent of all signs are both higher and wider than the standard 8 foot high by 21 foot wide sign panel used in SITELITE evaluations.

Table 6 summarizes the breakdown of sign panel sizes by height and width.

FIELD TESTING

The preliminary investigations identified ten sign lighting systems for field testing. Before field testing could begin sites had to be selected for installing the ten systems. The important considerations used in selecting sites are listed below.

Ten sign locations were required

Signs should be fairly close together for ease in conducting observer study and other field observations.

Signs should be approximately the same size for comparison purposes.

Sign sizes should be representative of the total sign population

Locations should be fairly close to Phoenix for ease of accessibility by ADOT personnel (for installation and maintenance) and by the research team (for field observations)

Ability to turn off roadway lighting (if any) for a few short periods of time to do telephotometer work.

TABLE 6. SUMMARY OF SIGN PANEL DIMENSIONS

Cumulative Percentage of Sign Panels with Height Less Than or Equal to that Shown

Height (feet)	Percentage
5	1.4
6	22.5
7	33.5
8	50.4
9	69.0
10	77.2
11	89.3
12	96.1
13	98.1
14	100.0

Cumulative Percentage of Sign Panels with Width Less Than or Equal to that Shown

Width (feet)	Percentage
6	2.0
7	2.6
8	9.1
9	10.5
10	20.4
11	30.0
12	37.9
13	45.5
14	51.5
15	57.7
16	65.3
17	71.8
18	79.9
19	83.8
20	88.6
21	92.9
22	94.9
23	96.0
24	97.7
25	99.4
28	100.0

Signs should be visible from at least 1/2 mile (no obstructions due to horizontal or vertical curvature or overhead structures) so that legibility distance can be evaluated.

Supporting structure and location over roadway should be such that lane closures during installation are minimized and motorist and worker safety are maximized.

The research team conducted nighttime field observations of 150 miles of Arizona freeway to identify candidate sites meeting the above criteria. Selected freeway segments were also reviewed at night with ADOT personnel. Final selection of the ten test sites was a joint decision by the research team and ADOT personnel. Nine of the test sites were on the Superstition Freeway (State Route 360) in Tempe and Mesa. The tenth location was on Interstate 10 in Tempe. With one exception, all sites had porcelain enamel backgrounds (the tenth site 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 Arizona Department of Transportation was very cooperative and took responsibility for installing the alternative lighting systems at the ten test sites. ADOT personnel removed previously existing fluorescent lighting, installed the lighting systems to be tested, and made wiring modifications to allow power consumption to be monitored during field testing. ADOT also accepted the responsibility of maintaining the sign lighting systems during the project.

A listing of the test site locations is given in Table 7.

TABLE 7. TEST SITE LOCATIONS

System Number	Light Source	Lamp Size	Fixture (Manufacturer and Model)	Number of Fixtures	Test Site Location: Superstition Freeway Milepost	Test Site Location: Direction	Sign Description (First Line of Legend)	Sign Panel Dimensions (Height x Width in Feet)	Location of Fixtures with Respect to Sign** A	B	C	D
1	Fluorescent	800 milliamp	Nu-Art NAFL	3 fixtures 6 lamps	1.64	EB	Rural Road 1/2	8 x 19	4'8"	5"	6'9"	0°
2	Clear Metal Halide	175 watt	Holophane Expresslite	2	5.85	EB	Alma School Rd 1/2	9 x 20	4'3"	20"	4'9"	0°***
4	Clear High Pressure Sodium	70 watt	Guth Sign-liter	2	8.92	WB	Mesa Drive 1/4	8 x 21	5'10"	5"	5'6"	13°
5	Clear Metal Halide	175 watt	Guth Sign-liter	2	7.93	WB	Junction SR87 1/4	8 x 21	4'11"	8"	5'3"	8°
6	Clear High Pressure Sodium	70 watt	General Electric Versaflood II	2	2.89	EB	McClintock Dr 1/4	8 x 19	5'3"	5"	5'6"	7°***
7	Clear Metal Halide	175 watt	General Electric Versaflood II	2	3.91	EB	Price Road 1/4	8 x 21	5'3"	5"	6'0" (left) 4'9" (right)	8°
8	Low Pressure Sodium	35 watt	Holophane Expresslite	3	8.90	EB	Stapley Dr. 1/4	8 x 18	5'0"	7"	4'1" (left) 0'0" (center) 4'8" (right)	16°***
10	Clear High Pressure Sodium	150 watt	Holophane Panel-Vue	1	3.93	WB	McClintock Dr 1/4	8 x 19	5'11"	5"	0'0"	3°
11	Clear Metal Halide	175 watt	Holophane Panel-Vue	1	I-10 mile-post 155.75	WB	Scottsdale	9 x 20	4'6"	5"	0'0"	11°
12	Clear Mercury Vapor	250 watt	Holophane Panel-Vue	1	7.91	EB	Mesa Drive 1/4	8 x 16	4'6"	5"	0'0"	14°

*This sign had a high intensity reflective background. All other signs had opaque porcelain enamel backgrounds.

**See Figure 1 for description of these dimensions. Dimensions shown are those as actually installed.

***After adjustment in November, 1985.

Field Testing - Sign Luminance

One aspect of field testing was the measurement of sign luminance. The 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 off of 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.

The sign luminance data was obtained for three purposes. First, to compare actual field performance with Illuminating Engineering Society recommended luminance levels. Second, to compare the actual performance of individual lighting systems with one another. And finally, to compare actual performance (based on luminance) to predicted performance (based on illuminance) by the SITELITE program.

A telephotometer was graciously loaned by FHWA for measuring luminance. The telephotometer was a Spectra Pritchard Photometer, Model 1980. It was constructed in 1975, and last factory calibrated in March, 1985. The Illuminating Engineering Society "Guide for Photometric Measurements of Roadway Sign Installations" was followed in measuring sign luminance. As directed by the telephotometer operation manual, measurements were made during relatively clear nights. All measurements were made between the hours of 3:00 a.m. and 6:00 a.m. to minimize the effects of headlight illumination.

The telephotometer was positioned just off the right-hand freeway lane, approximately 300 feet from the sign-face. It was mounted on a tripod and powered by a generator. The telephotometer was calibrated at each of the test sites before measurements were taken.

Measurements were recorded every two feet across the horizontal axis of the sign-face, and every one foot on the vertical axis. Data was recorded on a segmented chart representing the sign-face (See Table 9). Data was recorded for both the white legend and the green background.

Telephotometer readings were compared with Illuminating Engineering Society standards. Each of the ten lighting systems was designed, based on SITELITE program evaluations, to provide an average of at least 20 foot-candles of illuminance high by 20 foot wide sign panel. The 20 foot-candle 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 foot-lamberts and it assumes that white sign letters will reflect 70 percent of the illuminance. Therefore, field performance (telephotometer readings) were compared to the IES standard of 14 foot-lamberts.

Table 8 presents data on measured luminance for each of the ten lighting systems. 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 foot-lamberts on System 5 to 20.9 foot-lamberts on System 7. If the IES luminance standard of 14.0 foot-lamberts 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.

TABLE 8. 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

[1] See Table 7 for a description of each lighting system.

[2] Predicted 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.

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

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

As described later in this chapter, two of the systems which had measured luminance of less than 14 foot-lamberts (Systems Number 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. Table 8 presents estimated uniformity ratios based on telephotometer readings. The best uniformity ratio was 3.3:1 while 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 tabulated in Table 8 and for individual points on the sign face as shown in Table 9. 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 "run-of-the-mill 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 9. COMPARISON OF LUMINANCE MEASUREMENTS IN FIELD WITH SITELITE PREDICTION

COLUMN

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

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 illuminance level from the SITELITE program multiplied by 0.7.

Table 9 shows a comparison of the field performance and predicted performance for individual points on a sign face. The data presented are for Lighting System 1. This type of comparison was useful in identifying any usual problems or conditions for a sign lighting system. Review of field performance data suggested that the orientation of the fixtures, as installed, at three locations was incorrect. Site visits confirmed this. The tilt angles on the fixtures were readjusted and follow-up telephotometer measurements were made. (The Table 8 values for Measured Luminance include the follow-up measurements). The follow-up field measurements showed that the tilt angle of the fixtures can have a dramatic effect on both overall foot-candle levels and uniformity. This confirmed previous information provided by the SITELITE program.

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.

Field Testing - 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

Legibility Distance describes the distance from which the sign can be read.

Viewing Comfort describes whether the light source is so bright that it causes discomfort. Discomfort may occur as the motorist approaches the sign - due to the bright light - or just after passing the sign - due to 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.

Lighting Uniformity describes the range between bright spots and dark spots on the sign. (Note: Technically, the observers were evaluating "luminance uniformity" because they were seeing the light reflected off of the sign. To simplify things for the observers it was simply described to them as "lighting uniformity." Similarly, "lighting uniformity" is used in this report although "luminance uniformity" would be technically more correct.)

Color rendition describes the presence or absence of color distortion. With certain light sources, notably high pressure sodium and low pressure sodium, the sign colors appear much different in the nighttime than they do in the daytime.

Evaluation of these characteristics was done with an observer study.

Two different groups of observers were used in this human factors type study. The first group was composed of hired observers. The second group was composed of transportation professionals. The observer studies conducted with the two groups will be described separately, beginning with the hired observers.

Hired Observer Group - Study Description

Past research has confirmed the substantial effects age has on visual performance. These include a decrease in amplitude of accommodation, reduction in pupil size, decrease in rate and amount of dark and light adaptation, loss of transmission of light due to increased opacity of the eye media, reduction in sensitivity especially at low luminance levels, and degenerative changes in the various parts of the visual system including the retina.[1] For these reasons it was decided to test two different age groups, senior citizens, and young adults.

Twenty-nine observers, composed of 15 senior citizens and 14 young adults were recruited for this study. The Senior Citizen group was recruited from senior citizen centers in the local community. The young adult group was recruited from introductory psychology classes at Arizona State University. Other than targeting these two age groups no effort was made to recruit drivers with special characteristics. The only requirement to qualify as an observer, other than age, was that they be licensed to drive. The observers were not a random sample of the driving population.

The ages of the Senior Citizen group ranged from 61 to 86, the average being 70.2. The ages of the Young Adult group ranged from 18 to 33, the average being 20.9.

Nine females and six males comprised the Senior Citizen group. Seven females and seven males made up the Young Adult group.

The average length of residency in the city in which the experiment was conducted was between 12 and 13 years for both groups of observers.

Both groups of observers traveled on the freeway where the test sites were located on an average of between two and two and one-half times a week. The Senior Citizen group drove an average of 38 miles per week on the freeway, the Young Adult group an average of 48 miles.

[1] IES Handbook, pp. 3-11

Fourteen out of 15 members of the Senior Citizen group wore glasses. Five out of the 14 members of the Young Adult group wore glasses or contacts. The average corrected vision of the Senior Citizen group was 20/25, and ranged from 20/15 to 20/50. The average corrected vision of the Young Adult group was 20/20, and ranged from 20/15 to 20/30.

Preceding the start of the field test observers were given a visual acuity test. The results are given above.

Between thirty minutes and two hours after sunset observers began the field test. The route to be driven on the freeway was first explained and then shown on a map. Observers were then instructed on the meanings of the four factors being evaluated in the study (legibility distance, viewing comfort, lighting uniformity, and color rendition).

After the observers demonstrated a satisfactory understanding of what the factors meant the field test began.

The procedures used to evaluate each of the four characteristics are described below. Observers were seated in the front right passenger seat of an automobile.

Legibility Distance. The vehicle was driven at a constant speed of 55 mph toward each test site. The observer actuated a stopwatch at the moment they could distinguish all of the letters in the top line of the legend on a test sign. The stopwatch was stopped as the vehicle passed under the sign. The elapsed time was later used to calculate the legibility distance in feet.

Viewing Comfort. While approaching the sign and passing it the observer was asked to rate its viewing comfort on a five point scale - excellent, good, marginal, poor, abysmal.

Lighting Uniformity. Prior to the observation drive each observer was shown two illustrations showing good and poor lighting uniformity. While approaching the sign and passing it the observer was asked to rate its lighting uniformity, also on the same five point scale.

Color Rendition. The five point scale was also used to evaluate color rendition.

Two practice test sites were used by each observer before they began evaluation of the ten actual test sites. Each observer was driven past each test site two times. On the first run legibility distance and lighting uniformity were evaluated. On the second run viewing comfort and color rendition were evaluated.

Following the evaluations each observer completed two questionnaires (Figures 2 and 3). One questionnaire asked the observer the relative importance, to him, of legibility distance, lighting uniformity, viewing comfort, and color rendition. The second questionnaire asked him how important it was to him to be able to see the color green at night.

Although not included as a formal part of the research project, the hired observers also evaluated two non-illuminated signs. One sign had a reflectorized legend on an opaque background and the second sign had a reflectorized legend on high-intensity reflective sheeting (designated

Research Project
on
Evaluation of Alternative Light Sources
for Guide Sign Illumination

RELATIVE IMPORTANCE OF FACTORS FOR
SAFE AND EFFICIENT DRIVING

Observer Number _____
Date _______________

Examples	Driver 1	Driver 2	Driver 3	Driver 4
Factor 1	60	75	50	25
Factor 2	20	20	20	25
Factor 3	10	0	10	20
Factor 4	10	5	20	30
	100	100	100	100

Your Rating:

Color Rendition ____
Lighting Uniformity ____
Legibility Distance ____
Viewing Comfort ____

You have just spent over an hour observing overhead signs on freeways at night. During the experiment you were asked to evaluate four factors: legibility distance, light uniformity, viewing comfort, and color rendition. Based upon your observations, you have probably developed some opinion on the relative importance of each of these four factors to you as a nighttime driver. We would like you to fill out a rating sheet to show how much importance you place on each of the four factors.

You have a total of 100 points to allot in demonstrating how important each factor is to you. The examples on the rating sheet show different ways in which different drivers could assign importance to the four factors. You may assign as many or as few points to a factor as you desire. But you cannot use more than 100 points, and you must use exactly 100 points.

FIGURE 2. QUESTIONNAIRE NUMBER 1

Overhead signs on freeways have white letters on a green background. Some of the signs you viewed this evening appeared green and others did not appear green. How important is it to you to be able to see the color green at night on an overhead sign? (Circle one)

Very important

Somewhat important

Somewhat unimportant

Not important at all

FIGURE 3. QUESTIONNAIRE NUMBER 2

as Systems 21 and 22 in Tables 10 and 11). Both signs were interchange sequence signs and were approximately the same size as the illuminated signs. Legibility distance, viewing comfort, lighting uniformity, and color rendition were all evaluated.

Hired Observer Group - Results

The average legibility distance for all observers for the ten sign lighting systems was 862 feet. The average legibility distance for the Senior Citizen group was 844 feet, for the Young Adult group it was 879 feet.

In comparing the various lighting systems, the legibility distance ranged from a low of 794 feet for the Senior Citizen group on Lighting System 4, to a high of 952 feet for the Young Adult group on Lighting System 10. See Table 10. The legibility distance of a specific lighting system generally tended to fluctuate greatly from observer to observer.

As indicated in Figure 4, there is comparatively little variation among the legibility distances between lighting systems. Indeed, the time span between the greatest legibility distance and the shortest is only 1.96 seconds. Noteworthy, however, is that both Lighting Systems 10 and 2 consistently had noticeably greater legibility distances than the other lighting systems tested (1.03 seconds and .61 seconds respectively, when compared to the standard fluorescent lighting system (System 1). Lighting System 10 had the greatest legibility distance with an average of 932 feet.

For the characteristics of viewing comfort, lighting uniformity, and color rendition the observers rated individual signs as Excellent,

TABLE 10. AVERAGE LEGIBILITY DISTANCE

Lighting System[1]	Average Legibility Distance (Feet) Young Adult Group	Senior Citizen Group
1	899	802
2	924	897
4	873	794
5	850	839
6	912	811
7	842	861
8	820	856
10	952	912
11	*	832
12	837	835
21	801	690
22	931	797

*System not operational during testing of this group

[1]See Table 7 for a description of lighting systems 1, 2, 4, 5, 6, 7, 8, 10, 11 and 12. Lighting Systems 21 and 22 were not illuminated. System 21 had a sign with a reflectorized legend on an opaque background. System 22 had a sign with a reflectorized legend on a high intensity reflective sheeting background.

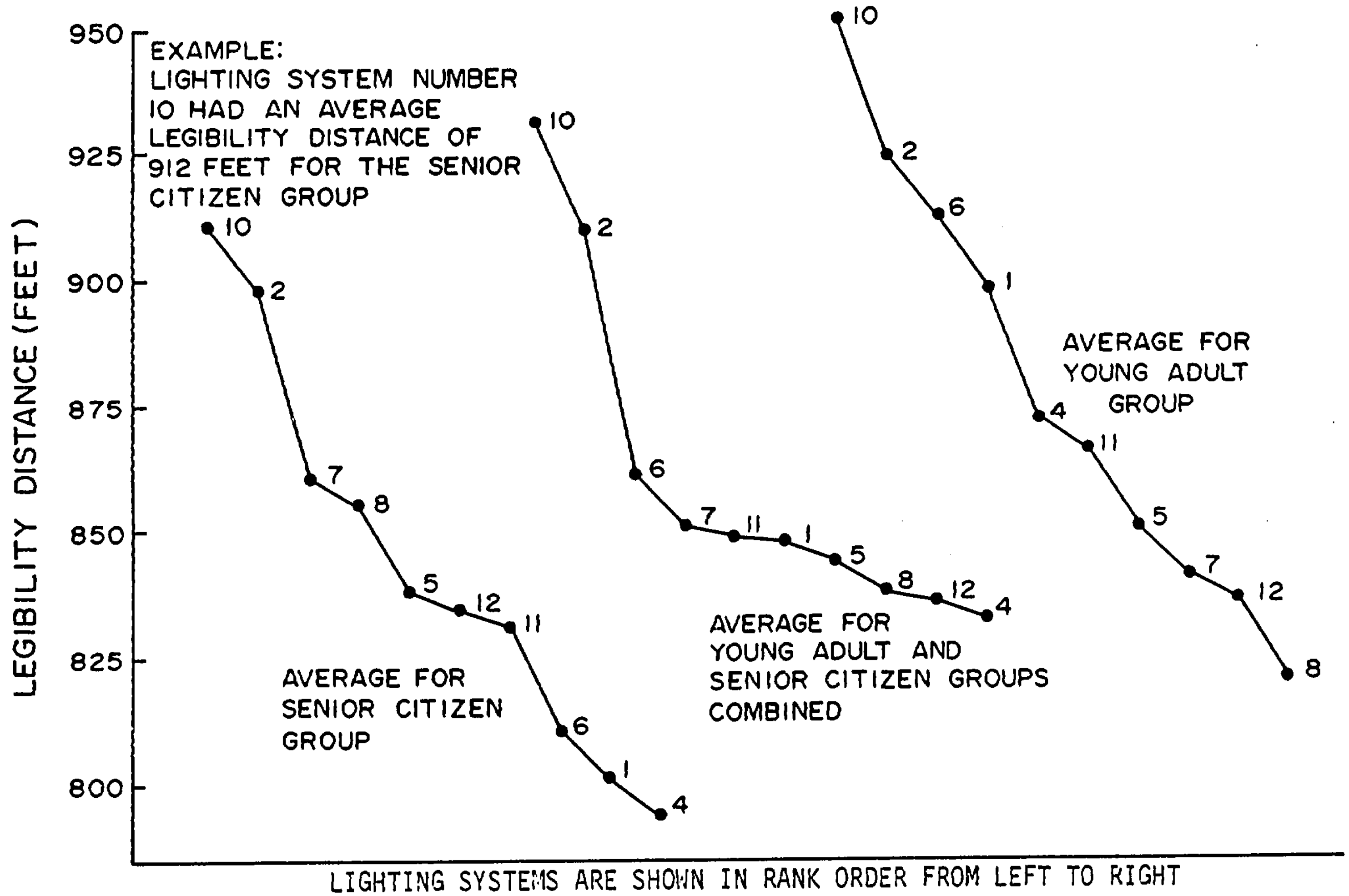


Figure 4. LEGIBILITY DISTANCES OF LIGHTING SYSTEMS BY GROUP

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.

Table 11 summarizes the viewing comfort scores. The average viewing comfort score given by all observers was 3.6. For the Senior Citizen group the average viewing comfort score was 3.5. The Young Adult group's average was 3.8. The group averaged scores ranged from a high of 4.4 on Lighting System 1 for the Young Adult group, to a low of 2.8 for both Lighting Systems 4 and 8 for the Senior Citizen group.

The average lighting uniformity score given by all observers was 3.4. For the Senior Citizen group the average was 3.3, for the Young Adult group it was 3.5. The averaged scores ranged from a high of 4.2 on Lighting System 1 for the Young Adult group, to a low of 2.3 on Lighting System 4 for the Senior Citizen group (see Table 11).

After the observer studies were conducted it was discovered that fixture orientation was incorrect on three test systems. After the tilt angle on these fixtures was adjusted the research team noted a significant improvement in lighting uniformity. It is likely that these three systems (Systems 2, 6, and 8) would have received better lighting uniformity ratings if they had been correctly oriented during the observer study.

The average color rendition score given by all observers was 3.2. For the Senior Citizen group the average was 3.3, for the Young Adult group it was 3.2. The averaged scores ranged from a high of 4.4 on Lighting System 1 for the Young Adult group to a low of 1.7 for Lighting System 8 for the Young Adult group (see Table 11).

TABLE 11. OBSERVER RATINGS FOR VIEWING COMFORT, LIGHTING UNIFORMITY AND COLOR RENDITION

Lighting System[1]	Viewing Comfort			Lighting Uniformity			Color Rendition		
	Young Adult Group	Senior Citizen Group	Professional Group	Young Adult Group	Senior Citizen Group	Professional Group	Young Adult Group	Senior Citizen Group	Professional Group
1	4.4	4.3	4.5	4.2	4.1	4.4	4.4	4.3	4.5
2	3.9	3.5	3.0	3.7	3.5	2.2	4.1	3.7	3.6
4	3.8	2.8	2.7	2.7	2.3	1.6	2.5	2.3	2.3
5	3.9	3.5	3.3	3.3	3.6	2.4	3.5	3.4	3.4
6	3.6	3.1	3.2	3.2	2.6	2.0	2.2	2.9	2.3
7	3.9	3.5	3.8	3.9	3.8	3.3	3.9	4.0	3.9
8	3.6	2.8	2.2	3.1	2.8	3.4	1.7	2.5	1.3
10	3.5	3.9	3.8	3.6	3.0	4.2	2.6	2.7	2.8
11	*	3.3	4.1	*	3.7	3.4	*	3.3	3.4
12	3.7	3.9	3.8	3.9	3.7	3.7	3.9	3.9	3.6
21	4.2	3.0	**	2.4	3.0	**	2.3	2.5	**
22	4.6	3.5	**	3.7	3.6	**	4.3	3.6	**

Numerical values correspond to the following subjective ratings:

5.0 = Excellent

4.0 = Good

3.0 = Marginal

2.0 = Poor

1.0 = Abysmal

*System not operational during testing of this group.

**System not tested

[1]See Table 7 for a description of lighting systems 1, 2, 4, 5, 6, 7, 8, 10, 11, and 12. Lighting Systems 21 and 22 were not illuminated. System 21 had a sign with a reflectorized legend on an opaque background. System 22 had a sign with a reflectorized legend on a high intensity reflective sheeting background.

As mentioned previously, each observer was asked to quantify the relative importance of legibility distance, lighting uniformity, viewing comfort, and color rendition after he had completed the field observations (see Figure 2). Table 12 summarizes the ratings given by the observers. Each value in the table represents the average rating given by observers in a particular group. The two observer age groups agreed with the order of importance of all four factors. Legibility distance, by far, was rated as the most important item studied. Viewing comfort was seen as the next most important factor. Closely following viewing comfort in perceived importance was lighting uniformity. The importance of color rendition was rated a distant last place among the four factors. The two observer age groups were also fairly consistent in the absolute values of the relative importance they placed on each item.

Observers also answered a questionnaire pertaining to the importance of color rendition (see Figure 3). Thirteen of the fifteen observers from the Senior Citizen group judged it to be either "somewhat important" or "very important." Conversely, 11 out of 14 observers from the Young Adult group saw color rendition as either "somewhat unimportant" or "not important" (see Table 13). Clearly, there was a difference of opinion between the younger and older age groups.

The non-illuminated signs are identified in Tables 10 and 11 as Lighting Systems 21 (opaque background) and 22 (high-intensity reflectorized background). The opaque background sign had a legibility distance less than that of any of the illuminated signs. The reflectorized background sign performed quite well for the Young Adult

TABLE 12. RELATIVE IMPORTANCE OF FOUR FACTORS

	Relative Importance of:			
	Legibility Distance	Viewing Comfort	Light Uniformity	Color Rendition
Young Adult Group	47	23	22	8
Senior Citizen Group	35	28	23	14
Young Adult and Senior Citizen Groups Combined	41	26	23	11
Professional Group	43	16	27	14

TABLE 13. IMPORTANCE OF COLOR RENDITION

	Importance of Seeing Green				
	Very Important	Somewhat Important	Somewhat Unimportant	Not Important	Total
Young Adult Group	0	3	4	7	14
Senior Citizen Group	8	5	2	0	15
Professional Group	0	7	4	3	14

group; its legibility distance was better than nine out of ten of the illuminated systems. In comparison, this sign did not perform as well for the Senior Citizen group; the legibility distance was comparable to the two lowest performing illuminated signs. However, in actual legibility time, this represents a mere one-half second difference from the average performance of all the illuminated signs.

In the areas of viewing comfort, lighting uniformity, and color rendition, the reflectorized background sign was rated better than the opaque background sign in every category by both observer groups. Compared to the illuminated signs, the opaque background sign compared unfavorably with one exception--the Young Adult group rated it very high in viewing comfort. The reflectorized background sign was favorably rated compared to the illuminated signs. In every category this sign rated better than at least half of the illuminated systems.

Professional Observer Group - Study Description

Fourteen transportation professionals made up the professional group of observers. These individuals were employees of the Arizona Department of Transportation, the cities of Phoenix and Tempe, the Federal Highway Administration, and Arizona State University. All were male volunteers. Ages ranged from early thirties to late fifties. Because the viewpoint of transportation professionals may vary from the typical driver, results from this group have been analyzed separately.

The procedures used by the professional group to evaluate each of the characteristics was slightly different from those used for the hired observers. The primary difference is that the professional group did not evaluate legibility distance. A secondary difference is that this group evaluated viewing comfort, lighting uniformity, and color rendition from a stationary position about 200 feet from each sign rather than from a moving automobile.

Approximately one hour after sunset this group began the field test. The route to be driven on the freeway was first explained and then shown on a map. Observers were then instructed on the meanings of the factors being evaluated in the study.

The observers were driven to within 200 feet of each test site where the vehicle they were traveling in stopped. Observers then had between three and four minutes to rate the test sites' viewing comfort, lighting uniformity, and color rendition. This procedure was repeated at each test site.

Following the evaluations, this group also filled out the two questionnaires pertaining to the relative importance of each factor, and also their opinion on the importance of seeing green at night.

Professional Observer Group - Results

Table 11 summarizes the scores given by the professional group for viewing comfort, lighting uniformity, and color rendition and compares those scores to the scores of the hired observer group. Generally, the lighting system which received the highest (and lowest) score from the professional group also received the highest (and lowest) score from the hired observer group.

The professional group quantified the relative importance of legibility distance, lighting uniformity, viewing comfort, and color rendition. The results are shown in Table 12. Compared to the hired observer group, the professional group placed lesser importance on viewing comfort. Both groups felt that legibility distance is most important and that color rendition is least important.

In regard to the importance of color rendition, half of the professional group rated it as "somewhat important." The other half rated it as either "somewhat unimportant" or "unimportant."

Field Testing - 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 very significant; the longer the time interval between routine maintenance visits, the lesser maintenance costs will be.

The one year field test period used in this study was not long enough to make conclusions about lamp life, as the lamp life of all lamps tested exceeded one year.

As a result, comparisons of lamp life can be based only on manufacturer claims. Shown below are the values for lamps tested in this study.

Fluorescent	800 milliamp	18,000 hours
Clear Mercury Vapor	250 watt	approx. 28,000 hours
Clear Metal Halide	175 watt	10,000 hours
Clear High Pressure Sodium	70 watt and 150 watt	approx. 28,000 hours
Low Pressure Sodium	35 watt	18,000 hours

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 that nearly all lamps are replaced before they fail. Sign lighting lamps are on for about 4,000 hours per year. ADOT uses a two year replacement period for fluorescent lamps which results in an age of about 8,000 hours when lamps are replaced (compared to an 18,000 hour average life).

Based on the manufacturer claims of lamp life the following number of years between group relamping were established for use in an economic analysis of each lighting system.

Fluorescent	2 years
Clear Mercury Vapor	3 years
Clear Metal Halide	1 year
Clear High Pressure Sodium	3 years
Low Pressure Sodium	2 years

Field Testing - Maintenance

During field testing ADOT's personnel kept detailed records of any maintenance required at the ten field test sites. Maintenance was required at some test site locations. A careful review of the maintenance which was performed showed that, in each case, none of the problems were attributable to the lighting system being tested. In all cases the maintenance was required by a malfunction external to the lighting system. All ten systems performed equally well in that they did not require maintenance.

Field Testing - Power Consumption

During field testing, power consumption for each of the lighting systems was periodically monitored by using a wattmeter.

Modifications to the electrical circuits were made at each of the test sites to provide an outlet for use of the wattmeter. These modifications allowed for the direct measurement of power consumption for the lighting system (including both lamps and ballast). The modifications did not affect the performances of the lighting systems nor did the measurement procedure interrupt the flow of power to the lamps.

Power readings were normally conducted once a month. The measurements were always taken at least two hours after the lamps stabilized--which takes up to one hour after they are turned on.

The wattmeters used in this study were supplied by ASU's Engineering Lab Services, and were calibrated just before their use.

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. The only significant change, occurring between August, 1985 and October 1985 was the result of a change in instruments--the original wattmeter was replaced. Although both wattmeters were calibrated, their accuracy is only ± 5 percent. A slight increase in power consumption was observed after the change in instruments.

Table 14 and Figure 5 present data on the power consumption by each lighting system. The current ADOT lighting system, using a fluorescent lamp is represented as System 1. It had the highest level of energy consumption with an overall average of 531 watts. This is in sharp contrast with the three most energy efficient lighting systems (System 4, 183 watts; System 10, 158 watts; and System 6, 148 watts). Each of these systems used a high pressure sodium lamp.

Power consumption for the low pressure sodium system (System 8) was much higher than expected. The system, which used three 35 watt lamps,

TABLE 14. POWER CONSUMPTION

System Number	Light Source	Lamp Size	Fixture	Power Consumption (watts)	Power Consumption Compared to Standard Fluorescent System (Percent)
1	Fluorescent	800 milliamp	Nu-Art NAFL	531	100
2	Clear Metal Halide	175 watt	Holophane Expresslite	386	73
4	Clear High Pressure Sodium	70 watt	Guth Signliter	183	35
5	Clear Metal Halide	175 watt	Guth Signliter	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

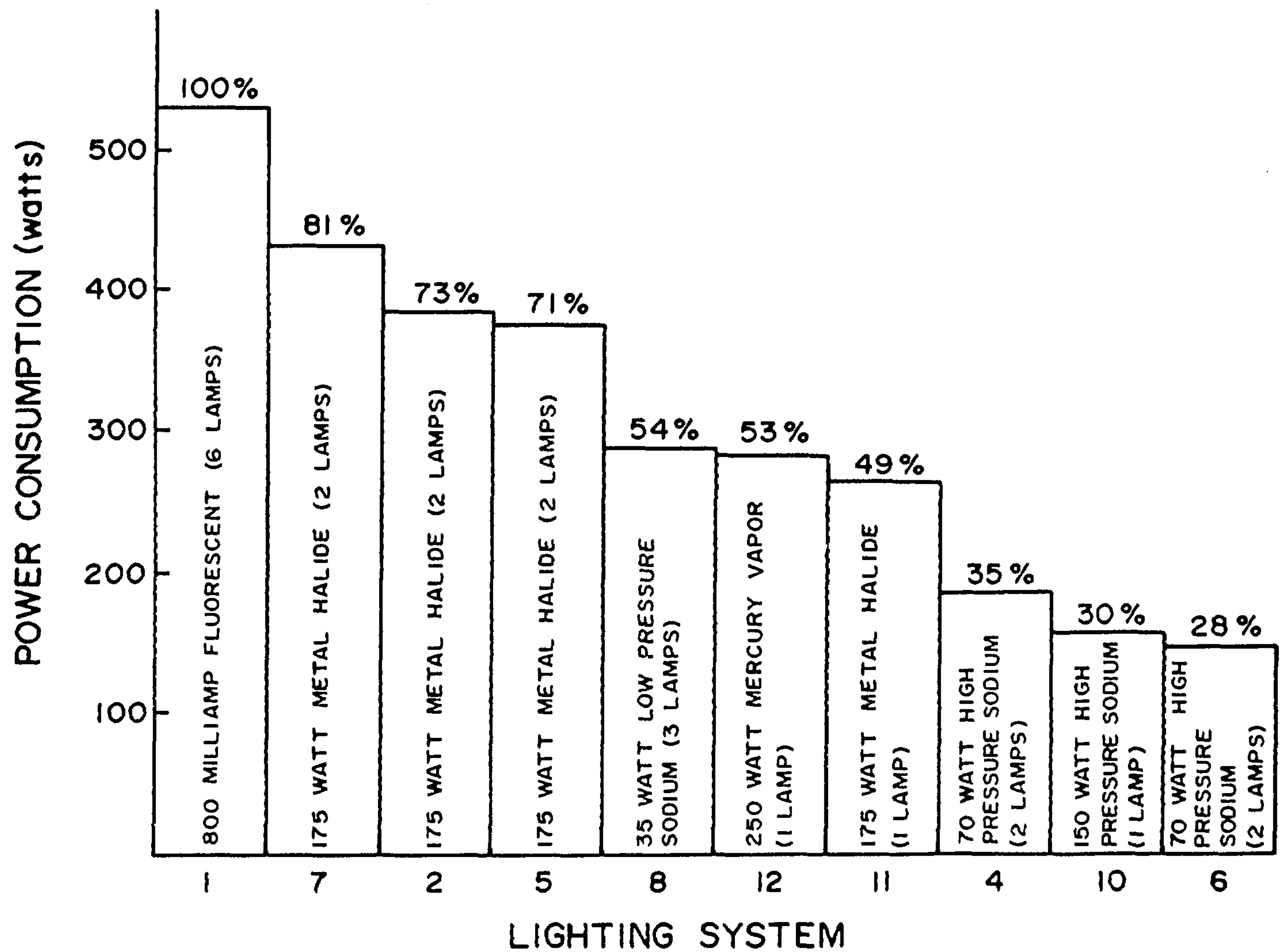


Figure 5. RELATIVE POWER CONSUMPTION

had a power consumption of 289 watts. No reason for this high value was discovered.

CHAPTER 4 - EVALUATION OF ALTERNATIVE LIGHTING SYSTEMS

This chapter presents an evaluation of the data presented in the previous chapter, shows the results of an economic analysis of the ten lighting systems, identifies the "best" of the ten lighting systems, and presents an estimate of the economic savings that could be realized if that system were used statewide in Arizona.

SIGN LUMINANCE

All ten lighting systems provided luminance levels within a relatively narrow range. Luminance levels generally meet the Illuminating Engineering Society guidelines for medium ambient light conditions. Two systems with lower luminance levels were found to have the best legibility distance in the observer study. Based on these results, all ten lighting systems provide satisfactory luminance levels.

LEGIBILITY DISTANCE, VIEWING COMFORT, LIGHTING UNIFORMITY AND COLOR RENDITION

The preceding chapter described the observer study findings for legibility distance, viewing comfort, lighting uniformity, and color rendition. As noted there, great differences in legibility distance between lighting systems were not observed. Ratings for viewing comfort, lighting uniformity, and color rendition were significantly different, however, as illustrated in Figure 6. To develop a composite rating of a lighting system's performance for these three factors a weighted approach was used.

The average score of each factor for a specific lighting system was multiplied by the value of the relative importance assigned to it by each group of observers. These weighted values were then summed both between and across groups. For example, in the case of viewing comfort

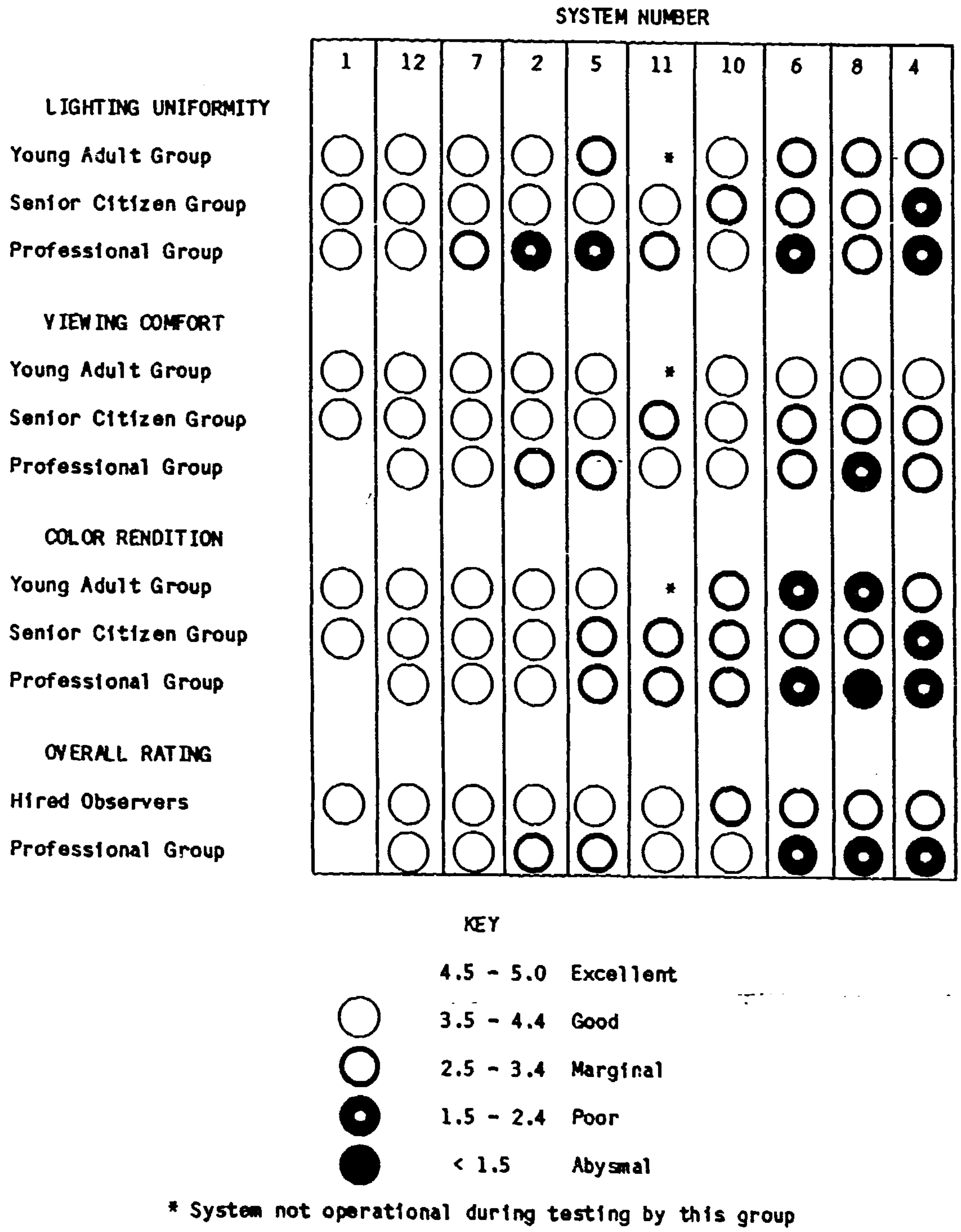


FIGURE 6. OBSERVER RATINGS OF LIGHTING UNIFORMITY, VIEWING COMFORT AND COLOR RENDITION

for the Senior Citizen group, the average rating for Lighting System 1 was 4.3. The relative importance the Senior Citizen group placed on the viewing comfort factor was 28.0 %. Thus, 4.3 was multiplied by .28. This procedure was then followed for the other two factors, lighting uniformity and color rendition, for Lighting System 1. Then all three scores were added together and divided by the sum of the relative importance of the three factors to give a total combined weighted score. The calculations are shown below in equation form.

$$\frac{\left(\text{viewing comfort score} \times \text{relative importance of viewing comfort}\right) + \left(\text{lighting uniformity score} \times \text{relative importance of lighting uniformity}\right) + \left(\text{color rendition score} \times \text{relative importance of color rendition}\right)}{\sum \left(\text{relative importance of viewing comfort} + \text{lighting uniformity} + \text{color rendition}\right)}$$

Similarly, this procedure was repeated for the data involving the Young Adult group on Lighting System 1. Finally, the Young Adult and Senior Citizen groups' scores were combined for an overall performance rating of Lighting System 1. This was the procedure used to determine the relative performance level of all lighting systems studied. This method was also used for the professional group.

The overall ratings are tabulated in Table 15. The overall ratings are also pictorially represented in Figure 6 where the lighting systems are listed in the order of their overall rating.

LIGHT POLLUTION CONCERNS

The Southwest is one of the four most important astronomical research locations in the world. The region houses the world's largest collection of research-quality telescopes.

TABLE 15. OVERALL RATING BY OBSERVERS

Lighting System	Overall Rating			
	Young Adult Group	Senior Citizen Group	Young Adult + Senior Citizen Combined	Professional Group
1	4.3	4.2	4.3	4.5
2	3.9	3.5	3.7	2.8
4	3.1	2.5	2.8	2.1
5	3.6	3.5	3.6	2.9
6	3.2	2.9	3.0	2.4
7	3.9	3.7	3.8	3.6
8	3.2	2.7	3.0	2.5
10	3.4	3.3	3.4	3.7
11	3.6	3.4	3.5	3.6
12	3.8	3.8	3.8	3.7

During the past two decades, light pollution has become an increasingly important problem to the astronomical community resulting in an adverse impact on the efficiency of astronomical research equipment. In Arizona the value of these installations approaches $300 million. Light pollution has degraded the usefulness of these facilities by roughly 15%, representing a substantial loss in financial investment. Thus, an important consideration in the selection of a light source for ADOT signs is the amount of light pollution damage created.

Shown below is the relative damage of the five different light sources tested in this study. The values shown are the percent of the astronomical spectrum obscured by each light source.

Low Pressure Sodium	1%
Clear Mercury Vapor	3 - 4%
High Pressure Sodium	42%
Fluorescent	100%
Metal Halide	100%

Although fluorescent lighting interferes with 100 percent of the spectrum, it does so less intensely than high pressure sodium does in affecting 42 percent of the spectrum. Thus, astronomers consider high pressure sodium to be more damaging than fluorescent.

ECONOMIC ANALYSIS

An economic analysis was performed to compare the ten sign lighting systems. The analysis considered the initial costs for fixtures, lamps, and the labor and equipment for installation as well as the annual operating costs for electricity, washing, relamping, and ballast replacement. Table 16 presents a tabulation of the cost information

TABLE 16. 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)[a]	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)[a]	0.8	0.8	0.8	0.8	0.0	0.8	0.8	0.8	0.8	0.8

[a] 2 person crew for washing and relamping
1 person crew for ballast replacement

used in the economic analysis. The following points describe various inputs to the economic analysis.

- o Prices for fixtures, lamps and replacement ballasts were obtained from local suppliers for purchases in both large and small quantities (the values in Table 16 are for large quantities).
- o Installation costs was based on an ADOT estimate of the amount of time required to install fixtures. An ADOT labor rate of $17.86 per hour and an equipment rate (for a truck) of $10.50 per hour were used to calculate cost.
- o A 10 percent interest rate was used.
- o Based on ADOT experience with fluorescent lighting systems, all lighting systems were estimated to have a useful life of 20 years. A salvage value of $0 was assumed.
- o Power consumption was based on actual experience during field testing. Annual operating time was 4,000 hours.
- o ADOT currently purchases electric power from at least three different utilities. An estimate of the weighted average cost paid by ADOT for electric power is 8.5¢ per kilowatt-hour.
- o It was assumed that the cost of electric power would escalate no faster than the cost of labor and replacement parts.
- o Current ADOT labor and equipment rates were also used for washing, relamping, and ballast replacement functions.
- o The time required to wash fixtures and to relamp were estimated based on ADOT's experience with fluorescent lighting systems.
- o Based on ADOT's past practice of group relamping, this same practice was applied to all ten lighting systems. The frequency of relamping was based on lamp life (see Chapter 3).

- The frequency of washing was based on the frequency of relamping and ADOT's past experience with dirt accumulation and washing needs (ADOT washes fluorescent systems once a year). For metal halide systems, where annual visits would be required for relamping, an annual washing was included. For the fluorescent system, the practice of annual washing was continued. For high pressure sodium and mercury vapor systems, where relamping would occur once every three years, a one and one-half year washing frequency was established. It was felt that a three year washing was certainly too long but that an annual washing might not be necessary (unlike fluorescent fixtures, where dirt can be trapped on the flat lens, high pressure sodium and mercury vapor fixtures have rounded refractors and dirt would tend to wash off). A once-a-year cleaning was established for the low pressure sodium system.
- 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.

A computer program, COSTLITE, provided by Lighting Sciences, Inc. was used to calculate annual costs. Table 17 presents the results for each of the ten lighting systems. The COSTLITE program calculates costs as follows.

<u>Initial Cost</u> - Costs for a system's fixtures, lamps, and their installation are determined.

<u>Annual Owning Cost</u> - A capital recovery factor for a 10 percent interest rate and a 20 year lifetime is applied to the initial cost to determine annual owning cost.

TABLE 17. 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

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 - This is lamp cost divided by the replacement period. Labor and equipment costs for lamp replacement are included in washing cost.

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

The four preceding items are added to determine Annual Operating Cost. None of these four items considers increases in costs of labor, equipment, lamps, and ballasts in future years. All annual costs are based upon current prices.

Total Annual Owning and Operating Cost is the sum of Annual Owning Cost and Annual Operating Cost.

Review of Table 17 shows very great differences in the annual costs of the ten 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 illumintate an 8 foot high by 20 foot wide sign. Initial cost is considerably less than other systems. Conversely, System 1 requires three lighting fixtures and has very high initial cost.

- o Systems 8, 5, 2, 7 and 1 have much higher annual operating cost. Four factors contribute to this. First, these systems have higher power consumption. Second, they all require annual washing. Third, they have shorter lamp life than most of the other systems. Fourth, the annual ballast replacement cost tends to be higher than the other systems.

Further evaluation of the data in Table 17 sought to determine if the basic results were sensitive to changes in any of the inputs. The findings are described below.

- o Table 17 was based upon fixture, lamp, and replacement ballast prices for large quantity purchases. Using prices for smaller quantity purchases, the ranking of the five most cost-effective systems did not change. There was also very little change in the relative cost of those five systems.
- o Total annual costs are very insensitive to differences in installation costs between systems.
- o Escalation in power cost would favor those systems with lesser power consumption, notably systems 10, 6 and 4.
- o Total annual costs are very insensitive to a change in the interest rate.
- o Frequency of relamping has a small effect on the relative annual cost of the ten systems. Washing frequency has a small to moderate effect on relative annual cost.
- o Changes in the relative price of fixtures would have a small effect on the relative cost of different systems.

It is emphasized that the cost information presented in Table 17 is for lighting a 20 foot wide sign. Systems 6, 4, 8, 5, 2, and 7 use two fixtures to light a 20 foot wide sign. For narrow signs these systems would be capable of lighting the sign with one fixture. Annual cost would be cut in half. For Systems 6 and 4 this would mean that their annual cost (approximately $90) would be even less than System 10.

The discussion thus far has compared the annual cost of ten different lighting systems for new installations. For this case the existing fluorescent system is inferior to all of the other nine alternatives. It is also very important to evaluate the economics of allowing existing fluorescent lighting systems to remain in place versus replacing them with a different system. The last column in Table 17 presents the annual cost of operating an existing fluorescent system. It treats the initial cost of the system as a sunk cost which has already been expended and for which there is no annual owning cost. Based on information provided by ADOT it uses an average age of ten years and a remaining useful life of ten years. It shows an annual operating cost of $294, a value nearly three times as large as the annual owning and operating cost of the most cost-effective system. This comparison clearly shows that serious consideration should be given to a retrofit program.

SELECTION OF A RECOMMENDED LIGHTING SYSTEM

This section describes the rationale which was used to select a recommended lighting system for use by ADOT. Table 18 is used to summarize the various factors considered in the selection process.

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 18, three systems received overall ratings of "Marginal" to "Poor"

TABLE 18. EVALUATION OF LIGHTING SYSTEMS

System Number	1	12	7	2	5	11	10	6	8	4	
Overall Rating by Observer Groups											
Hired Observers	Good	Good	Good	Good	Good	Good	Marginal	Marginal	Marginal	Marginal	
Professional Group		Good	Good	Marginal	Marginal	Good	Good	Poor	Poor	Poor	
Legibility	Good	Good	Good		Good	Good		Good	Good	Good	Systems 2 and 10 had greater legibility distances
Luminance Level	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	All systems had satisfactory luminance levels
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.

KEY

	4.5 - 5.0	Excellent
[thin open circle]	3.5 - 4.4	Good
[thick open circle]	2.5 - 3.4	Marginal
[filled circle with dot]	1.5 - 2.4	Poor
[solid circle]	< 1.5	Abysmal

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 or not the high pressure sodium light source has an acceptable color rendition. Based on the results of the observer study (the low relative importance which observers placed on color rendition), the 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 HPS 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.

In <u>legibility distance</u>, all ten lighting systems were about the same. Systems 2 and 10 had a slightly greater legibility distance. All ten systems had satisfactory <u>luminance levels</u>.

<u>Lamp life and maintenance requirements</u> were considered as part of the economic analysis.

From an <u>economic</u> standpoint it appeared that five systems should be considered--Systems 10, 12, 11, 6 and 4. As Table 17 shows, these are the five better systems for a 20 foot wide sign. As noted previously, however, the least expensive system for a 20 foot wide sign (System 10) is not the least expensive system for a narrow sign. Further analysis showed that System 6 would be most economical for signs up to 10 feet in width and that System 10 would be most economical for signs more than 10 feet in width. At this point the question of uniformity in equipment became important.

ADOT indicated a preference in uniformity in equipment for the following reasons.

- o A smaller and simpler inventory of spare parts and equipment (fixtures, lamps, and ballasts). Less space is required for warehousing at the main warehouse and satellite warehouses.
- o Procurement of inventory items is simplified.
- o Procurement in larger numbers of units may result in better prices.
- o Maintenance is simplified. Fewer spare parts items need to be stocked in maintenance trucks. The chances of a repeat visit to fix a problem (because the worker did not have the needed spare parts the first time) are reduced.
- o If a sign light is reported out, there is no question about what type of lighting system is involved.

In the opinion of both ADOT and the principal investigator the above advantages of equipment uniformity outweigh the approximately $9300 annual savings for using a mixture of lighting systems. Therefore, a decision was made to select a single lighting system.

The tremendous variety in sign sizes suggested that the total annual owning and operating costs presented in Table 17 for a 20 foot wide sign might not identify the least expensive lighting system for the 699 illuminated signs on the ADOT system. For example, if there were a very large number of signs 10 or less feet in width and only a few large signs, then System 6 might become most economical overall.

To determine systemwide cost for 699 signs the sign inventory was reviewed and for each lighting system the total number of fixtures required was determined based on sign width. The number of fixtures was multiplied by annual cost per fixture to yield a total annual owning and operating cost for the 699 signs. The results are shown in Table 18.

Considering all of the factors described above and summarized in Table 18, the following observations led to the selection of a recommended system.

- o 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.
- o Systems 4, 6 and 10 all use a high pressure sodium lamp. Systems 4 and 6 have significantly higher annual costs than System 10. They also received poorer ratings from the observer groups. Therefore, System 10 was preferred.
- o A comparison of the two remaining systems showed that System 12 provided better color rendition while 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 IF USED STATEWIDE

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 converted to the recommended lighting system the annual owning and operating cost would be $86,380. In addition to a lesser annual cost, ADOT would have a lighting system in place with a 20 year life as compared to a remaining life of approximately 10 years for the fixtures now in place.

The initial investment for a conversion would be significant but would result in a relatively short payback period. Initial cost for fixtures, lamps, and installation cost 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 two and one-half years.

It is anticipated that 231 new miles of freeway will be built in the Phoenix area during the next 20 years. Assuming that the same signing density will exist on new freeway mileage as on current freeway mileage, 1871 new signs will be installed during the next 20 years. If illuminated using the current fluorescent lighting system, the total annual owning and operating cost for these signs would be $583,241 per year. If the recommended lighting system is used the annual cost would be $230,270, a savings of $352,972 per year.

WAYS TO REDUCE LIGHT POLLUTION DAMAGE

The annual monetary value of light pollution damage to Arizona astronomical facilities is about $4.5 million. Although only a crude estimate can be made, it is estimated that the share of the damage caused by ADOT sign lighting facilities is about $15,000 per year. Fortunately, about half of this $15,000 in annual damages can be prevented by providing special treatment at a small number of sign lighting locations.

Since the effects of light pollution are inversely proportional to the distance to the 2.7 power of the light source from an observatory, those sign lighting systems closest to observatory facilities do the most damage. Based upon the actual locations of observatories, individual locations of illuminated signs, and the annual light pollution damage at each observatory, the relative damage of individual illuminated signs was determined.

Within the state as a whole, calculations showed that 3.3 percent of all illuminated guide signs create 16.0 percent of all light pollution damage. Another 13.7 percent of signs create 61.4 percent of all damage. Thus, there is a population of 17 percent of all signs which create 77.4 percent of all light pollution damage. In comparison, the 456 overhead signs located in the Phoenix area (representing 65.2 percent of all signs) create only 15.2 percent of the total light pollution damage.

Light pollution damage can be substantially reduced by making the following modifications to existing systems.

- The 23 signs located in Nogales create 16.0 percent of all light pollution damage. They can be converted to a mercury vapor lighting system (System Number 12). This conversion, combined with mounting the lighting system on top of the sign would reduce light pollution damage by well over 90 percent. Annual costs for mercury vapor systems at these locations would be less than the existing fluorescent systems.
- Within the past few years ADOT has implemented a practice of mounting lighting systems on top of the sign in the Tucson and Flagstaff areas. Continuation of this practice with the sign lighting system recommended by this study (System Number 10) can further reduce light pollution damage. Following this practice for the 77 signs located in Tucson, the 16 signs located in Flagstaff and the three signs located in Benson will reduce by

roughly one-half the 61.4 percent of all light pollution damage attributable to these 96 signs.

The above actions can reduce the overall light pollution damage by approximately 47 percent. All other signs, if the recommendations of this study are followed, would be converted from fluorescent to high pressure sodium. This conversion will have both negative and positive effects. On the negative side, high pressure sodium creates more light pollution damage than fluorescent. On the positive side, the recommended high pressure sodium system creates much less light (15,000 lumens versus 40,000 lumens) and does a better job of directing that light onto the sign face rather than letting it escape directly to the open sky. The overall effect should be a substantial reduction in light pollution damage emanating from these signs.

CHAPTER 5 - CONCLUSIONS

The study conclusions are as follows:

- The Arizona Department of Transportation has annual expenditures of 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 size of sign on the Arizona freeway system. The great variety in sign sizes is a challenge in selecting the best sign lighting system.
- Observers placed about 3 to 4 times more importance in legibility distance than in color rendition.
- All ten sign lighting systems tested provided satisfactory luminance. Only one of the systems had unsatisfactory lighting uniformity. All ten systems had about the same legibility distance.
- Positioning of fixtures with respect to the sign dramatically affects performance in terms of both foot-candles of illumination and lighting uniformity. Performance is particularly influenced by tilt angle.
- 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 Number 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. The projected savings for the 231 new miles of freeway to be built in the Phoenix area is $352,972 per year in owning and operating costs.
- The above savings can make resources available for other highway safety and mobility needs. The highway maintenance dollar can be stretched further and the effectiveness and efficiency of maintenance forces can be enhanced.
- The study results represent an evaluation of lighting system alternatives available in the marketplace in early 1984.
- Compared to illuminated signs, one non-illuminated reflectorized background sign performed very well in the observer study.
- Light pollution damage to Arizona astronomical observatories can be reduced by over 50 percent by modifying a small number of signs.

CHAPTER 6 - RECOMMENDATIONS

Based on the findings of this research project, the research team makes the following recommendations.

- Lighting System 10 should be adopted for use at all new installations (except for locations which would cause substantial light pollution damage). System 10 consists of a 150 watt clear high pressure sodium lamp in a Holophane Panel-Vue fixture.
- With the exceptions noted below, all existing fluorescent lighting systems should be converted to Lighting System 10. It is recommended that 23 signs in Nogales be converted to a mercury vapor system.
- ADOT should continue its practice of mounting sign lighting systems overhead (above the sign) in the Tucson and Flagstaff areas and extend this practice to Nogales and Benson. Before doing so with the recommended lighting system, the overhead mounting should be tested to ensure that no objectionable glare or other problems result from overhead mounting.
- A substantial portion of the benefit from conversion is the reduction in power cost. The economic analysis assumed that power costs would be reduced in proportion to the reduction in power consumption. Before converson is implemented ADOT should ensure that utility companies will continue to charge in proportion to power consumption and not per location served.
- The relative economics of different lighting systems was somewhat sensitive to fixture price. If the fixture price for System 10 increases substantially, ADOT should consider one of the other lighting systems.

- The efficiency of the ballast is important. ADOT should specify a maximum power consumption per fixture when procuring.
- One non-illuminated, reflectorized background sign performed very well in the observer study. ADOT should consider reflectorizing sign background, as an alternative to illuminations for future installations.

CHAPTER 7 - RECOMMENDATIONS FOR FURTHER STUDY

Two areas are recommended for further study as described below:

1. EVALUATION OF NON-ILLUMINATED GUIDE SIGNS

Compared to illuminated signs, one non-illuminated reflectorized background sign performed very well in the observer study. Based on recent research studies a number of states have decided to use reflectorized backgrounds in lieu of illumination on many of their overhead signs. The recent research suggests that reflectorized systems offer satisfactory performance for legibility. Advantages of non-illuminated signs include no annual power cost and improved worker safety due to greatly reduced maintenance needs.

It is suggested that a research study be conducted which includes the following.

- A review of research conducted by others. This review would determine the performance of reflectorized systems. Research reports on this subject conducted in Virginia, Pennsylvania, and Ontario are included in the List of References.
- A simple observer study to compare the legibility distance provided by non-illuminted reflectorized signs and illuminated signs. There are currently about 10 overhead signs on the Superstition Freeway which have reflectorized backgrounds. The observer study could be done on the Superstition Freeway without installing new signing materials.
- An economic analysis. The annual costs of owning and operating a reflectorized background could be compared to the annual owning and operating cost of an illuminated sign using the recommended sign lighting system.

With the large number of new signs to be installed during the next 20 years the possible economic benefits of reflectorized sign systems would be worth investigating.

2. THE IMPORTANCE OF SEEING GREEN AT NIGHT

No research has been done to conclusively determine whether it is important for the driver to see the color green on overhead signs at night. A human factors study to answer this question would be useful.

2A-16 Illumination and Reflectorization

Regulatory and warning signs, unless excepted in the standards covering a particular sign or group of signs, shall be reflectorized or illuminated to show the same shape and color both by day and night. All overhead sign installations should be illuminated where an engineering study shows that reflectorization will not perform effectively. Reflectorization, non-reflectorization, or illumination of guide signs shall be as provided in subsequent sections.

2A-17 Means of Illumination

Illumination may be by means of:

1. A light behind the sign face, illuminating the main message or symbol, or the sign background, or both, through a translucent material; or
2. An attached or independently mounted light source designed to direct essential uniform illumination over the entire face of the sign; or
3. Some other effective device, such as luminous tubing or fiber optics shaped to the lettering or symbol, patterns of incandescent light bulbs, or luminescent panels that will make the sign clearly visible at night.

The requirements for sign illumination are not considered to be satisfied by street or highway lighting, or by strobe lighting.

2A-18 Means of Reflectorization

Reflectorization may be by means of:

1. Reflector "buttons" or similar units set into the symbol, message and border; or
2. Reflective sheeting, either on the sign background or where a white legend is used on a black or colored background in the symbol or message and border.

GUIDE SIGNS - EXPRESSWAYS

2E-6 Reflectorization or Illumination

Letters, numerals, symbols, and borders shall be reflectorized. The background of expressway guide signs may be reflectorized or nonreflectorized. However, the mixing of signs with reflectorized and nonreflectorized backgrounds in the same general area should be avoided.

In general, where there is no serious interference from extraneous light sources, reflectorized signs will usually be adequate. However, on expressways where much driving at night is done with low beam headlights, the amount of headlight illumination incident to an overhead sign display is relatively small. Therefore, all overhead sign installations should normally be illuminated. The type of illumination chosen should provide effective and reasonably uniform illumination of the sign face and message. When a sign is internally illuminated the requirement for reflectorized legend and borders does not apply.

GUIDE SIGNS - FREEWAYS

2F-13 Color, Reflectorization, and Illumination

Color, reflectorization and illumination of freeway guide signs shall conform to the provisions for expressway guide signs set forth in sections 2E-5 and 2E-6. In addition, the background of all overhead signs that are not independently illuminated shall be reflectorized. When a sign is internally illuminated the requirements for reflectivity do not apply.

Technological developments have produced a variety of types of illumination for highway signs. Internally illuminated signs, having translucent faces, are especially effective for freeway use. Their use may be justified for some installations. Where internal illumination is used, the sign colors shall appear essentially the same by night and by day.

APPENDIX B

Excerpt from

An Informational Guide for Roadway Lighting

Published by the American Association of State Highway and Transportation Officials

March, 1976

ROADWAY SIGN LIGHTING

General

The standards which are used in sign design are fully discussed in the Manual of Uniform Traffic Control Devices (MUTCD). Generalizations are used in order to provide the designer with a broad guideline which can be used in standardizing the task of sign design and, at the same time, be assured that the design provides the motoring public with messages that quickly and accurately convey necessary information.

The visual factors which enable the sign to convey a message are:

1. The contrast of the sign with objects in the background.
2. The contrast between the letters or symbols and the sign face.
3. The luminance of the message and of the sign face.
4. The distance from which the sign is viewed.
5. The viewing time available.
6. The size of the letters or symbols and length of legend.
7. The angle from which the sign is viewed.
8. The color.
9. The obstructions in front of the message.

Many of these factors are interrelating, but unless each of the above factors is taken into consideration separately, the probability of providing a sign that quickly and accurately conveys the necessary information is reduced considerably.

The task of the lighting designer is to make the message visible and legible during the hours of darkness.

Reflectorized signs rely on the light from vehicle headlights reflected from the sign surface at night to provide adequate luminance for the sign message to be read. The current trend dictated by safety considerations is to move the sign further away from the edge of the roadway; consequently, the sign is not in a position that will fully utilize the light from vehicle headlights. Large signs are often mounted high over the traffic lanes where headlights cannot provide adequate illumination of the sign panel.

Warrant

Sign lighting is warranted where the sign will not be adequately visible at night.

Types of Sign Lighting

The three main types of sign lighting are:

1. External—The outside face of the sign is uniformly flooded with light from fixed sources.
2. Internal—The light source or sources are enclosed within the sign and the message is conveyed by the difference of color and translucence of the material in the sign face.
3. Energized Legend—The words or symbols of the message are made up of lamps or luminous elements that may be visible during the daytime as well as at night. This type of sign is most common in variable message signs because the arrangement of the energized elements may be altered.

This guide covers external type sign lighting only.

Area Classification

Ambient luminance is the brightness of the background against which the sign is to be viewed by the motorist. Because there is no approved method for classifying ambient luminance, nor is there an approved method of measurement, the following is assigned as a guide:

1. Low—Rural areas where objects at night are visible only in bright moonlight. There is little or no other lighting.
2. Medium—May contain small areas of commercial lighting and/or roadway lighting.
3. High—Central business districts, high level lighted roadways, brightly lighted commercial advertising signs or highly illuminated parking facilities.

Sign Luminance and Contrast

Luminance will determine how adequately the sign attracts the motorist's attention from competing distractions of other roadway lighting and surrounding advertising signs. The legibility of the sign message is controlled by the contrast of the luminance of the message with the luminance of the background.

Uniformity

Maximum to minimum uniformity of the incident light on the whole sign face must be controlled. Maximum and minimum points that are closely spaced will interfere with the contrast of the letters and background reducing legibility.

The uniformity (maximum/minimum) for the illumination of externally lighted signs should not exceed a ratio of 6:1 and, if practical, a ratio of 4:1 is desirable. The difference in brightness tends to disappear when the ratio approaches 4:1.

Sign Color Standards

Standardized sign colors have been established as described in the MUTCD. The lighting designer should be sure that the light source will adequately illuminate and preserve the colors on the sign.

TABLE 3

LUMINANCES AND ILLUMINATION FOR SIGN LIGHTING

The following may be used as a guide for luminance levels:

Ambient luminance	low	medium	high
Luminance*	7-14 fl	14-28 fl	28-56 fl
Illumination	10-20 fc	20-40 fc	40-80 fc

*Maintained reflectance of 70 percent for white sign letters.

Luminaire Placement

The design and placement of sign structures normally in use by each State may be different. Therefore, it would be of little value to state that the luminaires should be top, bottom, side, or remotely mounted. However, bottom mounting, if practical, is generally preferred.

Considerations which must be evaluated before selecting the luminaire mounting are as follows:

1. The luminaire housing or shadow should not obstruct the motorists' view of the sign message.
2. Specular reflection should not cause disabling glare.
3. Spill light from the luminaires should not be directed into the eyes of other motorists.
4. Spill light should not create confusing patterns of light on the roadway surface.
5. Maintenance problems should not be created by any of the mountings.

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