HIGHWAY RESEARCH RECORD

Number 179

Night Visibility

7 Reports

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Foreword

Seeing at night and the highway driving task are the basic ingredients of the night visibility problem. Night driving accidents continue to occur at a high rate, and many research aspects of the problem of night driving are explored by the papers in this RECORD. This research will be of prime interest to fellow researchers in the field of nighttime visibility. The information presented on lighting and signing aspects will be of concern to manufacturers of lighting equipment and sign materials, to highway and traffic engineers, and to those concerned with safety at night. The papers are of special interest and importance to highway lighting and sign designers.

Thompson and Fansler present a study of the cost-effectiveness of street lighting lamp mounting heights and a method of evaluating alternate lighting designs. They conclude that a lighting design employing unit mounting heights of 40 to 50 ft provides more effective and economical light than the conventionally used 30-ft mounting height. They also suggest techniques for better evaluation of alternate highway lighting systems.

A team from Michigan tested and evaluated legibility characteristics associated with sign face brightness. Using a variable illuminated sign, they were able to determine relationships between sign luminance and legibility, and as one result, were able to suggest minimum and optimum sign face brightness values for typical rural, suburban and urban conditions.

Anderson and Carlson have investigated the patterns of spray from passing vehicles on mile post markers located near shoulders of Interstate type highways. An optimum placement of 14 ft laterally and 6 ft above the edge of the pavement is suggested for these markers. Nighttime brightness readings over a period of 18 months were taken to arrive at this conclusion.

Finch and King of the University of California have developed a pavement reflectometer for making field measurements of the directional reflection characteristics of pavement surfaces. The paper describes this instrument and operating procedures.

The twelfth annual review of the chief literature in the night visibility field is presented by Richards, who again surveys this research universe and shows its salient features. These annual reviews are an important part of the committee's work and are valuable to those concerned with this complex realm of knowledge.

Coleman and Sacks of the Pennsylvania Department of Highways have made a study of the effect of screen mesh fencing on headlight glare reduction when installed in a narrow median. It was found that some enhancement in driver's visual comfort was achieved although admittedly, being only a case study, more evaluation and research are needed.

The final paper is an abstract of significant research in the evaluation of pavement making materials by a Texas researcher. Derived from a National Cooperative Highway Research Program project, the abstract indicates that improvement in nighttime marking is possible if the problem is approached in a systematic manner and materials are used in accordance to the indicated needs.

Contents

Economic Study of Various Mounting Heights for Highway Lighting

JAMES A. THOMPSON and BENDER I. FANSLER, U. S. Bureau of Public Roads

The basic purpose of this report is to study the cost-effectiveness of various luminaire mounting heights and to present a method of evaluating alternate lighting designs that will lead to more economical highway lighting.

Initial average horizontal footcandles and uniformity of illumination have been computed for one direction of two-, three-, and four-lane divided highways using overhead mercury luminaires mounted at 30, 40, 45 and 50-ft heights. The variation of footcandles and uniformity with different mounting heights and luminaire spacings are discussed. Estimated initial, equivalent annual capital, maintenance and power costs per mile are presented for overhead and bridge rail lighting. Floodlighting of interchange areas with luminaires mounted at 100 ft is evaluated, and costs are compared to a conventional system of overhead luminaires mounted at 30 ft.

It is concluded that lighting designs with mounting heights of 40 to 50 ft provide more economical and effective lighting than those requiring the usual 30-ft mounting height. Higher mounting heights normally provide for safer and more aesthetic lighting designs.

The information and techniques given should enable highway agencies to evaluate alternate highway lighting system designs more accurately, and thus provide a wiser expenditure of public funds.

•LIGHTING of controlled-access highways in urban areas is receiving more attention each year. As traffic volumes and operating speeds of vehicles have increased, demands for highway lighting have developed. Although several highway agencies have extensive lighting programs, many have limited programs or none at all.

Despite the fact that an economic study is generally a basic requisite for an engineering project, highway agencies have made little use of such studies when designing highway lighting. The information and techniques in this report will enable highway agencies to evaluate proposed lighting projects more accurately and to provide a wiser expenditure of public funds for these projects.

Methods for evaluating some of the cost differences of alternative designs are given, and other information is given on factors that may contribute to the design choice—factors which cannot be evaluated monetarily, such as aesthetics and safety.

The basic purposes of this report are to evaluate lighting designs of different mounting heights for controlled-access highways, to present a method of evaluating alternate lighting designs that will lead to more economical highway lighting, and to determine how mounting heights affect lighting cost. Designs are computed for use of (a) 250-watt

Paper sponsored by Committee on Night Visibility and presented at the 46th Annual Meeting.

lamps on two-lane roadways, (b) 400-watt lamps on two-, three-, and four-lane roadways, (c) 700-watt lamps on three- and four-lane roadways, (d) 1000-watt lamps on four-lane roadways, (e) bridge rail lighting, and (f) floodlighting an interchange area. The commonly used mounting height of 30 ft is compared to mounting heights of 40, 45, 50, 3½ (bridge rail) and 100 ft (floodlighting towers or poles).

The suggested method of an economy study can be used for evaluating all practical alternate lighting design proposals. This type of study can be used to support planning and decision-making, and it will result in more efficient and economical highway lighting installations, thus contributing to the safety and comfort of the road user, while enhancing the aesthetic quality of the highway.

HIGHWAY GEOMETRICS AND LIGHTING DESIGNS

The geometric and lighting design criteria are based on current design standards and practices. The designs were selected so that the principal variable would be the mounting height of the luminaire.

Only designs for divided, controlled-access highways are considered. The roadway for only one direction of a divided highway is evaluated. Comparable lighting designs are computed for two-, three- and four-lane pavements having 12-ft lanes with a 10-ft right shoulder, with the luminaire located over the right edge of traveled way. Interchange areas are evaluated separately. Bridge rail lighting is evaluated with the through roadway lighting.

A design level of initial illumination of 1.0 ft-c and average to minimum uniformity not exceeding 3 to 1 were used for all overhead lighting. In a few cases, design adjustment to produce acceptable lighting uniformity resulted in some deviation from the 1.0 ft-c. The minimum acceptable level of average initial illumination selected was 0.8 ft-c.

All overhead lighting designs are based on a single manufacturer's design charts, using clear mercury lamps. In the design for higher mountings, increased lamp wattages are required to keep the initial 1.0 ft-c illumination approximately constant. The 700-watt (34,600-lumen) and 1,000-watt (53,000-lumen) lamps are used when design requirements exceed the capacity of the 400-watt (19,500-lumen) lamp. The 250-watt (10,500-lumen) lamps are used for 30-ft mounting heights only. The 42-in., 33-watt (2,190 lumens at 300 ma) fluorescent lamps in 6-ft luminaires are used for bridge rail lighting design.

Bridge rail lighting, which would eliminate light poles, uses continuous fluorescent lights mounted adjacent to, or in lieu of, a bridge railing. Although the concept and design of low-mounted light is different from overhead lighting, comparisons are made on installations judged comparable. Horizontal footcandles, glare, and uniformity of illumination, which are the most common performance criteria used in designing a lighting system, do not appear to be a logical basis of comparison between low-mounted and overhead lighting. A recent research study (6) on bridge rail lighting reports that the average value of roadway illumination for rail lighting should be computed by a different method. Although the design methods are different, the low-mounted lighting is judged similar to the overhead system designs used in this study.

Other design criteria assumed to be constant for the lighting systems so that the principal variable would be the mounting height are:

1. Galvanized steel poles, anchor base, and concrete foundations;
2. Twelve-foot brackets, luminaire located over edge of traveled way;
3. Underground wiring system using cable-conduit;
4. Multiple system circuitry;
5. Power delivered at secondary voltage (no load center considered);
6. Median sufficient width so that lighting from oposite lanes not a factor;
7. Comparable pavement reflectance characteristics not requiring adjustments in computing average initial illumination;
8. Time and controls equivalent for all systems (therefore, not considered);
9. Medium semicutoff luminaires of IES types II and III (3); and
10. Ballast in luminaires.

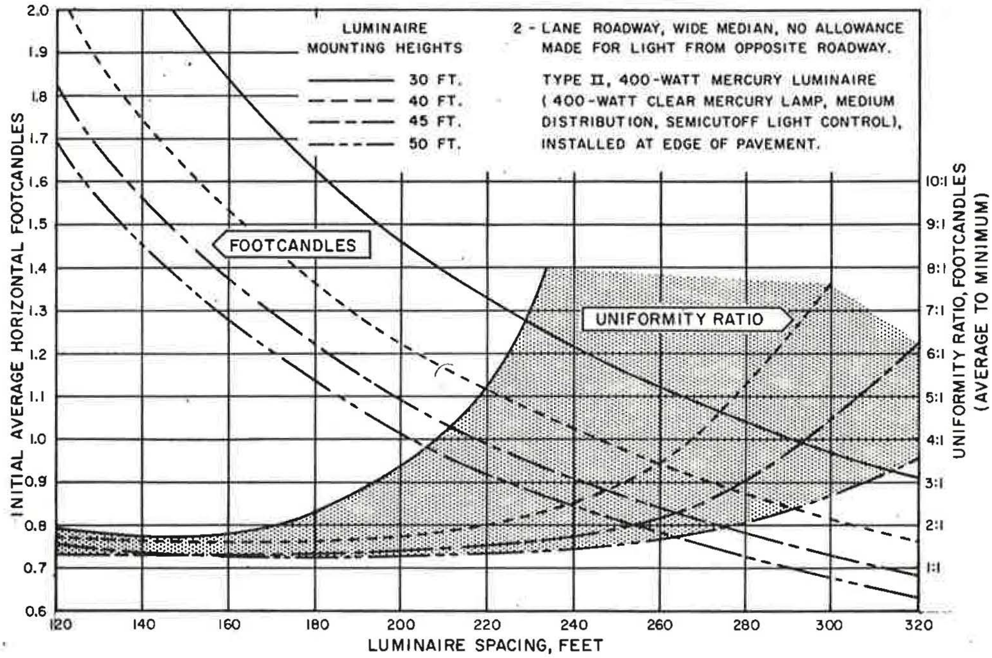

Figure 1. Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for two-lane roadway.

Interchange floodlighting may be designed so that mounting heights of the luminaires range from 80 to 150 ft. Each interchange should be evaluated separately for the mounting heights that would best fit the geometric features. A floodlighting system differs somewhat in concept from the 30 to 50-ft mounting height designs. Computed design values may be similar to controlled lens lighting, whereas roadway brightness (measured foot-Lamberts) may differ. The floodlighting design generally used was considered to be comparable to the overhead system designs.

The interchange area selected (Fig. 1) consists of 6.75 mi of separate roadways. Floodlighting designs using the 400 and 1000-watt lamps are evaluated. An industrial type, symmetrical distribution luminaire design using the 1000-watt lamps is also evaluated.

COST DATA CONDITIONS AND ESTIMATES

The cost data in this report are based on information considered typical of national averages. These data are given as a basis for determining relative initial, operating, and maintenance costs for lighting systems in which luminaires are installed at different mounting heights. These cost data should not be used as a guide for estimating the cost of specific highway lighting projects because material delivery charges, electric energy, labor rates, and other costs may vary with geographical locations.

Initial costs for individual items are combined to obtain a total initial cost per mile, which was statistically converted and is restated as an equivalent annual cost. Luminaire maintenance and lamp replacement costs are also computed and are stated as equivalent annual costs. The estimated costs of luminaire cleaning and lamp replacement are based on maintenance being performed by owners and users. Repairs necessitated by vandalism, pole knockdowns, and other miscellaneous factors are considered in the evaluation.

The basic formula used to determine the equivalent annual capital cost, EAC, of a lighting system for a life expectancy of n years, from an initial cost, C, at an interest rate i percent is

$$EAC = C \frac{i(1 + i)^n}{(1 + i)^n - 1}$$

The expression $i(1 + i)^n/(1 + i)^n - 1$ is called the uniform series capital recovery factor. As crf represents the uniform series capital recovery factor, the formula becomes EAC = C (crf - i% - n). For the computations in this study, n = 20 and i = 6%; therefore

$$EAC = C\ (crf - 6\% - 20)$$

The basic formula to find the present worth of a single investiment (I), n years in the future, at an interest rate i% is as follows:

$$PW\ of\ I = I \frac{1}{(1 + i)^n}$$

The expression $1/(1 + i)^n$ is called the single payment present worth factor. As pwf' represents the single payment present worth factor, the formula becomes PW of I = I (pwf' - i% - n). For the computations in this study, i = 6% and n = number of years hence that an investment is proposed; therefore

$$PW\ of\ I = I\ (pwf' - 6\% - n)$$

Normally, the lighting system constructed and operated by a governmental agency is financed from road user taxes in a method similar to that used to finance roadway construction. The road-user taxpayer, if allowed to keep this tax money, could invest it and earn a return. This lost-investment-opportunity cost should be the minimum interest used for determinations of the equivalent annual cost for an initial lighting investment.

TABLE 1

6 PERCENT COMPOUND INTEREST FACTORS[a]

Year	Single Pavyment Present Worth Factor (pwf')	Uniform Series Capital Recovery Factor (crf)
1	0.9434	1.06000
2	0.8900	0.54544
3	0.8396	0.37411
4	0.7921	0.28859
5	0.7473	0.23740
6	0.7050	0.20336
7	0.6651	0.17914
8	0.6274	0.16104
9	0.5919	0.14702
10	0.5584	0.13587
11	0.5268	0.12679
12	0.4970	0.11928
13	0.4688	0.11296
14	0.4423	0.10758
15	0.4173	0.10296
16	0.3936	0.09895
17	0.3714	0.09544
18	0.3503	0.09236
19	0.3305	0.08962
20	0.3118	0.08718

[a]These factors are based on investments made at the end of each year (maintenance, replacement and operation costs are assumed to be charges paid at the end of each year); zero time (n = 0) is assumed to be the day the installation is completed and operational.

A minimum interest rate should be established that is based on rates of investment opportunities foregone by the taxpayers, but it should be tempered by the element of risk for the 20-yr predicted life of the lighting system. The minimum attractive interest rate should include a safety factor as recognition that even the best engineering estimates are subject to error. Therefore, an interest rate of 6 percent is used for all present worth and capital recovery computations (Table 1). A 20-yr equipment life with no salvage value is used because 20 years is estimated to be the economic life of a majority of the system components.

It is assumed that the lighting system is owned by a governmental agency, which would eliminate taxes and insurance costs from the evaluation.

Procedures for maintaining a highway lighting system should be considered in the design of the system. However, because of the variations in mounting heights and the uncertainty in determining a maintenance factor for bridge rail lighting, and to a lesser degree for the 100-ft

TABLE 2

LUMINAIRE AND LAMP MAINTENANCE COST DATA

Luminaire Mounting Height (ft)	Luminaire Cleaning Schedule	Est. Cost of Cleaning Each Luminaire ($)	Lamp Wattage	Lamp Group Replacement Schedule (yr)	Est. Lamp Cost ($)
3½	Semiannually	2.00[a]	33	2	2.00
30	Semiannually	1.50	250 400	4	8.00 8.00
40	Annually	1.50	400 700 1000	4	8.00 14.00 16.00
45	Annually	1.75	400 700 1000	4	8.00 14.00 16.00
50	Annually	2.00	400 700 1000	4	8.00 14.00 16.00
100	Biannually	3.00	400 1000	4	8.00 16.00

[a]Estimate based on current maintenance practice, but more frequent cleaning would obviously be required to make this type lighting comparable with overhead lighting.

mounting heights, maintenance factors such as lumen maintenance and dirt were not included in the evaluation of the designs reported here. The omission of maintenance factors permitted logical comparisons of the designs. Luminaire cleaning schedules vary, depending on the mounting height, highway geometrics, traffic volumes, and location. The luminaire and lamp maintenance cost data selected for this study are given in Table 2; material and installation cost estimates are given in Table 3; and cost summary data are given in Tables 4 to 8. The total kilowatt electric load per luminaire is based on lamp wattage, plus ballast loss wattage, plus a line loss of 5 percent. Lighting operation is estimated at 4,000 hr/yr. The assumed current cost is $0.015 per kilowatt hr. Example computations for initial cost estimates and maintenance cost estimates are included in Appendixes A and B.

TABLE 3

MATERIAL AND INSTALLATION COST ESTIMATE

Item	Cost ($)					
	3½ Ft	30 Ft	40 Ft	45 Ft	50 Ft	100 Ft
Luminaire and ballast						
6-ft fluorescent	126	-	-	-	-	-
250-w mercury	-	92	-	-	-	-
400-w mercury	-	92	92	92	92	-
700-w mercury	-	-	144	144	144	-
1000-w mercury	-	-	158	158	158	-
400-w mercury floodlight	-	-	-	-	-	125
1000-w mercury floodlight	-	-	-	-	-	200
Lamps						
42-in. T6 fluorescent	2	-	-	-	-	-
250-w mercury	-	8	-	-	-	-
400-w mercury	-	8	8	8	8	8
700-w mercury	-	-	14	14	14	-
1000-w mercury	-	-	16	16	16	16
Poles	-	200	250	275	325	2000
Installation per luminaire[a]	40	350	400	425	450	750

[a]Including foundations, bolts, wiring, conduit, trenching, and all miscellaneous labor and materials; per pole.

TABLE 4

COST SUMMARY FOR TWO-LANE ROADWAY

Design and Cost Data	Mounting Height					
	30 Ft	30 Ft	40 Ft	45 Ft	45 Ft	50 Ft
Light distribution type	II	II	II	II	II	II
Lamp watts	250	400	400	400	400	400
Uniformity ratio	3.0:1	3.0:1	3.0:1	3.0:1	1.6:1	1.4:1
Avg. initial horizontal footcandles	0.83	1.50	1.00	0.79	1.00	1.00
Minimum footcandles	0.29	0.50	0.33	0.27	0.64	0.72
Luminaire spacing, ft	190	195	250	280	220	210
Luminaires, no./mi	28	27	21	19	24	25
Initial cost per mile	$18,200	$17,550	$15,750	$15,200	$19,200	$21,875
Annual costs per mile						
Equivalent capital	$ 1,587	$ 1,530	$ 1,373	$ 1,325	$ 1,674	$ 1,907
Equivalent maintenance	129	124	65	64	81	90
Power	512	770	599	542	684	713
Total	$ 2,228	$ 2,424	$ 2,037	$ 1,931	$ 2,439	$ 2,710

TABLE 5

COST SUMMARY FOR THREE-LANE ROADWAY

Design and Cost Data	Mounting Height							
	30 Ft	40 Ft	40 Ft	40 Ft	45 Ft	45 Ft	50 Ft	50 Ft
Light distribution type	II	II	II	II	II	II	II	II
Lamp watts	400	400	400	700	400	700	400	700
Uniformity ratio	3.0:1	3.0:1	2.3:1	3.0:1	1.8:1	3.0:1	1.8:1	3.0:1
Avg. initial horizontal footcandles	1.60	0.83	0.96	1.29	0.90	1.02	1.00	0.85
Minimum footcandles	0.53	0.27	0.42	0.44	0.50	0.33	0.55	0.28
Luminaire spacing, ft	150	255	220	225	220	265	190	290
Luminaires, no./mi	35	21	24	24	24	20	28	18
Initial cost per mile	$22,750	$15,750	$18,000	$19,392	$19,200	$17,160	$24,500	$16,794
Annual costs per mile								
Equivalent capital	$ 1,983	$ 1,373	$ 1,569	$ 1,691	$ 1,674	$ 1,496	$ 2,136	$ 1,464
Equivalent maintenance	161	65	75	104	81	91	101	87
Power	998	599	684	1,174	684	978	798	880
Total	$ 3,142	$ 2,037	$ 2,328	$ 2,969	$ 2,439	$ 2,565	$ 3,035	$ 2,431

TABLE 6

COST SUMMARY FOR FOUR-LANE ROADWAY

Design and Cost Data	Mounting Height								
	30 Ft	40 Ft	40 Ft	40 Ft	45 Ft	45 Ft	50 Ft	50 Ft	50 Ft
Light distribution type	III	III	II	III	II	III	III	II	III
Lamp watts	400	400	700	1,000	700	1,000	400	700	1,000
Uniformity ratio	3.0:1	2.4:1	3.0:1	3.0:1	3.0:1	3.0:1	2.2:1	3.0:1	3.0:1
Avg. initial horizontal footcandles	1.09	1.00	1.13	1.80	0.91	1.42	1.00	0.80	1.28
Minimum footcandles	0.36	0.43	0.36	0.60	0.30	0.47	0.47	0.27	0.43
Luminaire spacing, ft	185	180	220	210	255	250	160	280	265
Luminaires, no./mi	29	29	24	25	21	21	33	19	20
Initial cost per mile	$18,850	$21,750	$19,392	$20,600	$18,018	$18,354	$28,875	$17,727	$18,980
Annual costs per mile									
Equivalent capital	$ 1,643	$ 1,896	$ 1,691	$ 1,796	$ 1,571	$ 1,600	$ 2,517	$ 1,545	$ 1,655
Equivalent maintenance	134	90	104	118	96	104	119	92	104
Power	827	827	1,174	1,725	1,027	1,449	941	929	1,380
Total	$ 2,604	$ 2,813	$ 2,969	$ 3,639	$ 2,694	$ 3,153	$ 3,577	$ 2,566	$ 3,139

TABLE 7

COST SUMMARY FOR 3½-FT MOUNTING HEIGHT[a]

Initial cost per mile	$220,200
Annual costs per mile	
Equivalent capital	19,197
Equivalent maintenance	7,995
Power	4,290
Total	$ 31,482

[a]Design: 3½-ft roadway lighting designs provide for two continuous rows of luminaires, one on each side of roadway. This design is identical for two-, three-, or four-lane roadways. The luminaire is assumed to replace the top bridge rail. This design requires 1625 luminaires/mi.

SAFETY

Few subjects have received so much attention and so little opposition as highway safety. The three major variables of of highway safety are the driver, the vehicle, and the highway. Each variable considered separately is complex and indefinite; combined, these variables present a mass of intangibles so nebulous and replete with unsupported opinions that it is impractical to establish costs for accidents.

A recent study (7) reports that lighting contributes to safer highway operations during darkness, but formal research has not yet evaluated the degree of safety provided at night by highway lighting, nor has it established the degree of hazard created by the presence of lighting poles along the highway during daylight hours as well as at night. Regardless of this lack of conclusive evidence, it seems logical, when considering safety, to favor a lighting system designed for fewer poles per mile. It also seems logical to assume that operation in the interchange area would be safer if the number of lighting poles were reduced and the poles were located farther from the edge of the travelway. Towerlighting, in lieu of roadside poles, would provide such a situation. Lighting the entire interchange area rather than only the roadways might also improve safety.

The ability to see an object is reduced by glare in the field of view. The glare may be reduced by increasing the luminaire mounting height when candlepower values remain constant. If glare is reduced, it follows that the result will be better visibility and improved safety.

The authors, supported by observations, believe that an improvement in the uniformity of illumination, even if it involves a slight reduction in level of intensity, would provide better highway lighting. This is one of the advantages of higher mounting heights and should be evaluated as a safety improvement.

Bridge rail lighting cannot be evaluated in the same manner as general highway lighting; poles on bridges are not considered hazards because they are located on top of or behind the bridge parapet. Because the mounting height of the bridge rail lighting is approximately on a level with the driver's eye, any resultant glare would be a negative value in highway safety considerations. Also, because of the lack of light directed

TABLE 8

COST SUMMARY FOR INTERCHANGE FLOODLIGHTING[a]

Design and Cost Data	Mounting Height			
	30 Ft	100 Ft	100 Ft	100 Ft
Light distribution type	II	Flood	Floor	V
Lamp watts	400	400	1000	1000
Uniformity ratio	3:1	Approx. 3:1	Approx. 3:1	Approx. 2:1
Avg. initial horizontal footcandle	1.5	Approx. 1.0	Approx. 1.0	Approx. 1.0
Total no. of luminaires	183	492	204	108
Total no. of poles	183	12	12	27
Luminaires per pole	1	41	17	4
Initial costs	$118,950	$98,436	$77,064	$101,628
Annual costs				
Equivalent capital	10,370	8,582	6,718	8,860
Equivalent maintenance	844	2,268	1,269	672
Power	5,216	14,022	14,076	7,452
Total	$ 16,430	$24,872	$22,063	$ 16,984

[a]Through roadways are two 12-ft lanes, and all ramps are one lane except for the directional ramp which is two lane.

to the top and rear of the vehicles, a negative safety value may be introduced in the evaluation of bridge rail lighting. However, driving conditions during fog or other bad weather may be improved by bridge rail lighting because roadway delineation is improved.

AESTHETICS

All other design features being equal, the height of the pole can either enhance or detract from the aesthetic quality of the highway. On narrow roadways, lighting from 30-ft mounting heights is satisfactory. On wide roadways designed with a wide median, or more than one median, a 30-ft mounting height may require four or more rows of poles. The result could be an unsightly "forest of poles." A higher mounting height, combined when necessary with either 700 or 1,000-watt luminaires, may permit a reduction in both the number of rows and number of poles, which would improve the appearance of the highway at all times.

The taller poles are aesthetically acceptable when the ratios of roadway widths to pole heights are considered. When the design norm is considered to be 24-ft, two-lane, two-way roadway (two 12-ft lanes and two 10-ft shoulders) equipped with 30-ft poles, the ratio of roadway width to height of pole is 44:30, or approximately 1.5:1. Therefore, a 50-ft pole should be acceptable for roadway widths of 75 ft or more, and 100-ft poles or towers should be acceptable for roadway widths of 150 ft or more. Also, in areas where the type of property development adjacent to the highway is higher than the lighting poles, i.e., where there are industrial plants, high-rise apartments, or deep roadway cuts, taller poles, or even lighting towers, blend more readily with the local environment than the shorter poles. However if the adjacent area has one-story dwellings and the roadway cuts are shallow, use of shorter poles may be more desirable.

Towerlighting in wide interchange areas appears to be aesthetically desirable where acceptable width to height ratios exist. Lighting at night of landscaped areas between ramps enhances the appearance of the entire interchange area.

The spill of light off the highway, which may occur when the mounting heights are higher than the surrounding areas, could be either a positive or a negative factor in the design evaluation of highway lighting. The quality of the factor would depend on the property and the property owner. In a highly developed area where crime is a problem, spilled light could be an asset for owners of business and residential property. In relation to police protection, lighting is an asset in any area. Spilled light could be a negative factor and a source of complaints in private residential areas where crime is not a problem. In apartment dwelling and business areas, lighting is normally furnished in walking and parking areas, so spilled light from the highway may be desirable.

Bridge rail lighting has been promoted as an aesthetic improvement although it may break the continuity of overhead lighting for the highway. The use of rail lighting rather than lighting poles on bridges, seems to present a more pleasing appearance during the day. This factor would be more important in designs for bridge lighting on a parkway or scenic highway.

As in the evaluation of safety, a monetary value cannot be assigned to the aesthetic qualities of highway lighting, but for specific conditions some thought should be given to choosing a design to blend with the highway and adjacent property.

DISCUSSION OF RESULTS

The safest and most aesthetic overhead lighting system may be considered the one which provides adequate and effective illumination with the fewest poles. The number of poles per mile can be reduced by using higher mounting heights combined, when necessary, with higher wattage luminaires and lamps. As poles are the most costly component of the lighting system, a design which reduces the number of poles generally offsets the cost of taller poles, larger foundations, and larger luminaires. Lamps are a small part of the cost.

Three factors are of prime consideration in the effectiveness of any highway lighting system: level of illumination, uniformity of illumination, and control of glare. The uniformity of illumination may be more important than the footcandle level of illumination. And, as the mounting height of lamps is increased, the apparent improvement in light distribution may be better than a comparison of average to minimum uniformity ratios would indicate. It seems that the ratio of maximum to minimum illumination values should receive more consideration when alternatives are evaluated. Further study to determine a more positive evaluation of light distribution related to uniformity in level of illumination is recommended. Results of such a study might show that the road user's ability to perform the driving task is improved more by better uniformity in level of illumination than by an increase in the footcandles of illumination.

Luminaires having cutoff vertical light distribution help to reduce glare and may provide better visibility for the motorists than semicutoff luminaires. The least glare control is possible when noncutoff luminaires are used, and they probably should not be considered for expressway lighting.

With narrow medians, the higher the mounting height the better distribution of light on the opposite roadway. Because the position of the luminaire in relation to the traveled way is not as critical when higher mountings are used, it may be possible to use shorter bracket arms with some saving in initial cost.

When 30-ft mounting heights are used, a pronounced bright spot is present under or near each luminaire. The size and brightness contrast of these spots can be reduced considerably by use of higher mountings. Less variation is present in pavement brightness and the frequency of eye adaptation is lessened because the driver is not traveling through a succession of intermittent bright spots.

Figures 2 through 7 show that the 30-ft mounting height designs are more sensitive to spacing-uniformity ratios. As the mounting height is increased, the spacing-uniformity curves become flatter, indicating that the uniformity ratio is less sensitive to differences in luminaire spacing. This also suggests that the differences between designed

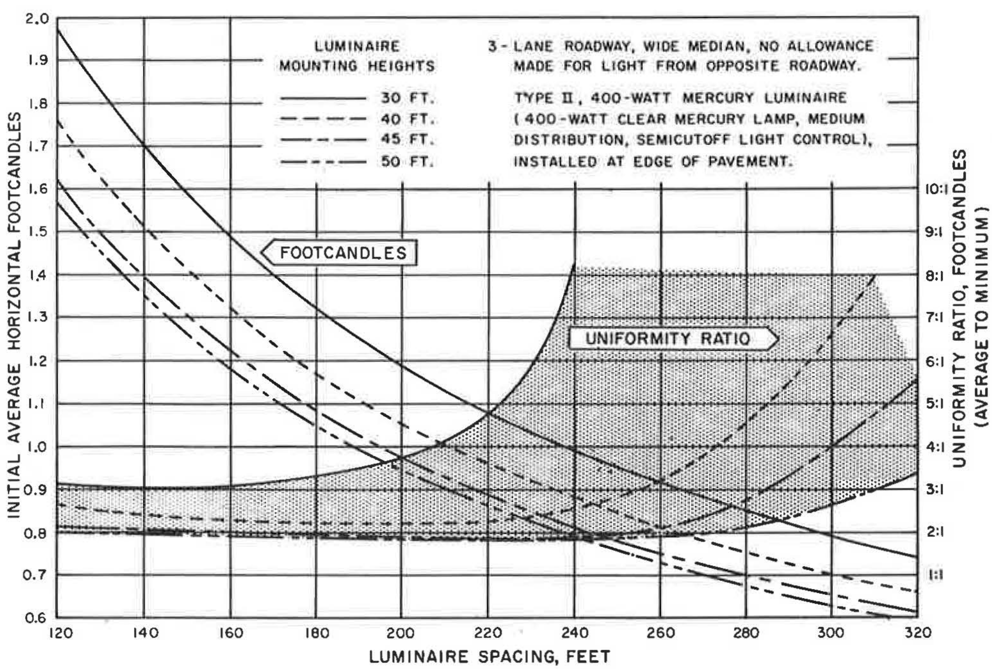

Figure 2. Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for three-lane roadway.

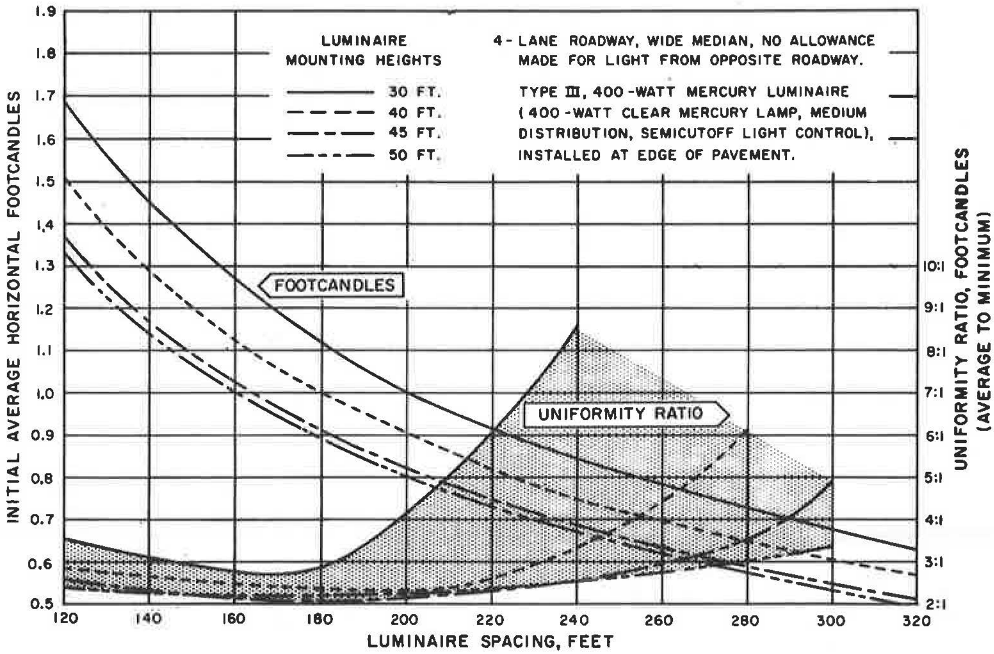

Figure 3. Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for four-lane roadway for 400-watt lamp.

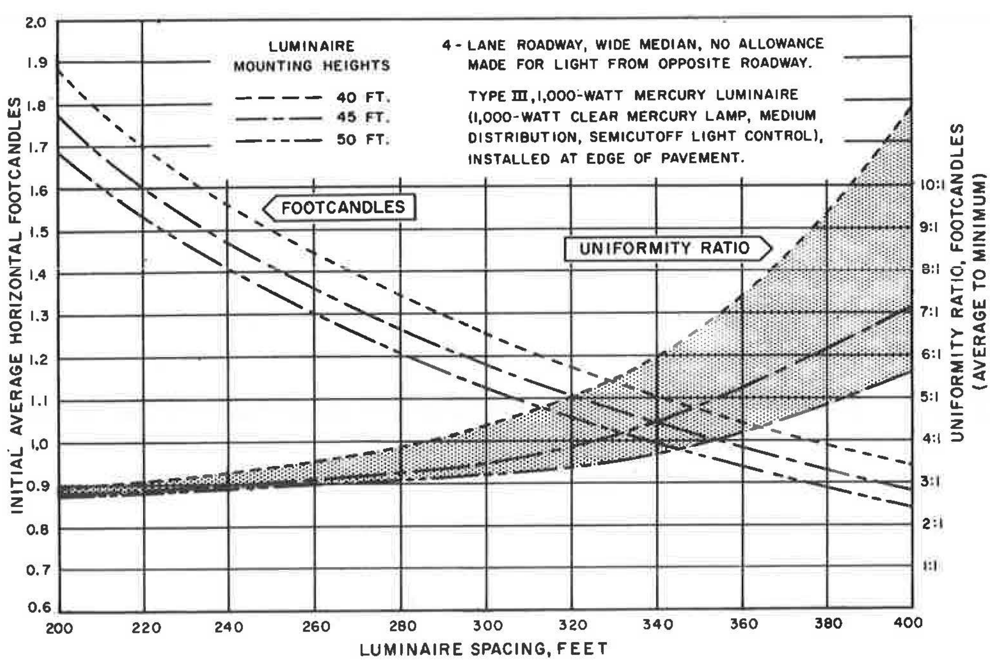

Figure 4. Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for four-lane roadway for 1000-watt lamp.

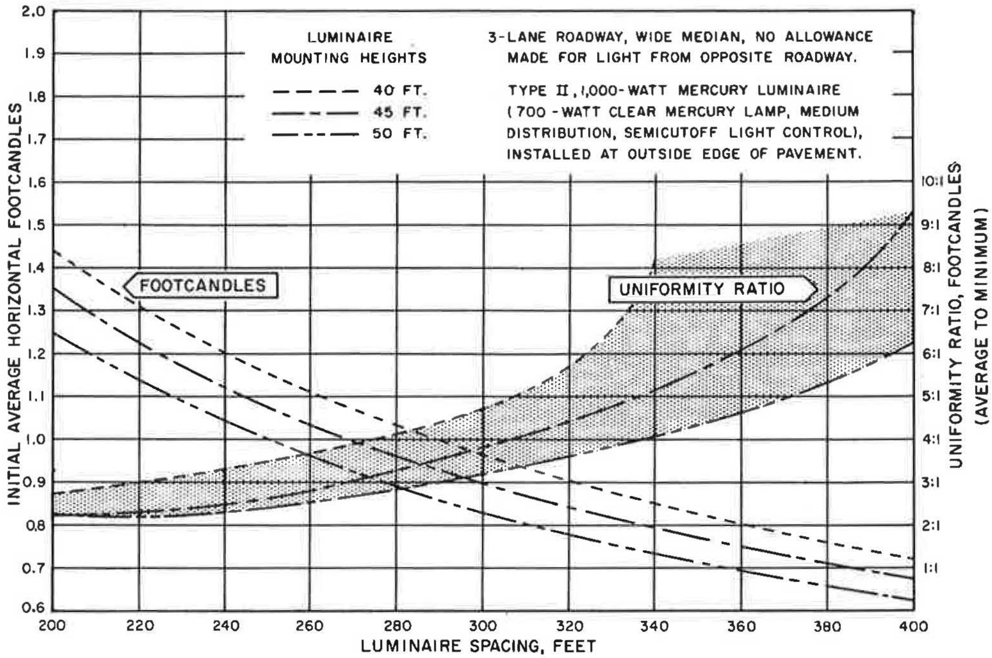

Figure 5. Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for three-lane roadway.

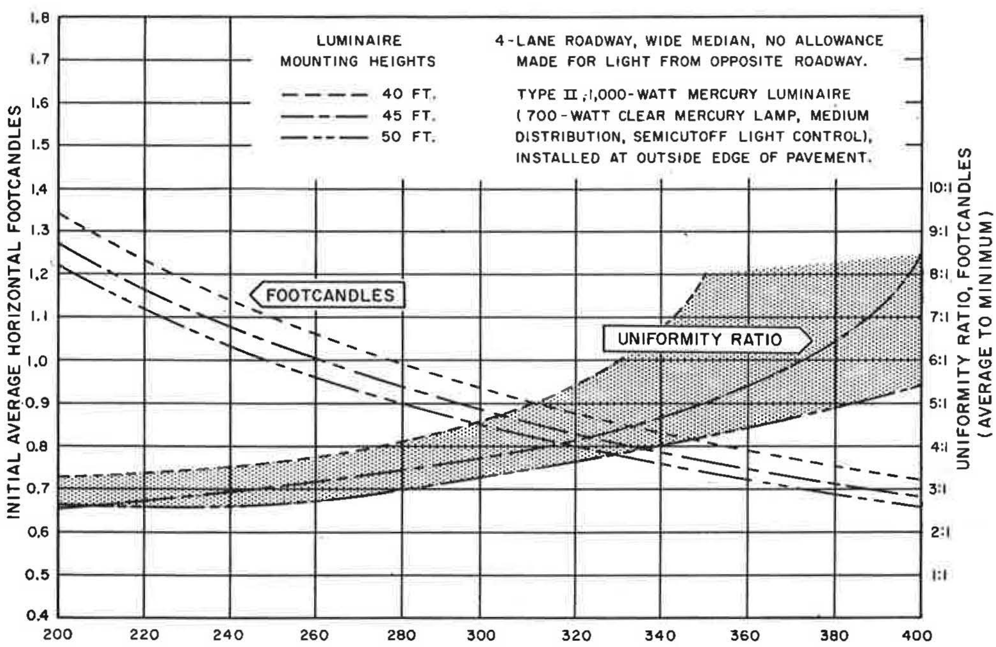

Figure 6. Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for four-lane roadway.

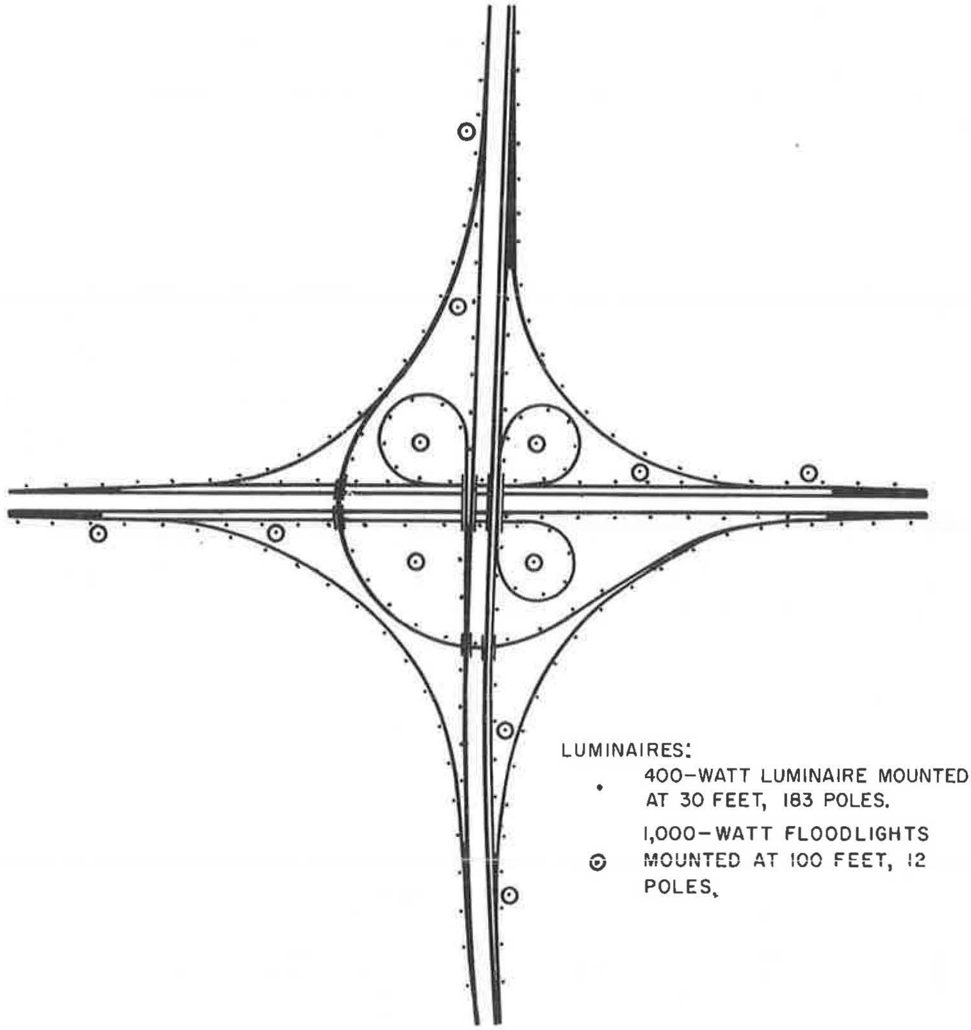

Figure 7. Interchange layout of lighting poles for 30 and 100-ft mounting heights.

and actual lighting results would be less as the mounting height is increased. A cost-effective analysis indicates that a mounting height of 30 ft is seldom the most desirable lighting for a divided, controlled-access highway.

The family of curves (Figs. 2-7) can aid in the preliminary design of a lighting system. For example, for a 30-ft mounting height of luminaires on a two-lane roadway, 1.5 initial footcandles are required for a 3:1 lighting uniformity ratio and 1.4 footcandles for a 4:1 uniformity ratio (Fig. 2). At the 30-ft mounting height it also shows that it is impractical to design for an 0.8 to 1.2 initial average horizontal footcandle level of illumination and provide an acceptable uniformity ratio.

A comparison with the 40-ft mounting height shows that designs for an 0.8 to 1.2 average level of illumination can be obtained with uniformity ratios of 8:1 or 1.7:1. For the same intensity, the uniformity ratio varies from 2.7:1 to 1.4:1 for a 45-ft mounting height and 1.6:1 to 1.2:1 for a 50-ft mounting height.

An analysis of the design and cost data indicates that a 45-ft mounting height would be the most economical lighting design for a two-lane roadway (Table 4). This height would also be better than a 30-ft mounting height in relation to safety and aesthetics.

A 50-ft mounting height would provide the most effective lighting, the best uniformity in illumination, and the least glare. The 30-ft mounting height would provide the greatest value of average initial footcandles.

For a three-lane roadway, a mounting height of 40 ft would be the most economical design (Table 5). A 45-ft mounting height would provide the most effective lighting. At a mounting height of 50 ft, glare would be least; also, the 50-ft mounting height design would provide the best system in relation to safety and aesthetics. The 30-ft mounting height results in the highest average initial footcandles. On the basis of the cost-effectiveness evaluation, the use of either a 45 or 50-ft mounting height would be favored.

On a four-lane roadway, a 50-ft mounting height would be a better lighting system on the basis of economy, uniformity, effectiveness, glare, safety and aesthetics (Table 6). The 40-ft mounting height would provide the most initial footcandles of illumination.

Bridge rail or low-mounted continuous fluorescent lighting (3½ ft) should be restricted to locations where overhead lighting cannot be used (Table 7). The total annual cost for such an installation is approximately 10 times that of conventional overhead lighting systems. Pavement brightness requirements may be met on two-lane roadways at the 3½-ft mounting height, but whether these requirements are met on three- and four-lane roadways is questionable. Although a rail lighting system contributes to the aesthetic appearance of a bridge and helps delineate the roadway at night, the problems inherent in maintaining such a lighting system, coupled with the increased annual cost, should rule out such a design except under unusual circumstances. Exposure of luminaires to dirt from frequent splashing from moisture on the highway makes it impractical to maintain the same degree of cleanliness possible with overhead lighting.

Definite conclusions regarding towerlighting for interchange areas from heights of 100 ft cannot be made from a study of a single interchange (Table 8). Several alternate systems are possible, and it appears that costs may be about equal to the costs of a conventional 30-ft mounting height design. Interchange floodlighting has not been used in this country, but installations now exist in Europe (12, 13). Safety and aesthetic considerations favor this type of lighting for interchanges because fewer poles are required, and recent lamp developments may encourage its use in the future. Actual installations are needed to evaluate fully the effectiveness and economy of this type lighting.

Flexibility in choice of equipment and design of highway lighting systems seems to increase in relation to the mounting height of the systems. Studies to determine the pavement brightness, glare and effectiveness in fog or wet pavement are needed.

The cost-effectiveness evaluation of specific lighting installations may vary, depending on warranting conditions, the type of property development adjacent to the highway, the highway geometrics, and the personal choice of the decision maker. Also, additional information regarding the differences in design criteria and field measurements would influence the final decision.

CONCLUSIONS

Highway lighting systems designed to use luminaires mounted at heights of 40 to 50 ft would be more economical and effective than designs for luminaires mounted at 30 ft. Use of these higher mounting heights generally would provide safer and more aesthetic lighting. The previously accepted standard mounting height of 30 ft may be considered undesirable for divided highways.

Many facets of the current design criteria need reevaluation in view of higher mounting height designs and recent lamp developments. Uniformity should be studied and thoroughly analyzed because the maximum to minimum ratio of illumination uniformity is a more logical basis for comparison of a lighting system's effectiveness than the average to minimum ratio currently in use.

The designs using higher mounting heights are more flexible and can be readily modified to use new lamp and luminaire improvements. Recent trends in lamp development are toward increased lamp efficiency and higher lumen output.

The cost of continuous low-mounted fluorescent bridge rail lighting is considerably greater than that of overhead lighting. Considering the questionable effectiveness and impractical maintenance of bridge rail lighting, it is concluded that it would not be a wise investment of public funds.

The cost information in this report is a relative value, and should not be used for project justification or budget preparation.

Whether future experimentation or research furnishes factual data or not, an engineering study such as this can lead to better lighting systems by providing a means for making relative comparisons of proposed designs. Even without more research or factual data, this type of study can be a means of comparing alternatives which will provide more economical and effective highway lighting systems.

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Appendix A

EXAMPLE COMPUTATIONS FOR INITIAL COST ESTIMATES[a]

M. H. (ft)	Installation Cost per Luminaire ($)	Luminaires per Mile	Initial Cost per Mile ($)	Equivalent Annual Capital Cost[b] ($)
3½	168	1625	220,200[c]	19,197
30	650	28	18,200	1,587
30	650	27	17,550	1,530
40	750	21	15,750	1,373
45	800	19	15,200	1,325
45	800	24	19,200	1,674
50	875	25	21,875	1,907
100	6422[d]	12[e]	77,064[f]	6,718[g]

[a]For two-lane roadway: initial cost per mile = installation cost/luminaire × number of luminaires/mile; installation cost/luminaire from Table 3; and number of luminaires/mile from Table 4.
[b]Equivalent annual capital cost = initial cost per mile × (crf - 6% - 20).
[c]$168 × 1,625 - $52,800 (cost of top br. rail) = $220,200.
[d]Cost of a single 100-foot pole with seventeen 1,000-watt floodlights.
[e]No. of 100-ft poles in the interchange area.
[f]Initial cost of lighting interchange.
[g]Equivalent annual capital cost of lighting interchange excluding maintenance and power.

Appendix B

EXAMPLE COMPUTATIONS FOR MAINTENANCE COST ESTIMATES

Equivalent annual maintenance cost per luminaire = Annual cost of cleaning (from Table 2) + Equivalent annual cost of lamp replacement

Equivalent annual cost of lamp replacement = I (pwf' - 6% - n) (crf - 6% - n)

3-½ ft M.H. { I = \$2.00; n = 2, 4, 6, 8, 10, 12, 14, 16 and 18

400-watt lamp { 30 ft M.H., 40 ft M.H., 45 ft M.H., 50 ft M.H., 100 ft M.H. — I = \$8.00; n = 4, 8, 12 and 16

1000-watt lamp { 30 ft M.H., 40 ft M.H., 45 ft M.H., 50 ft M.H., 100 ft M.H. — I = \$16.00; n = 4, 8, 12 and 16

For 3½ ft M.H.

I	n	(pwf' - 6% - n)	PW
\$2	2	0.8900	\$1.78
2	4	0.7921	1.58
2	6	0.7050	1.41
2	8	0.6274	1.25
2	10	0.5584	1.12
2	12	0.4970	0.99
2	14	0.4423	0.88
2	16	0.3936	0.79
2	18	0.3503	0.70
		Total PW =	\$10.50

Equivalent annual cost of lamp replacement for 3-½ M.H. per luminaire is

10.50 (crf - 6% - 20)
10.50 (0.08718) = \$0.92

For 30, 40, 45, 50, and 100 ft M.H.:
400-watt lamp (1000-watt lamp)

I	n	pwf' - 6% - n		
\$8 (\$16)	4	0.7921	\$ 6.34	(\$12.67)
8 (16)	8	0.6274	5.02	(10.04)
8 (16)	12	0.4970	3.98	(7.95)
8 (16)	16	0.3936	3.15	(6.30)
			\$18.49	\$36.96

Equivalent annual cost of lamp replacement per luminaire is

\$18.49 (\$36.96) × (crf - 6% - 20)
\$18.49 (\$36.96) × (0.08718) =
\$ 1.61 (\$ 3.22)

(1) M.H.	(2) Annual Cost of Cleaning (\$)	(3) Equiv. Annual Cost of Lamp Replacement (\$)	(2) + (3) Equiv. Annual Maintenance Cost Per Luminaire (\$)
3½ ft	4.00	0.92	4.92
30 ft (250 w)	3.00	1.61	4.61
30 ft (400 w)	3.00	1.61	4.61
40 ft (400 w)	1.50	1.61	3.11
45 ft (400 w)	1.75	1.61	3.36
50 ft (400 w)	2.00	1.61	3.61
100 ft (400 w)	3.00	1.61	4.61
40 ft (1000 w)	1.50	3.22	4.72
45 ft (1000 w)	1.75	3.22	4.97
50 ft (1000 w)	2.00	3.22	5.22
100 ft (1000 w)	3.00	3.22	6.22

Equivalent annual maintenance cost per mile (M) = Equivalent annual maintenance cost per luminaire (X) + Number of luminaires per mile (Y)

M for two-lane roadway:

M.H. (ft)	X	Y	M
3½	\$4.92	1625	\$7,995.00
30	4.61	27	124.47
30	4.61	28	129.08
40	3.11	21	65.31
45	3.36	19	63.84
45	3.36	24	80.64
50	3.61	25	90.25
100	4.61	41[a]	189.01[b]
100	6.22	17[a]	105.74[c]
100	6.22	4[a]	24.88[d]

[a]Average number of luminaires per 100-ft pole.
[b]Maintenance cost per 100-ft pole with forty-one 400-watt floodlights.
[c]Maintenance cost per 100-ft pole with seventeen 1000-watt floodlights.
[d]Maintenance cost per 100-ft pole with 4 type V industrial luminaires.

Luminance Requirements for Illuminated Signs

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G. M. SMITH and M. H. JANSON, Michigan Department of State Highways

Various combinations of black and white letters and backgrounds were night-tested in the field, using an internally illuminated sign, to collect data regarding the relationship between sign luminance and legibility over a wide range of ambient lighting conditions. Observers in three age groups were pretested for visual acuity and daylight sign legibility, before the night tests. Contrast level and direction were controlled, and the sign legend and background luminance were monitored photometrically. Minimum and optimum brightness values over a sign face are suggested for typical rural, suburban, and urban ambient illumination conditions. Recommendations are given for further needed research.

•IT HAS long been known that the brightness required for sign legibility at night depends on ambient lighting conditions. Although modern reflectorized signs have better night legibility than previously used painted signs, they are not a fully adequate solution in all situations. Engineers have found it necessary to provide artificial illumination in brightly lit urban areas if signs are to have adequate legibility. As electrical power is usually readily available in such areas, artificial illumination is not excessively expensive. Although it is known that the higher the level of ambient illumination and the more glaring lights there are in the driver's field of view, the more luminance is required, no data have been available on which standards for sign luminance could be based. A primary purpose of this study was to collect such data.

Previous research (1) showed that in dark rural areas without headlight glare from approaching traffic, the optimum luminance of a sign is about 10 ft-L. If luminance drops to about 1 ft-L, the decrease in legibility distance is not great, but further decreases in luminance result in serious loss of legibility. Even in dark rural areas, more sign luminance may be required where the driver faces the glare from headlights of approaching traffic, and certainly higher luminances are required in brightly lit areas with many glaring lights. This study was intended to find the relation between sign luminance and legibility, over a range of ambient illumination conditions from the darkest to the brightest a driver is likely to encounter.

In addition, the effect of reduced contrast, which occurs when the background as well as the legend of the sign is illuminated, was investigated. Such information would permit comparison of legibility of reduced contrasts with that of colored sign backgrounds, which were planned for study in a future experiment. As signs with a dark legend on a white background are of interest, as well as white letters on a dark background, both were included in the experiment. Because changes in vision take place with age, different age groups were compared in their sign-reading performance. Although the findings of this study have indirect implications for reflectorized signs, such applications are beyond its scope. Although other characteristics of the sign legend (such as stroke width, letter width, and spacing) are of interest, and the luminance required may be affected by changes in such characteristics, this study is concerned only with U. S. Bureau of Public Roads Series E letters with stroke width and spacing as used for large signs on the Interstate System.

Paper sponsored by Committee on Night Visibility and presented at the 46th Annual Meeting.

PREVIOUS RESEARCH

Beginning with the work of Forbes and his collaborators (2, 3), a number of studies of the legibility of highway signs have been reported. A complete review of this and related research, and an annotated bibliography, are given by Forbes, Snyder and Pain (4). The relation between sign luminance and night legibility has been studied in the laboratory (5), and in a field validation study (1) on a dark open road without headlight glare. The present study extends this work to encompass the range of ambient illumination a driver is likely to encounter.

To understand the effect of the luminance of a sign on the distance it can be read, consideration must be given to the adaptation level of the eye. On a dark open road the driver's retina is adapted to a low level, and his pupil is enlarged. In a bright urban area his retina adapts by becoming less sensitive to light, and his pupil is reduced in size, admitting less light to the eye. At a given adaptation level and pupil size, acuity (the ability of the eye to see detail) increases with increasing luminance, up to a point beyond which further increases in luminance result in no further increase in acuity, or even a decrease in acuity. A simplified explanation of this relationship, and reference to basic literature, was given in an earlier paper (5). Even for optimum sign luminance, however, the maximum legibility distance for a driver adapted to a dark rural road is about 15 percent less than in the daytime (3, 5); higher legibility distance should be obtainable in well-illuminated areas if the sign has optimal luminance.

In addition to adaptation level and pupil size, another factor affecting sign legibility is the presence of glaring light sources in the driver's field of view. In addition to headlights of opposing traffic, street lights, advertising signs, and even the sign being read may be sources of glare. Two types of effects of glare have been distinguished—discomfort glare and disability glare (6)—which behave quite differently. Although discomfort glare may affect the effort a driver will make to read a sign, the reduction of his ability to read it if he tries is a function of disability glare. The main source of disability glare is reduction in contrast of the visual image (6, 7). However, glare sources may also change the adaptation of the retina and the pupil size (8). It may even be possible for glare to improve the ability to see a very bright image when the eye is dark-adapted (9); such a phenomenon was reported by Forbes, Moskowitz and Morgan (10), who found that observers could read a very bright sign better with headlight glare than without it.

Finally, the age of the driver may affect the luminance-legibility relation at various ambient illumination conditions. The aging eye has a smaller maximum pupil size (11, 12), and reduced retinal sensitivity in the fully dark-adapted eye (13). In addition, the reduction in acuity caused by glare increases very considerably with age (14). Because the effects of such variables on sign legibility cannot adequately be predicted from laboratory data, they must be investigated in the field.

OBSERVERS, SIGNS AND TEST PROCEDURE

Observers

The observers were Michigan Department of State Highways employees and retirees. They ranged in age from 18 to 81, and each possessed a valid driver's license. For test purposes, they were divided into three age groups: 18 to 37, 38 to 57, and 58 and over. They were predominantly men and were of high occupational status; almost all were from the Office of Testing and Research and the Office of Design.

Average acuity of observers, measured (with eyeglasses, if normally used for driving) using a Bausch and Lomb orthorater, was 10.0—equivalent to 20/20 Snellen acuity. Although one would expect the younger group to have average acuity above 20/20 and the older group below 20/20, they were nearly equal, the younger and middle age groups averaging only slightly above 20/20 and the older group only slightly below.

Test Sign Messages

Test sign letters were made to specifications for Interstate guide signs. The sign permitted only three-letter words, which might differ greatly in legibility distance. To obtain words of nearly equal legibility, a preliminary experiment was conducted in the laboratory. The ten letters most frequently used in place names on Michigan's Interstate highways are A, D, E, I, L, N, O, R, S, and T. Sixty common words were constructed using BPR Series E 1-in. high white letters on black cards. Sixteen highway employees were tested individually by walking toward each word until they read it correctly, and the distance was recorded. Means and variances were calculated for each word; means ranged from 75 to 101 ft, and variances from 25 to 253 ft.

Eighteen words with nearly equal means and low variances were selected for use: AID, ARE, DEN, NOT, ONE, RAT, RED, ROT, SAD, SET, SIN, SIT, SOD, SON, TAR, TEN, TOE, and TON. Legibility distances for these words were obtained again in the daylight legibility trials, and corresponded closely to those obtained in the laboratory. The word AID had a large variance, however, and was replaced by NOD in the night experiment. All words with the letter L proved overly legible, so this letter was not used in the day or night experiments.

On both the day and the night test signs, the words were presented three at a time, with letters 13.3 in. high at the top, 10 in. at the center, and 7 in. at the bottom. Spaces between lines were 6½ and 4 in., and the top and bottom margins were 2½ and 4 in. Margins at the sides varied with word length from 2½ to 8 in. for the 13.3-in. letters, and were more than 6 in. for the smaller letters.

Daylight Testing

During daylight hours a few weeks before the night experiment, 150 observers were tested on their sign-reading ability. This was done by making trips past a truck-mounted sign and recording legibility distances for words displayed on the sign. These runs were made with two purposes:

1. To obtain acuity and sign-reading ability information on the observers, for use in the night experiment. These data were used to match groups for that experiment so that a given observer group would not accidentally contain persons of either all high or all low acuity.
2. To familiarize observers with the night testing situation, which was basically the same as used during the day. It was anticipated that a large portion of any learning and performance increment resulting from successive trials would occur during these daylight runs.

The 18 words were presented three at a time on a 48-in. square sign face. This sign face was mounted 7 ft above the pavement on the back of a pickup truck parked at the curb of a little-traveled residential street (Fig. 1). White letters were presented on a black background for these daylight runs.

Observers were driven past the sign one at a time at 15 mph, starting each run 3000 ft from the sign. They read the words as soon as they could. This reading distance was recorded by an experimenter in the back seat, from an odometer that measured distance in thousandths of a mile and was connected to a fifth wheel. Each observer made four runs past the sign face. Between runs, the three words were changed so that each observer viewed 12 different words.

Means for legibility distances were computed for each observer and for each word. Legibility distances were divided by letter height in inches to make them equivalent for different letter heights. Average daylight legibility for the observers was 73 feet per inch of letter height. As previously mentioned, average orthorater acuity was 10.0, equivalent to 20/20 Snellen acuity. The correlation between the two measures was 0.7.

A variance estimate for each observer was obtained by taking the range of his reading distances after eliminating the most extreme legibility distance from the 12 per observer. An observer for whom this figure exceeded 25 percent of his average legibility distance was classed as an alternate in the main experiment and used only if no one else was available.

Night Testing

In the night experiments, the effects and interactions of six variables were investigated: observer age, sign luminance, ambient illumination, contrast direction, contrast

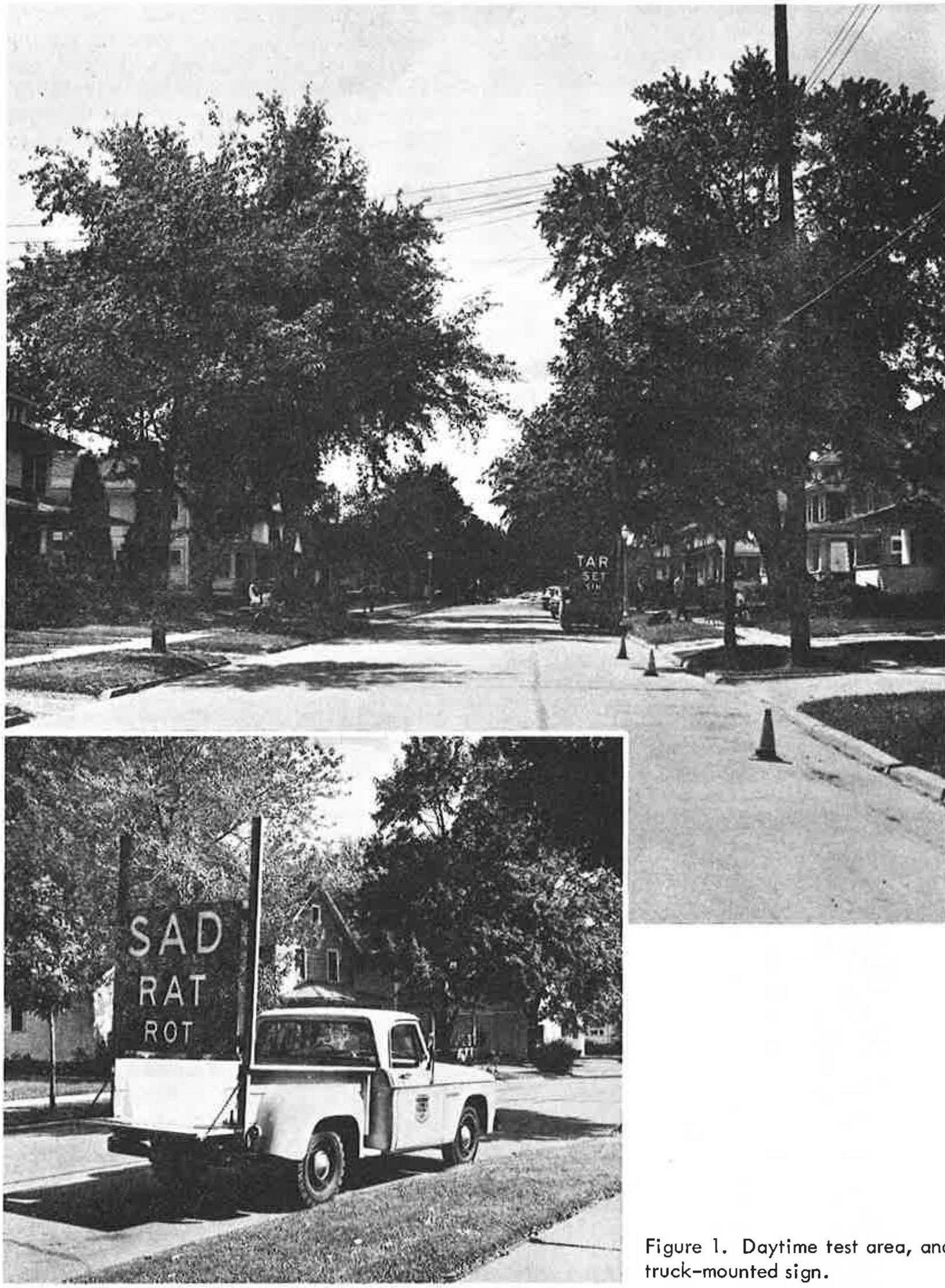

Figure 1. Daytime test area, and truck-mounted sign.

level, and letter height. Included in the ambient illumination conditions were situations in which the signs were read with and without headlamp glare from vehicles placed to simulate opposing traffic.

Figure 2. Illuminated case sign mounted on lift platform for night testing.

Sign Design and Construction—The internally illuminated sign was mounted on a hydraulically lifted platform on a 1-ton truck, which also carried a 110-volt generator with automatic voltage control (Fig. 2).

The sign face itself was a 48-in. square. Ordinary illuminated signs may have luminance variations of 10 to 1 or more across the sign face, and are designed for a single luminance level. This sign face was designed to produce sign luminances from 0.02 to 2500 ft-L, with variation across the sign face not more than ±15 percent at each luminance level. In addition, messages could be quickly changed for either white letters on a dark background or dark letters on a light background. Also, contrast between legend and background could be either high (near 100% with legend or background black) or lower (near 75%), with the light portion of the sign having a luminance four times that of the dark portion.

Illumination was provided by twenty-six 40-watt cool-white fluorescent lamps (Fig. 3). Twenty-four were mounted horizontally, and two vertically at the ends of the horizontal lamps. Crinkled aluminum foil, lining the area behind the lamps, permitted

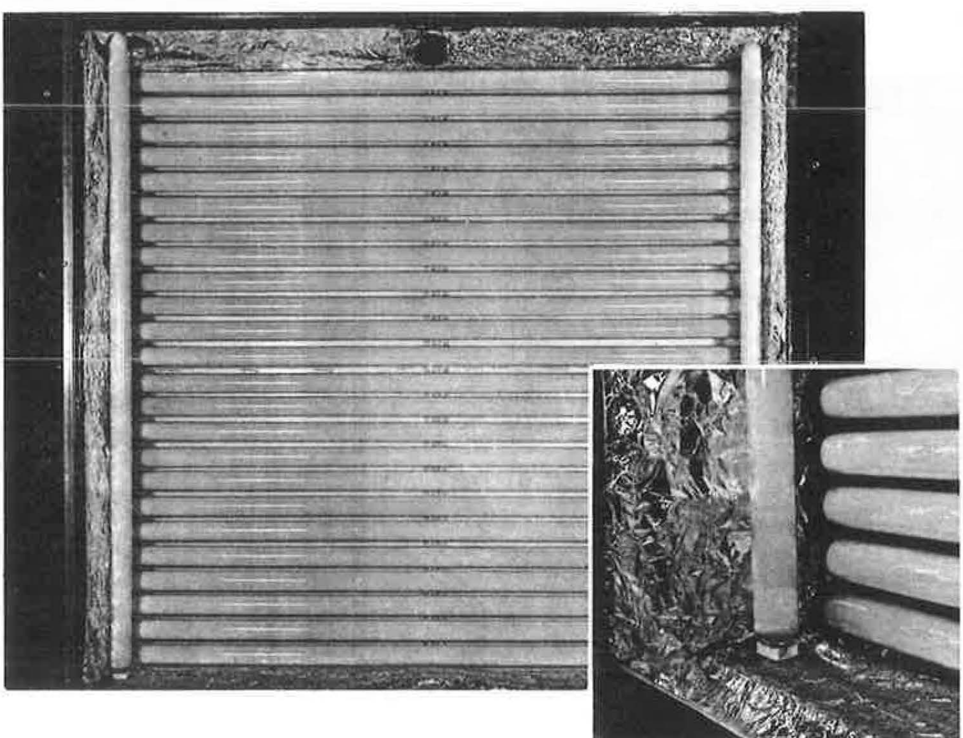

Figure 3. Interior of illuminated case sign, showing arrangement of 26 fluorescent lamps, and detail of corner showing foil; black disk at sign's top is a photocell for monitoring face luminance.

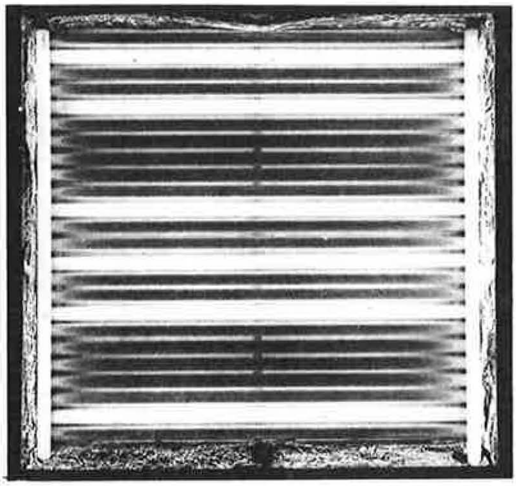

Figure 4. Large changes in face luminance were obtained by lighting varying numbers of lamps.

adjustment for even luminance across the translucent plastic face of the sign. Large changes in sign luminance were obtained by lighting different numbers of lamps (Fig. 4), and fine adjustments were made by variations in voltage. To obtain low luminance levels and maintain contrast levels in brightly lit areas where there was specular reflection from the shiny plastic face, a neutral density filter consisting of a large sheet of fine black broadcloth covered the sign face.

The fluorescent lamps were operated through standard rapid start ballasts and dimming ballasts, powered by a 2500-watt, 115-volt portable gasoline generator. A Sorensen model FRLD 750 voltage regulator with maximum 0.35 percent distortion and one-cycle recovery time prevented flickering caused by the unregulated generator source. The variable transformer and switching arrangement (Fig. 5) were installed in a control van parked next to the sign truck, and connected to the sign case itself by a 20-ft, 7-wire signal cable. The wires were connected to the barrier terminal strip in the sign module and distributed to various ballasts and lamps (Fig. 6).

Levels of face or legend brightness were controlled by a combination of switching and dimming the array of 26 fluorescent lamps. The operator could obtain a coarse adjustment of sign brightness by an internally mounted photocell, or by an externally mounted photocell on an arm that swung on hinges in front of the face. A Pritchard

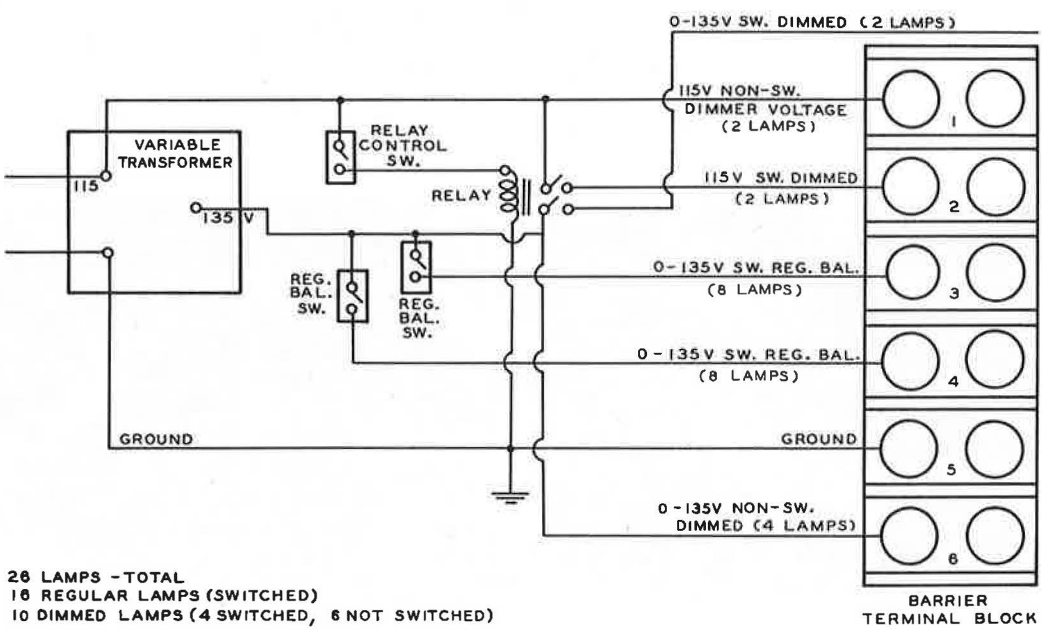

Figure 5. Voltage control and switches for test sign lamp ballasts.

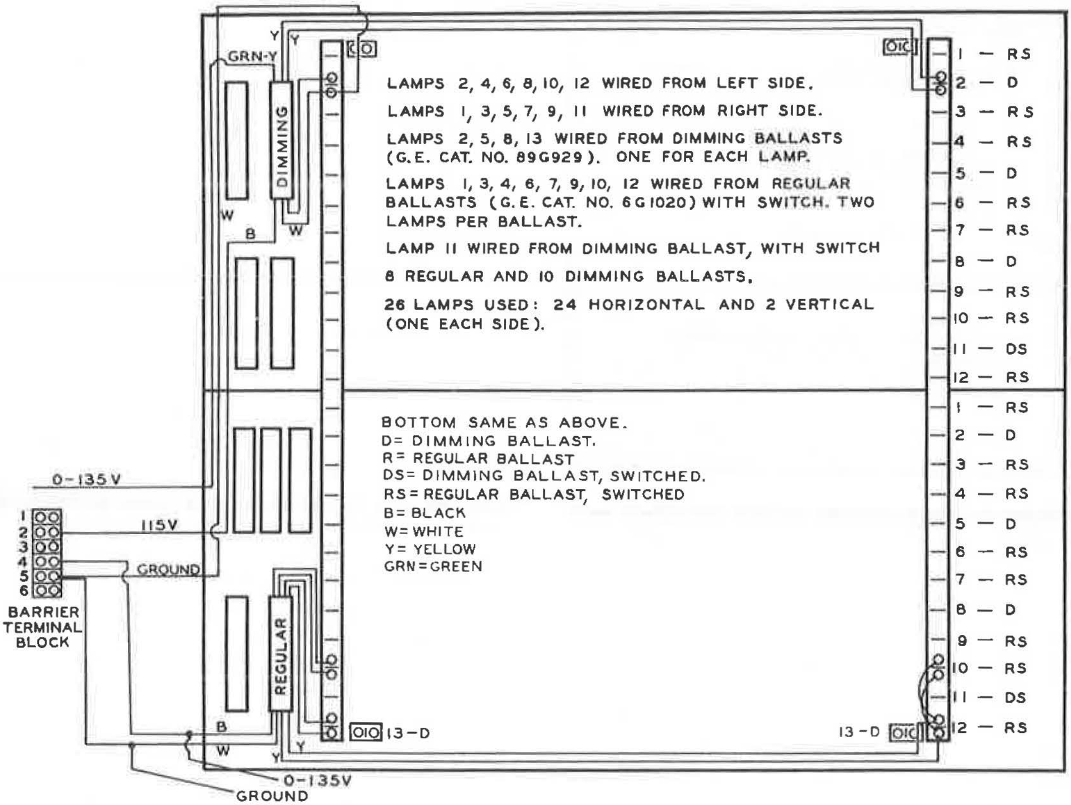

Figure 6. Test sign circuitry for ballasts and lamps.

photometer mounted on a truck 75 ft from the sign was used to monitor face brightness, and final adjustments were relayed by the photometer operator through an intercom to the control van. Figure 7 shows a typical array of vehicles involved in the night tests.

The combinations of variable voltage, switching off certain lamps, and the eight dimming lamps permitted continuous variation of sign luminance throughout the entire range.

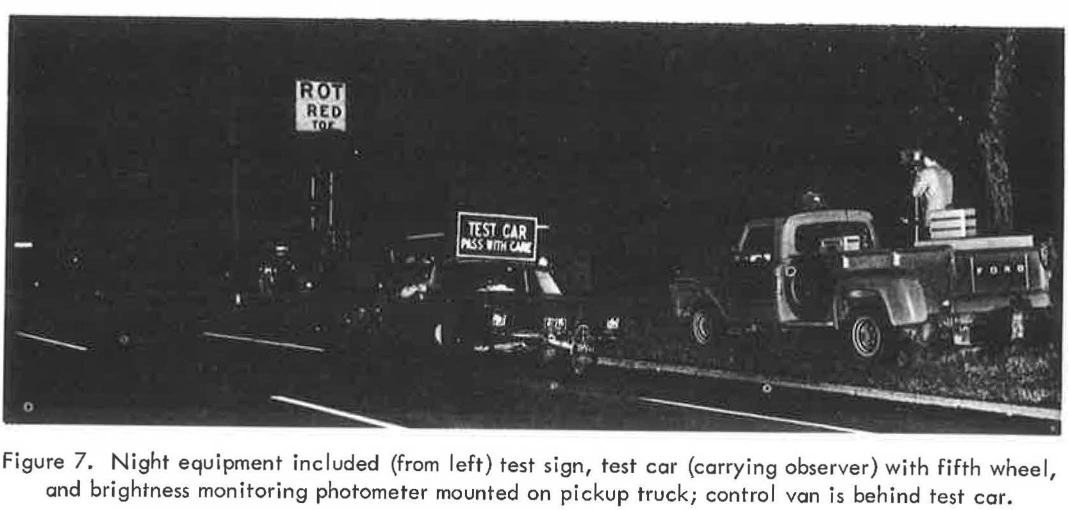

Figure 7. Night equipment included (from left) test sign, test car (carrying observer) with fifth wheel, and brightness monitoring photometer mounted on pickup truck; control van is behind test car.

Exact voltages and numbers of lamps lighted for each luminance level varied with ambient temperature and humidity. The lamps operated from standard ballasts could be reduced in brightness to 60 to 70 percent of their normal value by reducing voltage, and lamps operated from dimming ballasts could be reduced in this way to approximately 5 percent of original brightness without flickering.

Three different sign faces and four sets of letters were used to produce two contrast directions and two contrast levels. The faces were made of acrylic plastic. Letters were made of acrylic plastic or pressed board, formed on panels which were sized to obtain proper letterspacing within each word. The letter panels were slipped into position on tracks glued to the sign face (Figs. 8 and 9).

For light letters on a dark background with 100 percent contrast, letter outlines were cut and removed from pressed board panels which had been painted black. Clear acrylic strips were glued to the pressed board panels to hold isolated letter portions in position. The dark background was completed by applying black opaque tape to sign face areas outside of the letter panel areas.

For light letters on a dark background with 75 percent contrast, the letter outlines were cut and removed from pieces of polyethylene film (25% transmittance). The remaining portion was glued to a clear acrylic letter panel. A translucent plastic sign face was covered with the 25 percent transmittance polyethylene outside of the letter panel areas to complete the background.

For dark letters on a light background with 100 percent contrast, the letters were made of black opaque polyethylene film glued on clear acrylic letter panels. A translucent plastic sign face provided the background.

For dark letters on a light background with 75 percent contrast, the letters were made of 25 percent transmittance polyethylene film glued on clear acrylic letter panels. The same translucent plastic face was used for the background.

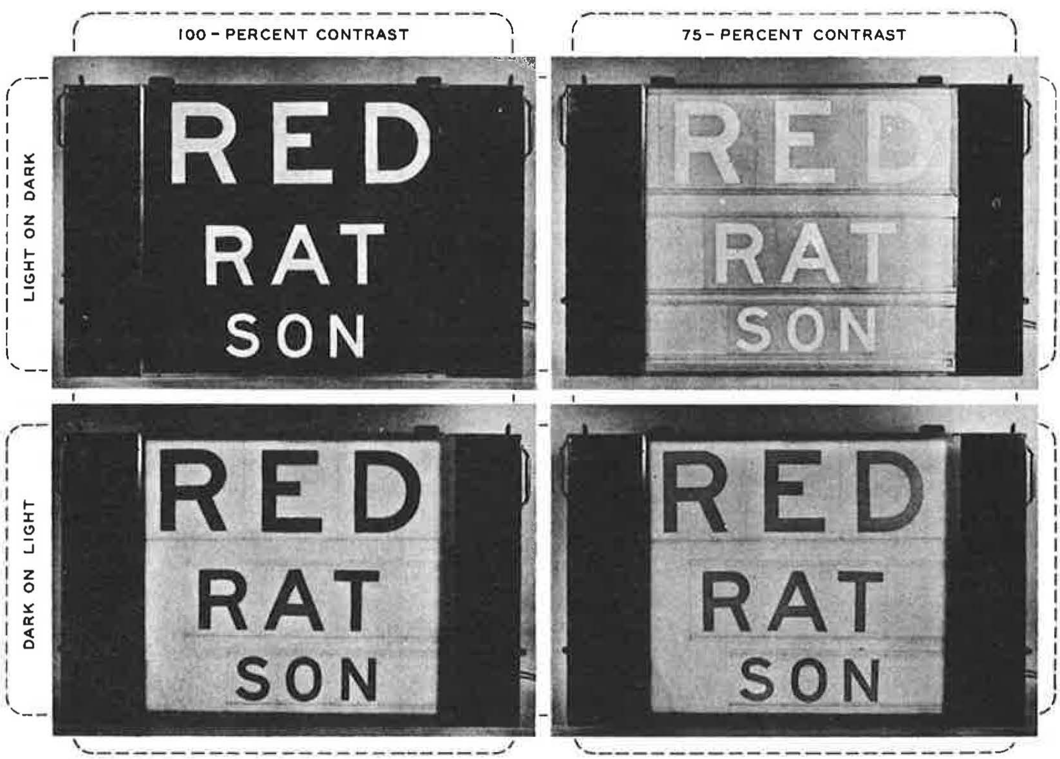

Figure 8. Typical combinations of sign face contrast level and contrast direction with internal and external illumination.

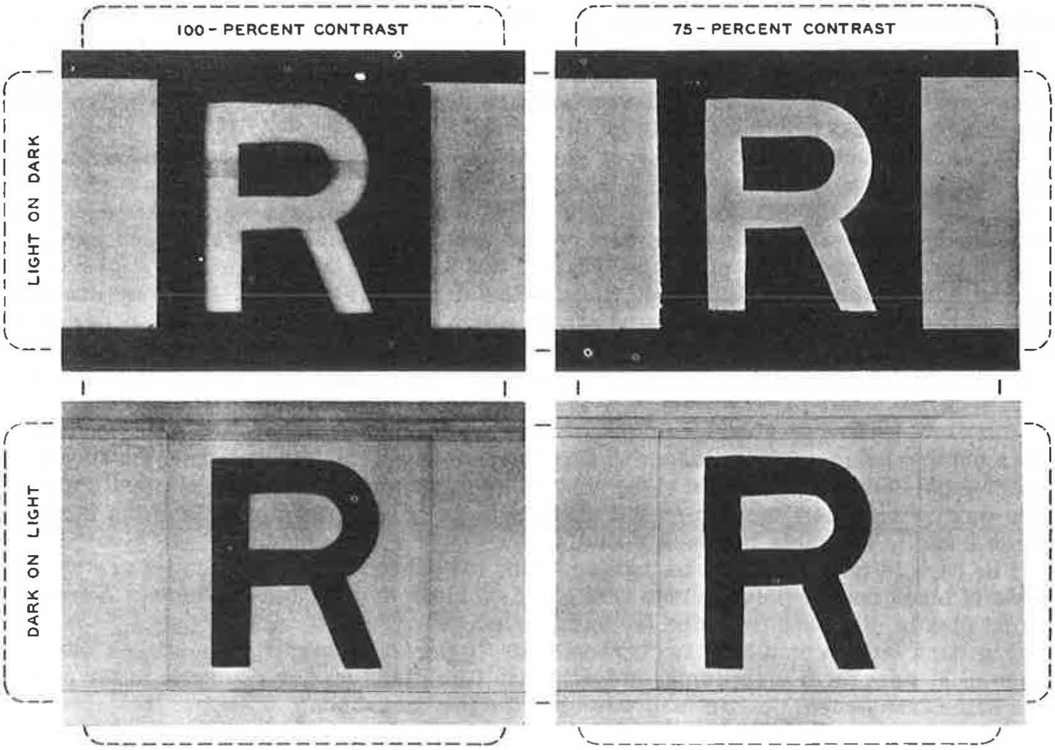

Figure 9. Typical combinations of letter contrast level and contrast direction with internal and external illumination.

Sign Variables—Sign luminance, contrast level, contrast direction, and letter height were manipulated at the sign itself. Each level of each of these variables was observed by each observer.

Five levels of sign luminance were used: 0.2, 2, 20, 200, and 2000 ft-L. A sixth level (0.02 ft-L) was originally included, but it was difficult to obtain such a low level reliably, particularly in brightly lighted areas. This range of luminance was considerably greater than encountered in highway or advertising signs, either illuminated or reflectorized, and was selected to investigate the effects of a sign's being too bright as well as not bright enough.

As described previously, the sign face permitted presenting dark letters on a light background and light letters on a dark background, each with contrast near 100 percent (actually 93 to 97%) and near 75 percent (actually between 72 and 78%). Each presentation of the sign included three words, one each in heights of 13.3, 10, and 7 in.

Ambient Illumination—Illumination and glare measurements, using the Pritchard photometer, were made at numerous locations. Three were chosen to provide the lowest and highest levels that a driver was likely to encounter, and also medium ambient illumination typical of lighted freeways. In addition, at the low and medium ambient locations, the lighting level was increased by headlamps simulating opposing traffic. This provided a total of five levels of ambient illumination. Each observer viewed the full range of sign variables under one of these five ambient lighting conditions.

A rural road paved with bituminous aggregate was used for low ambient illumination. A distant house provided the only illumination at the eye other than that of the sign and the test car's headlamps on low beam reflecting from the roadway. Illumination at the eyes of the observer was as low as possible (less than 0.01 ft-c) for a person in the front seat of an automobile with the headlamps on.

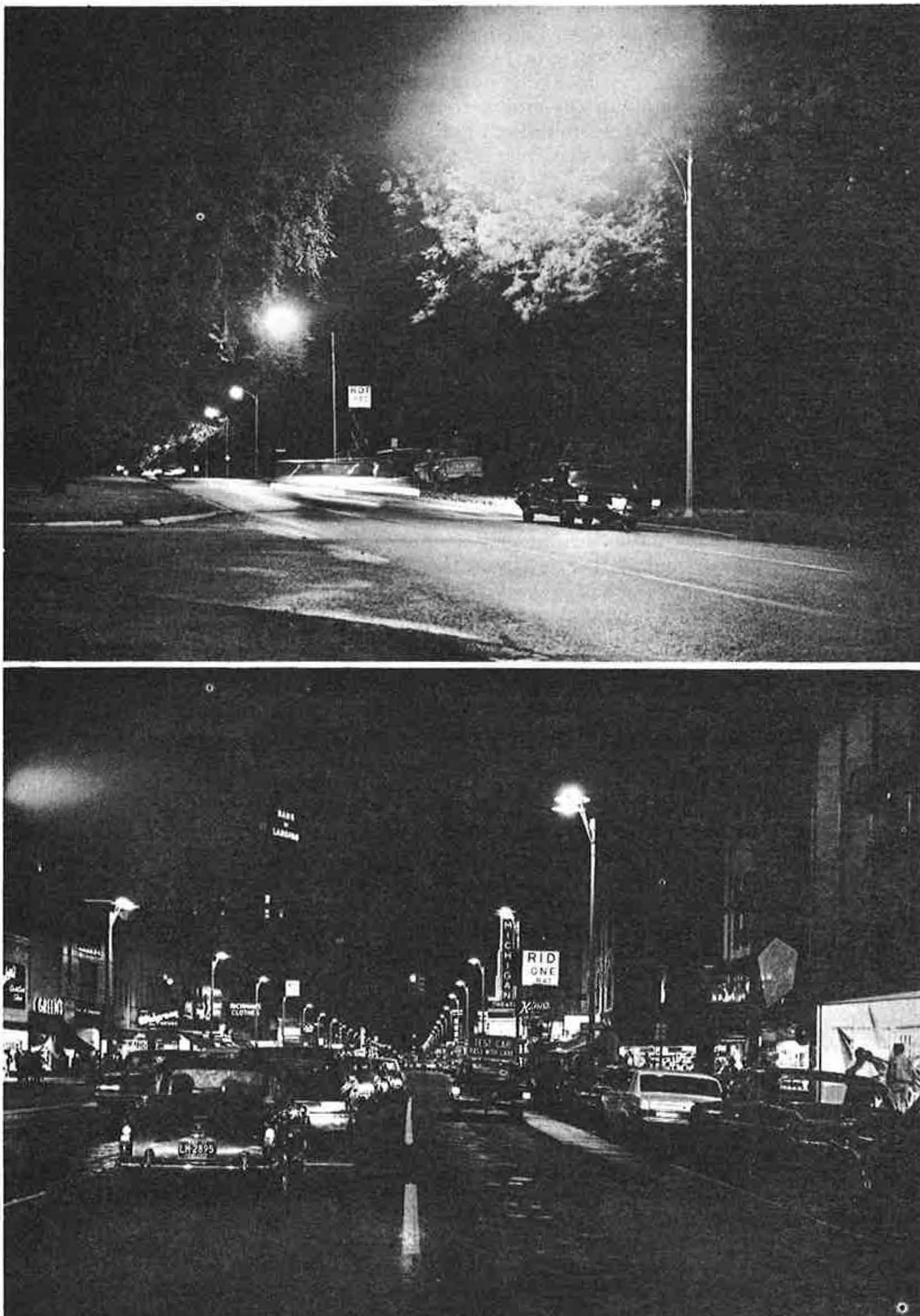

Figure 10. Night test areas for medium ambient illumination (top) and high ambient illumination (bottom).

The medium ambient location (Fig. 10) was the eastbound three lanes of a six-lane boulevard (Michigan Ave. between Lansing and East Lansing). The observer was shielded from headlights of opposing traffic by trees and shrubs in the 60-ft median. Illumination was provided by 400-watt mercury-vapor streetlight luminaires at a 31-ft mounting height, spaced along the right side at 150-ft intervals. There were no luminaires in the median. A small amount of advertising lighting, not near the roadway, was located along the route, adding only insignificantly to illumination and glare readings. Horizontal illumination ranged from 3 ft-c beneath the luminaires to 1 ft-c between luminaires. Average illumination in a vertical plane at the observer's eyes was 0.2 ft-c.

Washington Ave. in downtown Lansing (Fig. 10) was used for high ambient illumination. This six-lane asphalt street is among the most brightly lighted in Michigan. Twin 1000-watt luminaires at a mounting height of 35 ft are spaced opposite one another at 118-ft intervals on each side of the 75-ft wide street. Pavement illumination ranged from 11 ft-c beneath the luminaires to 5 ft-c between them. Advertising lighting lines both sides of the street. Normal headlight glare from cars constantly traveling the opposite direction contributed very little to the total illumination at the eye, and no attempt was made to conduct legibility tests with and without headlight glare. Average illumination in a vertical plane at the observer's eyes was 3 ft-c.

For glare conditions at the low and medium ambient illumination locations, cars were parked at the left side of the roadway with low beams on and engines running to provide nearly normal voltage to the headlamps. Twelve cars were spaced at 100-ft intervals from a point near the beginning of the legibility run, along its length to a point 200 ft beyond the sign. Glare cars were placed about 17 ft laterally from the observer at the low ambient location, and 15 ft laterally at the medium location. Although a single car with high beams might provide worse glare conditions than these, glare conditions similar to those in this study would be commonly encountered in heavy traffic conditions.

At each location, the bottom of the sign was 14 ft above the pavement. The nearest edge of the sign was placed about 2 ft laterally from the traffic lane curb. At the low and high ambient illumination locations, test cars traveled in the right lane, giving a lateral distance from the observer to the sign of 6 or 7 ft. At the medium illuminated location, travel in the inner lane was necessary for safety in left turns to return to the starting point. This gave a lateral distance of 25 ft from the observer to sign. Although placement of an illuminated sign is not critically important, as for reflectorized signs dependent on headlamp beams, the glare from streetlight luminaires is dependent on sign position. Although most sign placements would have glare from luminaires similar to that at these locations, if a luminaire were very near the line of sight of a driver reading a sign, legibility might be markedly reduced.

Experimental Procedure—Observations were made during hours of complete darkness in late summer and fall of 1964. Observers seated in the front seat with the driver were instructed to read the sign messages as soon as possible and to continue reading until told their response was correct. An experimenter in the back seat compared observer response with a prepared data sheet. He recorded fifth wheel odometer readings at the instant of correct response, and also when the test car passed the sign. Test runs were coordinated by radio from the test sign and began at least 2000 ft ahead of the sign. Vehicle speed was maintained at approximately 15 mph.

Three observers were tested each evening, in separate cars, usually requiring at least 2½ hr to complete all observations. At the low ambient location, cars maintained at least 300-ft headway so that headlamp beams or taillights of one car would not affect the adaptation level of the eyes of the observer in another car. At the other locations, closer distances were permitted because automobiles contributed only a small fraction of the total illumination.

Each observer made 20 runs past the sign in order to view all combinations of luminance, contrast direction, and contrast level. As a sign face change was required for each contrast-level contrast-direction combination, each of the five luminance levels was viewed before making this time-consuming change. With this restriction, all experimental conditions and messages were assigned in random sequence.

In scheduling the night tests, it was recognized that a revised target date for completion of testing and autumn weather conditions made it inadvisable to attempt to include all 150 observers used in daylight testing. Further, because of illness, resignations, transfers, and other factors, the full total was no longer available. Owing to these considerations, a sample of 60 observers was selected (20 from each of the three age groups), with alternates designated from the remainder.

As each of the 60 observers viewed the sign variables in only one of the five ambient conditions, there were 15 age-by-ambient condition groups of four observers each. To make groups as equal in ability as possible, the 20 observers in each age group were ranked by their daytime legibility scores, and divided into four blocks of five. The five observers in each block were then randomly assigned to the five ambient conditions. However, scheduling of observers was hampered by repeated cancellation of runs due to bad weather (rain or slight fog). When an observer could not be scheduled with the others in his group, an alternate was chosen having daytime legibility distance values as similar as possible. To complete the experiment before snow was on the ground, observers with acuities not closely matched were used.

RESULTS

Analysis

Mean log legibility distances, in feet per inch of letter height, were computed for each combination of experimental conditions, and an analysis of variance was carried out. The logarithmic transformation was used to make the linear model more congruent with the data. Effects of variables are expected to be proportional, i.e., if an observer reads a sign twice as far as another observer under one experimental condition, he would be expected to read a sign twice as far under another condition; therefore, their logarithms are expected to be additive. An analysis without this transformation was also carried out, with almost identical results.

Observers were less well matched in daytime legibility than the experimental design had anticipated. To make comparisons of ambient night illumination conditions more accurate, each observer's scores were adjusted to equate them in terms of daylight legibility distances. For example, if an observer's daylight legibility distance were 10 percent greater than the average of all observers, his night legibility distances were reduced proportionately so that differences in daylight acuity were controlled. Such an adjustment had no effect on the assessment of experimental conditions viewed by all observers. Except for the variables of age and ambient illumination, the analysis of variance and differences between experimental conditions were identical with and without this adjustment.

The analysis of variance is given in Table 1 in an abbreviated form. Besides the degrees of freedom and mean square for each main effect or interaction, the appropriate degrees of freedom and mean square for error are also listed. In each case, the error mean square is the interaction variance with blocks of observers; for example, the error mean square for A is the mean square A × G, and the error mean square for A × B is the mean square A × B × G.

The analysis of variance provides a guide in interpreting results. Effects or interactions that are statistically significant are assumed to reflect real differences worthy of interpretation, whereas those that are not significant may reflect differences that would not hold up in replication of the experiment.

Age

In spite of theoretical reasons for expecting deterioration of night vision with age, differences between age groups were not significant when averaged over all experimental conditions, whether analyzed with or without the adjustment for daylight legibility. There were only 15 observers in each age group (18 to 37, 38 to 57, 58 and over). To make precise comparisons among age groups, more observers would be needed per group. Also, observers in this experiment were personnel from highway research and design agencies, including a few who had retired from them. Such persons are more

TABLE 1
ANALYSIS OF VARIANCE FOR NIGHT TEST RESULTS

	Source of Variation	Degrees of Freedom for Source	Mean Square for Source	Degrees of Freedom for Error	Mean Square for Error (Source of Variation x G)	F-Ratio
		df	MS	df	MSE	F
Between Observers	A (Ambient Illumination)	4	0.6638	12	0.3757	1.77
	B (Age Group)	2	0.5411	6	0.2912	1.86
	A x B	8	0.1397	24	0.3158	0.44
	G (Blocks of Observers)	3	0.7344			
Within Observers	C (Contrast Direction)	1	1.8696	3	0.0497	37.62**
	A x C	4	0.0353	12	0.0606	
	B x C	2	0.1577	6	0.0585	26.96**
	A x B x C	8	0.0571	24	0.0473	1.21
	D (Contrast Level)	1	2.4917	3	0.0148	168.36**
	A x D	4	0.0165	12	0.0315	
	B x D	2	0.0474	6	0.0328	1.45
	C x D	1	0.0014	3	0.0765	
	A x B x D	8	0.0240	24	0.0177	1.36
	A x C x D	4	0.0327	12	0.0375	
	B x C x D	2	0.0125	6	0.0198	
	A x B x C x D	8	0.0166	24	0.0348	
	E (Luminance)	4	25.4841	12	0.0692	368.27**
	A x E	16	0.9128	48	0.1113	8.20**
	B x E	8	0.1501	24	0.0406	3.70**
	C x E	4	0.1300	12	0.0108	12.04**
	D x E	4	0.0290	12	0.0224	
	A x B x E	32	0.0258	96	0.0705	
	A x C x E	16	0.0323	48	0.0181	1.78
	A x D x E	16	0.0126	48	0.0172	
	B x C x E	8	0.0284	24	0.0195	1.46
	B x D x E	8	0.0060	24	0.0181	
	C x D x E	4	0.0234	12	0.0174	
	A x B x C x E	32	0.0155	96	0.0190	
	A x B x D x E	32	0.0161	96	0.0146	
	A x C x D x E	16	0.0203	48	0.0151	1.34
	B x C x D x E	8	0.0198	24	0.0101	1.96
	A x B x C x D x E	32	0.0130	96	0.0150	
	F (Letter Size)	2	0.1305	6	0.0107	12.20**
	A x F	8	0.0048	24	0.0201	
	B x F	4	0.0118	12	0.0193	
	C x F	2	0.1259	6	0.0042	29.98**
	D x F	2	0.0390	6	0.0034	11.82**
	E x F	8	0.0381	24	0.0050	7.62**
	A x B x F	16	0.0139	48	0.0151	
	A x C x F	8	0.0079	24	0.0020	3.95**
	A x D x F	8	0.0053	24	0.0050	
	A x E x F	32	0.0085	96	0.0049	1.73*
	B x C x F	4	0.0085	12	0.0030	2.83**
	B x D x F	4	0.0034	12	0.0033	
	B x E x F	16	0.0037	48	0.0056	
	C x D x F	2	0.0109	6	0.0028	3.89
	C x E x F	8	0.0099	24	0.0022	4.50**
	D x E x F	8	0.0059	24	0.0027	2.19
	A x B x C x F	16	0.0048	48	0.0050	
	A x B x D x F	16	0.0029	48	0.0022	
	A x B x E x F	64	0.0035	192	0.0043	
	A x C x D x F	8	0.0061	24	0.0031	1.97
	A x C x E x F	32	0.0033	96	0.0034	
	A x D x E x F	32	0.0056	96	0.0032	1.75*
	B x C x D x F	4	0.0014	12	0.0055	
	B x C x E x F	16	0.0075	48	0.0040	1.88*
	B x D x E x F	16	0.0021	48	0.0026	
	C x D x E x F	8	0.0064	24	0.0040	1.60
	A x B x C x D x F	16	0.0046	48	0.0026	1.77
	A x B x C x E x F	64	0.0030	192	0.0038	
	A x B x D x E x F	64	0.0035	192	0.0033	
	A x C x D x E x F	32	0.0049	96	0.0027	1.81*
	B x C x D x E x F	16	0.0037	48	0.0024	1.54
	A x B x C x D x E x F	64	0.0029	192	0.0032	

**Significant at 0.01 level.

*Significant at 0.05 level.

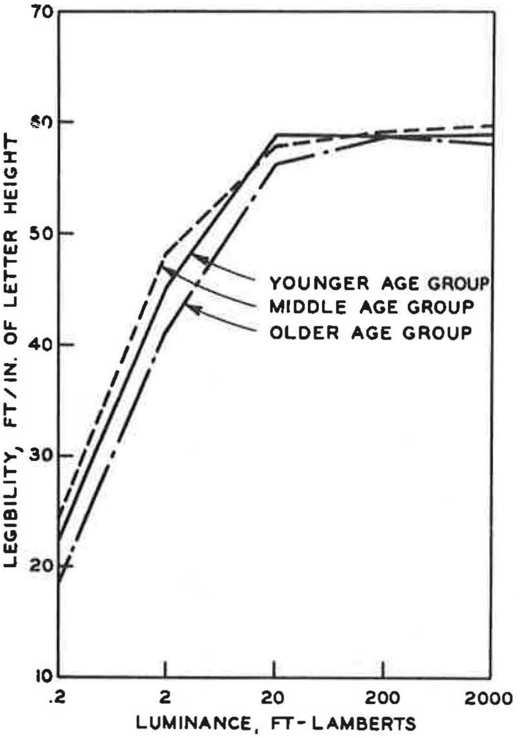

Figure 11. Effect of sign luminance on legibility by age groups.

likely to have glasses with a proper optometric correction than the average driver. Also, older persons in such an organization tend to be of higher rank, and it is possible that such a person would be less cooperative in finding time to be an observer in this experiment if his night vision were poor. Therefore, the failure to find overall differences between age groups should not be considered evidence that such differences do not exist in the population of drivers.

However, the large interaction of age with sign luminance should be noted. Figure 11 shows that there is little difference in legibility at the high sign luminance, but at low sign luminances the curves are farther apart. Unexpectedly, in this sample one finds the middle age group having the highest legibility values at low luminances, rather than the younger age group. When individual curves were examined it was clear that this was a result of two of the observers in the younger group having quite poor vision, both day and night. Another sample of observers would be expected to show the younger observers with highest legibility values at low luminance. Although differences are not clear, the data suggest a deficiency of older drivers toward low luminance signs that is greater at lower ambient illuminations.

Ambient Illumination

Overall legibility averages for the three ambient illumination conditions were not significantly different, but the large interaction with sign luminance was of major importance: a sign of low luminance is seen better in low ambient illumination, whereas a bright sign is seen better in high ambient illumination (Fig. 12). Each point represents the average over age groups, contrast directions, contrast levels, and letter sizes. Although details differ, depending on these variables, the main relation between ambient illumination and sign luminance is illustrated. For comparison purposes the Figure 12 curve for high ambient illumination with headlight glare is duplicated on the graph for results without headlight glare. Night testing without headlight glare was impractical on the downtown street, and headlight glare was a small proportion of the total glare at that location.

Figure 12 shows results for the three locations with and without low-beam headlight glare. Legibility of low-luminance signs at the rural low-ambient illumination was considerably affected by glare, reducing legibility distance to almost that of the medium-ambient condition without glare. The effect of headlamp glare at the medium level was not marked.

Without headlight glare, the sign at 0.2 ft-L was read at over twice the distance in the lowest ambient illumination (dark open road) than in the high ambient illumination (downtown). The reverse was true for the sign at 2000 ft-L; it was read about 10 percent farther away at the high ambient illumination. Legibility distances for the medium ambient illumination (typical luminaires) were between those for the extremes.

Although it might be tempting to recommend minimum luminances from these average results, such recommendations should be deferred until further results are considered.

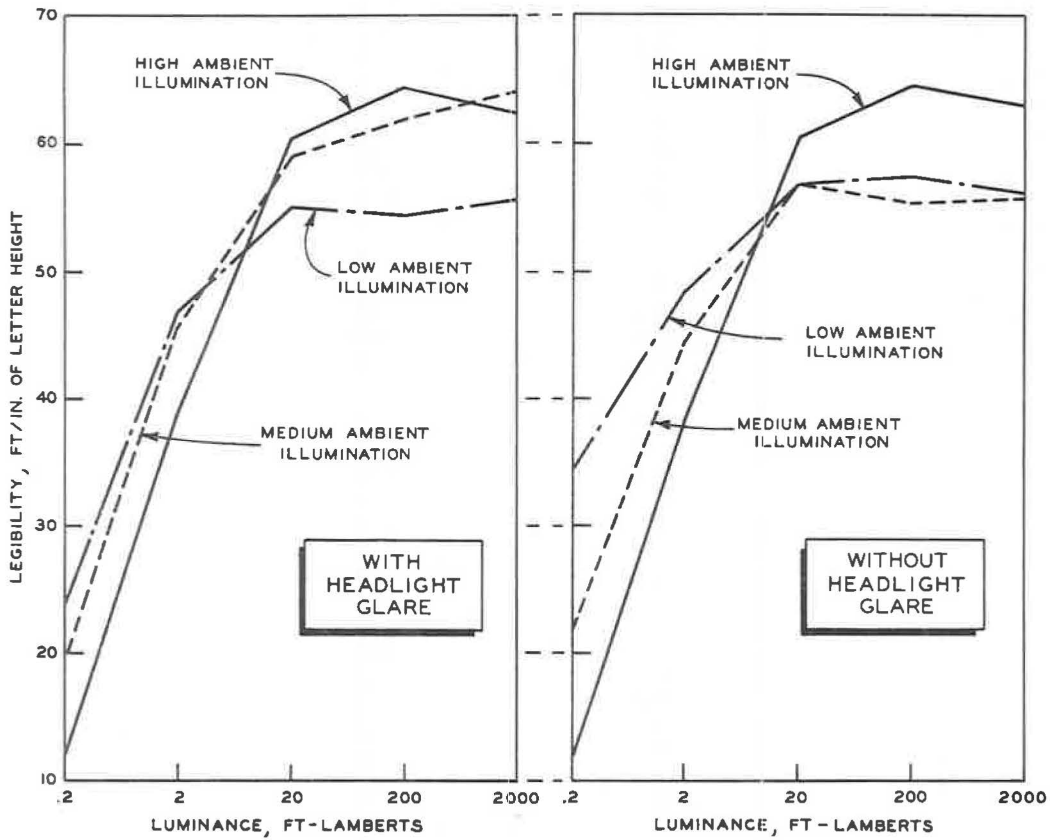

Figure 12. Effect of sign luminance on legibility for the three ambient illumination conditions with and without headlight glare.

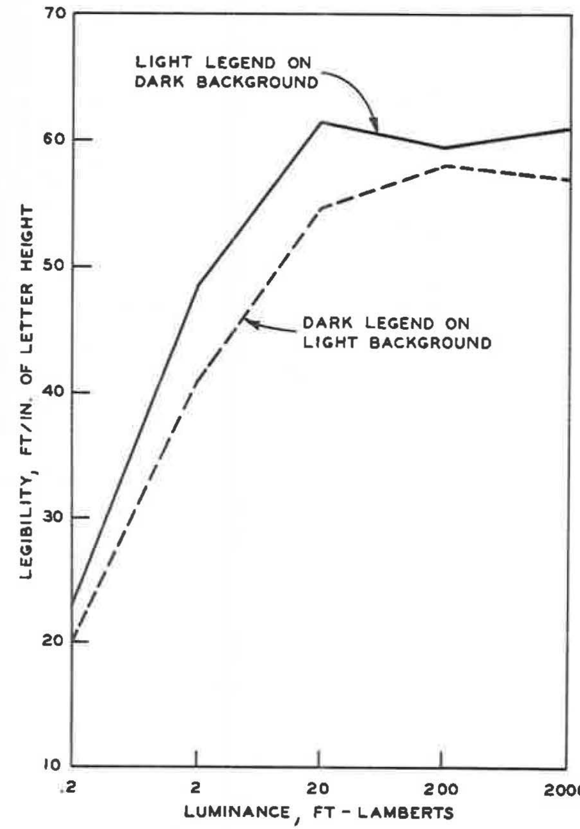

Figure 13. Effect of sign luminance on legibility for the two contrast directions.

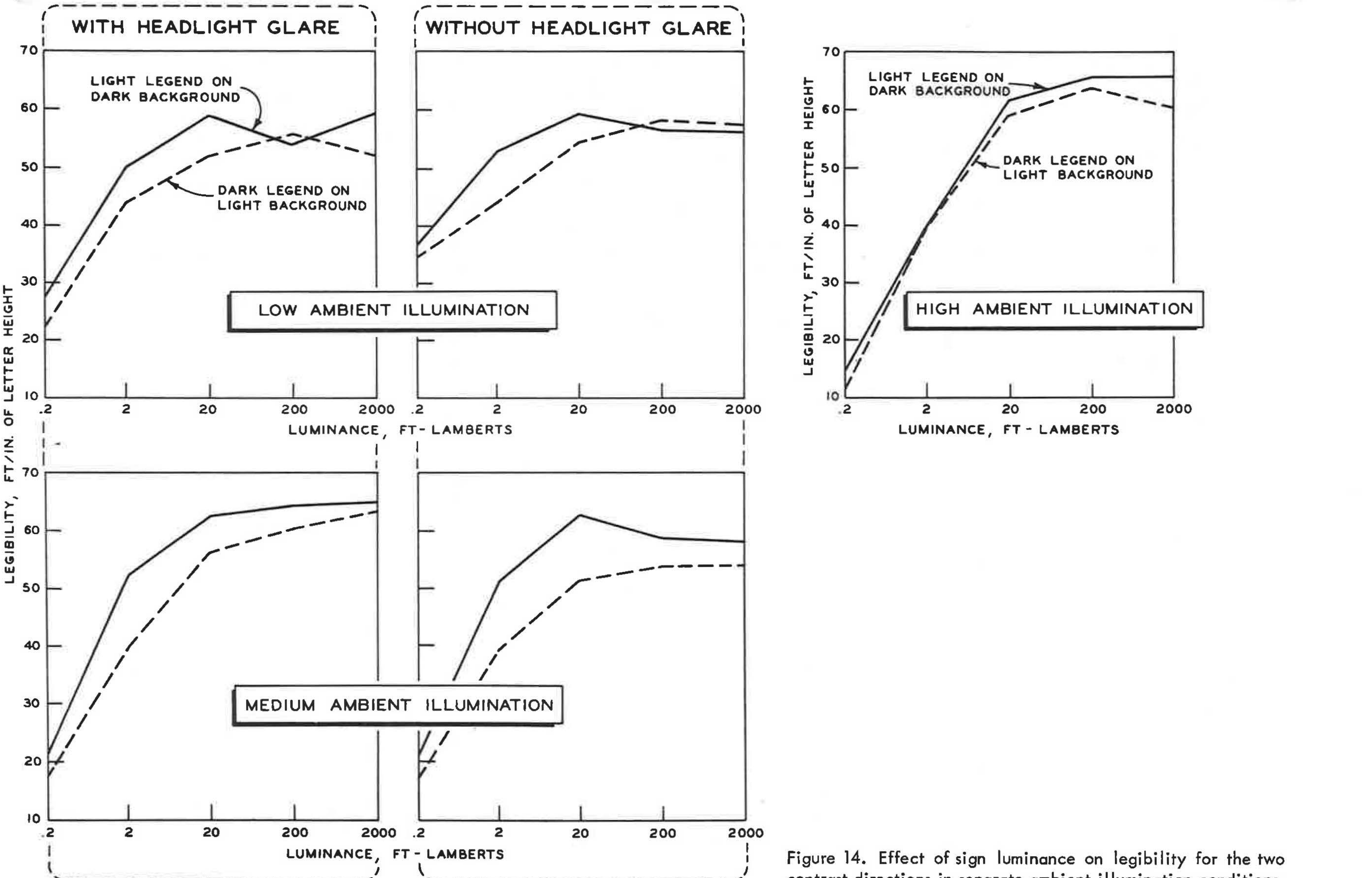

Figure 14. Effect of sign luminance on legibility for the two contrast directions in separate ambient illumination conditions.

Contrast Direction

The superiority of light letters on a dark background over dark letters on a light background was highly significant; averaged over all conditions, the difference was 11 percent. However, this superiority was not uniform; the significant interaction with sign luminance is shown in Figure 13. At low and at high luminances, the differences are small and not significant, but at intermediate luminances the differences are larger. The curve for black on white rises more slowly with increasing luminance, requiring higher minimum luminances for optimum legibility.

These same differences in curve shape were found earlier in the laboratory study by Allen and Straub (5). Figure 14 shows the results when plotted separately for each ambient illumination condition. Although the interaction of contrast direction by luminance by ambient illumination barely fails to be statistically significant, the data in Figure 14 suggest that the difference between contrast directions decreases to a negligible amount in high ambient illumination, which corresponds to a previous finding of little or no difference between contrast directions in daylight conditions (15).

Contrast Level

On the average, the high-contrast legends (near 100% contrast) were read about 12 percent farther away than the lower contrast legends (about 75% contrast). This amount of loss of acuity with contrast reduction checks closely with that found in laboratory studies of Cobb (16) and Blackwell (17). Although interactions with glare, age, and luminance might be expected, no large interactions were found. The only significant interactions involved letter size. These interactions were not large, and are discussed later in terms of an artifact of the experiment by which the adaptation of the eye was affected by the sign itself.

The fact that the effect of reduced contrast was about the same under all conditions suggests that separate luminance requirements are not necessary for signs with colored backgrounds. The loss of legibility due to contrast reduction also suggests, of course, that if the luminance of the dark portion of the sign is more than one-fourth the luminance of the bright portion, losses larger than 12 percent are to be expected. As it is possible that color contrast effects might affect legibility to a small extent, the exact amount of loss due to the contrast reduction caused by use of a colored background might not be the same as the amount found in the experiment.

Letter Size

Previous research, such as that of Forbes, Moskowitz and Morgan (10) and Allen (1), has shown that when sign luminance is held constant, legibility distance is very nearly proportional to letter size. If legibility is calculated in feet per inch of letter height, it is almost the same for any letter height. Of course, this is not true in general for reflectorized signs, because their luminance changes markedly with distance, depending on the light reaching them from headlamps and the optical characteristics of the material (18).

In the present study, however, highly significant differences were associated with the overall average legibility of the three letter sizes, with the smaller letters seen proportionately farther. This is not uniformly true, however. Letter size interacts significantly with most other variables, and with combinations of some of them. Although one might suspect that the relatively smaller border of the large letters could be producing these effects, the data are not consistent with this interpretation. Figure 15 shows that under all conditions, legibility of the three letter sizes is equal at low sign luminances, whereas the smaller letters are more legible at high sign luminances. The differences are larger for dark letters on a light background than for the other contrast direction, and also for 75 percent contrast. These effects were found at each ambient illumination level, and were more marked at the low ambient levels than at the high ones.

The only interpretation that fits the data seems to be that the bright sign itself was changing the adaptation level of the eye. Whether the retinal adaptation was changed,

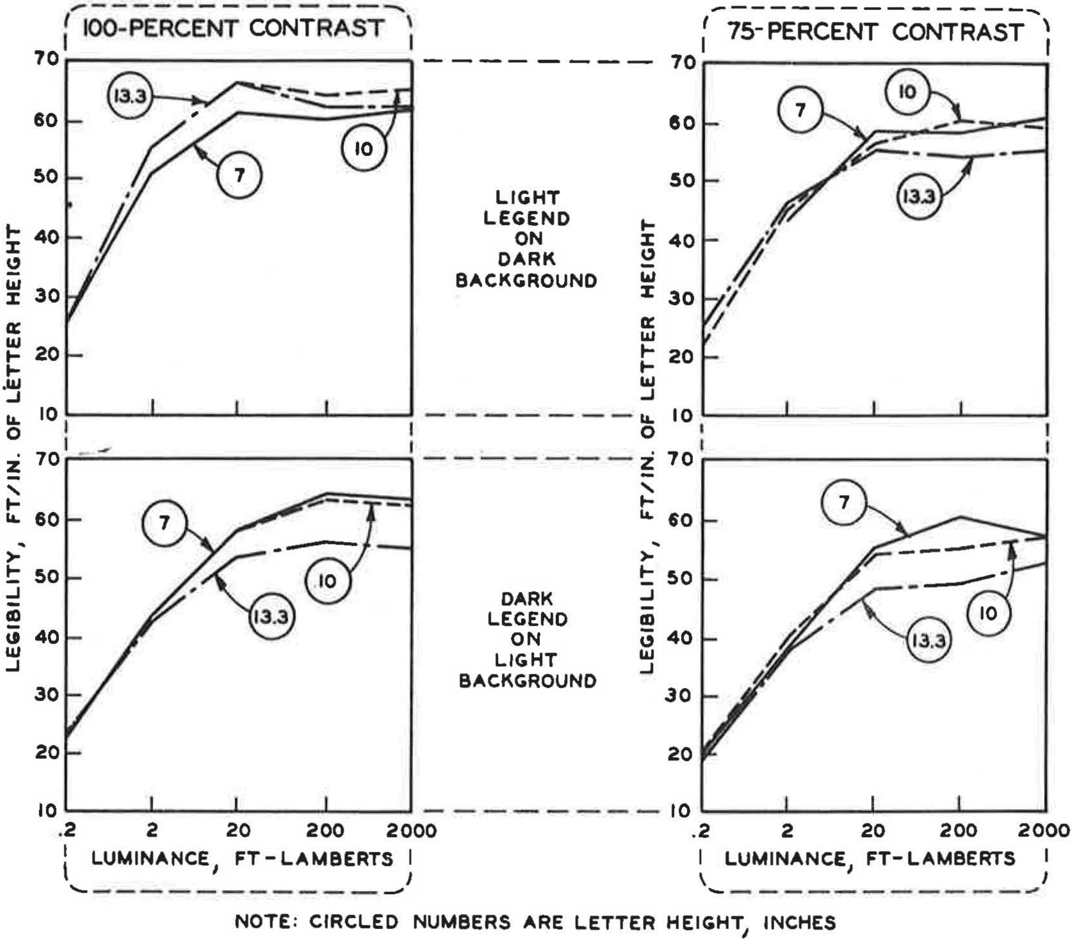

Figure 15. Effect of sign luminance on legibility for the three letter heights.

or pupil size, or both, is not clear. The observers kept their eyes on the sign continuously, trying to read each message as soon as possible. Apparently, the high brightness signs, particularly if most of the face was bright (black letters on white) or if the face was not dark (white letters with low contrast) gave sufficient light to the eye long enough to change the adaptation level (or pupil size), increasing acuity for the bright sign. Although, again, the number of observers was not large enough for age differences to emerge clearly, the data suggest that this effect is larger for the young observers. Apparently, older eyes do not change adaptation (or pupil size) as readily. Although it is impossible to be certain that this effect was taking place without measurements of adaptation level and pupil size, these findings certainly suggest that this factor be taken into account when interpreting results.

A driver ordinarily would not keep his eyes on the sign for such extended periods, and would not have such a facilitating effect of adaptation change to help him read such a bright sign. This suggests that the data slightly overestimate the legibility distance of black letters on a white background at high luminance levels. For these signs at low luminance levels, and for white letters on a dark background at all luminances, this factor would have negligible effect on the results. However, the fact that a bright sign may raise the adaptation level of the eye has other implications. Use of large, high-luminance, black-on-white signs may raise the adaptation level sufficiently to impair the driver's ability to see dark objects on the road ahead.

Individual Differences

When data for individual observers were compared, large individual differences were observed in effects of the variables. These large individual differences contributed to the lack of clear differences between age groups. Although differences in the effects of low luminances showed substantial individual variation, the differences were larger in responses to the very high luminances. The 2000 ft-L level appeared too bright to most observers, but when instructed to read as soon as possible, most could read at about the same distance as they read the 20 ft-L sign, and some at a greater distance. Others seemed not to be able to see such a bright sign clearly, but perhaps they were influenced by their belief that they could not read such a bright sign. Similar effects occurred for contrast reduction. Some observers consistently read the low contrast sign as well as the high contrast one, whereas others consistently read it at shorter distances. The extent to which the eye's adaptation was affected by the sign itself also appeared to show substantial individual differences and probably age differences. Glare readings on a Pritchard photometer and calculations of contrast reduction were made which theoretically should have resulted in correspondence between high and low contrast signs. However, individual responses to both glare and contrast were so different that efforts in this direction were abandoned. Research in which visual variables can be more precisely controlled is needed to characterize these individual differences and their changes with age.

DISCUSSION AND CONCLUSIONS

Recommended Minimum Luminances

The immediate practical question to be answered from this study is: what sign luminance is required for adequate legibility under various ambient illumination conditions? For a dark rural road without glare from headlights of opposing traffic, this investigation verified findings of the earlier study (1). Maximum legibility is achieved at about 10 ft-L for white Series E letters such as those used on large signs on Interstate routes. If a 10 percent loss in legibility can be tolerated, luminance as low as about 1 ft-L may be used. If luminances as low as 0.1 ft-L were permitted, legibility distances would be cut down seriously—to about 50 percent for the average driver, and perhaps 60 percent for the older driver. An absolute minimum cannot be specified, because one has to decide how much loss of legibility is permissible. Recommendations given here are intended to provide only a negligible loss.

To specify a minimum luminance one must consider the methods and materials available for sign fabrication and the economics and practicality of obtaining desired performance characteristics. Variations in luminance across the face of the sign become an immediate consideration and such variations can be great. The Institute of Traffic Engineers recommends in a report on externally illuminated signs that variations of 5 to 1 can be considered acceptable and 3 to 1 desirable (19). However, well-constructed illuminated signs have been encountered with variations of 10 to 1, even excluding the dark edges. Such variations are not apparent to the naked eye, unless the dark portions are sufficiently low in luminance to make a perceptible reduction in legibility (for instance, below 1 ft-L in a dark rural area). Although specifications for signs should be set only after full investigation of the problems of meeting them in practice, minimums of 10 ft-L for the main portion of the sign and 1 ft-L in the darkest portion would be desirable for optimum legibility. Of course, all recommendations should apply to signs as maintained in the field, rather than to new, clean ones.

Unless the driver is protected from the glare of opposing traffic, higher luminances are needed. In this study, glare cars with low beams were placed at 100-ft intervals, and were separated laterally about 17 ft from the observer (this separation corresponded to a 10-ft median without shoulders, with both vehicles in the lanes next to the median). For this condition, optimum luminance appears to be between 20 and 100 ft-L. Legibility distances would be cut to about 80 or 85 percent for 2 ft-L, about 70 percent for 1 ft-L, and about 45 percent for 0.2 ft-L. For such conditions, a desirable minimum would be 20 ft-L for the main portion of the sign, with a minimum of 2 ft-L at the darkest portion.

For the location chosen to be typical of the ambient illumination of lighted freeways (400-watt mercury-vapor luminaires with 150-ft spacing) without glare from opposing traffic, luminances for adequate legibility were only slightly higher. With glare from opposing traffic using lanes next to an 8-ft median, the results were nearly the same. It would appear higher adaptation level made the effect of glare less serious, and the glare from headlamps was not great compared to that from streetlight luminaires. The desirable minimum luminances for these conditions would be similar to those for the rural condition with glare from opposing traffic.

For the highest ambient illumination (about the highest a driver is likely to encounter in a downtown area), about 200 ft-L appears optimum, and serious loss of legibility occurs below 20 ft-L. A minimum luminance of 100 ft-L in the main portion of the sign, with a minimum of 10 ft-L in the darkest portion, would seem desirable.

One might question whether separate requirements are needed for the different ambient illumination conditions. Clearly, if all signs were illuminated uniformly at 20 ft-L, legibility would be very good at all locations, even if luminances as low as 10 ft-L were allowed at the darkest portions of the sign. But the difficulty and expense of achieving a close tolerance in uniformity of luminance over the sign brings up the question of maximum luninances.

Recommended Maximum Luminances

The results of this study do not give a good basis for determining the maximum allowable luminances. The observers had no task other than reading the test sign, and looked at it constantly until they had read the message in the smallest letter size. At the dark rural location without headlight glare, some observers remarked that the 200 ft-L sign was too bright, and the 2000 ft-L sign was considered much too bright to be read. They were instructed to read it as soon as possible anyway, and succeeded in doing so at about the same distances as for the 20 ft-L level. Ordinarily, however, a driver does not look constantly at the sign, and is not highly motivated to read it as soon as possible. The fact that he could read it at such a distance if he tried very hard does not imply that he would.

Also, the data suggested that high-luminance signs can change the adaptation level of the eye (or the pupil size, or both). This finding suggests that the driver's vision would be impaired for other tasks requiring dark adaptation. It seems unwise to install unnecessarily bright signs which are unpleasant to the driver and may impair his vision. In the authors' opinion, an upper limit of 30 ft-L seems desirable for rural locations, and luminances above 100 ft-L would definitely be too bright. For illuminated highways, luminances as high as 100 ft-L seem permissible. In brightly lit urban areas, luminances as high as 500, or perhaps even higher, might be satisfactory.

Other Sign Types

The preceding discussion of minimum and maximum luminances applies properly only to white Interstate Series E letters, with the stroke width and spacing used with them, against a dark background. The data for the 75 percent contrast letters give no evidence that different luminance requirements are needed for such white letters against colored backgrounds. If the background were more than one-fourth as bright as the legend, however, luminance requirements might be different, in addition to the loss of legibility associated with low-contrast signs. Maximum luminances would probably need to be reduced.

Although laboratory data (2) have indicated some interaction between luminance and letter series, the interaction was not large. Luminance requirements should be similar for other letter series, especially the similar ones (Series D and F). If a substantially narrower spacing between letters were used, the effect of luminance might be different. If letters of substantially narrower stroke width were used, luminance requirements (both maximum and minimum) should probably be higher.

For dark letters on a white background, there is a need for higher luminances for optimum legibility as well as lower legibility distances in the intermediate range of luminances. All of the recommended minimum luminances would need to be increased, except at the highest ambient illumination condition (Fig. 12). In rural locations, it appears that the maximum luminances should be decreased, at least for large signs.

A large sign with most of its face very bright might have a serious effect on the driver's dark-adaptation and, therefore, impair the driver's ability to see low-brightness objects. A sign with a very bright face also appears to be an unnecessary and undesirable source of veiling glare. Although the generally superior legibility of light letters on a dark background would probably not hold if a narrower spacing were used between letters (20), it appears that current practice, making little use of large white signs, is well founded.

Further Research Needed

The extent of the effect of the sign itself on the observer's adaptation level was not anticipated when the study began, and it was expected that 2000 ft-L would be sufficiently bright to cause a reduction in legibility as a result of the bright portions of the legend fusing together. However, similar results were obtained in an unpublished laboratory study by the senior author using the method described by Allen and Straub (5). Although observers in that study complained that 1000 ft-L was too bright to be seen clearly, they were able to read messages very well, with either long or short exposure times. Further research, in which adaptation level, pupil size, and characteristics of the visual task are varied systematically, is needed to determine the nature of the acuity-luminance relation at high luminances. As the data suggest substantial individual differences, an adequate sampling of observers at all age levels should be used.

On the practical side, further research is needed to tie the results of this study to the legibility of reflectorized signs, so that data will be available for a choice between reflectorized and illuminated signs for various signs and ambient illumination conditions.

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Project leader for this investigation was G. M. Smith, Supervisor, Photometry Unit, under direction of M. H. Janson, Head, Spectroscopy and Photometry Section. Research consultant from the project's inception was T. M. Allen, Associate Professor of Psychology, Michigan State University, who was subsequently assisted by F. N. Dyer.

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The test signs were designed and fabricated by J. V. Shaw and G. M. Smith. L. F. Holbrook and C. D. Church carried out the data processing and assisted with the statistical analysis. R. D. Cook and M. E. Scarlata aided in the preparation of equipment for field use. The late W. R. Jeffreys, formerly Classification Officer of the Personnel Division, helped with selection of observers.

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Vehicle Spray Pattern Study

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The purpose of this study was to investigate the pattern of spray from passing vehicles with respect to determining the optimum lateral and vertical placement of milepost markers for an Interstate-type highway with wide, paved shoulders. Quantitative data are presented from highway test installations over an 18-month study period.

Daytime brightness retention was very high, and no vehicle spray pattern or accumulation rate was obtainable from these data.

Photographs show the change in appearance of the signs after the 18-month test period, but do not give a true comparision of the relative brightness of the signs.

Nighttime brightness readings of reflex reflection proved to be the most effective instrumentation in determining the vehicle spray pattern.

From iso-brightness curves showing bands of equal nighttime brightness retention, the optimum sign placement was 14 ft out and 6 ft above the edge of the pavement. Placing signs at this location would have resulted in a nighttime brightness retention of over 50 percent for all the test signs in this study.

•A PREVIOUS study (1) measured changes in reflectivity of highway sign materials due to spray and splash on a two-lane, rural highway with turf shoulders. The purpose of the present study is similar: to investigate the pattern of spray from passing vehicles with respect to determining the optimum lateral and vertical placement of milepost markers for an Interstate-type highway with wider, paved shoulders.

METHOD OF STUDY

Study Site

Four test installations were made in suburban Bloomington and Richfield, just south of Minneapolis. The installations were placed on sections of highway that were tangent and level. Two installations were placed on I-494 west of Trunk Highway 100, facing eastbound and westbound traffic, and two installations were placed on Trunk Highway 36 north of I-494, facing northbound and southbound traffic. This arrangement insured that at least one installation was downwind from traffic and in the path of spray during all wet pavement conditions.

I-494 is a four-lane divided highway with a 42-ft depressed median and 10-ft paved shoulders, and Trunk Highway 36 is a four-lane divided highway with a 52-ft depressed median and 10-ft paved shoulders. The ADT volume on I-494 was 8,600 of which 13 percent were commercial vehicles, and the ADT volume on Trunk Highway 36 was 12,800 of which 11 percent were commercial vehicles. Traffic on both highways was almost equally divided between inbound and outbound lanes.

On I-494 the average speed for passenger vehicles was 60 mph, the 85th percentile speed was 65 mph, and the pace was 55 mph to 64 mph; whereas on Trunk Highway 36

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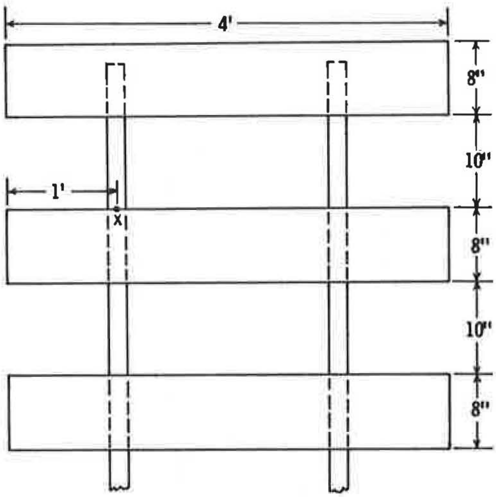
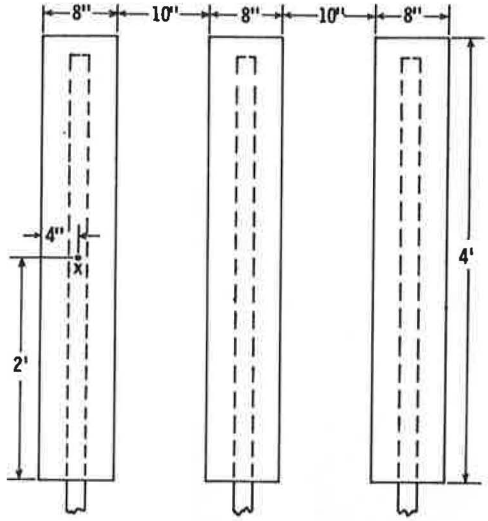


Note: Point x is 12' out and
4' up from edge of pavement.

Figure 1. Horizontal battery.



Note: Point x is 12' out and
4' up from edge of pavement.

Figure 2. Vertical battery.

the average speed for passenger vehicles was 55 mph, the 85th percentile speed was 60 mph, and the pace was 48 mph to 57 mph.

Test Installations

The test installations were made on January 6, 1965. Data were collected continually until the signs were removed on July 7, 1966.

Each test installation consisted of two batteries of panels, one battery with the long panel dimension vertical, the other with the long panel dimension horizontal. The two batteries in a single installation were spaced approximately 300 ft apart to permit photographing each battery individually (Figs. 1 and 2).

Plain, white reflectorized material was used on the panels to facilitate brightness measurements. No border or message was included on the signs.

Each installation also had a control panel placed out of the reach of any spray or splash, which showed only the effect of weathering. The control panels were 8 in. wide by 4 ft high, and were also covered with plain, white reflectorized material.

Procedure and Instrumentation

The effect of spray on the sign materials was measured with daytime and nighttime photographs and brightness readings. Local weather records were utilized to obtain amount and duration of precipitation and information on wind velocity and direction. Field investigations were made accordingly.

Daytime brightness readings and daytime and nighttime photographs were taken in the field the day the signs were installed and were repeated at varying intervals, following major changes in weather conditions. Nighttime brightness readings were performed in the laboratory, and the values were compared with an original sample of the reflective material.

Daytime brightness readings were taken with a Photovolt model 610 diffuse reflectance meter, which gives the reflectance of a surface expressed as a percent of the reflection of magnesium oxide. A magnesium carbonate block was used as a reference, and brightness readings were expressed as a percent of the original brightness.

Figure 3. Test sign 1 (Jan. 6, 1965).

Figure 4. Test sign 1 (July 6, 1966).

Nighttime brightness readings were taken with a Photovolt reflector button tester which measures reflex reflection. A ⅓-deg divergence angle and a 5-deg angle of incidence were used to eliminate specular glare. Brightness readings were expressed as a percent of the original brightness.

Figure 5. Test sign 2 (Jan. 6, 1965).

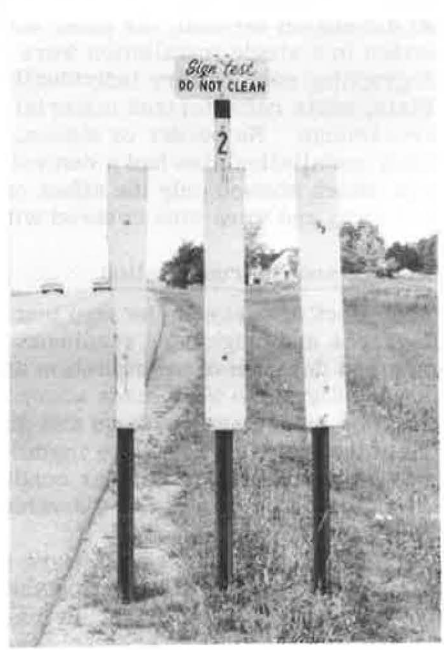


Figure 6. Test sign 2 (July 6, 1966).

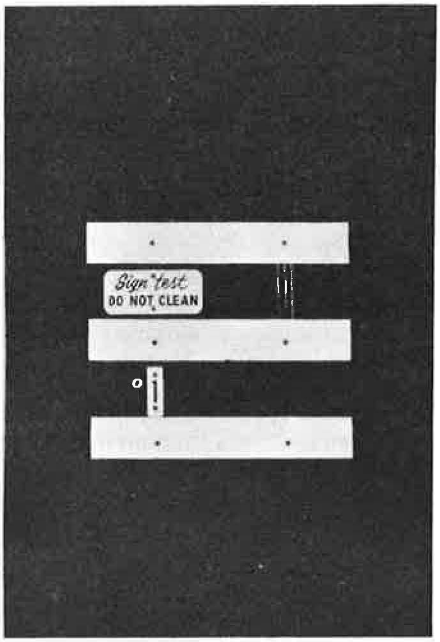


Figure 7. Test sign 1 (Jan. 6, 1965).

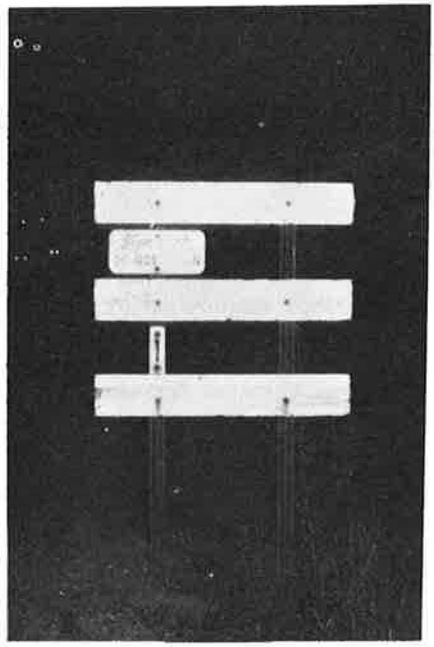


Figure 8. Test sign 1 (July 6, 1966).

To facilitate brightness readings, the panels in each battery were labeled A, B, and C from top to bottom or from left to right, and were divided into twenty-four 4-in. grid squares. Grid squares 1 through 12 ran from left to right across the top of the horizontal panels, or from top to bottom along the left edge of the vertical panels. Grid

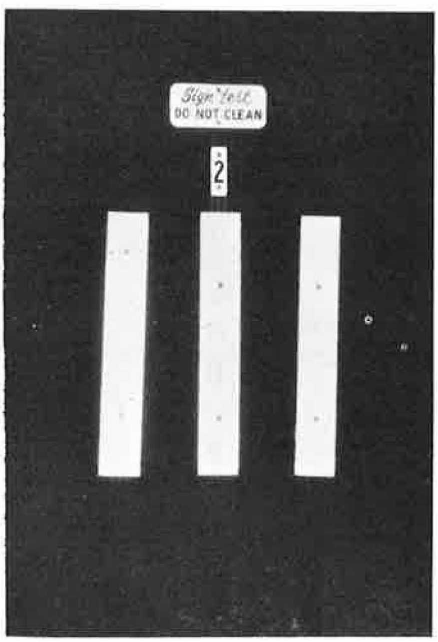


Figure 9. Test sign 2 (Jan. 6, 1965).

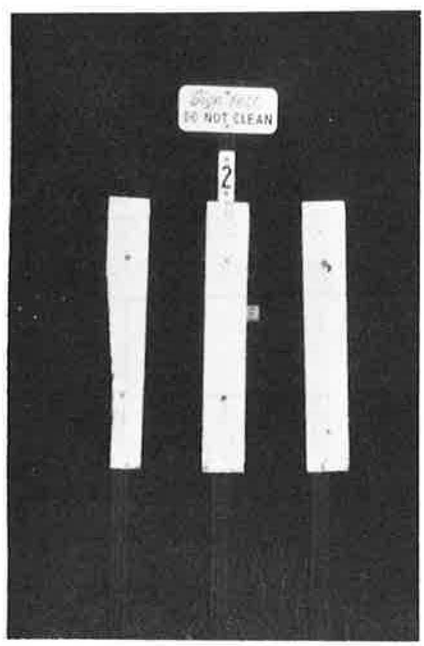


Figure 10. Test sign 2(July 6, 1966).

squares 13 through 24 ran from left to right across the bottom of the horizontal panels or from top to bottom along the right edge of the vertical panels. Brightness readings were taken for each grid square at a point that was representative of the entire square.

Daytime photographs were taken only on bright days with the sun in approximately the same relative position each time. Nighttime photographs were taken using a strobe "power pak" as the light source. All photographs were taken from just off the edge of the paved shoulder at a distance of approximately 20 ft from the signs.

PRESENTATION OF DATA

During the 18-month period that the test signs were in place the test site was subjected to various weather conditions including heavy snowfall, rain, sleet, high winds, and temperature extremes ranging from -28 to +99 F. Two severe storms occurred during this time period, a tornado on May 6, 1965, and a blizzard on March 17, 1966. The test signs were not damaged during these storms.

The signs were also subjected to other abuse. Test sign 7, facing eastbound traffic on I-494, was knocked down and destroyed by a hit-and-run vehicle, and no data are presented for this sign. Four other signs were chipped on the left edge by snowplows. Panel A of test sign 8 was struck several times and finally fell off its support. No data are presented for this panel.

Before and after photographs of the signs (Figs. 3-10) show the change in appearance of the signs after the 18-month period. The photographs do not give a true comparison of the relative brightness of the signs, however, and the spray pattern is not evident from them.

Daytime brightness readings revealed that the signs retained most of their daytime brightness throughout the study. Figures 11 through 14 show the amount of daytime brightness retention on each grid square for the 18-month study period. Over 90 percent of the original brightness was retained on all signs, with the exception of the extreme bottom of three panels. The control panels retained 98 percent of their original daytime brightness.

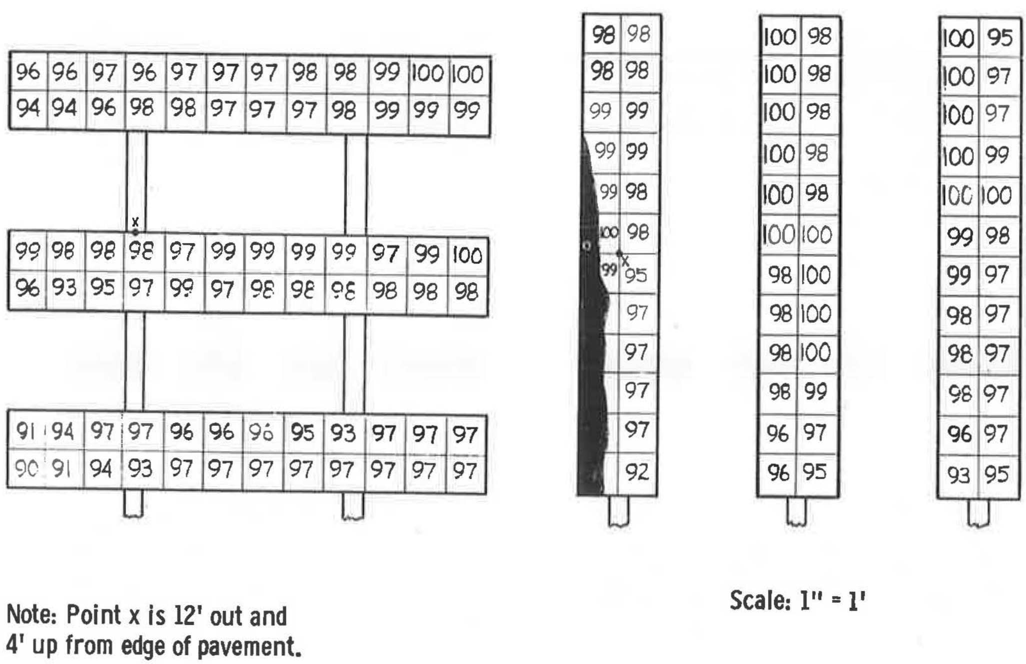
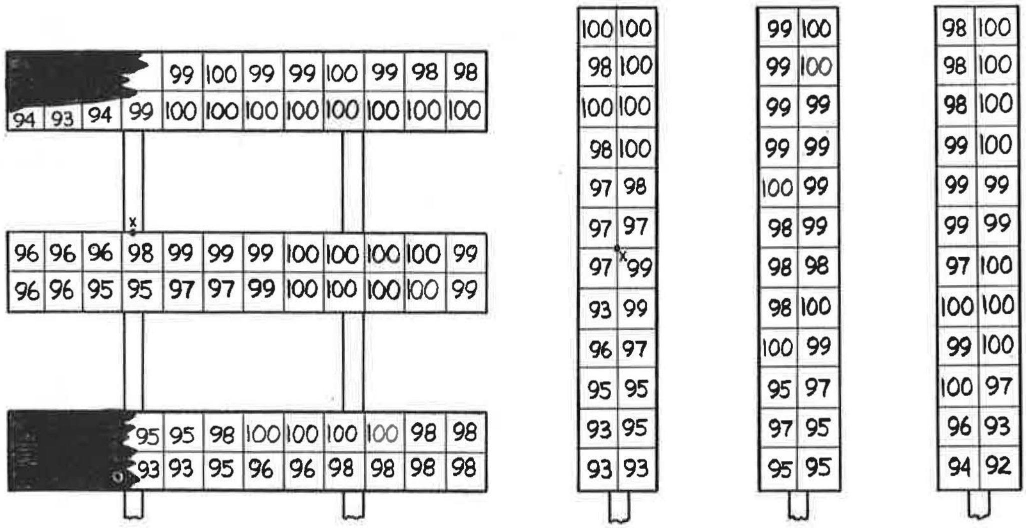


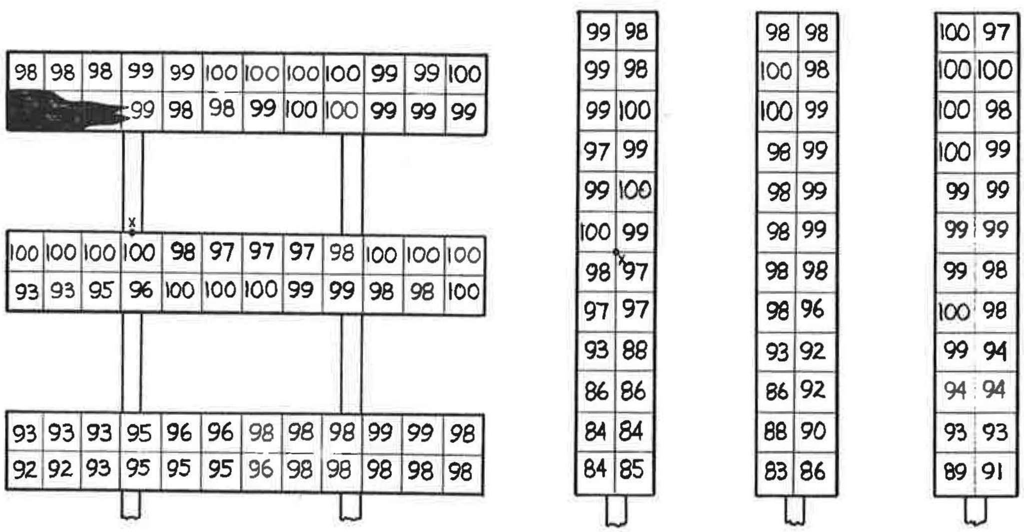
Figure 11. Percent daytime brightness retained, test signs 1 (left) and 2 (right).



Note: Point x is 12' out and
4' up from edge of pavement.

Scale: 1" = 1'

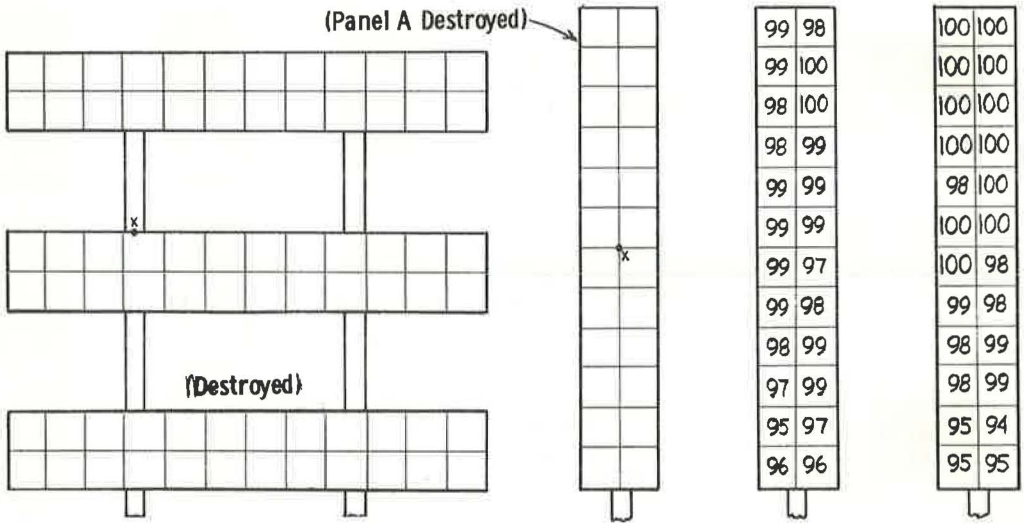
Figure 12. Percent daytime brightness retained, test signs 3 (left) and 4 (right).



Note: Point x is 12' out and
4' up from edge of pavement.

Scale: 1" = 1'

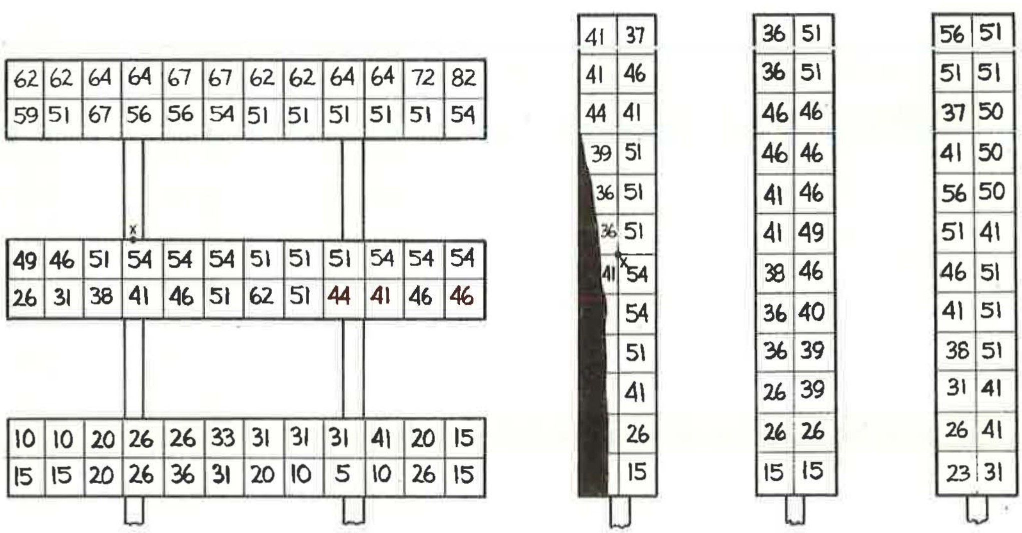
Figure 13. Percent daytime brightness retained, test signs 5 (left) and 6 (right).



Note: Point x is 12' out and
4' up from edge of pavement.

Scale: 1" = 1'

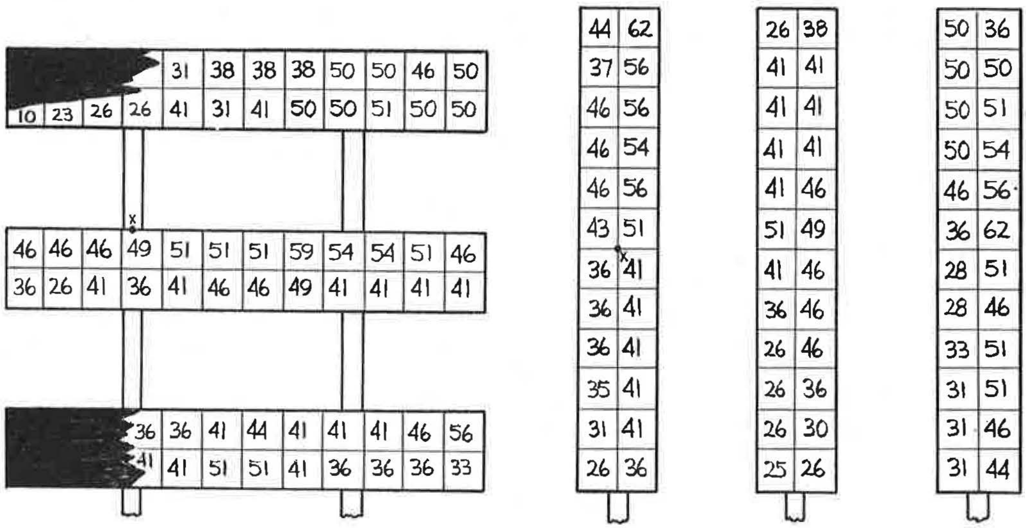
Figure 14. Percent daytime brightness retained, test signs 7 (left) and 8 (right).



Note: Point x is 12' out and
4' up from edge of pavement.

Scale: 1" = 1'

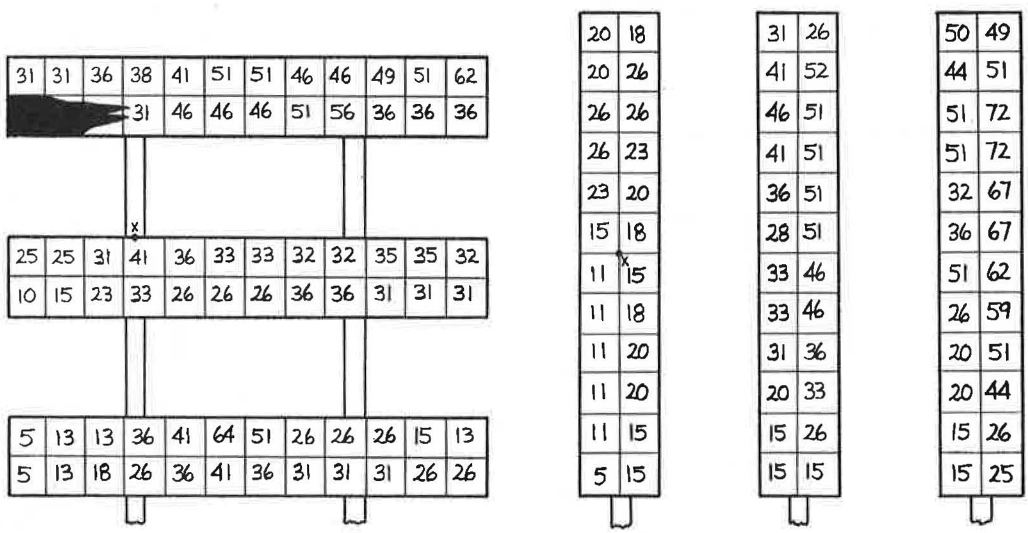
Figure 15. Percent nighttime brightness retained, test signs 1 (left) and 2 (right).



Note: Point x is 12' out and
4' up from edge of pavement.

Scale: 1" = 1'

Figure 16. Percent nighttime brightness retained, test signs 3 (left) and 4 (right).



Note: Point x is 12' out and
4' up from edge of pavement.

Scale: 1' = 1'

Figure 17. Percent nighttime brightness retained, test signs 5 (left) and 6 (right).

The signs were somewhat self-cleaning, and daytime brightness readings sometimes increased from one month to the next. This was especially true when snowplows coated the panels with a layer of fresh snow which melted. Because of this self-cleaning factor and the fact that the change in daytime brightness was very gradual, no vehicle spray accumulation rate was obtained.

As most of the daytime brightness was retained and no vehicle spray accumulation rate was obtained, only data on the percent brightness retained for the entire 18-month study period are presented.

The effect of spray on nighttime brightness was more pronounced. Only a few scattered grid squares retained over 80 percent of their original brightness. The readings at the bottom of some of the panels were as low as 5 percent brightness retention. The control panels retained 80 percent of their nighttime brightness. Figures 15 through 18 show the amount of nighttime brightness retention for each grid square. Nighttime brightness data were collected only at the end of the study, and the brightness retention values are for the entire 18-month study period.

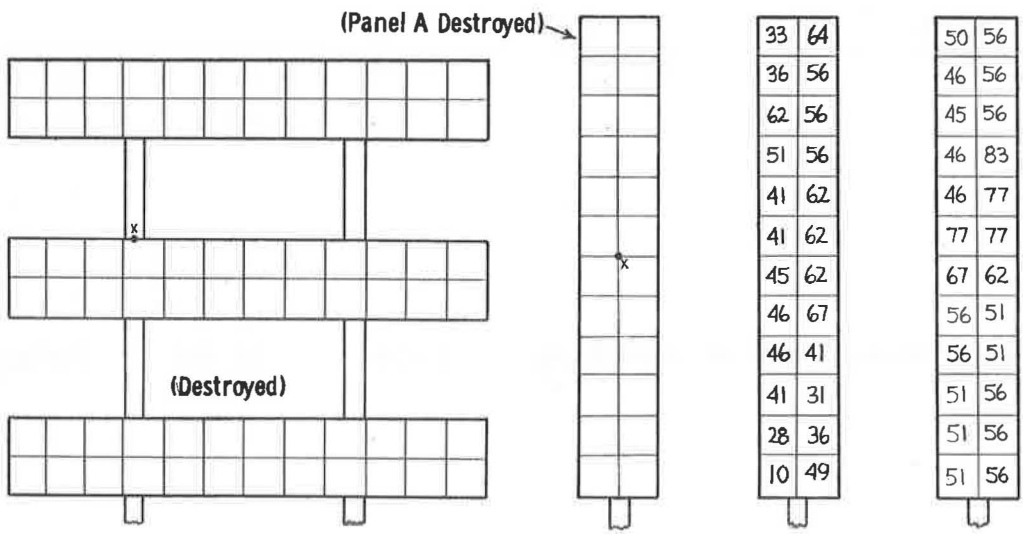
The shaded areas on the brightness retention drawings represent sections of the panels that were chipped off by snowplows. On test signs 3 and 5, the strikes on panel A were presumably made by a snowplow with the blade in the carry position.

ANALYSIS OF DATA

Daytime brightness retention was very high, and no vehicle spray pattern was discernible from these data.

Nighttime brightness data, however, proved to be quite effective in determining the vehicle spray pattern, and night visibility is of great importance. Prime consideration is therefore given to the effect of spray and weathering on the reflex reflectivity of the signs.

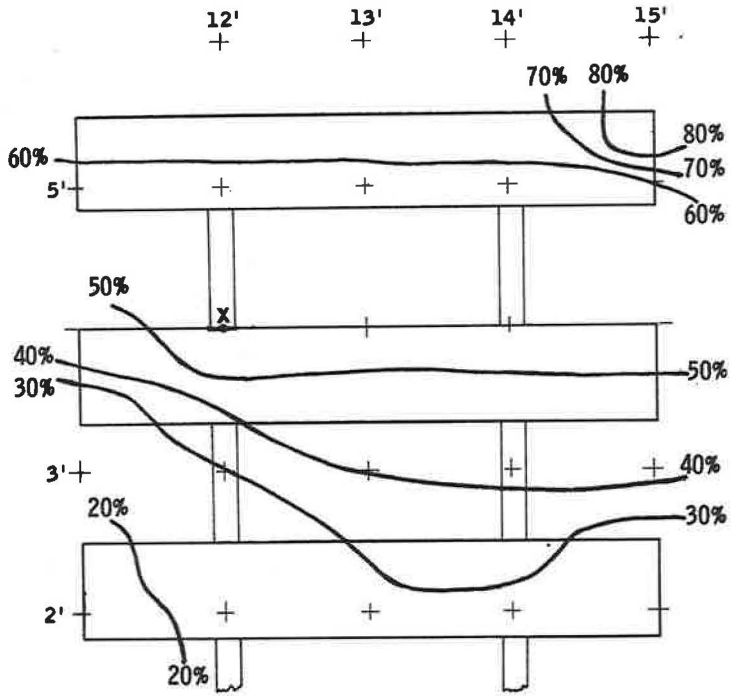
Iso-brightness curves, showing bands of equal nighttime brightness retention, are shown for each sign in Figures 19 through 25. At a sign placement of 14 ft out and 6 ft above the edge of the pavement, there is a significant increase in the amount of brightness retained. Above the 50 percent brightness retention lines, the bands are quite wide, whereas below these lines the bands



Note: Point x is 12' out and 4' up from edge of pavement.

Scale: 1" = 1'

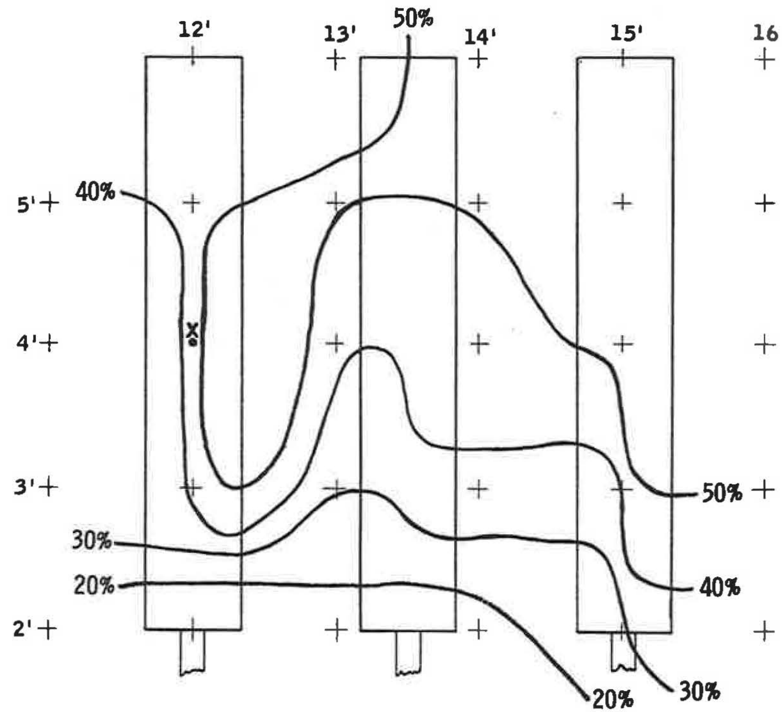
Figure 18. Percent nighttime brightness retained, test signs 7 (left) and 8 (right).



Note: Point x is 12' out and
4' up from edge of pavement.

Scale: 1" = 10"

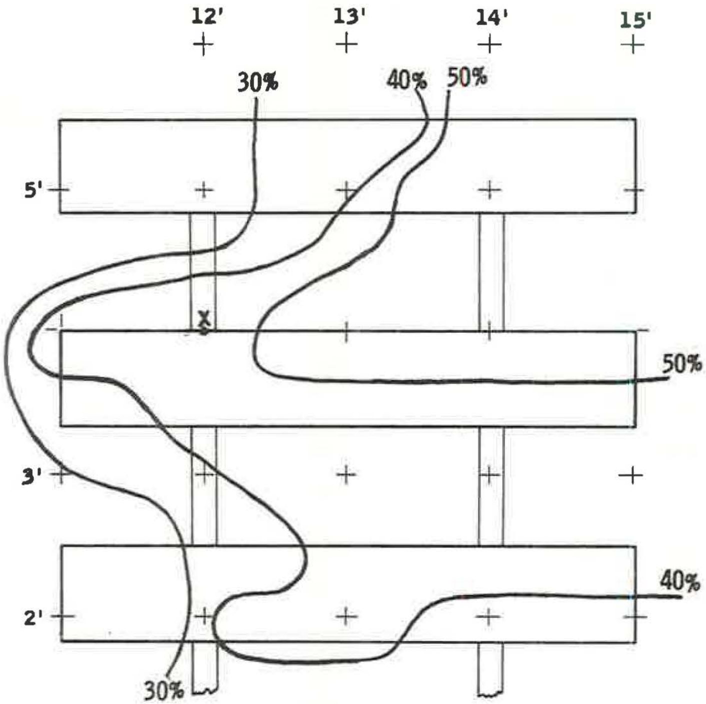
Figure 19. Nighttime iso-brightness curves, test sign 1.



Note: Point x is 12' out and
4' up from edge of pavement.

Scale: 1" = 10"

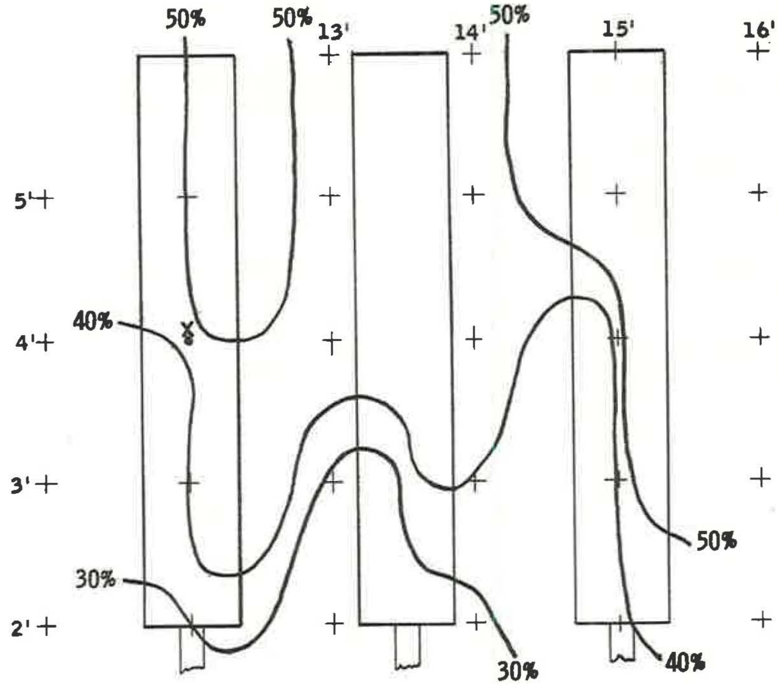
Figure 20. Nighttime iso-brightness curves, test sign 2.



Note: Point x is 12' out and 4' up from edge of pavement.

Scale: 1" = 10"

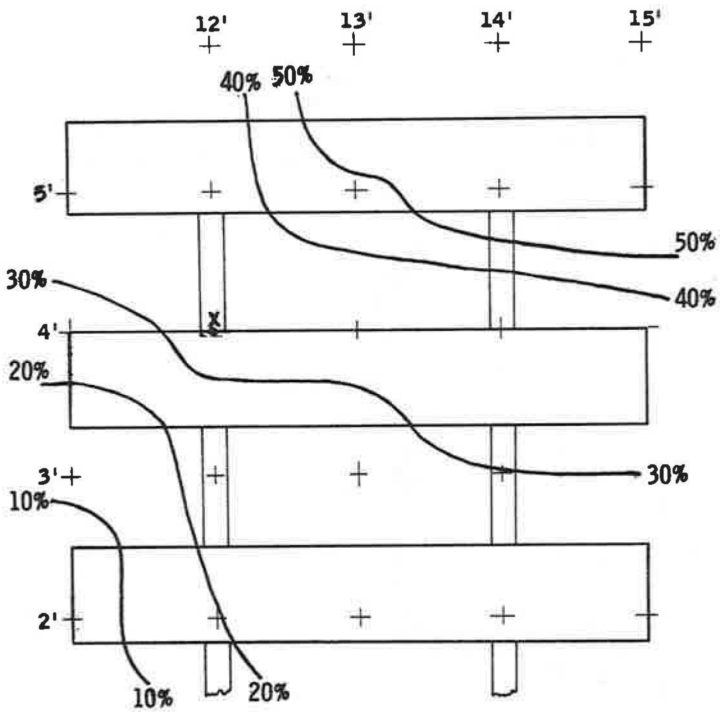
Figure 21. Nighttime iso-brightness curves, test sign 3.



Note: Point x is 12' out and 4' up from edge of pavement.

Scale: 1" = 10"

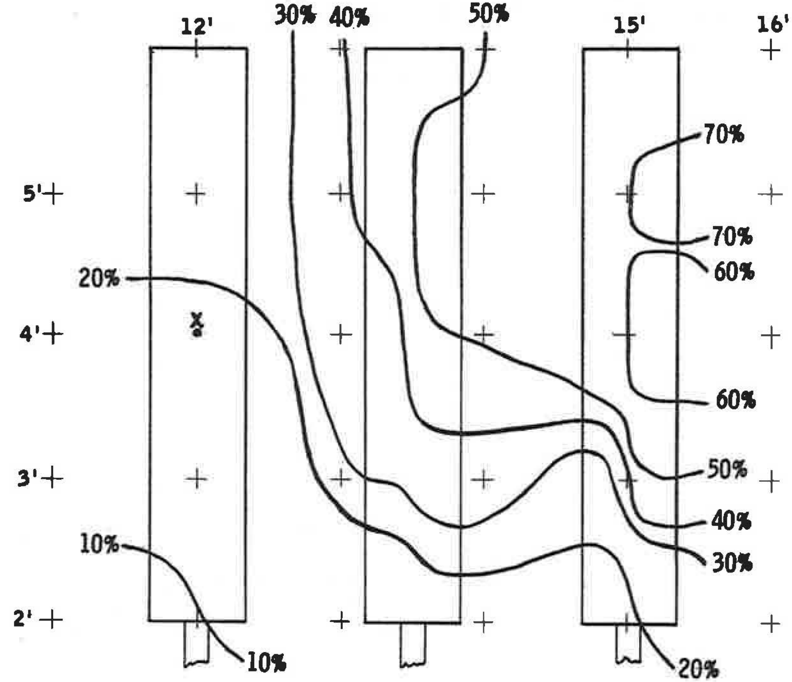
Figure 22. Nighttime iso-brightness curves, test sign 4.



Note: Point x is 12' out and 4' up from edge of pavement.

Scale: 1" = 10'

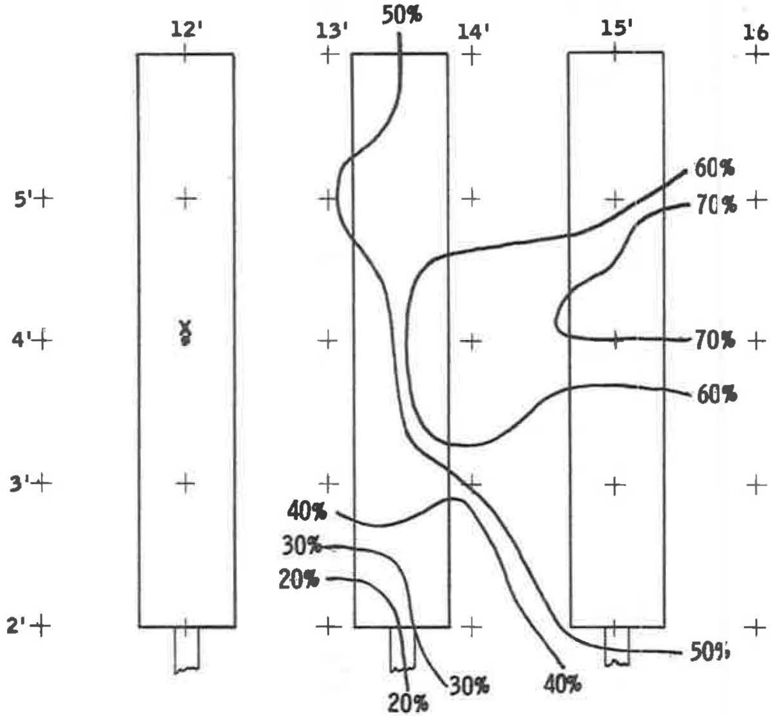
Figure 23. Nighttime iso-brightness curves, test sign 5.



Note: Point x is 12' out and 4' up from edge of pavement.

Scale: 1" = 10'

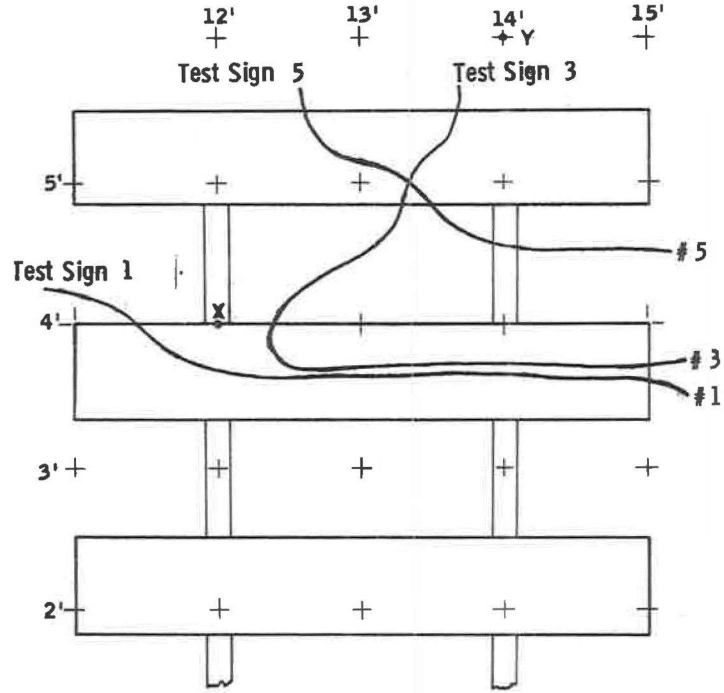
Figure 24. Nighttime iso-brightness curves, test sign 6.



Note: Point x is 12' out and 4' up from edge of pavement.

Scale: 1" = 10'

Figure 25. Nighttime iso-brightness curves, test sign 8.



Scale: 1" = 10"

Notes:
Point X is 12' out and 4' up from edge of pavement.
Point Y is 14' out and 6' up from edge of pavement.
Areas below and to the left of the curves retained less than 50% of their nighttime brightness.

Figure 26. Percent nighttime brightness retention curves.

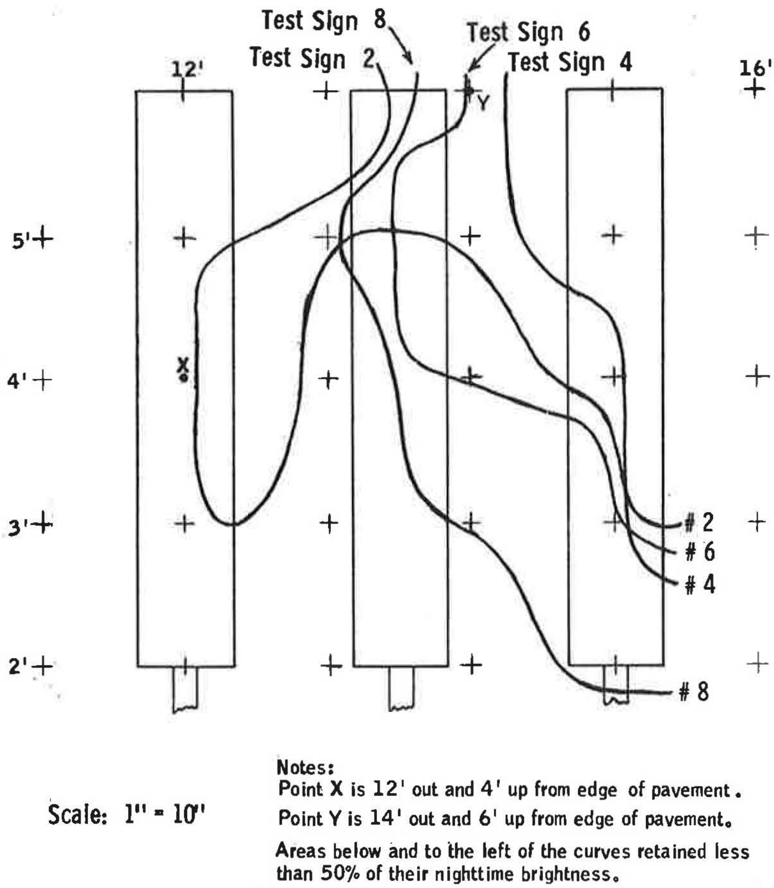


Figure 27. Percent nighttime brightness retention curves.

narrow sharply and there is a considerable loss in brightness retention. Analysis of the iso-brightness curves did not indicate whether the horizontal or vertical shaped milepost marker would be more advantageous from the standpoint of minimizing vehicle spray accumulation.

The 50 percent nighttime brightness retention curves for all the signs are shown in Figures 26 and 27. Areas below and to the left of these curves retained less than 50 percent of their nighttime brightness. These curves show that a sign placement of 14 ft out and 6 ft above the edge of the pavement would have resulted in a nighttime brightness retention of over 50 percent in practically all cases.

Predominant winds during the 18-month study period were from the southwest during the summer months and from the north and northwest during the winter months. Analysis of the spray patterns on the test installations indicates that there was no correlation between predominant wind direction and the vehicle spray patterns.

SUMMARY AND CONCLUSIONS

Daytime brightness readings did not provide an adequate measure of the vehicle spray pattern, and no vehicle spray accumulation rate was obtainable. Over 90 percent of the original daytime brightness was retained on all the signs, with the exception of the extreme bottom of several panels.

The photographs show the change in appearance of the signs after the 18-month test period, but do not give a true comparison of the relative brightness of the signs.

Nighttime brightness readings of reflex reflection proved to be the most effective instrumentation in determining the pattern of vehicle spray.

From iso-brightness curves showing bands of equal nighttime brightness retention, it was found that the optimum sign placement was 14 ft out and 6 ft above the edge of the pavement. Placing signs at this location would have resulted in a nighttime brightness retention of over 50 percent for all the test signs in this study.

A 6 ft mounting height would also be advantageous from a safety standpoint. Vehicles striking a sign mounted 6 ft high should pass beneath the sign, without the sign striking the windshield.

Snowplows made several strikes on portions of the sign panels closer than 2 ft from the edge of the paved shoulder, both while plowing and with the blade in the carry position. Placing signs 14 ft out from the edge of the pavement would expedite snow removal, and would also make mowing operations safer and more efficient.

ACKNOWLEDGMENTS

We are indebted to the Minnesota Mining and Manufacturing Company and, in particular, Homer Rector and Tom Harrington for cooperation in permitting us to use their Photovolt reflector button tester for measuring reflex reflection.

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A Simplified Method for Obtaining Pavement Reflectance Data

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A pavement reflectometer for measuring the directional reflectance properties of pavement surfaces was developed by the authors for making field measurements on several pavement surfaces. This paper describes the apparatus and the operating procedure and presents a typical set of directional reflectance factors obtained with the reflectometer.

•ALTHOUGH illuminating engineers in the United States now generally recognize that one of the principal objectives of roadway lighting is "to enhance the brightness of the pavement and the uniformity of brightness along and across the full width of the roadway..." (1), it is still common practice in this country to specify such lighting in terms of illumination rather than luminance. This practice implies that the roadway brightness patterns are adequate if the average horizontal illumination is at the recommended level. But rather than rely entirely on the light incident on the surface to reveal the roadway scene, we should consider the amount of light emitted from the surface in the direction of the observer, because the information needed by the motorist to evaluate the visual scene is provided by the brightness patterns on the roadway (2). In this regard, the roadway ahead of the motorist should present an average brightness adequate to maintain eye adaptation, a minimum brightness to assure adequate visibility of any object on or near the roadway, and a uniformity sufficient to maintain continuity within the visual scene, to insure comfort, and to render frequent and rapid eye movements by the driver unnecessary. Many illuminating engineers have long been aware of the inadequacy of an illumination specification, and have frequently suggested roadway luminance as a substitute parameter for design purposes, but the latter has seldom been used in this country.

The statement, "the apparent brightness of the pavement depends upon the intensity and angle of incident and reflected light and the pavement reflecting characteristics (specular and diffuse) at typical angles of view" (1), perhaps gives a clue to the reasons for adhering to an illumination specification even though it is generally acknowledged that a luminance specification would be preferable. Whereas levels of illumination are relatively easy to determine, either by measurement or calculation, the derivation of roadway luminance from photometric data involves tedious measurement of pavement reflectance, as well as a formidable number of calculations. Developments in recent years, however, have greatly simplified this task, a straightforward method for computing roadway luminance having been previously reported by one of the authors (2). The calculations, moreover, by their repetitive nature, lend themselves readily to simple computer programming.

Nevertheless, the lack of reliable information concerning the reflecting characteristics of pavements seems to be a retarding factor in this process. Several attempts in the past to measure directional reflectance factors for representative roadway surfaces have met with only limited success (3, 4, 5). Field and laboratory studies have produced few published data, and of this only the field data appear usable. The collection of field data has generally employed either visual photometry or photographic

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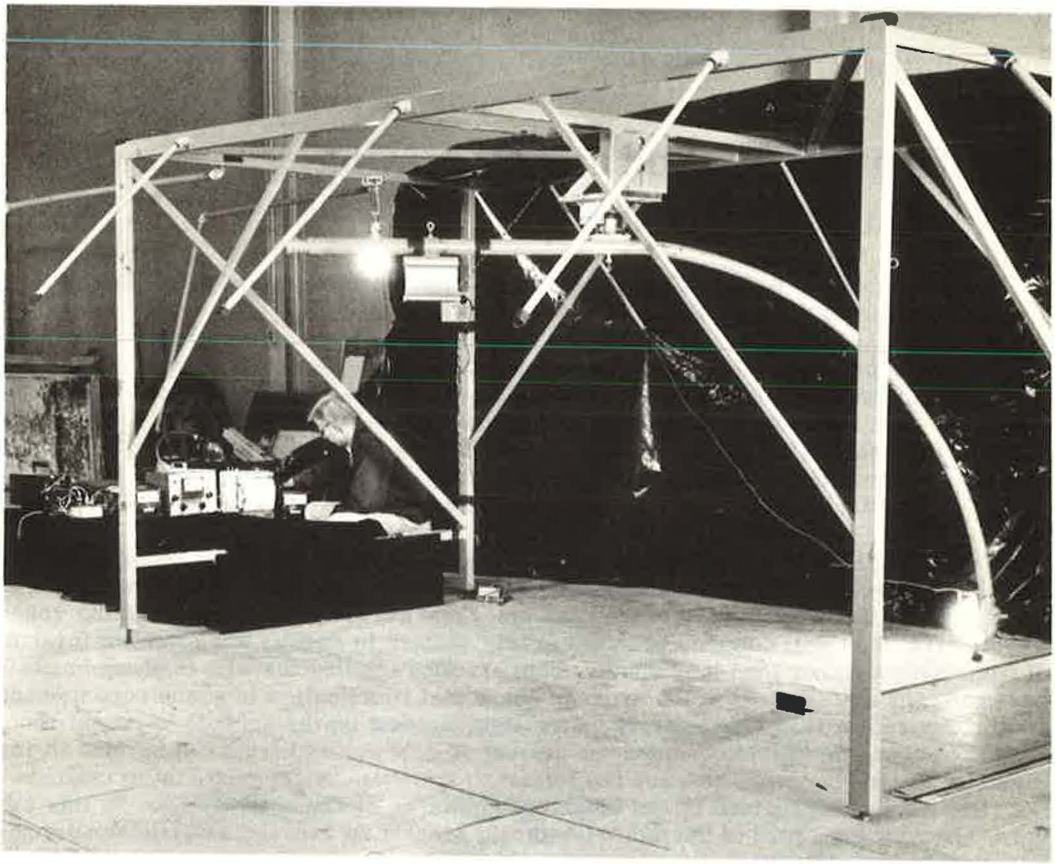

Figure 1. Pavement reflectometer, set up for operation.

techniques, and while both of these methods offered advantages at the time they were used, the direct reading instruments available today provide a basis for a more mechanized and less time-consuming procedure.

This paper describes a method of obtaining the directional reflectance factors of road surfaces based on field measurements with a pavement reflectometer developed by the authors. The operation of the apparatus is described and a typical set of directional reflectance data in the form of curves is shown.

PAVEMENT REFLECTOMETER

The reflectometer (Fig. 1) is basically a form of goniometer consisting essentially of an incandescent lamp mounted on a curved rotating boom and a rigidly mounted telephotometer with provisions for angular position adjustments (Fig. 2). By means of detents in the boom, the lamp may be positioned to illuminate a given spot on the pavement surface from any of a number of vertical angles. The boom is motor driven and rotates the lamp through a 360-deg horizontal angle about the illuminated spot. The telephotometer is aimed and focused on the illuminated spot, and its position can be adjusted to correspond to typical driver viewing angles.

The output of the telephotometer is amplified and fed to a strip-chart recorder which provides a continuous trace of the telephotometer output as the boom rotates the lamp through 360 deg. The amplitude of the trace is directly proportional to the output of the

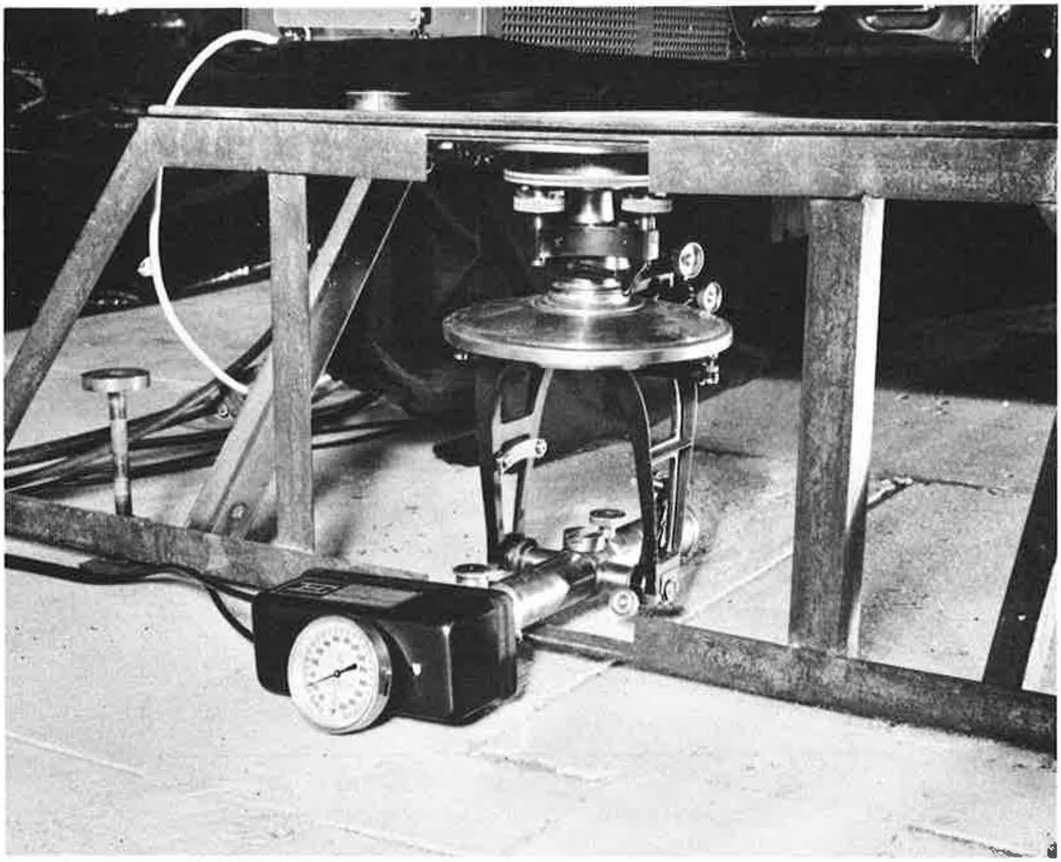

Figure 2. Telephotometer used in pavement reflectometer.

telephotometer, and previous calibration allows the determination of the directional reflectance factor of the pavement surface for any combination of observer and light source positions.

The overall dimensions of the reflectometer permit it to fit within a single 12-ft traffic lane. The framework is made of steel members braced and welded to form a rigid structure.

The reflectometer boom has a 4-ft radius and is driven by a 115-VAC, 10-rpm, synchronous motor through a gear train salvaged from a radar antenna turntable.

The light source, a 120-volt, 300-watt, type R-40 inside-coated reflector lamp, is accurately positioned on the boom by a spring-loaded pin and detent arrangement. Locations corresponding to vertical angles of 5, 20, 35, 50, 60, 65, 70, 75, 80, 82, 84, and 86 deg are provided for. Adjustments are also provided for the alignment of the lamp. Figure 3 shows the isocandle diagram for the lamp in percentage of maximum candlepower. The central 30-deg cone is quite uniform, the greatest deviation from the maximum being approximately 10 percent.

The telephotometer consists of a modified surveyor's transit and a photomultiplier tube whose signal is fed into a dc amplifying unit. Provision is made within the telephotometer for inserting various apertures to limit the acceptance angle and filters to correct for the color response of the phototube. Figure 4 shows the stray-light rejection curve for the aperture used in obtaining the data in this paper. This curve shows

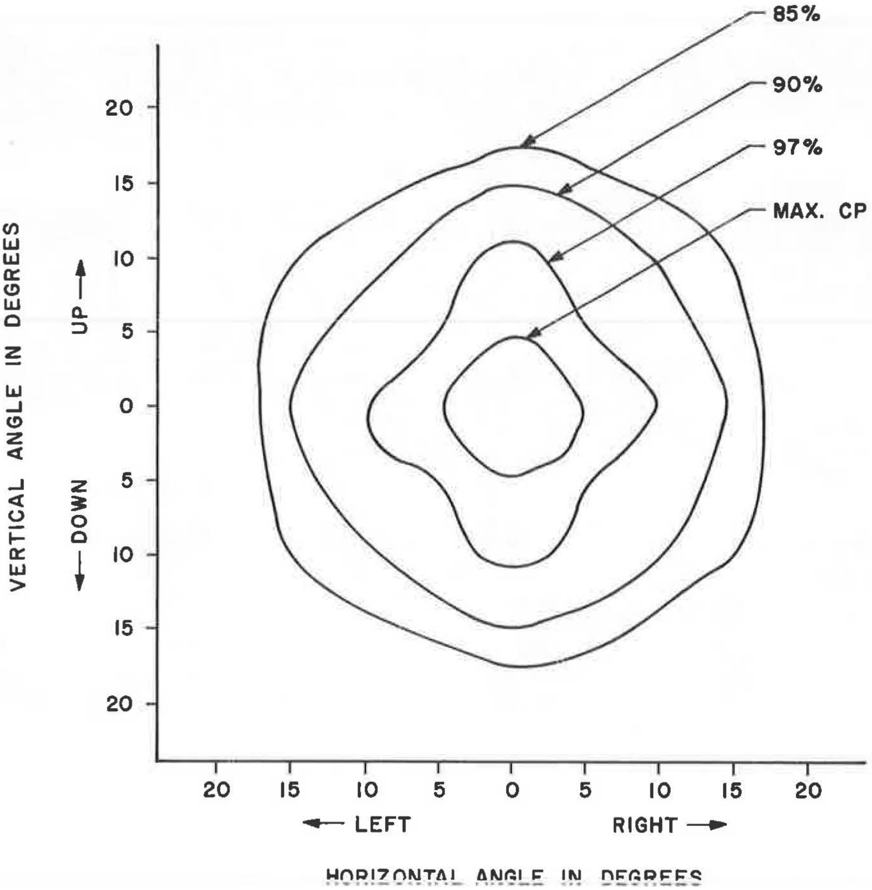

Figure 3. Isocandle diagram for test lamp used in pavement reflectometer.

the effective acceptance angle to be approximately 3 min. The output of the telephotometer-amplifier unit is calibrated in terms of foot-Lamberts. Standardizing checks are performed by making luminance measurements on a strip of white matte blotting paper with both the telephotometer and a spectra brightness spot meter ($^1/_2$-deg UB model) and comparing the results.

The framework of the "tunnel" in which the telephotometer is housed serves to position the instrument precisely relative to the illuminated spot on the pavement surface; the distance between the telephotometer and the center of the illuminated spot is 12 ft. A covering over the tunnel provides additional stray light protection, and the entire tunnel can be moved to either left or right to simulate various observer lane positions. Various viewing distances are simulated by placing spacers of appropriate thickness under the rear legs of the tunnel, and thus elevating the telephotometer.

The output of the telephotometer-amplifier unit is recorded on a 5-in. strip chart, with the repeated actuation of a microswitch in the boom-drive mechanism causing the recording chart to be marked at 5-deg intervals to simplify the data reduction (Fig. 5).

The pavement reflectometer requires a 115-volt ac power source. Some of the equipment for regulating, stabilizing, and monitoring both the primary power and the various electrical elements of the system is shown in Figure 1.

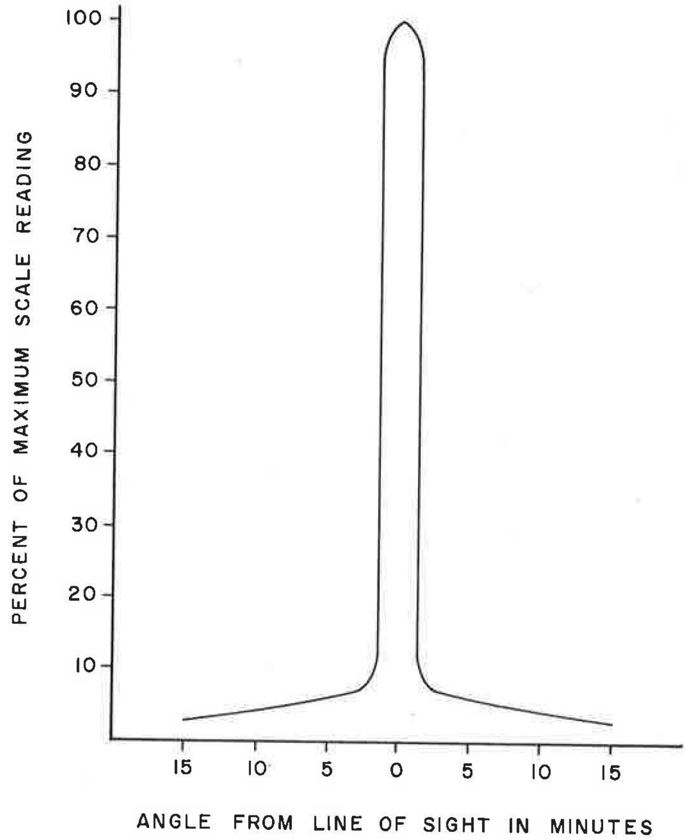

Figure 4. Stray-light rejection curve for telephotometer used in pavement reflectometer.

OPERATING PROCEDURE

The reflectometer, partially disassembled, is customarily transported to the site of a flatbed truck and then completely assembled in place. Each leg of the goniometer framework is adjusted by a leveling screw so that the lower end of the boom rotates in a plane parallel to the surface of the roadway and the center of the illuminated area on the pavement is located by stretching two wires diagonally between the legs of the framework.

To avoid interference from external light sources, the entire reflectometer is enclosed by a lightproof covering. With the cover in place, final adjustment of the apparatus is made as follows: a source of light approximating a point source is placed in the center of the pavement area illuminated by the goniometer lamp, and the telephotometer is visually aligned with this source. After the initial visual alignment, fine adjustments are made to obtain a maximum reading on the recording equipment. The telephotometer is then ready to make measurements for one observer viewing position and viewing angle. Before actual test data are taken, however, the operation of the apparatus is checked by placing a strip of white, matte-finish paper on the roadway test spot and recording the photometer output for a single 360-deg rotation of the goniometer boom. The resulting trace is compared to a similar trace produced under laboratory conditions and if there is no discrepancy, the equipment is assumed to be functioning properly.

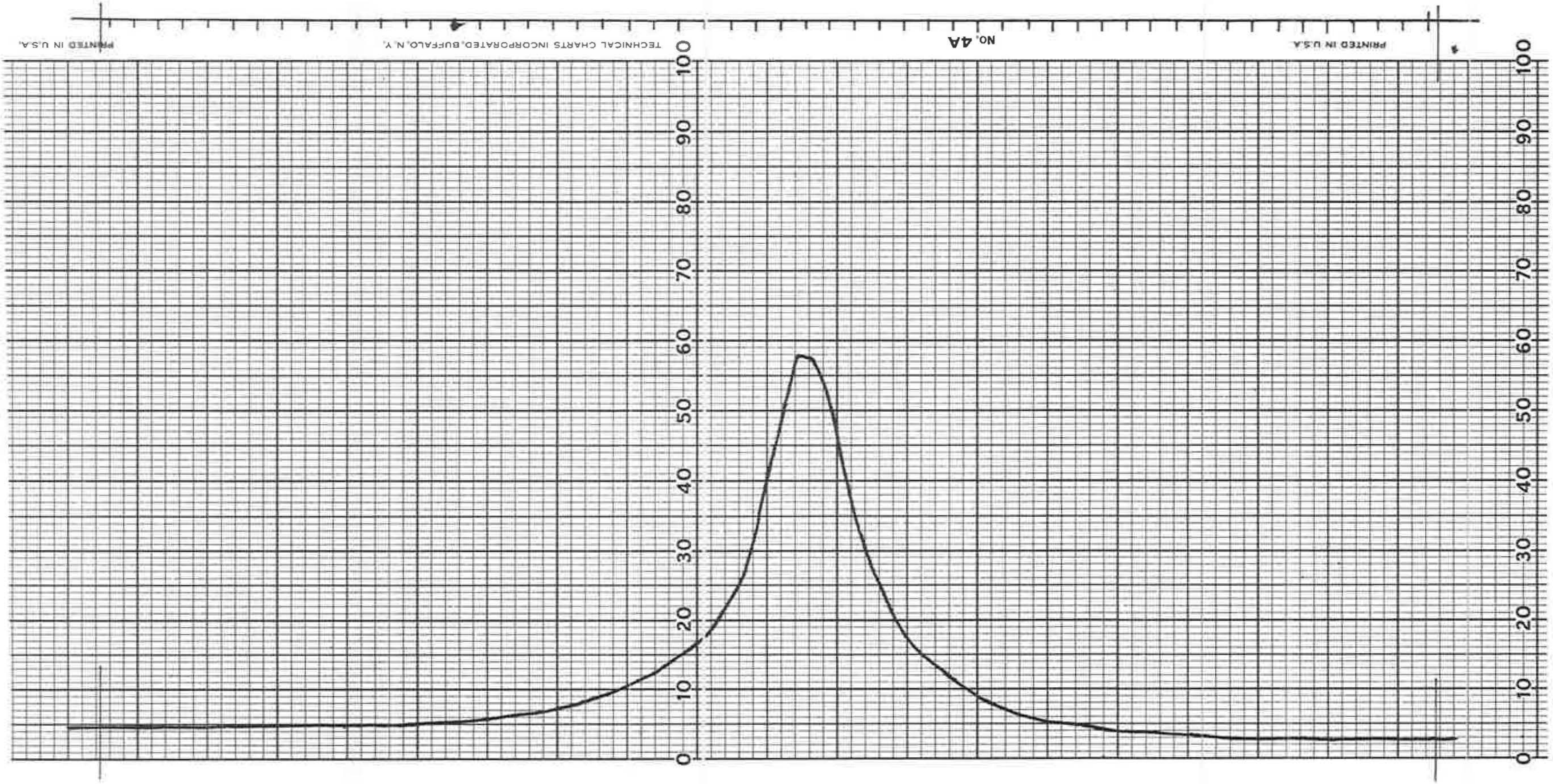

Figure 5. Typical strip-chart trace obtained with pavement reflectometer.

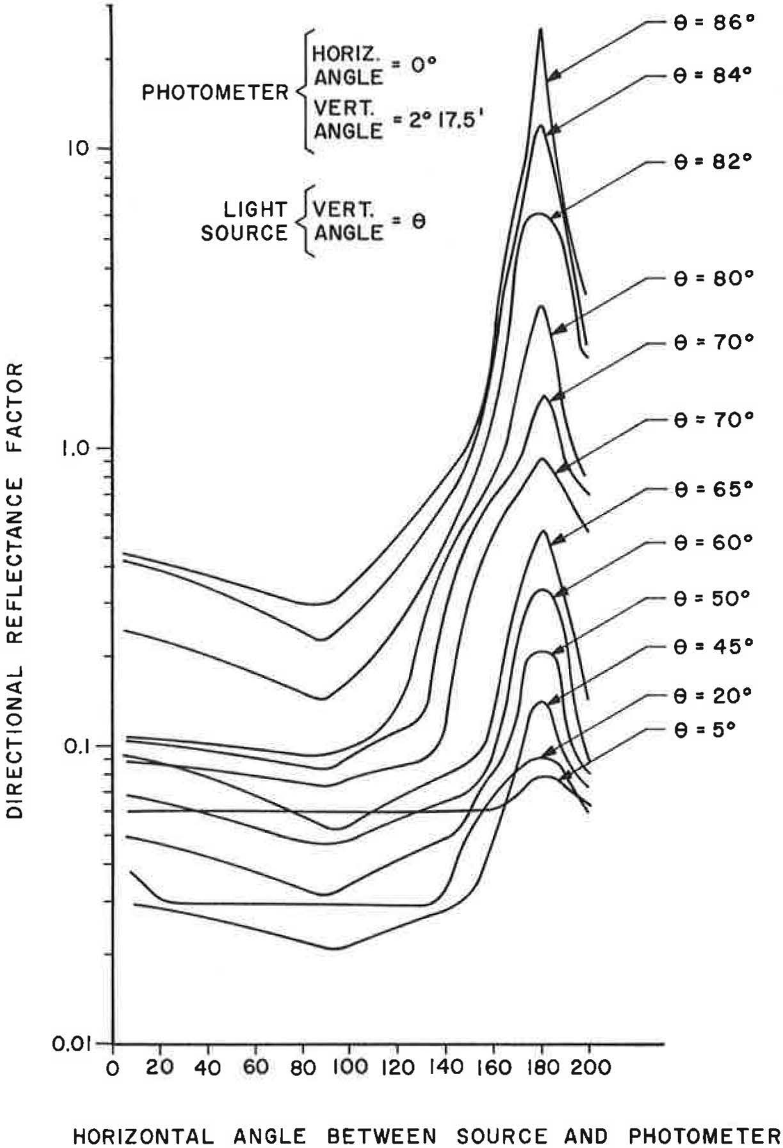

Figure 6. Directional reflectance factors for an epoxy surface asphaltic pavement.

Chart recordings are made with the goniometer lamp at each of its 12 boom settings so that all the previously mentioned vertical angles from 5 to 86 deg are covered. At this point, the apparatus is again checked by the white test strip. In addition, the calibration of the apparatus is further checked by making horizontal footcandle measurements in the center of the illuminated area. The telephotometer is now moved to a new position and the whole procedure of aiming, adjusting, checking, and recording repeated. This is done for as many viewing angles as time permits.

DISCUSSION OF TEST RESULTS

Figure 6 shows a set of typical curves of directional reflectance factors as a function of horizontal and vertical angles of incident light for an observer position at a horizontal viewing angle of zero degrees and a vertical angle corresponding to a viewing distance of 100 ft. The values for such a plot are read from the strip-chart traces at 5-deg intervals. A method for using these directional reflectance factors and other readily available photometric data in making roadway luminance calculations is described elsewhere (2). The curves shown are for an epoxy-surface asphaltic pavement. Similar data have been compiled for other observer viewing positions and angles and for other pavement surfaces (6). Plotting of the reflectance factors is necessary only for visualizing the data more clearly, because a high-speed electronic computer is capable of handling the individual reflection factors picked at 5-deg intervals directly from the strip-chart recording. A total of 864 reflectance factors are necessary to describe one observer viewing angle and twelve vertical angles of the light source. Even the smaller computers have adequate storage capacity to accommodate data for several observer viewing angles.

The pavement reflectometer was used to make repeated measurements on the same type of roadway surface. Agreement between the reflectance factors obtained at different locations is quite good.

Even with the degree of mechanization achieved with this reflectometer, data gathering is still a relatively slow process. Equipment setup time is approximately three hours and the time required to obtain recordings for one driver viewing angle and twelve vertical angles of the source is about one hour.

In many field locations it is difficult to obtain a well-regulated 115-volt, ac power supply. In addition, any nearby traffic can present a safety hazard to both the equipment and its operators. Many of these problems can be eliminated by a similar apparatus designed for laboratory use in conjunction with readily available pavement core samples. Such a device is now being worked on by the authors.

CONCLUSIONS

The pavement reflectometer described was developed and used for measuring the directional reflectance characteristics of pavement surfaces in the field. The directional reflectance factors so derived enable the illuminating engineer to design or evaluate proposed roadway lighting systems on the basis of roadway luminance rather than roadway illumination. Although the amount of data collected with this apparatus to date is small, it does provide a relatively efficient means of accumulating comprehensive data on various types of pavement surfaces.

The field collection of data on pavement surface characteristics has always been a cumbersome and slow process, and the nature of the problem is such that a laboratory setup appears to be the answer to the problem of collecting a large volume of data on several pavement surfaces.

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Vision at Levels of Night Road Illumination

XII. Literature 1966

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•FROM the 1966 literature on vision the following may be of use to those interested in the night visibility problem (52). Schmidt and Connolly (59) summarize many of the problems of seeing and driving. Connolly (20) reports on the London conference of the Illuminating Engineering Society. A detailed report on traffic safety became available (43). Richards (53) discusses the visual aspects of driver licensing. Two new books are available on the anatomy of the eye (50, 56). Bouman and Vos (66) edit the Delft 1965 Symposium on Vision at Low Luminances.

Information on the transmission of the eye media in vivo and in vitro are in good agreement and show the eye media to be more transparent than was found in earlier studies (2, 12). Gregory (33) introduces the psychology of seeing and Rubin (57) reviews the physiology of the eye. While Ratliff's (48) book has little direct application to night driving seeing it does contribute toward an understanding of eye movements, central nervous function and other aspects of vision.

Connolly (18) points out how modern automobile design reduces the information available to the driver and as a result overloads a handicapped visual system. Allen (1) warns against the 30 percent loss of seeing with tinted windshields which is of concern to driving at night and a handicap to drivers deficient in red color vision. A brief report of the London conference on mirrors (39) discusses rear view seeing and Carruthers (85) summarizes the problems of plane and convex mirrors for truck drivers.

A standing observer detects humans in full moonlight at about 29 yards and with no moon at about 19 yards (Taylor, 68). Blackwell, Schwab, and Pritchard (11) discuss highway lighting requirements; indicating that 1.3 ft-c would be required to see a small black dog 200 ft ahead in the driving lane and 1.85 ft-c to see a manikin in a long gray coat at the same distance. Clark (14) describes the characteristics of incandescent lamps including the tungsten-iodine lamps. The cost of lighting provides less light than the previously cited figures indicate (13). Logan and Siegel (83) give measurements of outdoor brightness and discuss glare. Transition lighting at tunnels requires more than 10 percent of the surround luminance to avoid the black hole effect and Schreuder (60) indicates the changes in lighting necessary for the adaptation of the eye without reducing traffic flow.

Cole and Brown (16, 17) report that red traffic signal lights need be four times brighter to be seen by protanopes who have severe red deficient color vision. Against a sky of 30,000 ft-L the red light should have a luminance of 160-260 cd and for protanopes should be 600 cd. A surround helped only when the brightness of the signal was less than optimum. Misalignment of headlights 1°-2° upward decreased seeing distance 25 percent (Rumar, 55).

Reflectionization with glass beads is recommended to increase the brightness of white road lines (78) and lights embedded in ramps replace painted lines for parking guides (7). Spencer and Levin (67) discuss a button light system for traffic guidance on turnpikes.

Raised brake lights easily seen by following cars and switching coupled to the accelerator could aid orderly traffic movement (Crosly and Allen, 22). Yamaguti (79) states that sodium nitrate polarizers would give 2.7 times more light than Polaroid polarizers, which would meet SAE standards and provide no glare headlights.

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Driving in fog is not likely to be improved by infrared viewing devices (9). Additional stronger 21 cp red rear lamps are recommended by Davey (23) to lessen rear end collisions in fog and Wilson (77) discusses daylight driving problems in fog.

Elenius and Karo (27) report that in stationary night blindness, mesopic were higher than photopic thresholds; the latter were within normal limits. Aulhorn and Harms (10) describe a mesoptometer for testing vision at 0.009 to 0.03 ft-L with a projector using 6 different contrasts of Landolt rings. Glare sensitivity is measured as recovery from 10 seconds exposure to auto headlights at 2° against a peripheral field luminance of 0.003 ft-L. Night myopia tests are made at 0.03 ft-L.

The visual system has a 40 msec period within which an eye movement response to a step stimulus can be canceled by responding to a following incompatible response (75). About 0.3 sec, Hempstead (35) reports, is the basic observation time for motion perception of a display, including observing and transmission through the central nervous system to realign the eye for the next transmission to the brain. Leibnitz and More (41) conclude that accommodation and convergence can mediate size constancy only to 1 m (3.3 ft).

A binocular, infrared pupillograph with an accuracy of 1 percent is described by Clarke et al (15). Pupil diameter according to Kahneman and Beatty (65) is a measure of the amount of material being processed in the memory system. Forbes et al (29) measure visibility of signs while the subject also works at another task, approximating a driving task. High brightness signs are seen first at night and lower brightness signs against a low background. Two different observer response patterns are being investigated. Many drivers fail to see signs according to Johansson and Rumar (37) raising the question of how many signs are too many. Eye movements during driving are reported by Connolly (19) to be 3-4° with an occasional 20° on superways, and 25-35° in slow traffic, with a few movements of 40° or even 50°. Acuity and contrast sensitivity decline with age (54).

Color vision is reviewed by de Valois and Abromov (69). The Ciba Symposium (51) is published and the duality doctrine is questioned therein by Pedler and Wilmer. Walraven and his associates (72) propose a color vision theory which assumes three receptors and transmission of a brightness signal summated from all and two antagonistic chromaticness signals. Deuteranomalous individuals have a different shaped relative sensitivity curve and the amount the adapted against green is shifted toward the red may be a useful measure of deuteranomaly (73).

Linksz (42) recommends the Farnsworth D-15 as a simple clinical test for color vision defects. Vos and Kishto (70) continue the discussion of the Stiles-Crawford effect and chromostereoscopy and give an example of green rather than red being the advancing color (low illumination and a large pupil).

Color names influence reports of signal color recognition as Das (24) has shown when "difficult" is substituted for "white" and problems occur in blue and yellow recognitions. A German report (8) indicates successful use of color coded traffic lanes. Yellow glasses, Dobbins (25) reports, make detection of humans more difficult and cause them to appear further away in jungle surroundings than with unaided vision. Deuteranomolous people in traffic see colors slower and less accurately than normals, more so when their vision was not corrected to a 20/20 normal. Certain defectives should be limited to speeds not over 50 mph (Spiecker, 66).

French statistics also indicate that younger and older drivers have more accidents than those of middle age. Jani (36) finds stereoscopic vision to decline after 45 years of age.

Possible drug effects on driving continue to raise questions. Lynn (44) summarizes the regulations for aeroplane pilots and his advice should be extended to automobile driving at night when there are less clues to keep the driver alert. Schreuder (61) would allow only tea or coffee as stimulants for pilots.

Selzer and Weiss (62) based on Michigan experience report that alcoholics were responsible for more than half of the fatal accidents, and that a program is necessary to protect society from the inevitable results now labeled "accidents." Similar information from Illinois (5) shows that drinking is associated with accidents, often with one-car collisions and recommends the reduction of the 0.1 percent blood alcohol standard to 0.08 percent. Walker (71) emphasizes the conclusion that chronic alcoholism is a larger factor in accidents than previously thought. Gramberg-Danielsen (30) found eye movements to be slower and more irregular after alcohol intake, but sensory effects did not correlate with blood alcohol concentration and the effect of alcohol resembled that of oxygen lack.

Green (31), Green and Spencer (32), Ellis (82), and Walsh (88) describe ocular side-effects of drugs and Werner (74) of tranquilizers. Molson (46) reports that, an antihistaminic, Phenergan, had no effect on an eye-hand coordination test for 1 to 2 hours, but caused a significant deterioration beginning at 3 hours. The 17th Nordic Ophthalmological Congress (20) discusses drugs, reporting side-effects, cataracts, pressure changes, retinopathy and little change in visual acuity or contrast. Oxygen does not always improve night vision, and Kent (38) reports that after fasting, the administration of glucose improves thresholds while breathing oxygen at one atmosphere.

Porter (47) comments that it is remarkable that no part of the driving test is given at night. Some 92 factors contributed to 17 fatal accidents making difficult assigning the major causes of the accidents. Haile (34) reports on visual factors, such as not looking, couldn't see the obstacle, or individuals with defective vision, but unaware of it. General attitudes may be testable and useful for detecting accident proneness (McFarland, 45). Shaw (63) reports personality tests useful for selecting bus drivers in Africa. Richards' discussion on the vision testing aspect of a driver examination was summarized (58). The AOA-AAMVA driver screening booklet is revised (80).

A survey in Wisconsin found 35 percent of the driving public to have deficient vision; 15 percent dangerously low (6).

Smith and Weale (64) show that some British spectacle frames are unsuitable for driving because the visual fields are reduced. Photographs and field plots reveal how vision is obscured as the head is tilted, turned, or when looking to the rear. Some frames even obstructed the area of the pupil.

Porter (47) recommends the British Supra frame for auto drivers with no lower rims and high up temples. Antireflection coating is desirable, likewise splinter-proof lenses. An anonymous article (4) recommends for driving: the best possible prescription (for the nearsighted the usual distance prescription is not adequate for night driving) coated lenses, lenses fitted close to cornea to give a wide field of view, frame adjusted so that it will not slip down the nose, light weight (plastic lenses), thin rims (preferably metal) and with a good case that will keep the spectacles clean when not in use and stored in the automobile. It is suggested that some firm should make a suitable frame for motorists.

The question of whether driving is a right or a privilege is analyzed and Reese (49) indicates that better regulation could follow the concept that it is a right. Time-lapse motion picture photography is useful for traffic analysis (21). Ezel (28) reports on the contributions from Indiana University sponsored by the American Optometric Foundation. The ten million dollar grant (3) to the University of Michigan should contribute useful research on problems of motoring.

Greenshields (89) finds steering-rate patterns and proposes using them as measures for driver fatigue. Gordon (87) analyzing eye position and movements reports that the center and side lines on a road are the main references for guidance of the vehicle. The Pulfrich effect from unequal amounts of light to the eyes can be a danger in driving and a source of accidents (Wilson, 76). Dynamic visual acuity is related to age and sex and may need differential treatment if it should become a test for a license (84). Extrafoveal acuity falls off rapidly. Milladot's (90) measures reveal a slow decrease peripherally to about 30 minutes of arc and then a more rapid fall off to 7°. He found acuity 77 percent at 30 min, 62 percent at 1°, 42 percent at 2.5°, and 32 percent at 5°. Accident proneness is not necessarily a result of 0.66-0.75 vision. More accidents occurred when the right rather than the left eye had the poorer vision. "Probably the ocular changes in question are due to a traffic-endangering, central suppresion of the image of the impaired eye. If a speed limit is imposed, an increased minimum braking retardation should also be demanded," concludes Gramberg-Danielsen (91). Pollock (92) reports visual acuity to average 20/50 ages 79-95, 20/40 to 20/50 ages 79-85, and 20/60 ages 86-95 years.

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An Investigation of the Use of Expanded Metal Mesh as an Anti-Glare Screen

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•PROBLEMS in night driving introduced by headlight glare from opposing traffic are well known to both the motoring public and highway engineers. In 1962 the Pennsylvania Department of Highways tested a new product, expanded metal mesh, for use as a headlight barrier. Anti-glare screen, a headlight barrier fence constructed of expanded metal mesh and mounted on top of the median barrier, is intended as a solution to the headlight glare problem on divided highways with medians of insufficient width.

The purpose of this research project was (a) to formulate preliminary anti-glare screen design criteria, (b) to test these criteria by means of trial installations, and (c) to determine, if possible, the economics or feasibility of anti-glare screen installation.

BASIC DESIGN CONSIDERATIONS

The success of any anti-glare screen design is highly dependent on the height of the headlight barrier and the nature of the material of which it is constructed.

To keep costs to a minimum, the headlight barrier was constructed to the minimum height that would allow it to perform its intended function. To determine this height, a theoretical study of the optics of the problem was undertaken, involving consideration of the following parameters: (a) cross-sectional roadway geometry, (b) longitudinal roadway geometry, (c) lateral separation of opposing vehicles, (d) driver eye height, (e) vehicle headlight height, (f) horizontal headlight beam spread, and (g) vertical headlight beam inclination.

The cross-sectional geometry considered for design purposes involved a four-lane divided highway having a 10-ft median, 12-ft lanes, and a ⅛-in./ft cross slope down and away from the median. The longitudinal roadway geometry was assumed to be straight and level. The lateral separation of opposing vehicles used in the design involved having the glare source in the shoulder lane and the glare-receiving driver in the median lane. Driver eye height was assumed as 4 ft, thus the operator of a passenger car was considered in the design, as opposed to a truck driver. The vehicle headlight height was taken as 2 ft 6 in. The headlight was assumed to be aimed on high beam with a 1-deg upward inclination above the headlight axis. The horizontal beam spread of glare-inducing light was assumed as 14 deg off center.

The theoretical study resulted in a required headlight barrier height of 3 ft 9 in. above the inside edge of pavement. To substantiate this finding a field check was made by erecting a temporary 100-ft long anti-glare screen in an unused parking lot. A mock roadway was delineated on either side of the screen, and several opposing vehicle runs were made with the screen height varied from 3 ft 9 in. to 4 ft 1 in. It was the opinion of the participating drivers that a height of 4 ft 1 in. was required.

Because the theoretical study involved a number of assumptions regarding such factors as headlight characteristics, it was decided to be on the conservative side and adopt a 4-ft 1-in. required barrier height for design of a pilot study installation.

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Several characteristics of expanded metal mesh influenced its selection as the headlight barrier material. It is fabricated from flat sheets forming a diamond shaped pattern with $\frac{3}{16}$-in. wide strand widths angled at approximately 20 deg to the plane of the original sheet. When viewed at a perpendicular it consists of approximately 85 percent open space, but when viewed at a flat angle, as it would be by an approaching motorist, it appears to be a solid sheet, thereby blocking the headlight glare from an opposing vehicle. This characteristic allows the material to perform the required light interception while not imposing as strong a feeling of transverse constriction as might be produced with a solid barrier. In addition, the openness of expanded metal mesh prevents it from acting as either a wind or snow screen, an action that could cause serious drifting in its vicinity.

With the questions of required screen height and the basic material resolved, consideration was next given to the method of suspending the screen along the median. Although expanded metal mesh, whether steel or aluminum, is strong enough to resist wind and snow forces as well as to support its own weight, it is hardly suitable to stand up under vehicular impact. Therefore, it was decided that anti-glare screen would be designed as an expanded metal mesh fence mounted on top of a steel back-to-back beam median barrier.

Because the median barrier itself serves to block light up to its height of 1 ft 11½ in., a 2-ft 2-in. wide expanded metal mesh panel was required to achieve a headlight barrier height of 4 ft 1 in., ½ in. of mesh depth vertically overlapping or falling between the back-to-back beams of the median barrier.

Briefly, the resolved anti-glare screen design involved drilling 2 holes in the median barrier post, bolting 3 in. channel bars erected on 12-ft 6-in. centers to the median barrier, and strapping the expanded metal mesh panels to the channel bars. Tension wires, connected to the mesh by wire fasteners, were used at the top and bottom to reduce sag and wind vibration.

PILOT STUDY SITE SELECTION

To test anti-glare screen as a headlight barrier on the mainline of a divided highway as well as on two-way ramps or direct connections with sharp curvatures, two different study sites were selected. A 2.7-mi section of Interstate 76 was designated for testing the value of anti-glare screen on the mainline. This roadway offered wide variation in both horizontal and vertical geometry, with curves as sharp as 5 deg and grades up to 3 percent. The cross section of this route is that previously described in the discussion of design considerations.

To test the suitability of anti-glare screen erected on a sharp curve, a 1700-ft section of the direct connection linking I-83 with US 11-15 was also selected for study. This section includes a spiral terminating in a 400-ft radius circular curve. The roadway cross section at this site is basically the same as that of I-76, except that the median is only 4 ft wide.

After the two sites were selected, final design criteria were resolved and construction plans drawn. Plans for the I-76 installation called for half the length of the anti-glare screen to be constructed with steel expanded metal mesh and half with aluminum; a median barrier had already been constructed a few years earlier. The plans for the shorter I-83 installation called for the simultaneous erection of a steel median barrier.

COSTS AND INSTALLATION

Because the I-83 test installation was only 1700 ft long and involved the simultaneous construction of a median barrier, this discussion is restricted to those findings concerning the longer, 2.7-mi, I-76 installation.

On two occasions, the I-76 anti-glare screen installation was advertised. Each time only one bid was received; in the first the bid for the in-place installation plus 10 percent surplus materials (to be set aside for purposes of maintenance) was approximately $69,000, and in the second approximately $67,000. These bids were rejected as excessive.

Figure 1. Device usedto expedite post drilling operation.

Figure 2. Drilling of post holes.

Figure 3. Bolting of channel bar to median barrier post.

Figure 4. Tension wires to support expanded metal mesh.

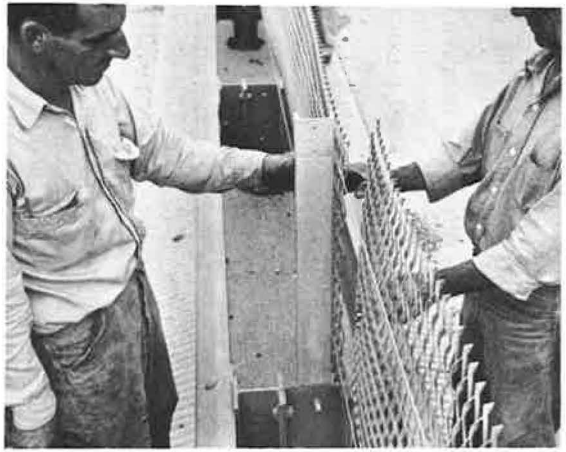

Figure 5. Positioning and overlapping mesh at channel bar.

Figure 6. Strapping mesh to channel bar.

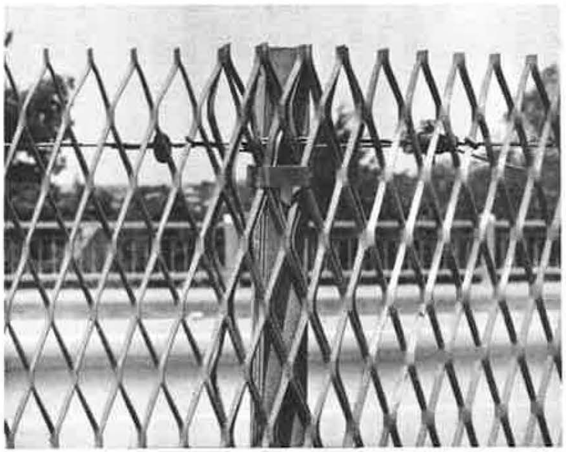

Figure 7. Mesh fastened to tension wires.

Figure 8. Completed anti-glare screen installation.

Plans were then reformulated to purchase the required materials and perform the actual installation using Department work forces. The materials were successfully advertised and purchased for $15,390. Department forces required 24 days during September 1963 to complete the job at an estimated cost of $6190 for manpower and machinery. Thus the entire installation was completed for a total cost of $21,580 or about $1.51 per lineal foot.

The extreme difference in cost, $21,580 vs $67,000, between doing the job with Department maintenance work forces as opposed to private contractor can be partially explained by the apprehension that exists concerning any work performed on I-76. Because this road is Pennsylvania's most heavily traveled facility, the rigid traffic controls required during construction can be rather costly. Nevertheless, significant savings in construction costs were achieved.

An important step in the field erection of the anti-glare screen is the drilling of the required two holes in the existing median barrier uprights. These holes are used to fasten the 3-ft channel bars to the median barrier; the bars serve as line posts to support the expanded metal mesh. The maintenance foreman contrived a special jig with which a hand drill could be immediately positioned at the two points required, greatly expediting the drilling procedure. The construction process is shown in Figures 1-8.

EVALUATION OF INSTALLATIONS

In general, the I-76 installation has been a success. However, the I-83 installation terminating in the 400-ft radius curve was severely damaged on many occasions, even when no median barrier contact was apparent. This was attributed to the rear overhang of large trucks which can easily span one-half of the narrow 4-ft median at this site. For this reason the I-83 installation had to be dismantled even though the anti-glare screen's optical performance was satisfactory. The remainder of this section is devoted to the evaluation of the I-76 installation.

Physically, the 2.7-mi I-76 installation has well withstood the test of time. Surprisingly little maintenance has been required. Of the originally installed 1136 expanded metal mesh panels, each spanning 12½ ft, only 21 panels had to be replaced. Maintenance costs have been approximated at $1376 over a 3-yr period, or about $0.03 per foot per year. This figure even includes minor repair to the supporting median barrier structure.

Regarding the two mesh materials, weathering produced little difference between the galvanized steel and aluminum panels. However, the steel mesh was superior in three respects. Its initial cost was only 7/9 that of the aluminum mesh. Steel mesh is more rigid than aluminum mesh; during installation the aluminum mesh required greater care, to avoid distortions due to handling. Immediately after installation, the aluminum panels spanning the solid-ground-to-structure joint failed due to vibration of the structure and had to be replaced with steel panels.

From a traffic operational standpoint, no detrimental effects could be attributed to the installation of the anti-glare screen. Studies of speed and lateral placement characteristics, jointly conducted with the Bureau of Public Roads, both before and after the installation did not indicate any disturbance to the traffic stream. The BPR also conducted before and after tests of driver tension and glare exposure, but the results are not yet available.

The tested anti-glare screen design was predicated on intercepting opposing headlight glare on a level roadway, with little attention given horizontal curvature in the design of the screen height. As expected, the screen successfully blocked opposing headlight glare on level roadways as well as at vertical crests. However, in vertical sags with short transition curves where the drivers' eyes and opposing vehicle headlights are on the two different grades forming the sag, headlight glare occurred for short periods of time until both vehicles were on the same grade. This was expected as the previous study of the optics involved showed that to elimate all opposing headlight glare, for example in a sag involving a +3 percent and -3 percent grade, it would have been necessary to erect an anti-glare screen at heights in excess of 15 ft

TABLE 1

ACCIDENT STATISTICS—BEFORE[a] AND AFTER[b] STUDY

Accident Type	No. of Accidents																	
	Control Section 1[c]						Control Section 2[d]						Anti-Glare Screen Section[e]					
	Before			After			Before			After			Before			After		
	Day	Night	Total	Day	Night	Total	Day	Night	Total	Day	Night	Total	Day	Night	Total	Day	Night	Total
Fatal	0	1	1	0	1	1	0	0	0	1	2	3	1	1	2	0	0	0
Injury	8	3	11	10	4	14	35	31	66	37	26	63	14	12	26	12	7	19
Property damage	16	18	34	25	13	38	70	54	124	92	58	150	32	17	49	30	16	46
Total	24	22	46	35	18	53	105	85	190	130	86	216	47	30	77	42	23	65

[a]Includes 2-yr period, Sept. 1961 through Aug. 1963.
[b]Includes 2-yr period, Oct. 1963 through Sept. 1965.
[c]LR 769, Sta. 154 to Sta. 250, 9600 ft.
[d]LR 769, Sta. 451 to Sta. 622, 17,100 ft.
[e]LR 769, Sta. 251 to Sta. 393, 14,100 ft.

at certain critical points along the road. Therefore, the 4-ft 1-in. screen height employed in the test installation represented a practical solution to the problem. The test installation did, in fact, greatly reduce the amount of potential glare.

The success of the practical solution was evident from the many favorable letters received from drivers residing in the Philadelphia area and newspaper editorials.

Inasmuch as the effects of anti-glare screen installation on traffic accident occurrence cannot be rigidly ascertained in a 2.7-mi test section, a before and after accident study was conducted to indicate whether anti-glare screen tended to increase accident frequency as observed by the British Road Research Laboratory (1). The study revealed that the section of roadway encompassing the anti-glare screen installation had a lower frequency in the 2-yr after period than in the 2-yr before period. This was in contrast to the experience at the two contiguous control sections employed in the accident study. These statistics are given in Table 1.

When accident frequency at the anti-glare screen installation was compared to that at control section 1 by means of the Fischer-Irwin test, the decrease in accidents in the after period along the screen was statistically significant at the 15 percent level (85% certainty). When compared to control section 2, the decrease in accidents along the screen was statistically significant at the 7 percent level. These findings were based on all accidents, both day and night. A decrease in night accidents in the area of the anti-glare screen also occurred. It is concluded that anti-glare screen definitely increases the comfort level experienced in night driving and does not negatively affect the accident history along its length.

CONCLUSIONS

1. The installation of anti-glare screen constructed of expanded metal mesh at a height of 4 ft 1 in. above the inside pavement edge is a practical way of effectively reducing headlight glare.
2. Steel is a superior material for an expanded metal mesh anti-glare screen.
3. The combination of median barrier and anti-glare screen helps prevent frequent and excessive damage.
4. Anti-glare screen is not practical along sharp curves having narrow medians. Too much damage from truck overhang can be expected.
5. Anti-glare screen does not adversely affect traffic flow characteristics.
6. Anti-glare screen installation appears to reduce traffic accident frequency.
7. From observation as well as public opinion it can be concluded that anti-glare screen installation greatly increases the night driving comfort level.
8. Because a quantitative evaluation of the benefits of anti-glare screen has not been achieved with respect to its cost, future installations will have to be justified more by engineering judgment than by any other means.

REFERENCE

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Nighttime Use of Pavement Delineation Materials

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ABRIDGMENT

•MANY pavement marking materials in common use lose their effectiveness to a marked degree during periods of darkness in adverse weather. In this study, ways of improving delineation of roadways under wet and dry conditions by either improving techniques utilizing existing materials or developing new materials and techniques were investigated. Glass beads as used in pavement marking materials are affected by many variables, including their composition, surface treatment, diameter, gradation, rate of application, surface on which they are applied, the depth of imbedment in the binder, orientation of the binder with the light source, refractive index, shape, imperfections, method of application, the type of failure of the binder, and the covering water films encountered during periods of precipitation. Raised reflectorized markers perform in relation to many of the same variables as binders reflectorized with glass beads; however, they represent a different technology and are subject to other external influences.

By taking into consideration the many variables, it is possible to select not one but several techniques for improving the performance of pavement marking materials in the day and night, wet and dry conditions. An attempt has been made to approach the problem of marking pavements in a systematic manner wherein one qualifies the surface to be marked, determines the water film thicknesses to be encountered and then selects one of several marking systems that will perform under the imposed conditions.

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