

DETERMINATION OF SIGN LETTER SIZE REQUIREMENTS FOR NIGHT LEGIBILITY BY COMPUTER SIMULATION

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A previously developed computer simulation program was used to examine the adequacy of letter sizes on existing signing along a 20-mile stretch of Interstate highway. A total of 63 signs were analyzed in detail for minimum required legibility under three sets of conditions: daylight, high-beam illumination, and low-beam illumination. Although the standards of signing, according to accepted traffic engineering criteria and according to adherence to pertinent signing manuals, were found to be above average, computer analysis revealed considerable deficiencies. These deficiencies were most pronounced for low-beam illumination and were especially severe for overhead signs. The analysis revealed letter size deficiencies for 27 percent of all signs for daylight, 35 percent for high-beam illumination, and 49 percent for low-beam illumination. For guide signs, the corresponding figures were 39, 44, and 63 percent. Only 1 of 13 overhead signs was found to be adequate for low-beam illumination. Considerable variation in required letter height was found even between identical signs. Analysis of these variations and of the other deficiencies revealed a disproportionate influence of apparently minor changes in approach horizontal and vertical alignment.

•PREVIOUS research (1) has shown that the prime determinant of sign legibility, expressed as feet of legibility per inch of letter height, is luminance expressed in foot-lamberts. An empirically derived functional relationship between these two variables is shown in Figure 1.

A computer program has been developed that will determine the brightness of reflected signs under various conditions of illumination. [The use of an earlier version of this program to investigate parametric relationships concerning sign brightness is reported in this Record by Adler and Straub (4).] The program, documented in detail elsewhere (2) and described briefly in the Appendix, follows the general procedure described by Straub and Allen (3). As presently constituted the program permits the insertion into computer storage of an actual highway alignment, taken from construction plans, and the determination of the brightness of any sign at any point along this alignment for any specified type of vehicle approaching in any specified lane. This paper is a report of the application of this computer analysis to the signing currently in place on a stretch of Interstate highway.

TEST SITE

The tests were carried out on a stretch of Interstate 85 located in Durham and Orange Counties, North Carolina, near the city of Durham. Table 1 gives a general summary of pertinent site characteristics.

The road in question is a modern Interstate highway running in a general east-west direction. For purposes of this analysis a 20-mile section of the eastbound roadway was selected. The original signing plans were obtained and field-checked. At the time of the field check a total of 94 signs were noted. Their distribution by type is given in Table 2. This table also shows the number and types of signs selected for analysis. The

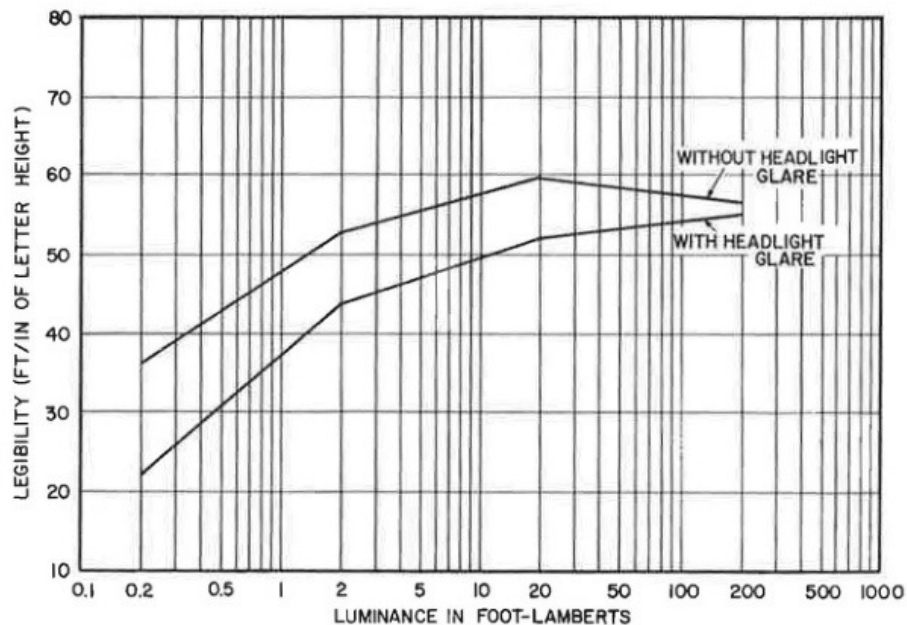


Figure 1. Legibility as a function of luminance.

signs selected for analysis were generally those contained in the original signing plans and found at the same location at the time of the field check.

A total of 63 signs were analyzed. Input data for the program were prepared from the construction plans, the signing plans, and the North Carolina signing specifications (5). The sign material characteristics used were those for WAFT Silver Scotchlite (a registered trademark of the 3M Company) after 5 years or more of exposure as supplied by the manufacturer.

Prior to the analysis the entire section was inspected, under both daytime and night-time conditions, by an experienced traffic engineer. In his judgment the existing signing, as a whole, came up well to accepted Interstate standards. The major criticism made was that the classification of some of the interchanges as minor or intermediate, as inferred from the number and location of advance guide signs, was open to question and that some of these could equally have been signed as intermediate or major respectively.

Night inspection of the roadway also revealed that some of the demountable copy had deteriorated considerably and

TABLE 1
TEST SITE CHARACTERISTICS

Length	20.2 miles
Number of lanes	4 and 6
Lane width	12 ft
Median	30 ft and variable
AADT	18,000
Average speed	63.0 mph
Accidents/mile/year	3.52
Number of interchanges	14
Average interchange spacing	1.6 miles
Percentage of commercial traffic	28.6
Percentage of out-of-state traffic	21.3

TABLE 2
SIGNS ON I-85

Type	Analyzed	Not Analyzed	Total
Regulatory			
Do not litter	0	3	3
Speed limit	3	4	7
Reduce speed ahead	0	1	1
Warning			
Merging traffic	14	0	14
Ice on bridge ^a	0	11	11
Low clearance ^b	0	2	2
Guide			
Advanced guide	13	1	14
Exit direction	13	0	13
Exit	13	0	13
Destination and distance	2	0	2
Supplementary exit	0	1	1
Confirmatory route marker ^c	5	0	5
Miscellaneous ^d	0	8	8

^aFolding signs, observed in closed position.

^bOpposite-mounted at one location.

^cOne location with three shields.

^dIncludes crossroad identification and city limit signs.

TABLE 3

EXISTING AND REQUIRED LETTER SIZE

Sign No. (1)	Type ^a (2)	Type of Mount- ing ^b (3)	Re- quired Legi- bility Dis- tance (ft) (4)	Apparent Brightness (ft-lambert)						Existing Letter Height (in.)					Required Letter Height (in.)		
				400 ft		600 ft		800 ft		U. C. (11)	L. C. (12)	Caps (13)	Numer- als (14)	Numer- als in Shield (15)	Day (50 ft/in.) (16)	High Beam (17)	Low Beam (18)
				High (5)	Low (6)	High (7)	Low (8)	High (9)	Low (10)								
1	ED	GR	460	6.90	0.96	9.77	0.89	8.19	0.71	16	12				10	12	10
2	EX	GR	410	3.22	0.48	1.93	0.27	1.07	0.17			12			10	10	10
3	MT	GR	460	11.53	2.04	12.56	3.65	8.21	4.90			8			10	10	8
4	EX	OH	490	4.69	0.24	5.28	0.18	4.25	0.14					12	10	12	13.33
5	TT	OH	540	6.50	0.26	6.15	0.20	4.95	0.17	16	12			12	12	12	16
6	CR	GR	430	8.52	0.95	10.46	0.86	8.52	0.63			7		12	10	10	10
7	SL	GR	430	3.20	0.47	3.65	0.31	4.44	0.31			8	16		10	10	12
8	DD	GR	600	3.79	0.64	3.03	0.53	2.15	0.40	13.33	10		13.33		12	13.33	16
9	AG	GR	630	4.95	0.70	7.64	0.75	7.34	0.61	16	12	10	15		13.33	13.33	16
10	ED	GR	570	4.17	0.68	4.08	0.63	3.55	0.54	16	12				12	13.33	13.33
11	EX	GR	410	7.44	0.86	9.46	0.82	6.66	0.62			12			10	10	10
12	MT	GR	460	8.29	0.93	10.01	0.85	6.92	0.64			8			10	10	10
13	CR	GR	430	15.69	0.72	7.65	0.25	2.05	0.10			7		12	10	10	10
14	AG	GR	690	15.34	0.87	13.45	0.47	3.21	0.37	16	12	10	15	12	16	16	18
15	ED	GR	630	4.32	0.56	6.90	0.57	6.42	0.49	16	12			12	13.33	13.33	16
16	EX	GR	410	2.65	0.37	1.33	0.21	0.69	0.12			12			10	10	12
17	MT	GR	460	3.35	0.56	1.98	0.38	1.02	0.17			8			10	12	12
18	MT	GR	460	3.36	0.56	1.98	0.38	1.32	0.25			8			10	12	12
19	CR	GR	430	8.20	0.89	9.72	0.81	6.95	0.50			7		12	10	10	10
20	SL	GR	430	10.62	1.41	13.32	1.91	9.64	2.91			8	16		10	10	10
21	DD	GR	610	5.44	0.71	8.17	0.73	7.34	0.58	13.33	10		13.33		13.33	13.33	13.33
22	AG	GR	690	10.46	0.84	8.40	0.57	4.16	0.22	16	12	10	16, 15		16	16	18
23	ED	GR	630	5.64	0.72	8.63	0.77	8.77	0.97	16	12	16	16		13.33	13.33	16
24	EX	GR	410	7.57	0.87	9.84	0.83	8.20	0.62			12			10	10	10
25	MT	GR	460	8.46	0.95	10.40	0.86	8.48	0.64			8			10	10	10
26	CR	GR	430	8.03	0.86	9.81	0.80	8.18	0.60			7		12	10	10	10
27	SL	GR	430	7.68	0.85	9.50	0.80	6.19	0.43			8	16		10	10	10
28	AG	GR	800	4.46	0.64	6.52	0.63	6.04	0.49	16	12	16, 12, 10	16, 15		16	18	24
29	MT	GR	460	5.52	0.68	3.33	0.46	2.07	0.35			8			10	10	12
30	EX	OH	590	5.95	0.26	5.74	0.32	3.21	0.30	16	12	16, 12	16		12	13.33	16
31	TT	OH	510	2.37	0.18	5.22	0.18	4.98	0.30	16	12	12		12	12	12	—
32	AG	GR	590	6.49	0.96	9.47	0.90	8.04	0.72	16	12	10	15		12	12	13.33
33	MT	GR	440	16.40	0.87	9.88	0.31	4.53	0.28			8			10	10	12
34	MT	GR	440	15.53	0.64	6.66	0.25	1.98	0.10			8			10	10	10
35	ED	GR	560	11.67	0.68	5.49	0.18	1.49	0.08	16	12	10			12	12	16
36	ED	GR	530	5.35	0.73	8.07	0.77	7.51	0.61	16	12				12	12	12
37	EX	GR	400	6.11	1.17	8.31	2.36	7.90	2.73			12			8	10	10
38	MT	GR	440	1.67	0.30	1.47	0.25	1.17	0.27			8			10	12	12
39	RL	GR	480	6.27	0.80	8.82	0.80	7.86	0.62	16	12	10			10	10	12
40	ED	GR	450	6.16	0.78	8.68	0.78	7.78	0.61	16	12				10	10	10
41	EX	GR	400	7.31	0.84	9.44	0.81	8.15	0.62			12			8	10	10
42	MT	GR	440	8.16	0.91	10.21	0.84	8.42	0.64			8			10	10	10
43	TT	GR	740	6.20	0.82	10.73	1.24	9.17	1.75	16	12	15, 10	15	15	16	16	16
44	ED	GR	520	21.98	1.37	16.88	0.54	11.43	0.46	16	12	10			12	12	12
45	EX	OH	490	5.26	0.25	3.64	0.15	2.38	0.10	16	12				10	12	13.33
46	ED	OH	650	4.71	0.39	3.44	0.19	2.35	0.11	16	12	15, 10	15	15	13.33	16	—
47	EX	OH	680	2.85	0.38	2.99	0.25	2.41	0.16			7		15	16	16	20
48	MT	GR	440	8.41	0.96	9.25	0.75	4.79	0.31			8			10	10	10
49	EX	GR	580	3.60	0.58	4.79	0.64	5.97	0.59	16	12	15		15	12	13.33	13.33
50	MT	GR	440	4.43	0.73	3.45	0.59	2.87	0.50			8			10	10	10
51	CR	GR	590	6.15	0.69	8.36	0.68	6.10	0.55			7		12	12	12	13.33
52	SG	GR	530	9.92	2.46	9.46	0.86	3.72	0.24	16	12	10			12	12	12
53	EX	OH	510	2.90	0.40	5.01	0.35	5.09	0.33	16	12	10			12	12	13.33
54	ED	OH	650	5.05	0.39	5.37	0.23	4.75	0.22	16	12	12, 10	15	15	13.33	16	18
55	TT	OH	490	5.17	0.24	5.33	0.17	4.55	0.15			18			10	12	13.33
56	MT	GR	440	6.12	0.63	7.88	0.62	7.18	0.52			8			10	10	10
57	EX	OH	580	4.95	0.26	5.37	0.18	2.82	0.20	16	12	15		15	12	13.33	—
58	ED	OH	630	3.89	0.22	3.49	0.14	2.55	0.19	16	12	12, 10	10		13.33	16	—
59	TT	OH	500	2.12	0.18	2.30	0.13	2.29	0.17			18			10	16	—
60	EX	GR	560	8.00	1.66	16.44	0.83	3.77	0.13	16	12	12			12	12	12
61	MT	GR	440	11.86	2.16	16.33	3.93	9.13	0.31			8			10	10	10
62	AG	GR	590	5.20	0.65	5.85	0.46	3.33	0.21	16	12	15, 10	15	15	12	13.33	16
63	ED	GR	540	8.90	1.55	11.96	3.40	7.54	5.30	16	12	15, 10		15	12	12	12

^a ED = exit direction; EX = exit; MT = merging traffic; TT = "through traffic"; CR = confirmatory route marker assembly; SL = speed limit; DD = destination and distance; AG = advance guide; RL = "right lane"; SG = supplementary guide.

^b GR = ground-mounted; OH = overhead-mounted.

whereas for low beams the curve "without headlight glare" was used. The luminance value was obtained by straight-line interpolation for the required reading distance from the computer results. The letter heights, computed by dividing required reading distance, are shown to the next highest "standard" size. [Standard size refers to sizes normally commercially available, for both cutout and demountable letters. These are also the sizes listed in the Standard Alphabets (8).] It should be noted that if the "no headlight glare" curve of Figure 1 had been used to compute these values, some of the required letter heights for high-beam illumination would have been actually smaller than those computed for daytime use.

DISCUSSION OF RESULTS

Comparison of the computed letter size requirements with the letter sizes actually required was made in terms of standard letter sizes. Table 4 gives the statistical distribution of this comparison. Two separate comparisons were made, one for all signs analyzed and one for guide signs (exclusive of confirmatory route markers) only. A total of 41 signs fell into this latter category.

The "actual" size used in the comparison was the largest size letter on the sign. In cases where lowercase lettering was used in the largest size line, the height of the lowercase letter governed. It should be noted that considerable differences are encountered when the smaller "subsidiary" copy is examined. This includes such items as the cardinal direction for route markers, the exit message in advance guide or exit direction signs, and all other copy which, in accordance with the AASHO Manual (9), requires smaller letter sizes.

Figure 3 is a graphical representation of the data in Table 4; it shows a considerable degradation of performance when the illumination median goes from daylight through high beam to low beam. The cumulative distributions, plotted in Figures 4 and 5 for the two cases considered, show that 73 percent of all signs are adequate for daylight illumination, 65 percent for high beam, and 51 percent for low beam.

When guide signs only are considered, the situation is much more serious. The comparative figures for complete adequacy are 71, 56, and 37 percent respectively. Although several instances were noted where low-beam requirements were equal to, or even

TABLE 4
LETTER SIZE COMPARISON

Category	Day		High Beam		Low Beam	
	Percent	Cumulative Percent	Percent	Cumulative Percent	Percent	Cumulative Percent
All Signs						
Larger than required	+4	3.2	3.2			
	+3	4.8	8.0	6.3	3.2	3.2
	+2	3.2	11.2	1.6	7.9	11.1
	+1	34.9	46.1	33.3	41.2	38.1
Adequate	0	27.0	73.1	23.8	65.0	50.8
	-1	19.0	92.1	19.0	84.0	65.1
	-2	7.9	100.0	14.3	98.3	82.5
Smaller than required	-3		1.6	100.0	7.9	90.4
	-4					
	-5				1.6	92.0
	∞				7.9	100.0
Guide Signs						
Larger than required	+4	4.9	4.9			
	+3	—	4.9	2.4	2.4	
	+2	4.9	9.8	—	2.4	2.4
	+1	21.9	31.7	19.5	21.9	19.6
Adequate	0	39.1	70.8	34.2	56.1	36.8
	-1	17.2	88.0	21.9	78.0	51.4
	-2	12.2	100.0	19.5	97.5	73.3
Smaller than required	-3		2.4	100.0	12.2	85.5
	-4				—	85.5
	-5				2.4	87.9
	∞				12.2	100.0

Note: Excess or deficiency expressed in terms of "standard" letter sizes.

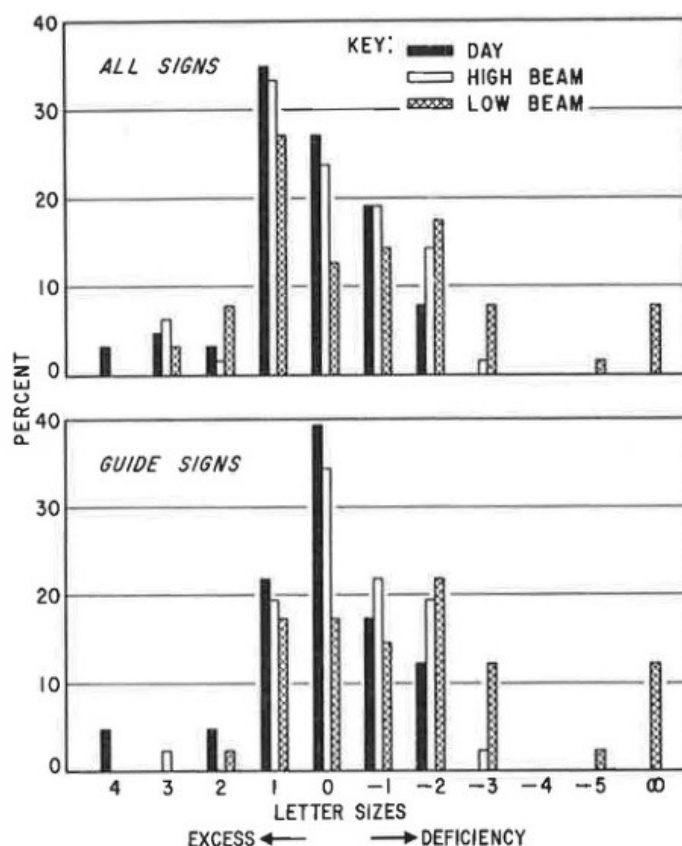


Figure 3. Letter size comparison.

smaller than, those for the other two conditions investigated, the overall impact of these figures is that low-beam illumination appears to be inadequate for signs designed under current standards. The important fact to be noted is that 5 of the 13 overhead-mounted signs were completely "illegible" under low-beam illumination; i.e., the computed brightness at the point of required first legibility was less than 0.2 ft-lambert, the lowest value for which legibility data are available. Seven of the eight overhead signs for which legibility could be computed were found to require letters two or more standard sizes higher than that required for daytime conditions.

One additional point should be made concerning the computations for overhead signs. Each sign was analyzed individually; i.e., the reading time was computed on the basis of the message on that sign alone. A strong case can be made, however, for considering an overhead sign assembly, sign bridge, or butterfly as a single message to be read in its entirety by the approaching driver. In that case the reading time would be considerably longer, the required legibility distance increased considerably, and the required letter sizes correspondingly larger. For the 13 signs included in the 5 overhead sign assemblies considered here, the average required legibility distance would increase from 560 to 780 ft or by almost 40 percent.

Table 5 gives a computation of minimum letter size under the assumption that each of the overhead assemblies is considered as a single sign. The brightness values used were the average for the signs making up the assembly; otherwise the computations are as previously described.

The increase in minimum required letter sizes is immediately apparent, amounting to at least 2 standard sizes for all conditions investigated. It can also be seen that 3 of the 5 assemblies are "illegible" under low-beam illumination, and the 2 assemblies that can be made legible can be made so only by using letter sizes that approach the limits

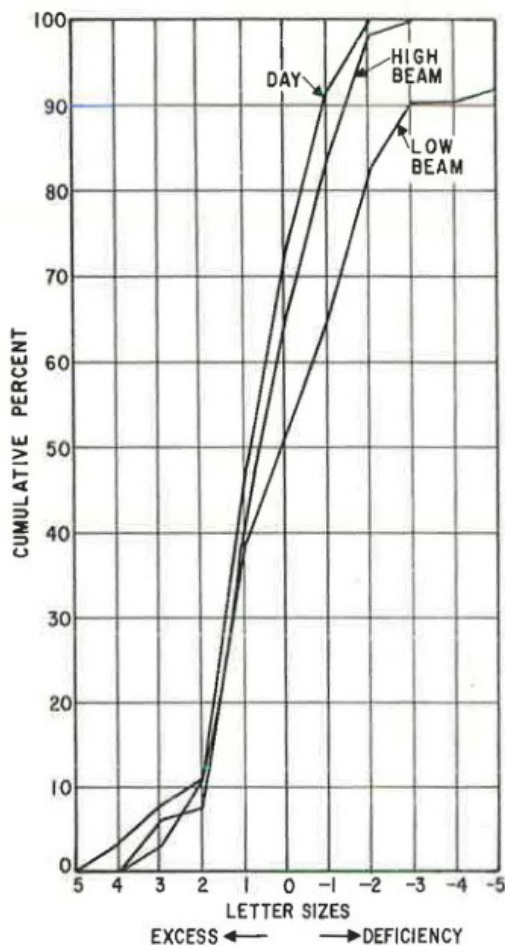


Figure 4. Letter size comparison, cumulative distribution, all signs.

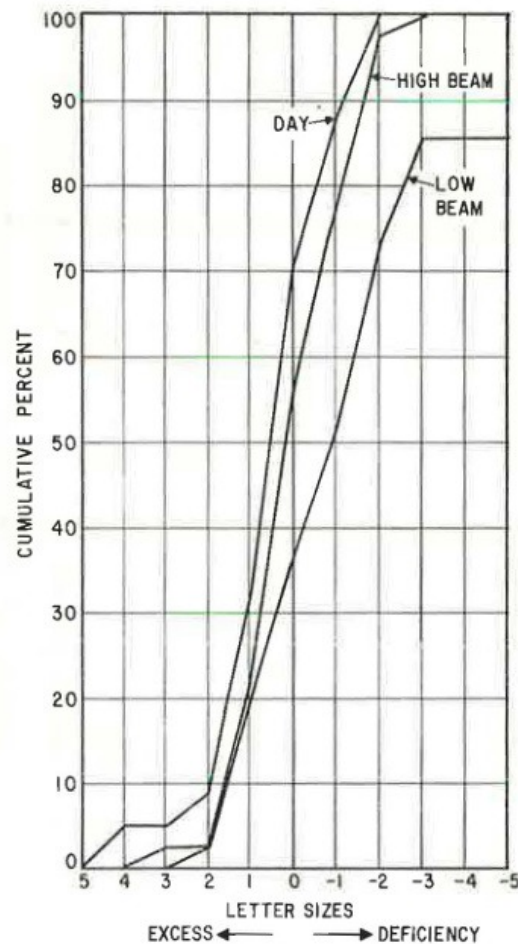


Figure 5. Letter size comparison, cumulative distribution, guide signs only.

of practical feasibility. In this connection it should be mentioned that the analysis was made while using constant sign panel sizes. The increase in panel size necessitated by the increase in letter size would result in lower luminance because of higher deflection angles as well as in increased required legibility distance as a result of moving the last reading point upstream. Both of these conditions would, in turn, result in still larger letter sizes.

TABLE 5
OVERHEAD SIGNS

Assembly	Signs	Required Legibility Distance (ft)	Existing Letter Height (in.)					Required Letter Height (in.)		
			U. C.	L. C.	Caps	Numerals	Numerals in Shield	Day (50 ft/in.)	High Beam	Low Beam
A	4, 5	630	16	12			12	13.33	13.33	—
B	30, 31	700	16	12	16, 12	16	12	16	16	20
C	45, 46, 47	930	16	12	15, 10, 7	15	15	20	24	—
D	53, 54, 55	830	16	12	18, 12, 10	15	15	18	18	22
E	57, 58, 59	800	16	12	18, 15, 12, 10	10	15	16	18	—

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[illegible]

Figure 6. Typical computer output, sign luminance.

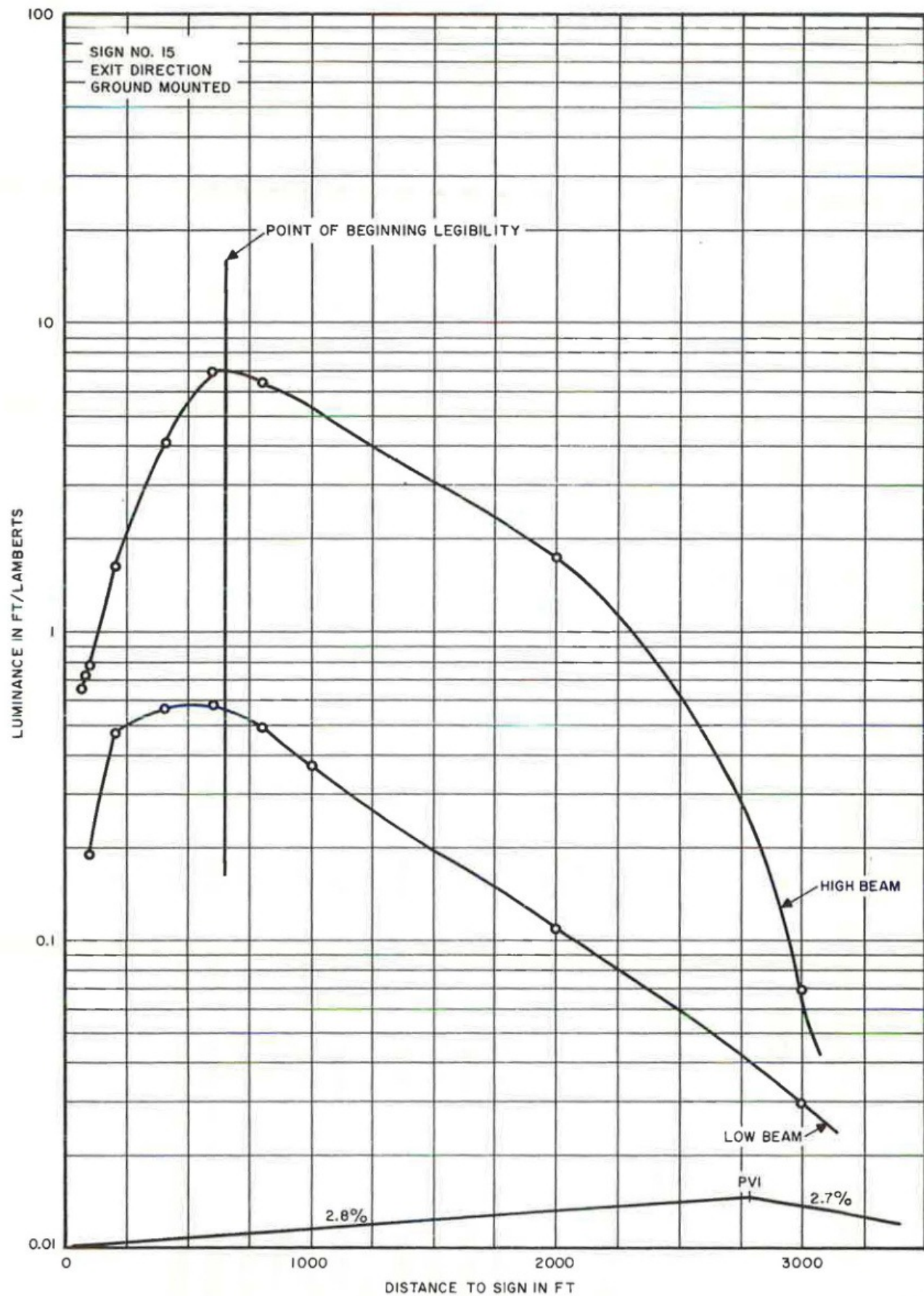


Figure 7. Luminance versus distance, sign 15.

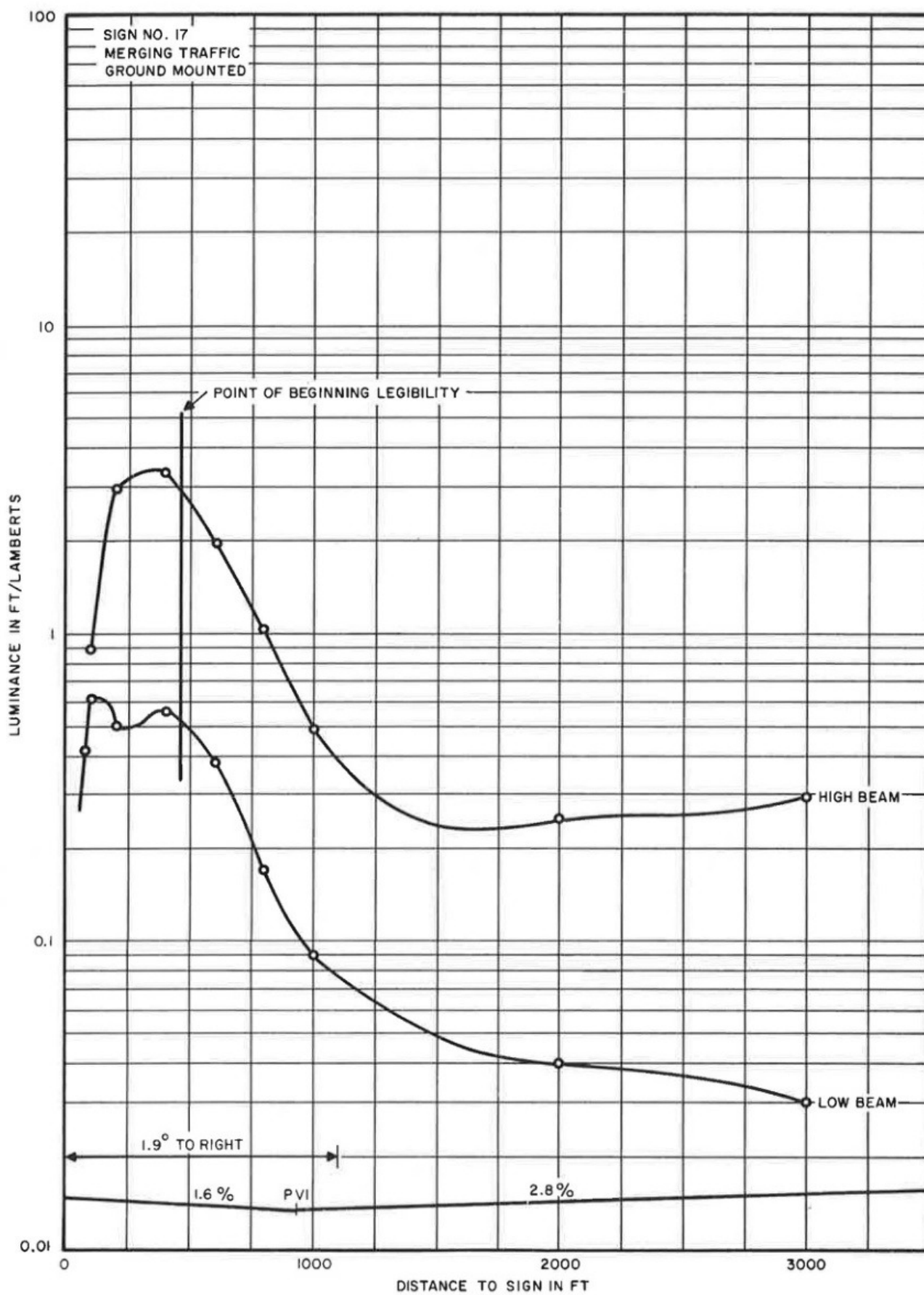


Figure 8. Luminance versus distance, sign 17.

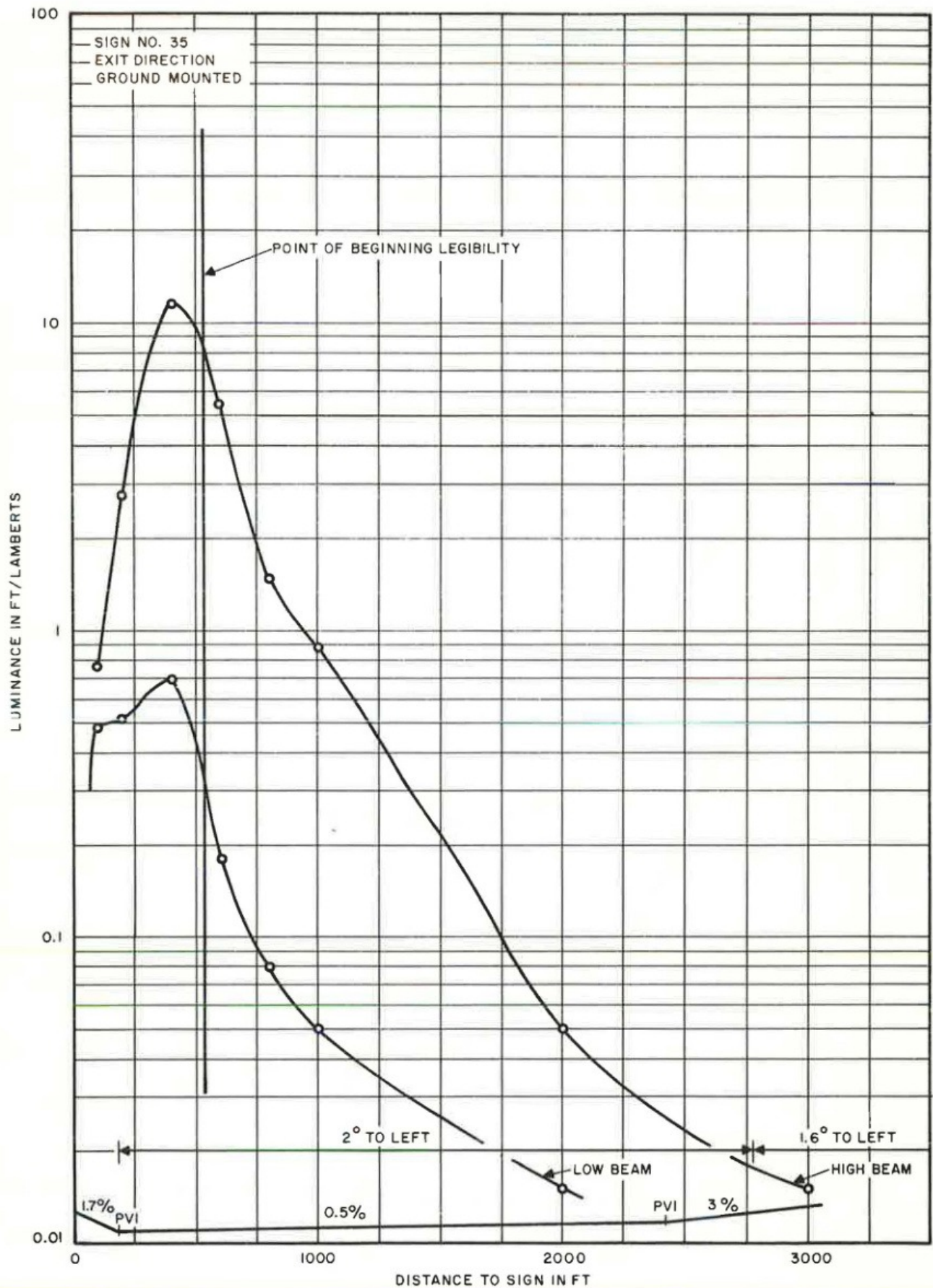


Figure 9. Luminance versus distance, sign 35.

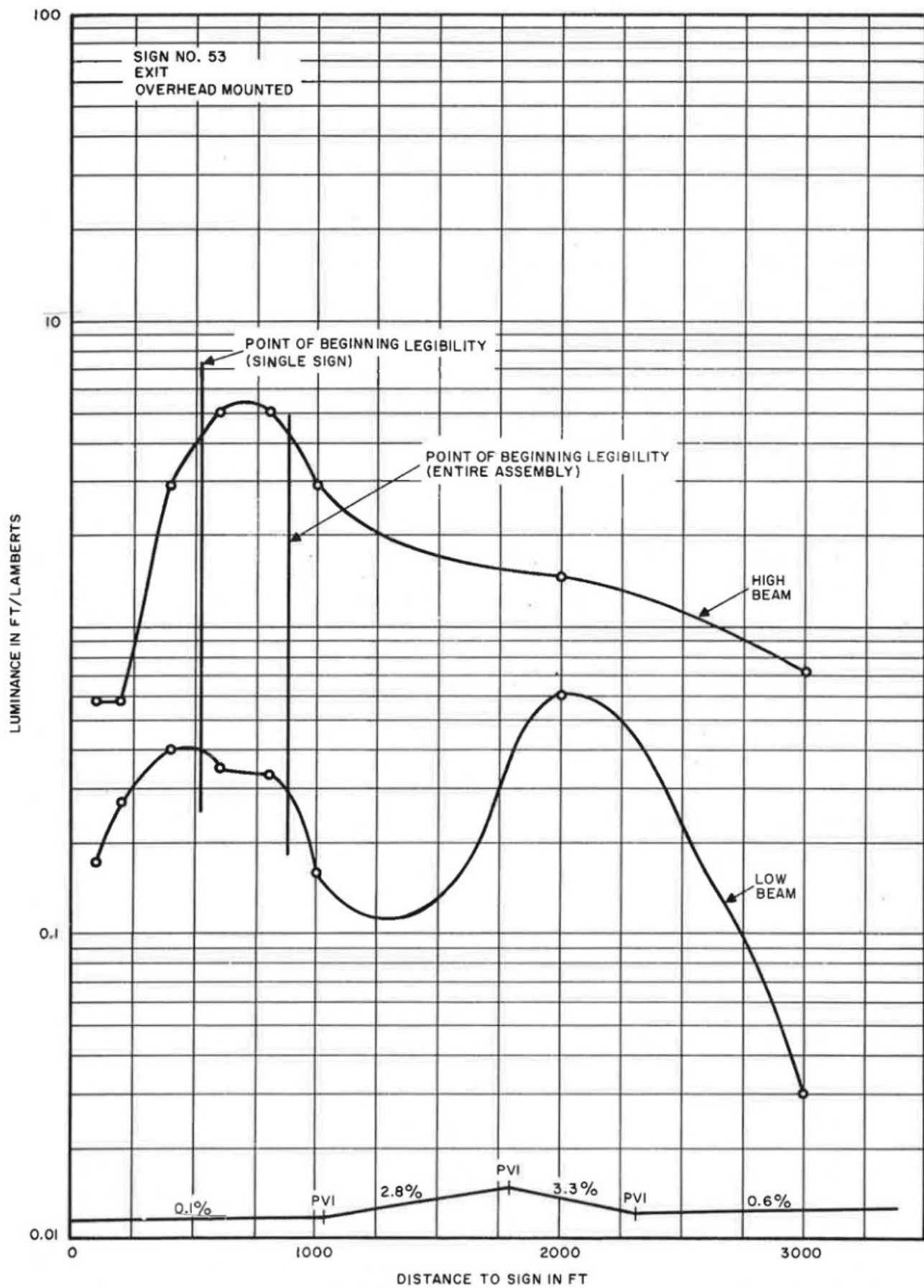


Figure 10. Luminance versus distance, sign 53.

It is also worth noting that all of the analyses were made using luminance values computed for the center of the sign. Examination of a typical computer output sheet (Fig. 6) shows that some variation exists between values for the center and values for the extremities. If worst case, instead of center, luminance had been used in the calculations, still higher computed letter heights would have been obtained.

Close examination on the data and computed results of Table 3 shows the considerable variation that exists for apparently identical signs. For instance, the 14 merging traffic signs analyzed all required 10-in. letters for daytime conditions. However, when analyzed for nighttime conditions using low-beam illumination, the analysis showed one location where 8-in. letters were required, 8 locations that required 10-in. letters, and 5 locations where 12-in. letters were required. The variation increases as sign size increases. Signs 55 and 59 are identical overhead-mounted 9- by 12-ft signs with the legend through traffic. However, analysis shows a difference of two standard sizes in the high-beam case and a difference between "legible" and "illegible" in the low-beam case.

This great variance is due to the enormous influence that apparently minor changes in horizontal and vertical alignment, especially the latter, have on the distribution of headlight illumination reaching the signs and on the resulting luminance. Figures 7 through 10 are plots of luminance versus distance from the signs for six signs used in the analysis. At the bottom of each sign the approach horizontal and vertical alignments are shown. Absence of horizontal alignment information indicates a tangent section.

Worthy of note is the smooth curve of Figure 7 that has no alignment changes but does have a continuous downgrade throughout the entire approach. Figure 8 shows a discontinuity in the low-beam curve in the area of combined vertical and horizontal alignment changes. However, these changes are not severe enough to affect the high-beam curve. Figure 9 shows an extremely sharp peak due to a horizontal curve to the left, with the sign at the beginning of the subsequent upgrade tangent section. Finally, Figure 10 shows the effect of extreme changes in vertical alignment, extreme by Interstate standards of design, on the approaches to a sign.

One final point should be made concerning these results. The signs, as analyzed, were located laterally in accordance with the standards in effect at the time of installation (1960). They are, therefore, quite close to the edge of the shoulder. A change to a 30-ft offset, as currently required, would have major effects on the computed results. Reference to Figure 2 clearly shows that any increase in S would increase distance AB and therefore distance BC . This would result in having the point of first legibility moved further upstream, requiring larger letter sizes. The effects of this increased offset were discussed in detail in a previous paper (10).

CONCLUSIONS

This case study, in applying the computer simulation program to determine requisite letter size of signs for adequate nighttime visibility, demonstrates the versatility that this approach has as a tool for the optimum design of signs. The wide variations in results noted point up the necessity of designing each sign for the exact conditions and location for which it will be used. Finally, the great variation noted between sign design for high-beam use and that for low-beam use, which, as stated, would have been even higher if the assumption of no headlight glare had been made, underlines the need to determine the prevailing headlight use. Two published studies on headlight use (11, 12) indicate that reliance should not be placed on high-beam illumination. Because the results of these computations show the inadequacy of relying on low-beam illumination for overhead-mounted signs, the conclusion seems inescapable that overhead signs require fixed illumination if they are to serve their purpose properly and effectively.

In closing this discussion, it should be emphasized that this section of highway analyzed is signed well in accord with all Manual requirements at time of installation. Furthermore, comparison of actual field conditions with the signing plans indicate that every effort has been made to correct deficiencies in signing that have become apparent since the opening of the highway. The deficiencies revealed by the present analysis are not,

therefore, attributable in any way to the North Carolina highway department. Similar, or worse, results could undoubtedly have been obtained in any other jurisdiction, especially those that still use nonreflectorized sign backgrounds. The deficiencies noted represent deficiencies in the present state of the art of sign design for night legibility as reflected in the Manual and in design procedures.

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Appendix

PROGRAM DESCRIPTION

The computer program, called ROADSIGN, has been written to simulate a motorist driving on a road at night with headlights on and approaching a sign on the road. The program computes the luminance at the four corners and at the center of the sign as apparent to the driver of the vehicle traveling along an existing, proposed, or hypothetical highway and approaching the sign.

The simulation takes into account the following parameters that together constitute the major influences on sign legibility:

1. Distance from sign;
2. Automobile headlight output;
3. Sign material reflectance;
4. Highway alignment and profile;
5. Sign location and attitude with respect to the highway;
6. Vehicle geometry;
7. Location of driver within vehicle;
8. Location of vehicle on highway;
9. Atmospheric transmissivity;
10. Variations in vehicle voltage as they affect headlights; and
11. Variations in sign reflectance as typically caused by aging and weathering.

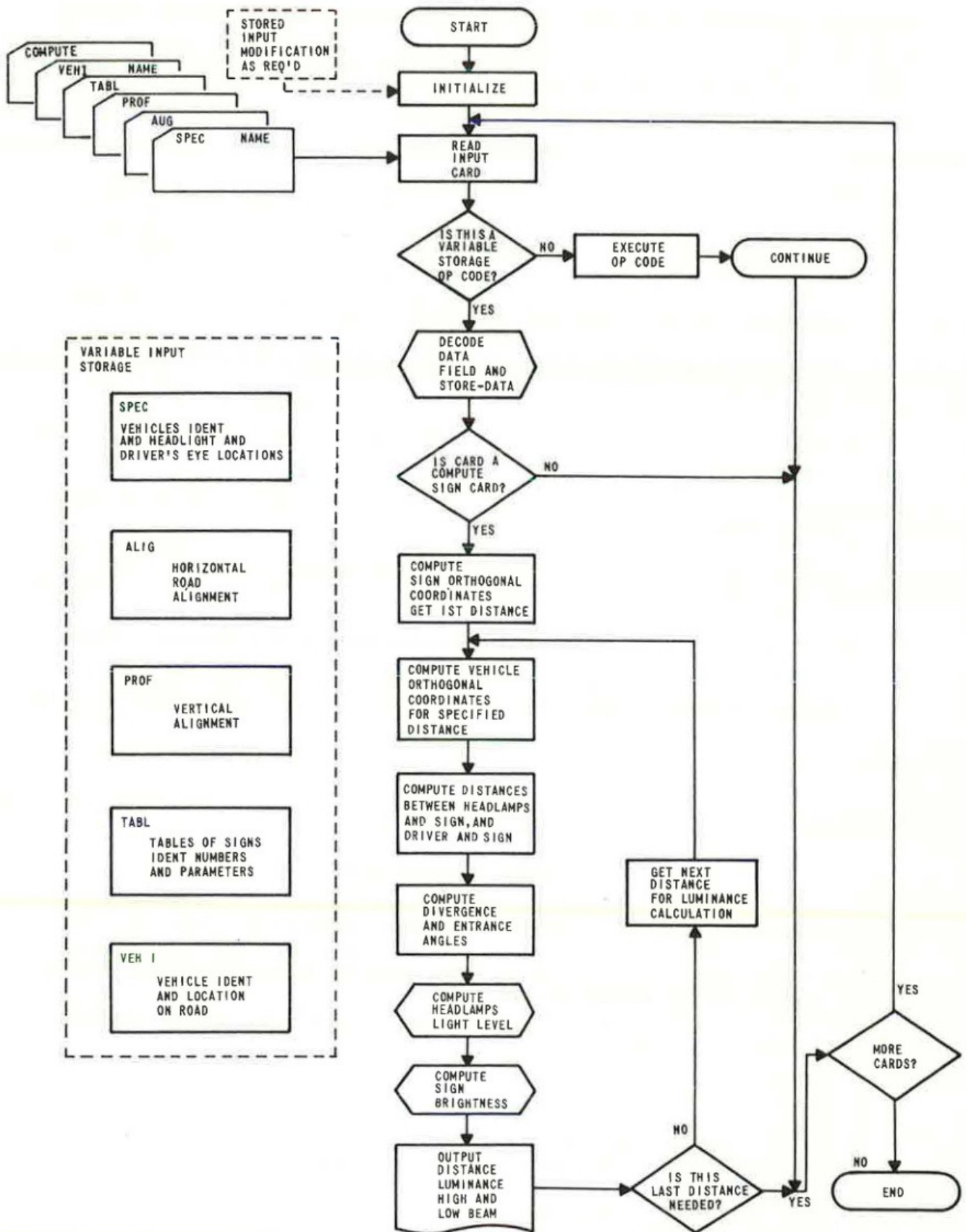


Figure 11. Program block diagram.

ROADSIGN has been designed to take into account these factors with a high degree of flexibility. In addition, in order to accommodate future expansion, the program has been structured so that additional factors not considered part of the original simulation can be incorporated without revision of the basic program structure. As currently constituted the program can handle any combination of horizontal and vertical curvature. It cannot handle spirals or other transition curves that must be approximated by circular curves. It also cannot handle crown or superelevation.

The program is written in Fortran IV to run on an IBM 360/40 or larger computer. In its present form the program will handle up to 100 signs on any length of highway containing no more than 98 horizontal and 98 vertical curves. The program is designed to handle up to 10 different vehicular configurations. The isocandle distribution tables of 5 common standard headlight types are stored internally and others can be input. The specific luminance tables for three commercially available retroreflective materials (two types of sheeting and one type of button) are also internally stored, and others may be input.

The program operates as shown in Figure 11. In general, the logic functions so as to determine the location of vehicle head lamps, driver's eyes, and sign (both center and corners) in orthogonal space. It then computes the distances between these three sets of points for each distance stored.

By using the distances computed as well as the inputs describing illumination levels, specific luminance, divergence and entrance angles, and other factors characterizing or affecting light level, the program calculates apparent sign luminance. Following each set of calculations, the program outputs results via the line printer.

Options available by means of selection of the proper control card include the choice of different types of vehicles approaching the sign of interest and/or the computation of a number of signs of the same or different configurations placed along the same highway.

The specific study reported on herein dealt with an alignment containing 29 horizontal curves and a profile containing 56 vertical curves. The sign table contained a total of 63 signs. The actual computer elapsed time required to calculate the luminance of all the 63 signs as the vehicle approached each sign from 3,000 ft to 40 ft was 12 min 47 sec. This time included reading in and checking the card inputs, storing the information, making preliminary calculations, dumping into the printer these preliminary calculations, further checking, and finally outputting 63 pages of luminance values (Fig. 6) for both high- and low-beam illumination.