PB89233555

U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA-RD-88-197
May 1989

Overhead Guide Sign Visibility Factors,

Volume II: Appendixes

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

NOTICE

Technical Report Documentation Page

1. Report No. FHWA-RD-88-197	2. Government Accession No. PB89-233555/AS	3. Recipient's Catalog No.
4. Title and Subtitle OVERHEAD GUIDE SIGN VISIBILITY FACTORS, Volume II: Appendixes		5. Report Date May 1989
		6. Performing Organization Code
7. Author(s) A.C. Stein, Z. Parseghian, R.W. Allen, C.E. Wolf		8. Performing Organization Report No. STI TR-1209-1-II
9. Performing Organization Name and Address Systems Technology, Inc. 13766 S. Hawthorne Blvd. Hawthorne, CA 90250		10. Work Unit No. (TRAIS) NCP 3A2a-2012
		11. Contract or Grant No. DTFH61-83-C-00141
12. Sponsoring Agency Name and Address Offices of Safety & Traffic Operations (R & D) Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Monitor: R.N. Schwab (HSR-30)

16. Abstract

The project discussed in this report concerned the night use of overhead guide signs, including button and reflectorized copy and all practical combinations of reflectorized and opaque backgrounds. This project was a follow-up effort to the literature review by Gordon.[1] Gordon's review found areas requiring further investigation, including the comparison of nonilluminated-nonretroreflectorized signs with both illuminated-nonretroreflectorized and retroreflectorized signs.

The current project included the investigation of current signing practices throughout the country, development of a set of in-use luminance values for current overhead guide sign materials, development of life cycle costs for current signing materials and practices, and determination of driver response characteristics for these overhead guide sign systems.

These goals were met through review of the literature, field testing, and static and dynamic laboratory testing. While the results of the tests are presented, no attempt has been made to draw conclusions from these data.

Volume I, FHWA-RD-88-196, contains a summary of the entire study.

17. Key Words Overhead Guide Signs, Sign Detection, Luminance, Visibility, Simulator Studies	18. Distribution Statement No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	260	A12

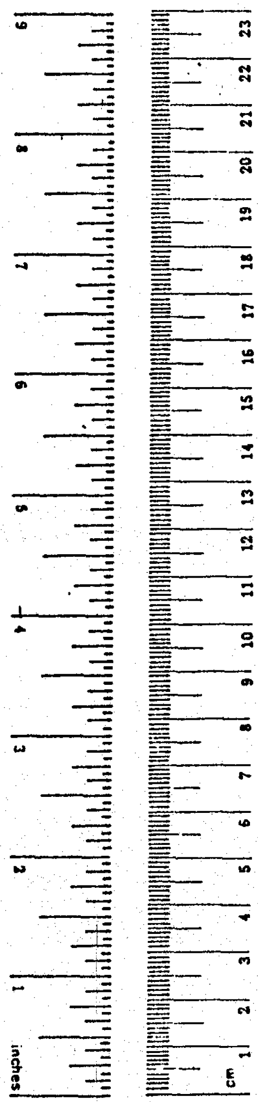
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

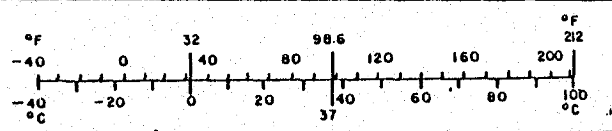


TABLE OF CONTENTS

VOLUME I

VOLUME II: APPENDIXES

VOLUME II: APPENDIXES (continued)

LIST OF FIGURES

VOLUME I

VOLUME II: APPENDIXES

VOLUME II: APPENDIXES (continued)

Figure | Page

VOLUME II: APPENDIXES (continued)

Figure | Page

VOLUME II: APPENDIXES (continued)

Figure | Page

Figure | Page

VOLUME II: APPENDIXES (continued)

LIST OF TABLES

VOLUME I

VOLUME II - APPENDIXES

VOLUME II - APPENDIXES

Table | Page

VOLUME II - APPENDIXES

Table Page

VOLUME II - APPENDIXES

Table | Page

APPENDIX A. LITERATURE REVIEW

Determine User Requirements

The first task on the project involved an extensive review of the literature. This was done to ensure that all relevant materials concerning the detection requirements for overhead guide signing were incorporated in the remainder of the project. As some of the original focus of the project dealt with sign legibility, both detection and legibility references were sought.

The literature search began with a search of the STI technical library. With over 40,000 separate citations, and specific cataloged items dealing with vision and visibility, eye movement, detection, and perception, this search provided a good start on developing a data base of relevant citations.

Following this in-house search, a computerized search of several data bases was conducted over the Lockheed DIALOG and SDC Orbit references services. The specific data bases searched were:

- CONFERENCE PAPERS INDEX - an index of the papers presented at most of the major conferences held throughout the world.
- COMPENDEX - a compilation of engineering and technical articles.
- DISSERTATION ABSTRACTS ONLINE - the machine-readable form of the Comprehensive Dissertation Index.
- MAGAZINE INDEX - an index of over 370 American magazines.
- NTIS - the National Technical Information Service, a repository for all government published technical reports and articles.
- SOCIAL SCISEARCH - a multidisciplinary index of behavioral and related sciences.
- PSYCINFO - the machine readable form of Psychological Abstracts.
- SAE - the complete publications of the Society of Automotive Engineers
- SCISEARCH - a multidisciplinary index in science and technology.

- SSIE CURRENT RESEARCH - A compilation by the Smithsonian Institution of all current government, and most privately funded, research projects.

- TRIS - a composite file of abstracts, documents and other holdings relevant to transportation. Included in this file are the Highway Research Information Service holdings.

Following the computerized data base search, several manufacturers were contacted to determine what information they may be able to provide which was not available from other sources. These companies have been extremely willing to provide a continuous flow of information. The bibliography found at the end of this appendix includes many publications which have been received after the completion of this task, some were published as recently as a few months ago.

The basic findings of this task have been discussed thoroughly in the main text of this report, and little data was uncovered which added to the review of Gordon. The key points of the review were:

- Drivers spend only 25 to 50 percent of their time attending to the control and guidance functions of driving. This leaves at least 50 percent of the drivers' time available for search and detection of overhead guide signs.

- If control, guidance, and other driving functions considered "major" by the driver cause an overload, the driver will shift from a parallel processor to a serial one. This means that if sign detection is considered "minor", some signs may be missed.

- The driver has the following tasks in responding to highway signs: (1) detection, (2) identification, (3) decision, (4) response, and (5) maneuver.

- The first four functions will take between 4.0 and 11.5 seconds. Maneuver is estimated at 8 seconds per lane change.

- Given these times, a 1300-ft sight distance requirement is not unreasonable.

Bibliography - Determine User Requirements

Allen, T.M., Dyer, F.N., Smith, G.M. and Janson, M.H. "Luminance requirements for illuminated signs." Highway Research Record No. 179, 1967, pp. 16-37.

Avant, L.L., Brewer, K.A., Thieman, A.A. and Woodman, W.F. Recognition errors among signs. Ames, IA: Iowa State University, 1984.

Bryan, N., Casner, D., Klotz, R., and Knisley, H. A limited evaluation of reflective and non-reflective background for overhead guide signs. Washington, DC: National Academy of Science, 1978 (NCHRP Project 75-19).

Caltrans Reflective Sheeting Study Team. Use of reflectorized vs. illuminated overhead mounted guide signs. Sacramento, CA: California Department of Transportation, 1978.

Caltrans Overhead Guide Sigh Review Team. Establishing priorities for operation and maintenance of overhead guide signs. Sacramento, CA: California department of Transportation, 1981.

Cole, B.L. and Hughes, B.K. "A field trial of attention and search conspicuity." Human Factors, 1984, 26(3).

Cook, M.L., Allen, R.W. and Stein, A.C. "Using rewards and penalties to obtain desired subject performance." Proceedings of the Seventeenth Annual Conference on Manual Control, Pasadena, CA: Jet Propulsion Laboratory, 1981.

Cottrell, B.H., Jr. Comparative analysis of reflective sheeting. Virginia Highway and Transportation Research Council, Report VHTRC 82-R22, 1981.

Eklund, K. "The conspicuity of traffic signs and factors affecting it." Reports from TALJA, 1968, 6.

Fisher, D.L. and Papazian, B. "Response times and traffic sign design: Application of the critical path and op methods." Proceedings of the 27th Annual Meeting of the Human Factors Society, 1983, pp. 165-169.

Forbes, T.W. Research on traffic sign requirements. Final Report. East Lansing, MI: Michigan State University, 1967.

Forbes, T.W. Luminance and contrast requirements for sign legibility -- additional results and applications. Presented at the Annual meeting of the Transportation Research Board, 1976.

Forbes, T.W. Acuity, luminance and contrast for highway sign legibility, samples of research methods and results, a review of fifteen selected studies by various investigators. East Lansing, MI: Michigan State University, 1980.

Forbes, T.W., Snyder, T.E. and Pain, R.F. A study of traffic sign requirements. Volume II: An annotated bibliography. East Lansing, MI: Michigan State University, 1968.

Forbes, T.W., Saari, B.B., Greenwood, W.H., Goldblat, J.G. and Hill, T.E. "Luminance and contrast requirements for legibility and visibility of highway signs." Transportation Research Record No. 562.

Godthelp, J. The perceptibility of traffic control signs at night: A field study on the effect of a new type of retroreflective material. Report IZF 1979-C1. Soesterberg, The Netherlands: Institute for Perception TNO, 1979

Gordon, D.A. Night visibility of overhead guide signs: A review of the literature. Report No. FHWA/RD-84/087. Washington, DC: Federal Highway Administration, 1984.

Hanscom, F.R. and Berger, W.G. Motorist response to highway guide signing, final report. Volume I: Field evaluation measures. NCHRP 3-21. Falls Church, VA: Biotechnology, Inc, 1976.

Harlemink, M.D., Hemsley, G., Duncan, D., Kuhk, R. and Titishov, T. Evaluation of reflectorized sign sheeting for non-illuminated freeway overhead guide signs. Downsview, Ontario, Canada: Ontario Ministry of Transportation and Communications, 1984.

Hahn, K.C., McNaught, E.D. and Bryden, J.E. Nighttime legibility of guide signs. Report NYSDOT-ERD-77-RR 50. Albany, NY: Engineering Research and Development Bureau, 1977.

Hills, B.L. and Freeman, K.D. "An evaluation of the luminance contrast requirements of highway signs." AARB Proceedings, 1970 5(3), pp. 67-94.

Hughes, P.K. and Cole, B.L. "Search and attention conspicuity of road traffic control devices." Australian Road Research, 1984, 14(1), pp. 1-9.

Hughes, P.K. and Cole, B.L. "Can the conspicuity of objects be predicted from laboratory experiments?" Ergonomics, 1986, 29(9), pp. 1097-1112.

Jones, H.D., Raska, J.G. and McNees, R.W. Evaluation of overhead sign background materials and mercury vapor sign lights. Austin, TX: State Department of Highways and Public Transportation, 1983.

Jung, F.W. and Titishov, A. Standard target contrast: A visibility parameter beyond luminance, to evaluate the quality of roadway lighting. HOS-86-03. Downsview, Ontario, Canada: Research and development branch of the Ontario Ministry of Transportation and Communications, 1986.

Kobetsky, K.F. Illumination of overhead signs. Presented at the 1981 meeting of SASHTO, Atlanta, GA.

Lerner, N.D. and Gallagher, V.P. Visual complexity of nighttime driving scenes. Proceedings of the 27th Annual Meeting of the Human Factors Society, 1983, pp. 216-219.

Mace, D.J. and Pollack, L. "Visual complexity and sign brightness in detection and recognition of traffic signs." Transportation Research Record 904, 1984, pp. 33-41.

McNees, R.W. and Messer, C.J. Level of service evaluation of freeway guide signing. Presented at the annual meeting of the transportation Research Board, 1984.

Olson, P.L. Minimum requirements for adequate nighttime conspicuity of highway signs. Report UMTRI-88-8. Ann Arbor, MI: UMTRI, 1988.

Olson, P.L. and Bernstein, A. Determine the luminous requirements of retroreflective highway signing. UM-HSRI-77-6. Ann Arbor, MI: HSRI, 1977.

Olson, P.L. and Bernstein, A. "The nighttime legibility of highway signs as a function of their luminance characteristics." Human Factors, 1979, 21(2), pp 145-160.

Olson, P.L., Sivak, M. and Egan, J.C. Variables influencing the nighttime legibility of highway signs. UMTRI-83-36. Ann Arbor, MI: UMTRI, 1983

Perchonok, K. and Pollack, L. Luminous requirements for traffic signs. Report No. FHWA/RD-81/158. Washington, DC: Federal Highway Administration, 1981.

Robertson, R.N. Evaluation of high intensity sheeting for overhead highway signs. VHTRC 75-R24. Charlottesville, VA: Virginia Highway & Transportation Research Council and FHWA, 1974.

Robertson, R.N. and Shelor, J.D. Using encapsulated-lens reflective lens sheeting on overhead highway signs. Charlottesville, VA: Virginia Highway & Transportation Research Council, 1977.

Sivak, M. Human factors and road safety: Overview of recent research at the University of Michigan Transportation Research Institute, UMTRI-84-16. Ann Arbor, MI: UMTRI, 1984.

Sivak, M and Olson, P.L. Optimal and replacement luminances of traffic signs: A review of applied legibility research. UMTRI-83-43. Ann Arbor, MI: UMTRI, 1983

Sivak, M. and Olson, P.L. Optimal and minimal luminance characteristics for retroreflective highway signs. Ann Arbor, MI: UMTRI, 1984.

Sivak, M., Olson, P.L. and Pastalan, L.A. Effect of driver's age on nighttime legibility of highway signs. UM-HSRI-79-52. Ann Arbor, MI: HSRI, 1979.

Solomon, D. Interstate sign tests. U.S. Bureau of Public Roads, unpublished.

Straub, A.L. and Allen, T.M. "Sign brightness in relation to position, distance and reflectorization." Highway Research Bulletin 146, 1956, pp. 13-44.

Transportation Research Record 611. Railroad-highway crossings, visibility, and human factors. 1976, entire issue.

van Norren, D. Overhead signs without external illumination ? Part I: Literature review and calculations. Report IZF 1978-C20. Soesterberg, the Netherlands: Institute for Perception TNO, 1978.

van Norren, D. Overhead signs without external illumination ? Part II: Experiment on legibility distance. Report IZF 1978-C28. Soesterberg, the Netherlands: Institute for Perception TNO, 1978.

Woltman, H.L. and Youngblood, W.P. An assessment of indirect factors affecting reflective sign brightness. St. Paul, MN: 3M Company, 1976.

Woltman, H.L. and Youngblood, W.P. Evaluating nighttime sign surrounds. St Paul, MN: 3M Company, 1977.

Youngblood, W.P. and Woltman, H.L. "A brightness inventory of contemporary signing materials for guide signs." Highway Research Record No. 377, 1971, pp. 69-71.

Youngblood, W.P. and Woltman, H.L. "Relation between sign luminance and specific intensity of reflective materials." Transportation Research Record 681, 1978, pp. 20-24.

Determine the Value of Color Coding of Highway Signing

Highway signs make use of three characteristics to convey their meaning to the driver: color, shape, and legend[1]. While the legend conveys the specific information contained on the sign, the fact that highway engineers have chosen to differentiate signs by shape and color indicates that they believe this information to be beneficial to the driving population. This is based on the belief that the shape/color combination is visible at distances beyond the legibility distance of the sign, and also that these factors will help the detectability of the sign when placed in visually complex environments.

---

1 For the purposes of this review "legend" refers to either symbol or word messages.

Previous research has resulted in the establishment of standards for sign color and shape based on the intent of the sign, and for the definition of both letter and symbol sets for the various legends. The question this review addresses is the extent that drivers understand and use sign background color, and the need for color coding of various types of highway signing. This will be accomplished by analyzing the results of several previous studies.

An early study conducted by the Virginia Highway Research Council used a review and pencil test to study the awareness of drivers to various sign colors and shapes.(1) The results indicated that drivers demonstrated a measurable lack of recognition of highway sign colors and shapes. Color recognition ranged from 20 percent correct for Orange to 85 percent correct for Red, Green was correctly identified only 24 percent of the time. Shape recognition was much better, with Squares correctly identified by 45 percent of drivers, and the Octagons by 89 percent. When color and shape were combined the range almost covered the spectrum, 20 percent of those tested correctly identified the Orange Diamond and 93 percent correctly identified the Red Octagon. The Green Rectangle was correctly identified by only 39 percent of respondents, while 28 percent gave no answer at all.

The results of this study indicate that drivers lack basic knowledge concerning the color and shape codes currently used for highway signing. It is particularly disturbing that 7 percent of drivers were not able to correctly identify the STOP sign configuration out of the highway environment. Shape/color configurations used for overhead interstate guide signs were among the worst performers. Less than 50 percent of drivers were aware that green rectangular signs provided guidance information, and almost 30 percent were unwilling to even attempt a guess of the correct answer. The results of this study alone might make a strong case for abandonment of the shape and color standards, but other studies have proven that in many cases these cues are helpful to the driver.

A 1957 study by Birren found that shape and color were sufficient to overcome an incorrect legend on a STOP sign.(2) In this study the word

STOP was replaced by the word TOPS. Drivers were stopped after proceeding through the intersection and asked what the sign legend had been. Eighty-six percent were unaware that the legend had been changed, and the author gives no indication that there was any noncompliance to the sign's intent. This indicates that, when a STOP sign is located and used appropriately, shape and color alone are sufficient for correct motorist recognition and interpretation.

Birren also suggests that black is not appropriate for use in route guidance signs, and that green is preferred. His statements, however, are not based on scientific investigation, but rather on theoretical beliefs. More recent research has investigated the requirements for route guidance signing.

These studies have been divided into two basic categories, legibility and detectability. Legibility refers to the point at which the driver is able to read the sign legend. Detectability refers to the point at which the sign has attracted the driver's attention. There have been many more studies on the legibility of sign message than on the detectability of the sign itself.

Legibility

Blackwell, Pritchard and Schwab found that the lower the contrast between legend and background, the higher the background luminance required to maintain a given performance level.(3) Forbes confirmed this finding, and found that differences in contrast ratio more than made up for a brighter background when comparing glance legibility of white on black and white on green signs.(4) The differences, however, were not significant when placed in the driving context.

A 1979 study by Olson and Bernstein validated the inverse relationship between the contrast ratio and background brightness.(5) They also found more highly reflective backgrounds permitted slightly longer legibility distances, and were less sensitive to changing background conditions.

Olson, Sivak and Egan found legibility increasing rapidly with luminance and contrast, but found a point at which further increases in contrast were ineffective this improvement.[6] They also found that the contrast requirements required to achieve a given legibility level are directly correlated to the surrounding luminance. When studying older drivers they found similar results, but note that older drivers require more contrast than younger drivers for a given performance level. Finally, Raska and Jones found night legibility of reflectorized signs a function of contrast ratio, and found that color differences were insignificant when compared to contrast ratio.[7]

Detectability

Sign detectability, or conspicuity, refers to the ability of the sign to attract the attention of the motorist. This is a precursor to the requirement for legibility, for if the sign is not detected it can't be read. For a sign to exhibit good detectability characteristics it is only necessary that it be obvious to the driver at some point before the legibility distance, and at that point give adequate notice of the approaching sign so that the driver can continue driving safely while preparing to read the sign. There are times when the detectability of the sign is almost irrelevant, such as during "rush hour" traffic. In this case the driver will most certainly have time to read the sign, even if the detectability is beyond the theoretical legibility distance. Detectability is of key importance when traffic is flowing at maximum speed and capacity. In these cases failure to detect a sign could result in incorrect driver response or unsafe actions.

Hughes and Cole discuss two kinds of conspicuity: attention conspicuity where the observer's attention is not specifically directed to the likely occurrence of the target object, and search conspicuity which refers to the ease of target detection when the observer is directed to search for the target.[8] Both types of conspicuity are relevant when discussing highway signs. Regulatory and warning signs need to exhibit good attention conspicuity, for they are not likely to be signs for which the driver is continually searching. Guide signs, on the other hand, probably do not need to exhibit good attention conspicuity, for when guide sign information is needed, a driver, is likely to be searching for it.

Both Hughes and Cole, and Jenkins and Cole conducted experiments comparing attention and search conspicuity.(8, 9) The findings were similar, with attention conspicuity hit rates being lower than search conspicuity hit rates. In the first study search conspicuity ranged from 2.5 to 5 times better than attention conspicuity, with the differences comparing sign size. The second study compared sign type and found similar differences. For freeway direction signs, in the second study, attention conspicuity was 26 percent while search conspicuity was 75 percent. Both studies were conducted during daytime hours, so the results are likely to be different at night.

Forbes and his colleagues studied color and brightness as a function of sign visibility.(10) Their findings indicated that both sign brightness and sign/background contrast assisted in the visibility of the sign. For best visibility they found that signs should be darker against a light background and lighter against a dark background. As part of the same series of experiments Forbes presented pairs of colored signs against various colored backgrounds to determine which were seen first.(11) In all cases the bright green signs outperformed the black ones, but the dim green signs were equal to, or worse than, the black sign in all cases but one.

While not specifically related to highway signing, Christ reviewed the research relevant to color coding of visual displays.(12) He supports the use of color with his statement:

> "The most clear-cut finding is that if the color of a target is unique for that target, and if that color is known in advance, color aids both identification and searching."

The final experiment discussed in this review was conducted by Woltman, Stanton and Stearns.(13) It used video disc technology to present either white on green or white on black highway guide signs. Six identical pairs of nighttime scenes were presented in which only the sign color differed. The presentation was limited to a time period comparable to accepted detection/recognition models. The results were favorable for the green background, with these signs performing over three times better than the black background signs.

Concluding Remarks

It appears, from the results of this brief review, that color enhances both sigh detectability and legibility. In most cases this is true. From the 1957 Birren work to the recent Woltman study color has been shown to assist drivers in understanding which visual objects in the driving environment are needed to safely negotiate the road system.[2, 13] Color enhances the legibility of signs, provides brighter backgrounds, and when compared to black backgrounds, makes the job of detection easier.

Unfortunately, the Virginia study found that drivers are unaware of the meaning of the colors, and in many cases are not aware of the color/shape combinations used in current highway signing.[1] The Australian work has shown that when searching strategies are employed by drivers, they are quite successful in detecting highway signs.[8, 9] Finally, the work of Forbes found sign/background color combinations where black signs outperformed their colored counterparts.[11]

Does this mean that we should abandon, or retain, the current color coding scheme? In light of the conflicting results reported above, the answer is not an easy one.

When one looks at the causes of traffic collisions, human factors predominate; and recognition errors lead the list.[14] If consistent color coding of highway signs will help drivers recognize the various types of highway signs, color coding should be retained. While a significant portion of the subjects in the Virginia study were not familiar with the current color coding system, the research is over 20 years old, and hopefully the percentage of drivers familiar with the color coding system has increased. Even if the percentages are the same today as in 1966, there is no reason to penalize the drivers who are aware of the system.

There is, however, sufficient evidence for allowing variances to the coding system. An example, currently under study, of a permissible variance is the advance information overhead guide sign. This sign provides the driver information about upcoming exits on the interstate system. The signs are, by code, green with white legends. In some States the signs are made of a nonretroreflective material and are illuminated at night for the express purpose of appearing green. If the lights are not used the sign background appears black. If the current research indicates that, when the lights have been extinguished, drivers are able to detect these signs at some safe point before they are legible, there is no reason to require illumination or retroreflective materials. This would be supported by the Australian research, as these signs are usually detected using the search conspicuity paradigm. Additionally, these signs are located in specific locations in the driver's view, and seldom compete with other signing for the driver's attention.

With the exception of the previous example, color coding appears to be in the best interest of traffic safety. When traffic signs must compete with advertising signs and other lights in the visual field they need all the help they can get. The Woltman study presented such situations, and the results strongly support the use of color coding of highway signs.[13]

APPENDIX B. DETERMINE LUMINANCE AND ARRAY OF VARIOUS SIGN MATERIALS

Several of the studies reviewed in the literature review phase of the project reported luminance values for in-use materials; however, there was no direct comparison between these in-use materials and new materials of the same type. Luminance values for new materials have been reported in the literature, but these values have generally been made under strict laboratory conditions, and not using typical vehicle lighting conditions. Additionally, the manufacturers stated values for a particular material represents a <u>minimum</u> value. It is common practice to manufacture materials with luminance values which exceed these values so that any deterioration which may occur between the time of manufacture and the time of installation will still result in an installation which meets the manufacturers' specifications for the material.

During this phase of the project, three distinct types of data were obtained. First, luminance data on current in-use materials was gathered at several different highway locations; at the same time photographic data was gathered to determine the visual setting of these typical overhead guide sign locations. Finally, luminance data on new materials was collected at the 3M test track in St. Paul, Minnesota.

Field Measurement of In-Use Materials

Data gathering in the field was accomplished at four locations: suburban Virginia in the area surrounding Washington, D.C., Albuquerque and Santa Fe, New Mexico, Los Angeles, California and the Oakland bay area were the original locations selected for these data gathering sessions. These areas were chosen for their geographical differences. One of our original assumptions was that differences in geographical setting would result in different visual scenes. The photographic investigation found that this was not the case, and while these areas present a completely different visual scene during the day, at night there was no appreciable difference. Listings of the signs from which data were obtained, by area, are found as tables 1 through 4. From the data presented in tabular form in the main body of the report, and in figures 1 and 2 here researchers were unable to determine differences in the luminance values for the various materials.

Luminance data were gathered using a Pritchard Model 1980-A photometer and a Cassegrain Lens with a focal length of approximately 2,000 mm. This unit was placed on the right shoulder of the roadway, and the lens was raised to a typical driver eye height of 39 in. The photometer was aimed at four background and four legend locations on each sign. Two experimenters observed the output of the photometer and recorded the highest "typical" value observed. When an abnormally high value was observed the experimenters looked at the flow of traffic to see if a cause for the value was obvious. Typically a vehicle was observed with a badly mis-aimed headlight, and the abnormal reading was discounted. After 5 minutes of observation at each spot location on the sign, the experimenters compared notes on the high values recorded. Data from the four sign locations were combined, and the highest observed value was recorded as the luminance value for the sign.

When the data were compared there appeared to be no differences between the various sign materials. The overall data summaries are found in figures 1 and 2. It was hypothesized that the apparent similarity of the signs was due to a combination of factors adding to variability in the observed measurements. This hypothesis was confirmed by additional examination of the literature. Data plots of various data are found as figures 3 through 20.

An additional set of signs were discovered which allowed further comparison of the various materials under conditions which reduced a great deal of the variability. In the original tests, sign comparisons were made between signs located in different areas, on different nights, with different weather conditions and different traffic patterns. We discovered that, as part of a California Department of Transportation (CalTrans) study, a sign bridge was erected with three signs: one with encapsulated lens background and legends; one with encapsulated lens background and enclosed lens legends; and the last with a porcelain background (nonretroreflective) and button reflector legends.

These signs, located in the Oakland bay area, were measured using the techniques outlined for the earlier tests with one exception. Instead of using the highest observed photometer reading, a strip chart was attached to the photometer and 5 minutes of continuous data were recorded. The high and low values of these readings were then recorded as the luminance for each of the materials.

The data gathered for these signs did show differences between the materials. Many of the variability factors in the earlier comparisons were eliminated in these tests. First, all signs were located on the same sign bridge. While there were slight differences in the angle of measurement, the weather was the same, mounting practices were identical, dirt and other use factors were equal, etc. In addition to luminance data, legend/background contrast ratios were calculated for each of the signs. The luminance and contrast ratio data are found in table 5, and the data for these tests are also plotted as part of figures 1 and 2.

Test Track Measurement of New Materials

To allow comparison of new and in-use materials, tests were conducted on new materials at the 3M test track in St. Paul, Minnesota. The data collection techniques were quite similar. The identical equipment was used as in the field tests (without the strip chart recorder), but instead of using free flowing traffic to illuminate the sign a test vehicle located at specified distances from the sign was used. Instead of the photometer being mounted on the shoulder of the roadway, it was placed next to the driver's door. Two vehicles were available, so it was possible to make comparisons between a single 200 mm halogen sealed beam headlight (U.S. standard), and a 165 mm, H-4 halogen low beam headlight (European standard). In both cases the headlights were aimed just prior to testing using a mechanical aiming device.

For the U.S. standard headlight system, measurements were obtained for the following nonilluminated materials every 250 ft from 250 ft to 1500 ft, and for the same materials illuminated at 1000 ft:

- Encapsulated lens sheeting, green.
- Encapsulated lens sheeting, white.

- Enclosed lens sheeting, green.
- Enclosed lens sheeting, white.
- Prismatic lens sheeting, green (Type 1).
- Prismatic lens sheeting, green (Type 2).
- Prismatic lens sheeting, white.
- Encapsulated lens sheeting, green (used, placed in service 1972, removed 1984).
- Encapsulated lens sheeting, white (as above).
- Porcelain sign material, green.
- Button copy legend.
- A reference light source.

Data were obtained for the European headlight system on the same array of materials at 1500 ft, and for the encapsulated lens and enclosed lens materials at the other distances. For the European system, illuminated measurements were made at the 500-ft distance.

The data were then tabulated and plotted. A summary of the on-road data, for the U.S. system headlights, is also found on figures 15 and 20. The tabular results are found in tables 6 and 7, while the other plots are found as figures 21 through 22.

Summary of the Results

A summary of the results of this task is presented below:

- The brightest material tested was the Button Copy.
- For in-use materials:
    - White is brighter than green.
    - Reflective sheeting is brighter than porcelain.
    - The rank ordering of green materials was: encapsulated lens, enclosed lens, nonretroreflective.
    - The rank ordering of white materials was: button copy, encapsulated lens, enclosed lens.

- For new materials the results were identical, except that prismatic lens materials were brighter than encapsulated lens materials and not as bright as button copy.
- New materials are brighter than used ones.
- To obtain accurate field test results, it is necessary to control as many variables as possible.
- Use of a strip chart recorder with the photometer will provide the most accurate means of recording data.

The purpose of these tests was the determination of sign luminance levels which would be appropriate for use in the laboratory tests. As discussed above, there is a large variance in the luminance levels of in-use overhead guide signs. We found that legend luminance varied from -2.0 log ft lamberts to 0.9 log ft lamberts, and background luminance varied from -2.4 log ft lamberts to -0.7 log ft lamberts.

Tables 1 to 6, which follow, are the inventories of the data. Following is a brief description of the information contained on these tables:

<u>Column name</u>	<u>Meaning</u>
SIGN	The sign legend, for identification purposes.
DISTANCE	The distance to the sign.
MATERIAL	The first reference is for the legend, the second is for the background. BUT = Button copy. ENCL = Enclosed lens retroreflective material. ENCP = Encapsulated lens retroreflective material. OPQ = Opaque background (porcelain enamel).
ILLUM TYPE	Type of illumination present and operating. FLOUR = Fluorescent tube. HPS = High pressure sodium. MV = Mercury vapor.
LEGEND/BACKGROUND	These columns list the luminance values measured. For tables 1 to 4, 6 and 7 the values are in ft lamberts, for table 5 both ft lamberts and log ft lamberts are given.
COMMENTS	General comments.

Table 1. Washington, DC sign inventory.

WASH D.C. AREA:

SIGN	DISTANCE	LEGEND	BACKGROUND	MATERIAL	ILLUM TYPE	COMMENTS
						RT ARROW MEASURED, SIGN CRACKED
MC LEAN	?	0.0665	0.0044	ENCL/ENCL	---	LEFT ARROW MEASURED
LEESBURG	?	0.1250	0.0100	ENCL/ENCL	---	DARK
95 NS	300	0.1080	0.0225	ENCL/ENCL	---	DARK
644 E	300	0.1220	0.0315	ENCL/ENCL	---	BRIGHT
95 NS	300	0.1410	0.0225	ENCL/ENCL	---	BRIGHT
644 E	300	0.2290	0.0315	ENCL/ENCL	---	
COMMERCE	300	0.2650	0.0365	ENCL/ENCL	---	ADVANCED WARNING SIGN
SO. PENTAGON PARKING	525	0.4510	0.0792	ENCL/ENCL	MV	
395 SO.	525	0.5340	0.1710	ENCL/ENCL	HPS	
COLUMBIA PIKE	525	0.5400	0.0803	ENCL/ENCL	HPS	
TO 395	525	1.4000	0.0860	ENCL/ENCL	HPS	
395-1 NO	550	0.3900	0.0650	ENCL/ENCL	---	
BOUNDARY CHANNEL	550	0.7150	0.0570	ENCL/ENCL	MV	SHIELD SHAPE
1 NORTH	600	0.1380	0.0385	ENCL/ENCL	---	"3" MEASURED
395 NORTH	600	0.2720	0.0250	ENCL/ENCL	---	"N" MEASURED
1 NORTH	600	1.0800	0.0385	BUT/ENCL	---	"N" MEASURED
395 NORTH	600	1.2000	0.0250	BUT/ENCL	---	
MARYMOUNT COLLEGE	675	0.3180	0.0803	ENCL/ENCL	---	CRACKED
GLEBE RD	675	0.3340	0.0496	ENCL/ENCL	HPS	
NATIONAL HOSPITAL	675	0.3370	0.0703	ENCP/ENCP	---	
RICHMOND	800	0.4080	0.0370	ENCL/ENCL	MV	
BOUNDARY CHANNEL	800	0.4440	0.0600	ENCL/ENCL	MV	
CRYSTAL CITY	800	0.5090	0.0438	ENCL/ENCL	MV	
CLARK ST	800	0.5540	0.0633	ENCL/ENCL	MV	
WASHINGTON BLVD	1000	0.1035	0.0251	ENCL/ENCL	---	
495 TYSON	1000	0.1100	0.0330	ENCL/ENCL	---	
MEMORIAL BRIDGE	1000	0.1250	0.0265	ENCL/ENCL	---	
FT. MYER	1000	0.1650	0.0500	ENCL/ENCL	---	
MEMORIAL BRIDGE	1000	0.4500	0.0785	ENCL/ENCL	---	
TO 66 W	1000	0.6700	0.0650	ENCL/ENCL	---	BKGD VERY CRACKED
SO. PENTAGON PARKING	1050	0.5070	0.0610	ENCL/ENCL	HPS	BKGD VERY CRACKED
395 RICHMOND	1050	0.7950	0.0586	ENCL/ENCL	HPS	
NATIONAL AIRPORT	1700	0.3860	0.1050	ENCL/ENCL	MV	
1 NORTH	1700	0.4500	0.0690	ENCL/ENCL	---	
1 NO. 14 ST	2150	1.9900	0.5500	ENCL/ENCL	MV	
395 NO.	2150	6.3700	0.6890	ENCL/ENCL	MV	
RADAR DETECTORS ILLEGAL	2650	0.0958	0.0120	ENCP/ENCP	---	BLACK BACKGROUND
TRAVEL INFORMATION	2650	0.1210	0.0296	ENCP/ENCP	---	BLUE BACKGROUND
SPEED CHECKED BY RADAR	2650	0.2030	0.0173	ENCL/ENCL	---	BLACK BACKGROUND
WELCOME TO VIRGINIA	2650	0.3950	0.0415	ENCL/ENCL	MV	BLUE BACKGROUND
BOUNDARY CHANNEL DR.	2650	0.4750	0.0620	ENCL/ENCL	MV	
MT. VERNON	2650	0.5100	0.0825	ENCL/ENCL	MV	

Table 2. Albuquerque, NM sign inventory.

ALBUQUERQUE:

SIGN	DISTANCE	LEGEND	BACKGROUND	MATERIAL	ILLUM TYPE	COMMENTS
WYOMING BLVD.	525	0.3330	0.0445	ENCL/ENCL	MV	SMOKE IN AIR, 1/3 LIT
LOUISIANA BLVD. SO.	525	0.5010	0.0278	ENCL/ENCL	---	
40 WEST	1225	0.1300	0.0232	ENCL/ENCL	---	
CANDEL BLVD.	1225	0.1900	0.0460	ENCP/ENCP	---	
40 EAST	1225	0.3140	0.0240	ENCL/ENCL	---	
LOUISIANA BLVD. NO.	1575	1.1600	0.2610	BUT/ENCL	MV	
WYOMING BLVD. SO.	2175	0.1237	0.0305	ENCL/ENCL	---	NOT VISIBLE, SMOKE IN AIR
WYOMING BLVD. NO.	3600	0.0404	0.0387	BUT/ENCL	---	NOT VISIBLE, SMOKE IN AIR

Table 3. Santa Fe, NM sign inventory.

SANTE FE:

SIGN	DISTANCE	LEGEND	BACKGROUND	MATERIAL	ILLUM TYPE	COMMENTS
COCHITI PUEBLO	800	0.4620	0.0693	ENCP/ENCP	---	
COCHITI PUEBLO	800	0.7020	0.0305	ENCP/ENCP	FLOUR	
CERRILLOS RD	900	0.1380	0.0245	ENCP/ENCP	---	
NO. 25	900	0.1620	0.0263	ENCP/ENCP	---	
ST. FRANCIS DR	900	0.2580	0.0190	ENCP/ENCP	---	
14 SO.	1100	0.1990	0.0301	ENCP/ENCP	---	
SO. 25	1100	0.2010	0.0266	ENCP/ENCP	---	
CERRILLOS RD	1100	0.2200	0.0301	ENCP/ENCP	---	
OLD PECOS TRAIL	1700	0.1220	0.0535	ENCP/ENCP	---	
NO. 25	1700	0.2600	0.0295	ENCP/ENCP	---	
ST. FRANCIS	1700	0.3520	0.0285	ENCP/ENCP	---	
COCHITI PUEBLO	2650	0.0640	0.0124	ENCL/ENCL	---	OUR LIGHTS
COCHITI PUEBLO	2650	0.2700	0.4620	ENCL/ENCL	FLOUR	
COCHITI PUEBLO	2650	0.2750	0.0330	ENCL/ENCL	---	FREE FLOWING TRAFFIC

Table 4. Los Angeles, CA sign inventory.

LA AREA:

SIGN	DISTANCE	LEGEND	BACKGROUND	MATERIAL	ILLUM TYPE	COMMENTS
PUENTE AVE	502	0.0830	0.0107	BUT/OPQ		BKGRD LOOKS BEATEN W HAMMER
BALDWIN PARK BLVD 1/4 MI	502	0.2400	0.0690	BUT/OPQ		
BARRANCA	853	0.0954	0.1790	BUT/ENCL		BUTTON LEGEND
CITRUS	853	0.1035	0.1790	ENCP/ENCL		RETRO LEGEND
CITRUS	1003	0.0570	0.0360	BUT/ENCP		BUTTON LEGEND, SLIGHT HAZE
BARRANCA	1003	0.1350	0.0360	ENCP/ENCP		RETRO LEGEND, SLIGHT HAZE
CITRUS	1605	0.2300	0.0310	ENCP/ENCL		RETRO LEGEND
BARRANCA	1605	0.2950	0.0426	ENCP/ENCP		RETRO LEGEND
BARRANCA	1605	0.3120	0.0310	BUT/ENCL		BUTTON LEGEND
CITRUS	1605	0.4050	0.0426	BUT/ENCP		BUTTON LEGEND
AZUSA AVE 1/2 MI	1756	0.3530	0.0294	BUT/OPQ		
BALDWIN PARK BLVD	1756	0.6700	0.0650	BUT/OPQ		BRIGHTER PART OF BKGRD MEASURED
BALDWIN PARK BLVD	1756	0.6700	0.0300	BUT/OPQ		LGD MEASURED BETW BUT & BKGRD
PUENTE AVE 1/4 MI	1856	0.1220	0.0405	BUT/OPQ		
AZUSA AVE 1/2 MI	2508	0.1540	0.0267	BUT/OPQ		
PACIFIC AVE 1 MI	2508	0.2900	0.0558	BUT/OPQ	FLOUR	
AZUSA AVE EXIT ONLY	3010	0.5950	0.7200	BUT/OPQ	FLOUR	
FRANCISQUITO AVE	3260	0.1700	0.1100	BUT/OPQ		
AZUSA AVE EXIT ONLY	3762	0.2040	0.0707	BUT/OPQ	FLOUR	

Table 5. Luminance and contrast ratio data for the Oakland tests

SIGN	MATERIAL	DISTANCE	LUMINANCE LEGEND LUM.	LUMINANCE LEGEND LOG	LUMINANCE BACKGROUND LUM.	LUMINANCE BACKGROUND LOG	CONTRAST RATIO
(LOW VALUES)							
1	ENCP/ENCL	300	0.010	-2.000	0.005	-2.347	2.22
1	ENCP/ENCL	500	0.020	-1.699	0.006	-2.222	3.33
1	ENCP/ENCL	700	0.035	-1.456	0.005	-2.301	7.00
1	ENCP/ENCL	900	0.030	-1.525	0.006	-2.260	5.45
1	ENCP/ENCL	1100	0.080	-1.097	0.008	-2.125	10.67
1	ENCP/ENCL	1300	0.050	-1.301	0.007	-2.155	7.14
2	BUT/OPQ	300	0.020	-1.699	0.020	-1.699	1.00
2	BUT/OPQ	500	0.060	-1.222	0.006	-2.222	10.00
2	BUT/OPQ	700	0.060	-1.222	0.004	-2.456	10.00
2	BUT/OPQ	900	0.100	-1.000	0.004	-2.456	28.57
2	BUT/OPQ	1100	0.075	-1.125	0.004	-2.456	20.83
2	BUT/OPQ	1300	0.150	-0.824	0.005	-2.301	30.00
3	ENCP/ENCP	300	0.025	-1.602	0.015	-1.824	4.55
3	ENCP/ENCP	500	0.050	-1.301	0.010	-2.000	5.00
3	ENCP/ENCP	700	0.040	-1.398	0.010	-2.000	4.00
3	ENCP/ENCP	900	0.200	-0.699	0.020	-1.699	10.00
3	ENCP/ENCP	1100	0.050	-1.301	0.010	-2.000	5.00
3	ENCP/ENCP	1300	0.200	-0.699	0.015	-1.824	13.33
(HIGH VALUES)							
1	ENCP/ENCL	300	0.070	-1.155	0.015	-1.024	4.67
1	ENCP/ENCL	500	0.215	-0.668	0.103	-1.648	9.56
1	ENCP/ENCL	700	0.195	-0.710	0.022	-1.658	8.86
1	ENCP/ENCL	900	0.205	-0.688	0.022	-1.668	9.53
1	ENCP/ENCL	1100	0.215	-0.688	0.019	-1.733	11.62
1	ENCP/ENCL	1300	0.250	-0.602	0.025	-1.602	10.00
2	BUT/OPQ	300	0.160	-0.796	0.040	-1.398	4.00
2	BUT/OPQ	500	0.230	-0.638	0.023	-1.638	10.00
2	BUT/OPQ	700	0.230	-0.638	0.022	-1.658	10.45
2	BUT/OPQ	900	0.215	-0.668	0.023	-1.638	9.35
2	BUT/OPQ	1100	0.230	-0.638	0.023	-1.638	10.00
2	BUT/OPQ	1300	0.750	-0.125	0.070	-1.155	10.71
3	ENCP/ENCP	300	0.022	-1.658	0.022	-1.658	1.08
3	ENCP/ENCP	500	0.120	-0.921	0.080	-1.097	1.05
3	ENCP/ENCP	700	0.145	-0.839	0.040	-1.398	3.63
3	ENCP/ENCP	900	0.210	-0.678	0.040	-1.398	5.25
3	ENCP/ENCP	1100	0.180	-0.745	0.050	-1.301	3.60
3	ENCP/ENCP	1300	0.350	-0.456	0.050	-1.031	7.00

Table 6. Luminance data for new materials, U.S. standard headlamp.

	U. S. STANDARD HEADLAMP						
	1500'	1250'	1000 ILLUM	1000'	750'	500'	250'
ENCAPSULATED GREEN	0.2680	0.3080	1.0650	0.2655	0.3205	0.1960	0.0826
ENCAPSULATED WHITE	1.2790	1.4775	8.7750	1.2825	1.6505	1.0590	0.4600
ENCLOSED GREEN	0.1085	0.1170	0.8950	0.0975	0.1315	0.0935	0.0820
ENCLOSED WHITE	0.5805	0.6675	10.2100	0.5790	0.7860	0.6005	0.4580
PRISMATIC GREEN (1)	0.6528	0.8203	1.4700	0.7340	0.8425	0.4724	0.2100
PRISMATIC GREEN (2)	0.5520	0.5900	1.2750	0.5285	0.6150	0.3633	0.1630
PRISMATIC WHITE	4.3817	5.1513	18.1750	4.1200	4.8350	3.0038	1.1300
USED ENCAP GREEN	0.2113	0.2425	1.3100	0.2170	0.2755	0.1915	0.0835
USED ENCAP WHITE	1.3675	1.5200	9.8250	1.3500	1.7150	1.3450	0.5650
NON-RETRO GREEN		0.0087	1.5150	0.0108	0.0081	0.0097	0.0092
BUTTON COPY		7.8500	21.5000	7.5000	6.9250	4.9500	1.0000
REFERENCE	213.5000	248.5000	253.0000	259.0000	280.6667	282.3333	278.0000

Table 7. Luminance data for new materials, European headlamp.

	EUROPEAN HEADLAMP						
	1500'	1250'	1000'	750'	500' ILLUM	500'	250'
ENCAPSULATED GREEN	0.006975	0.007725	0.008200	0.009550	0.011200	0.012000	0.012600
ENCAPSULATED WHITE	0.033900	0.037350	0.040250	0.046850	0.053100	0.059350	0.064300
ENCLOSED GREEN	0.002810	0.002975	0.003050	0.003500	0.004075	0.005050	0.005800
ENCLOSED WHITE	0.015850	0.017250	0.018150	0.020950	0.023900	0.027800	0.031000
PRISMATIC GREEN (1)	0.019600						
PRISMATIC GREEN (2)	0.013400						
PRISMATIC WHITE	0.115250						
USED ENCAP GREEN	0.005850						
USED ENCAP WHITE	0.036000						
NON-RETRO GREEN					0.237000		
BUTTON COPY					4.590000		
REFERENCE	25.300000	26.600000	27.300000	27.100000	27.200000	27.800000	28.100000

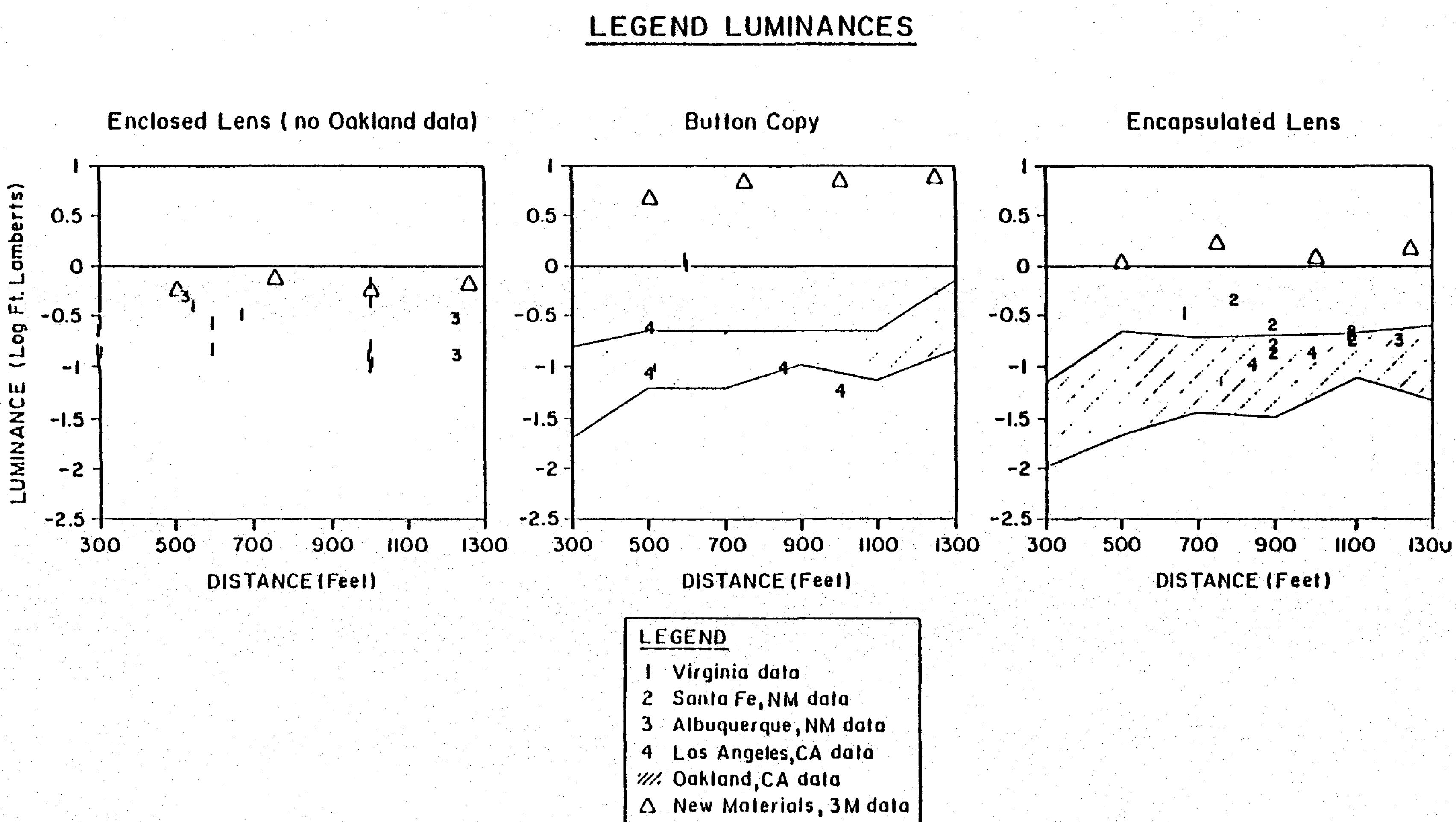


Figure 1. All legend luminance data.

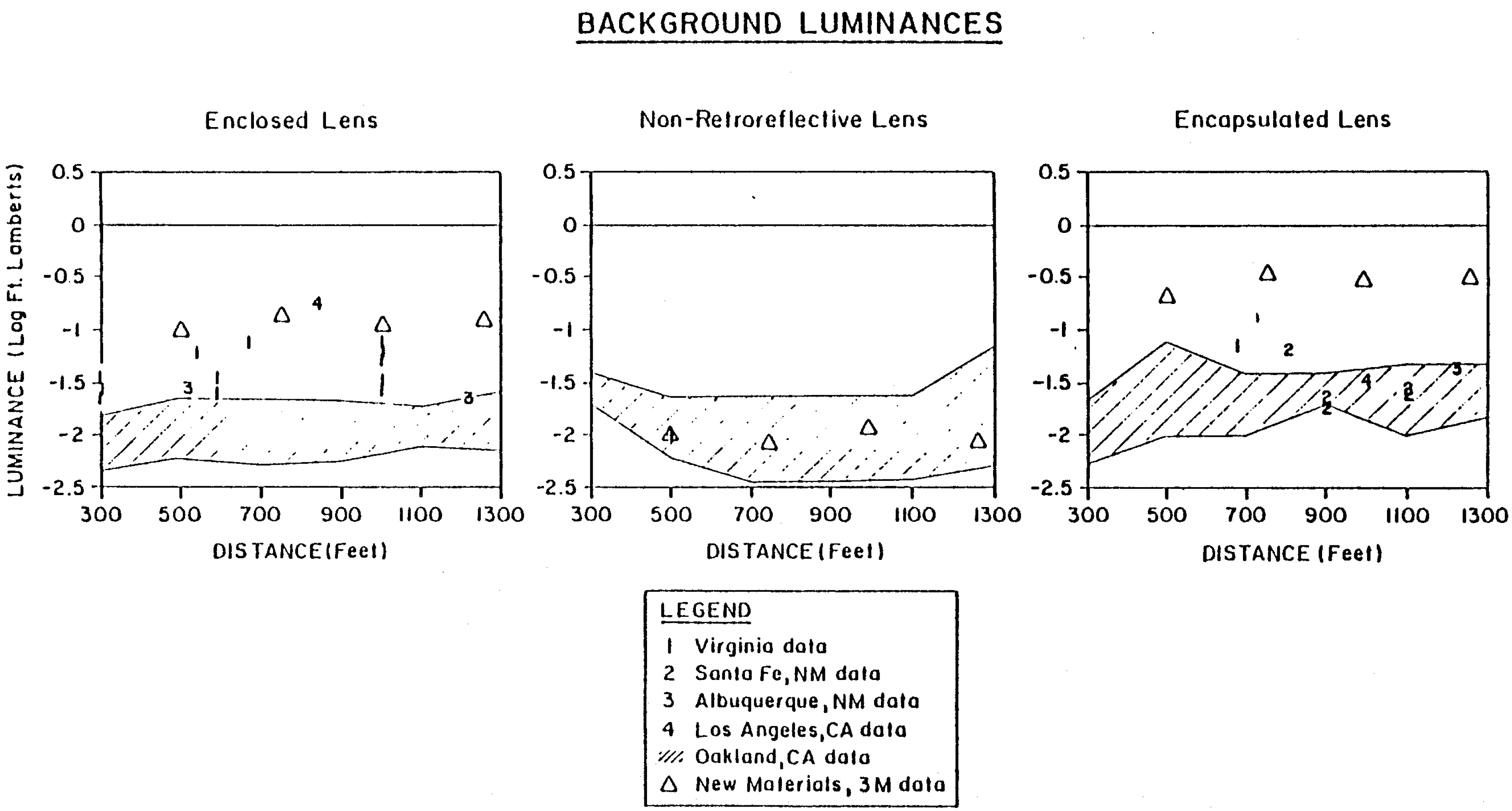


Figure 2. All background luminance data.

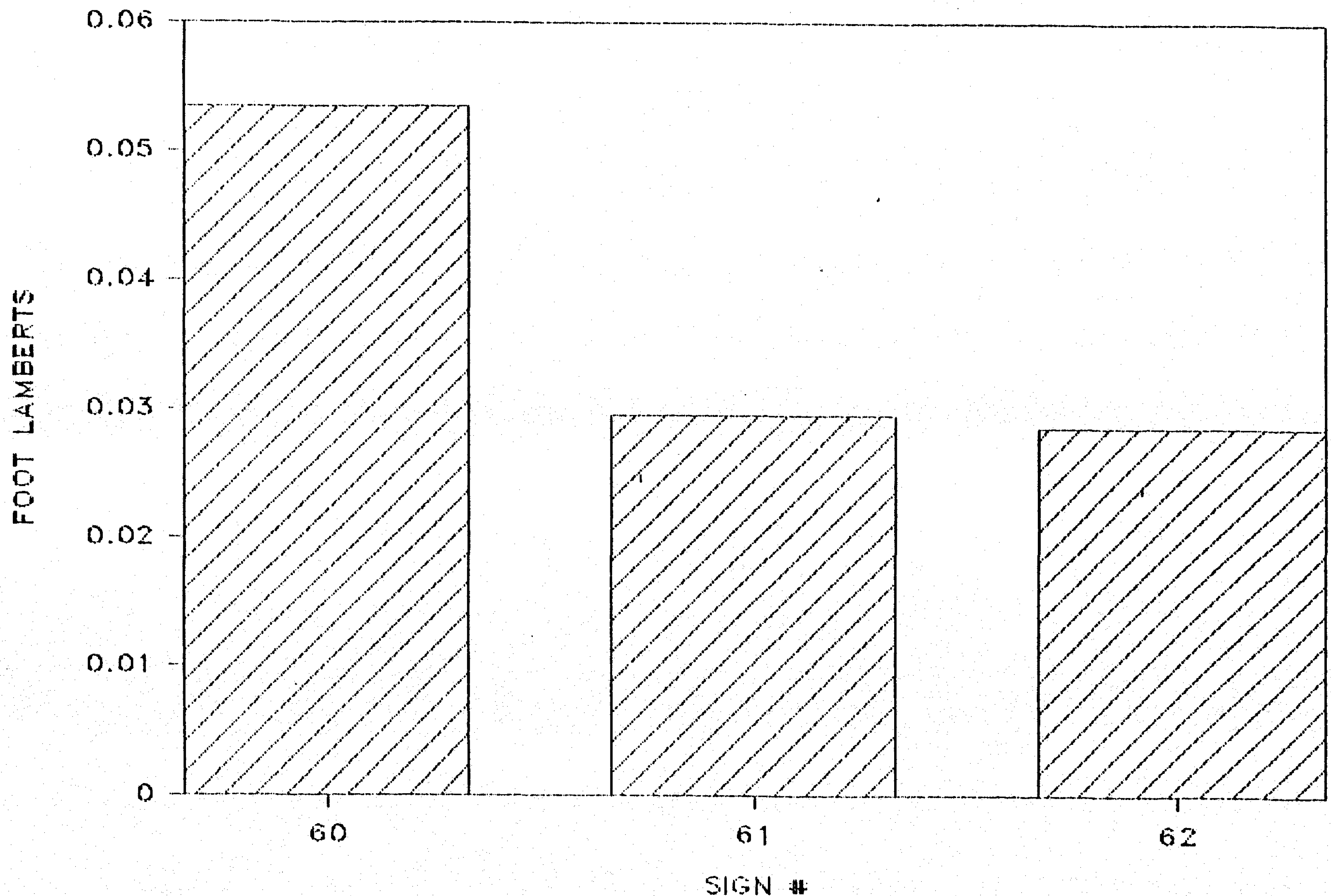


Figure 3. In-use material luminance data, encapsulated background, 1700 ft.

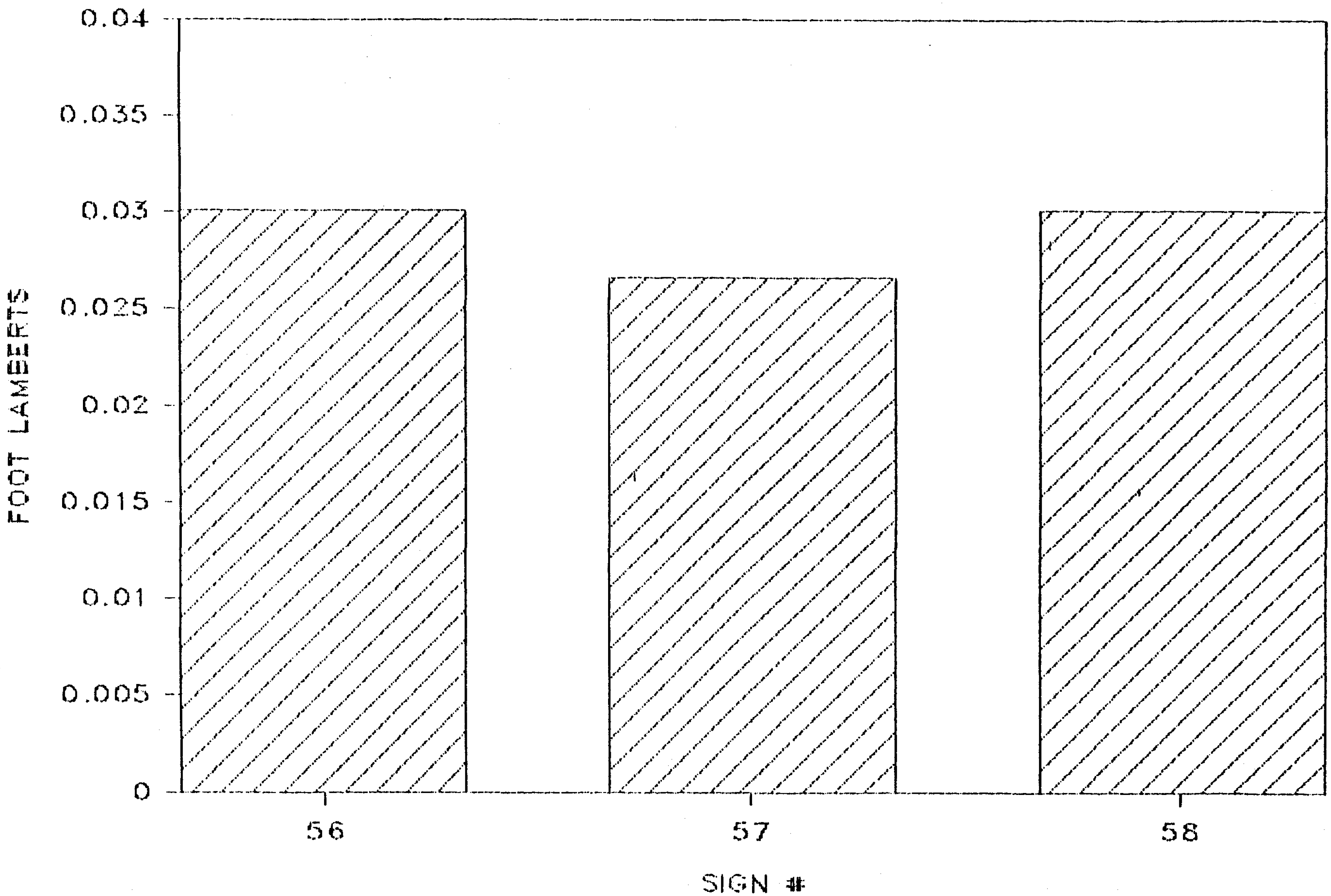


Figure 4. In-use material luminance data, encapsulated background, 1100 ft.

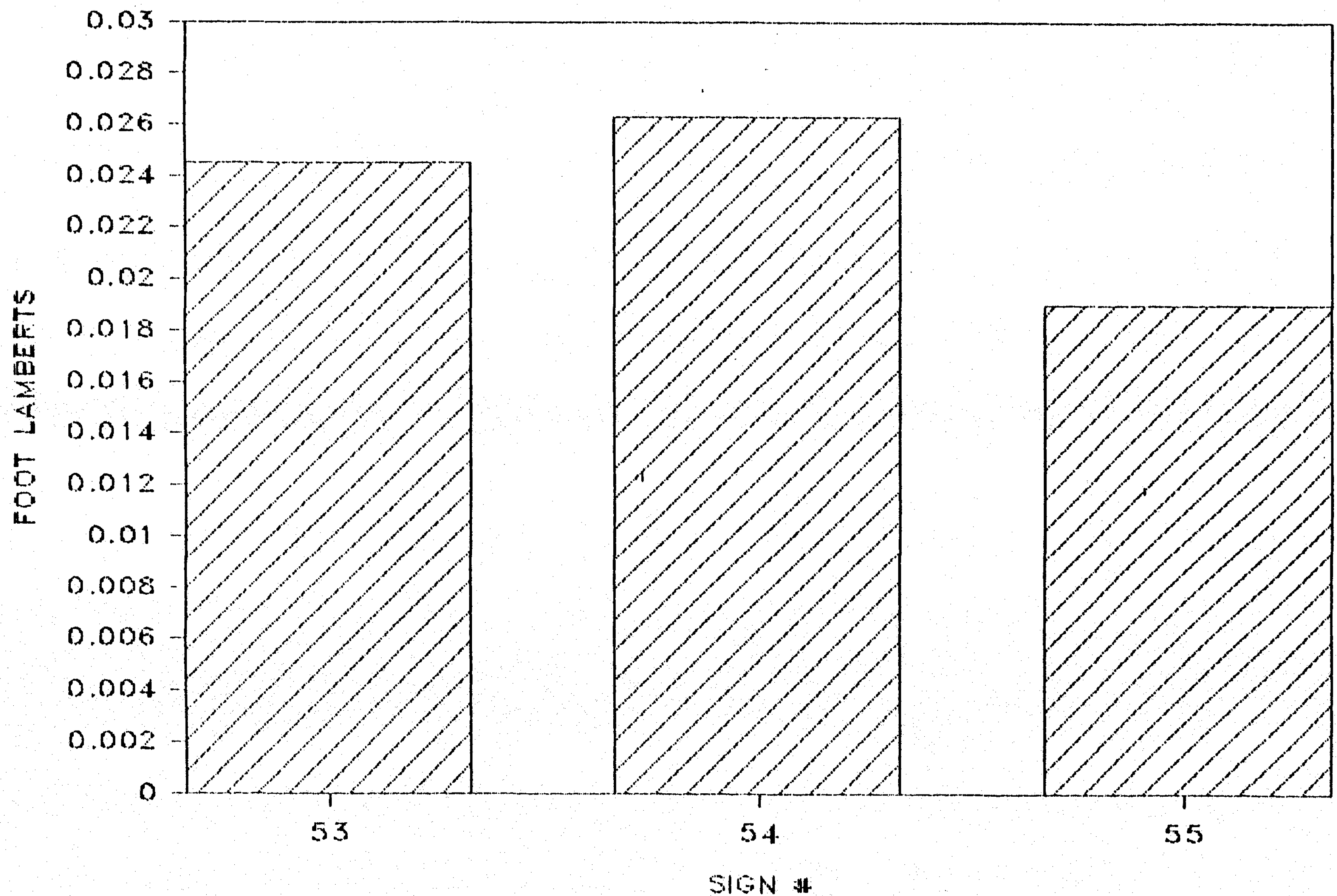


Figure 5. In-use material luminance data, encapsulated background, 900 ft.

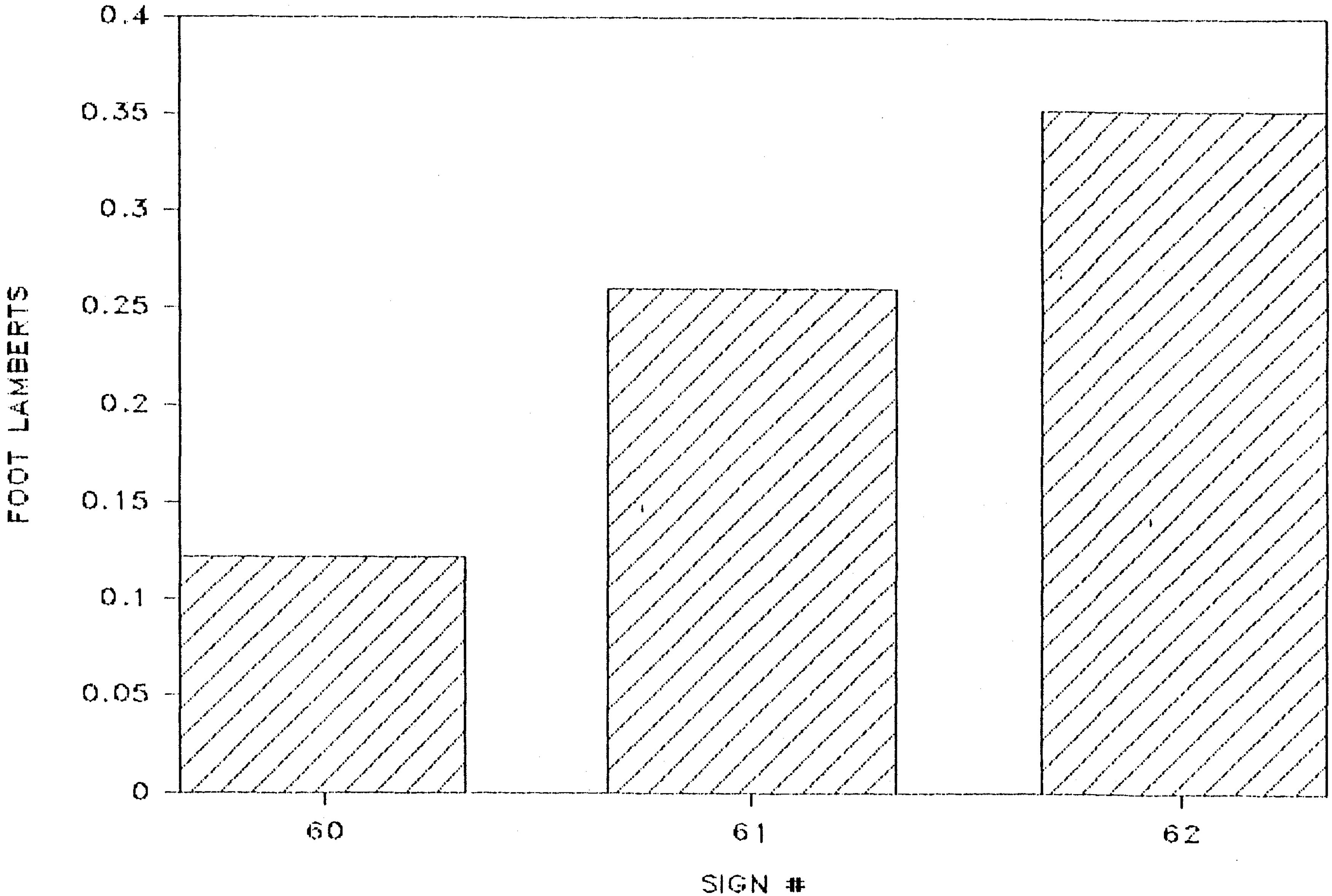


Figure 6. In-use material luminance data, encapsulated legend, 1700 ft.

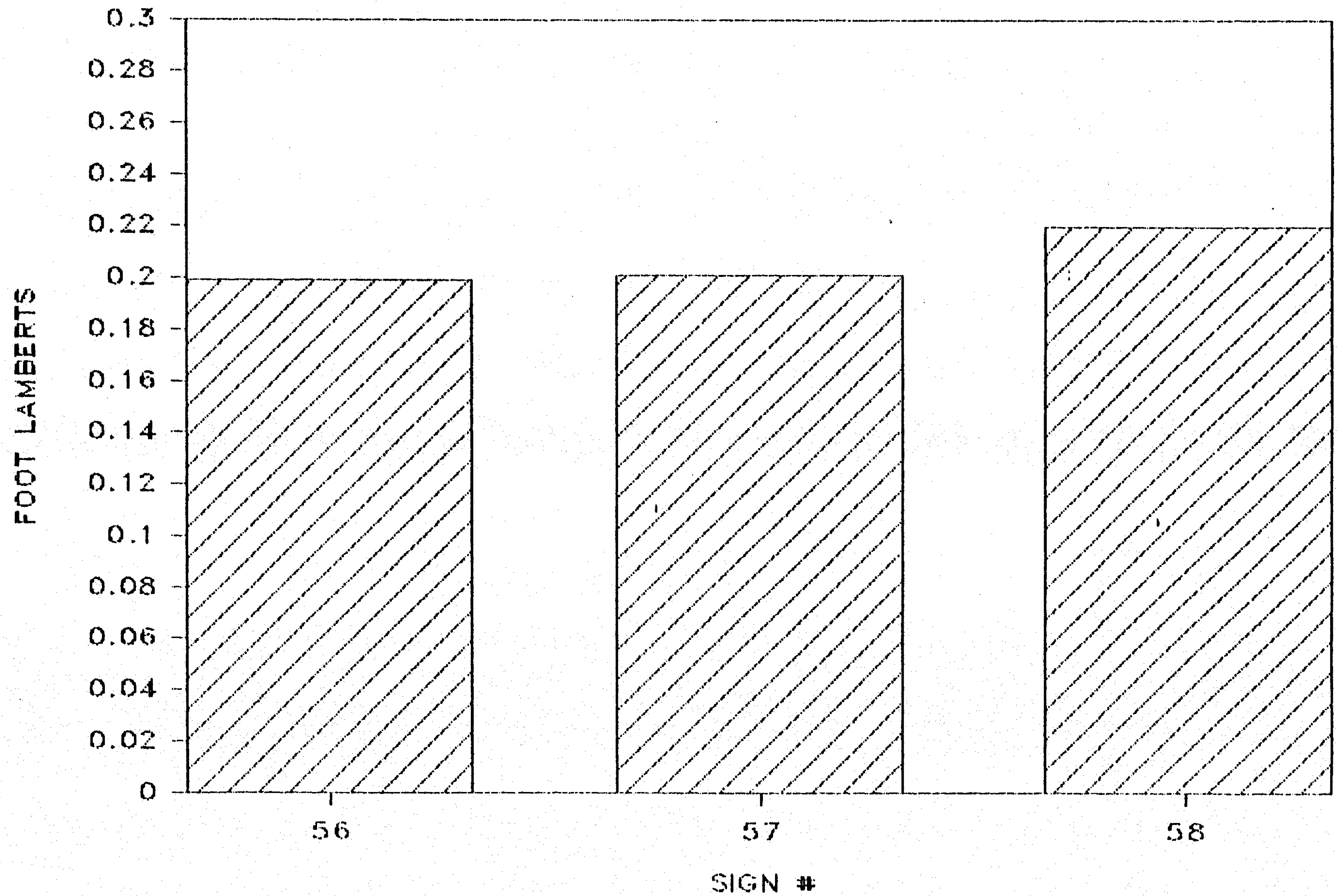


Figure 7. In-use material luminance data, encapsulated legend, 1100 ft.

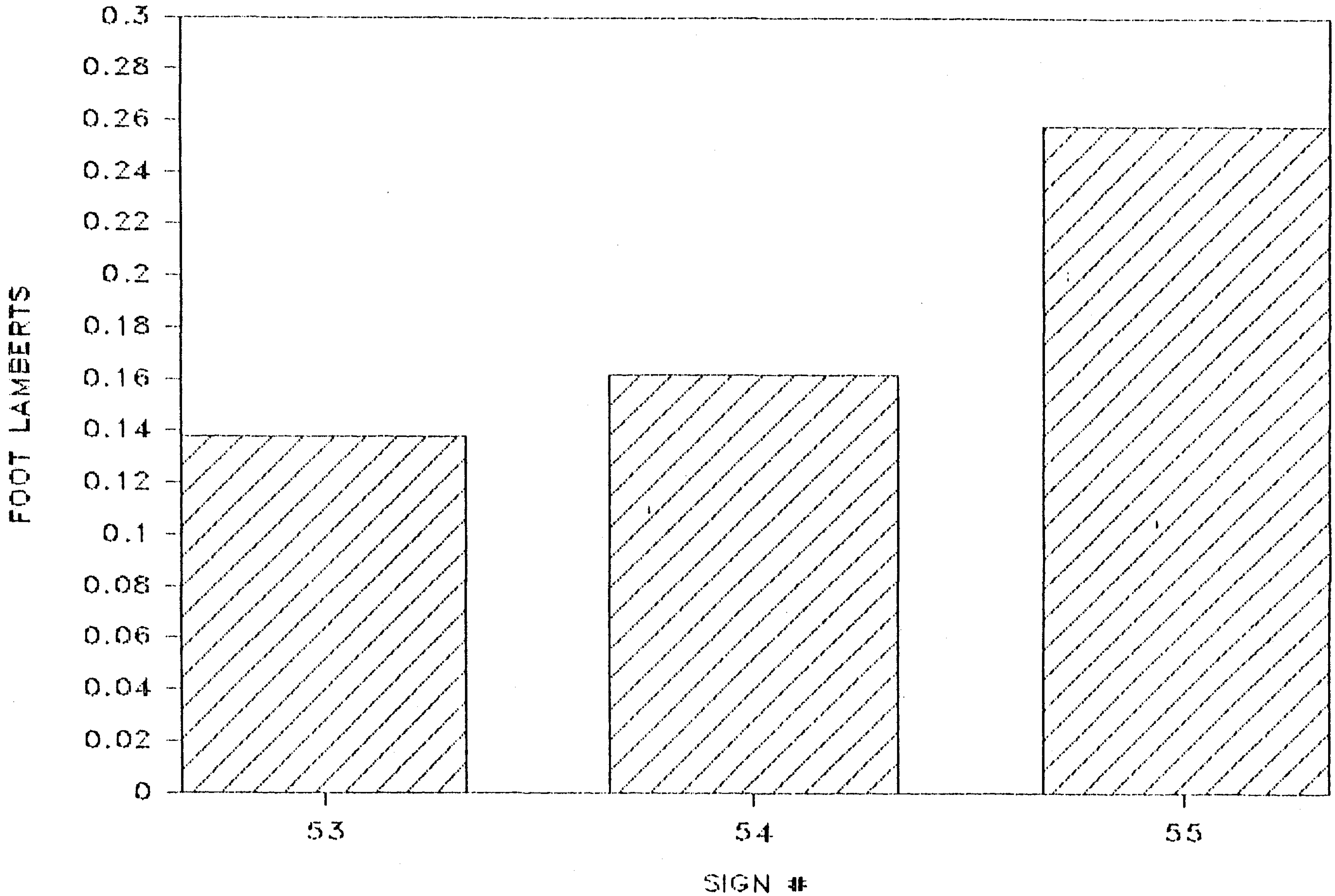


Figure 8. In-use material luminance data, encapsulated legend, 900 ft.

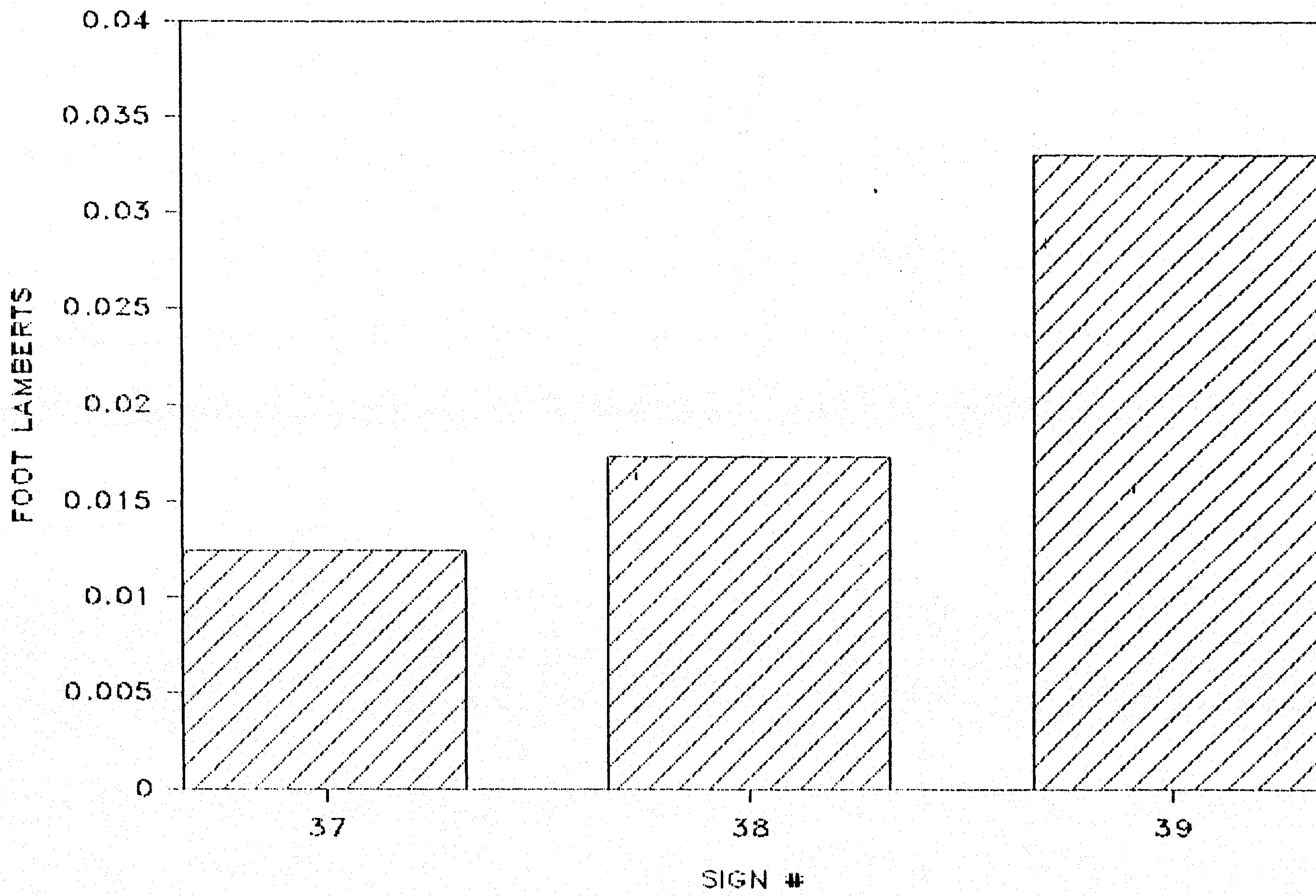


Figure 9. In-use material luminance data, enclosed background, 2650 ft.

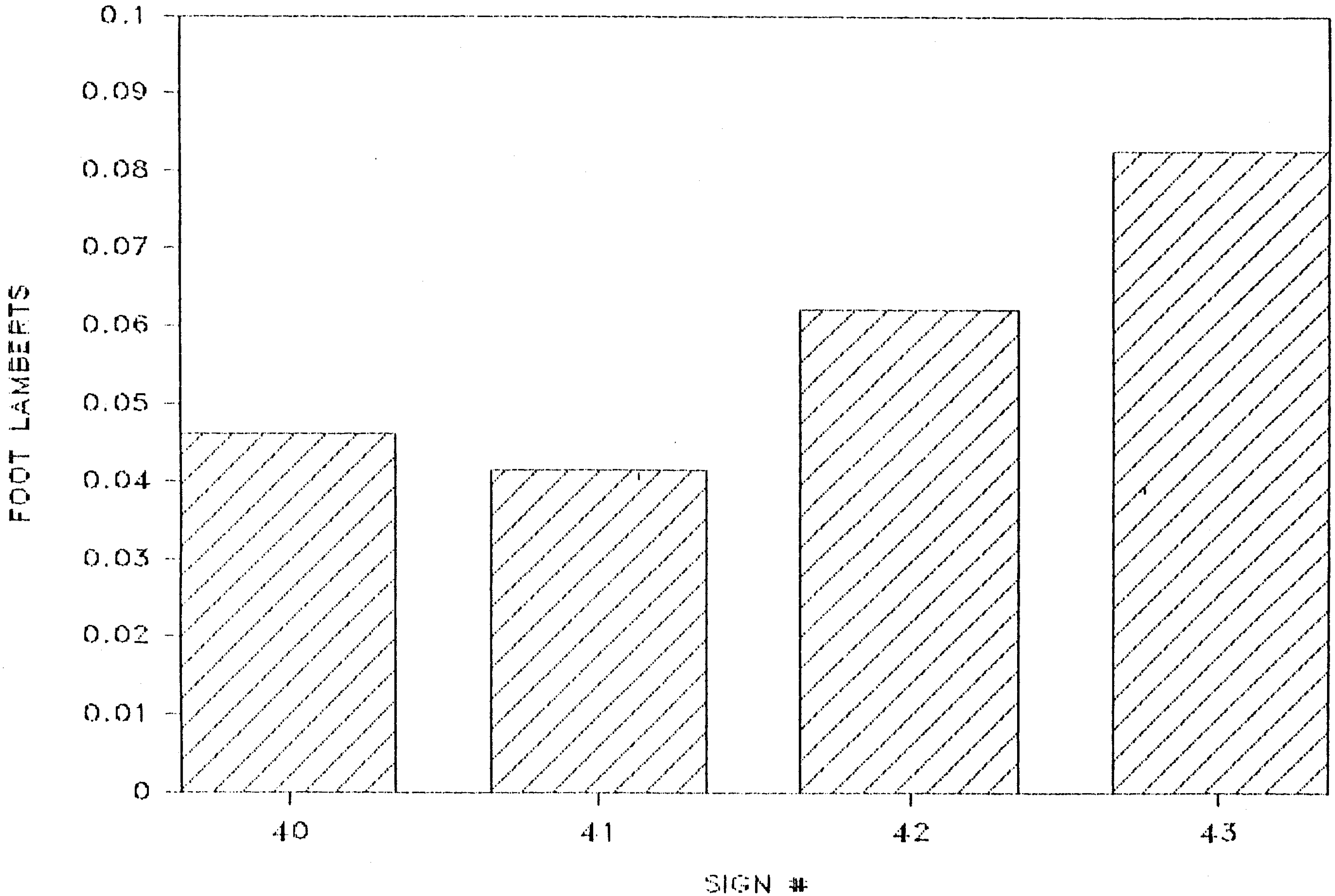


Figure 10. In-use material luminance data, enclosed background, 2650 ft. illuminated.

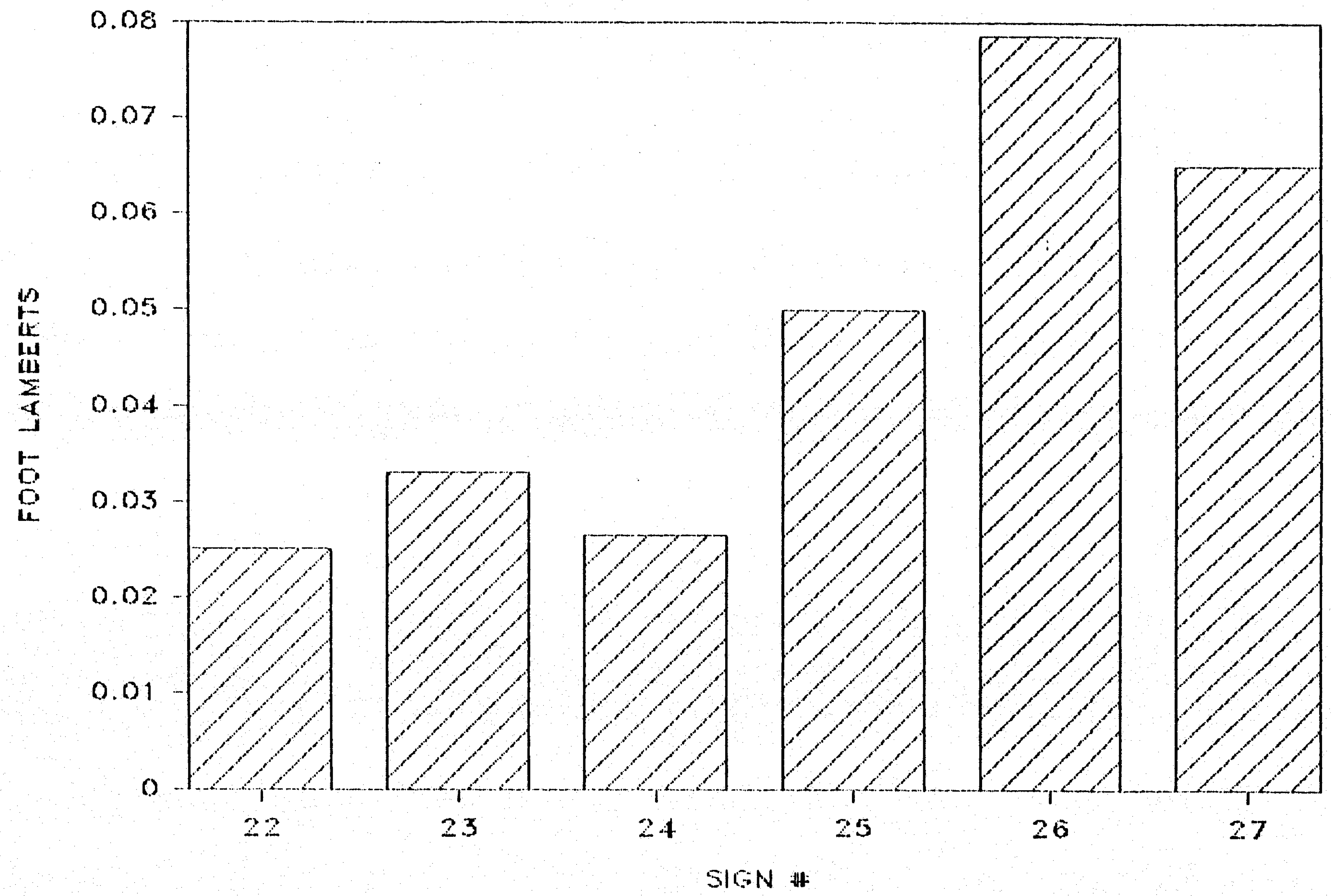


Figure 11. In-use material luminance data, enclosed background, 1000 ft.

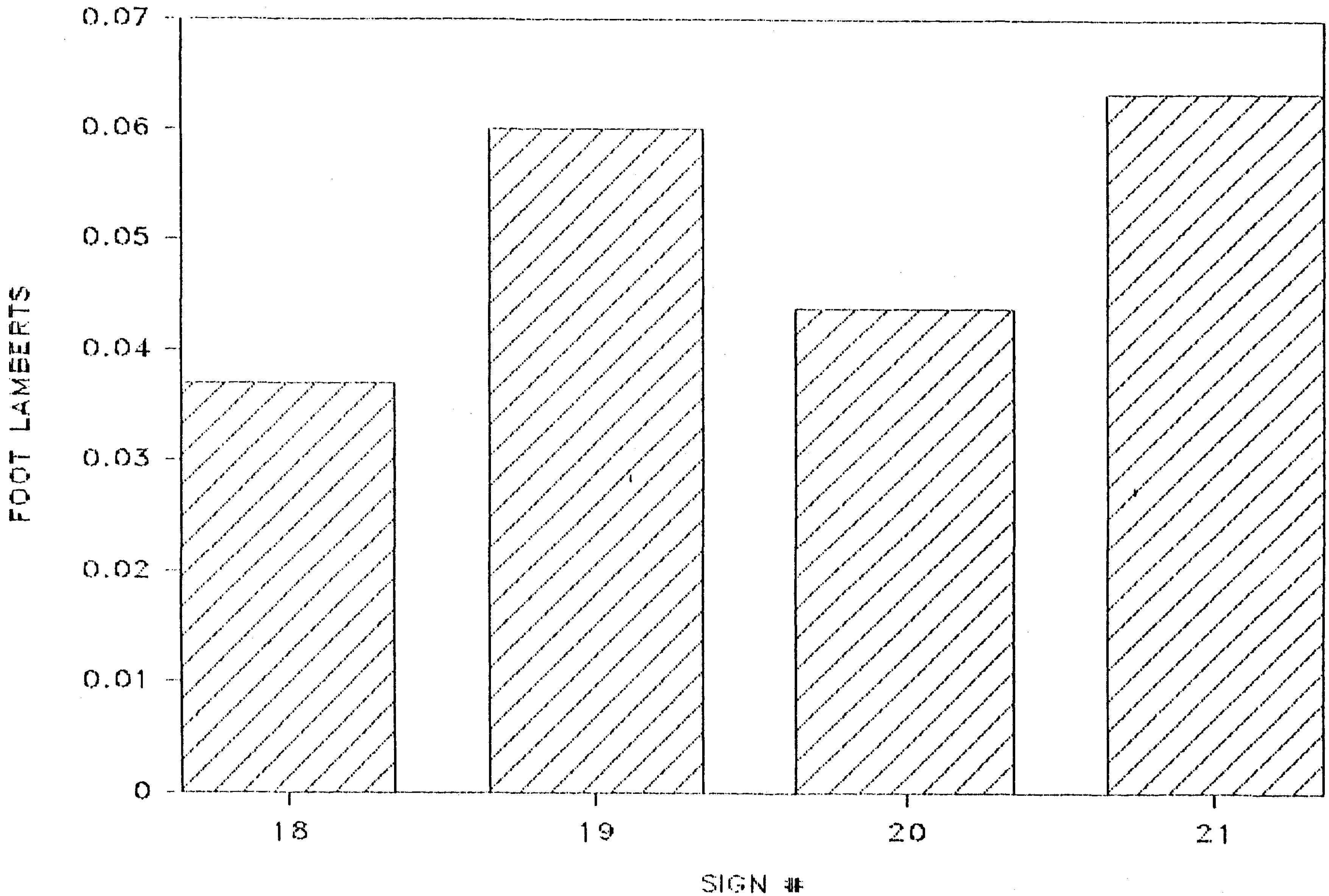


Figure 12. In-use material luminance data, enclosed background, 800 ft, illuminated.

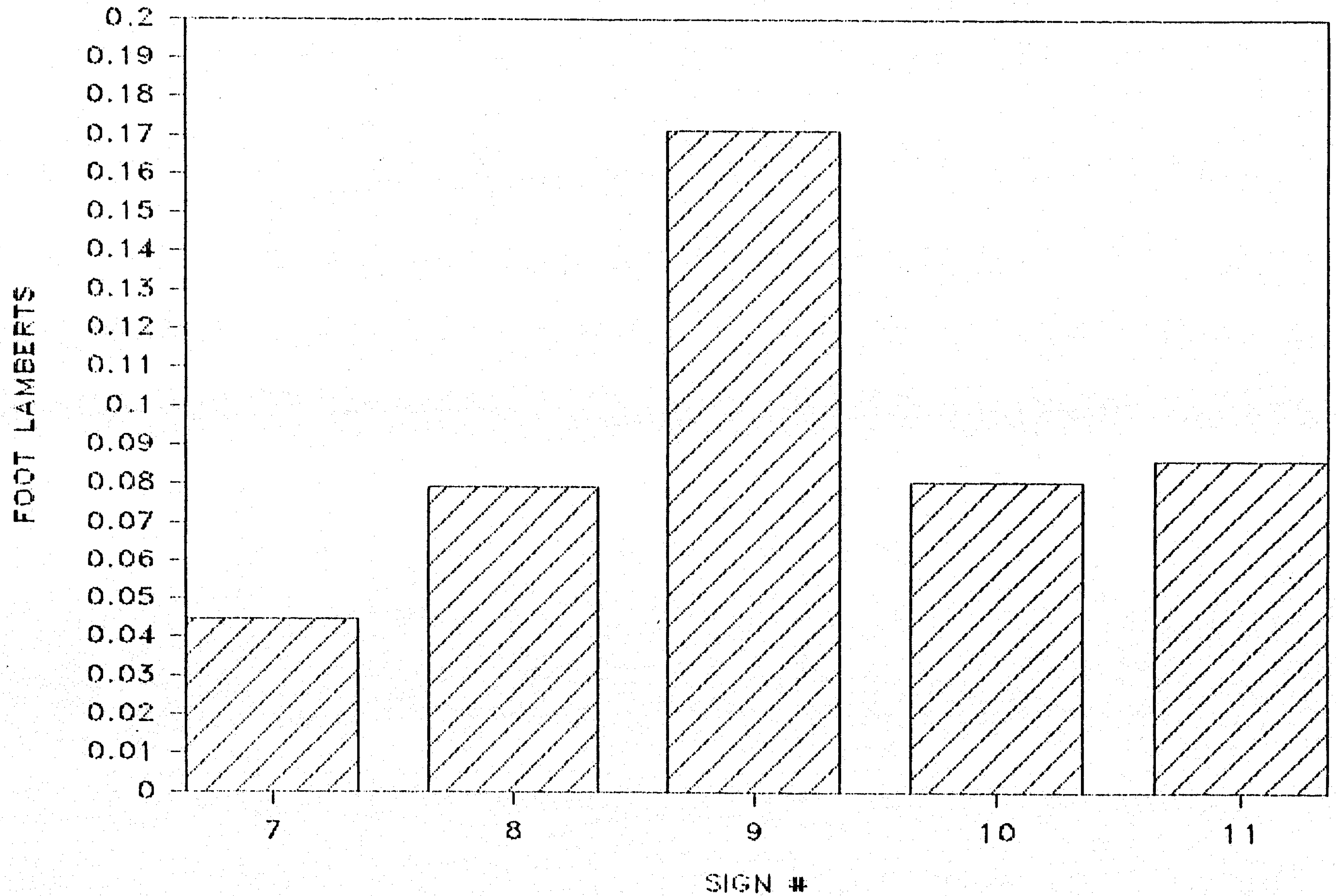


Figure 13. In-use material luminance data, enclosed background, 525 ft, illuminated.

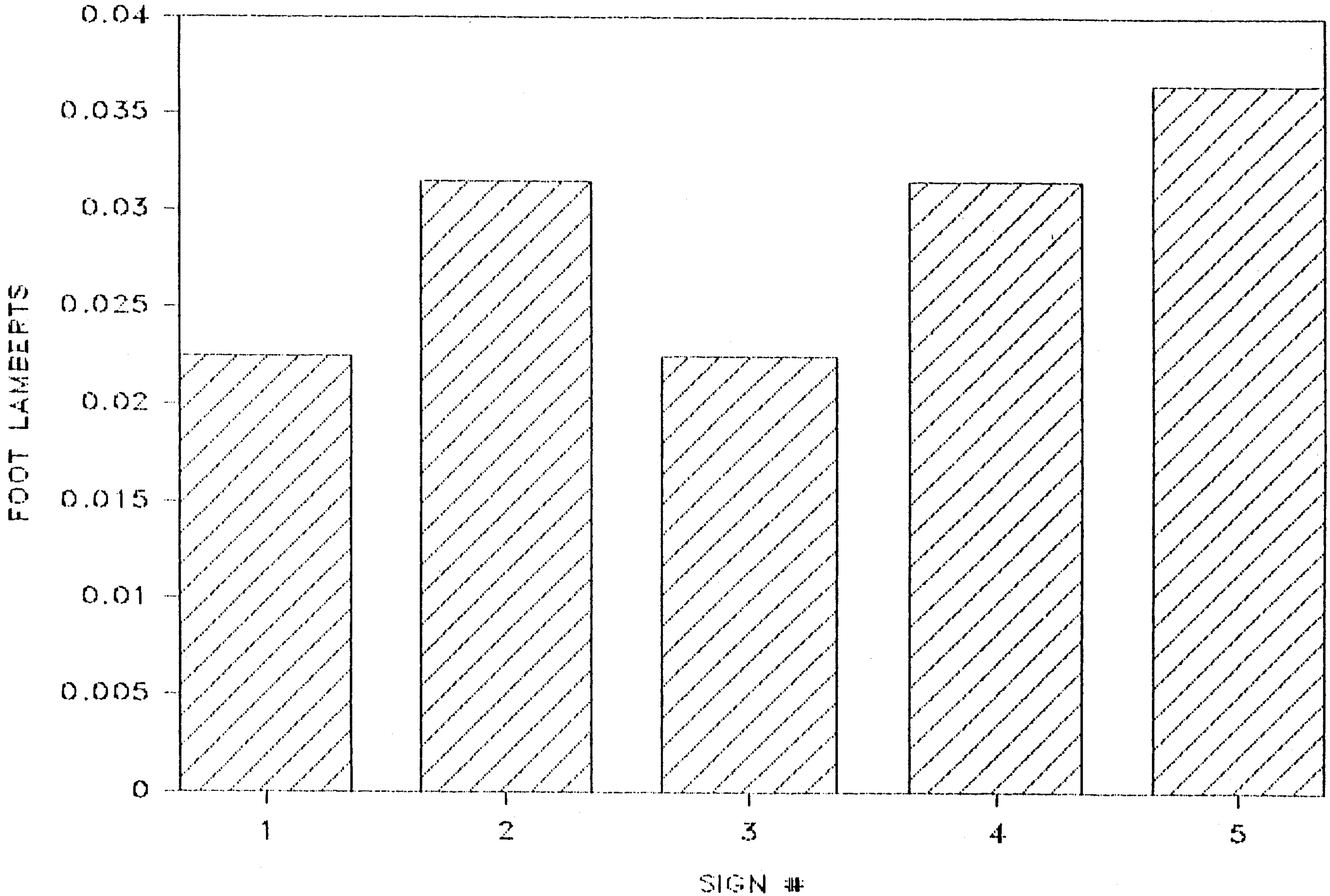


Figure 14. In-use material luminance data, enclosed background, 300 ft.

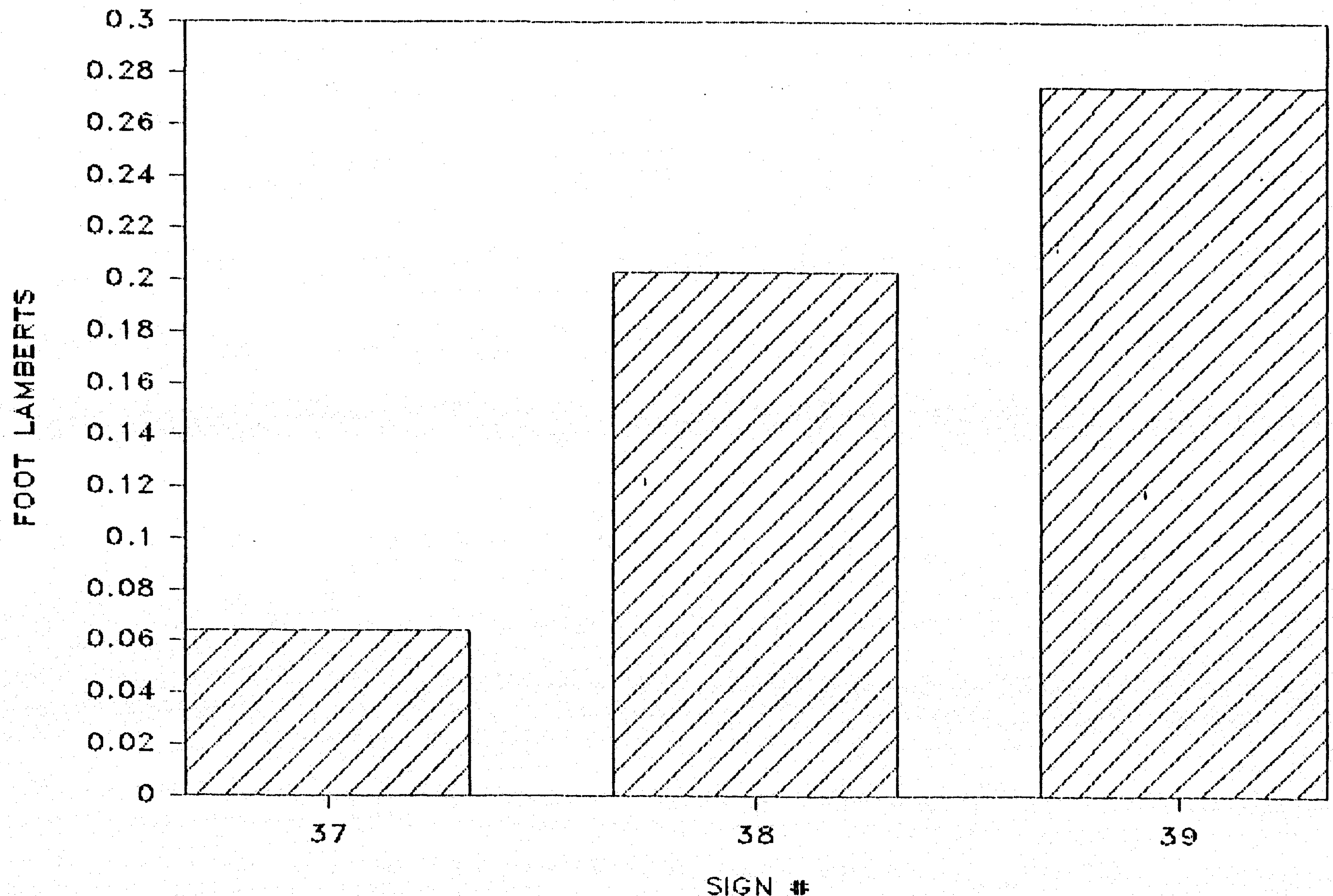


Figure 15. In-use material luminance data, enclosed legend, 2650 ft.

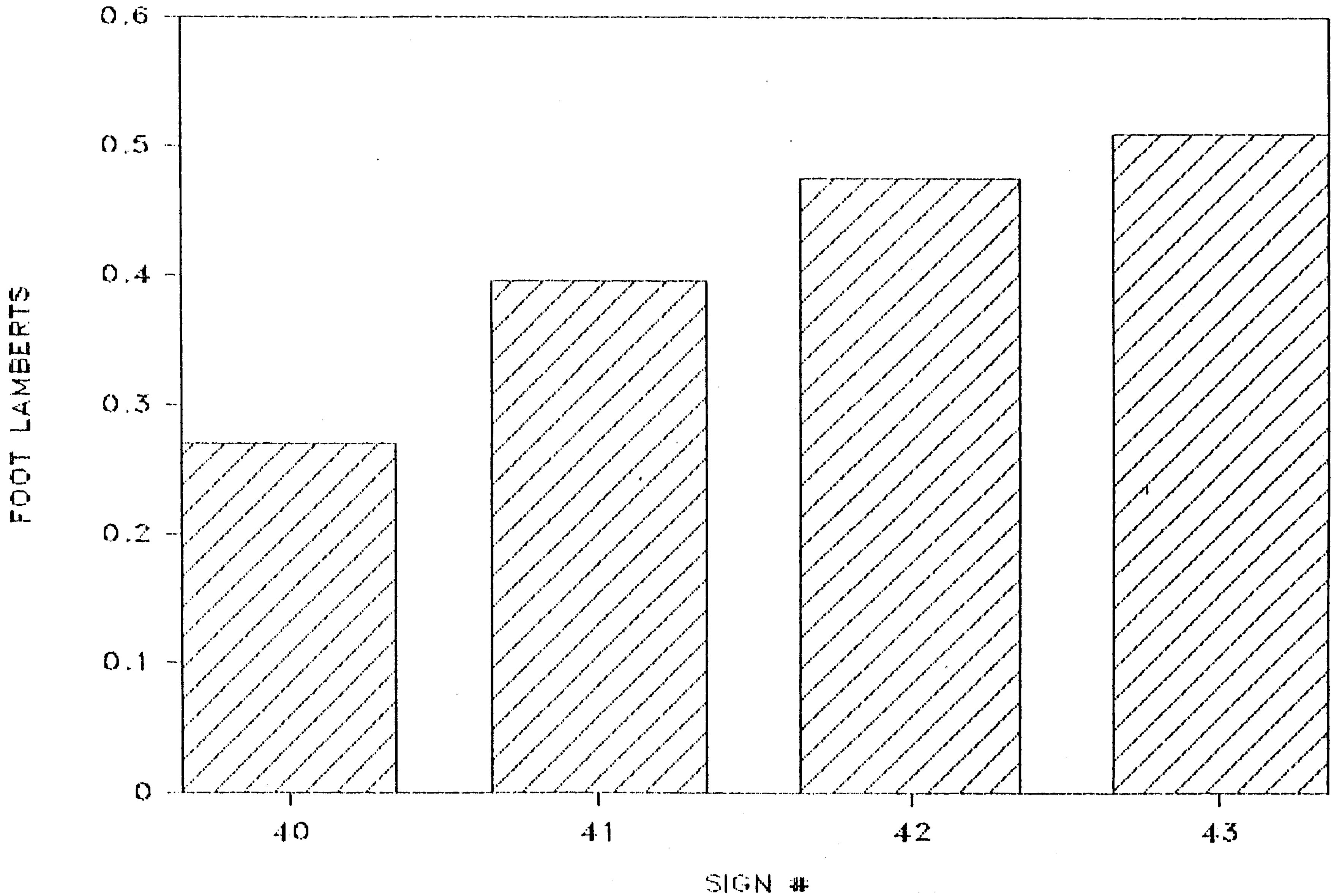


Figure 16. In-use material luminance data, enclosed legend, 2650 ft, illuminated.

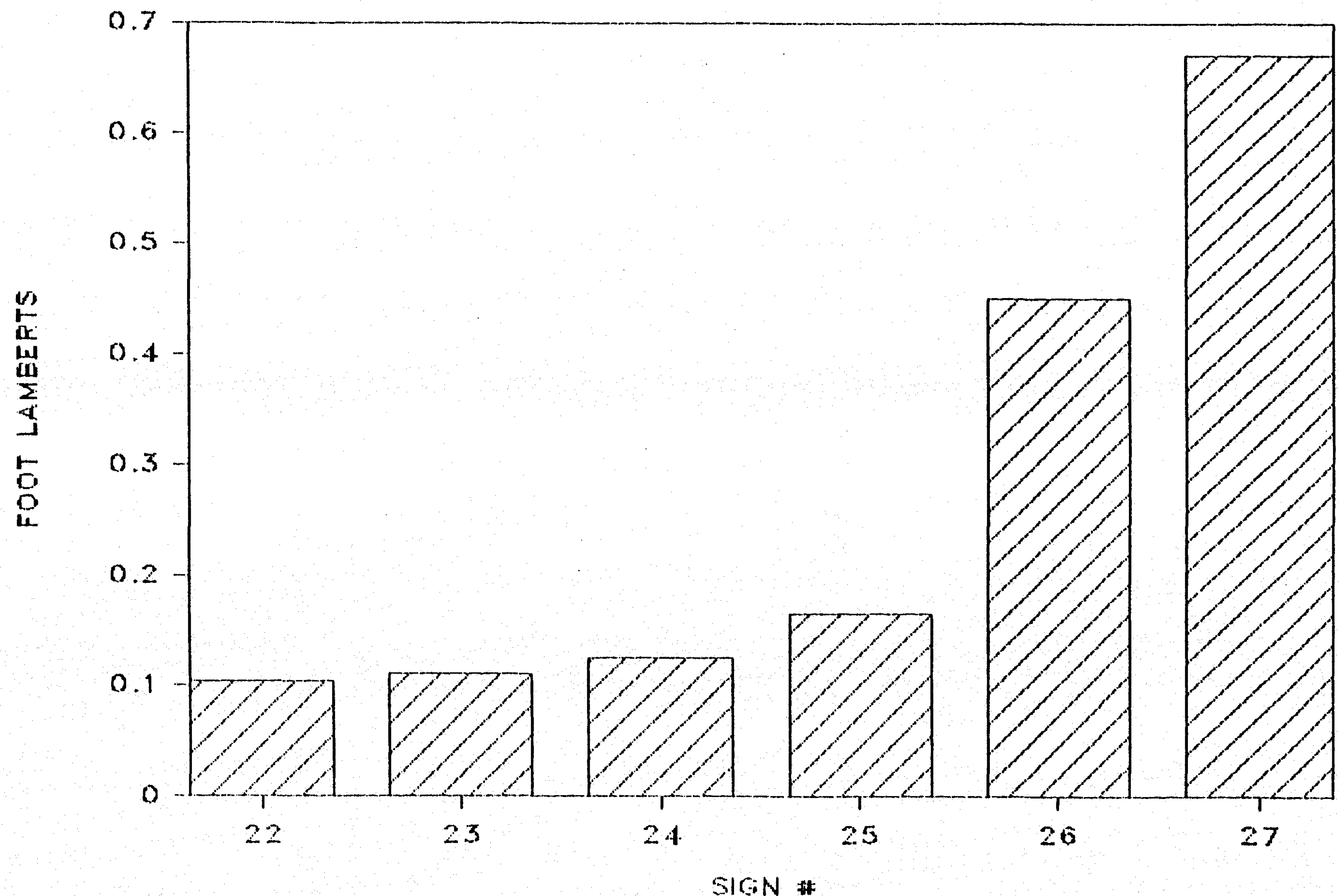


Figure 17. In-use material luminance data, enclosed legend, 1000 ft.

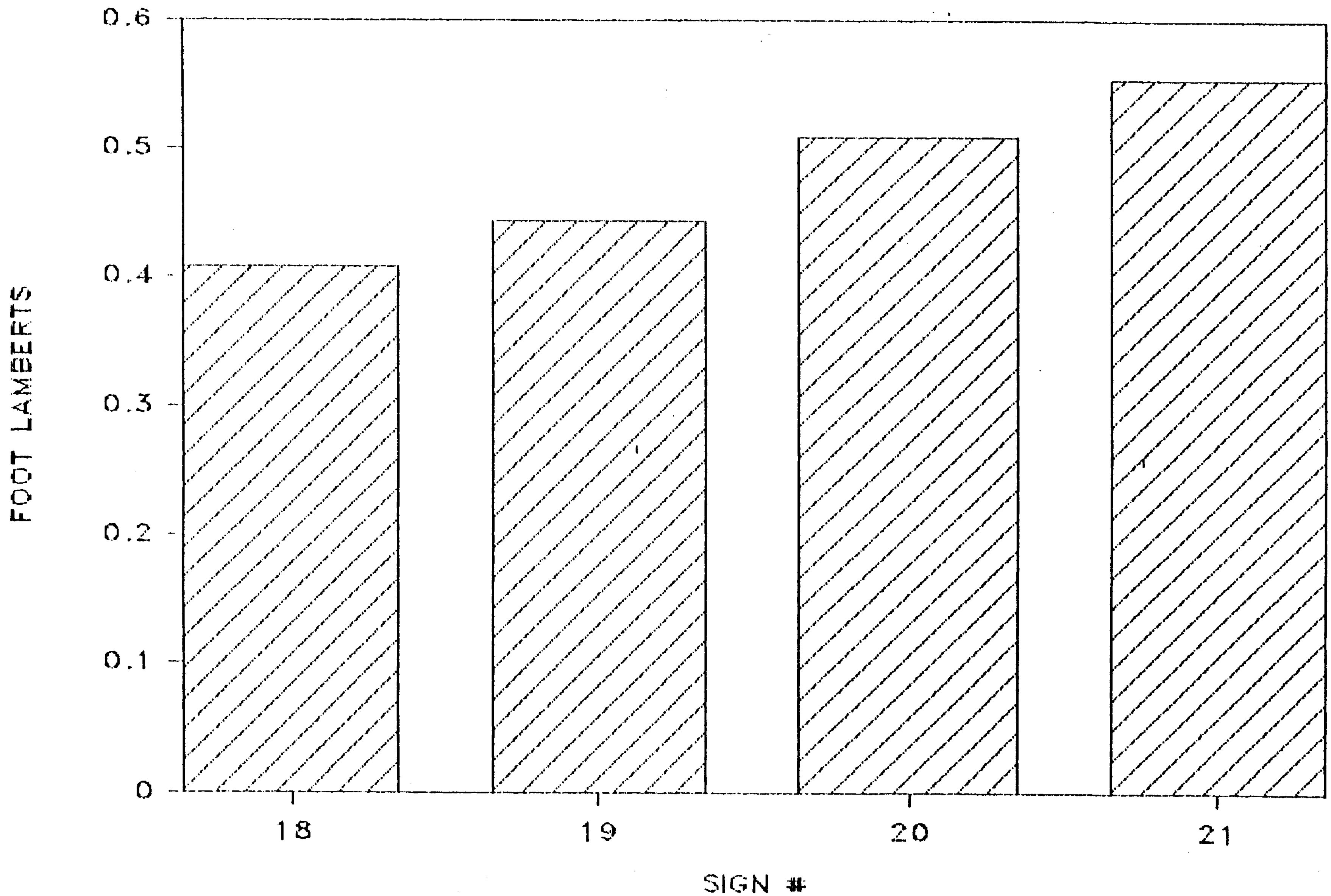


Figure 18. In-use material luminance data, enclosed legend, 800 ft, illuminated.

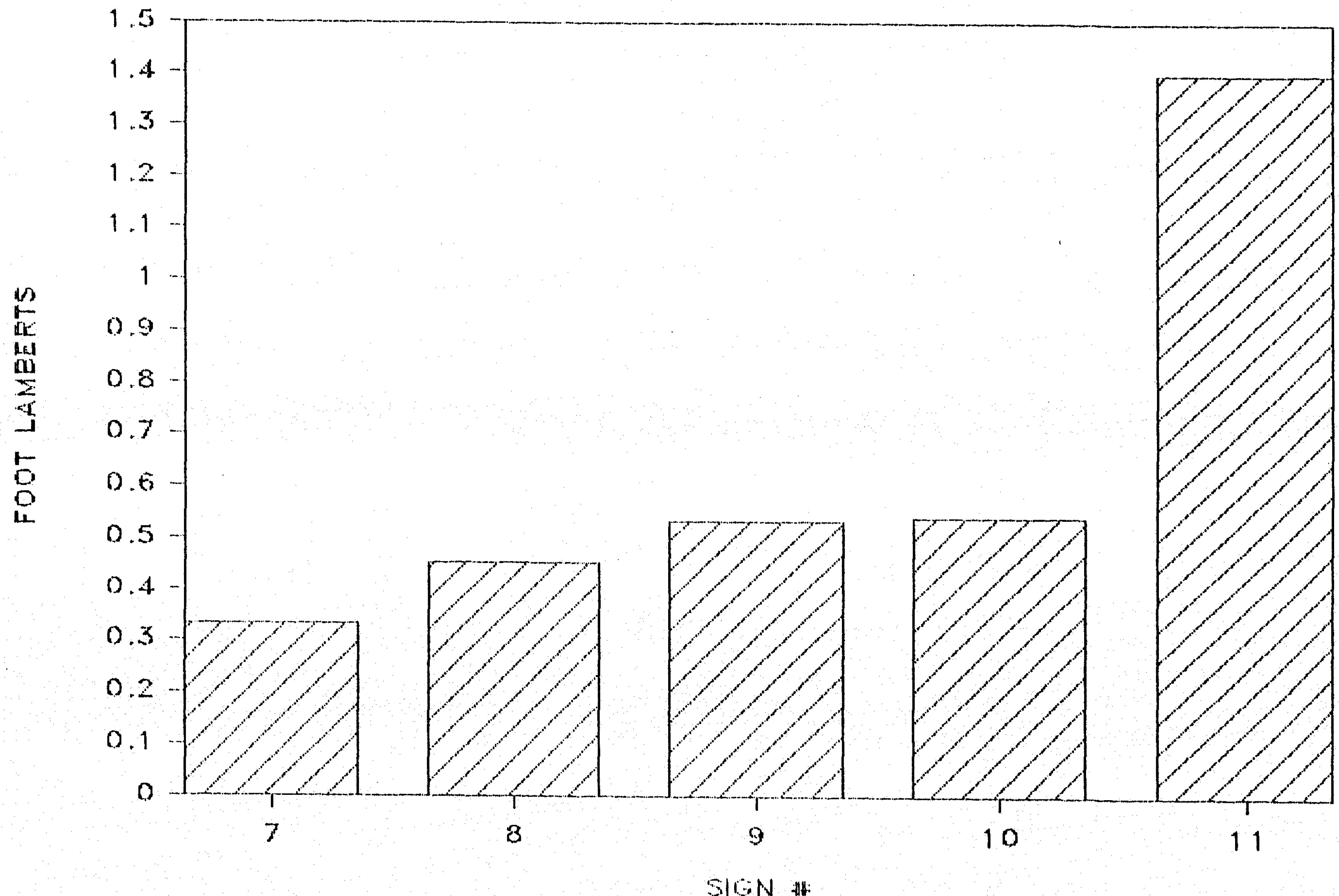


Figure 19. In-use material luminance data, enclosed legend, 525 ft, illuminated.

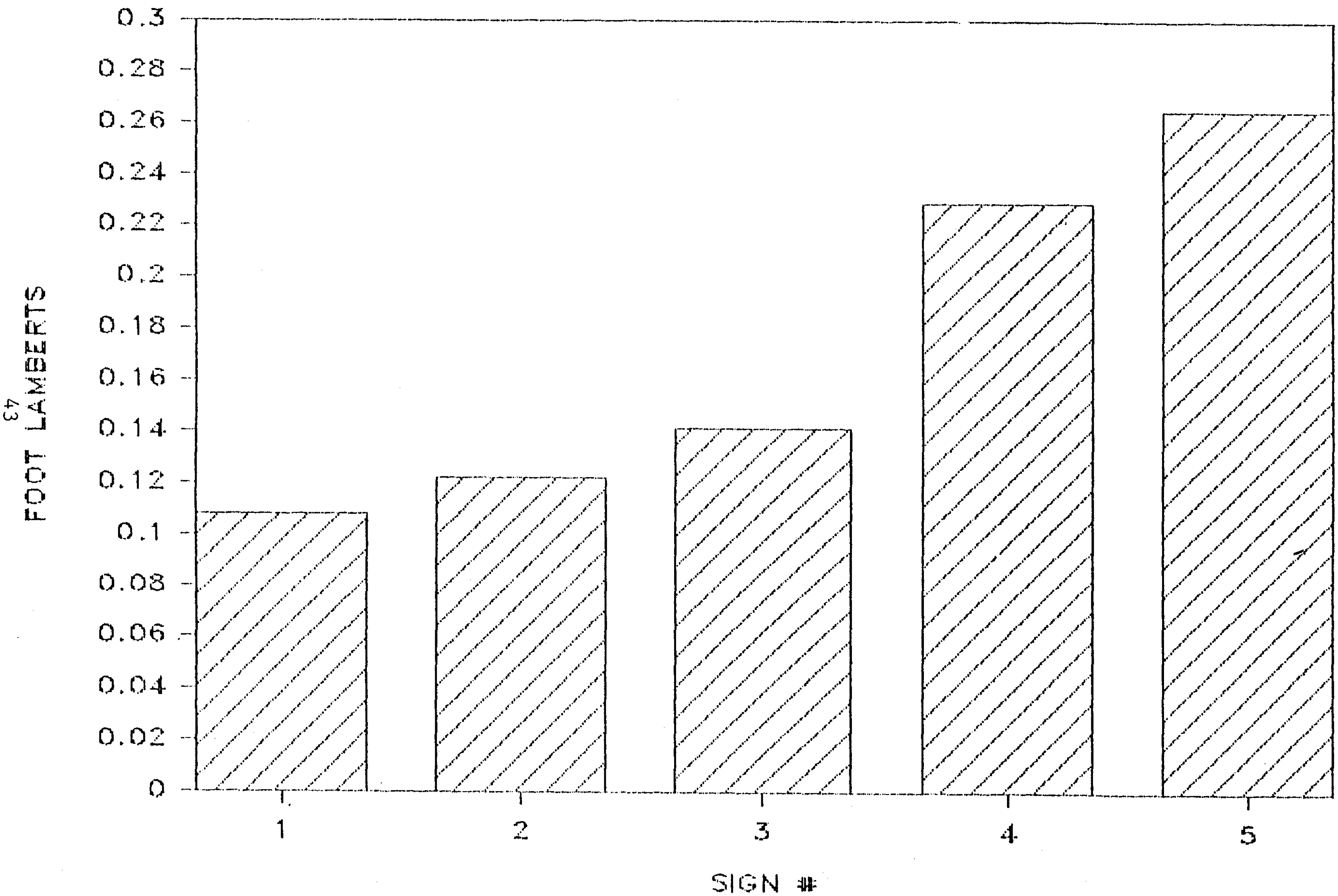


Figure 20. In-use material luminance data, enclosed legend, 300 ft.

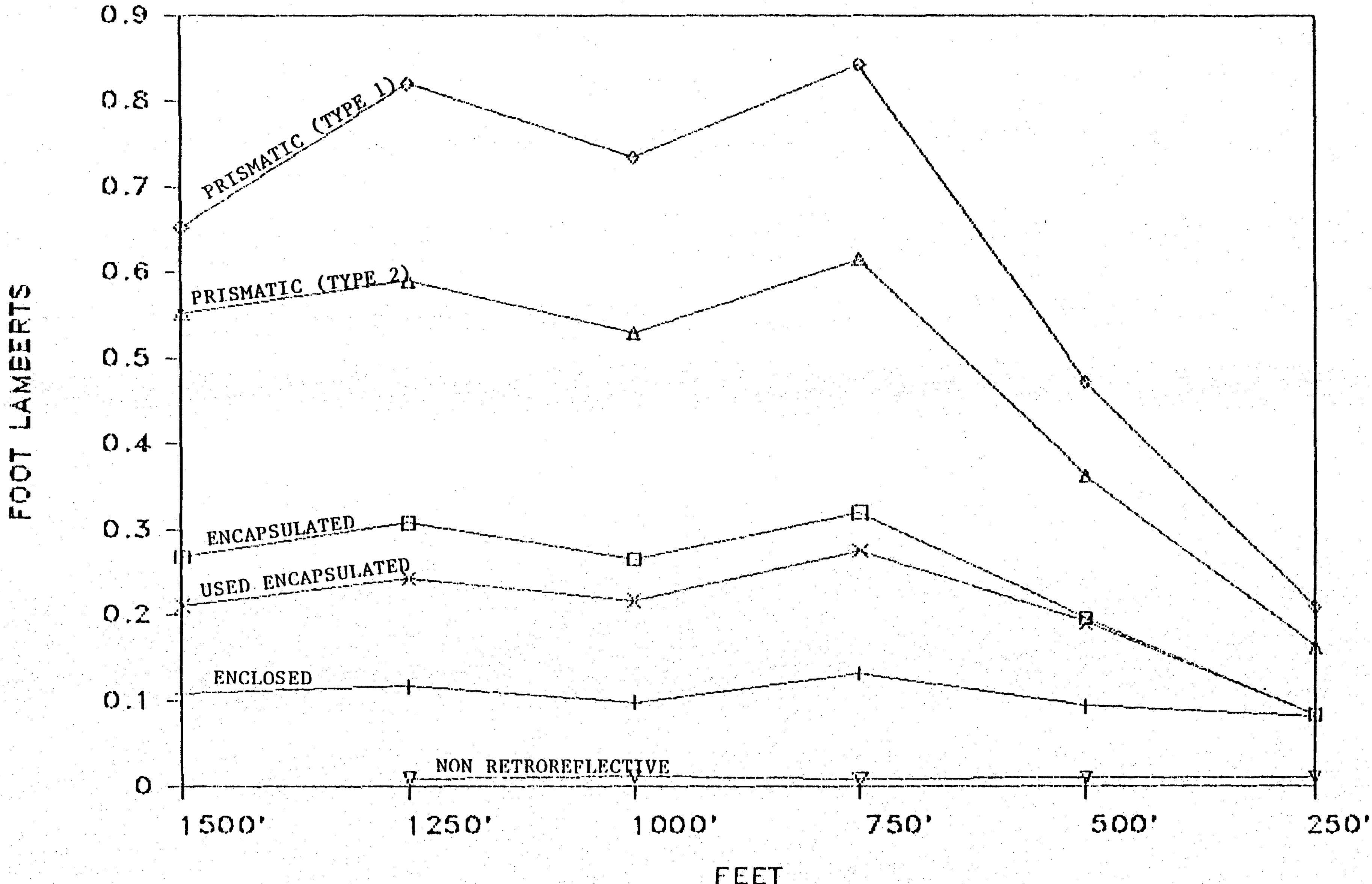


Figure 21. Luminance of new green retroreflective materials under U.S. standard headlamps.

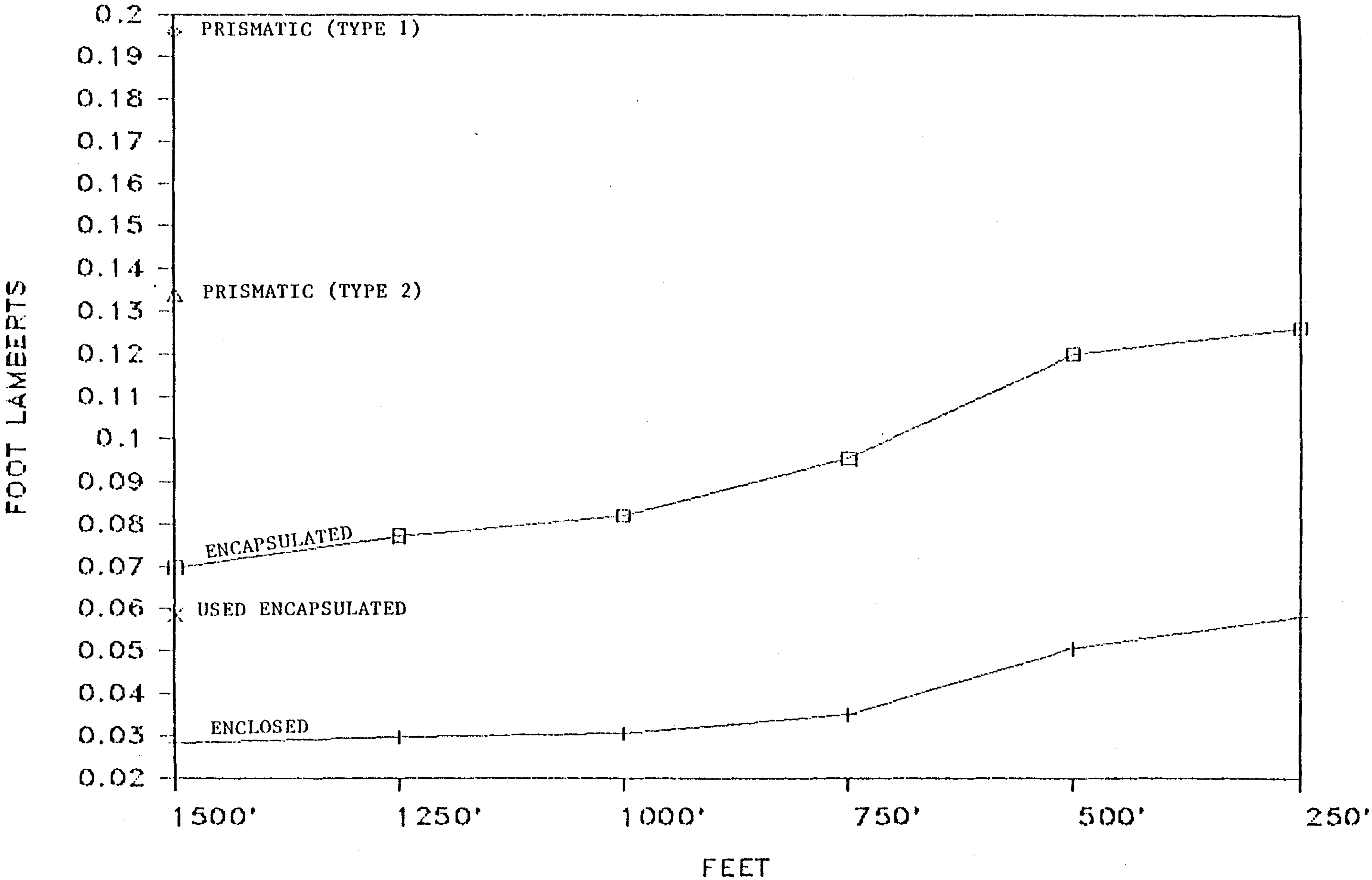


Figure 22. Luminance of new green retroreflective materials under European standard headlamps.

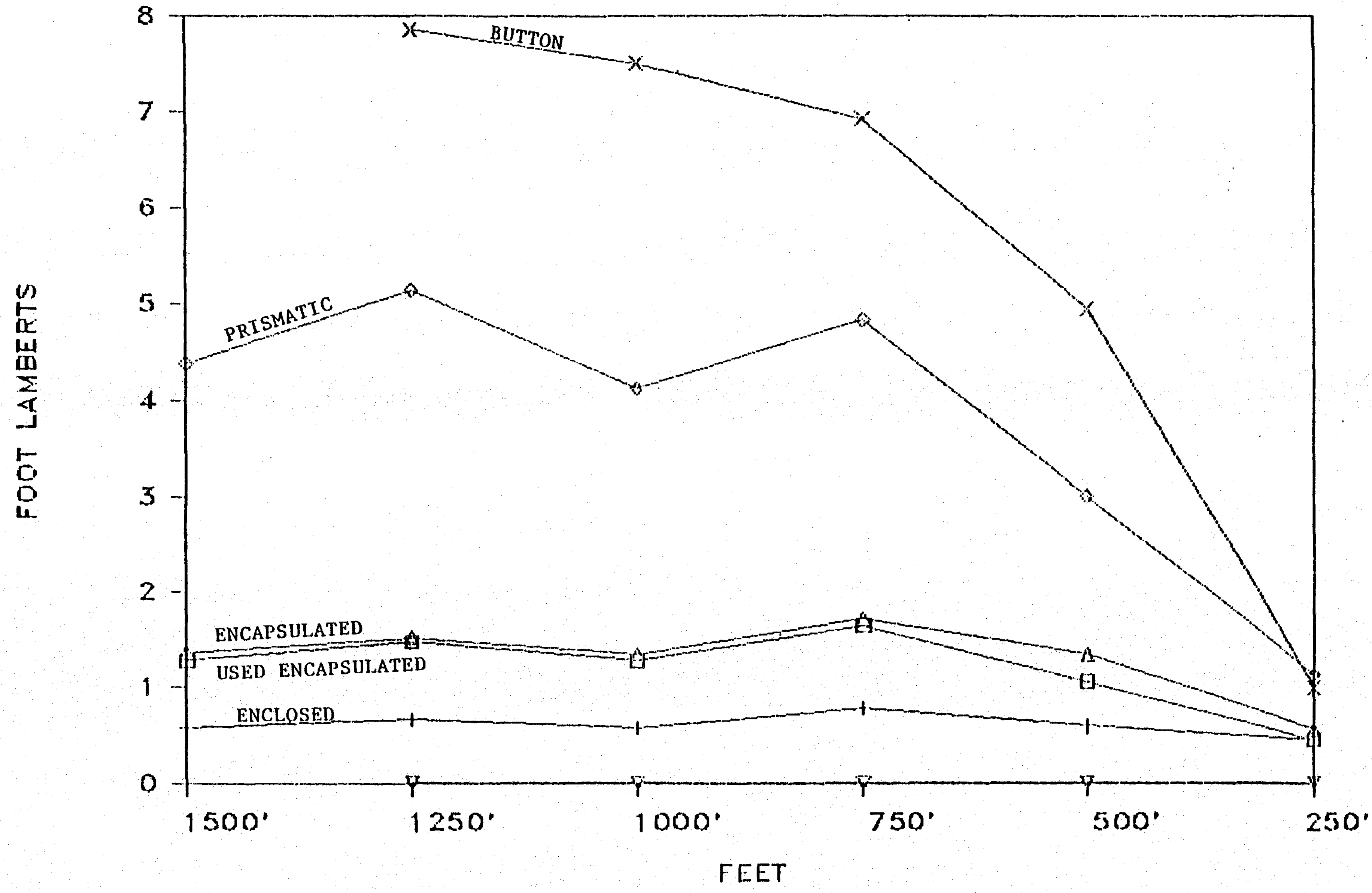


Figure 23. Luminance of new white retroreflective materials under U.S. standard headlamps.

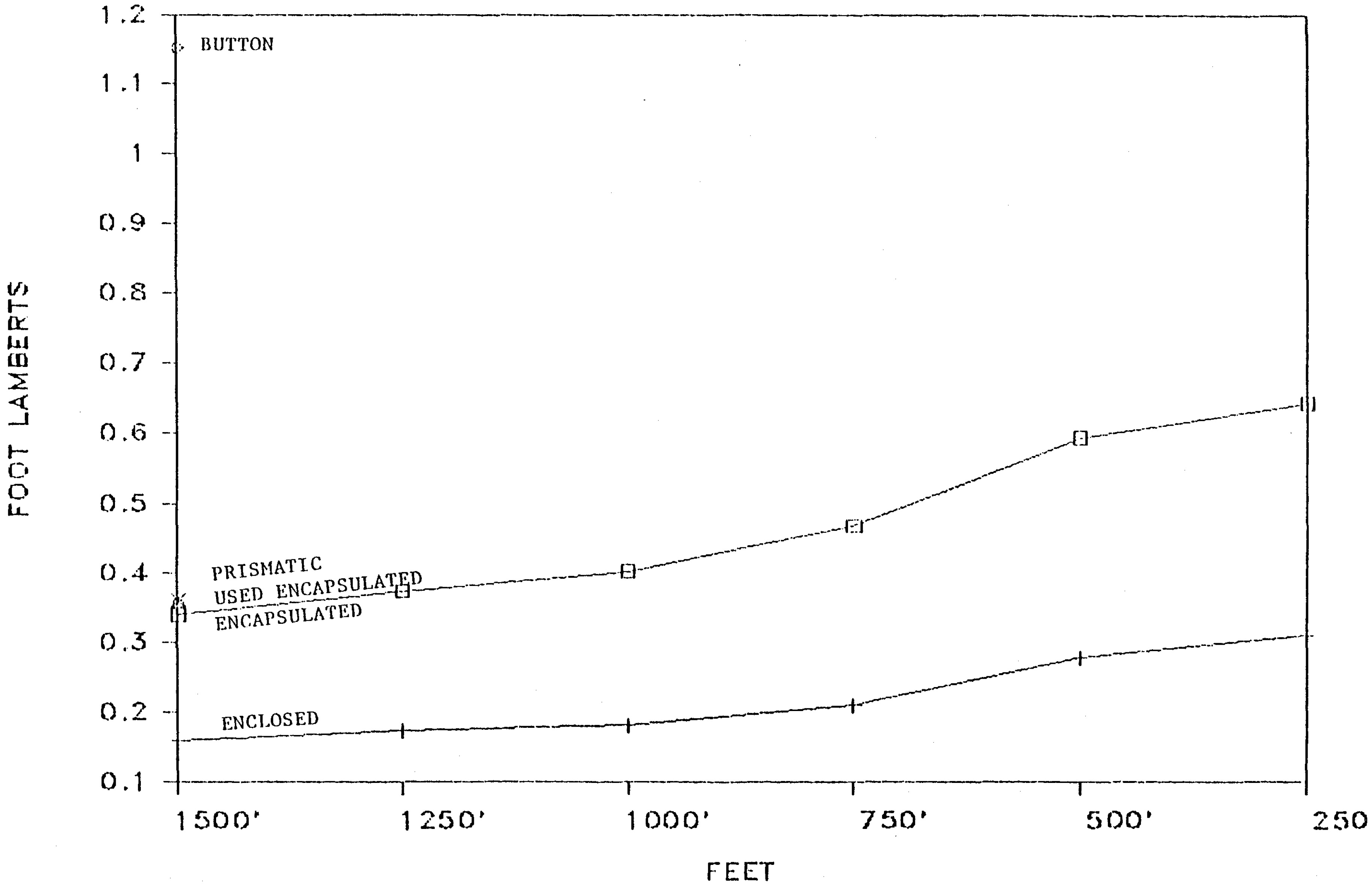


Figure 24. Luminance of new white retroreflective materials under European standard headlamps

APPENDIX C. LABORATORY CONSPICUITY STUDY

Purpose

The laboratory study was developed as a screening tool to help identify situations where drivers may have problems detecting overhead guide signs. In addition, we used these tests to determine the relative effects of color, luminance, background complexity and obscuration on the detection distance of the sign. Use of the static laboratory equipment, described later in this appendix, allowed the testing of a large number of subjects at a reasonable cost.

Stated as null hypotheses, the following statements were tested:

- Background color has no effect on the drivers' detection distance.
- Sign brightness has no effect on the drivers' detection distance.
- Sign obscuration has no effect on the drivers' detection distance.
- Background complexity has no effect on the drivers' detection distance.

Experimental Design

A diagrammatic representation of the experimental design is found in Volume I of this report. Basically, the following overhead guide sign variables were tested:

- Three colors: green, gray and black.
- Three luminance levels -
    - Green and gray backgrounds at equal background luminances approximating encapsulated lens materials (identified as "bright").
    - A green background at a luminance 60 percent of the bright luminance (identified as "dim").
    - A black background at a luminance 45 percent of the bright luminance.

- Four levels of sign obscuration: none, one-third, two-thirds, and full (where no sign was presented).

- In addition to the above sign variables, three levels of background complexity were tested: "low" which was a typical rural scene, "medium" which was typical of scenes found in suburban areas; and "high" which was a typical urban scene.

In the design, the color and luminance variables were collapsed as indicated above. In the real world, signs appear either green or black, but an additional color was required to test the effect of color as an aid to detection. The possible outcomes of the tests could indicate that:

- Color alone is responsible for improved sign detection.

- Luminance alone is responsible for improved sign detection.

- An interaction of color and luminance is responsible for any improvement.

To separate the variables it was only necessary to rank order the signs. If the first statement were true then green signs would perform best. If the second statement were true then the bright green and gray signs would perform equally, and would be detected at further distances. Finally, if the combination of the elements is needed, then the bright green sign will be better than the gray one, which will be followed in turn by the others.

An incomplete factorial was used because the experimental apparatus was limited to 120 stimulus slides. There were some obvious choices for elimination: the "full" obscuration is really a no-sign condition, and does not need to be presented at each color/luminance level. A list of the test conditions used is found in table 8.

Experimental Apparatus

The tests were conducted using the STI computer controlled slide presentation and data acquisition system. This system uses a micro-computer to control two slide projectors and measures the responses of up to six subjects at a time. A diagrammatic representation of the presentation layout is found in figure 25. This system has the advantages of systematically controlling the presentation of the visual stimuli, efficiently testing a large number of subjects in a relatively short period of time, and storing the data on the analysis computer in the required format. The system includes:

- An IBM-PC compatible computer.
- An interface box for connecting the computer with the joystick controllers and the slide projectors.
- Two Kodak Ektagraphic slide projectors.
- A projection screen.
- Six joystick controllers.

A computer program controls the lamps and advancing mechanisms on the slide projectors. It is also responsible for collecting the response data from the joystick controllers. Response data includes response time from onset of the slide presentation and joystick response. Correctness is calculated by comparing the joystick response with a control file which lists both "correct" and "partially correct" answers.

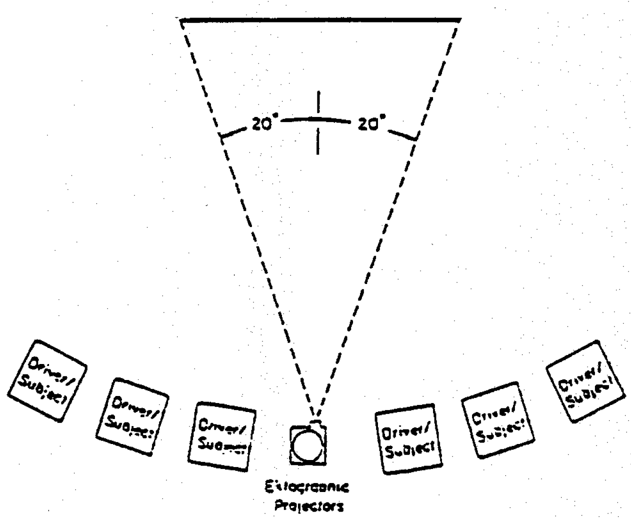


Figure 25. STI computer controlled slide projector data acquisition system.

Stimulus Materials

The stimulus materials for the experiment were 35 mm slides made from several elements. Various interstate highway scenes in the Los Angeles area were photographed. These areas were selected to provide the various background complexities desired. Several backgrounds were selected for each of the desired complexities (ie., rural, suburban and urban) and these were photographed with various levels of traffic. The photographs were taken with a 2-1/4 in format camera located at a typical driver's eye height, and at a location in the traffic lane typical of the driver's seat position. The negatives were enlarged to 16 by 20 in, and provided the "canvas" for the rest of the image.

Several sign legends were developed for the study. They contained information which was designed so that, for a correct response, the driver was required to read the sign. For example, on action signs the word "right" was spelled "rght" so that is was the same length as "left." The specific legends used are found in table 9. The actual signs were made by combining a clear acetate overlay containing the legend and border (in white) and a sample of sign background material. The overlay was placed on the sign background material and the resulting sandwich was photographed on a copy stand. Background colors were green, gray and black. The resulting "sign" was printed at various sizes so that, when placed on the background canvas, it appeared as the correct size for the intended distance.

Sign obscuration was accomplished by placing a truck, or overpass bridge, over the desired portion of the sign. Again photographic images were created which were appropriate in size for the intended distance.

The stimulus slide was created by placing the appropriate images on the background canvas and photographing the image with Polaroid 35 mm slide film. This film was used as it provided green sign backgrounds which almost exactly matched the encapsulated and enclosed lens materials. Slide luminance was determined by measuring the resulting sign image with the Pritchard photometer using the photopic filter. The photopic filter was used as it corrected the measured luminance of the stimulus slide to the color sensitivity of the human eye. As the eye is most sensitive to colors in the green range, use of the filter ensured that differences measured by the photometer would be observed by the subjects.

The brightest green image was chosen to represent the encapsulated lens material, and its actual measurement (without the filter) fell within the boundaries of the Oakland data for encapsulated lens material. The gray background sign luminance was developed to have essentially the same luminance (with the filter) as the bright green sign. This required a measured luminance (without the filter) of almost twice the green value. A dim green sign image was created by controlling the exposure of the sign placed on the canvas so that when the slide was produced the sign was approximately 60 percent the luminance of the bright green sign. The black sign background was similarly created to be 45 percent the luminance of the bright green sign.

Subjects

The subjects for this test were recruited through advertisements placed in newspapers, and on bulletin boards in local grocery stores, laundromats, at the local DMV office, etc. A total of 100 subjects completed the tests. They were equally divided by sex, and further grouped into three age groups: under 25, 25 to 55, and 55 and over.

Each subject was given a visual acuity test in the test apparatus. A modified rambling E eye chart was used, and the subject responded to the figure using the joystick. In general, as age increased, visual acuity decreased, however none of the subjects had corrected vision which was less than a snellen score of 20/40.

Testing

Subjects were tested six at a time. Subjects sat before the screen, joystick in hand, and responded to slides as they were presented. To establish an appropriate mental set, an instruction slide was given prior to a series of stimulus slides. This instruction slide indicated the name of the exit that the subjects were to look for. The subjects' joystick responses were based on the information provided in the stimulus slide. If the stimulus slide had the appropriate exit name, and indicated the direction for exiting (an action sign), the subjects were to move the joystick in the appropriate direction. If the stimulus slide had the appropriate name, and indicated a distance to the exit (an advance information sign), the subjects were to move the joystick forward. If a sign was present in the stimulus slide, but either was not legible or was not the desired exit name, the subjects were instructed to press the button on the joystick. Finally, if no sign was presented in the stimulus slide, the subjects were instructed to move the joystick to the rear. Each subject received training on the system prior to actual testing, and testing was not started until all subjects were performing satisfactorily.

A reward-penalty structure was employed to motivate the subjects' performance. Rewards were given for correct response, and were scaled to the individual response time[2]. The faster the subject responded, the greater the reward. If an incorrect response was recorded the penalty was equal to the maximum possible reward. Thus subjects were able to maximize their reward for responding promptly, but only after they were sure that they were giving a correct response. In addition each subject was paid a participation fee which covered their travel expenses and time.

Results

The major results of these tests are summarized below:

- Color appears to enhance overhead guide sign detection as the green signs out-performed the gray and black signs. This difference was only apparent when the sign was significantly obscured.

- Sign obscuration appears to be the major factor resulting in poor overhead sign detection.

- Background complexity does not have a major effect on overhead guide sign detection.

In addition to the response correctness results presented in Volume I, response time was analyzed for each sign. First, a cumulative plot of response time for correct responses was prepared. Next, the 80th percentile response time was calculated for each of the response plots. The 80th percentile was chosen as it provided more stable response differences than either the 85th or 90th percentile data. These times were compared and provide further support for the above conclusions. Copies of each of the response plots are found as figures 26 to 145.

---

2 Response time in the laboratory experiment was measured by determining the time from presentation of the slide until the subject moved the joystick.

Table 8. Experimental test conditions.

DISTANCE	SIGN MATERIAL	SIGN PRESENCE	BACKGROUND COMPLEXITY	ILLUMINATION	FIGURE NUMBER
700'	--	NONE	LOW	NO	26
700'	--	NONE	DISTRACTION	NO	27
700'	--	NONE	DISTRACTION	NO	28
700'	--	NONE	CLUTTER	NO	29
700'	--	NONE	HIGH	NO	30
700'	--	NONE	HIGH	NO	31
700'	ENCPS/ENCPS	2/3 OBSTR	HIGH	NO	32
700'	ENCPS/ENCL	2/3 OBSTR	HIGH	NO	33
700'	BUT/NRETRO	2/3 OBSTR	HIGH	NO	34
700'	ENCPS/ENCPS	2/3 OBSTR	HIGH	YES	35
700'	ENCPS/ENCPS	1/3 OBSTR	HIGH	NO	36
700'	ENCPS/ENCL	1/3 OBSTR	HIGH	NO	37
700'	BUT/NRETRO	1/3 OBSTR	HIGH	NO	38
700'	ENCPS/ENCPS	1/3 OBSTR	HIGH	YES	39
700'	ENCPS/ENCPS	FULL	LOW	NO	40
700'	ENCPS/ENCL	FULL	LOW	NO	41
700'	BUT/NRETRO	FULL	LOW	NO	42
700'	ENCPS/ENCPS	FULL	LOW	YES	43
700'	ENCPS/ENCPS	FULL	DISTRACTION	NO	44
700'	ENCPS/ENCL	FULL	DISTRACTION	NO	45
700'	BUT/NRETRO	FULL	DISTRACTION	NO	46
700'	ENCPS/ENCPS	FULL	DISTRACTION	YES	47
700'	ENCPS/ENCPS	FULL	CLUTTER	NO	48
700'	ENCPS/ENCL	FULL	CLUTTER	NO	49
700'	BUT/NRETRO	FULL	CLUTTER	NO	50
700'	ENCPS/ENCPS	FULL	CLUTTER	YES	51
700'	ENCPS/ENCPS	FULL	HIGH	NO	52
700'	ENCPS/ENCL	FULL	HIGH	NO	53
700'	BUT/NRETRO	FULL	HIGH	NO	54
700'	ENCPS/ENCPS	FULL	HIGH	YES	55
1000'	--	NONE	LOW	NO	56
1000'	--	NONE	DISTRACTION	NO	57
1000'	--	NONE	DISTRACTION	NO	58
1000'	--	NONE	CLUTTER	NO	59
1000'	--	NONE	HIGH	NO	60
1000'	--	NONE	HIGH	NO	61
1000'	ENCPS/ENCPS	2/3 OBSTR	HIGH	NO	62
1000'	ENCPS/ENCL	2/3 OBSTR	HIGH	NO	63
1000'	BUT/NRETRO	2/3 OBSTR	HIGH	NO	64
1000'	ENCPS/ENCPS	2/3 OBSTR	HIGH	YES	65
1000'	ENCPS/ENCPS	1/3 OBSTR	HIGH	NO	66
1000'	ENCPS/ENCL	1/3 OBSTR	HIGH	NO	67
1000'	BUT/NRETRO	1/3 OBSTR	HIGH	NO	68
1000'	ENCPS/ENCPS	1/3 OBSTR	HIGH	YES	69
1000'	ENCPS/ENCPS	FULL	LOW	NO	70
1000'	ENCPS/ENCL	FULL	LOW	NO	71
1000'	BUT/NRETRO	FULL	LOW	NO	72
1000'	ENCPS/ENCPS	FULL	LOW	YES	73
1000'	ENCPS/ENCPS	FULL	DISTRACTION	NO	74
1000'	ENCPS/ENCL	FULL	DISTRACTION	NO	75
1000'	BUT/NRETRO	FULL	DISTRACTION	NO	76
1000'	ENCPS/ENCPS	FULL	DISTRACTION	YES	77
1000'	ENCPS/ENCPS	FULL	CLUTTER	NO	78
1000'	ENCPS/ENCL	FULL	CLUTTER	NO	79
1000'	BUT/NRETRO	FULL	CLUTTER	NO	80
1000'	ENCPS/ENCPS	FULL	CLUTTER	YES	81
1000'	ENCPS/ENCPS	FULL	HIGH	NO	82
1000'	ENCPS/ENCL	FULL	HIGH	NO	83
1000'	BUT/NRETRO	FULL	HIGH	NO	84
1000'	ENCPS/ENCPS	FULL	HIGH	YES	85

Table 8. Experimental test conditions (continued).

DISTANCE	SIGN MATERIAL	SIGN PRESENCE	BACKGROUND COMPLEXITY	ILLUMINATION	FIGURE NUMBER
1300'	--	NONE	LOW	NO	86
1300'	--	NONE	DISTRACTION	NO	87
1300'	--	NONE	DISTRACTION	NO	88
1300'	--	NONE	CLUTTER	NO	89
1300'	--	NONE	HIGH	NO	90
1300'	--	NONE	HIGH	NO	91
1300'	ENCPS/ENCPS	2/3 OBSTR	HIGH	NO	92
1300'	ENCPS/ENCL	2/3 OBSTR	HIGH	NO	93
1300'	BUT/NRETRO	2/3 OBSTR	HIGH	NO	94
1300'	ENCPS/ENCPS	2/3 OBSTR	HIGH	YES	95
1300'	ENCPS/ENCPS	1/3 OBSTR	HIGH	NO	96
1300'	ENCPS/ENCL	1/3 OBSTR	HIGH	NO	97
1300'	BUT/NRETRO	1/3 OBSTR	HIGH	NO	98
1300'	ENCPS/ENCPS	1/3 OBSTR	HIGH	YES	99
1300'	ENCPS/ENCPS	FULL	LOW	NO	100
1300'	ENCPS/ENCL	FULL	LOW	NO	101
1300'	BUT/NRETRO	FULL	LOW	NO	102
1300'	ENCPS/ENCPS	FULL	LOW	YES	103
1300'	ENCPS/ENCPS	FULL	DISTRACTION	NO	104
1300'	ENCPS/ENCL	FULL	DISTRACTION	NO	105
1300'	BUT/NRETRO	FULL	DISTRACTION	NO	106
1300'	ENCPS/ENCPS	FULL	DISTRACTION	YES	107
1300'	ENCPS/ENCPS	FULL	CLUTTER	NO	108
1300'	ENCPS/ENCL	FULL	CLUTTER	NO	109
1300'	BUT/NRETRO	FULL	CLUTTER	NO	110
1300'	ENCPS/ENCPS	FULL	CLUTTER	YES	111
1300'	ENCPS/ENCPS	FULL	HIGH	NO	112
1300'	ENCPS/ENCL	FULL	HIGH	NO	113
1300'	BUT/NRETRO	FULL	HIGH	NO	114
1300'	ENCPS/ENCPS	FULL	HIGH	YES	115
1600'	--	NONE	LOW	NO	116
1600'	--	NONE	DISTRACTION	NO	117
1600'	--	NONE	DISTRACTION	NO	118
1600'	--	NONE	CLUTTER	NO	119
1600'	--	NONE	HIGH	NO	120
1600'	--	NONE	HIGH	NO	121
1600'	ENCPS/ENCPS	2/3 OBSTR	HIGH	NO	122
1600'	ENCPS/ENCL	2/3 OBSTR	HIGH	NO	123
1600'	BUT/NRETRO	2/3 OBSTR	HIGH	NO	124
1600'	ENCPS/ENCPS	2/3 OBSTR	HIGH	YES	125
1600'	ENCPS/ENCPS	1/3 OBSTR	HIGH	NO	126
1600'	ENCPS/ENCL	1/3 OBSTR	HIGH	NO	127
1600'	BUT/NRETRO	1/3 OBSTR	HIGH	NO	128
1600'	ENCPS/ENCPS	1/3 OBSTR	HIGH	YES	129
1600'	ENCPS/ENCPS	FULL	LOW	NO	130
1600'	ENCPS/ENCL	FULL	LOW	NO	131
1600'	BUT/NRETRO	FULL	LOW	NO	132
1600'	ENCPS/ENCPS	FULL	LOW	YES	133
1600'	ENCPS/ENCPS	FULL	DISTRACTION	NO	134
1600'	ENCPS/ENCL	FULL	DISTRACTION	NO	135
1600'	BUT/NRETRO	FULL	DISTRACTION	NO	136
1600'	ENCPS/ENCPS	FULL	DISTRACTION	YES	137
1600'	ENCPS/ENCPS	FULL	CLUTTER	NO	138
1600'	ENCPS/ENCL	FULL	CLUTTER	NO	139
1600'	BUT/NRETRO	FULL	CLUTTER	NO	140
1600'	ENCPS/ENCPS	FULL	CLUTTER	YES	141
1600'	ENCPS/ENCPS	FULL	HIGH	NO	142
1600'	ENCPS/ENCL	FULL	HIGH	NO	143
1600'	BUT/NRETRO	FULL	HIGH	NO	144
1600'	ENCPS/ENCPS	FULL	HIGH	YES	145

Table 9. Experiment sign legends.

Kettle Dr 1 Hilton Ave 2 Pinon Hwy 3	Pinon Hwy RGHT EXIT
Hilton Ave 1 Pinon Hwy 2 Haida Dr 3	Pinon Hwy LEFT EXIT
Pinon Hwy 1 Haida Dr 2 Center St 3	Harbor Rd RGHT EXIT
Harken Rd 1 Harold Rd 2 Harbor Rd 3	Harbor Rd LEFT EXIT
Dundee St 1/4 Collins Ave 1 Dunkirk Dr 1 1/2	Brice St RGHT EXIT

Table 9. Experiment sign legends (continued).

Bruce St	1/2
Grant Dr	3
Elmwood Dr	3 1/2

Brice St
LEFT EXIT

Brice St	1/2
Arden Ave	1
Hudson Br	1 1/2

Taylor Rd
RGHT EXIT

Moody Dr	1
White Blvd	2
Ogden Ave	3

Taylor St
LEFT EXIT

Trevor Ln	3
Riverview Rd	4
Ash St	5

Walton St
RGHT EXIT

Taylor Rd	4
Birch Ave	5
Carmen St	6

Walton St
LEFT EXIT

Table 9. Experiment sign legends (continued).

```
Sydney Ave      1
Latimer Rd      2
Hillside Ave    3
```

```
Bruce St
RGHT EXIT
```

```
Heron Ave       1
Lagamorph Ln    2
Parrot Rd       3
```

```
Heron Ave
RGHT EXIT
```

```
Egret St        1
Colobus Ave     2
Lemur St        3
```

```
Bruce St
LEFT EXIT
```

```
Heron Ave
LEFT EXIT
```

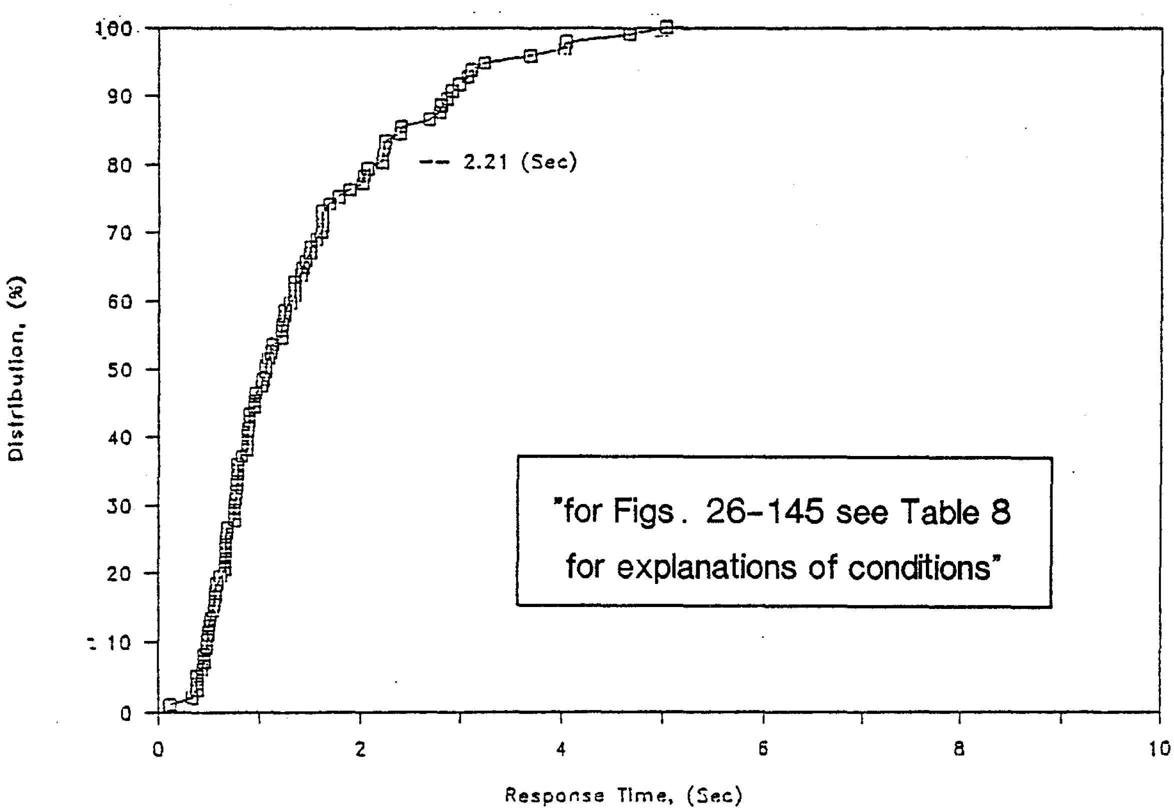


Figure 26. Distribution of correct responses, stimulus slide 1.

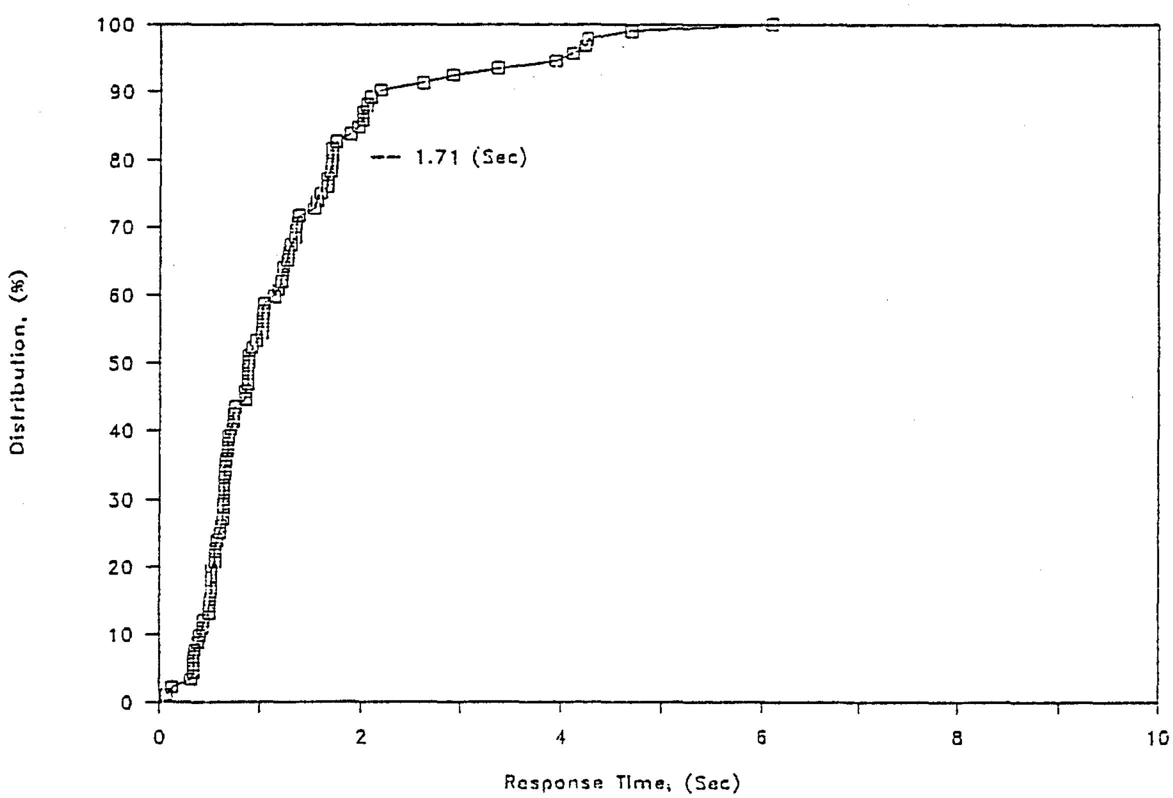


Figure 27. Distribution of correct responses, stimulus slide 2.

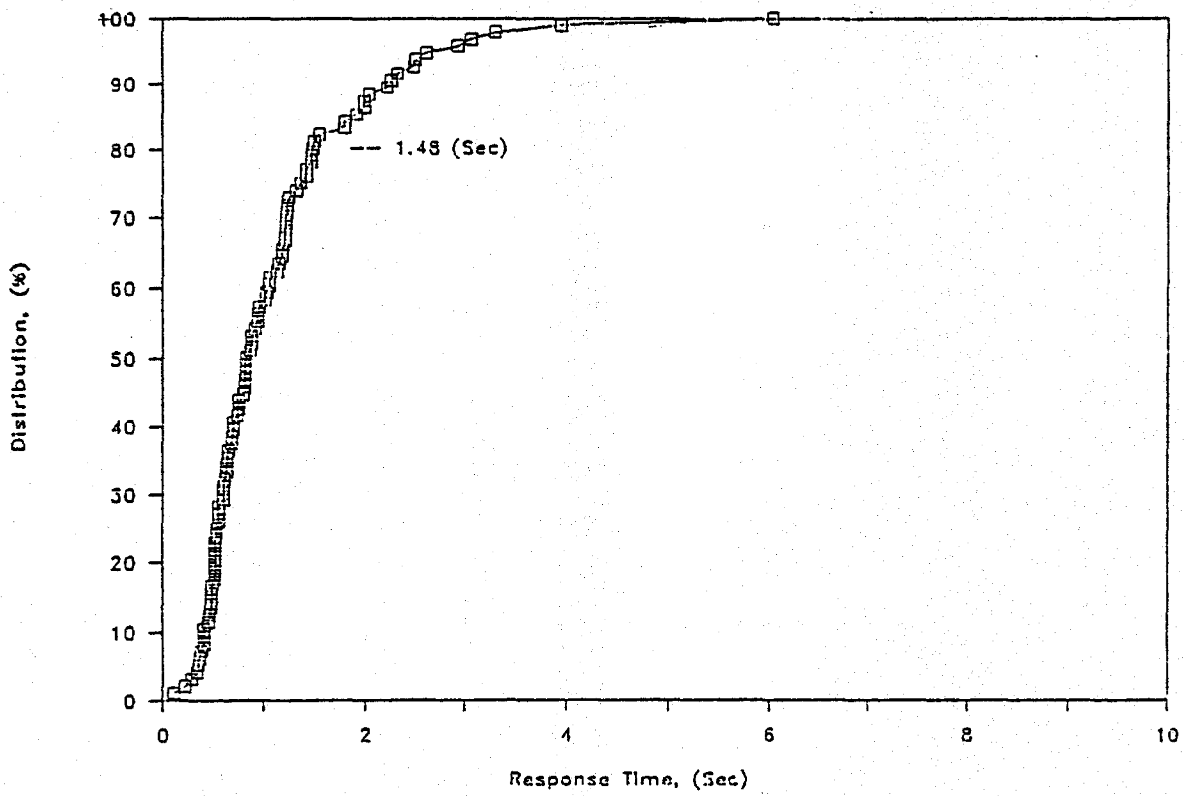


Figure 28. Distribution of correct responses, stimulus slide 3.

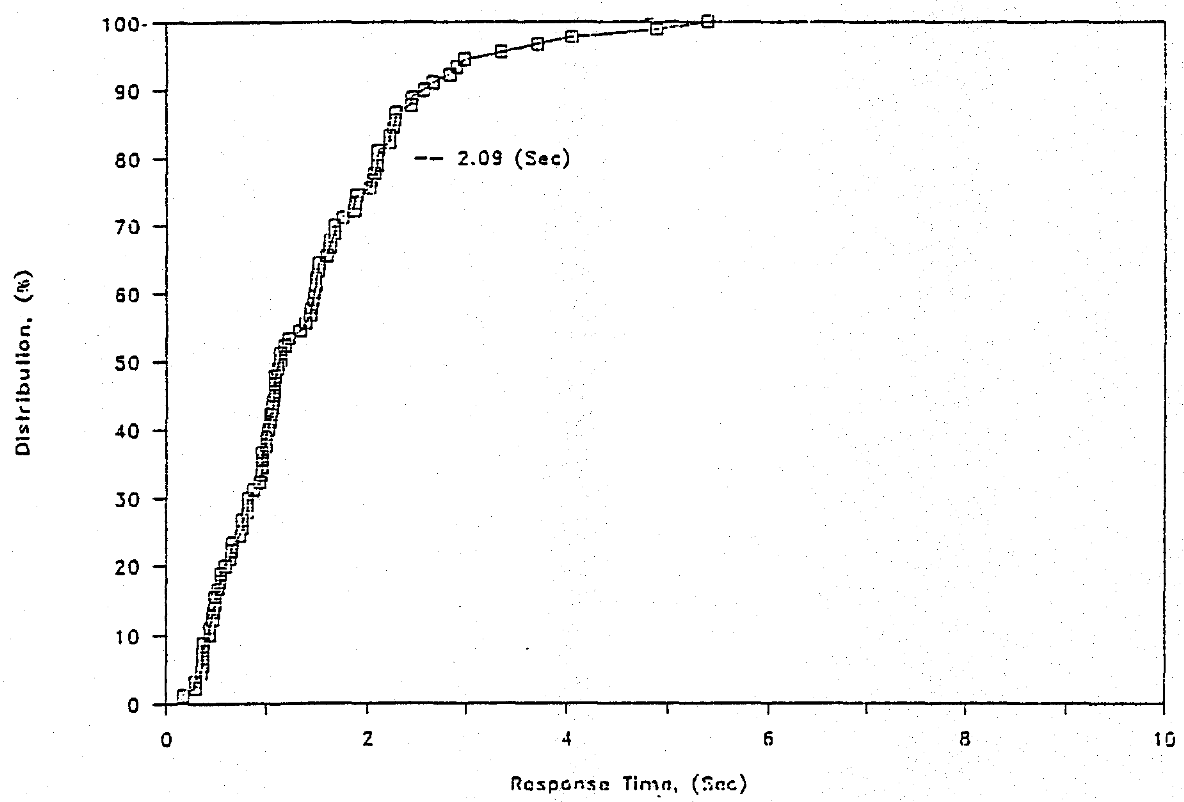


Figure 29. Distribution of correct responses, stimulus slide 4.

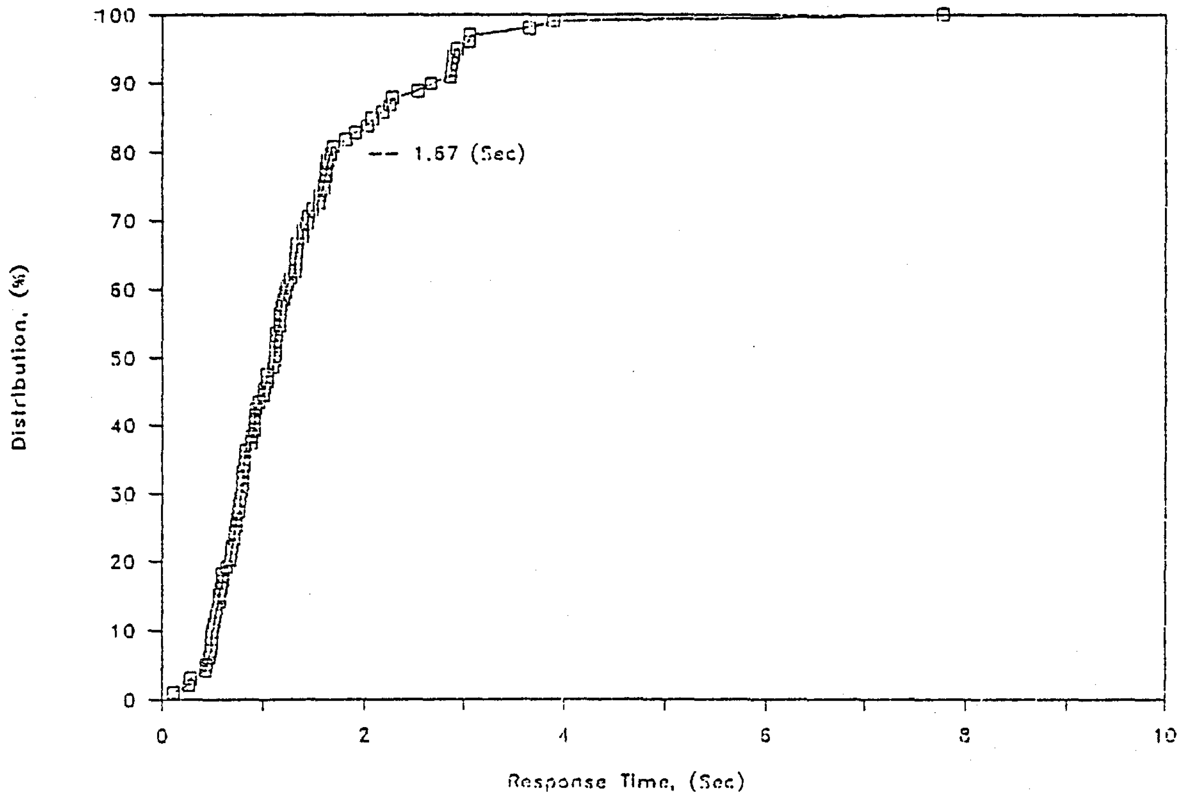


Figure 30. Distribution of correct responses, stimulus slide 5.

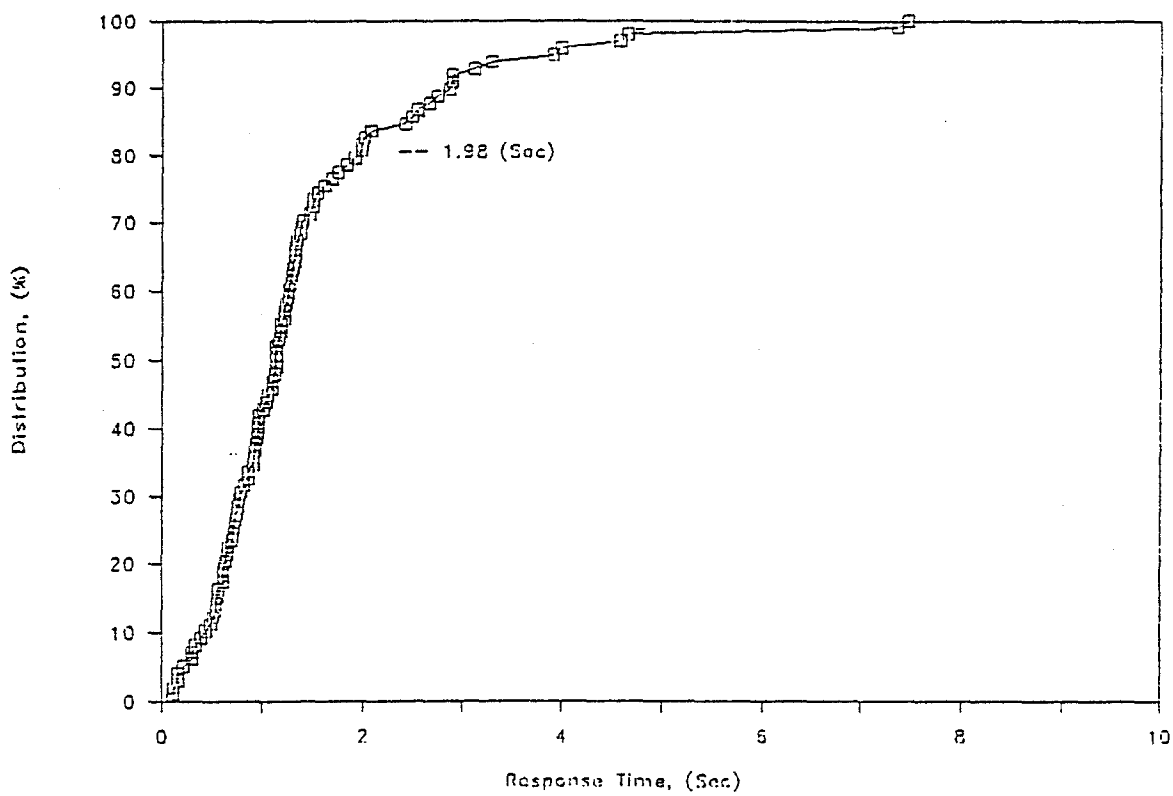


Figure 31. Distribution of correct responses, stimulus slide 6.

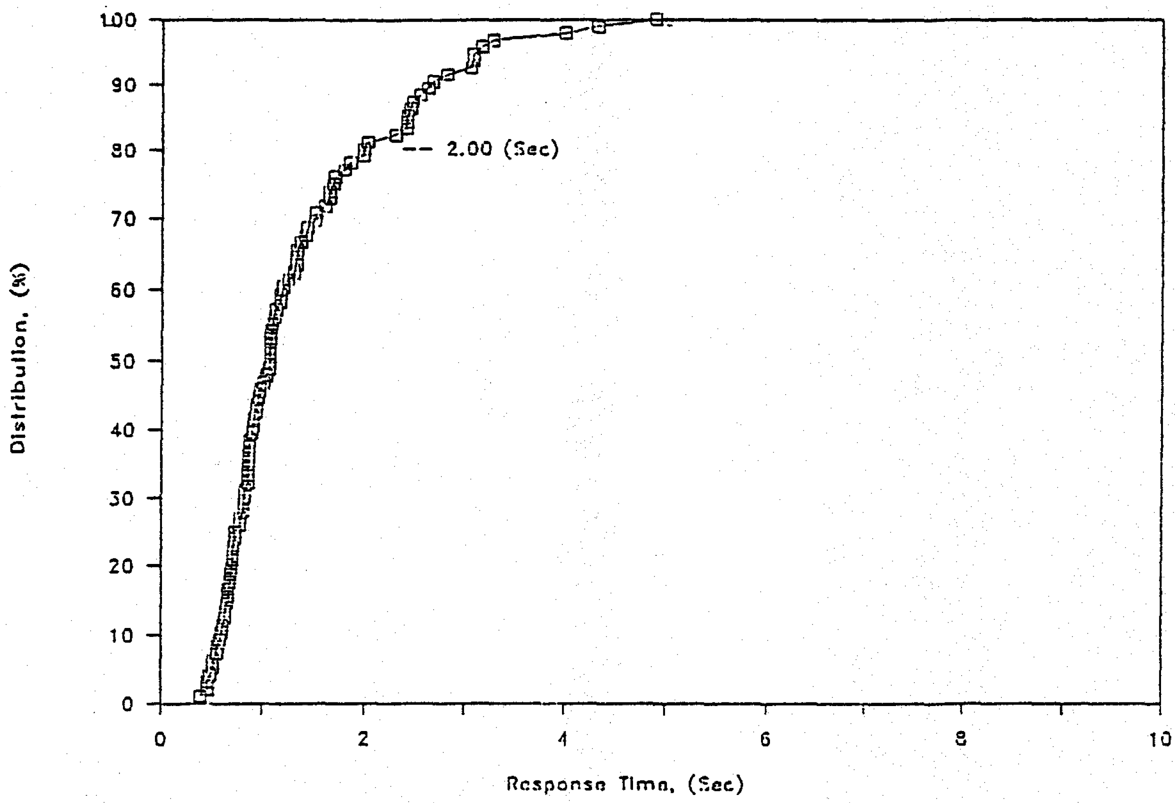


Figure 32. Distribution of correct responses, stimulus slide 7.

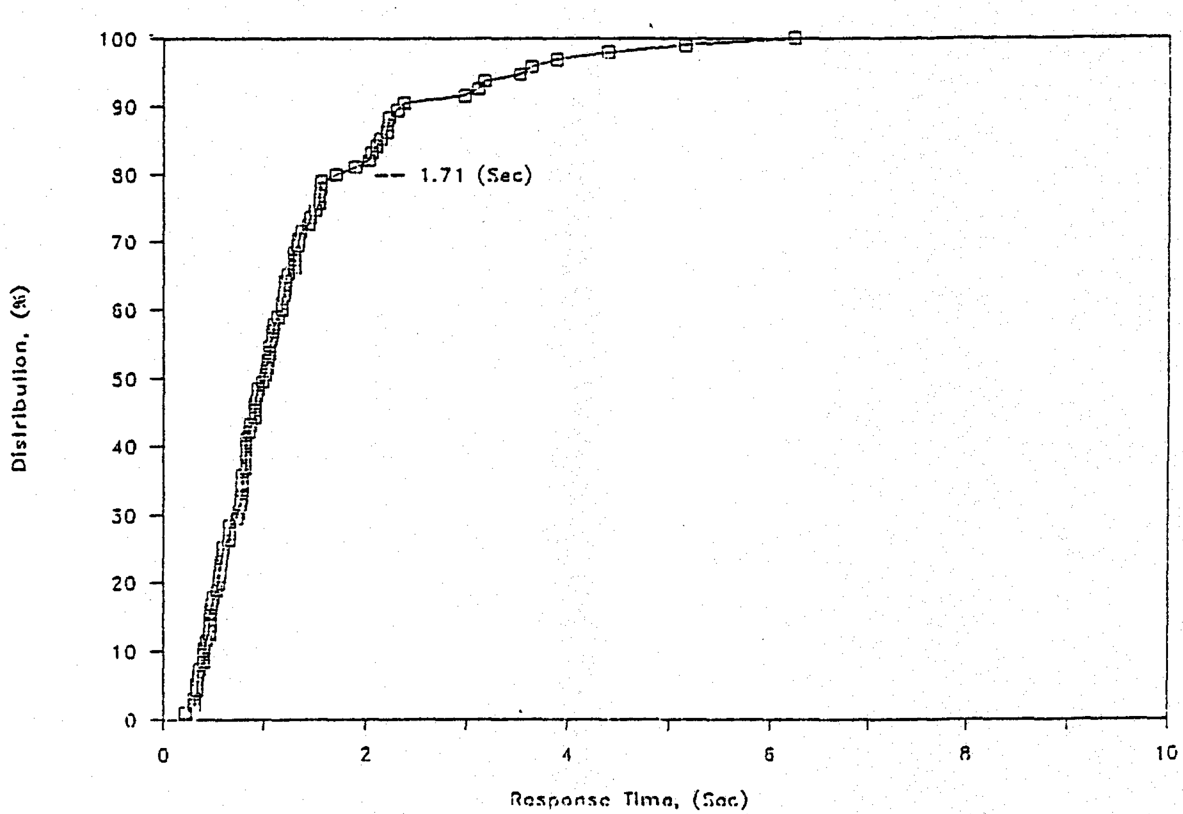


Figure 33. Distribution of correct responses, stimulus slide 8.

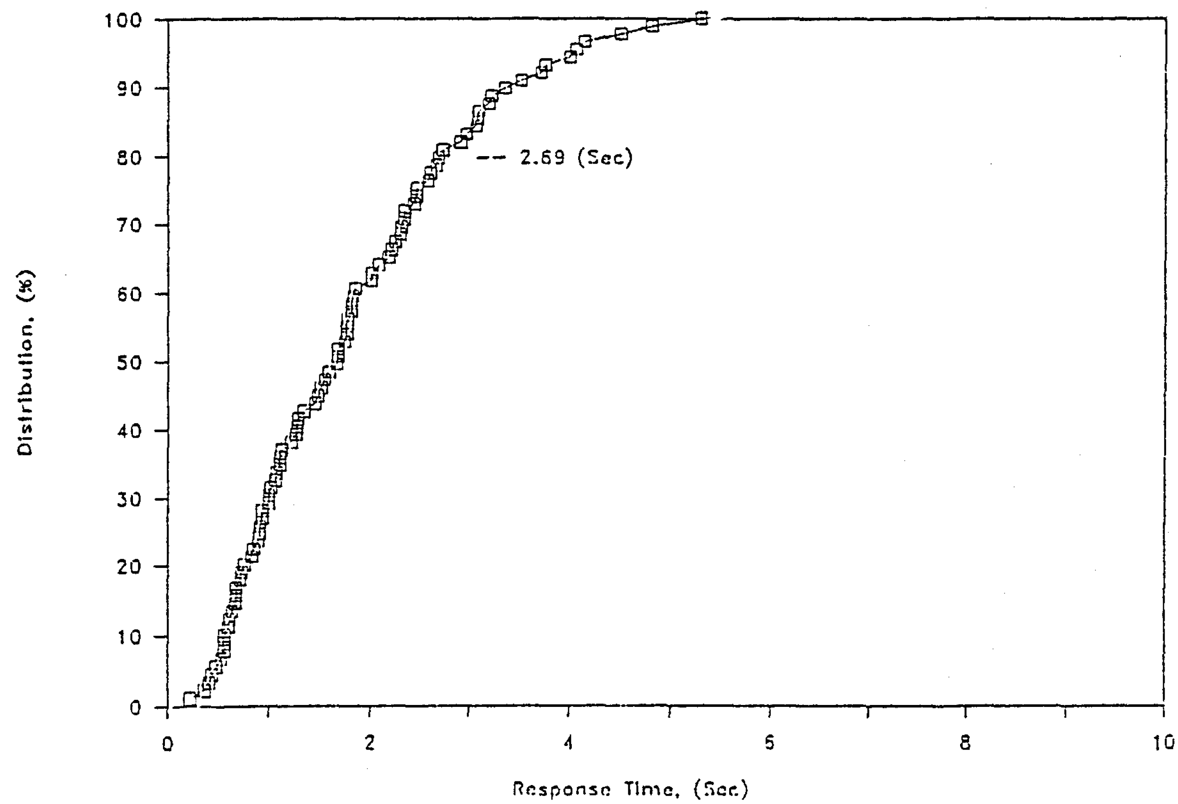


Figure 34. Distribution of correct responses, stimulus slide 9.

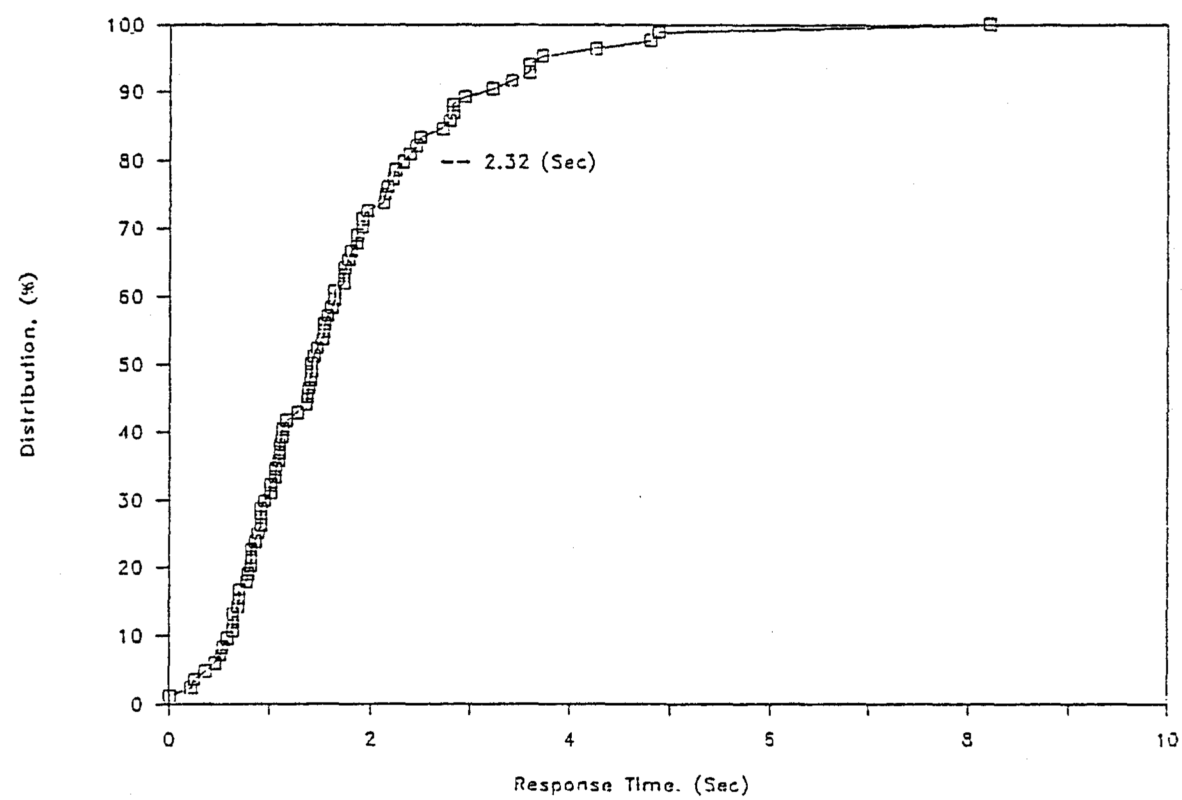


Figure 35. Distribution of correct responses, stimulus slide 10.

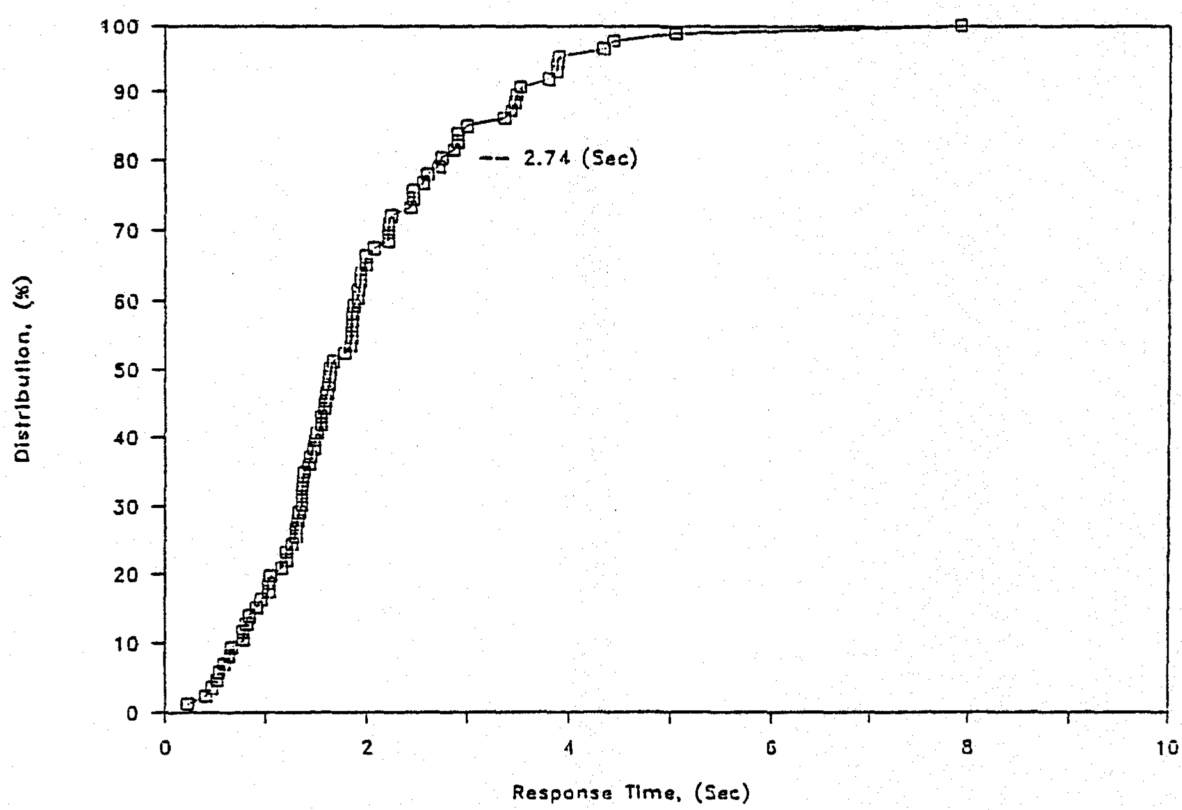


Figure 36. Distribution of correct responses, stimulus slide 11.

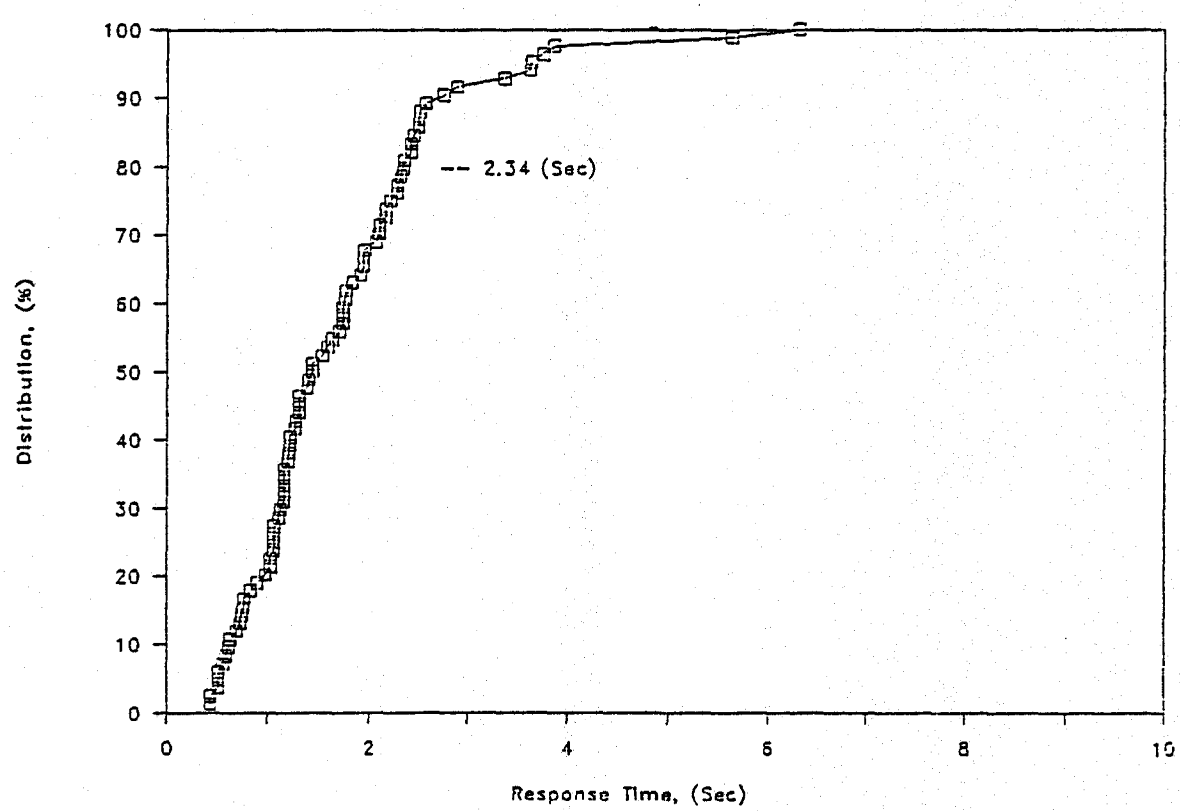


Figure 37. Distribution of correct responses, stimulus slide 12.

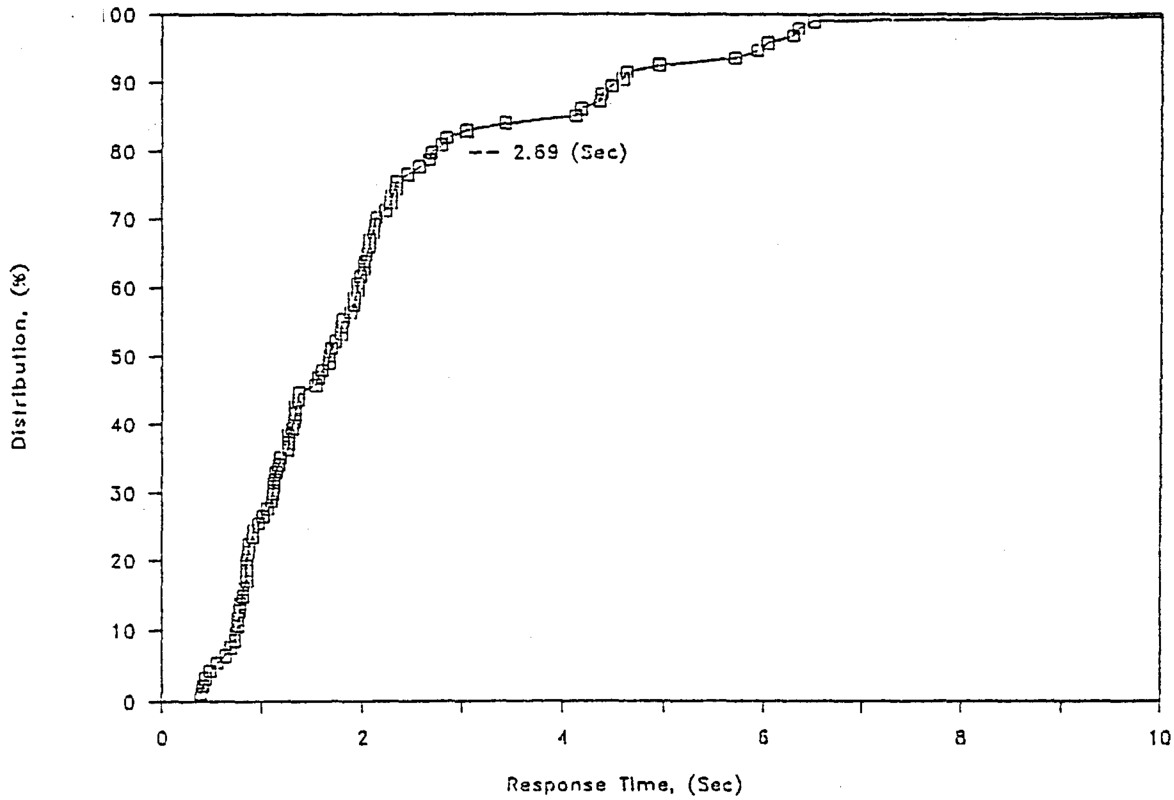


Figure 38. Distribution of correct responses, stimulus slide 13.

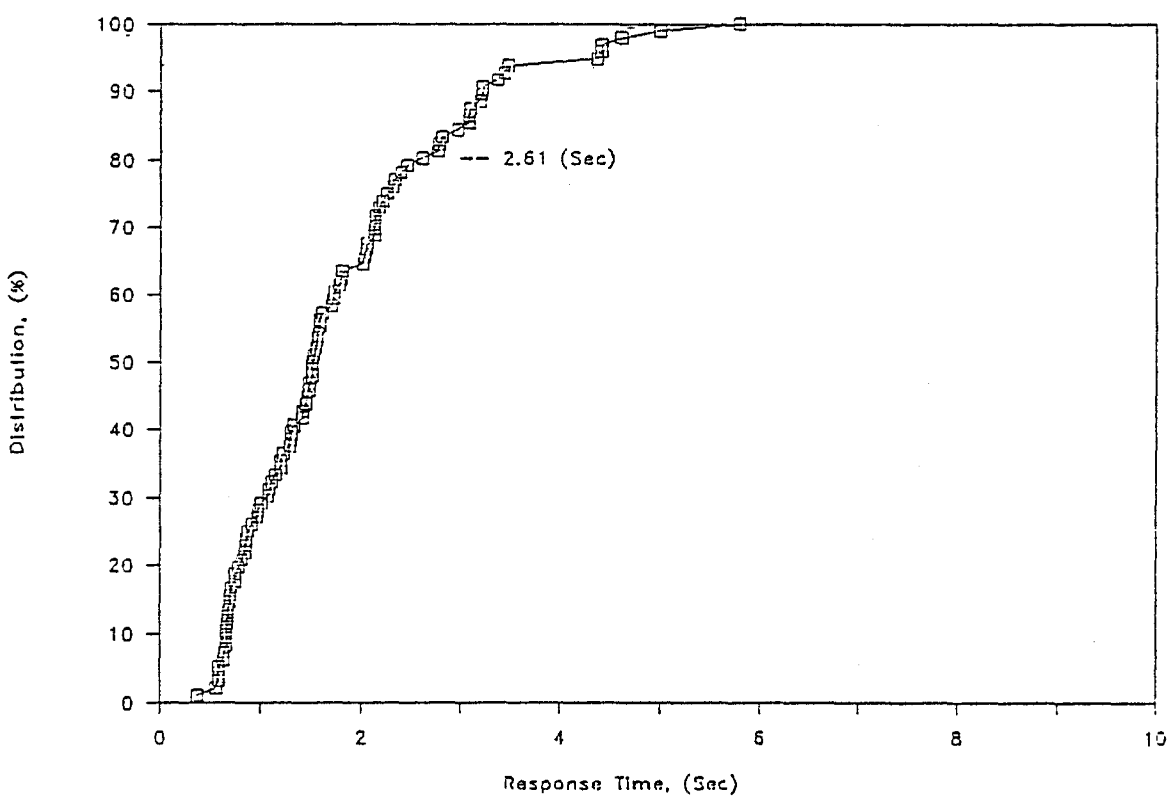


Figure 39. Distribution of correct responses, stimulus slide 14.

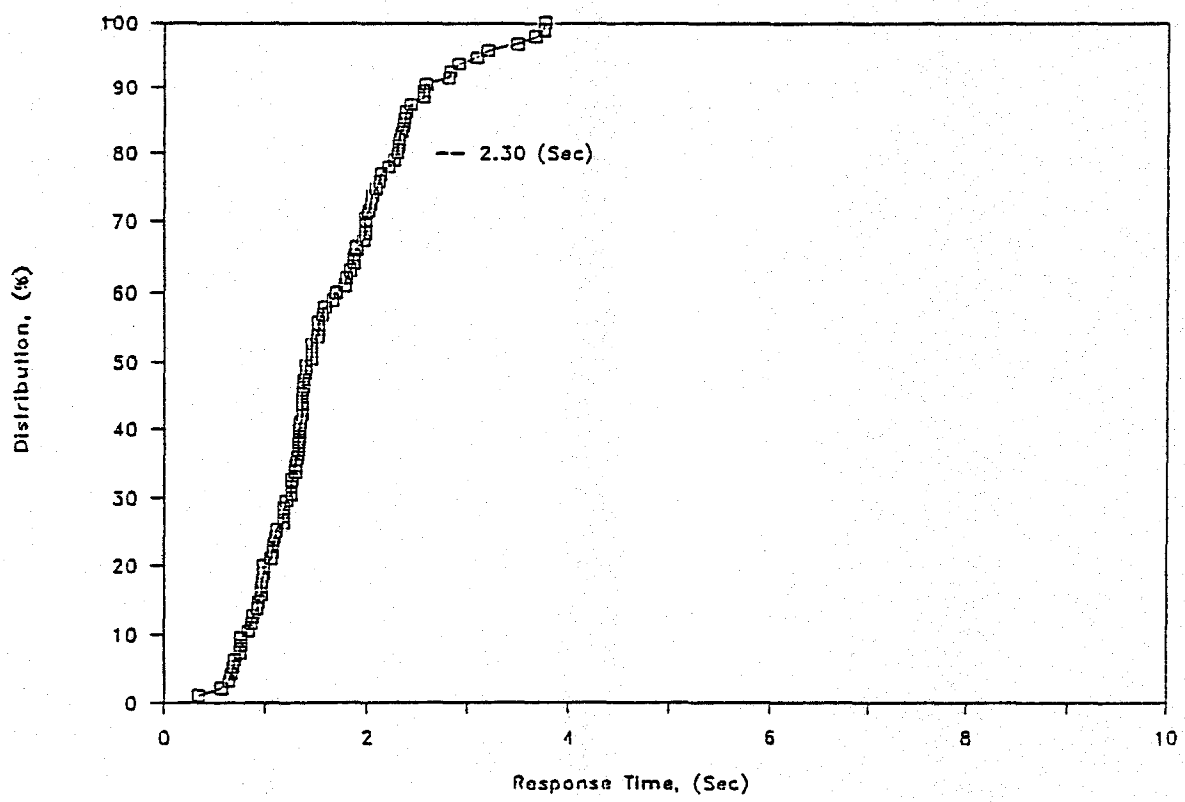


Figure 40. Distribution of correct responses, stimulus slide 15.

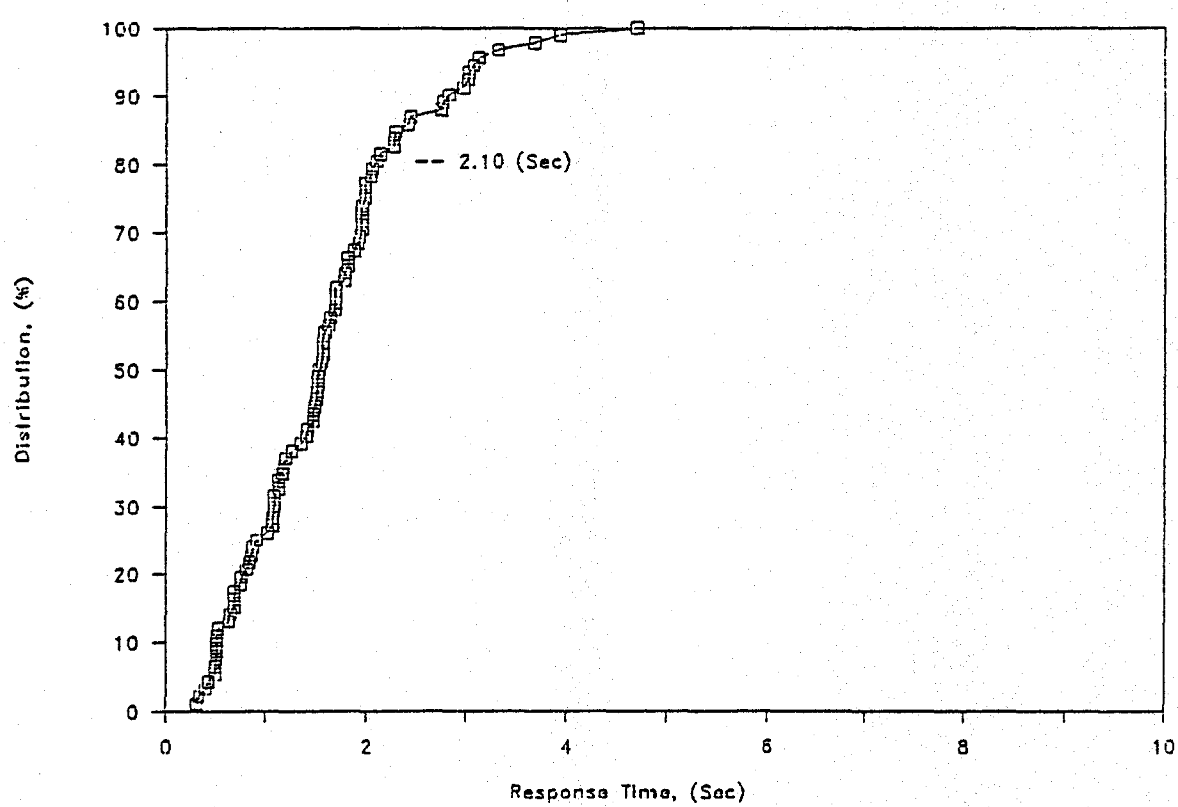


Figure 41. Distribution of correct responses, stimulus slide 16.

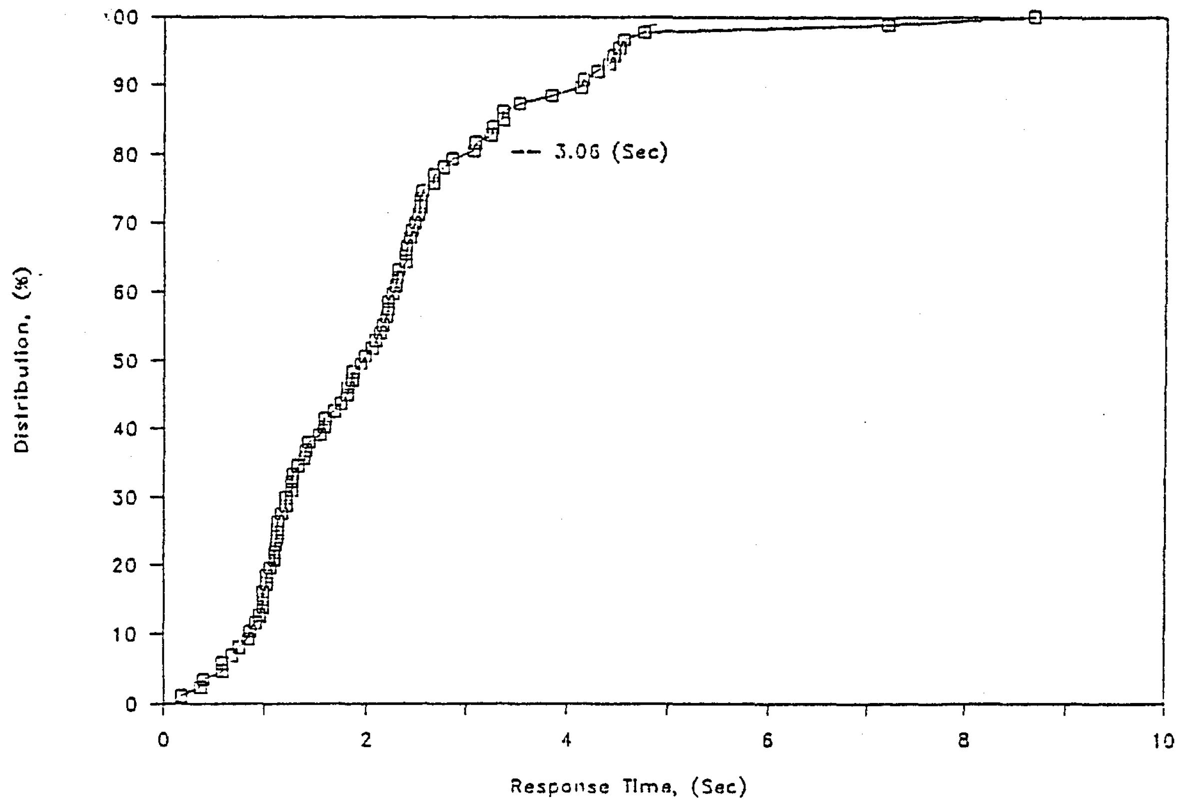


Figure 42. Distribution of correct responses, stimulus slide 17.

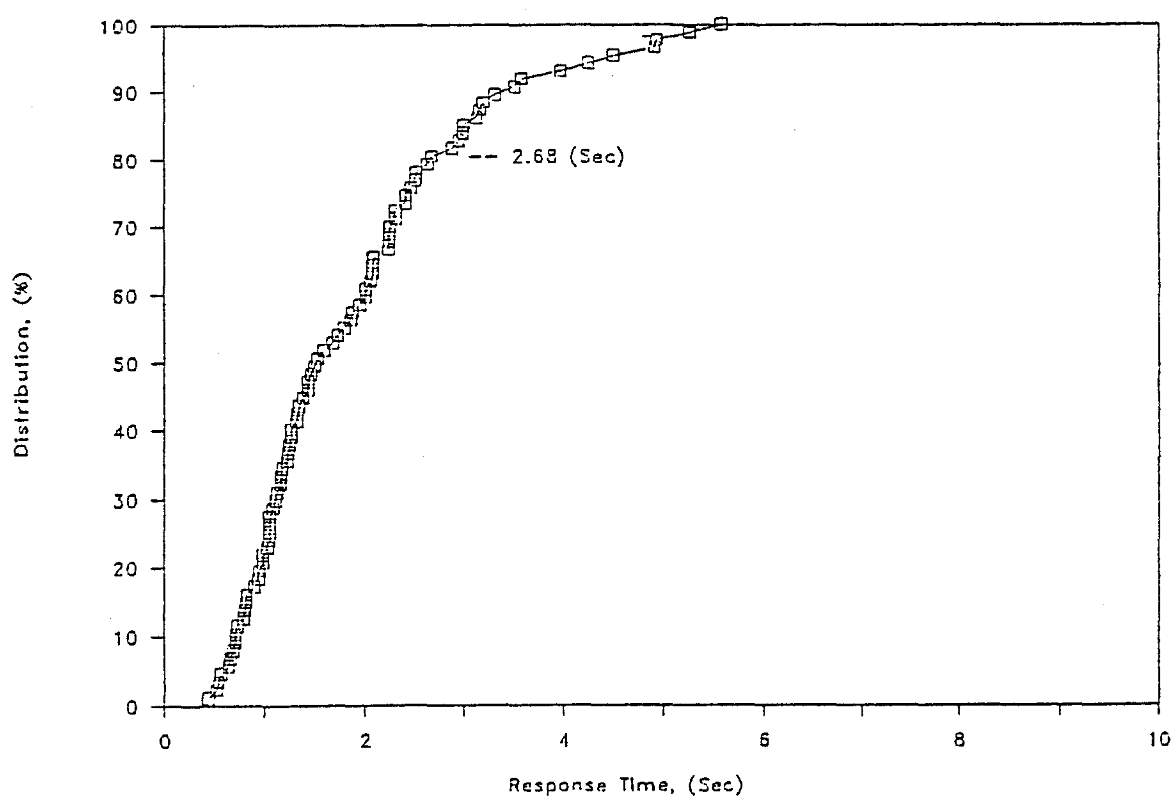


Figure 43. Distribution of correct responses, stimulus slide 18.

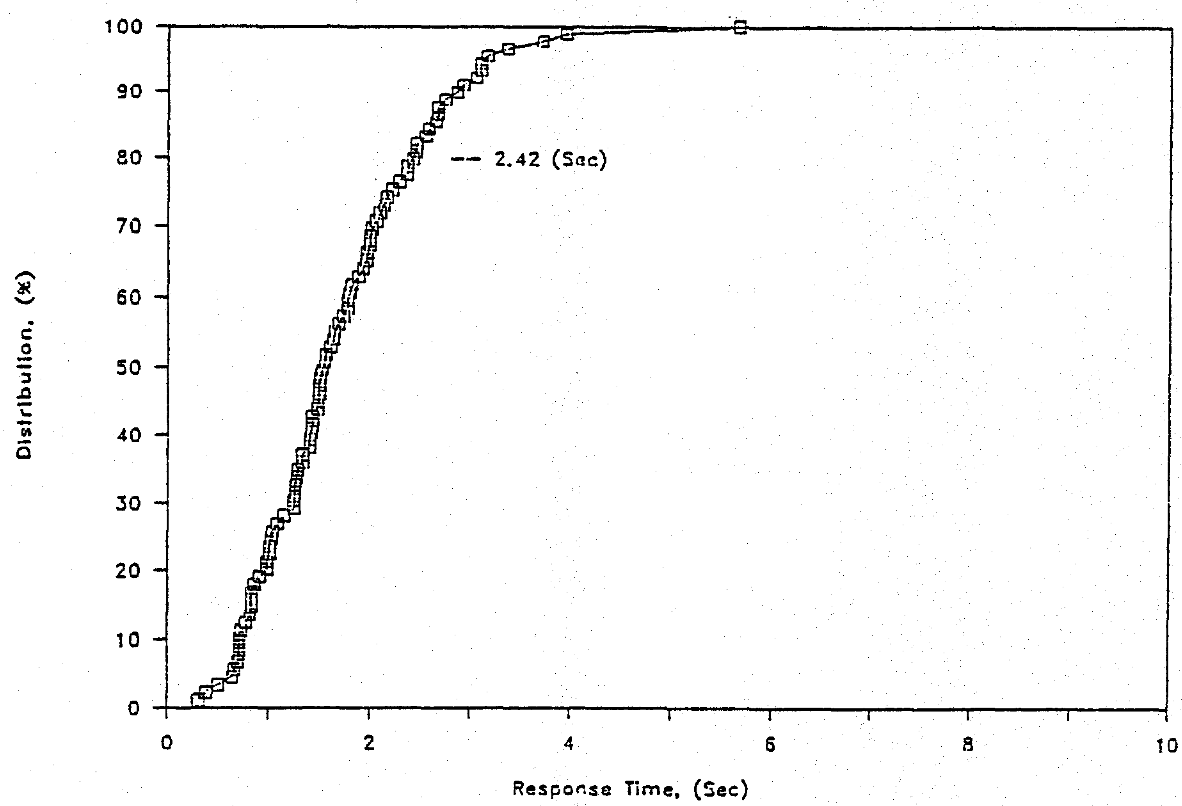


Figure 44. Distribution of correct responses, stimulus slide 19.

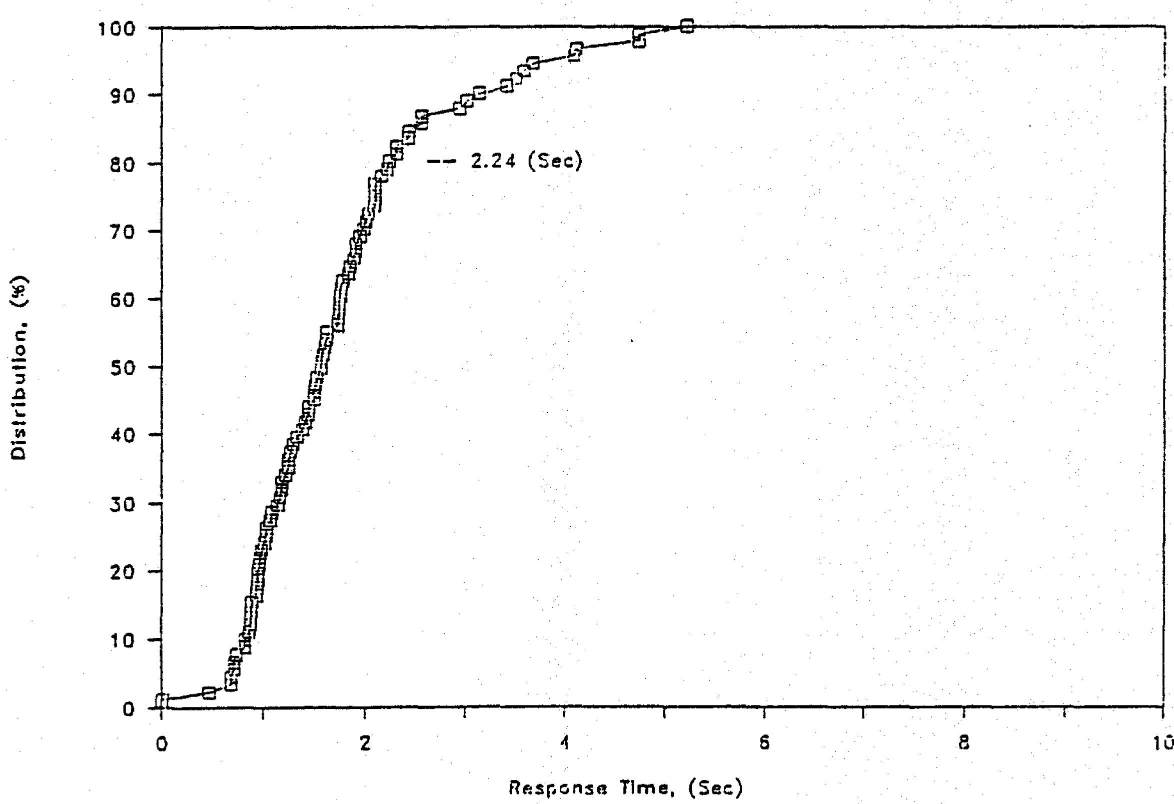


Figure 45. Distribution of correct responses, stimulus slide 20.

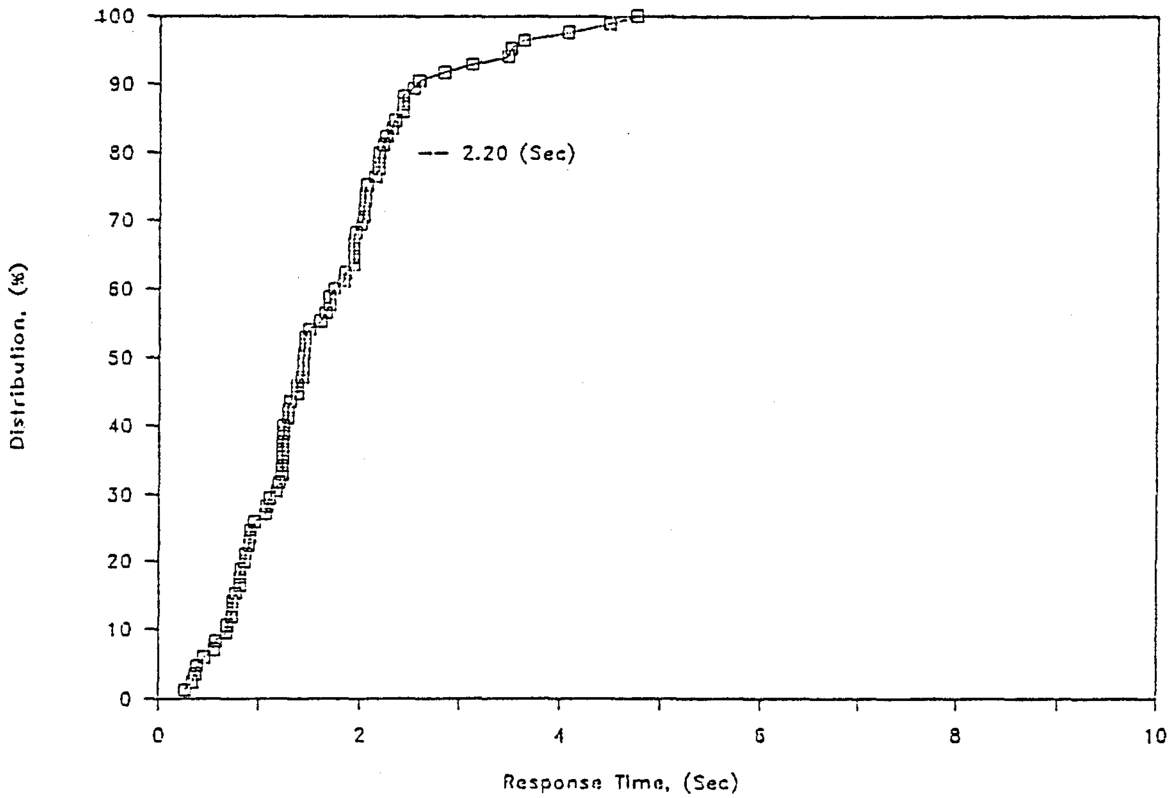


Figure 46. Distribution of correct responses, stimulus slide 21.

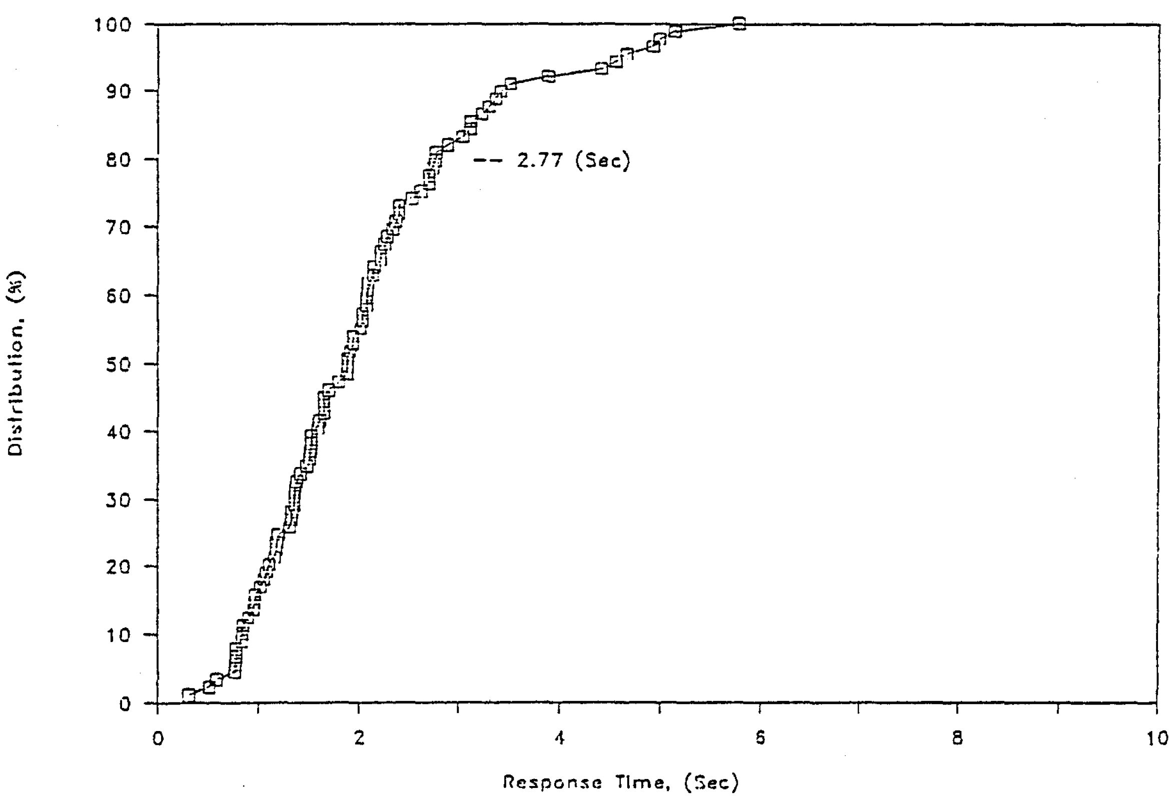


Figure 47. Distribution of correct responses, stimulus slide 22.

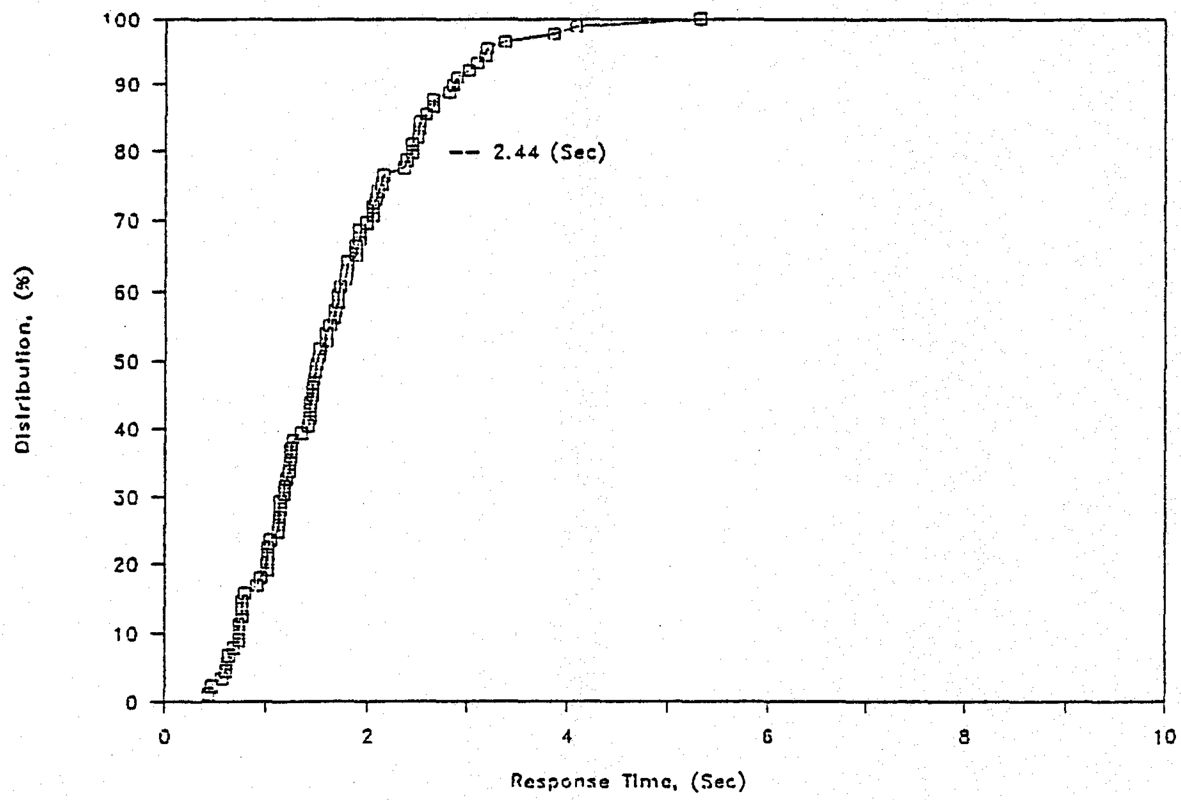


Figure 48. Distribution of correct responses, stimulus slide 23.

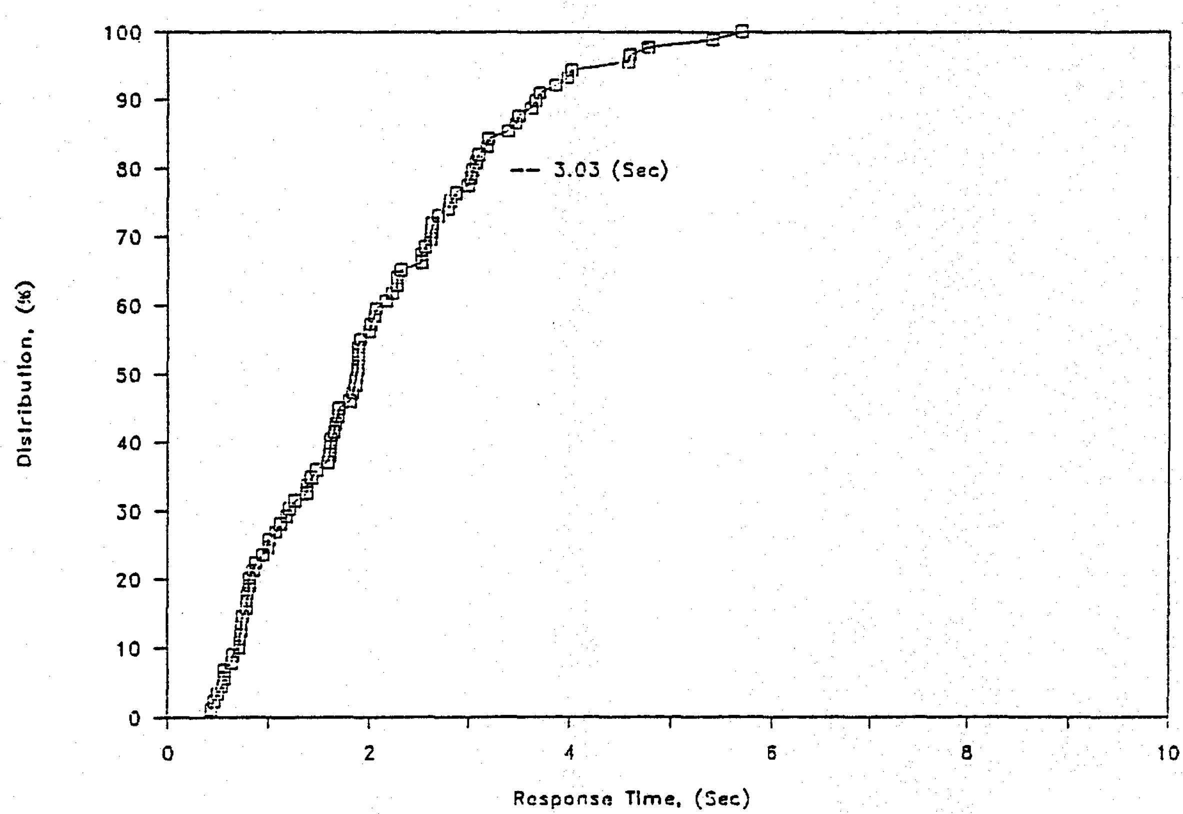


Figure 49. Distribution of correct responses, stimulus slide 24.

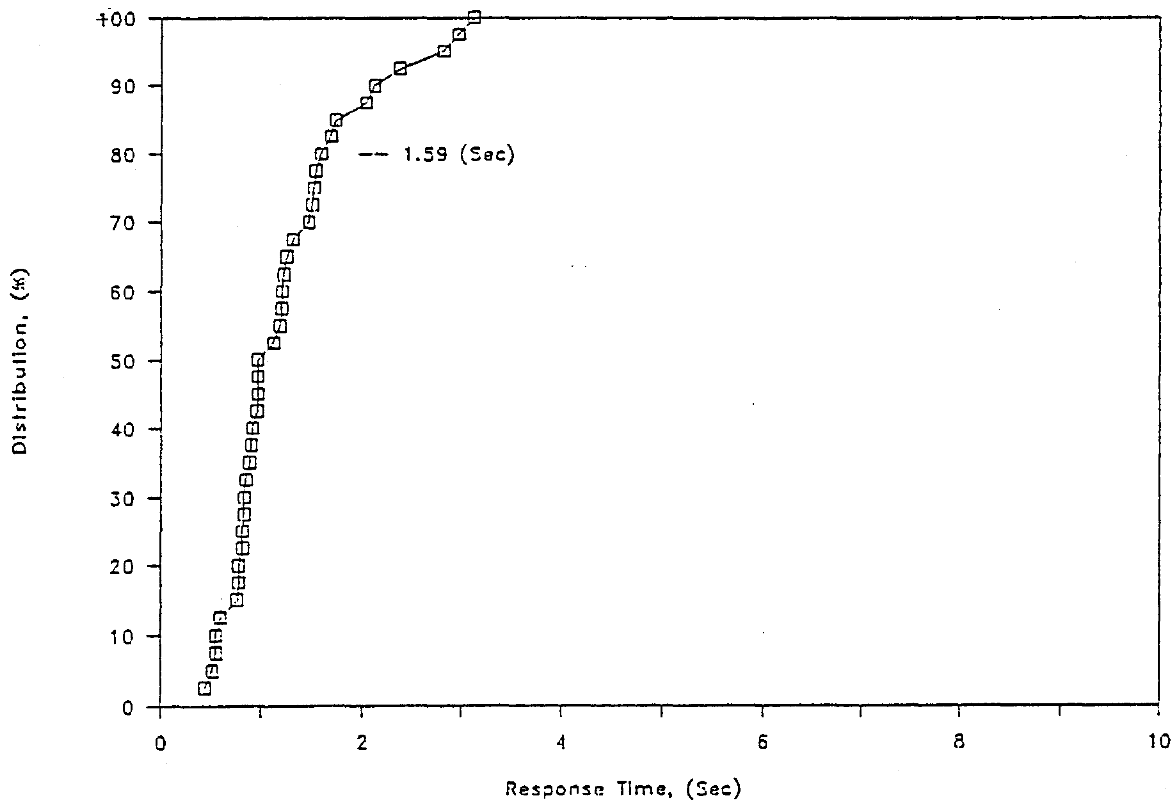


Figure 50. Distribution of correct responses, stimulus slide 25.

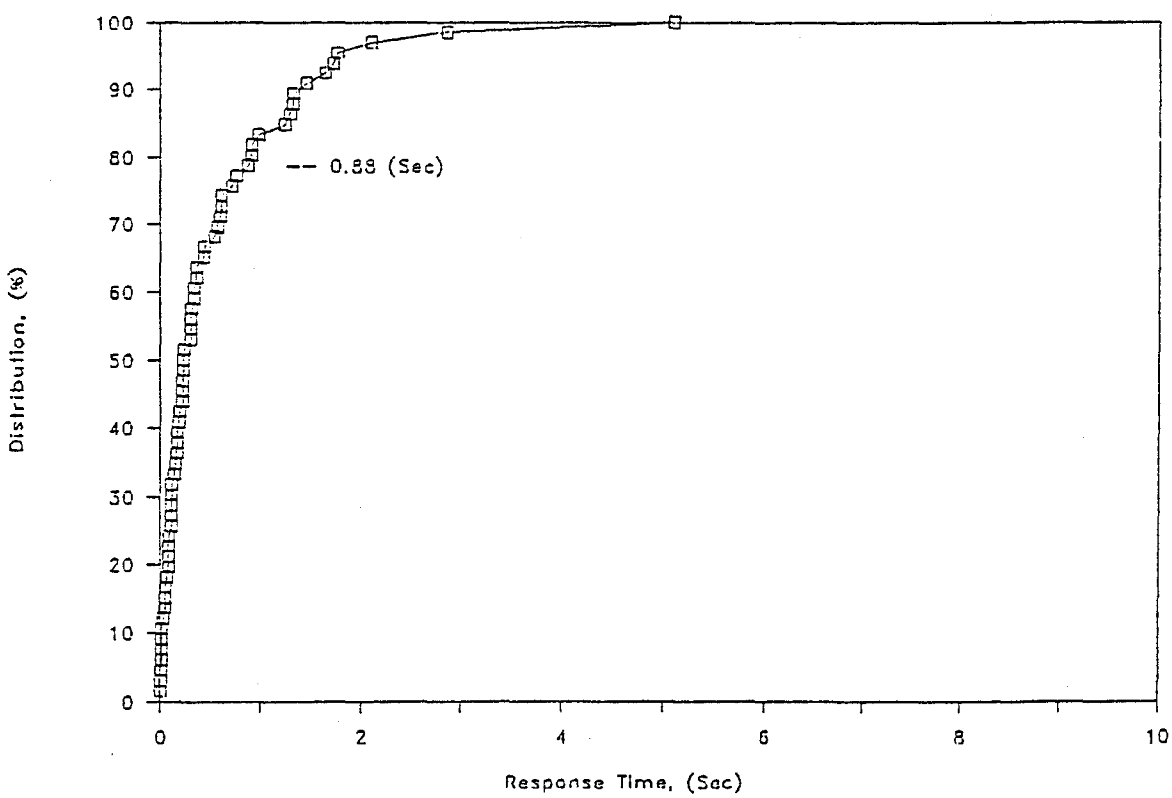


Figure 51. Distribution of correct responses, stimulus slide 26.

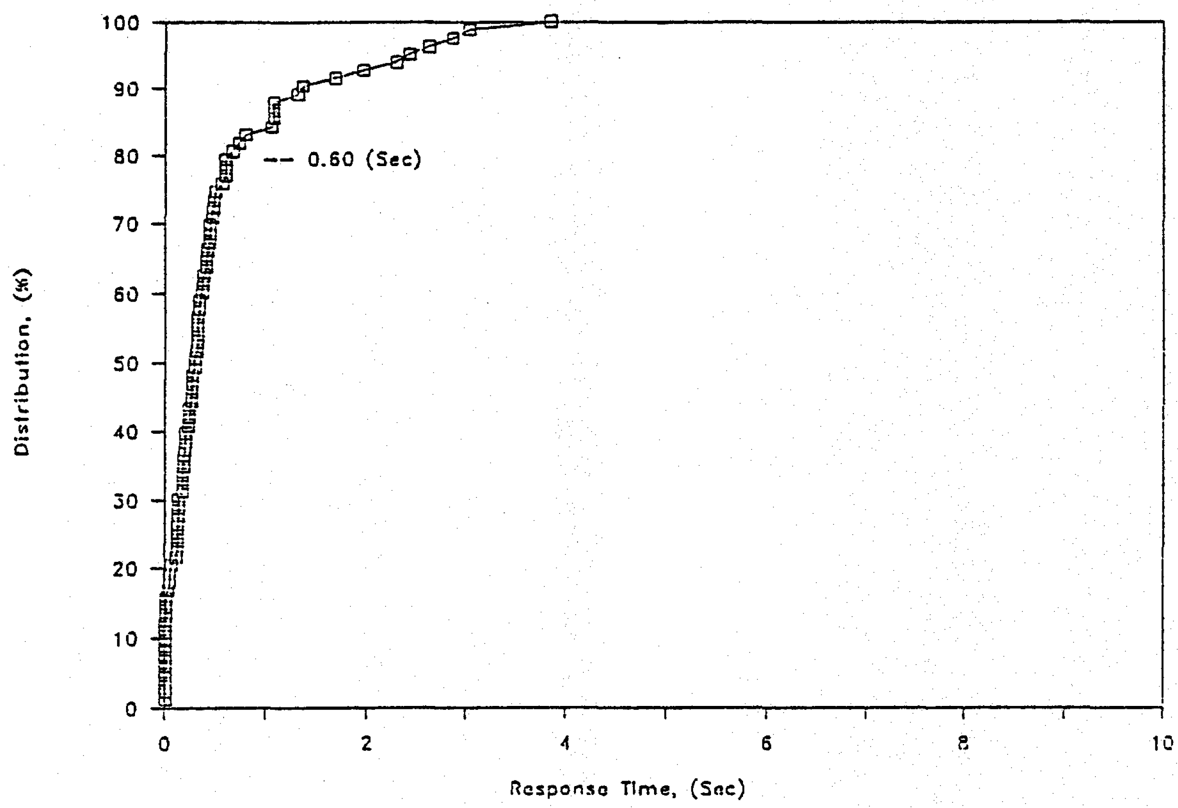


Figure 52. Distribution of correct responses, stimulus slide 27.

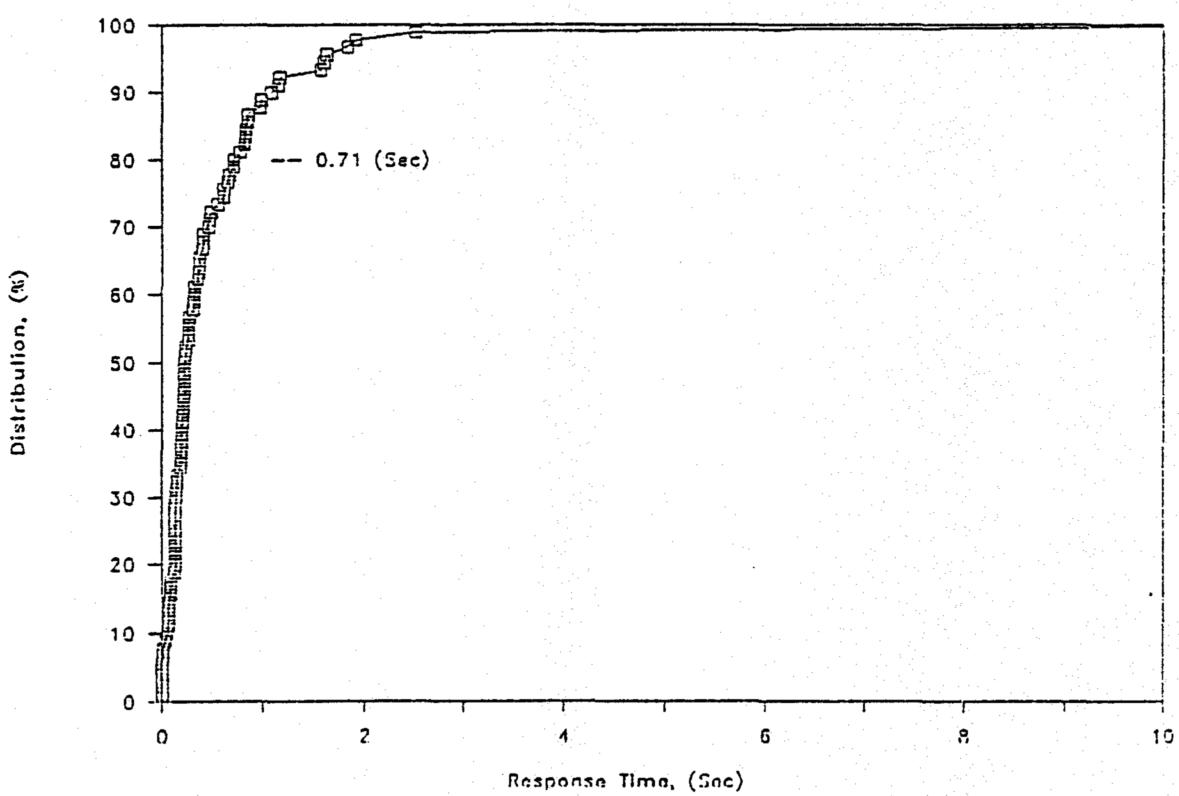


Figure 53. Distribution of correct responses, stimulus slide 28.

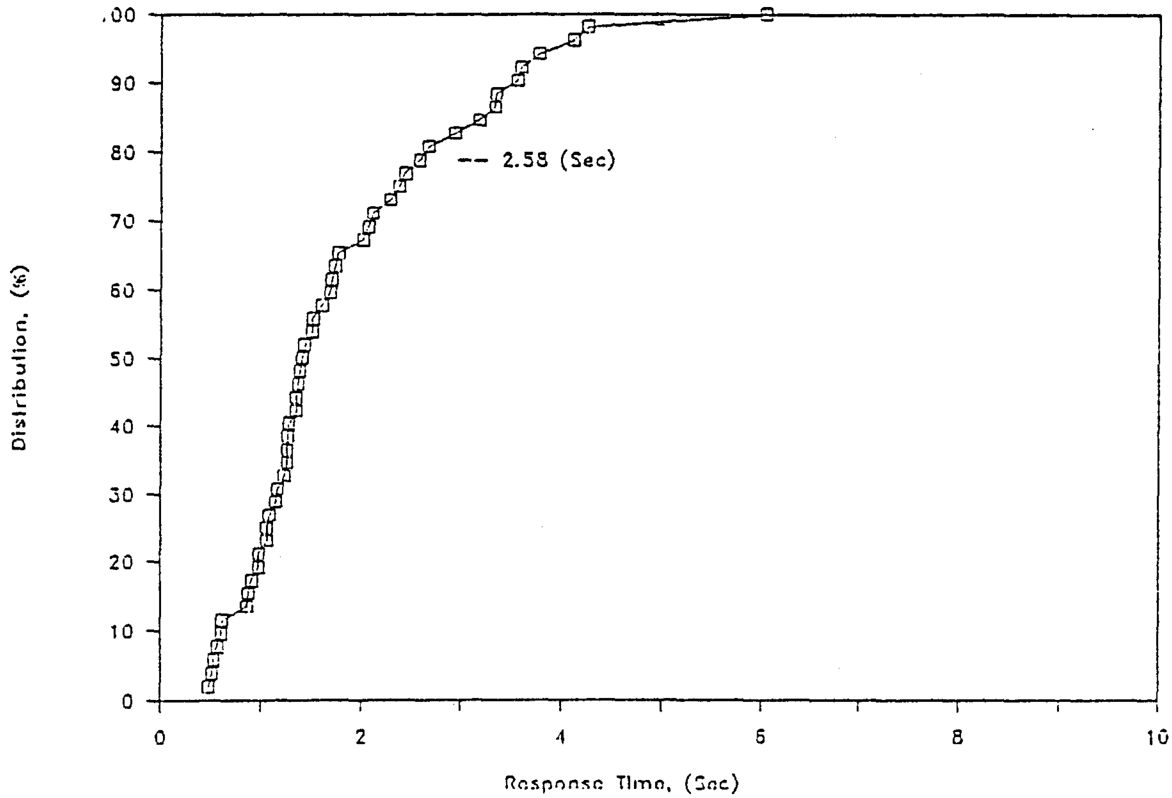


Figure 54. Distribution of correct responses, stimulus slide 29.

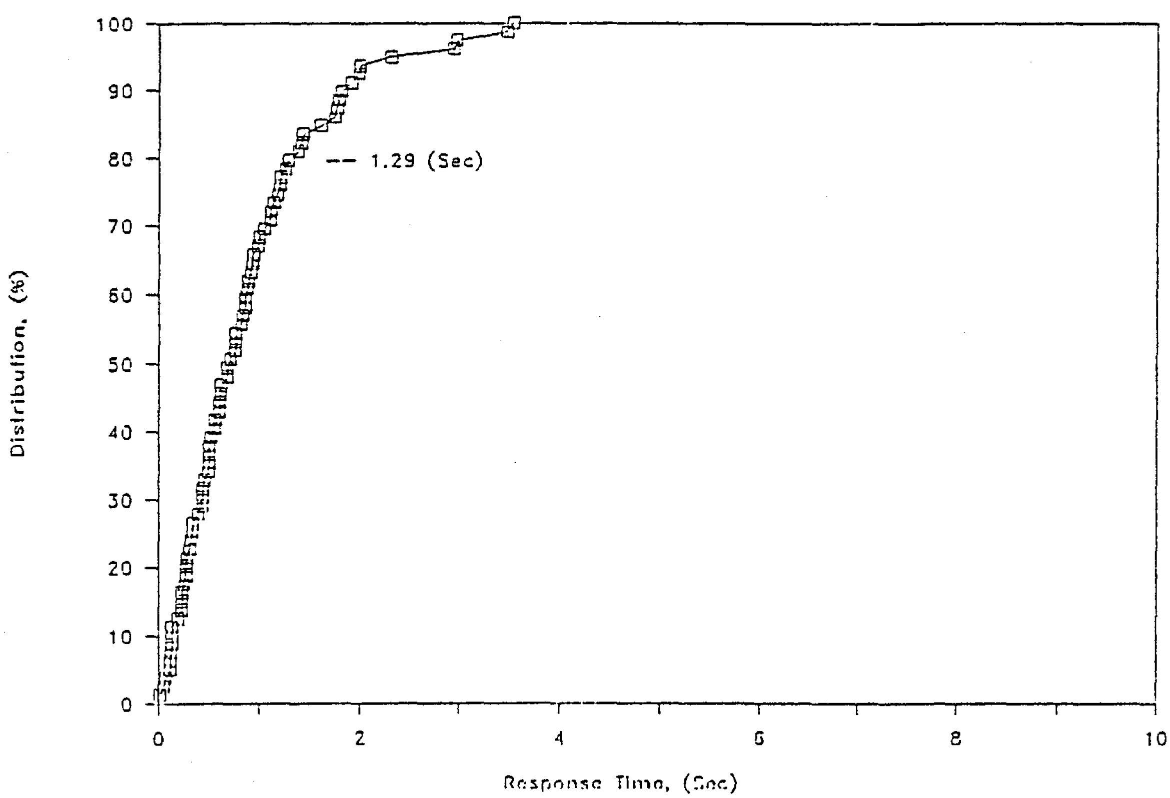


Figure 55. Distribution of correct responses, stimulus slide 30.

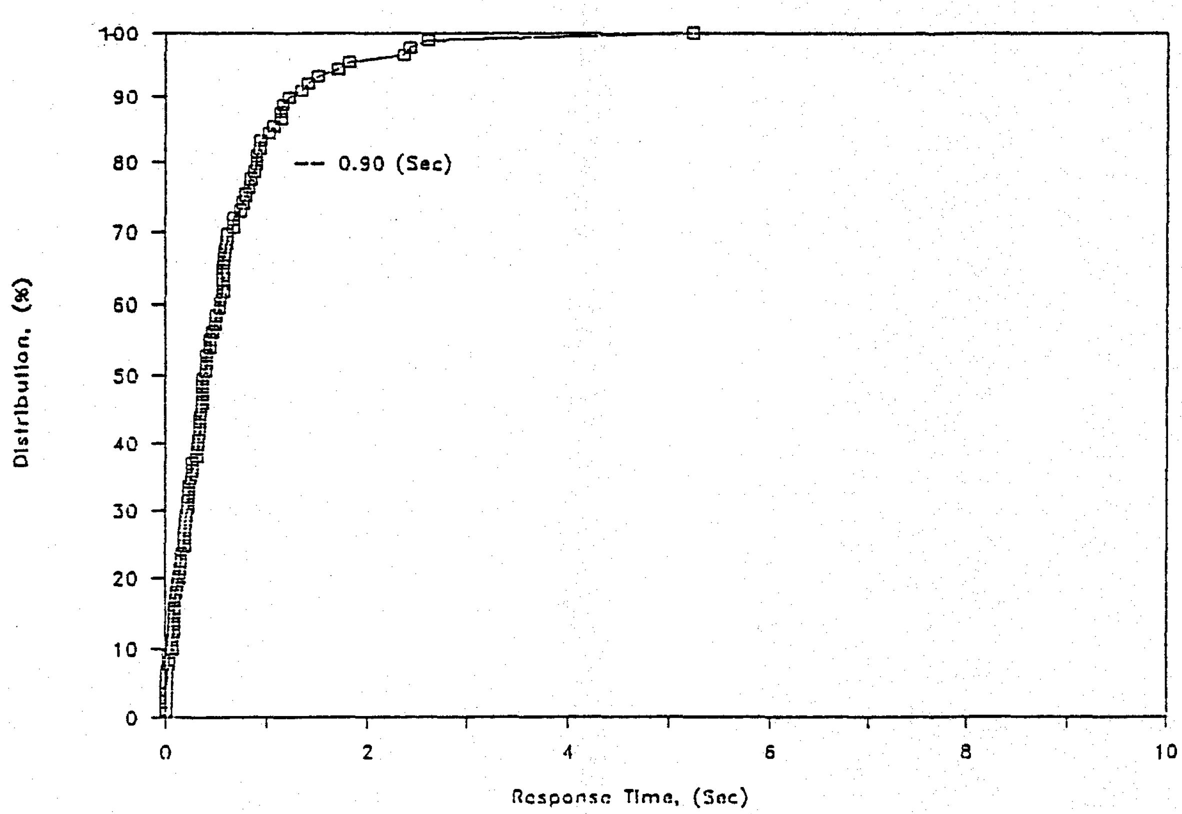


Figure 56. Distribution of correct responses, stimulus slide 31.

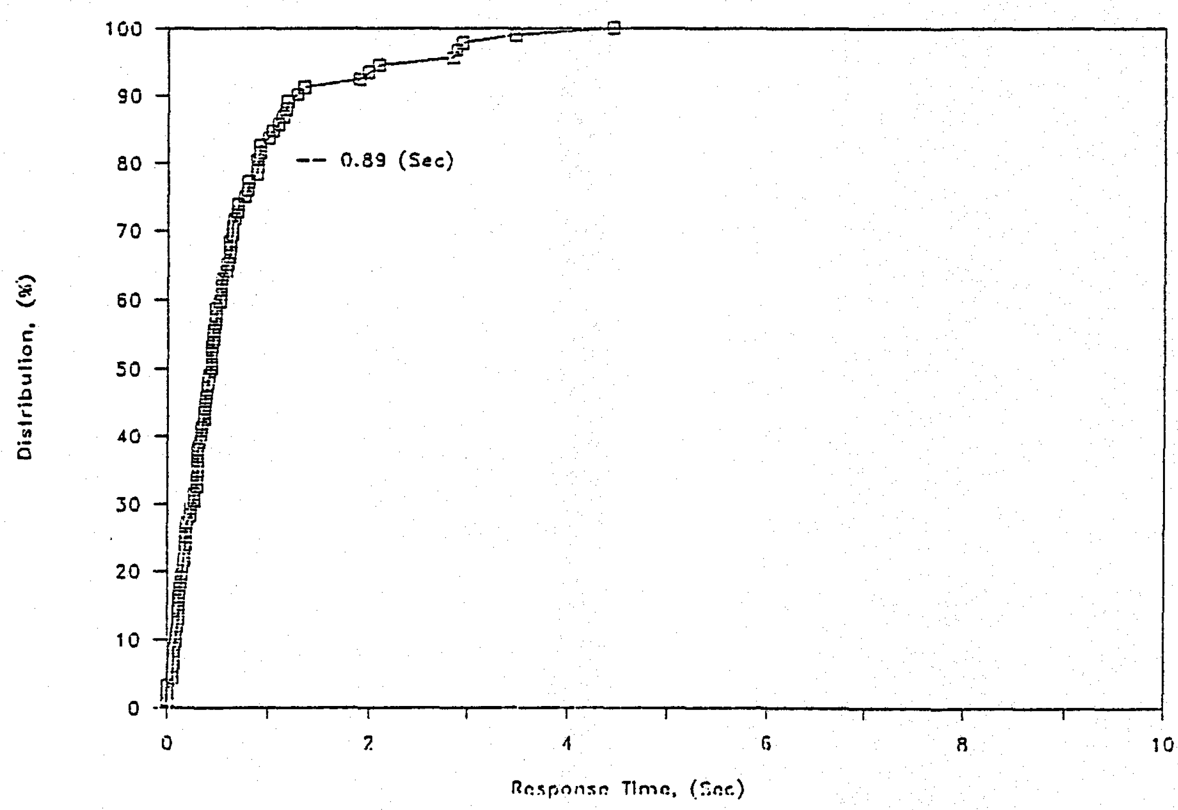


Figure 57. Distribution of correct responses, stimulus slide 32.

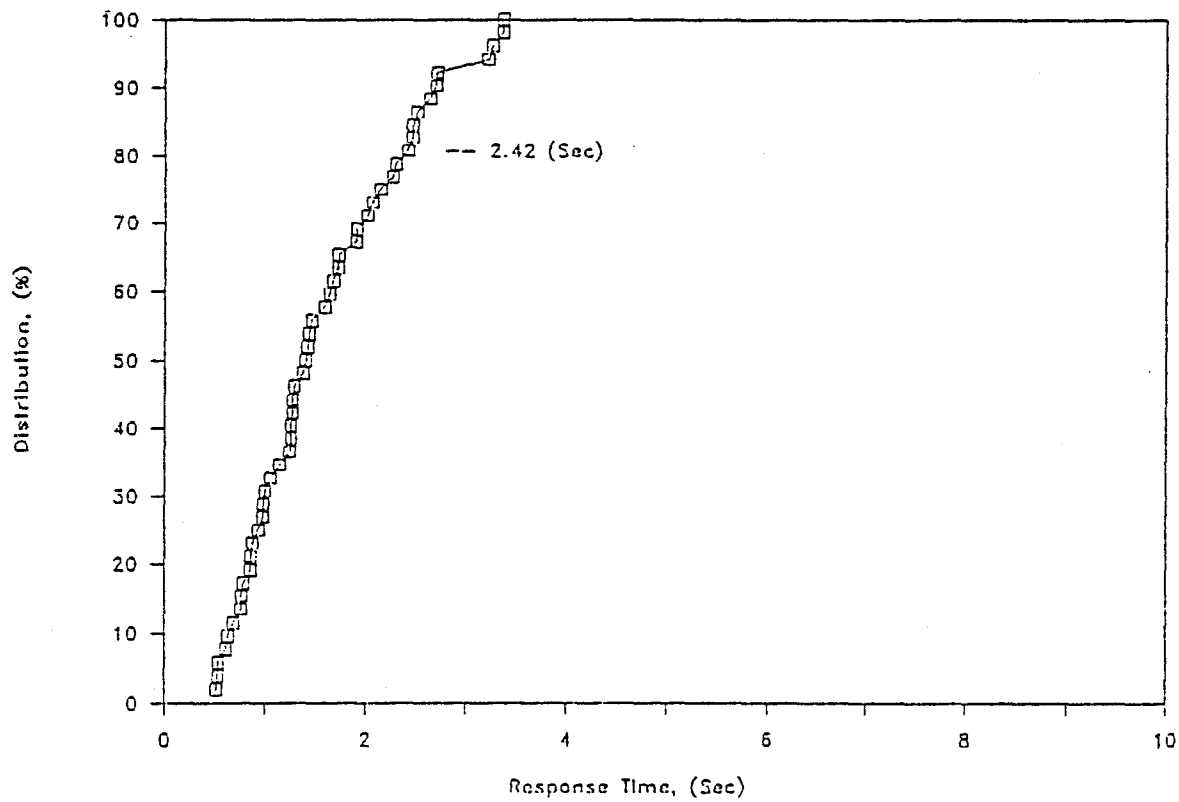


Figure 58. Distribution of correct responses, stimulus slide 33.

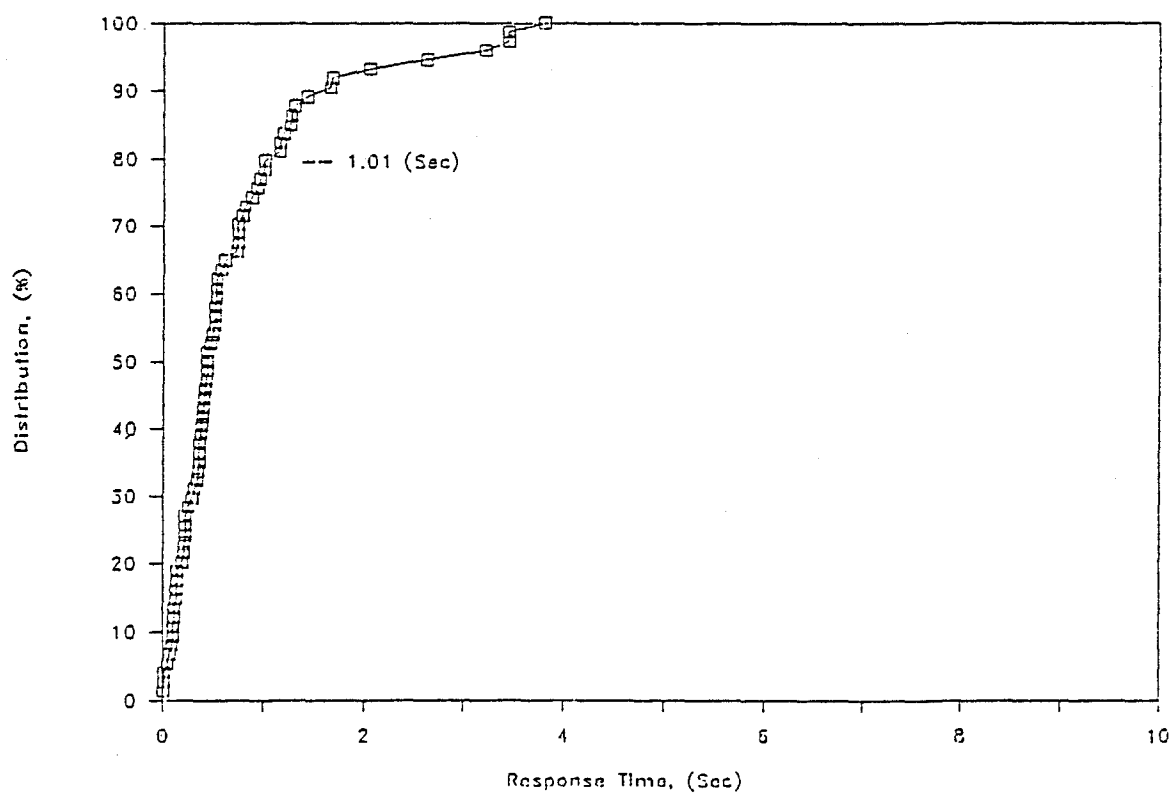


Figure 59. Distribution of correct responses, stimulus slide 34.

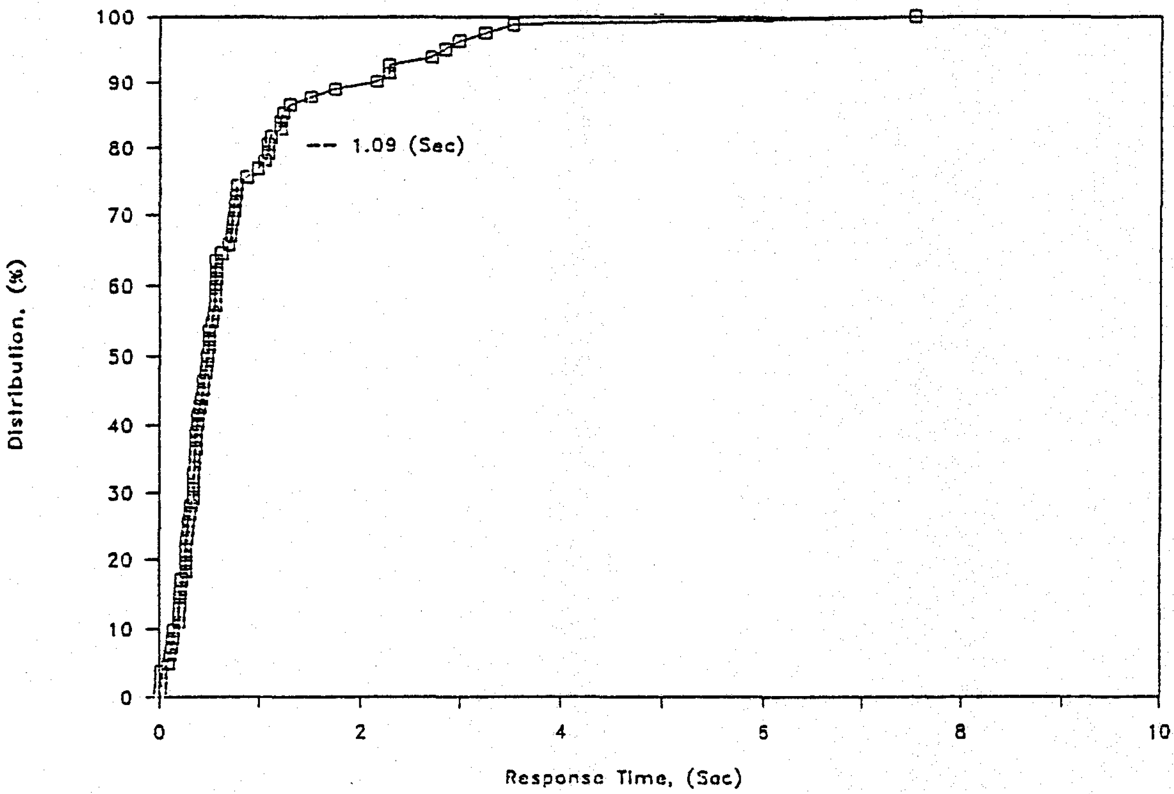


Figure 60. Distribution of correct responses, stimulus slide 35.

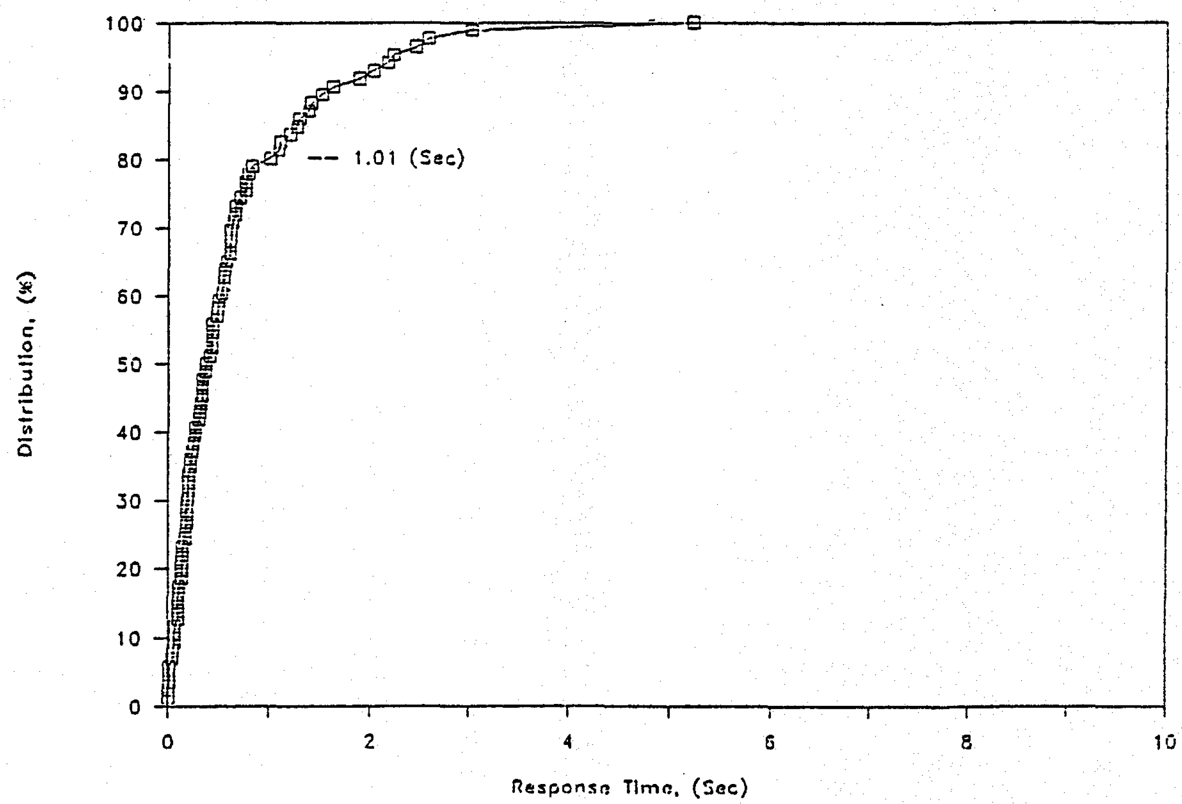


Figure 61. Distribution of correct responses, stimulus slide 36.

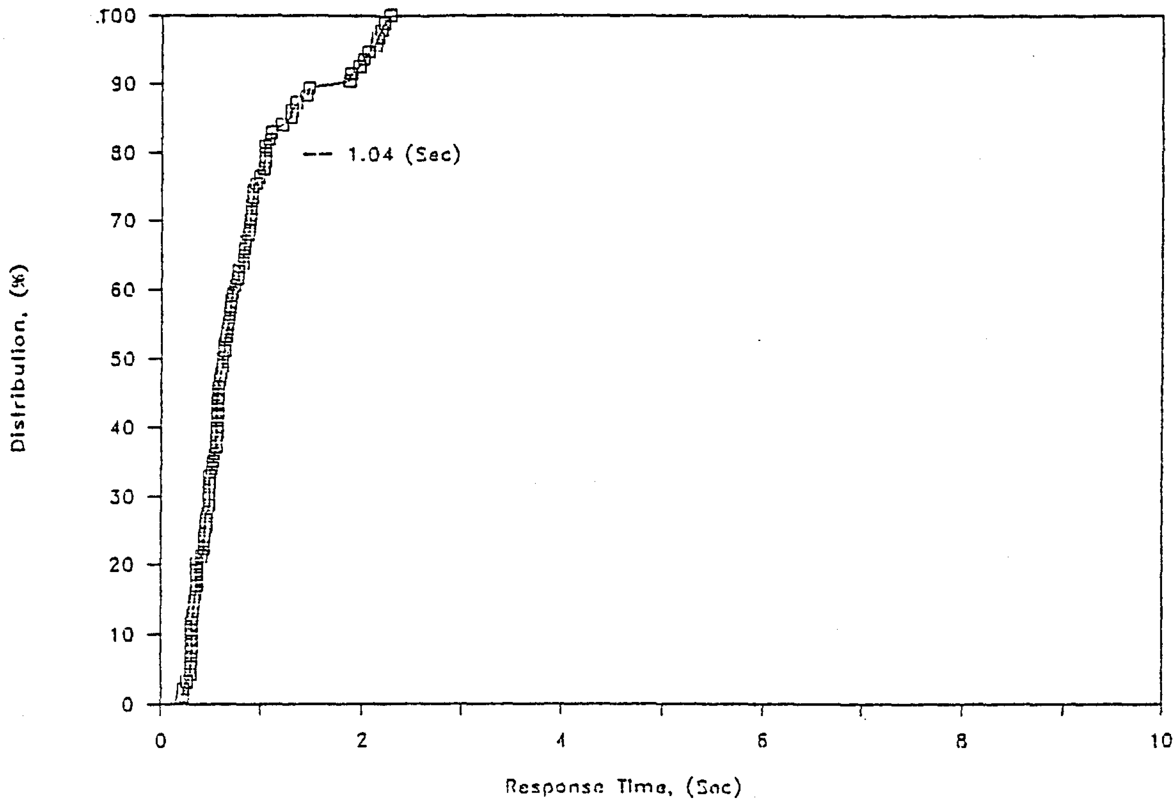


Figure 62. Distribution of correct responses, stimulus slide 37.

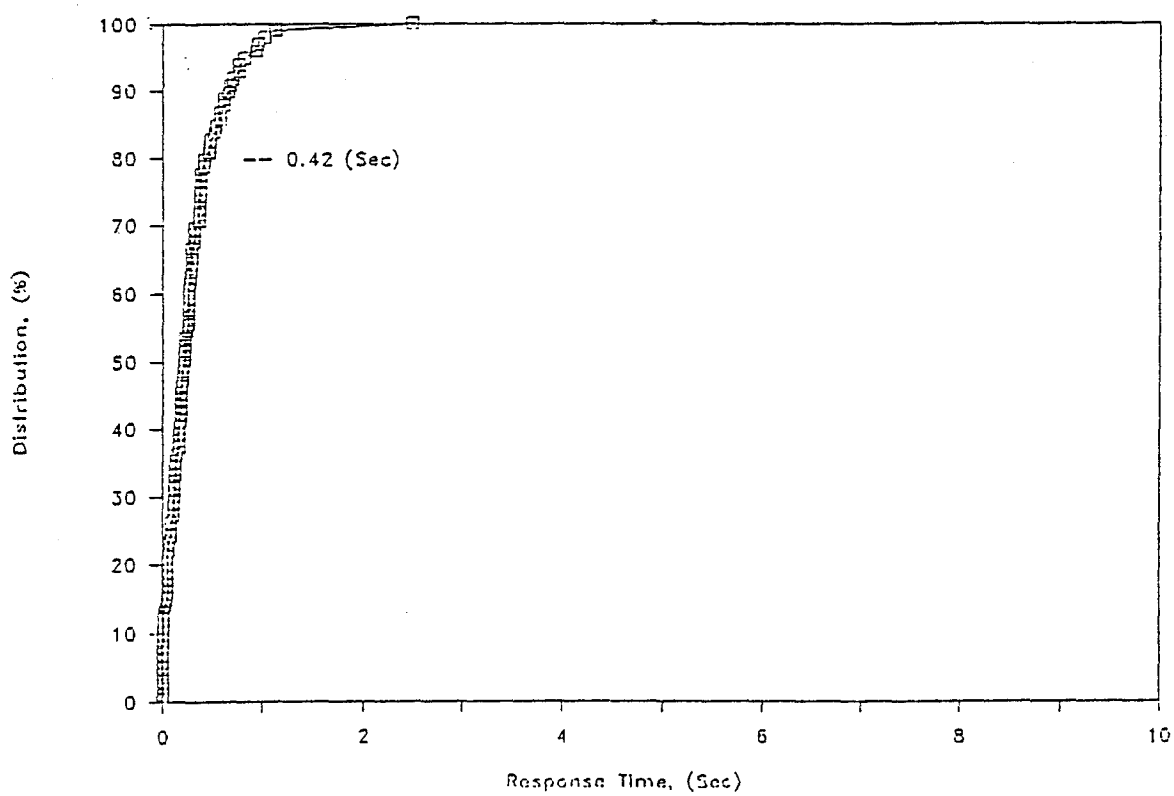


Figure 63. Distribution of correct responses, stimulus slide 38.

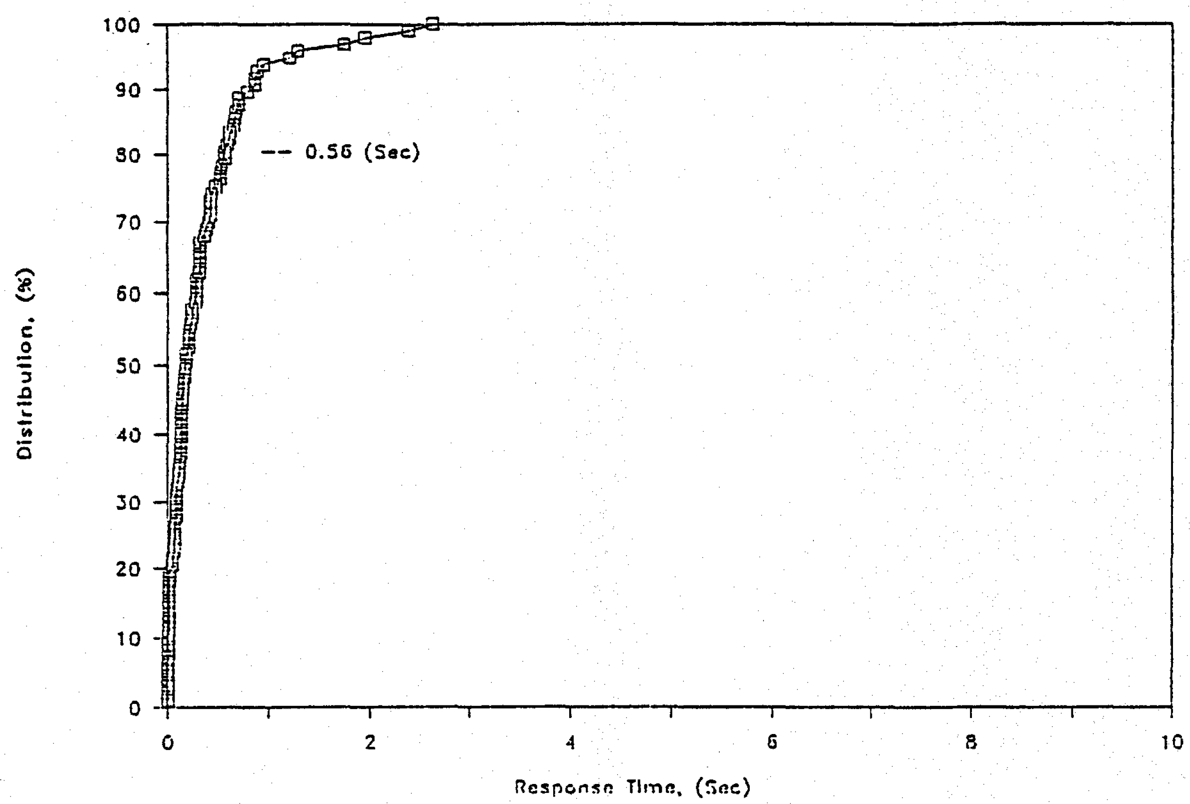


Figure 64. Distribution of correct responses, stimulus slide 39.

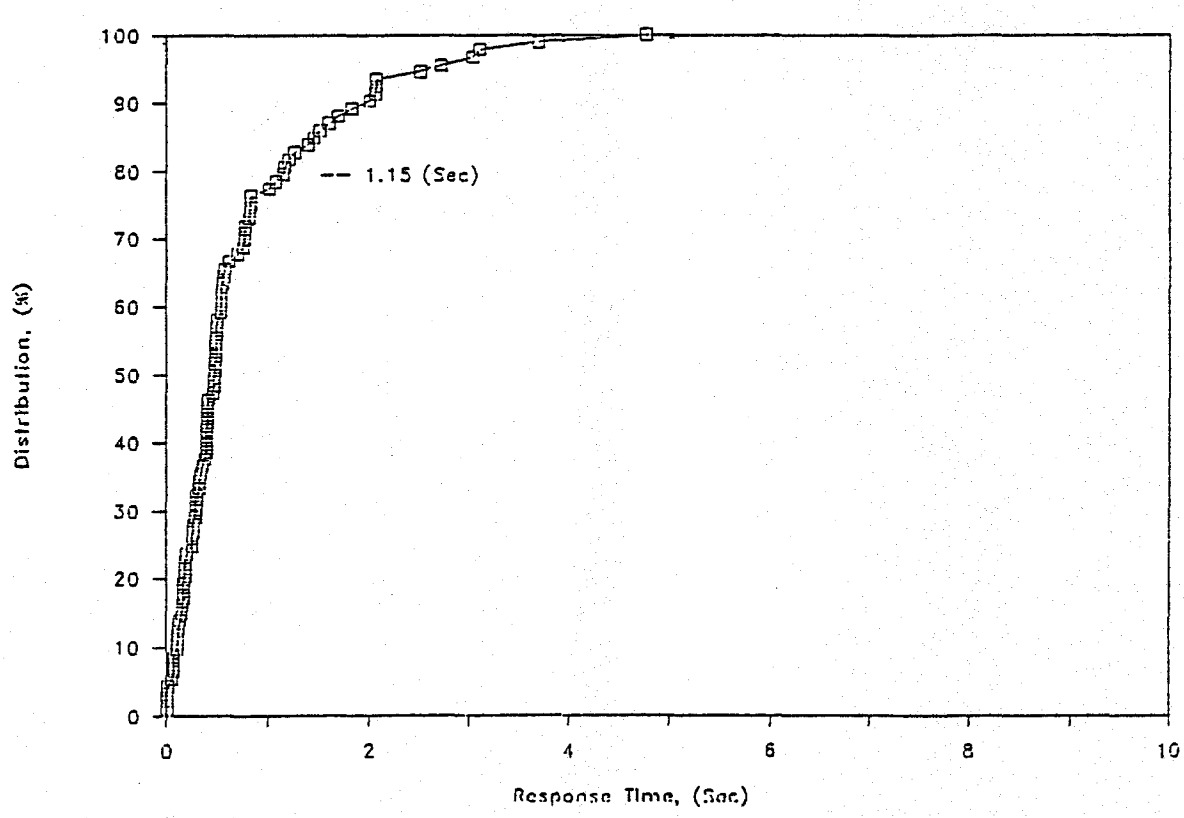


Figure 65. Distribution of correct responses, stimulus slide 40.

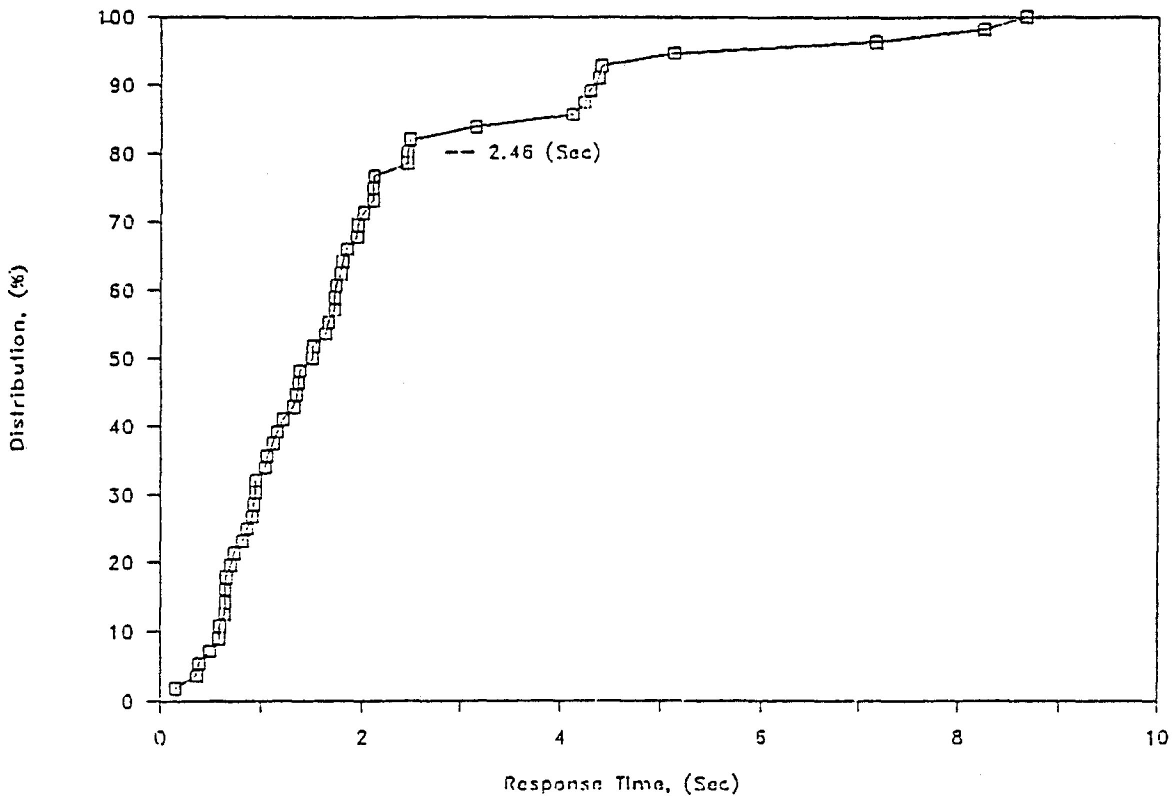


Figure 66. Distribution of correct responses, stimulus slide 41.

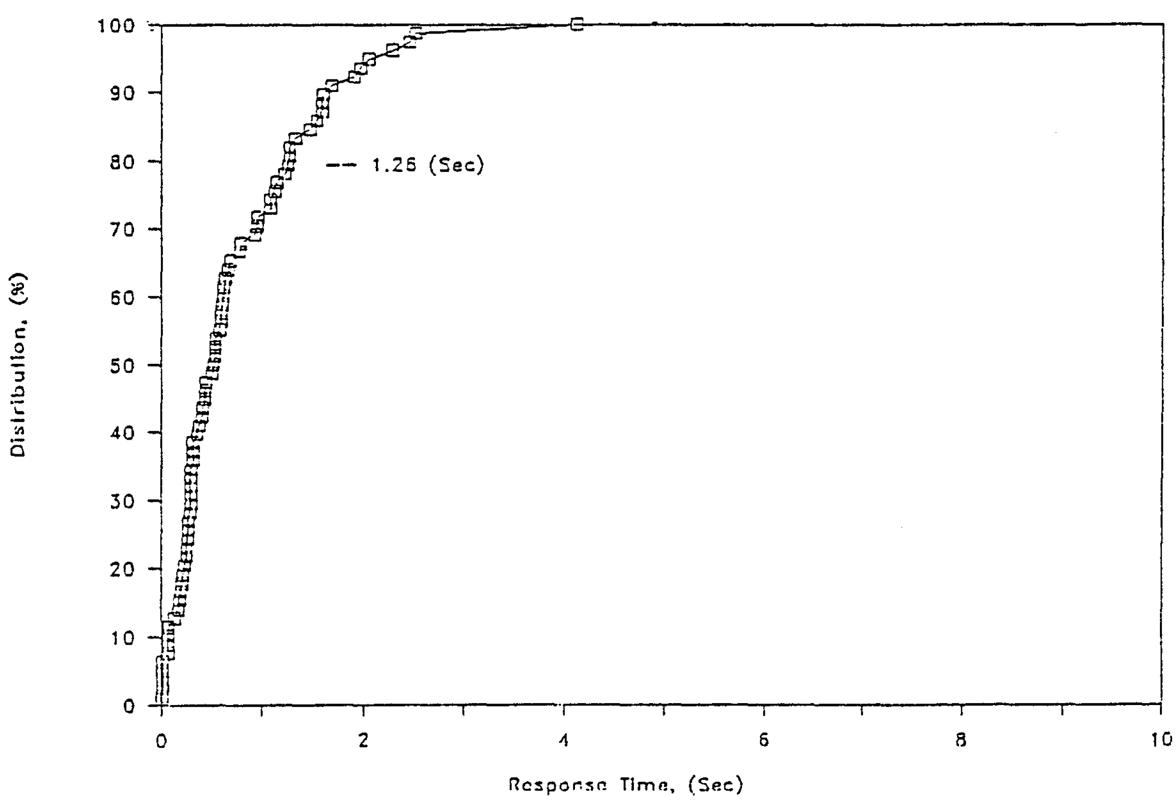


Figure 67. Distribution of correct responses, stimulus slide 42.

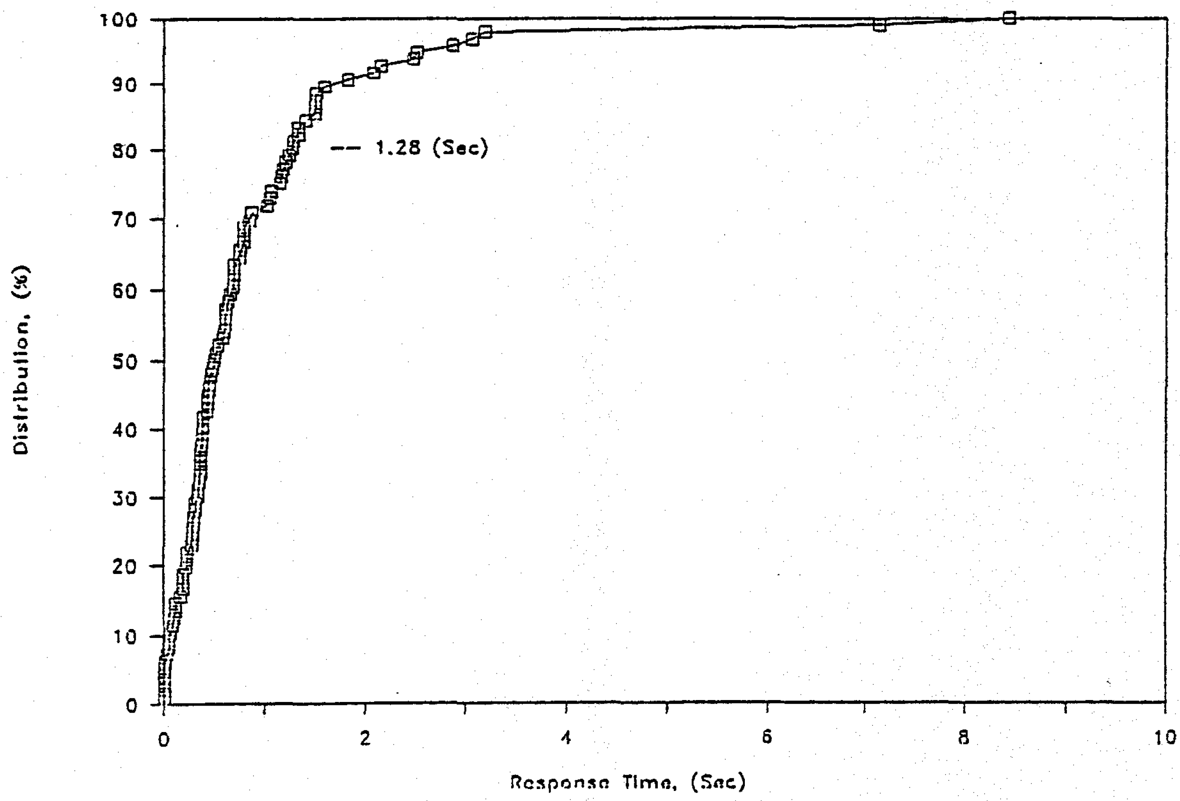


Figure 68. Distribution of correct responses, stimulus slide 43.

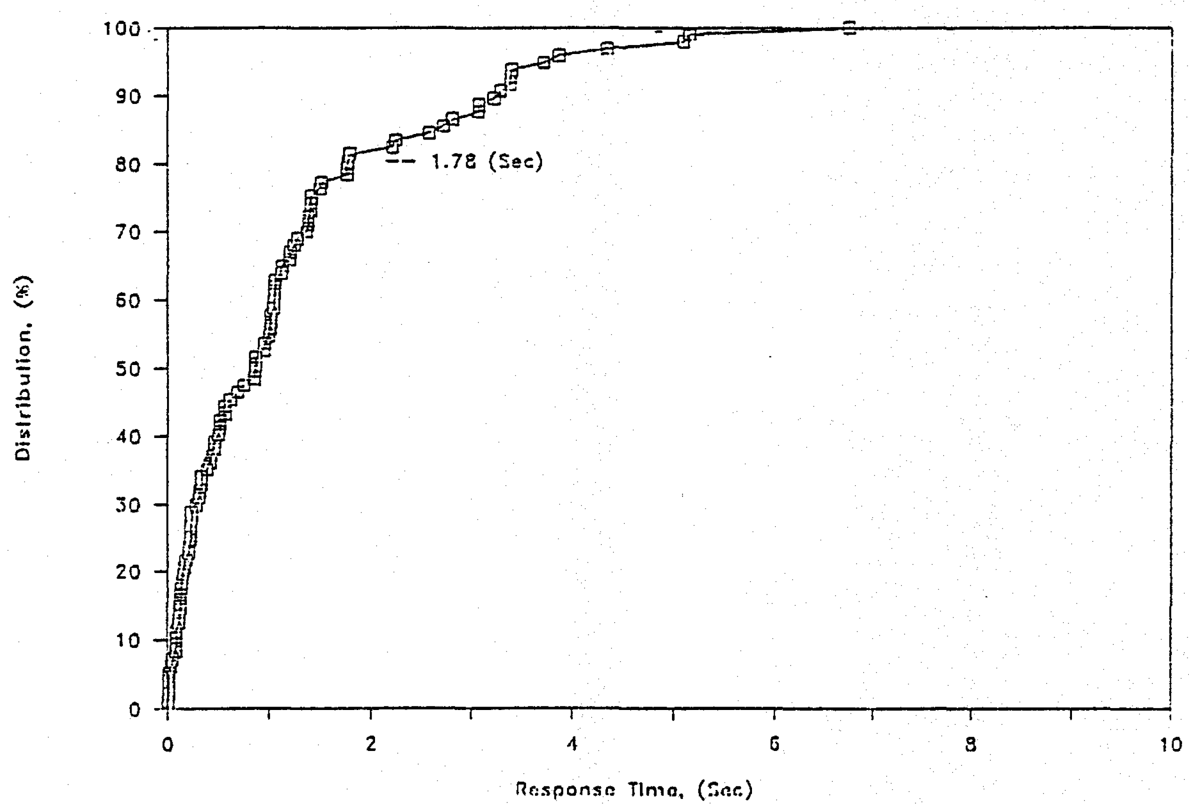


Figure 69. Distribution of correct responses, stimulus slide 44.

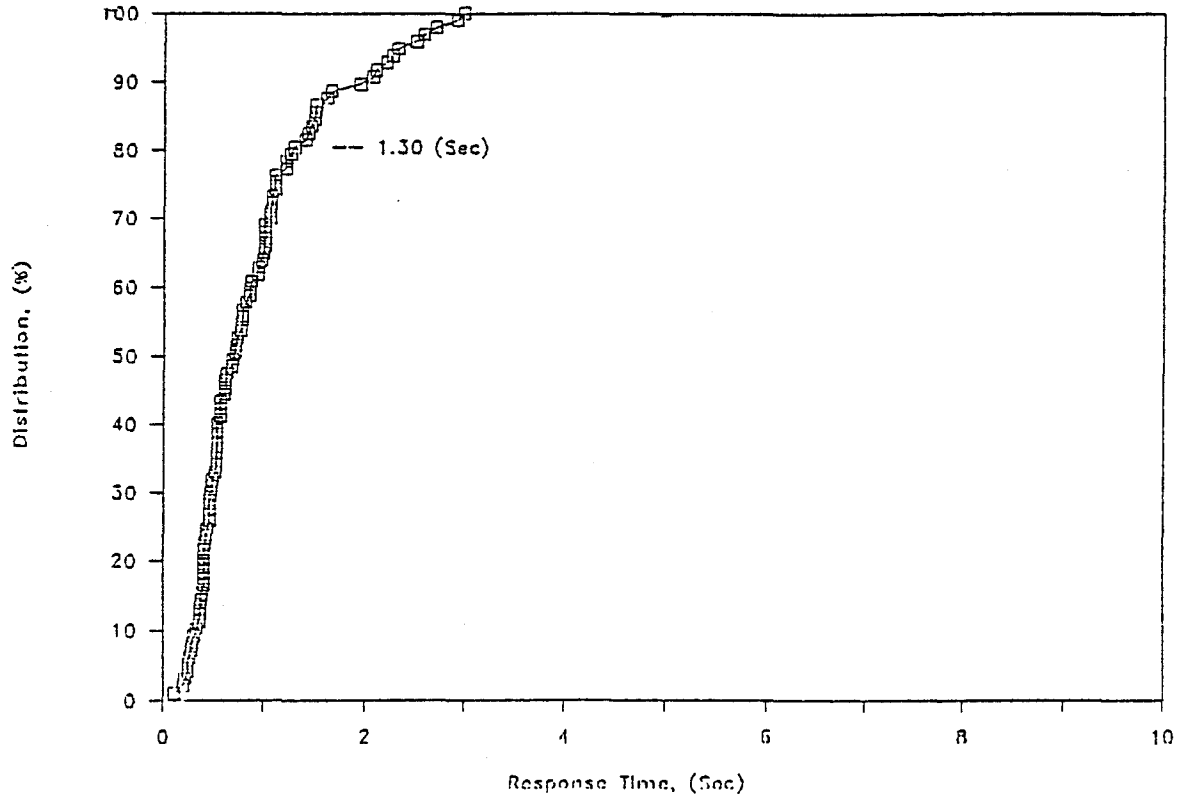


Figure 70. Distribution of correct responses, stimulus slide 45.

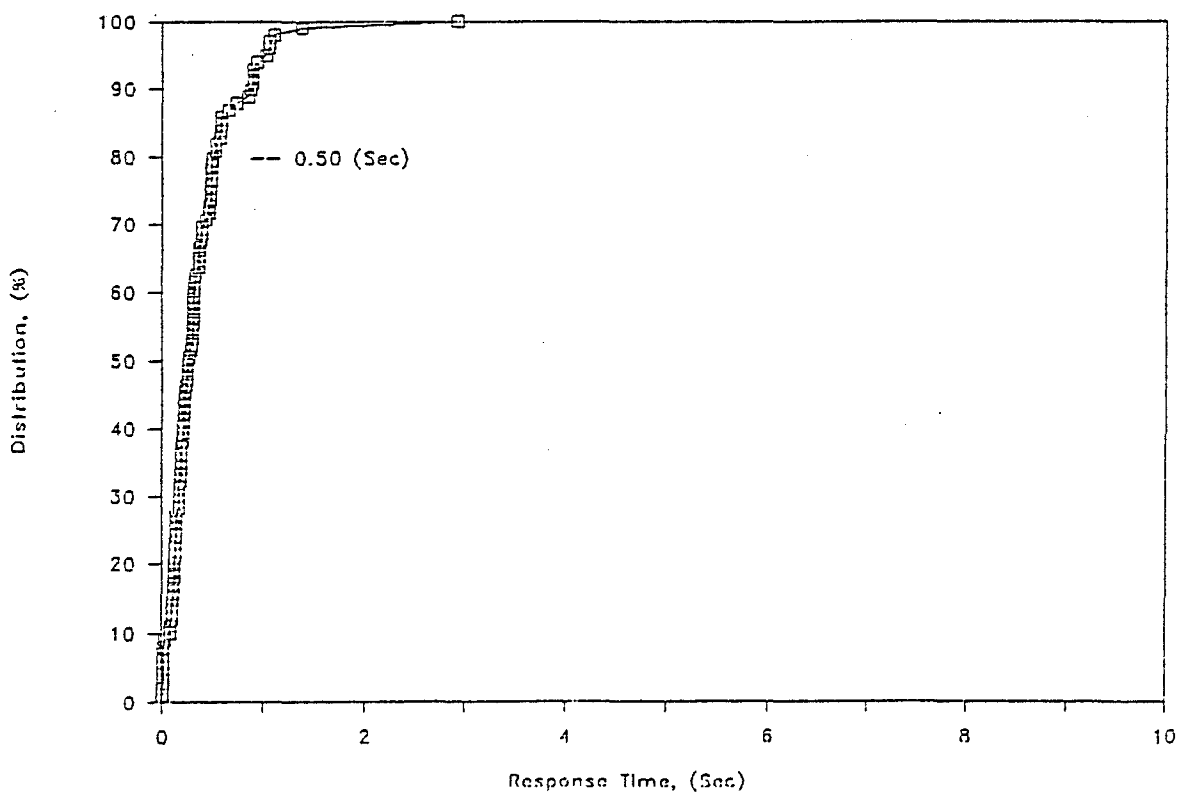


Figure 71. Distribution of correct responses, stimulus slide 46.

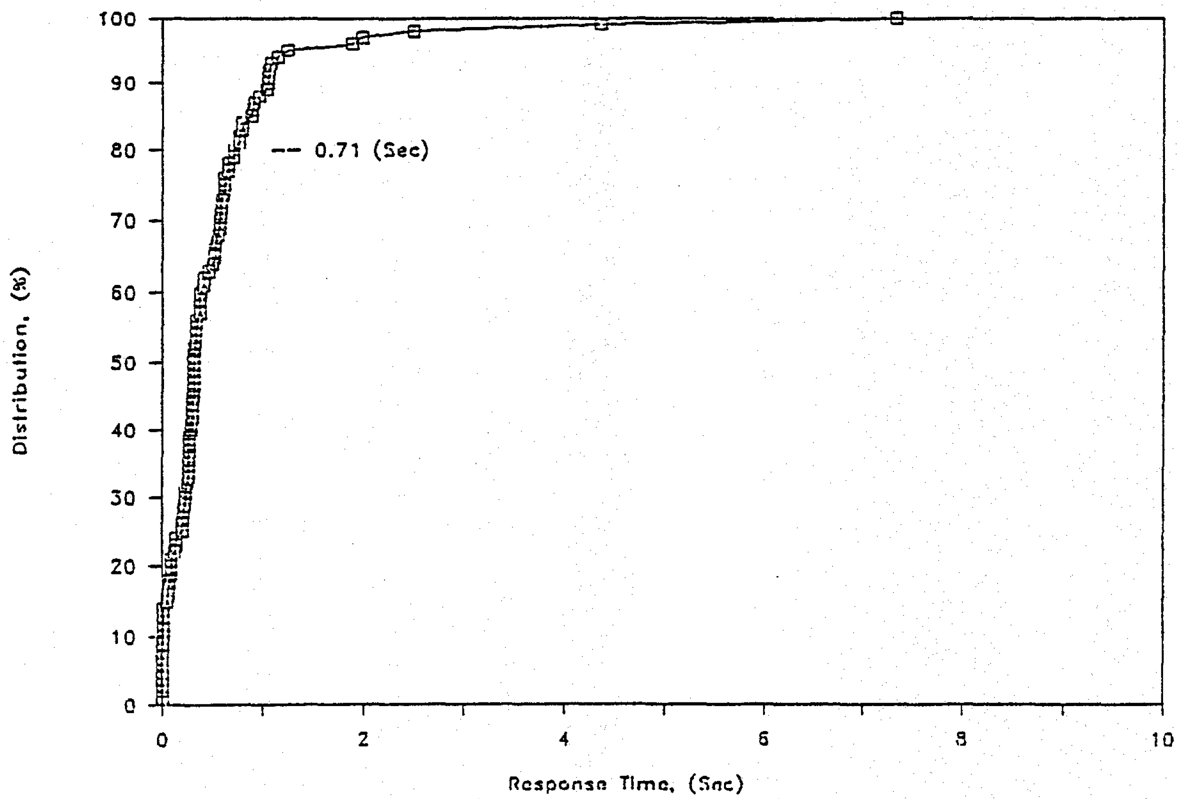


Figure 72. Distribution of correct responses, stimulus slide 47.

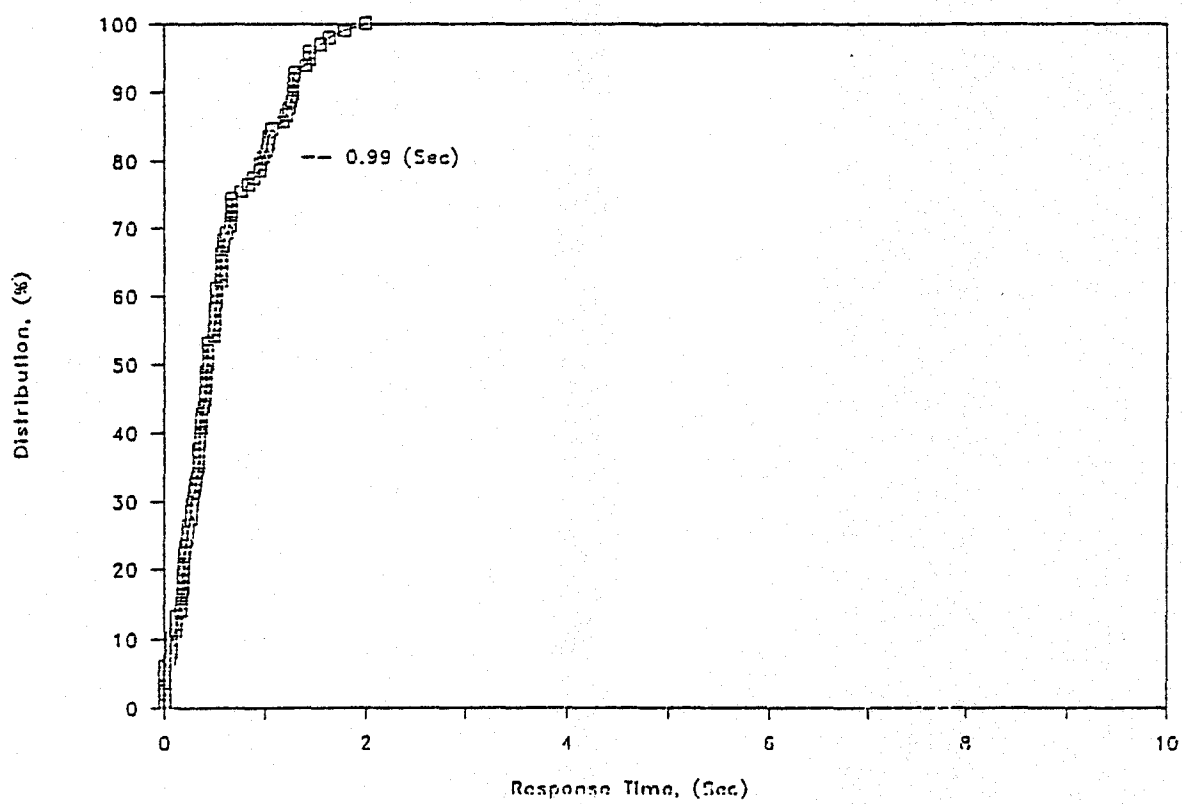


Figure 73. Distribution of correct responses, stimulus slide 48.

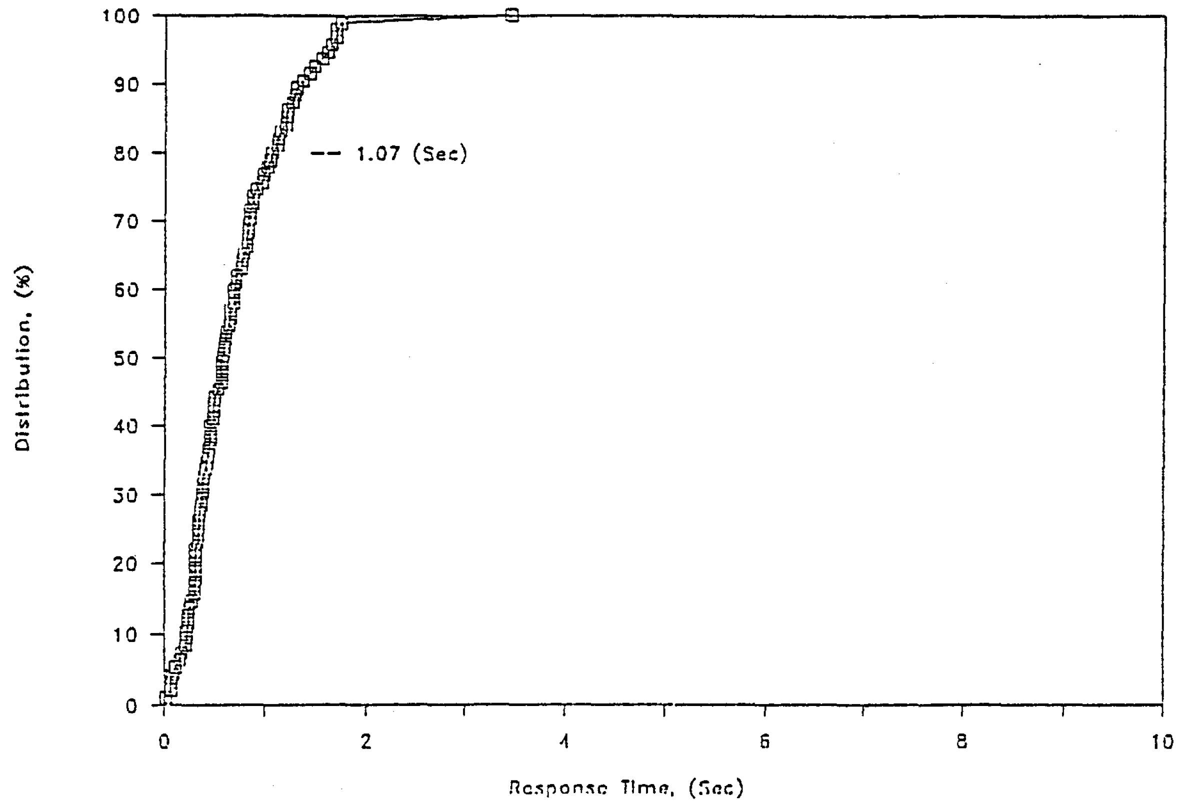


Figure 74. Distribution of correct responses, stimulus slide 49.

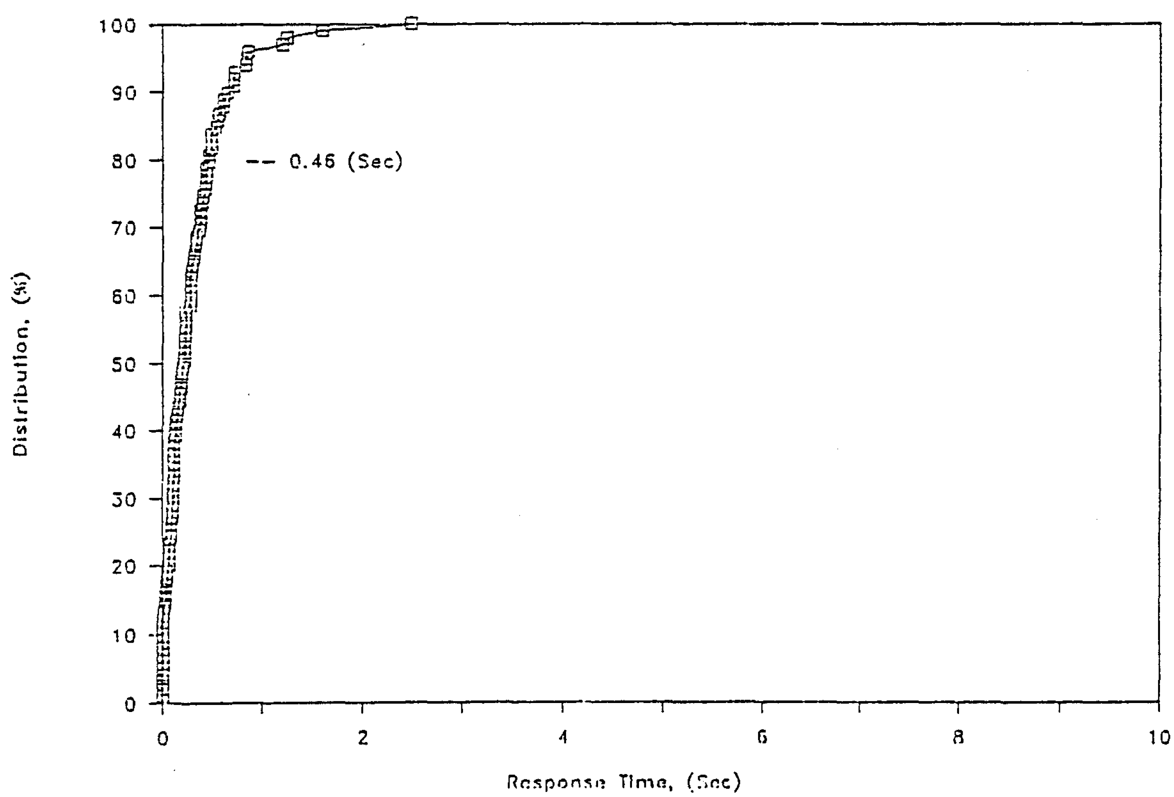


Figure 75. Distribution of correct responses, stimulus slide 50.

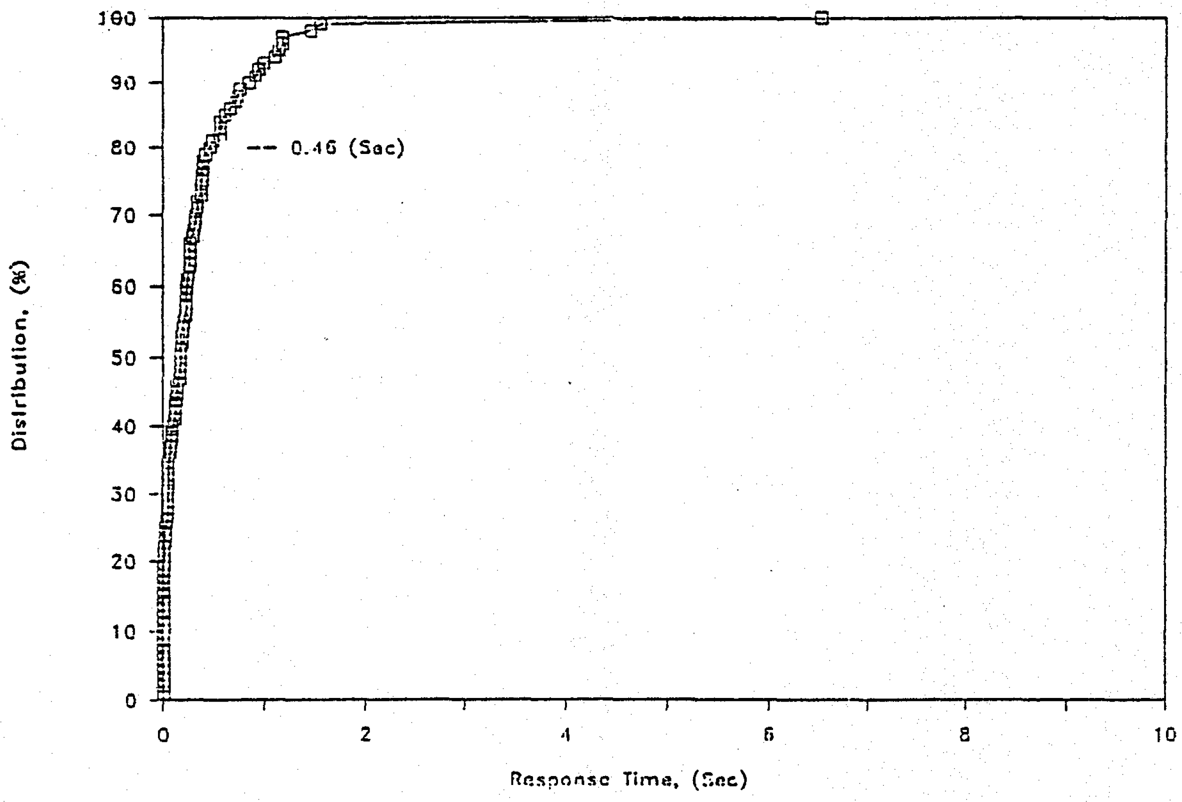


Figure 76. Distribution of correct responses, stimulus slide 51.

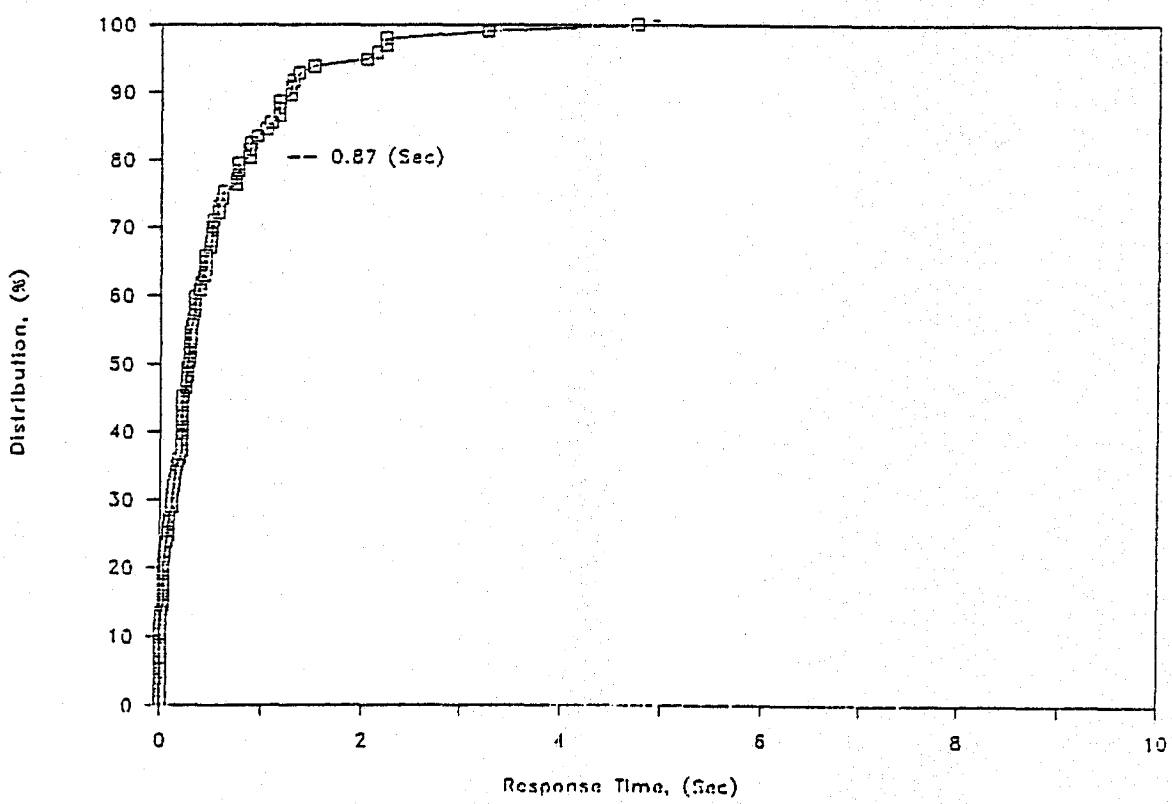


Figure 77. Distribution of correct responses, stimulus slide 52.

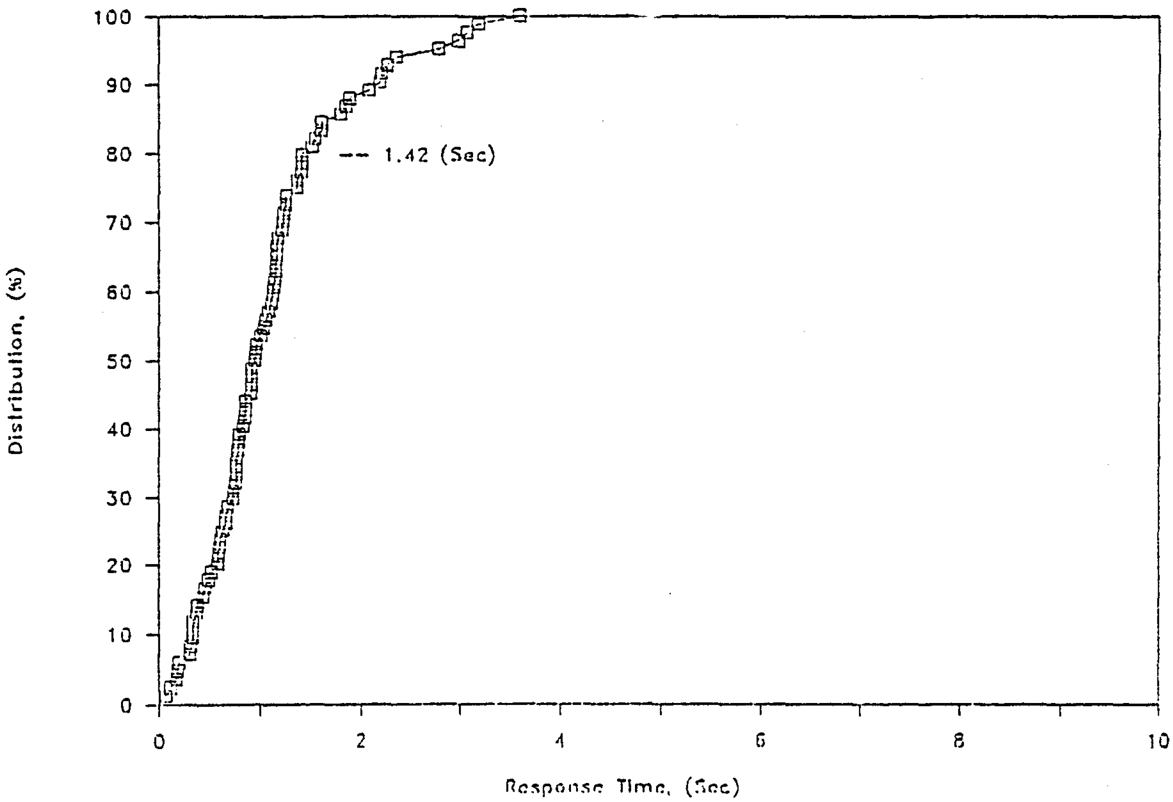


Figure 78. Distribution of correct responses, stimulus slide 53.

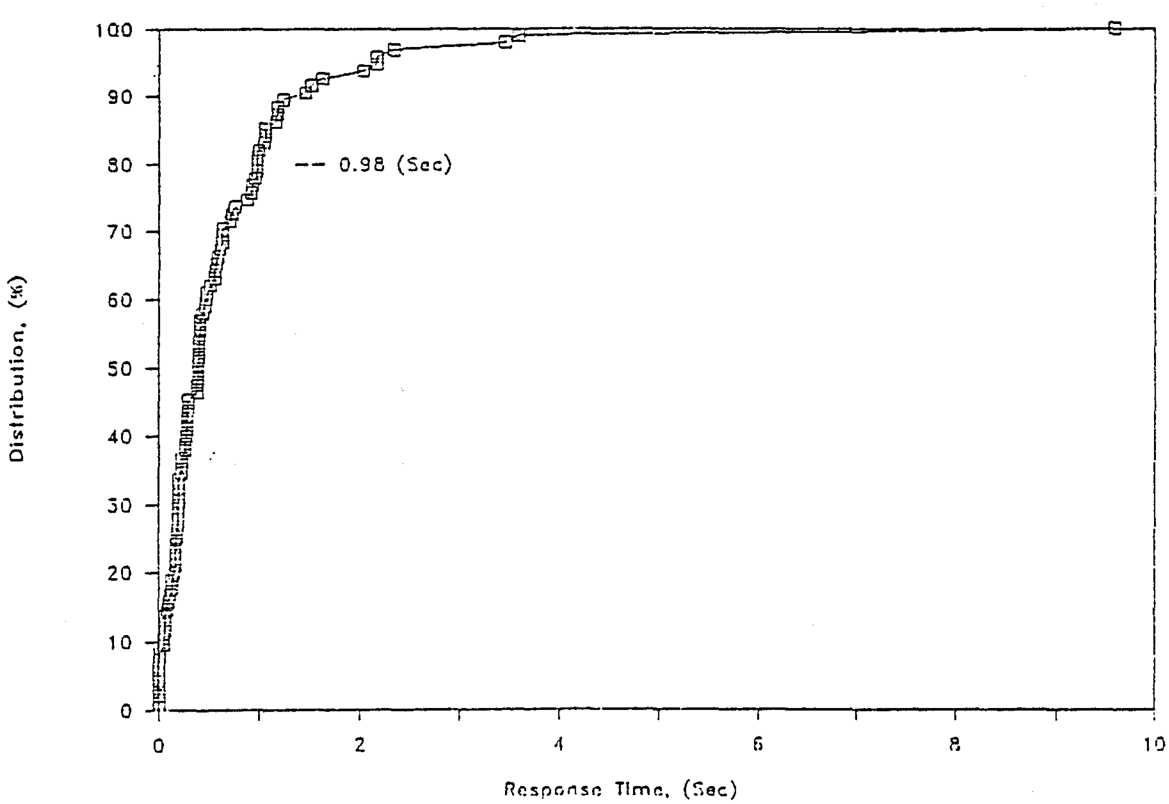


Figure 79. Distribution of correct responses, stimulus slide 54.

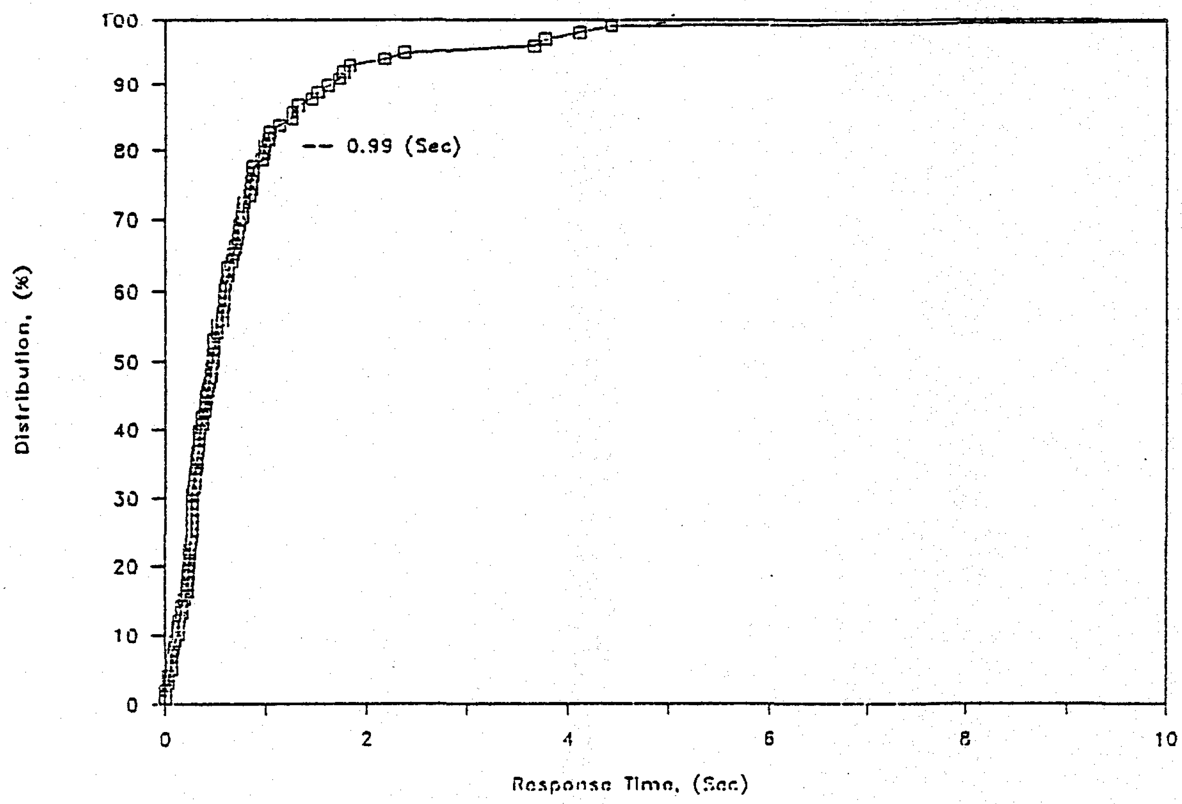


Figure 80. Distribution of correct responses, stimulus slide 55.

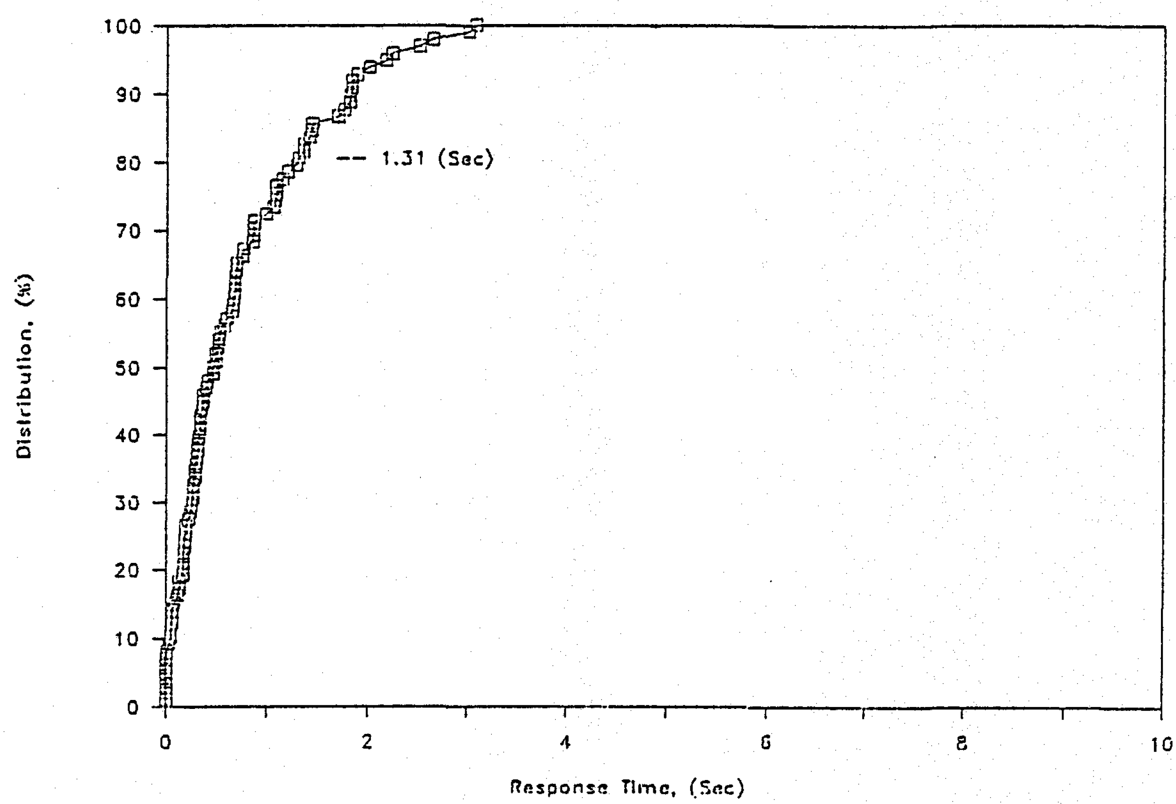


Figure 81. Distribution of correct responses, stimulus slide 56.

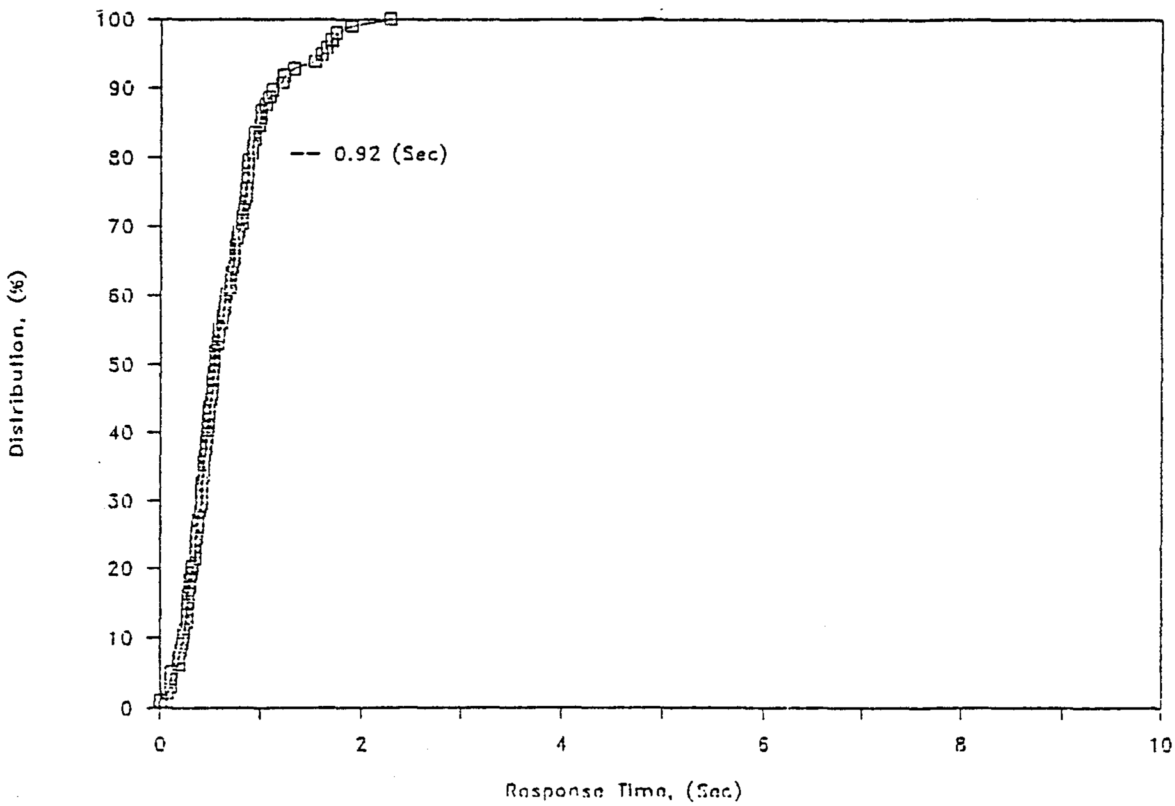


Figure 82. Distribution of correct responses, stimulus slide 57.

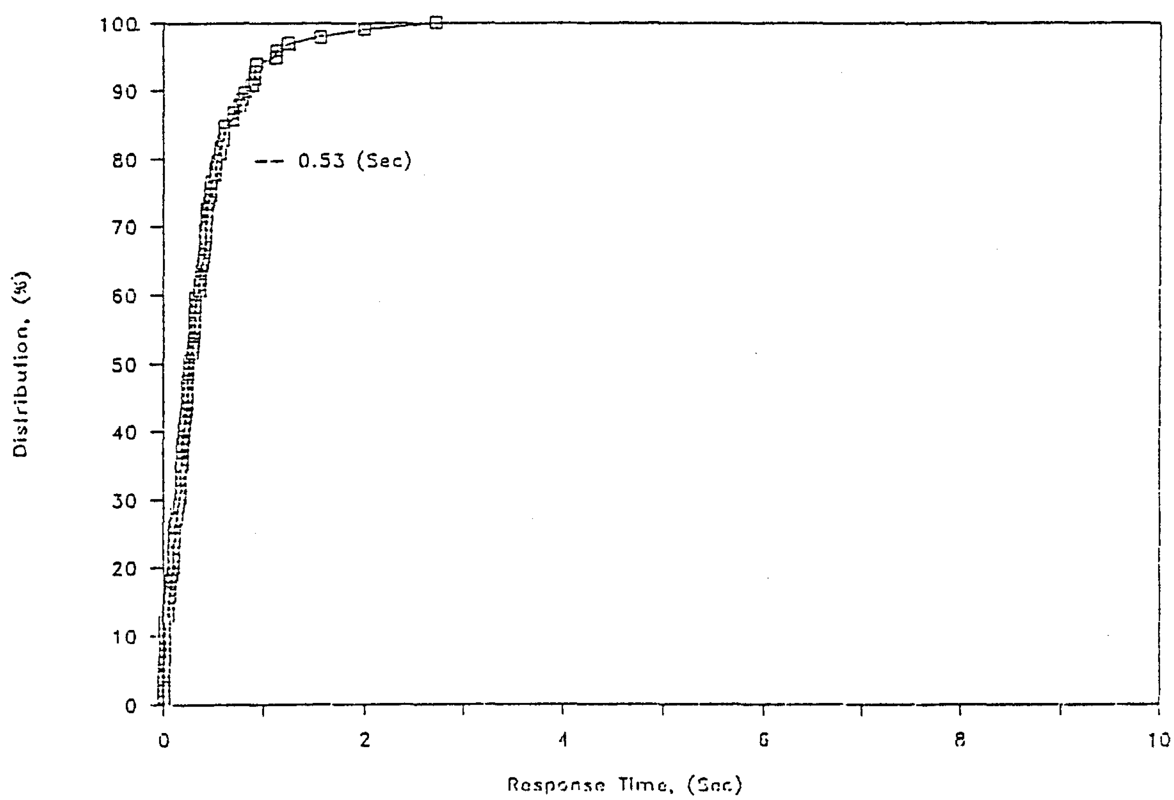


Figure 83. Distribution of correct responses, stimulus slide 58.

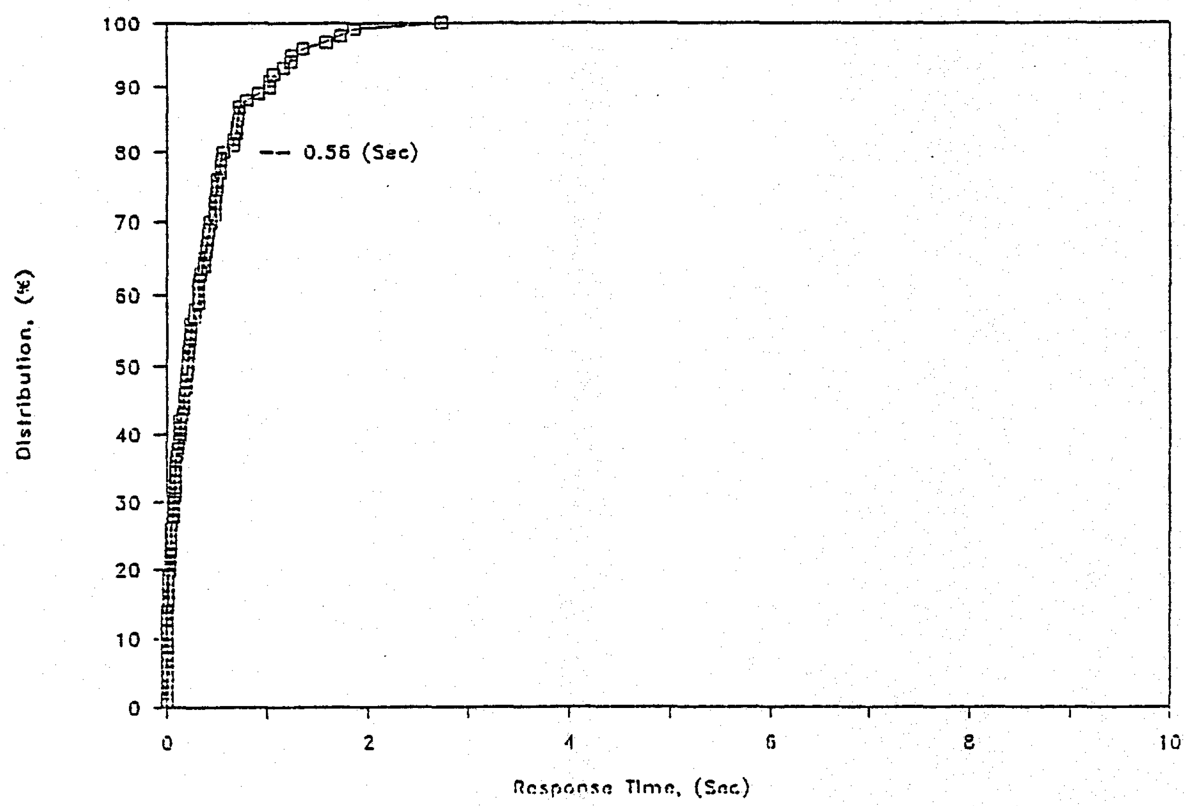


Figure 84. Distribution of correct responses, stimulus slide 59.

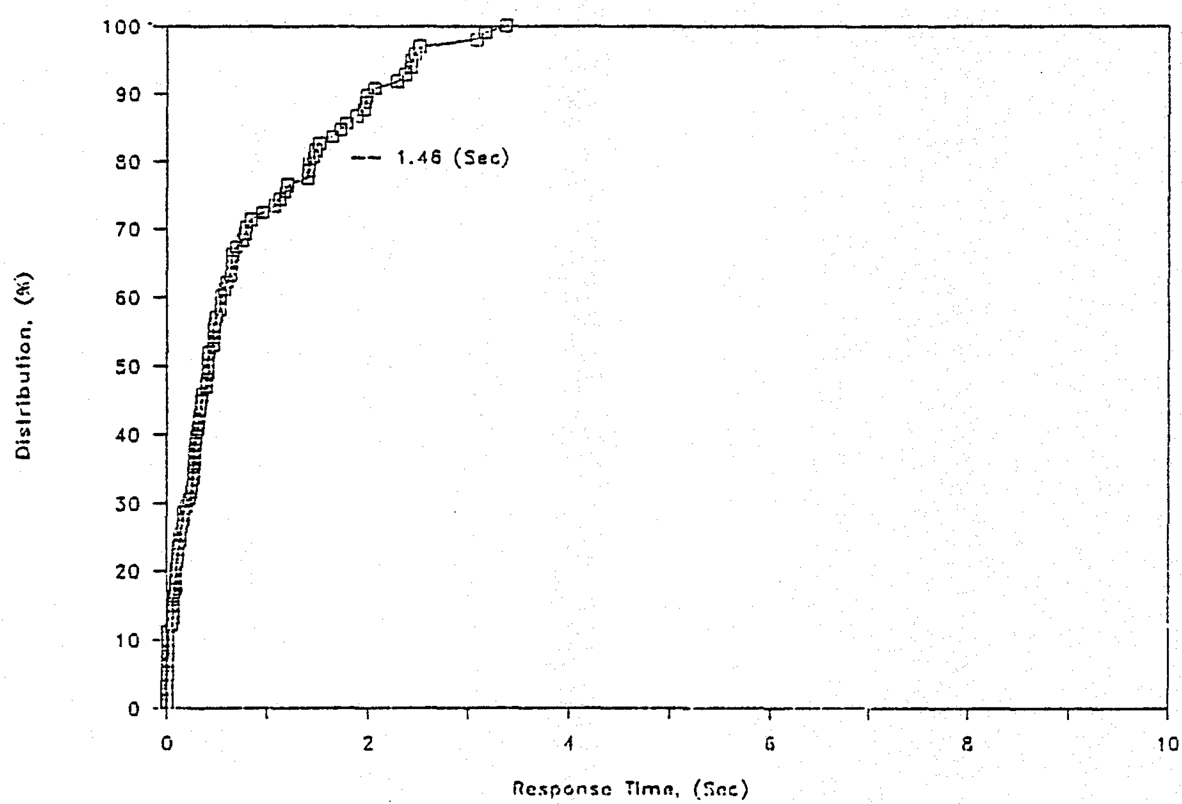


Figure 85. Distribution of correct responses, stimulus slide 60.

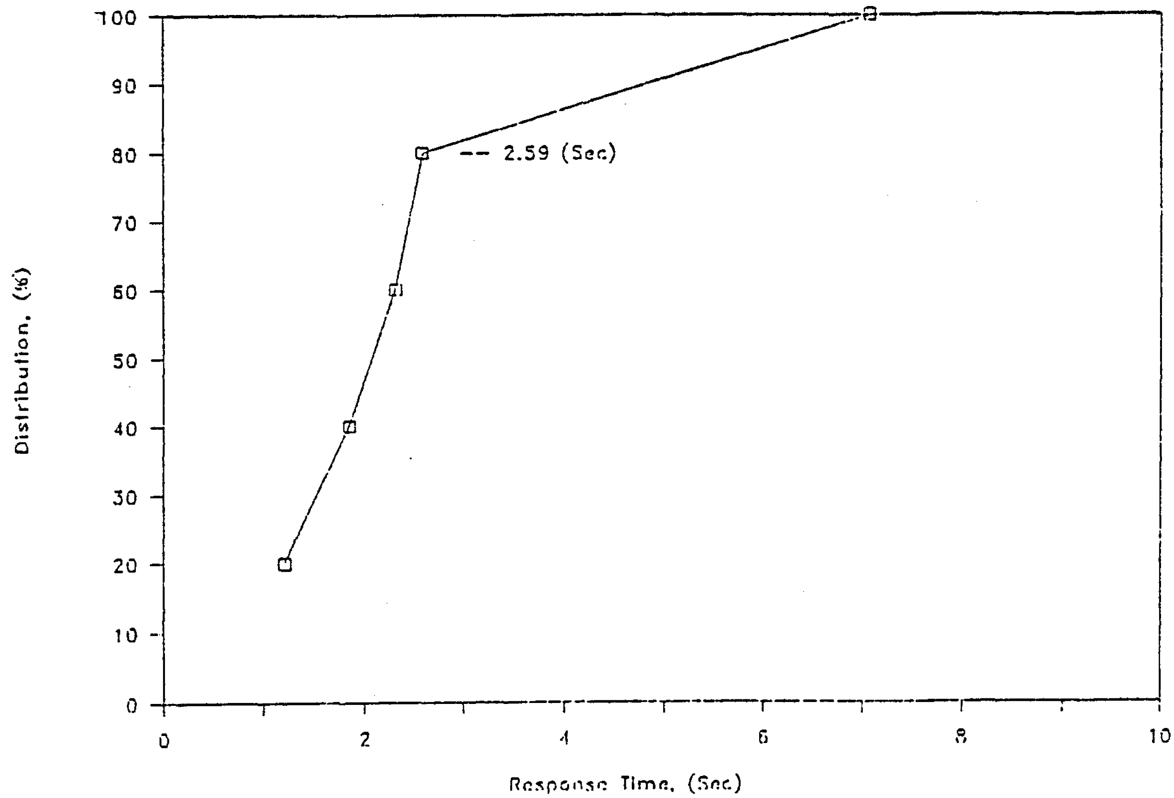


Figure 86. Distribution of correct responses, stimulus slide 61.

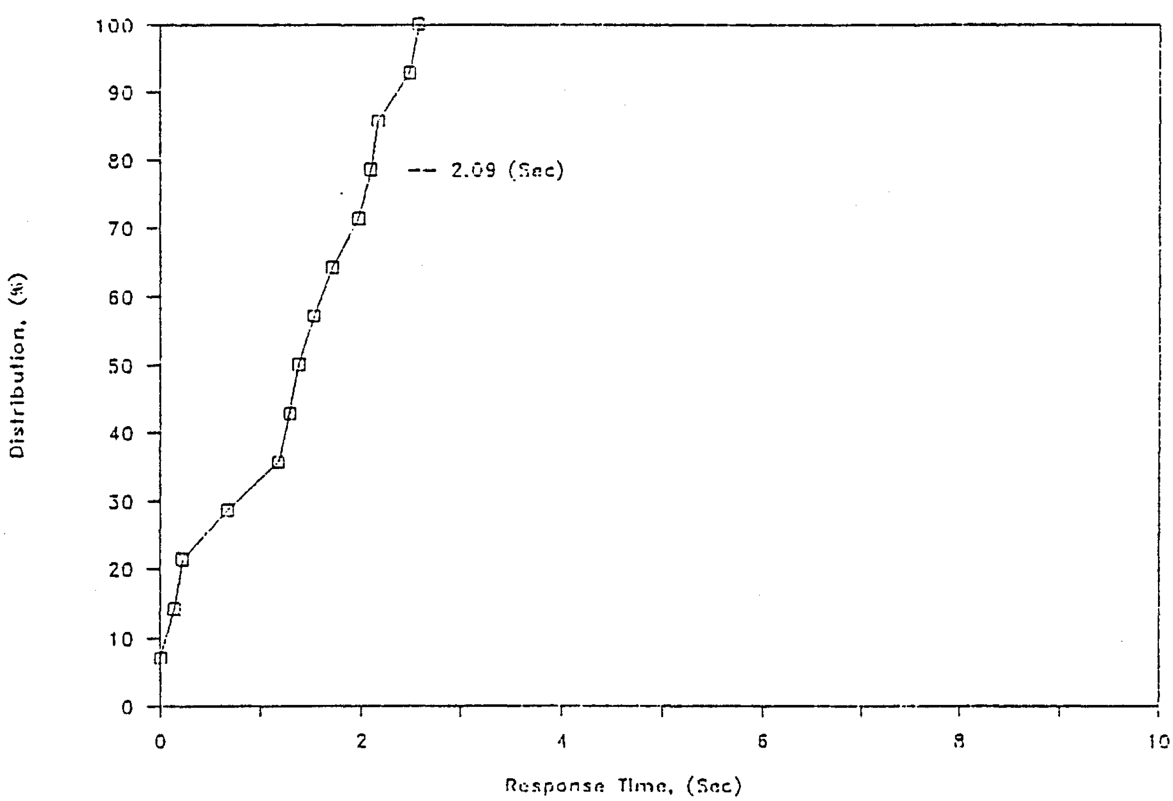


Figure 87. Distribution of correct responses, stimulus slide 62.

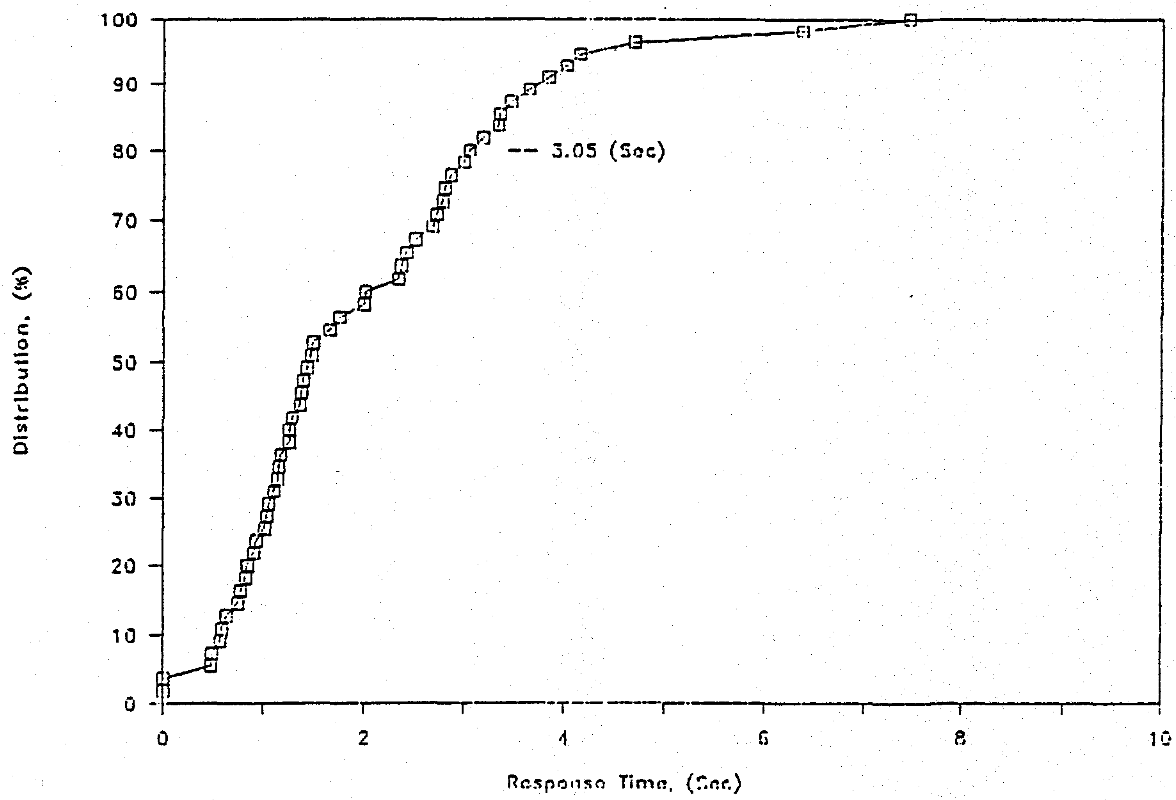


Figure 88. Distribution of correct responses, stimulus slide 63.

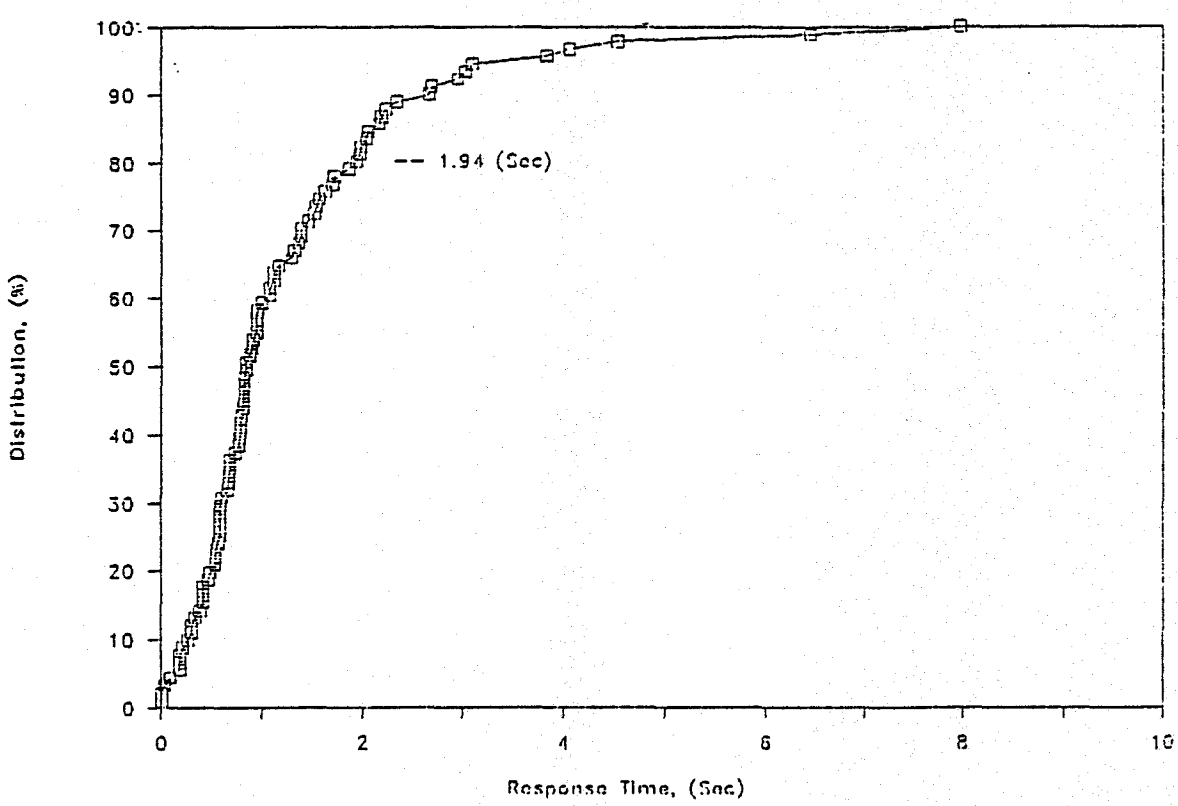


Figure 89. Distribution of correct responses, stimulus slide 64.

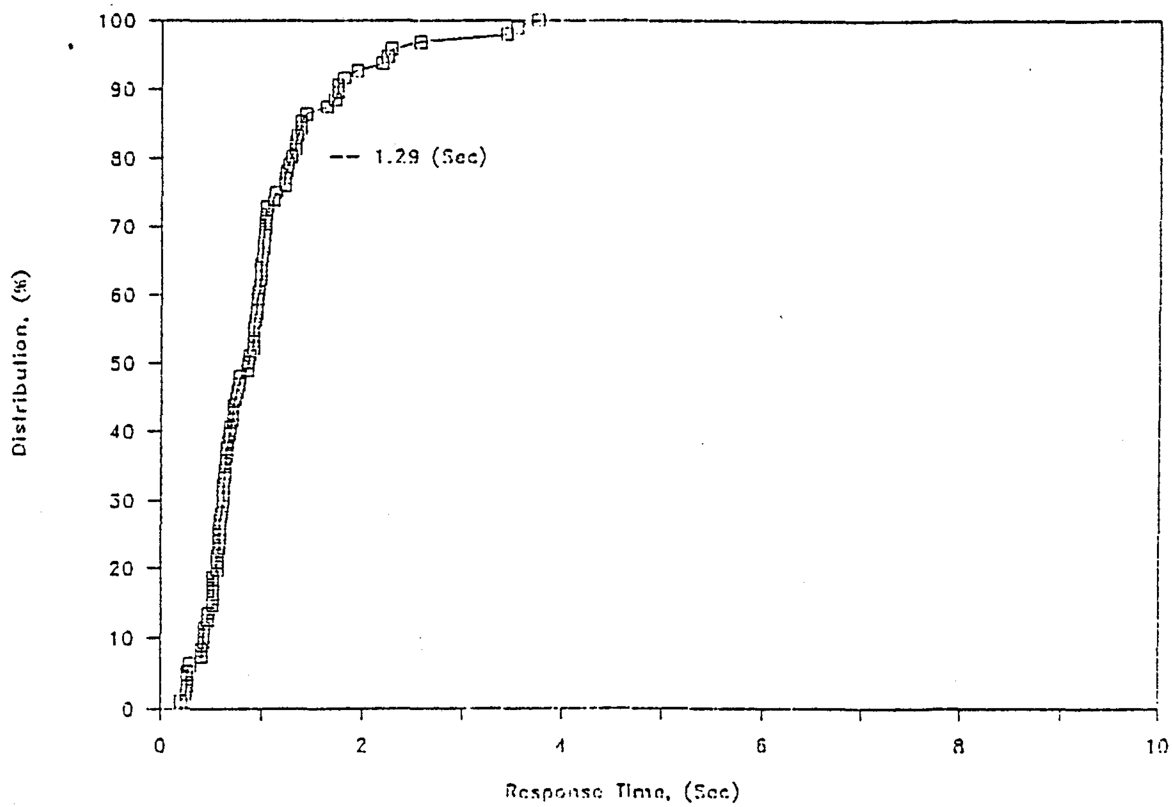


Figure 90. Distribution of correct responses, stimulus slide 65.

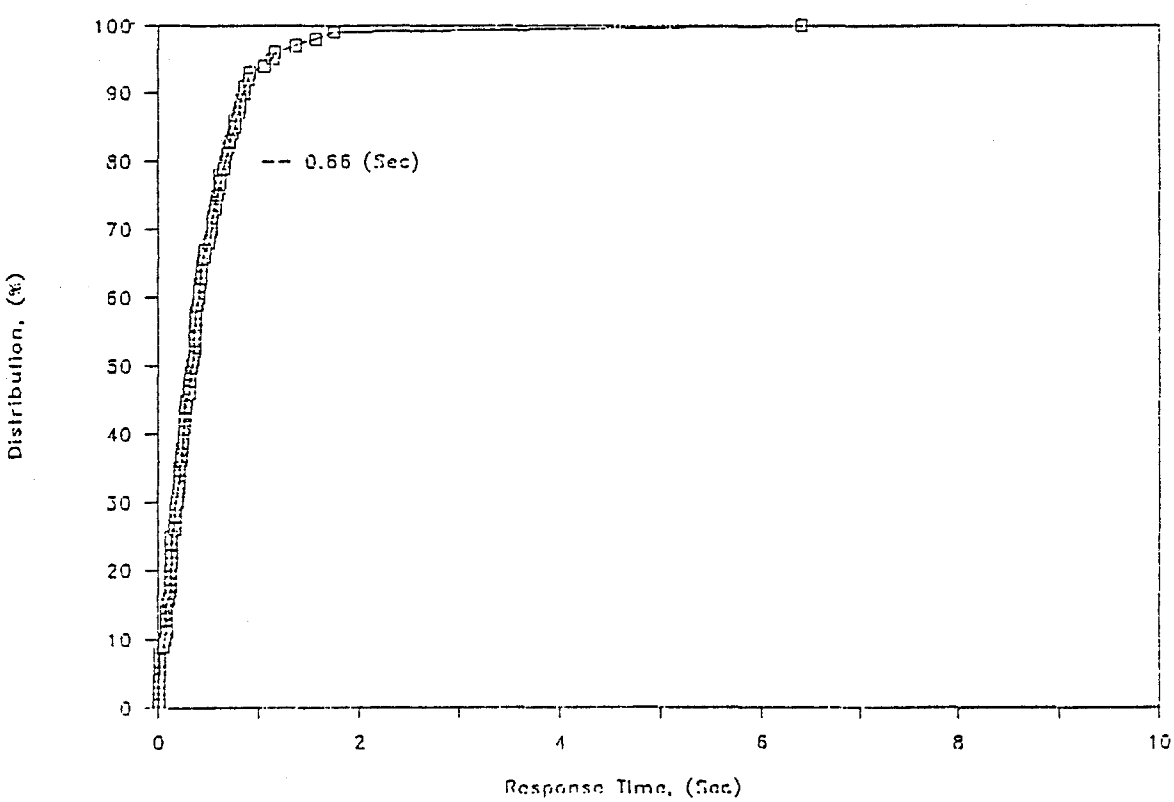


Figure 91. Distribution of correct responses, stimulus slide 66.

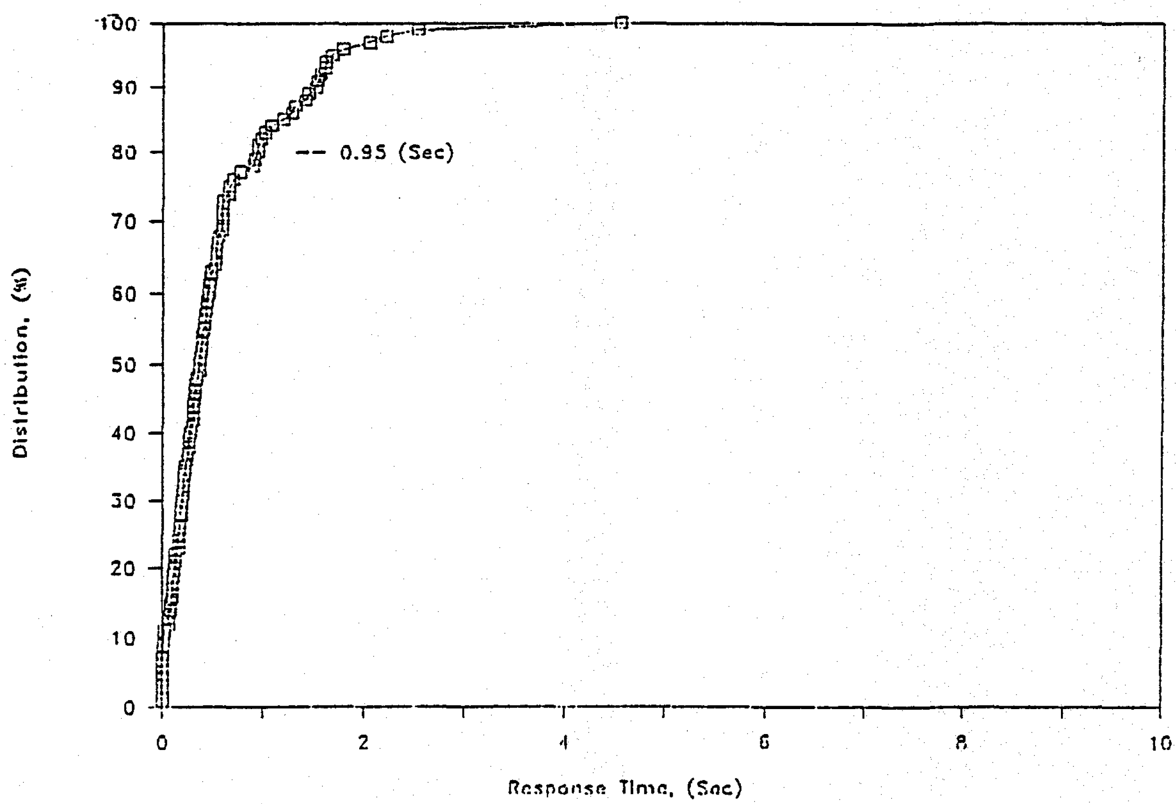


Figure 92. Distribution of correct responses, stimulus slide 67.

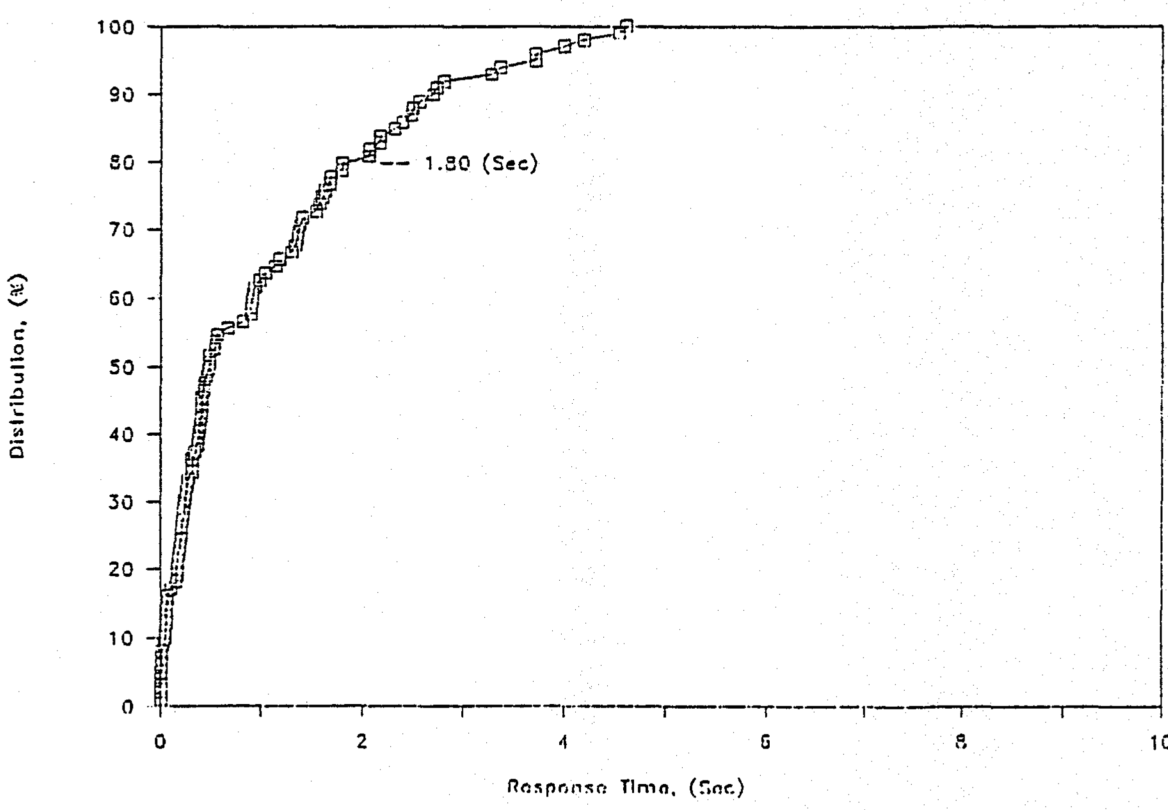


Figure 93. Distribution of correct responses, stimulus slide 68.

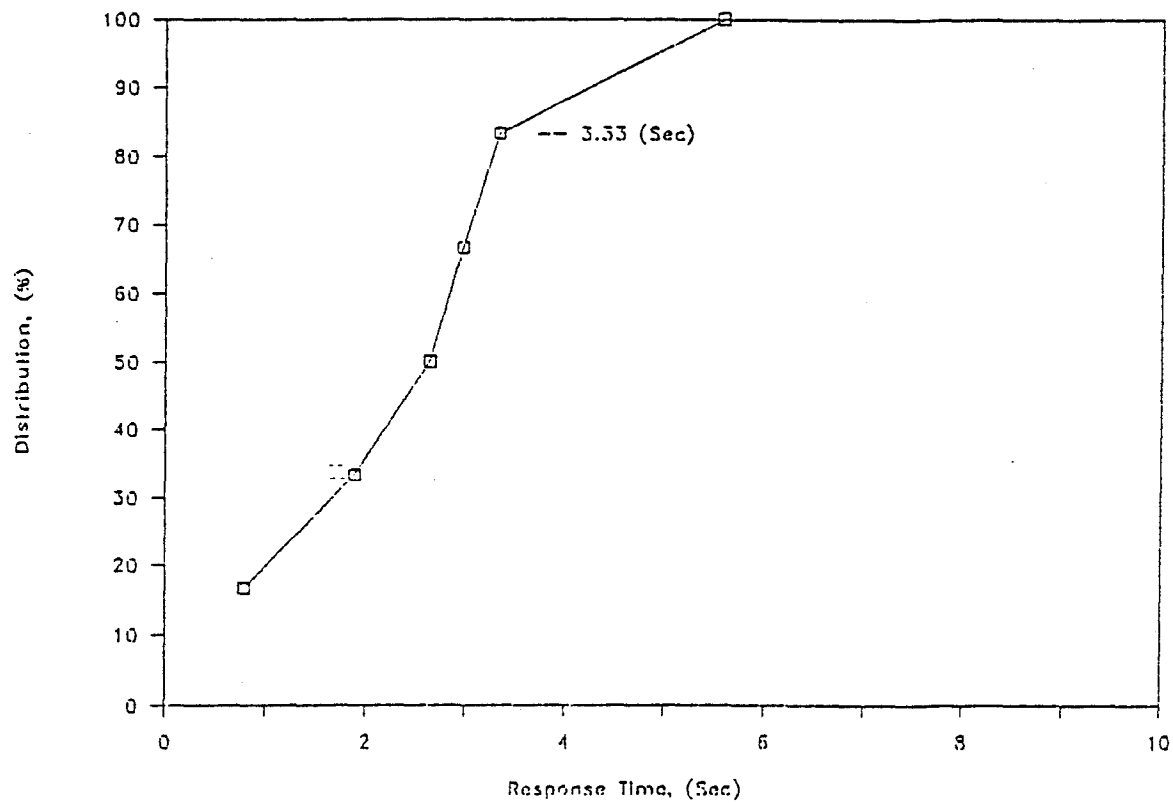


Figure 94. Distribution of correct responses, stimulus slide 69.

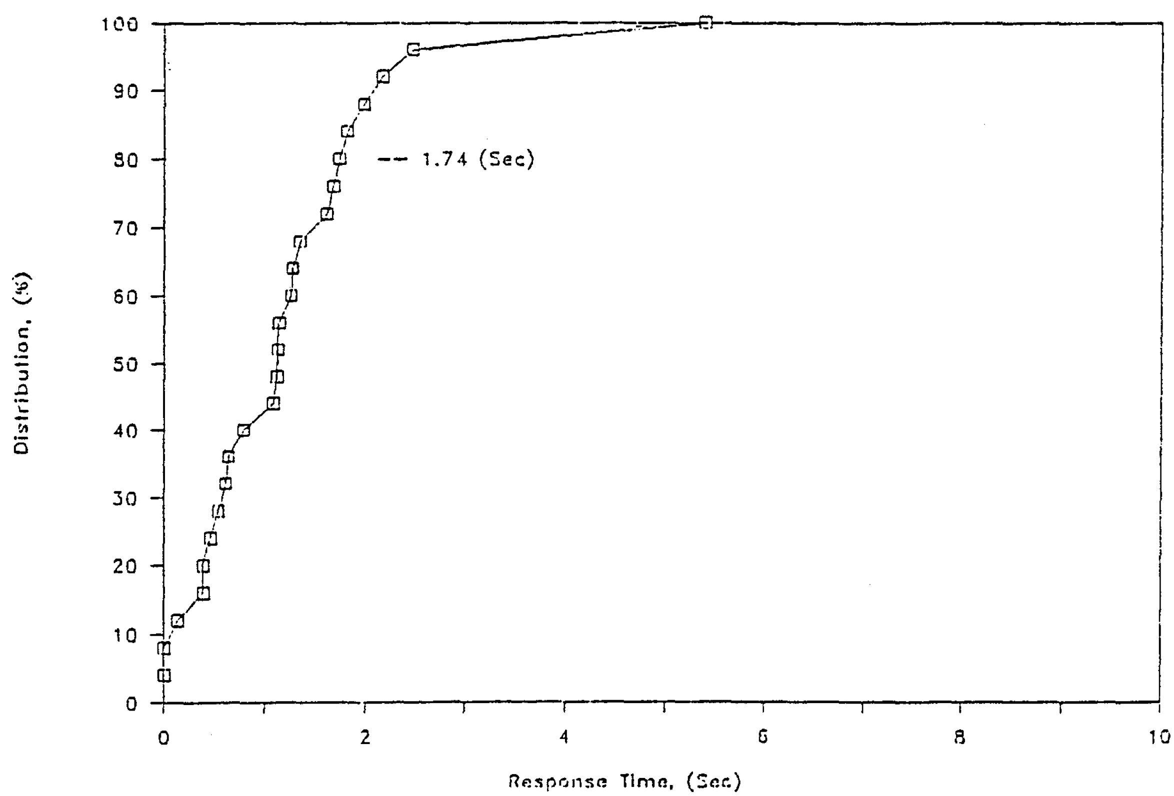


Figure 95. Distribution of correct responses, stimulus slide 70.

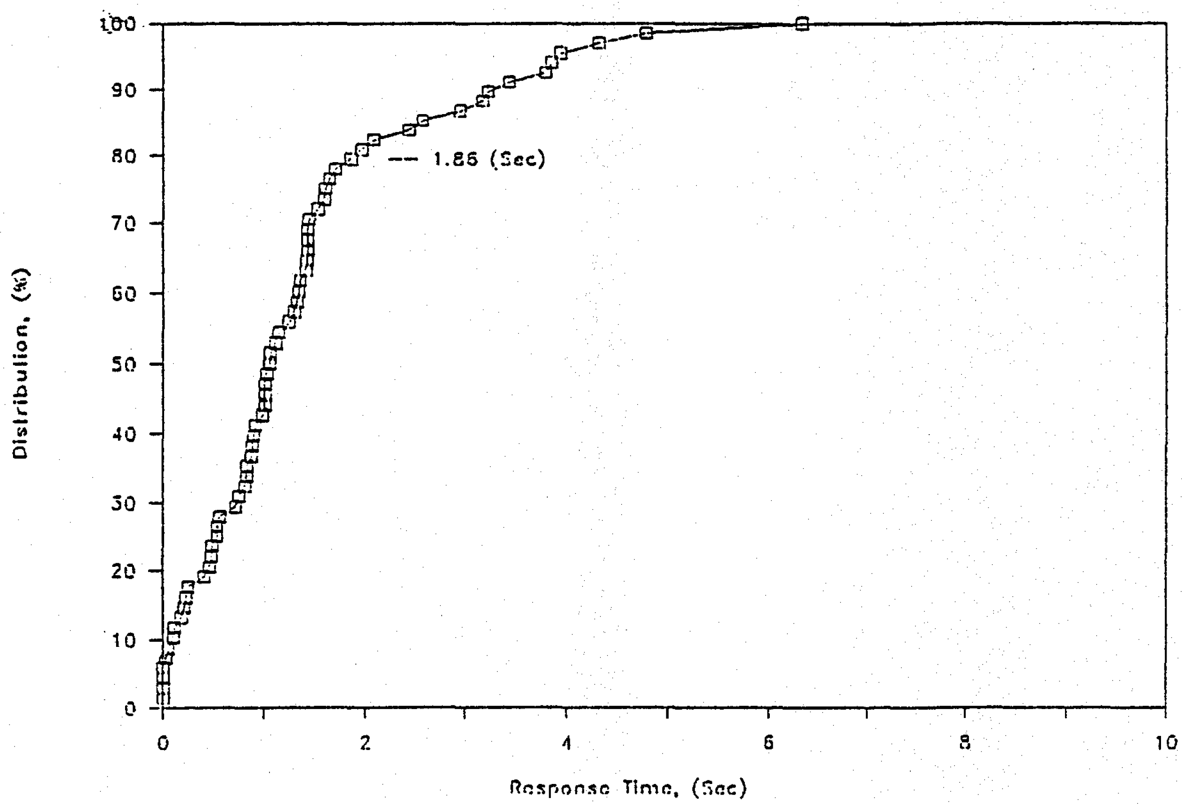


Figure 96. Distribution of correct responses, stimulus slide 71.

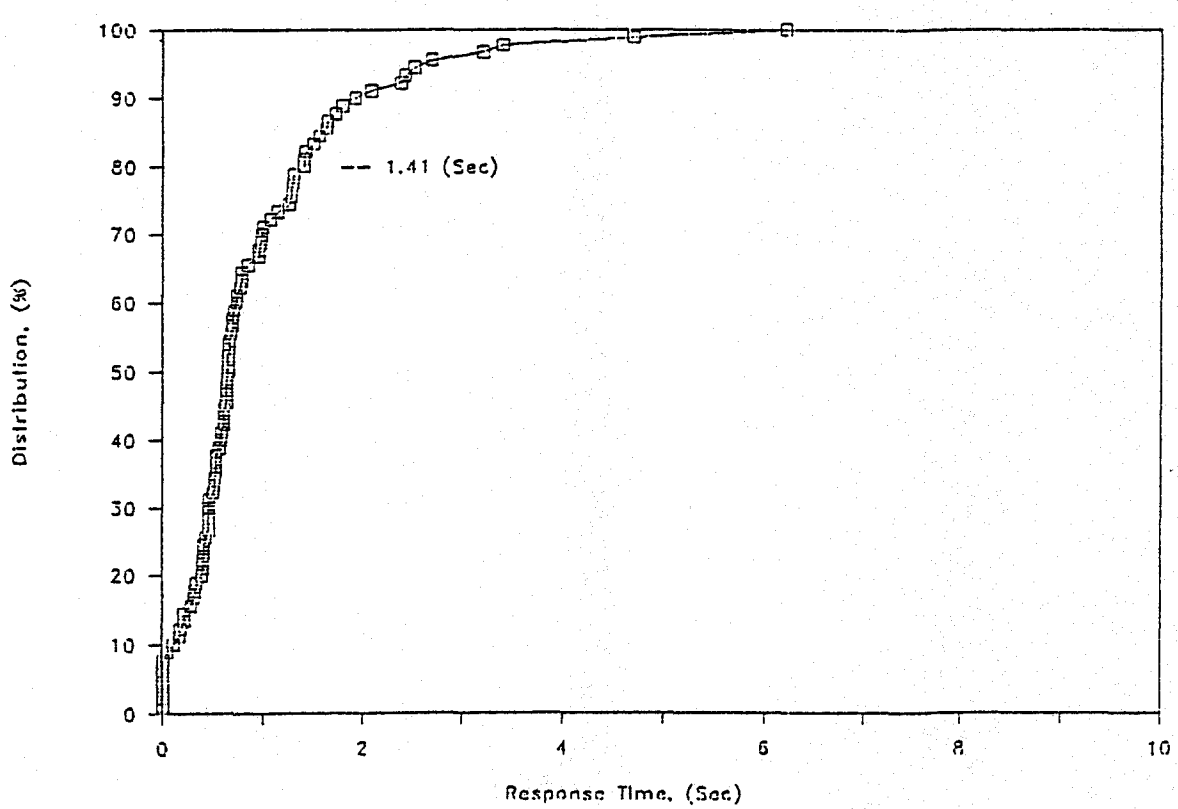


Figure 97. Distribution of correct responses, stimulus slide 72.

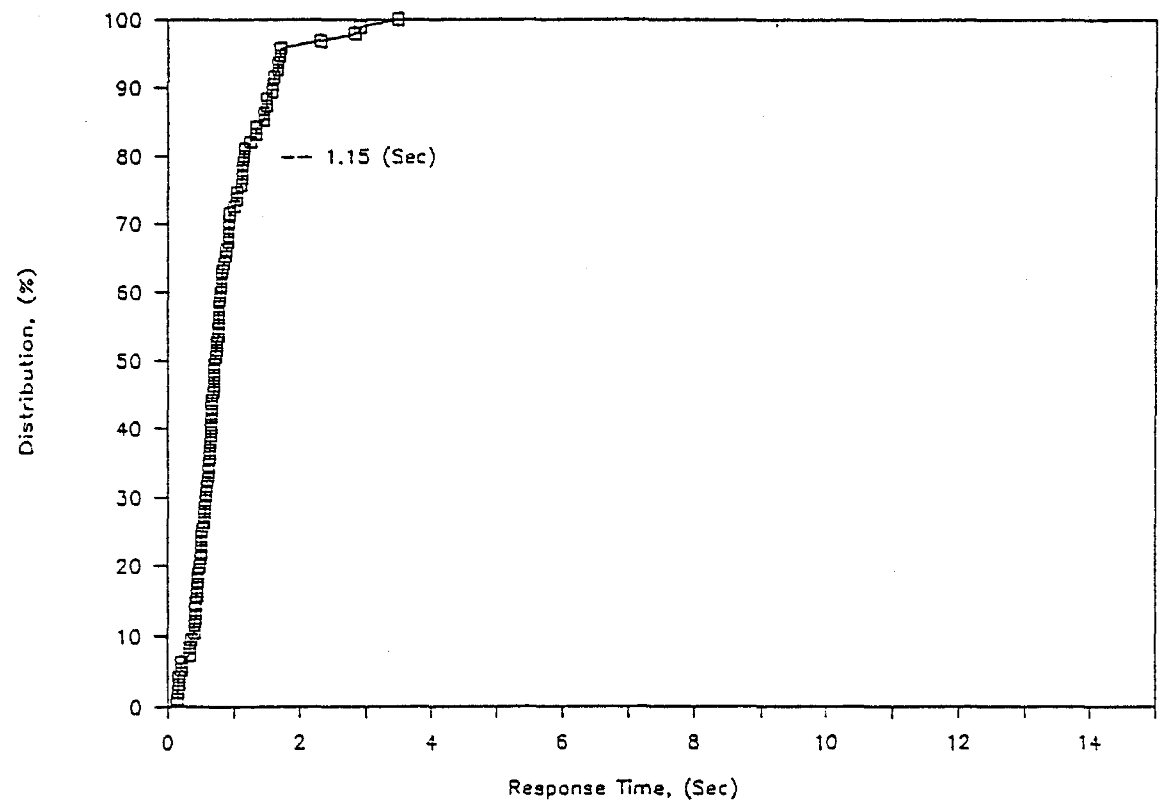


Figure 98. Distribution of correct responses, stimulus slide 73.

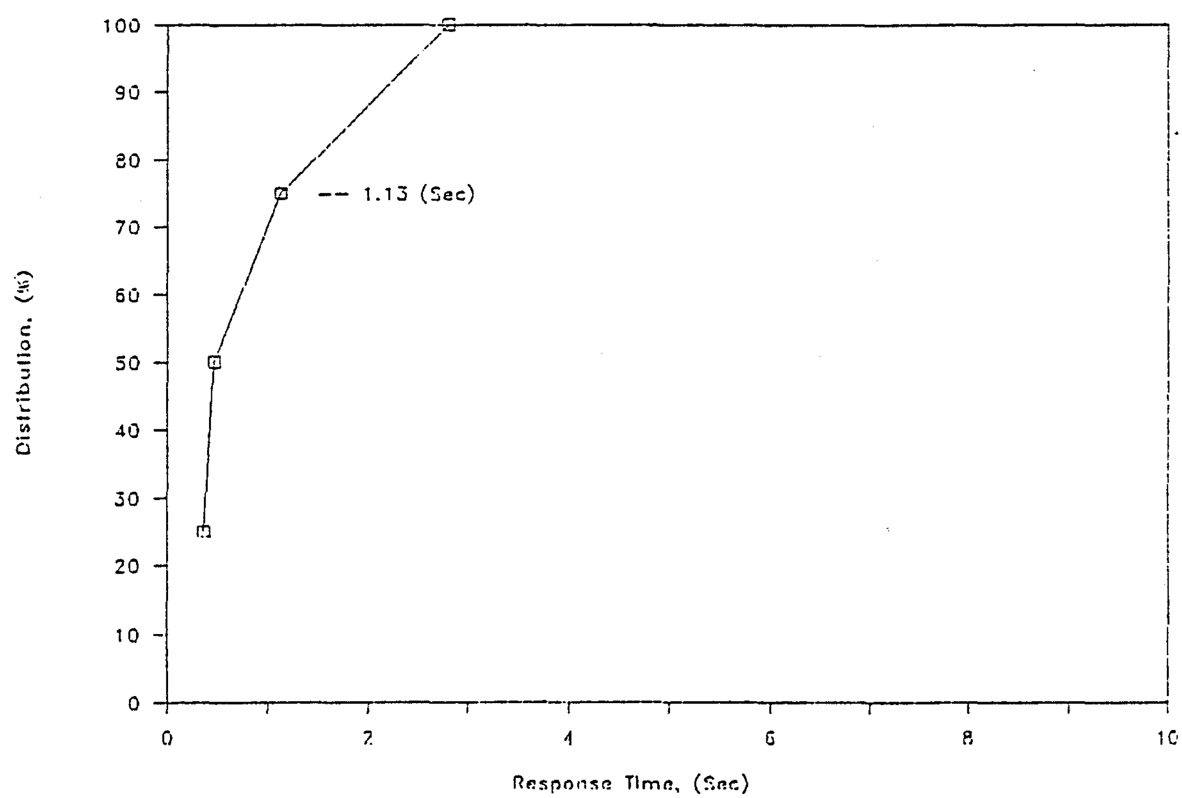


Figure 99. Distribution of correct responses, stimulus slide 74.

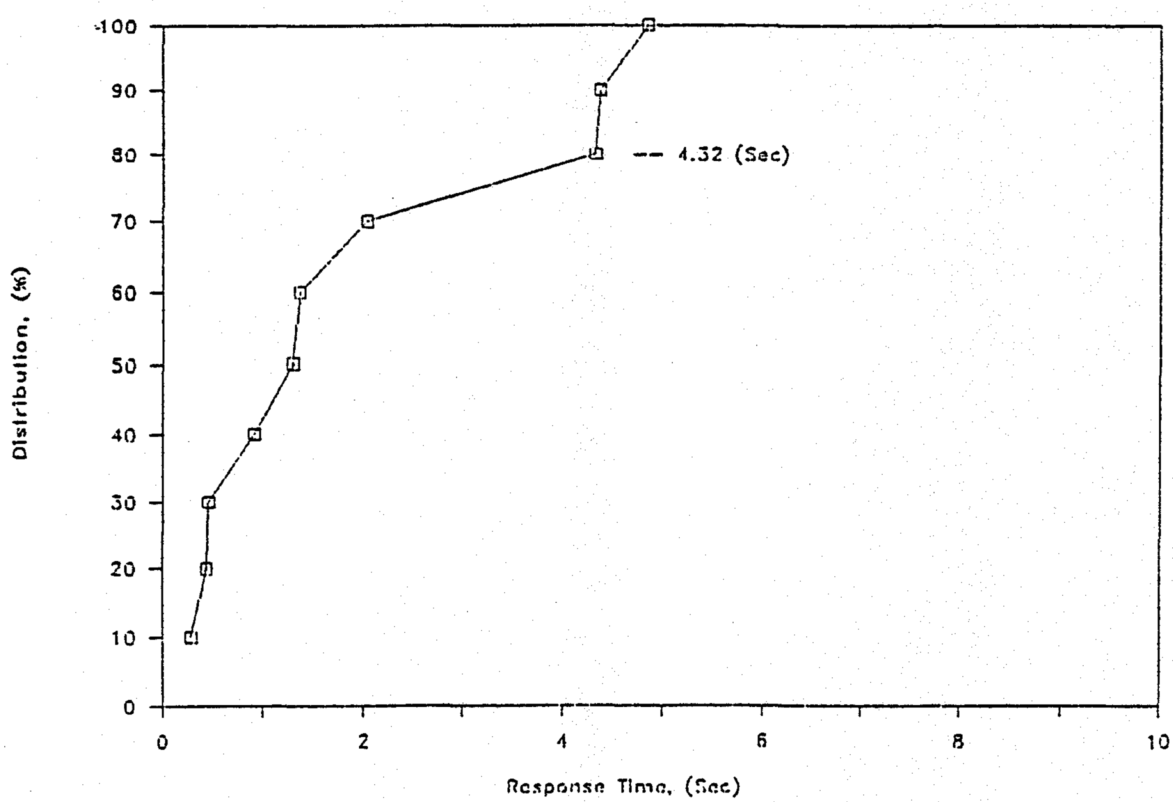


Figure 100. Distribution of correct responses, stimulus slide 75.

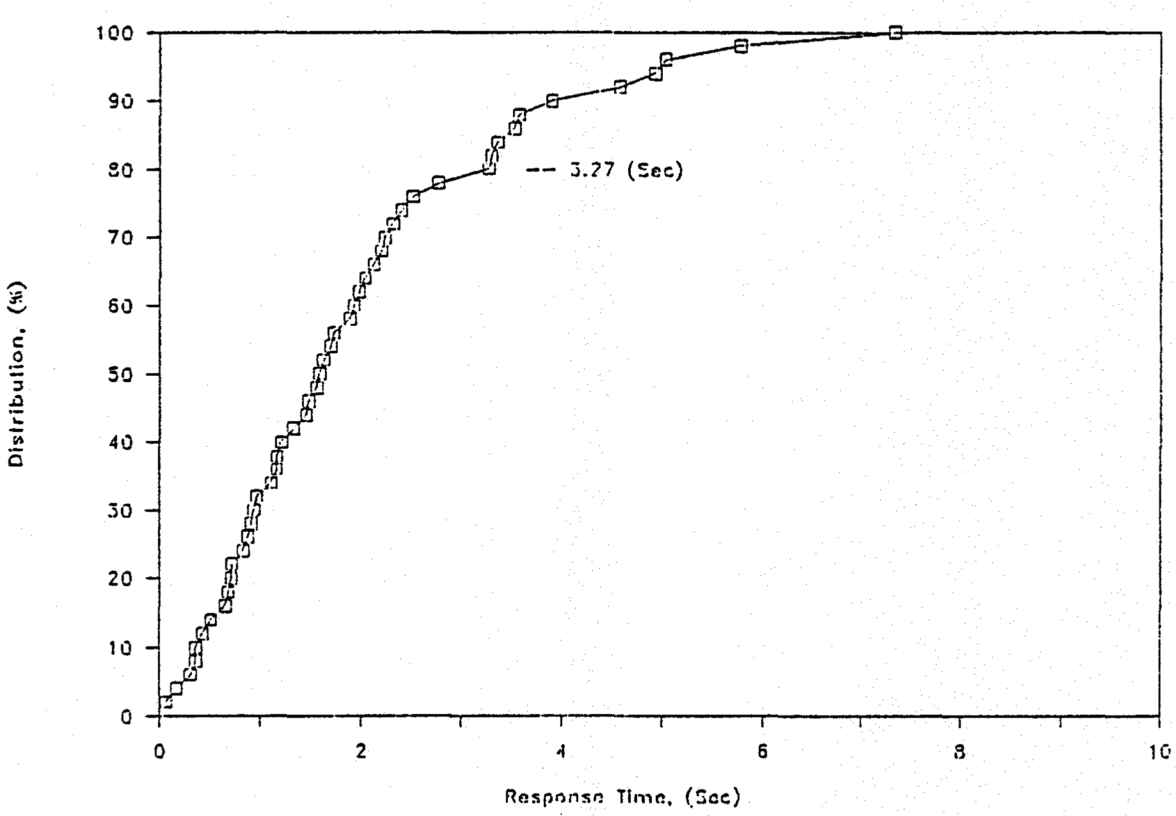


Figure 101. Distribution of correct responses, stimulus slide 76.

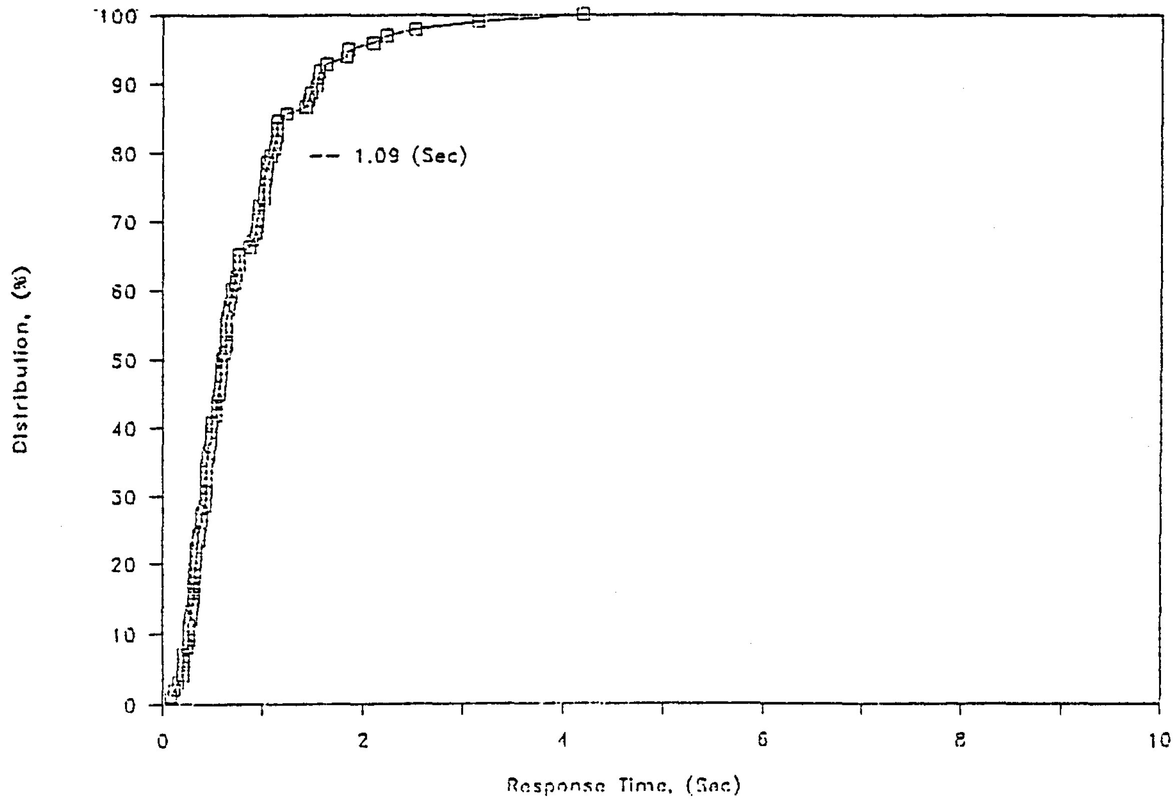


Figure 102. Distribution of correct responses, stimulus slide 77.

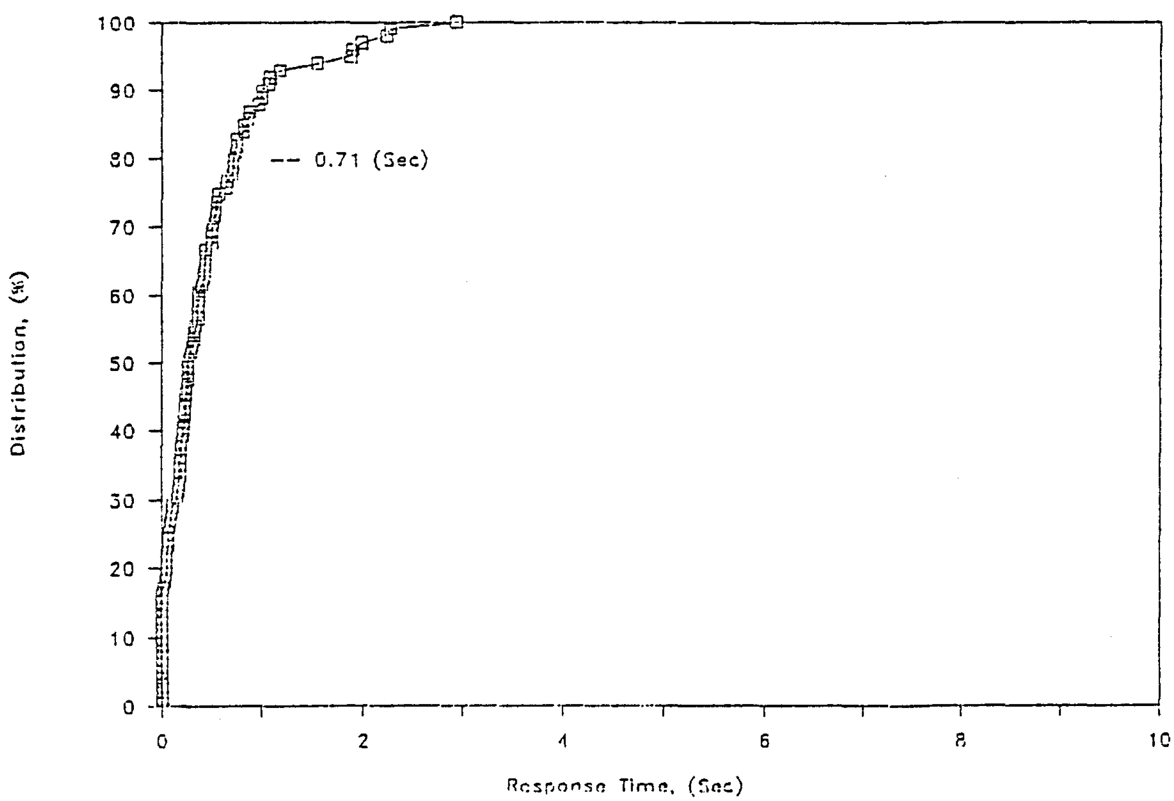


Figure 103. Distribution of correct responses, stimulus slide 78.

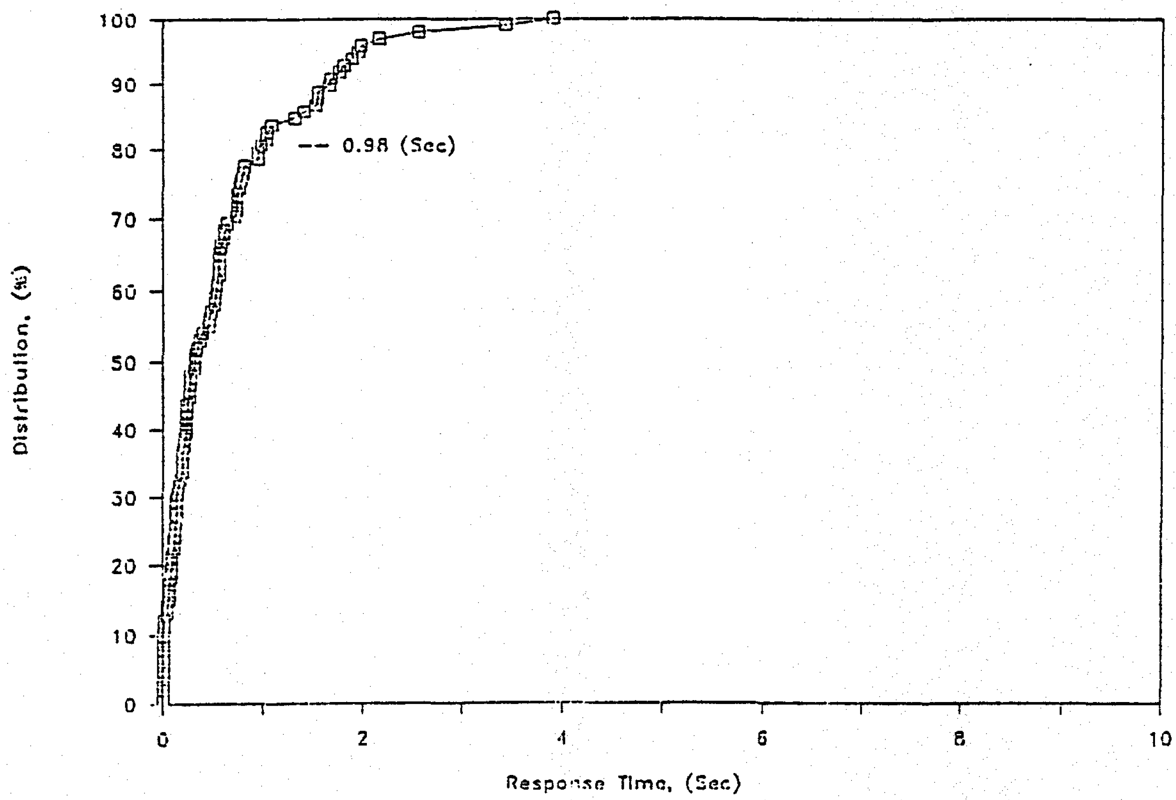


Figure 104. Distribution of correct responses, stimulus slide 79.

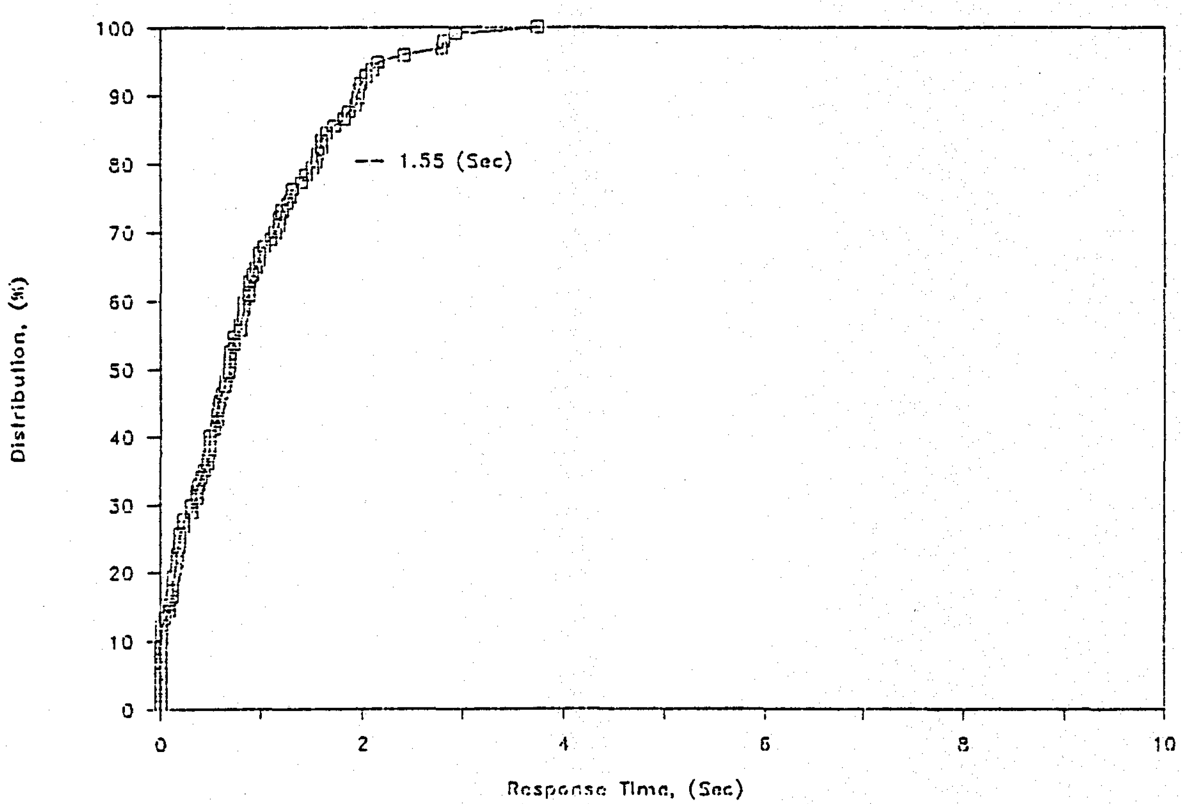


Figure 105. Distribution of correct responses, stimulus slide 80.

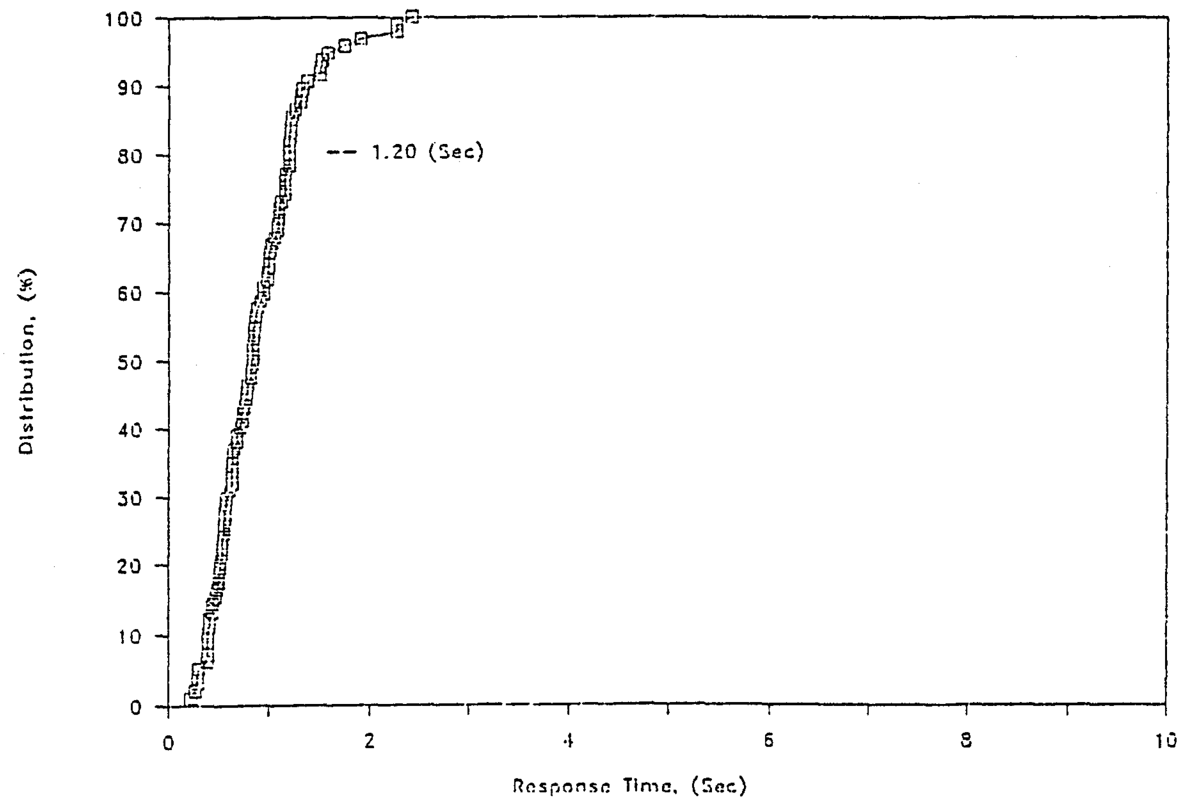


Figure 106. Distribution of correct responses, stimulus slide 81.

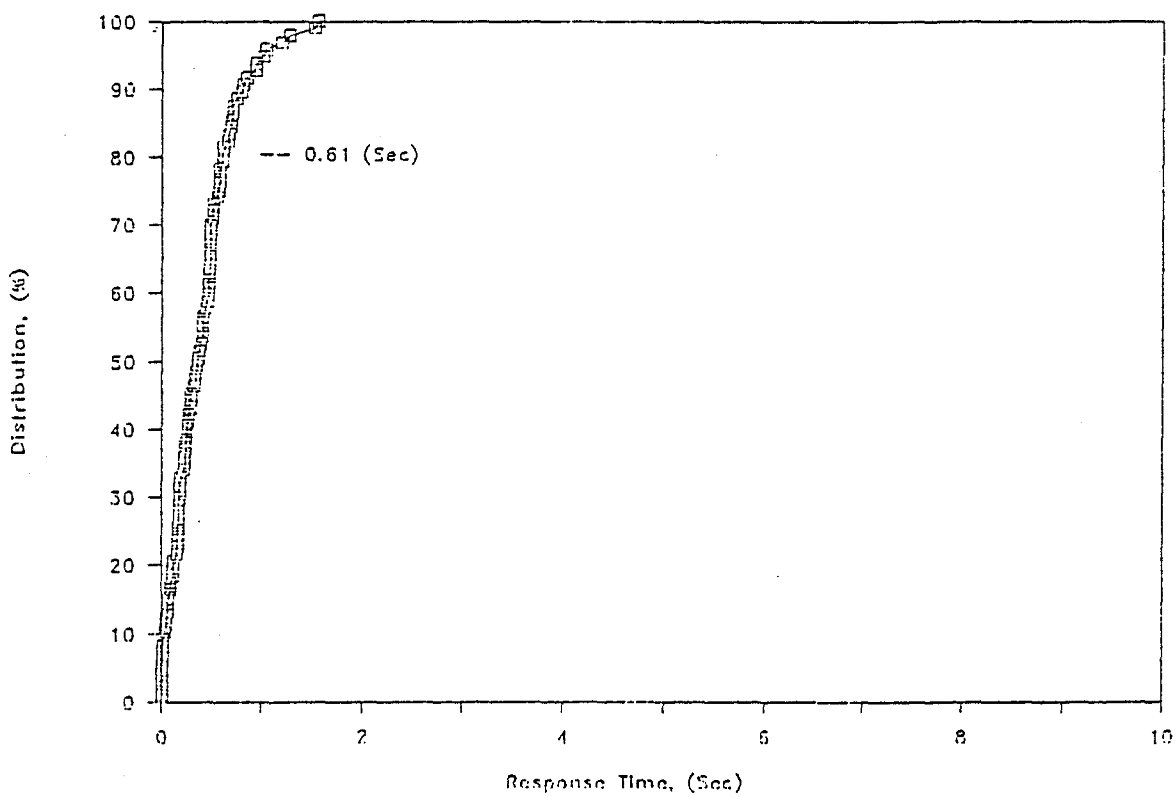


Figure 107. Distribution of correct responses, stimulus slide 82.

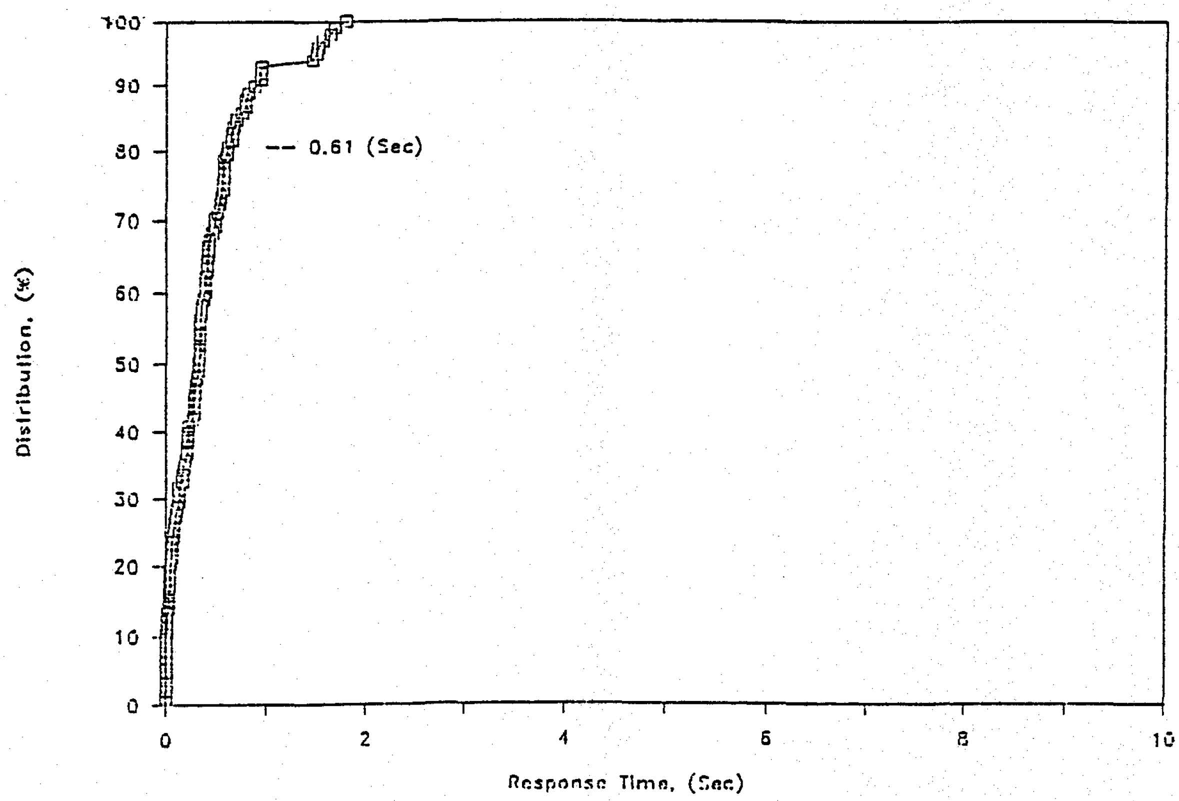


Figure 108. Distribution of correct responses, stimulus slide 83.

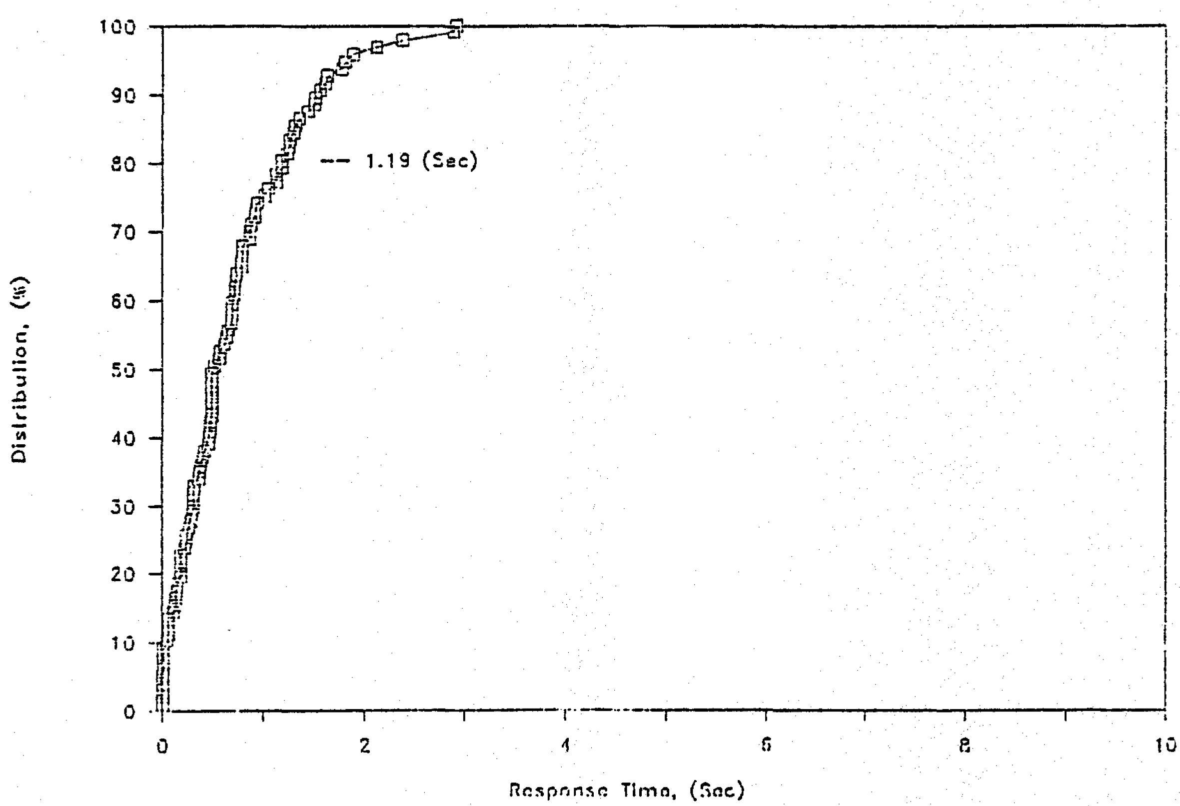


Figure 109. Distribution of correct responses, stimulus slide 84.

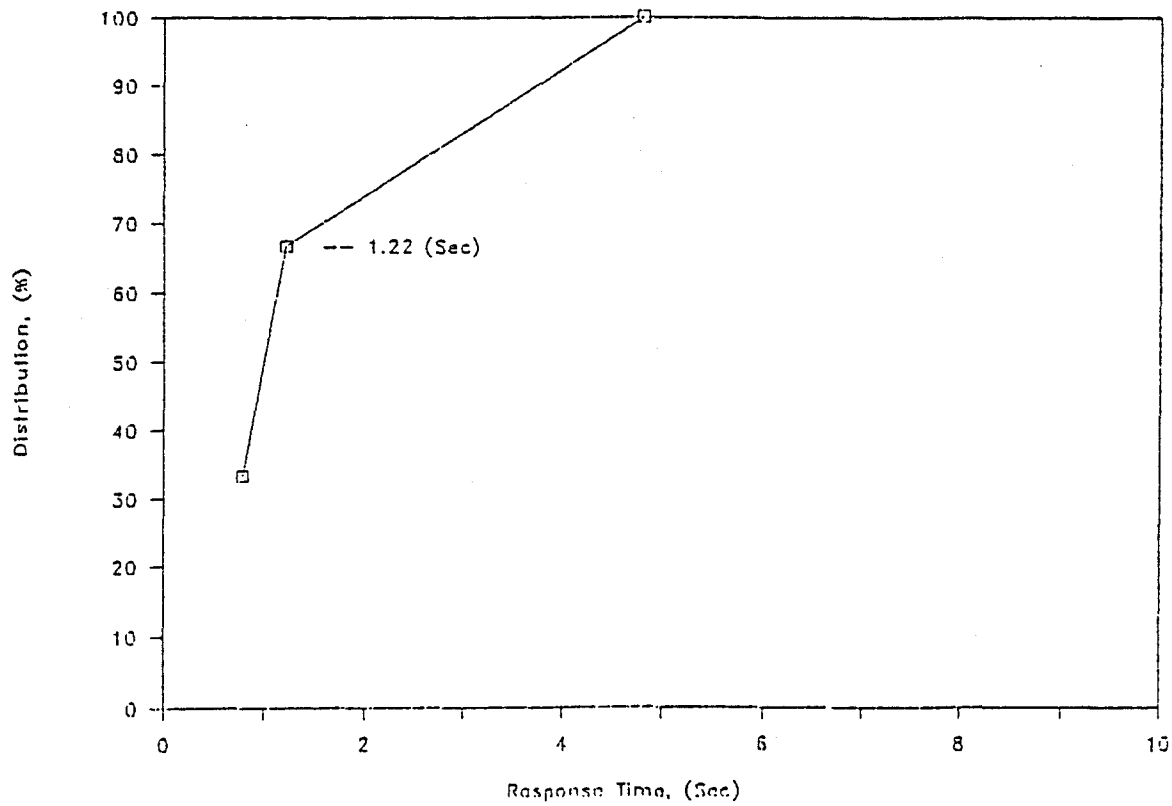


Figure 110. Distribution of correct responses, stimulus slide 85.

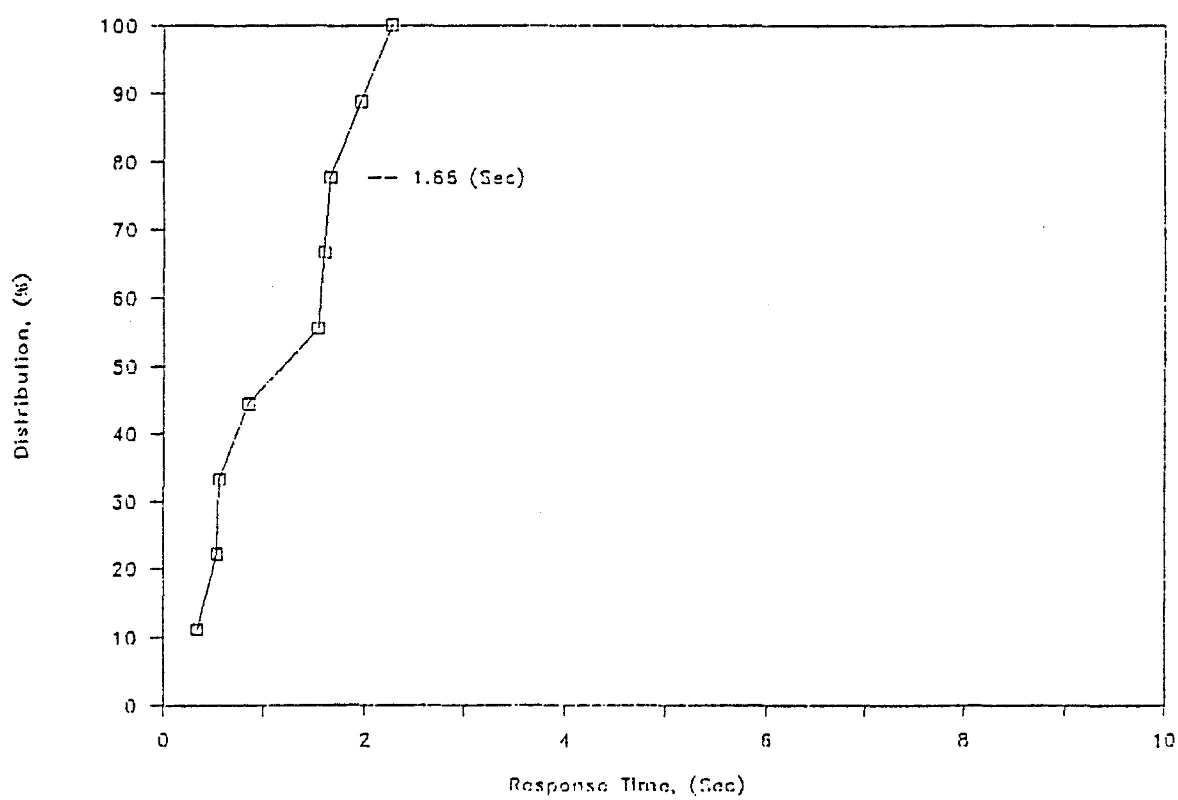


Figure 111. Distribution of correct responses, stimulus slide 86.

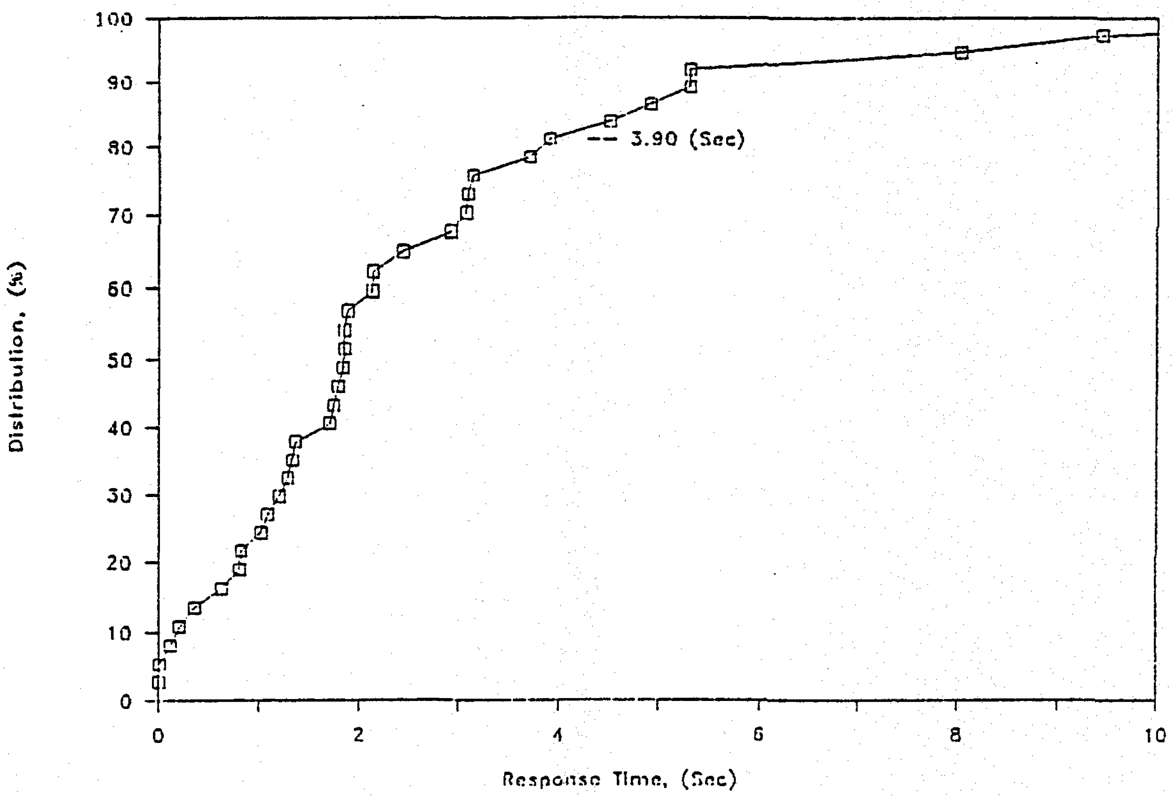


Figure 112. Distribution of correct responses, stimulus slide 87.

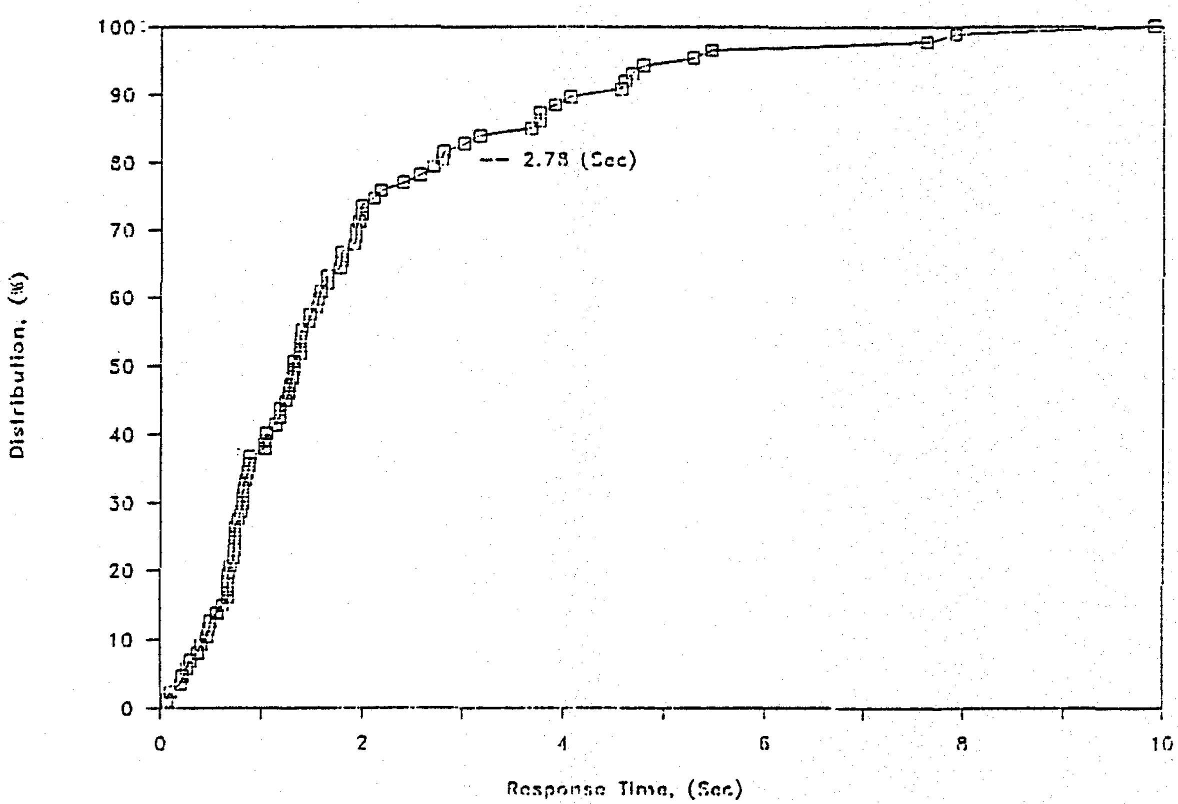


Figure 113. Distribution of correct responses, stimulus slide 88.

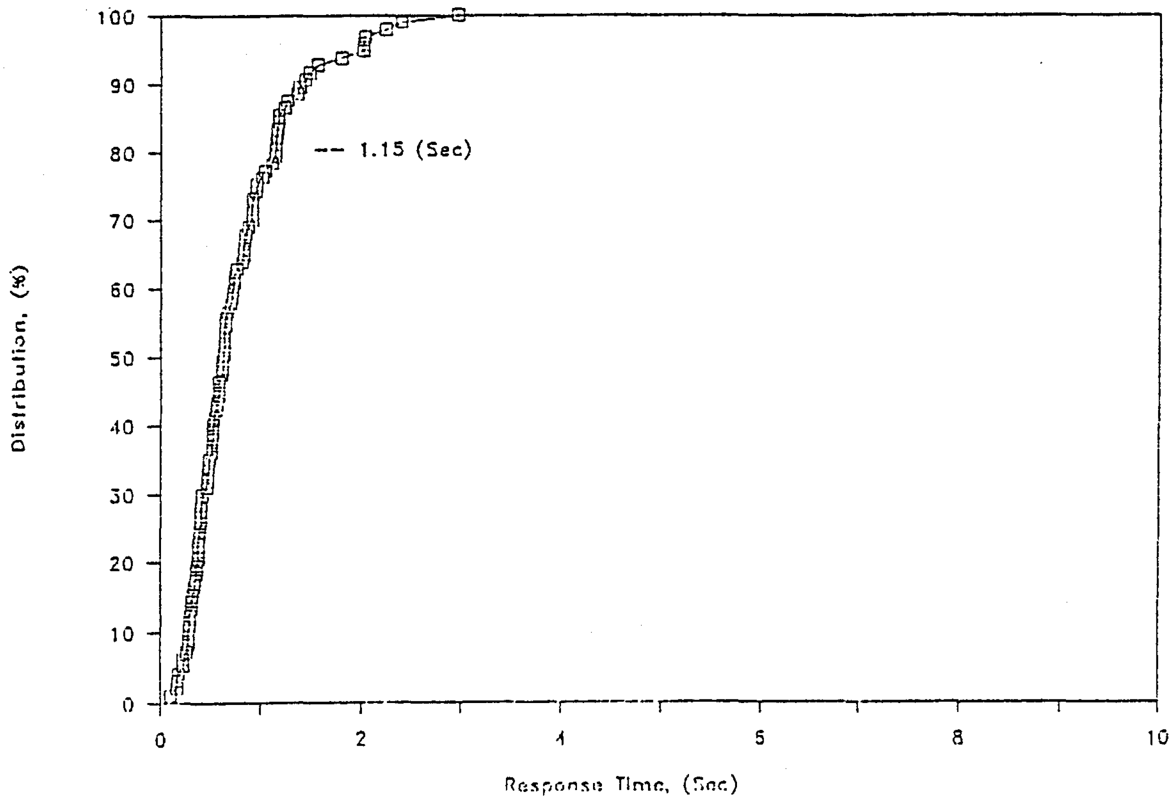


Figure 114. Distribution of correct responses, stimulus slide 89.

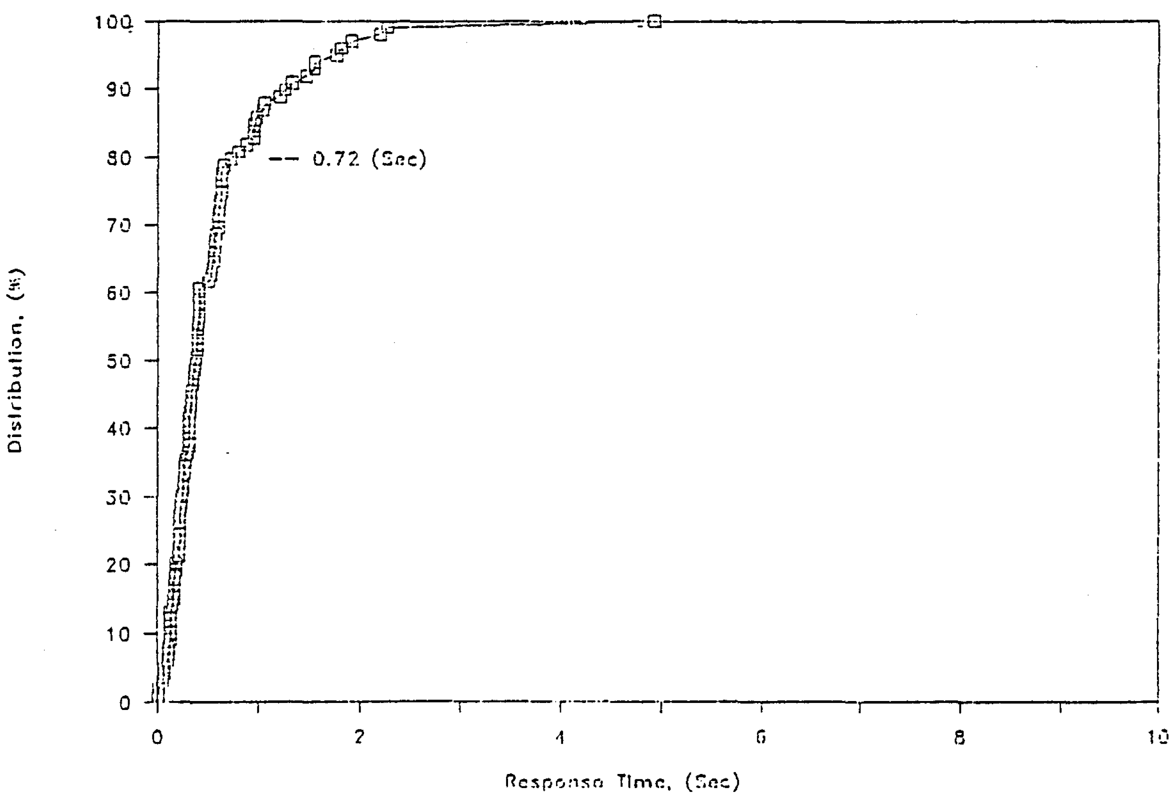


Figure 115. Distribution of correct responses, stimulus slide 90.

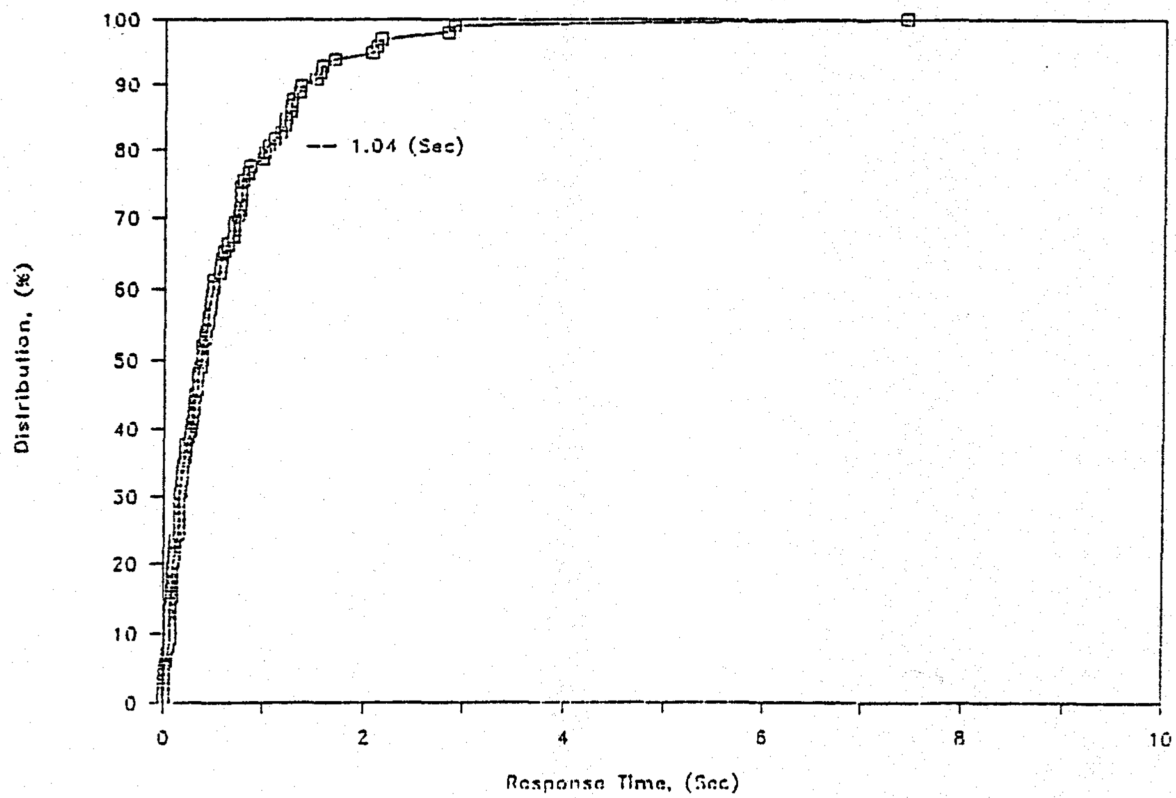


Figure 116. Distribution of correct responses, stimulus slide 91.

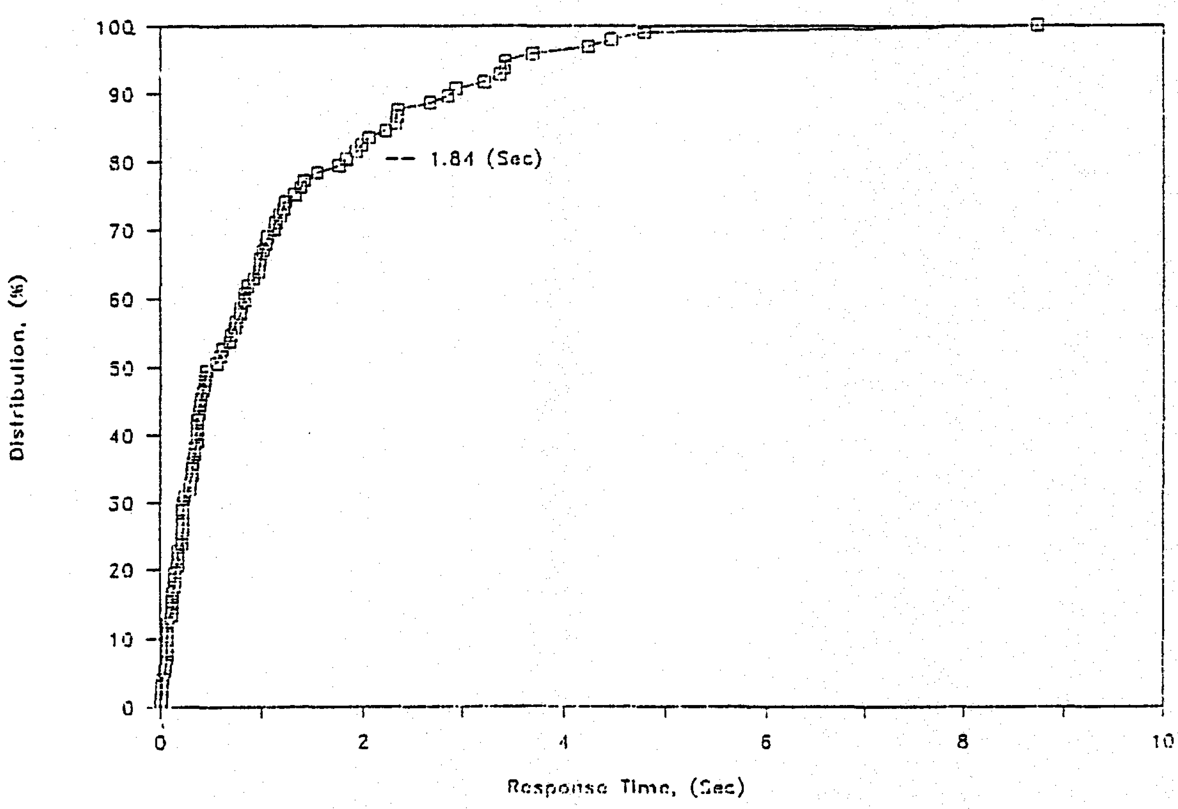


Figure 117. Distribution of correct responses, stimulus slide 92.

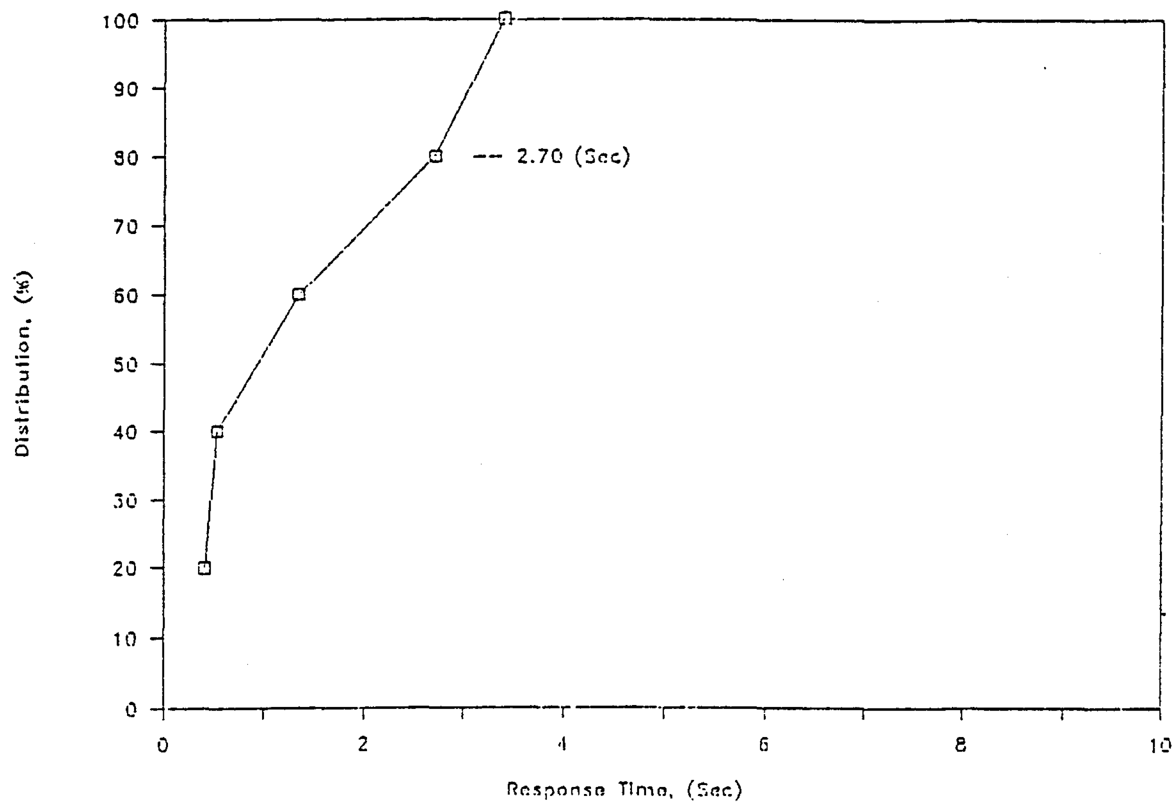


Figure 118. Distribution of correct responses, stimulus slide 93.

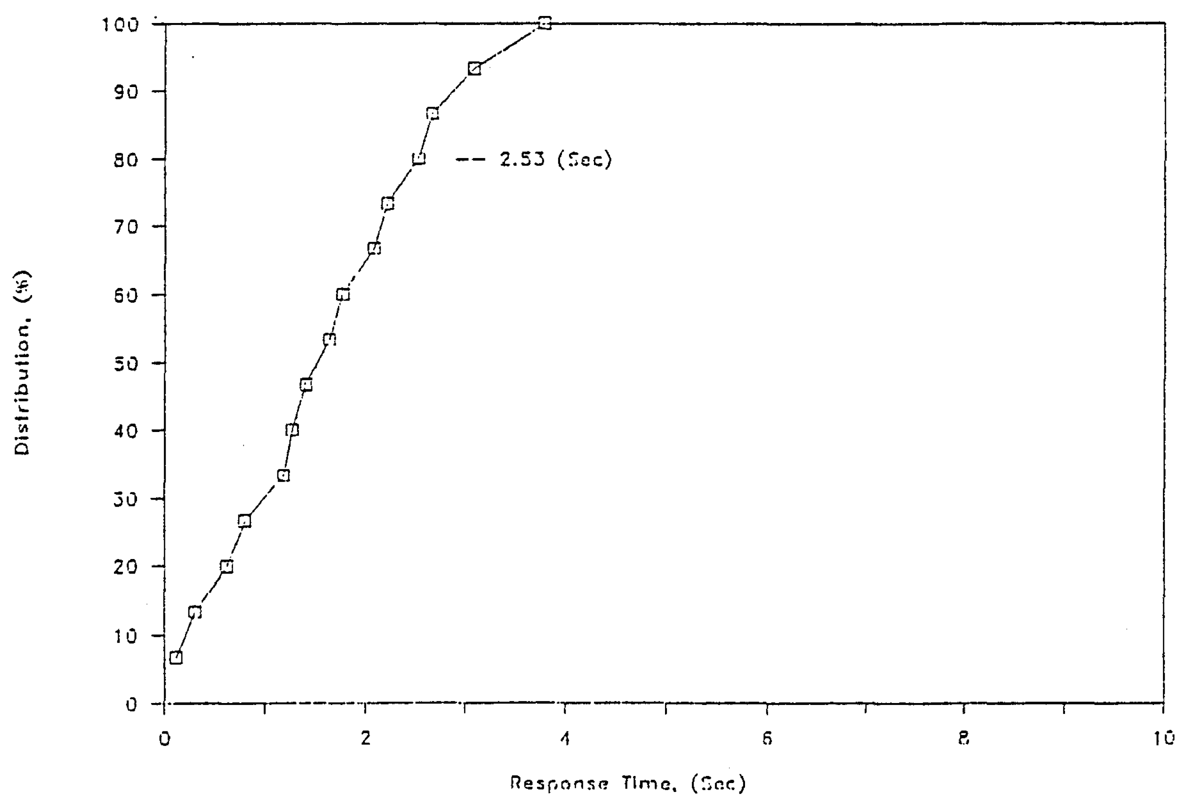


Figure 119. Distribution of correct responses, stimulus slide 94.

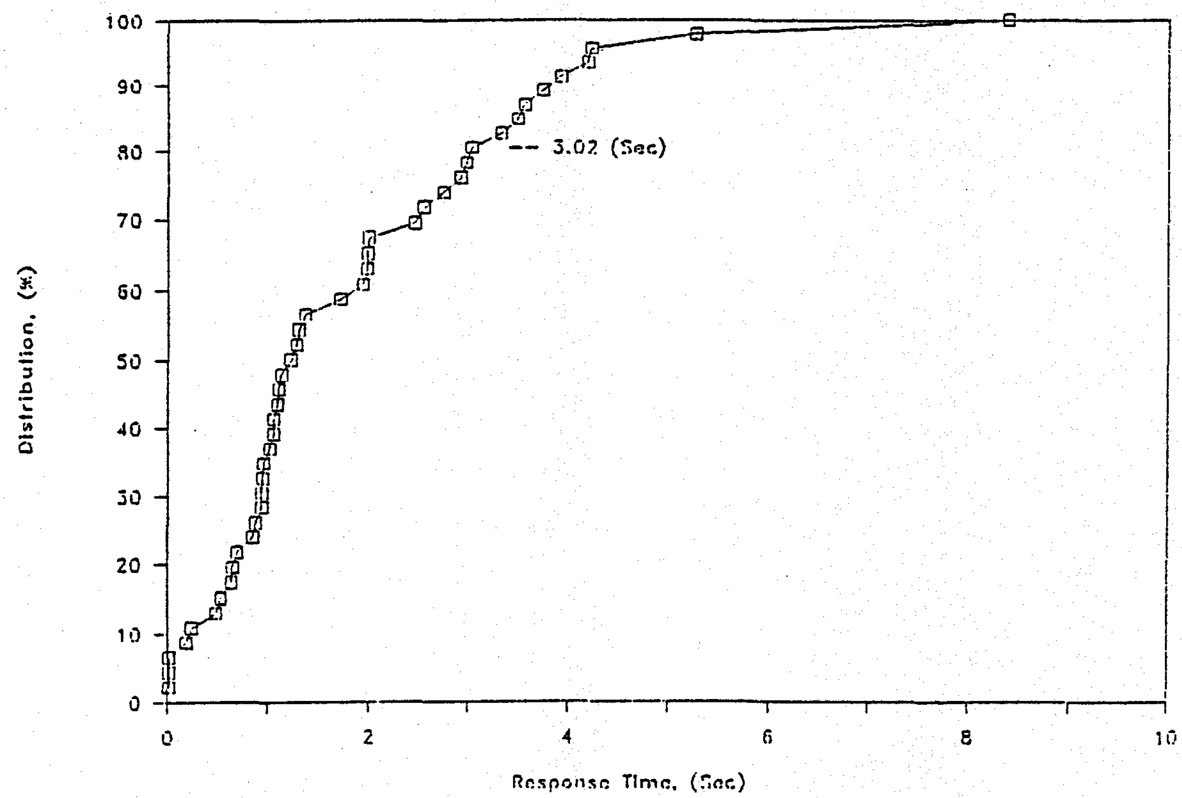


Figure 120. Distribution of correct responses, stimulus slide 95.

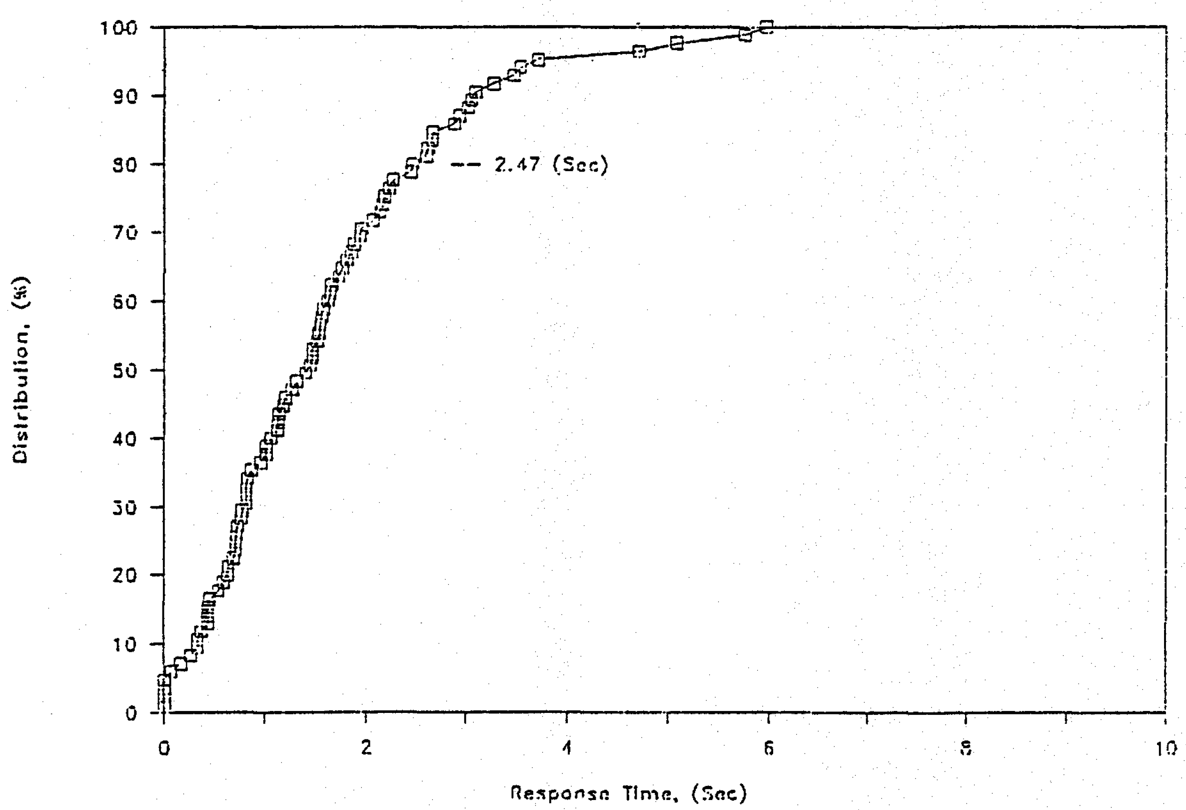


Figure 121. Distribution of correct responses, stimulus slide 96.

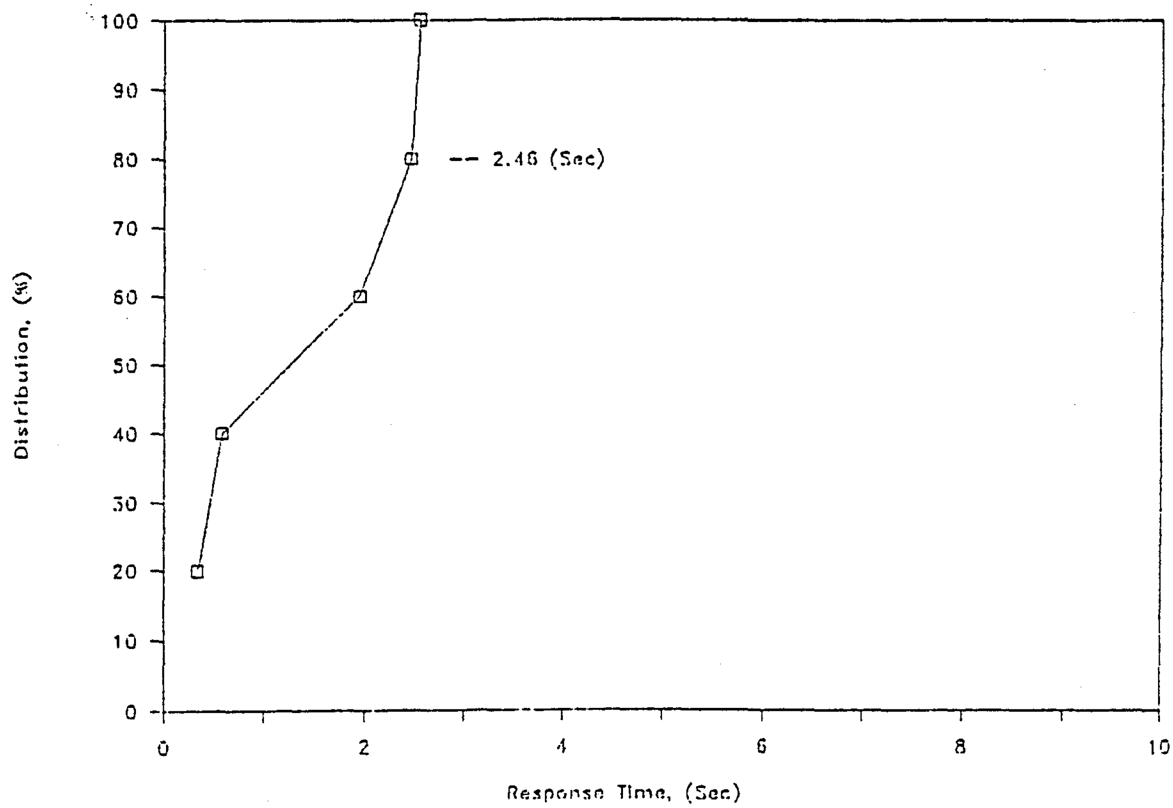


Figure 122. Distribution of correct responses, stimulus slide 97.

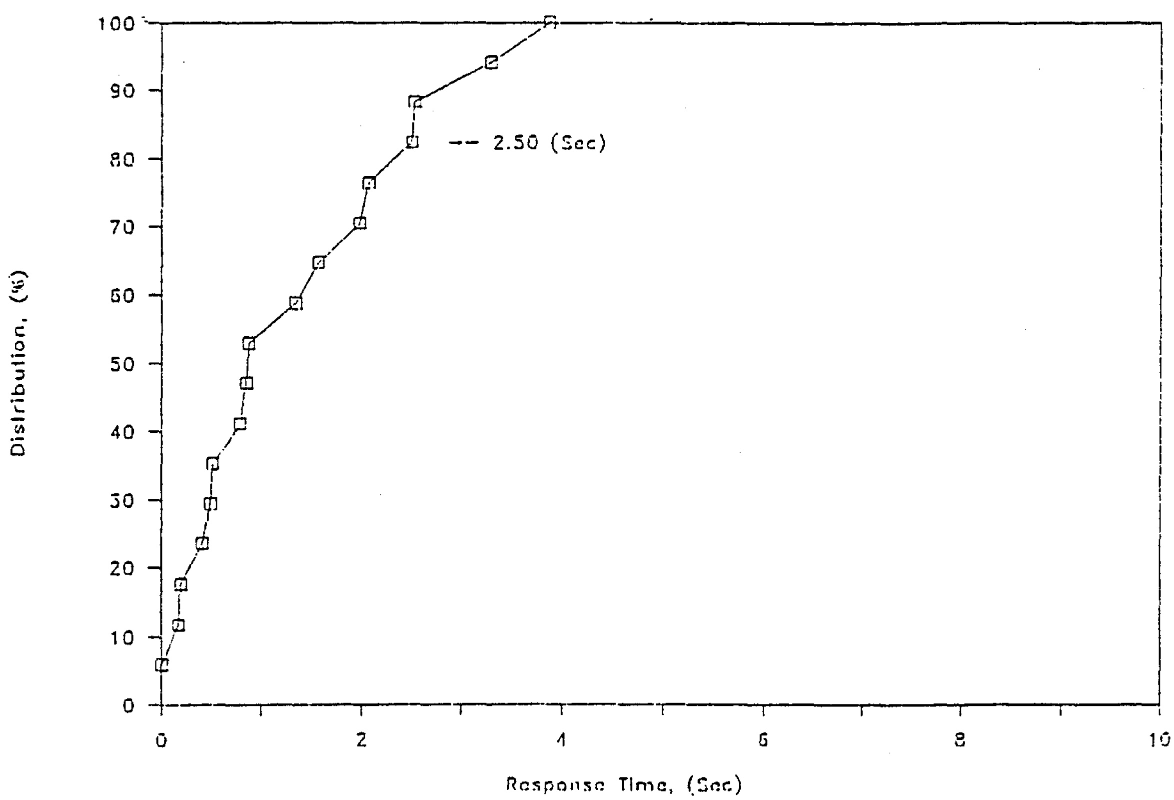


Figure 123. Distribution of correct responses, stimulus slide 98.

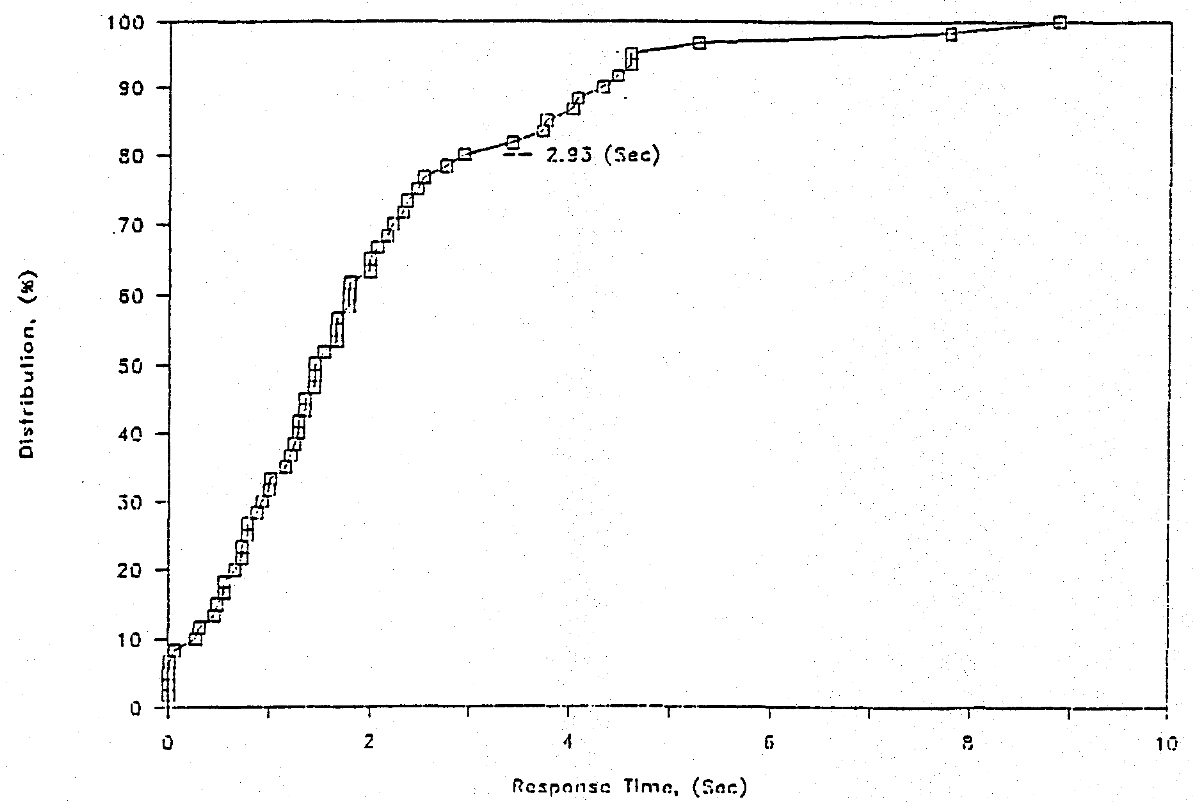


Figure 124. Distribution of correct responses, stimulus slide 99.

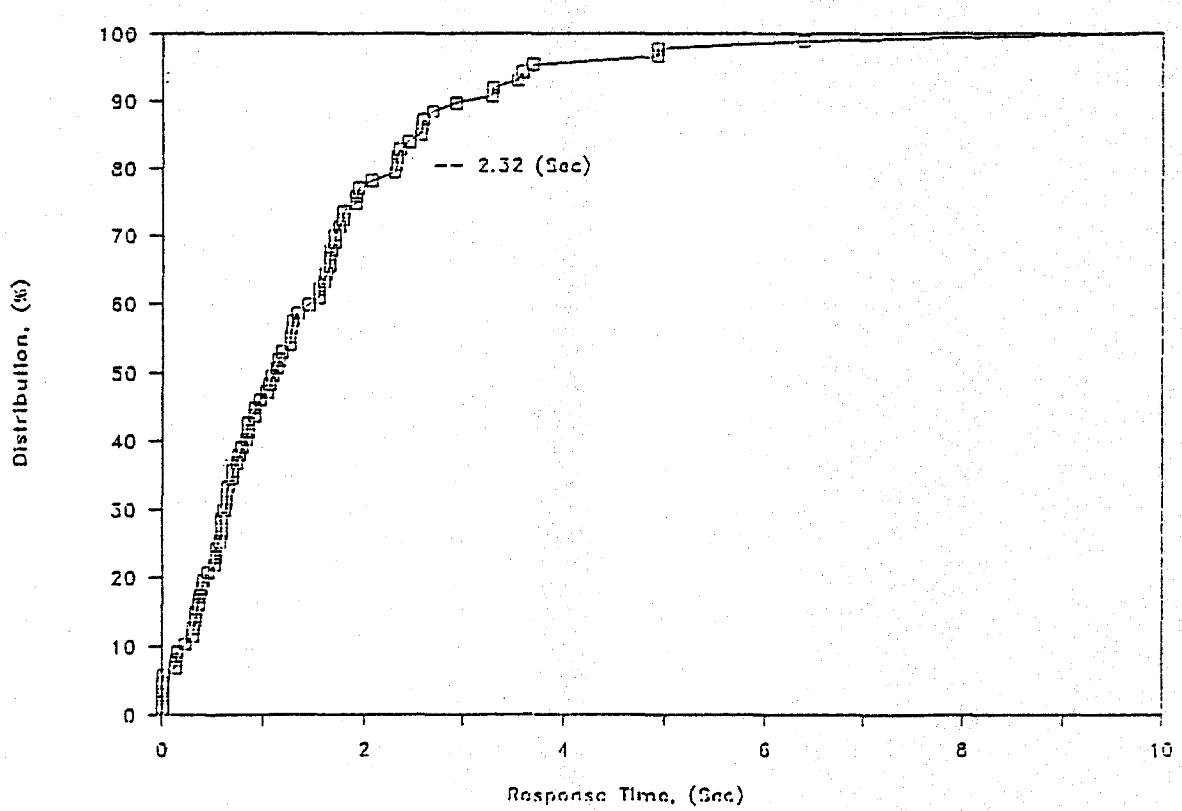


Figure 125. Distribution of correct responses, stimulus slide 100.

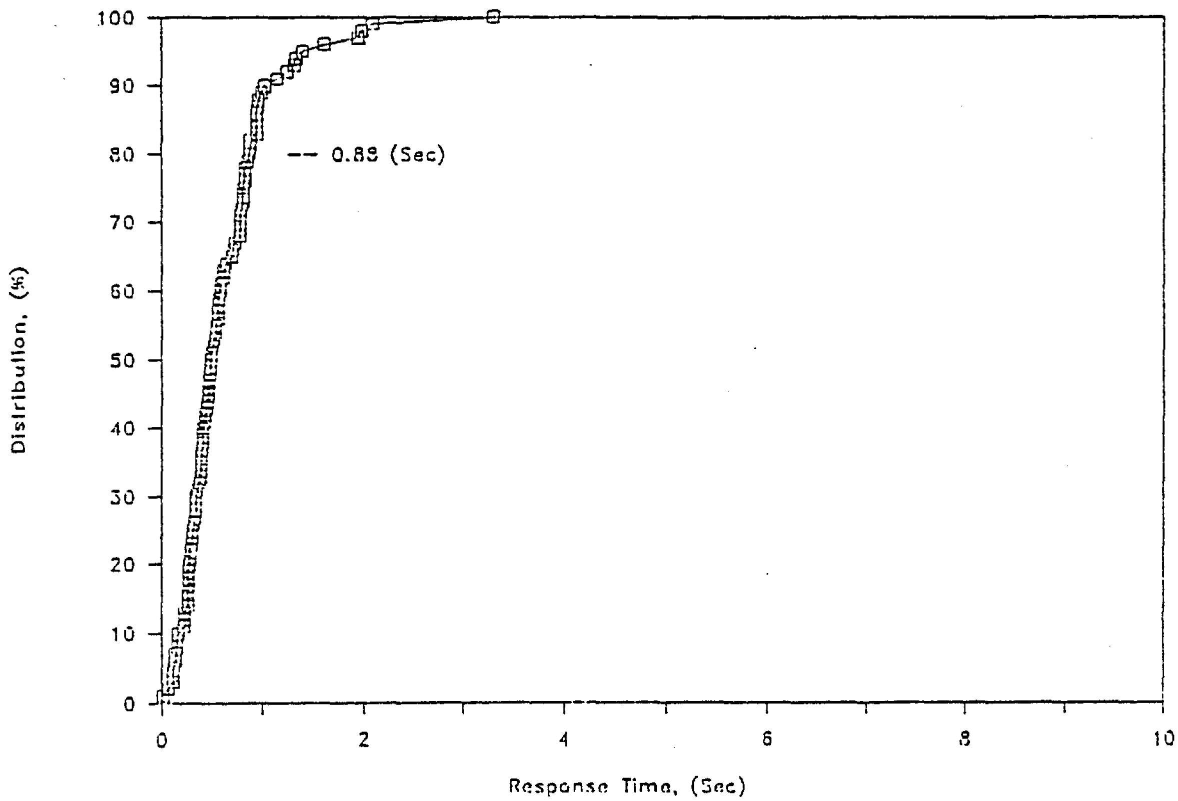


Figure 126. Distribution of correct responses, stimulus slide 101.

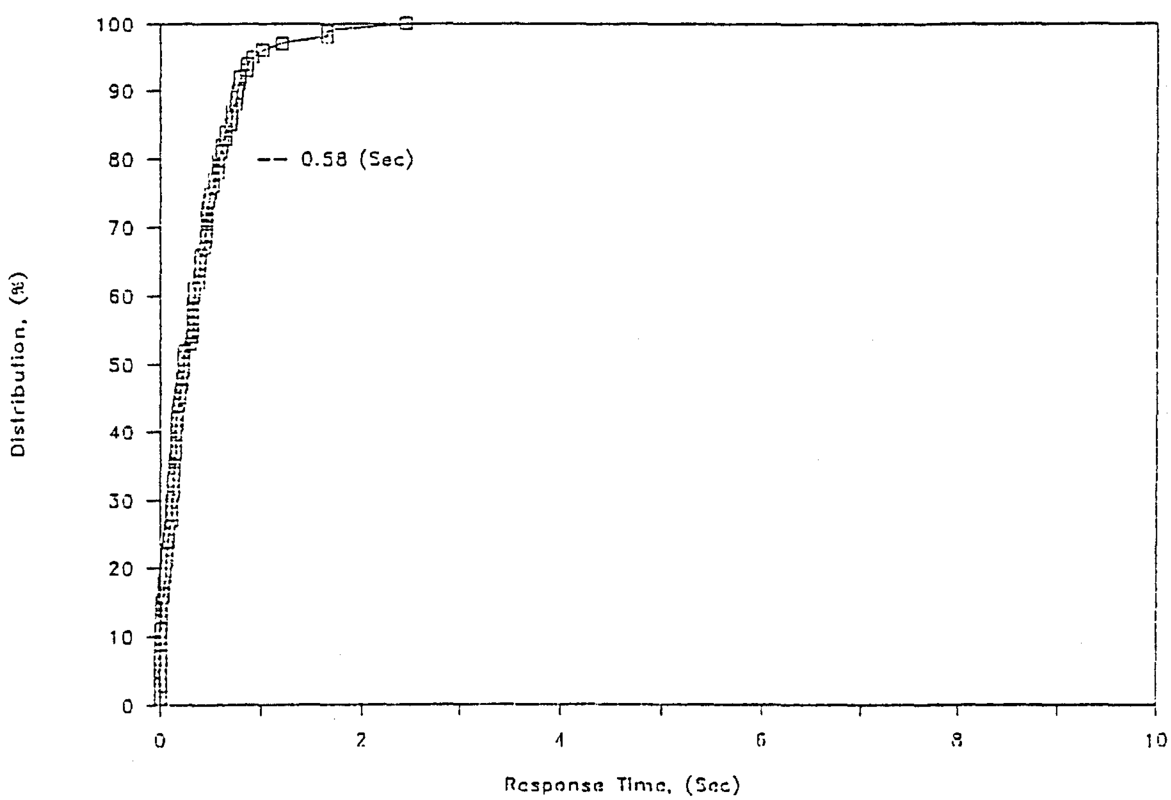


Figure 127. Distribution of correct responses, stimulus slide 102.

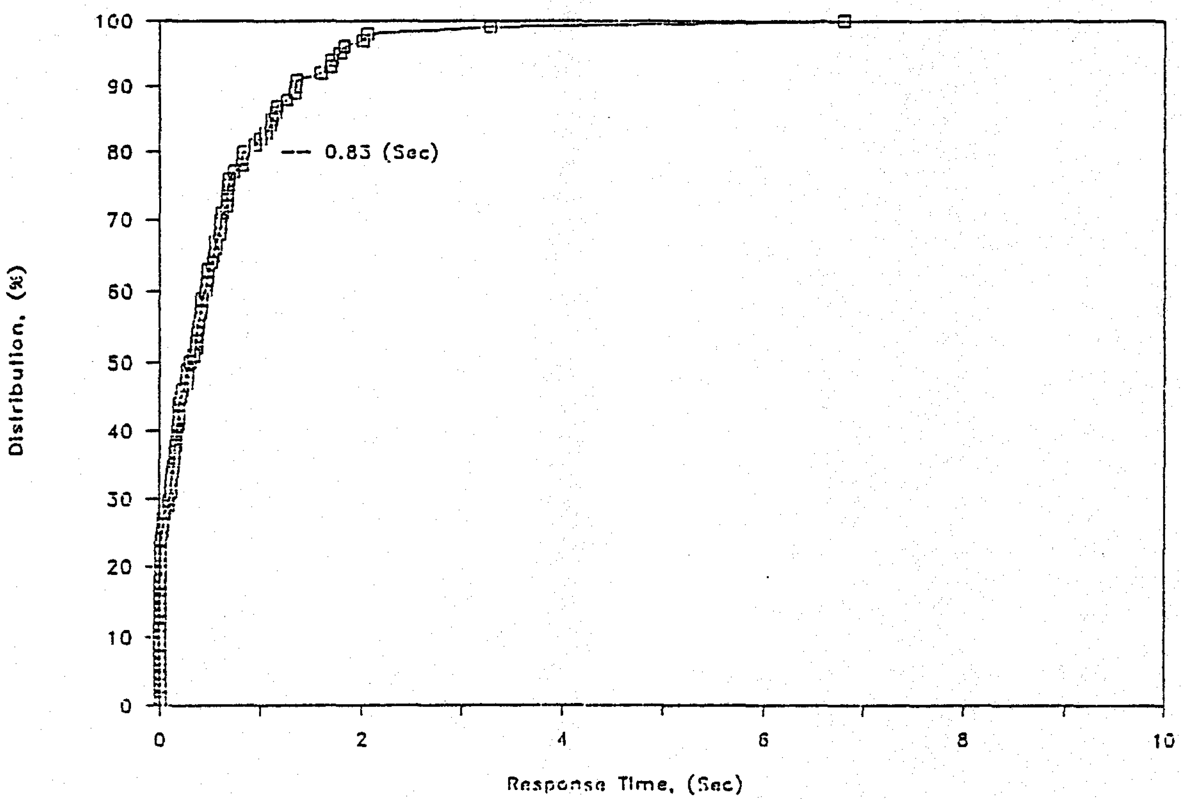


Figure 128. Distribution of correct responses, stimulus slide 103.

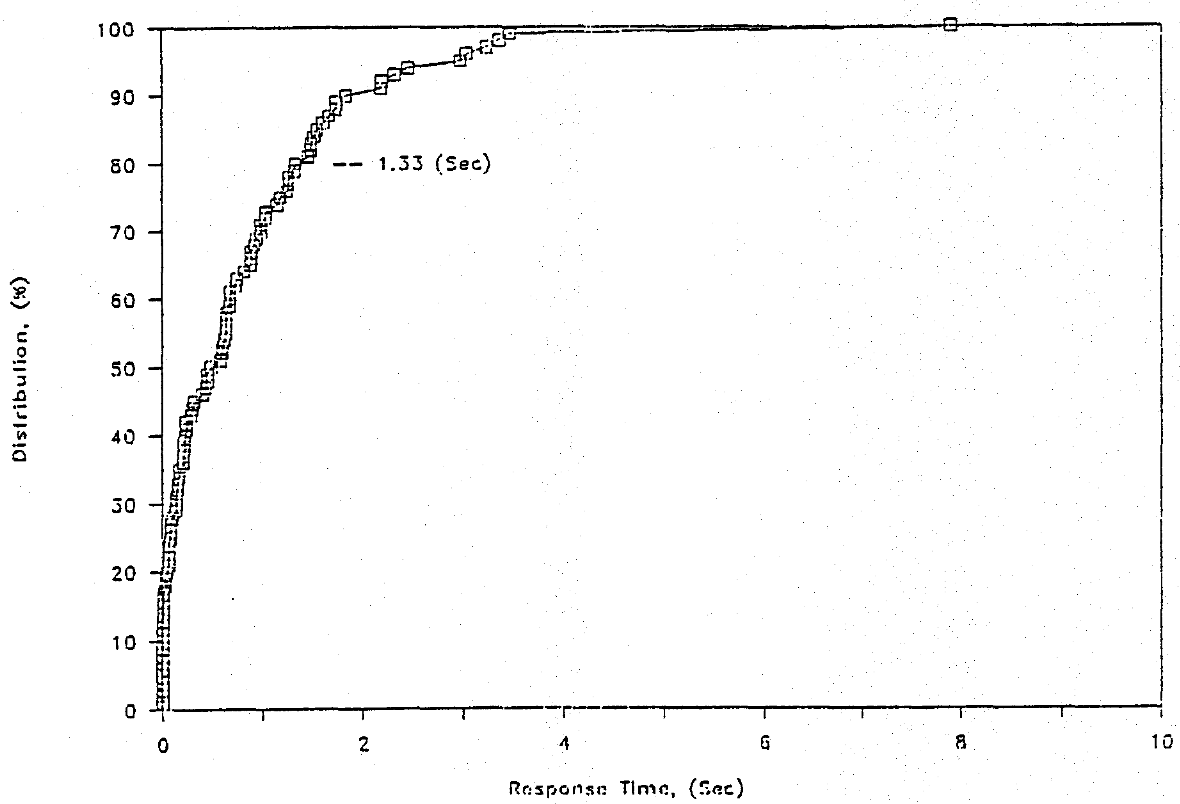


Figure 129. Distribution of correct responses, stimulus slide 104.

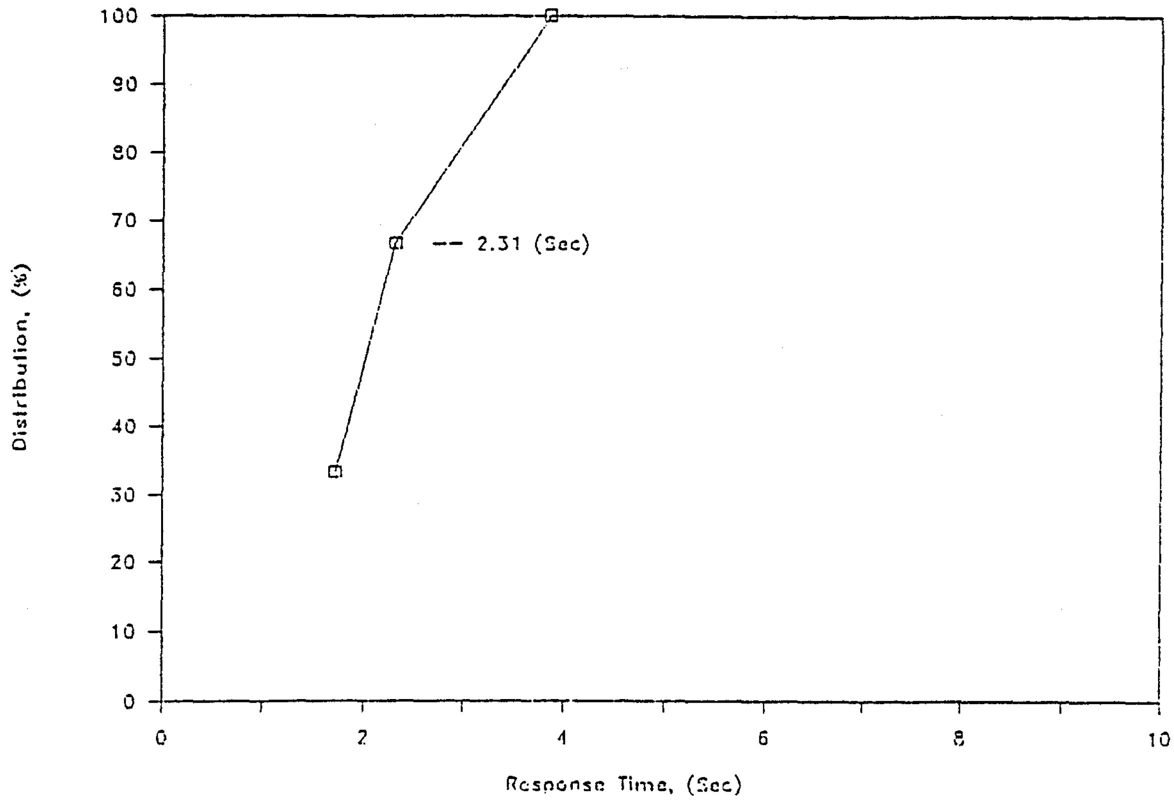


Figure 130. Distribution of correct responses, stimulus slide 105.

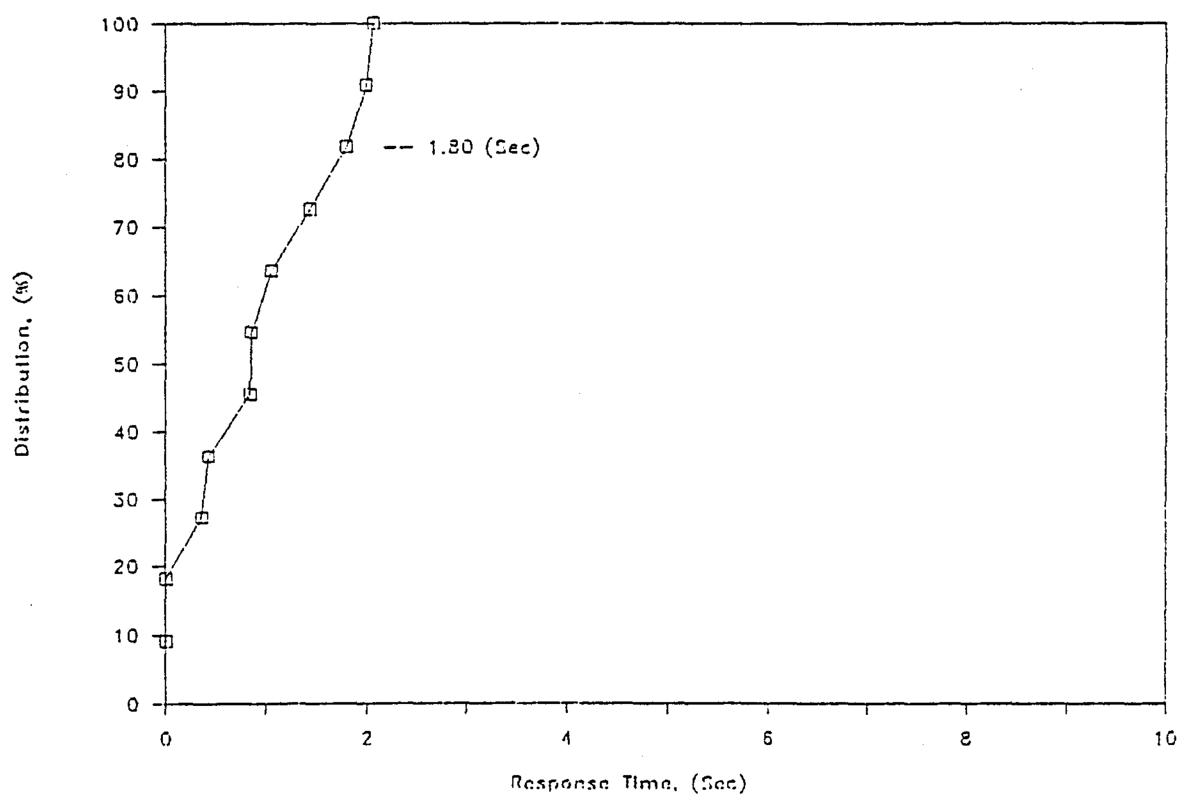


Figure 131. Distribution of correct responses, stimulus slide 106.

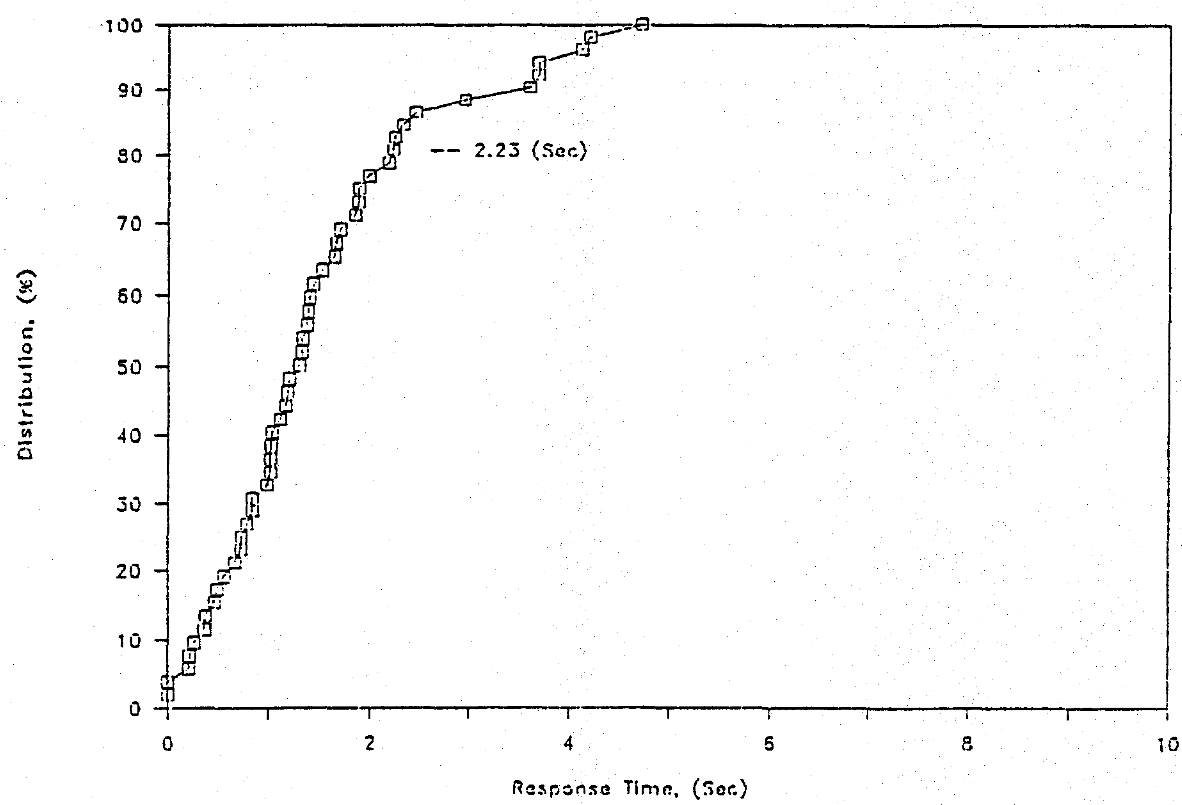


Figure 132. Distribution of correct responses, stimulus slide 107.

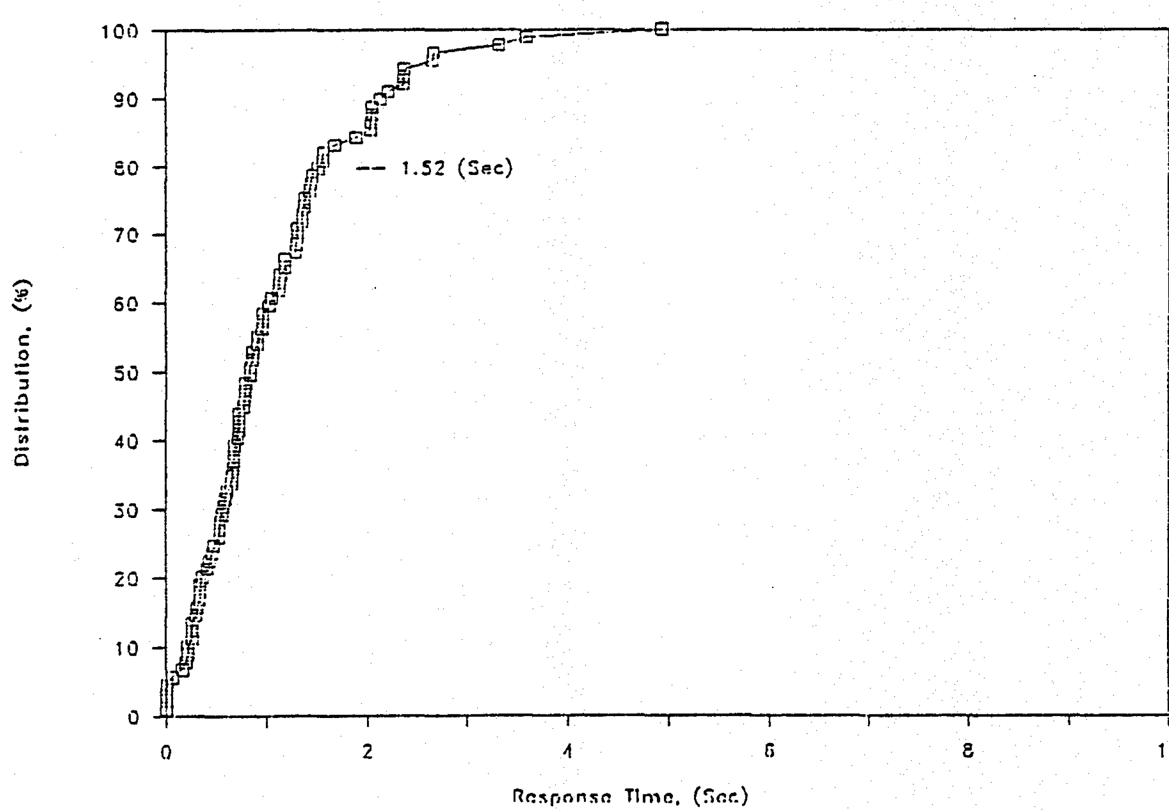


Figure 133. Distribution of correct responses, stimulus slide 108.

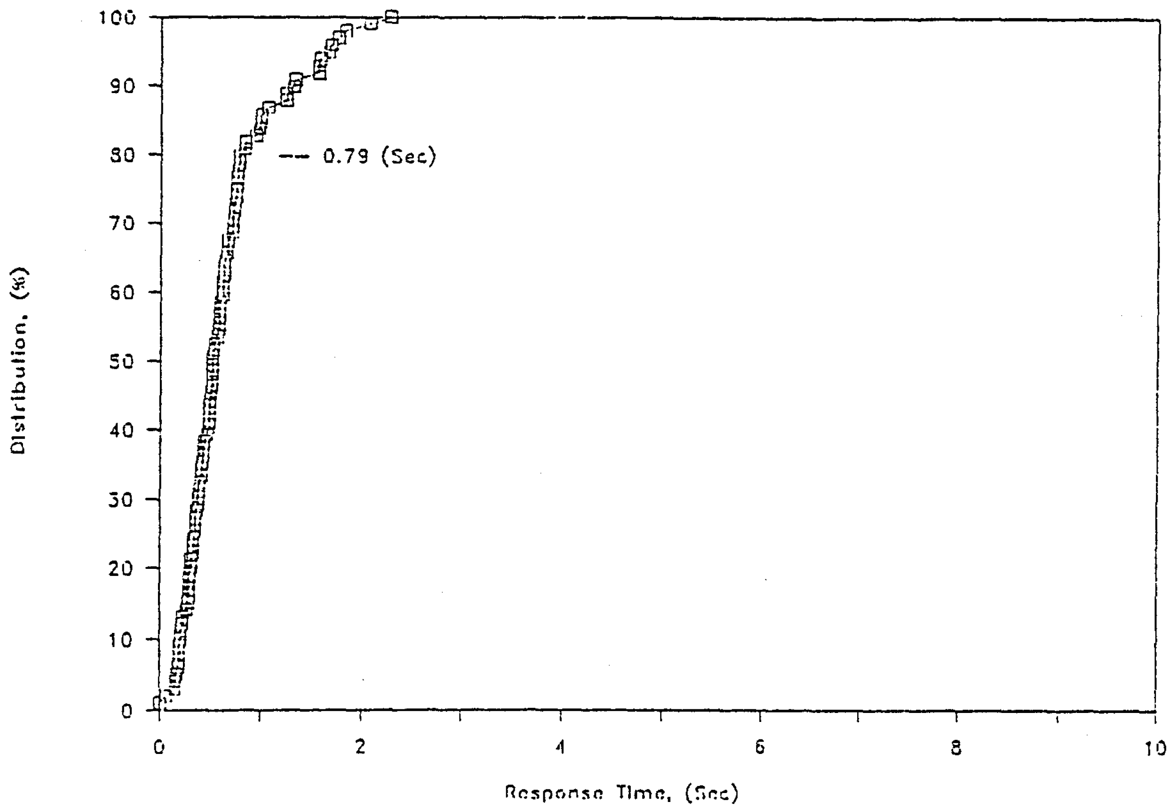


Figure 134. Distribution of correct responses, stimulus slide 109.

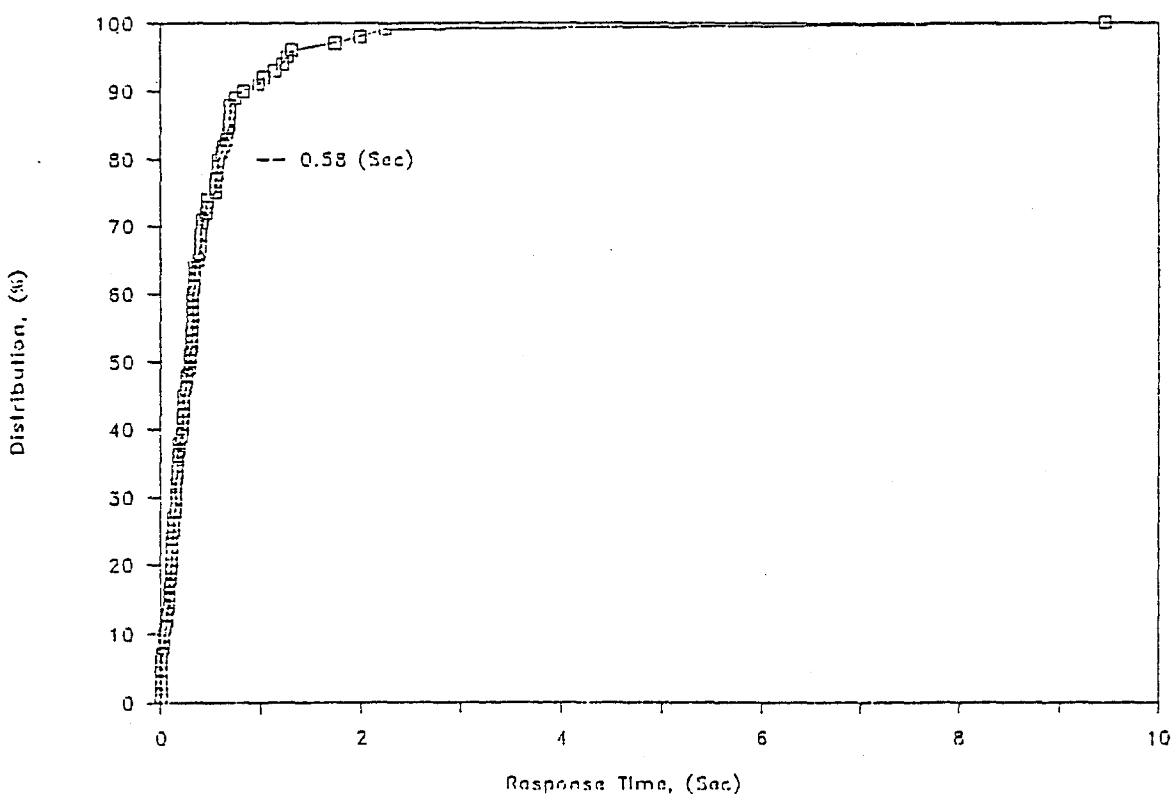


Figure 135. Distribution of correct responses, stimulus slide 110.

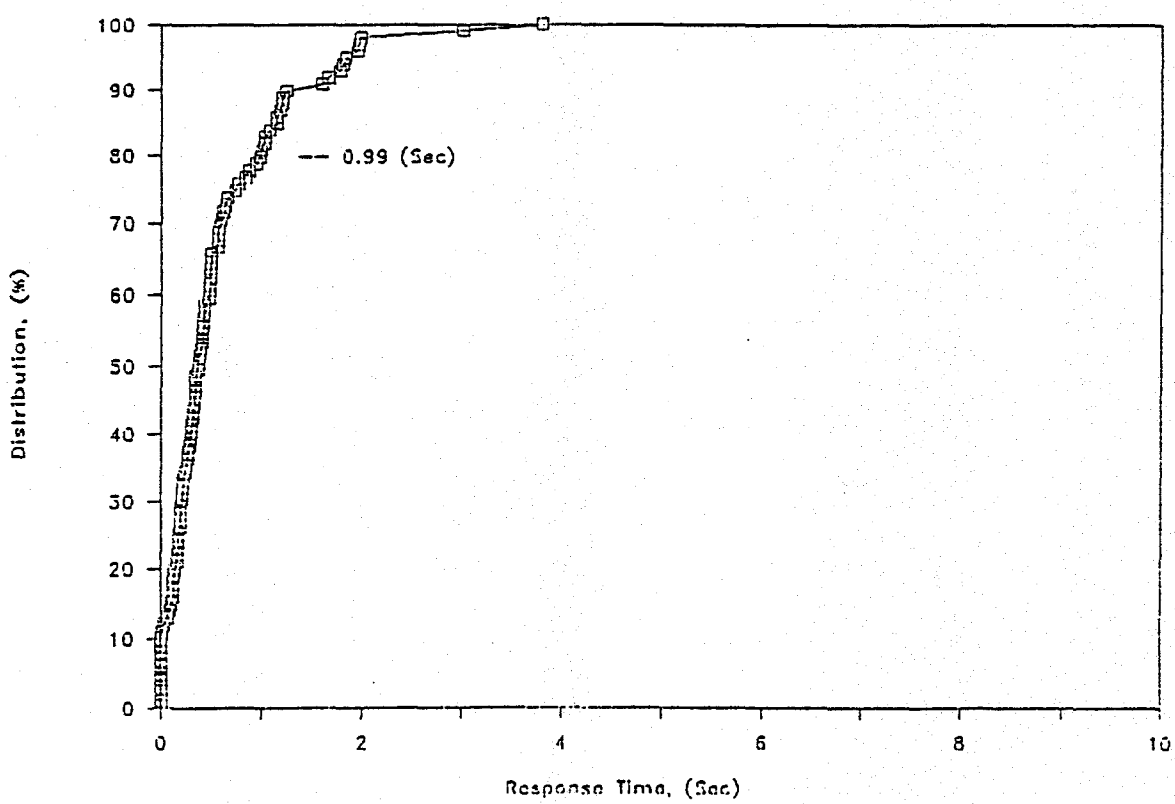


Figure 136. Distribution of correct responses, stimulus slide 111.

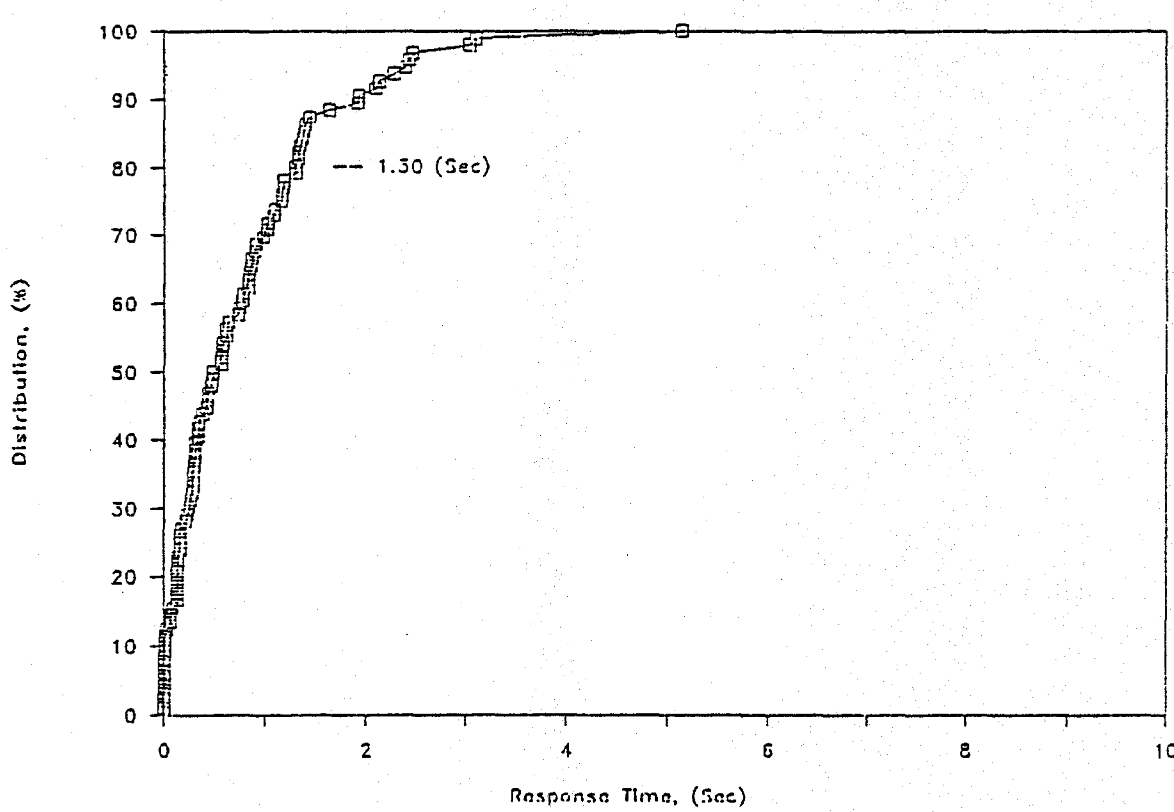


Figure 137. Distribution of correct responses, stimulus slide 112.

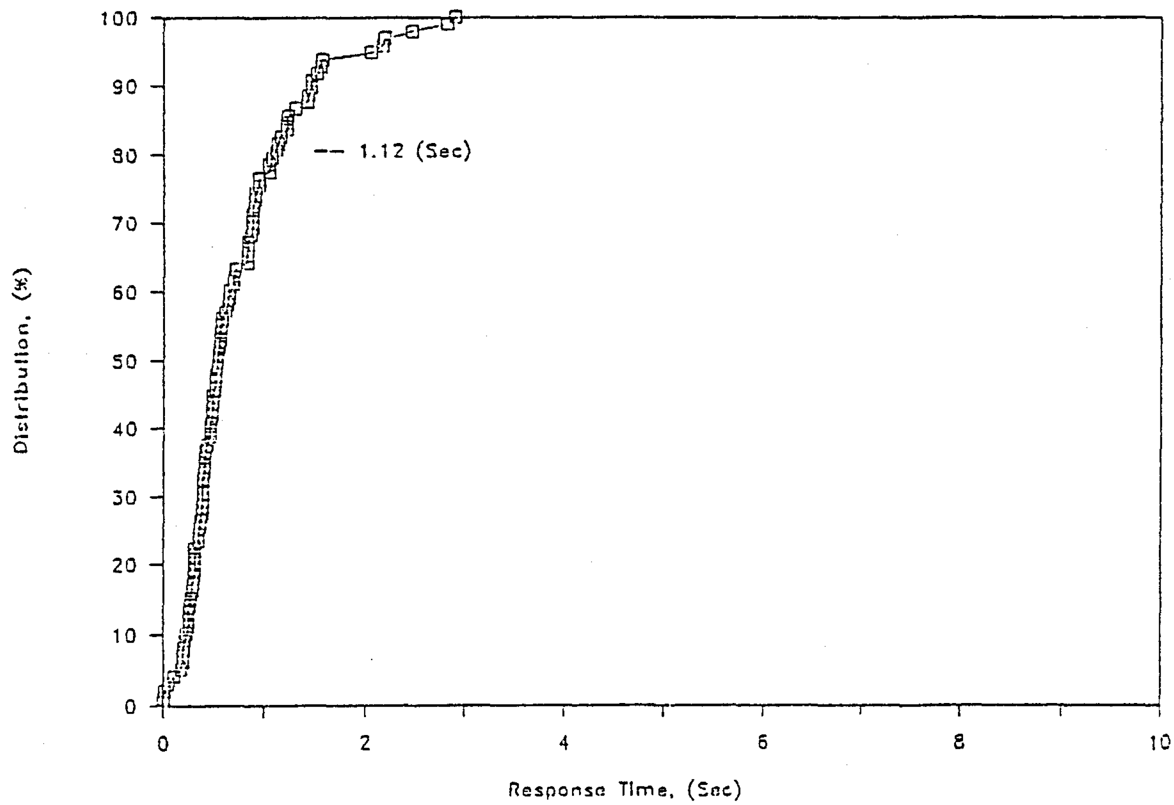


Figure 138. Distribution of correct responses, stimulus slide 113.

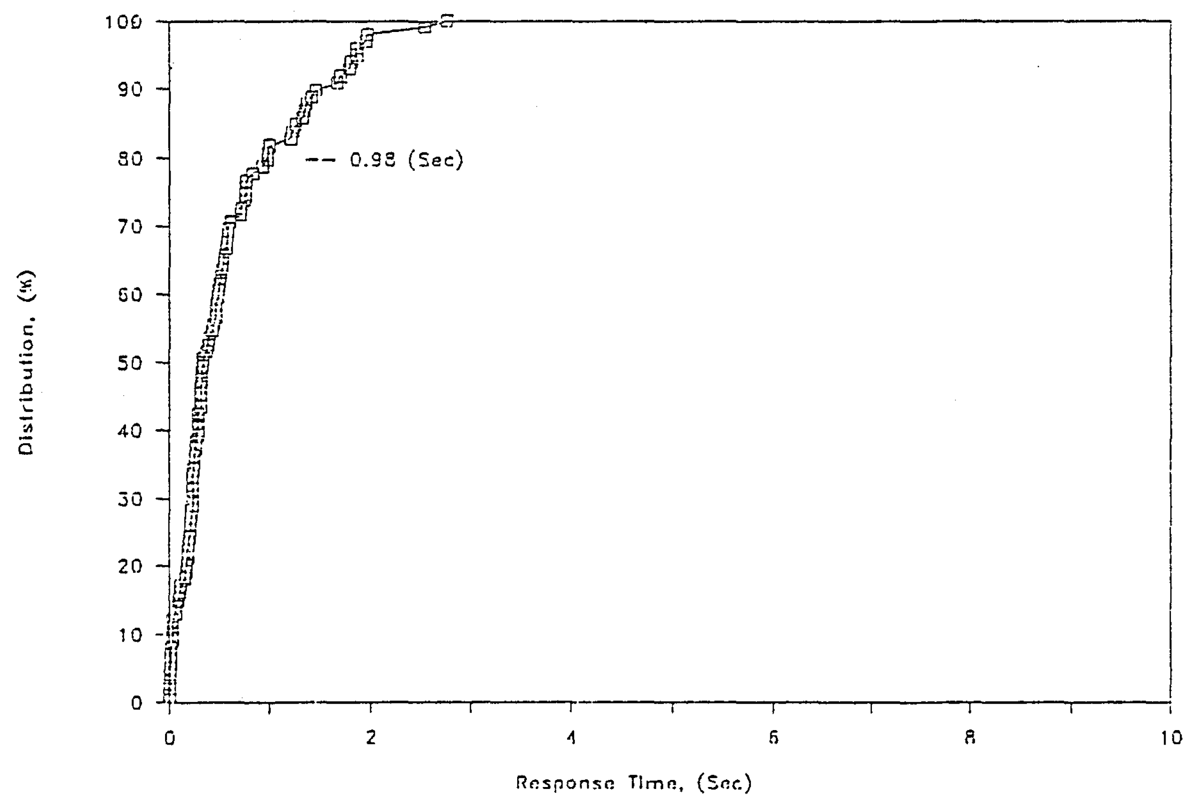


Figure 139. Distribution of correct responses, stimulus slide 114.

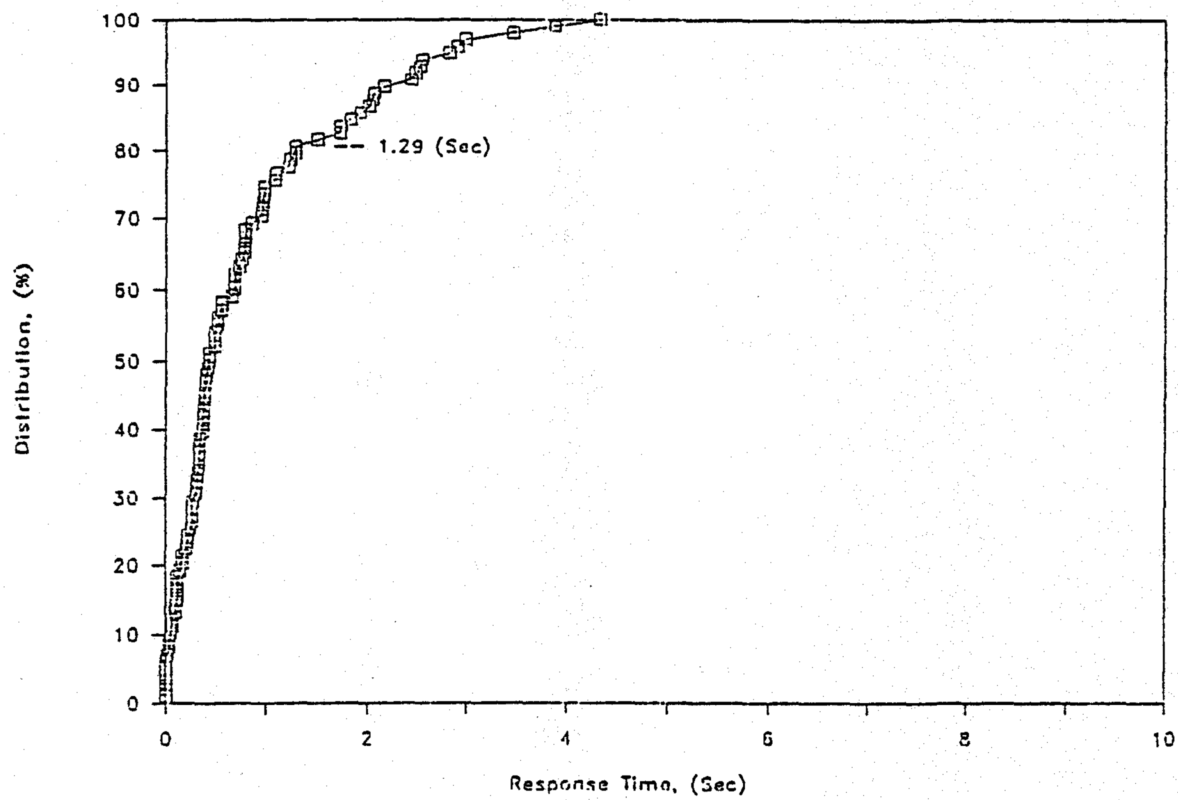


Figure 140. Distribution of correct responses, stimulus slide 115.

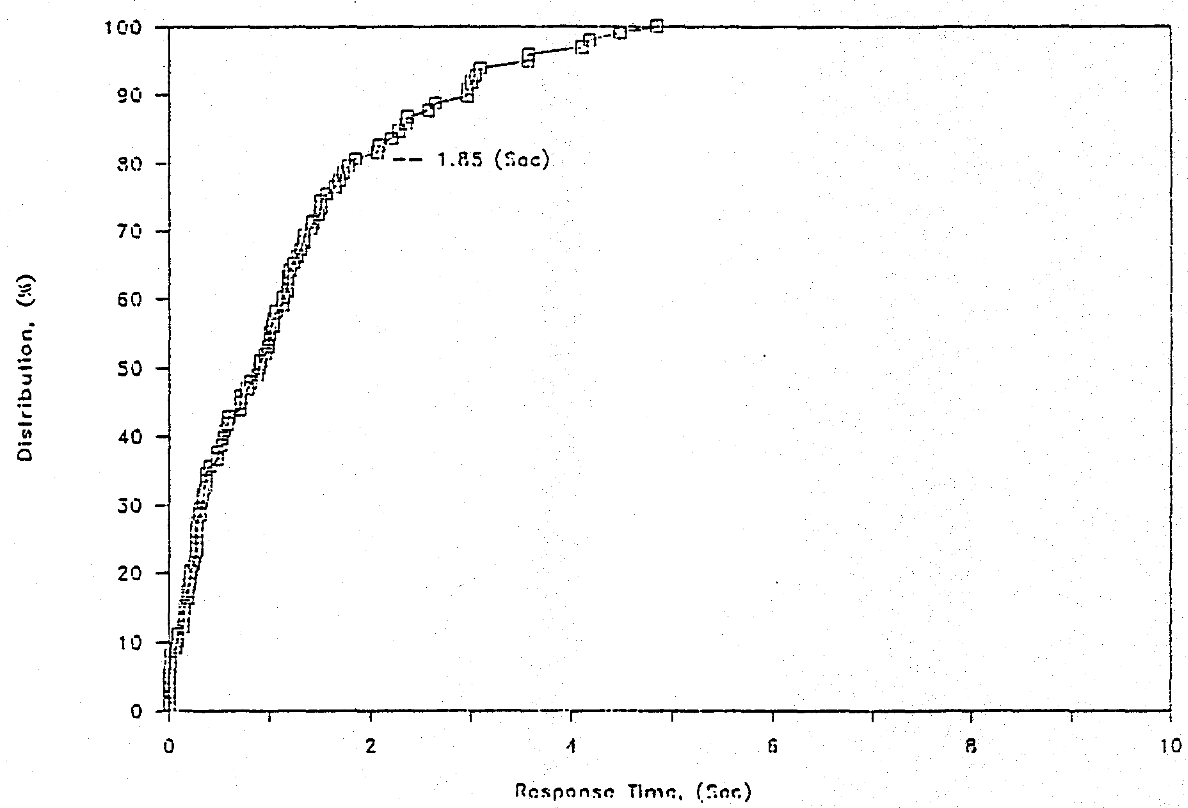


Figure 141. Distribution of correct responses, stimulus slide 116.

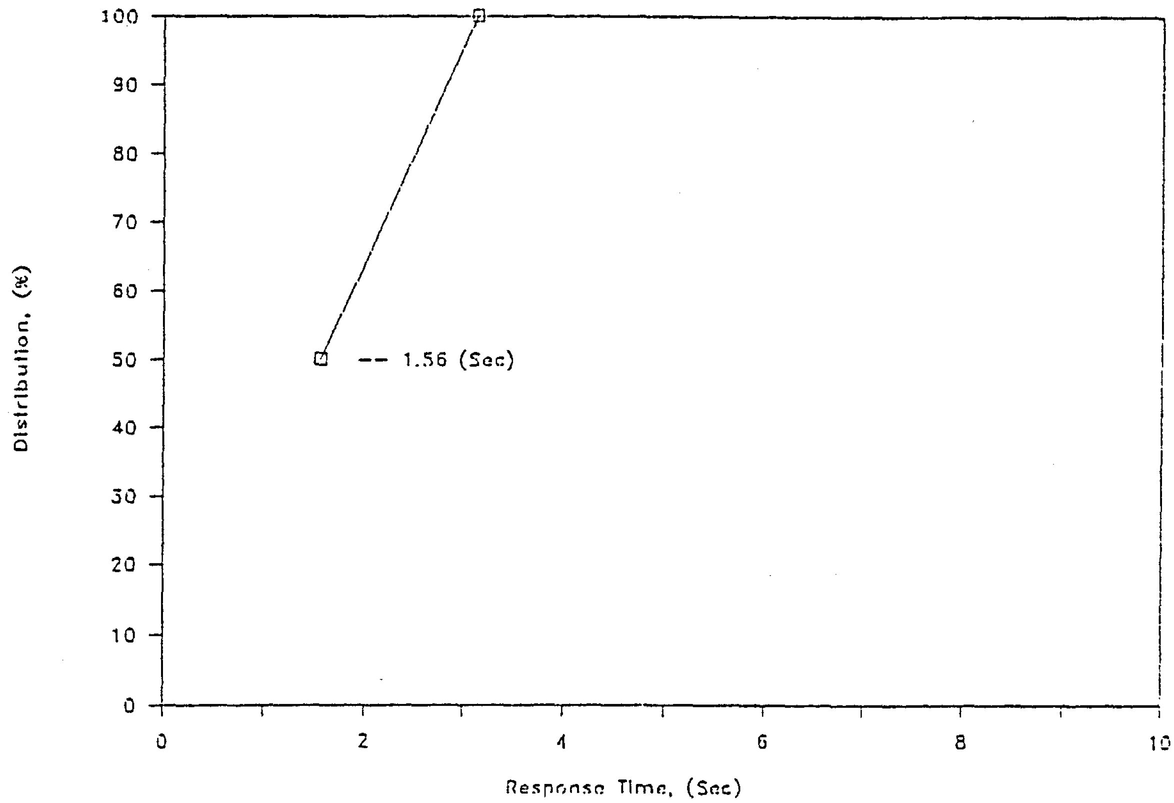


Figure 142. Distribution of correct responses, stimulus slide 117.

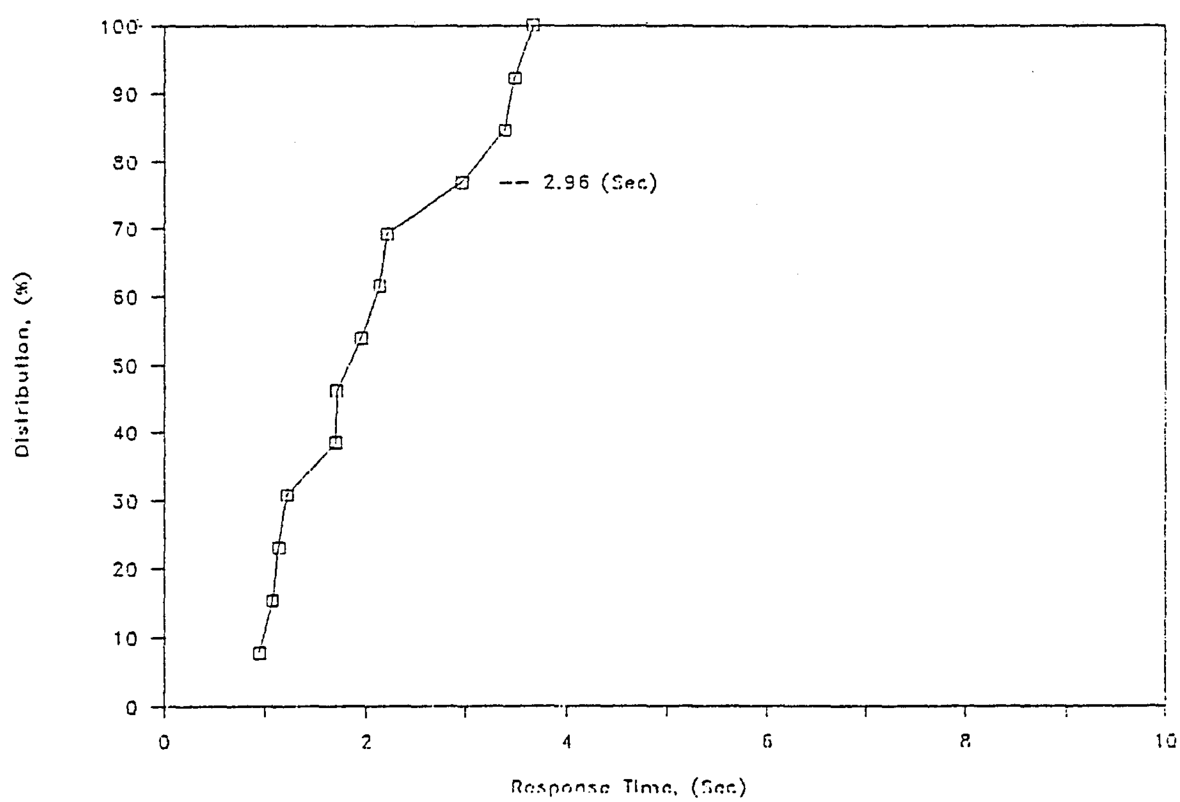


Figure 143. Distribution of correct responses, stimulus slide 118.

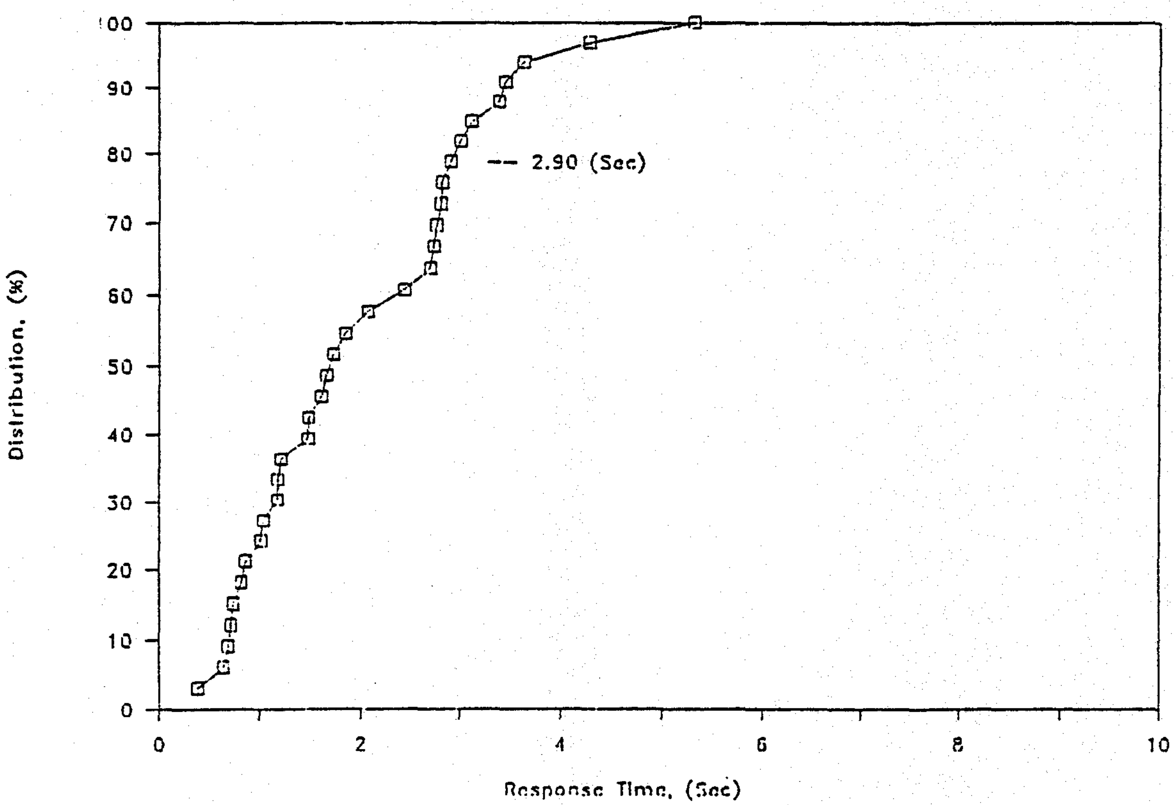


Figure 144. Distribution of correct responses, stimulus slide 119.

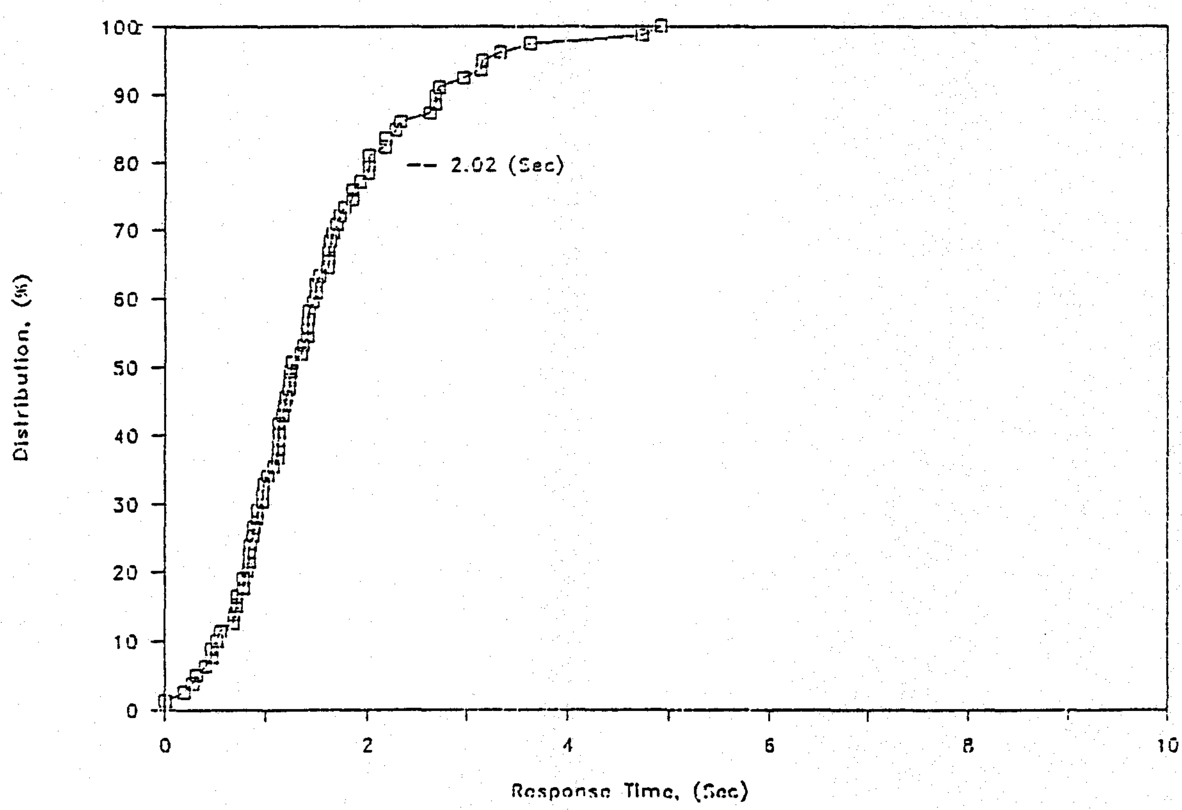


Figure 145. Distribution of correct responses, stimulus slide 120.

APPENDIX D. DETERMINE SPEED AND ACCURACY OF RESPONSE USING THE FHWA HIGHWAY SIMULATOR (HYSIM)

Purpose

The HYSIM study was developed to validate the results of the laboratory conspicuity study using an interactive driving simulator and dynamic sign presentation. Additionally, the HYSIM experiments allowed for more accurate determination of the drivers' response distances. Based on the laboratory conspicuity study the following hypotheses were tested:

- Green signs will provide greater detection distances than will black signs.
- Brighter signs will perform better than dim signs.
- As a sign become progressively obscured, its performance will decrease.
- Background complexity will have no effect on sign response.
- Age and sex will not have an effect on the data.

Because the HYSIM tests allowed the use of more types of overhead guide signs than could be used in the static tests, the following hypothesis was added:

- Sign type will have no effect on the drivers' response distances.

Experimental Design

A full-factorial experimental design was used to test the effects of:

- Five color/luminance levels -
  - A bright green background, approximating an illuminated overhead guide sign.
  - A medium green background, approximating a nonilluminated encapsulated lens overhead guide sign.
  - A medium black background at the same luminance as the medium green.

    - A dim green background, approximating a nonilluminated enclosed lens overhead guide sign.
    - A dim black background at the same luminance as the dim green.
- Three levels of sign obscuration; none, one-third and two-thirds.
- Two background complexity levels were tested; "low" which was typical of a dark rural background scene with no fixed lighting, and "high" which was typical of a somewhat less rural scene with a few lights on the horizon.

Experimental Apparatus

The tests were conducted using the FHWA HYSIM driving simulator. The simulator consists of a vehicle cab; a roadway display system which presents computer generated images of the roadway including intersections and interchanges; and a sign projection system which can present up to four different roadway signs, displaying them at a distance of approximately 750 ft, and bringing them closer to the driver as a function of the vehicle's speed. The equations of motion for the vehicle are computed in the systems minicomputer, which also presents the events according to a predetermined control file, and gathers the data on-line.

The simulator is fully interactive, which means that the driver has complete control of speed and steering. A typical interstate highway scene was used for the tests. Various signs were presented along the route including speed limit signs, route number signs and overhead guide signs. The driver was asked to proceed from a starting location to a specified destination. During the drive, the driver was required to negotiate curves and maintain an appropriate speed. Along the way various overhead guide signs directed the driver to either proceed straight or take various interchange exits. By following the signs the driver completed the drive and arrived at the proper destination. The driver was asked to "flash" the vehicles bright lights each time an overhead guide sign appeared, and was instructed to follow the instructions on the sign if it contained directional information to the desired location.

Stimulus Materials

The stimulus materials for the experiment were 35 mm slides created by the FHWA graphics department. Three sign types were designed for the study. One required the driver to choose from two alternatives, typical of locations where interstate highways split. The second required a choice from three alternatives; an exit sign indicated two destinations for an upcoming interchange or the driver could stay on the current route. The final sign gave the driver five alternatives, first and second exits on both the right and left, and the option of remaining on the current route. Sign obscuration was accomplished by blocking off the appropriate segment of the sign at the bottom. The background complexity signs were created by the same laboratory. In this case they created slides which contained two levels of point source lights which were placed above the horizon, and to the drivers right and left at the horizon.

Slide luminance was determined by measuring the resulting sign image with the Pritchard photometer. The brightest green image was chosen to represent an illuminated, and while we were unable to get quite the luminance required, it was very close. The medium brightness was intended to be similar to encapsulated lens material, and its actual measurement fell within the boundaries of the Oakland data. The dim brightness was essentially the same luminance as enclosed lens materials.

Subjects

Thirty-six subjects were recruited through advertisements placed in local newspapers. The subject population was equally divided by sex, and distributed fairly evenly between the age range of 17 to 74. When divided into younger (<=35) and older (>35) age groups, however, the men were slightly older than the women.

Each subject's visual capability was measured and compared with that of the general population. Subject's were administered both a static visual acuity test using the rambling E eye chart in the simulator and a contrast sensitivity test in the lab. Each subject's performance on the rambling E chart was converted to a score from 0 to 100. A score of 100 represents a subject's visual acuity equivalent to a standard Snellen acuity of 20/30 vision. In general, visual acuity decreased as age increased (figure 146). An averaging of the rambling E scores, divided by age and sex is seen in Figure 147. The decreased visual acuity observed for the over 35 males may be due to the higher average age of this group.

The results of the contrast sensitivity eye test are shown in table 10 and on figure 148. The average test scores are shown on the contrast sensitivity evaluation form. The shaded area represents the contrast sensitivity of 90 percent of the population between the ages of 10 and 70. The participants fall within the two dashed lines which is the upper region of the normal population shaded area.

Testing

After training in the HYSIM, each subject was asked to drive two experimental runs. The background complexity was changed for each of these runs so that each subject saw all of the test conditions. For each background complexity the subjects drove a scenario lasting approximately 1 hour. During the scenario, which presented a typical interstate roadway and scene, the subject was to react to various road signs, negotiate curves, and obtain route guidance information from the overhead guide signs to arrive at the proper destination. Subjects were instructed to respond each time an overhead guide sign was present, and to obey the sign if the proper destination was present.

A reward-penalty structure was employed to motivate the subject's performance. In addition to being paid a participation fee, rewards were given for completing the run, duplicating the real-world contingency of arriving at a destination safely; and for beating a reference time, simulating the real-world desire to drive with the flow of traffic, and for correct sign response. Penalties were assessed for receiving a ticket, being involved in an accident, or incorrectly responding to a route guidance sign.

Results

Data collected included response distance, response time, and correctness. The response data were the direct result of the driver's overt response when the sign became visible. Correctness was determined by observing whether the driver took the proper route at an interchange.

It was possible for a given sign to be visible at a sufficient distance for detectability, and for the driver to respond correctly to the sign message; but have some factor result in an unsafe lane change maneuver close to the interchange point. To be able to identify this situation, lane profile data were obtained for each interchange. Typical lane profile data are shown in figures 149 through 154. There was no indication that any factor or combination of factors resulted in unsafe lane change maneuvering.

An Analysis of Variance (ANOVA) was run to determine the effects of (1) color/luminance, (2) background complexity, (3) sign obscuration, (4) sign type, and (5) subject's sex on response distance, response time, and response correctness. To account for possible age differences, age was treated as a covariate. The ANOVA outputs are included as tables 11 through 25. The basic findings of the study reinforce the findings of the earlier laboratory tests:

- Green signs perform better than black ones.
- The brighter a sign the better it performs.
- Increasing sign obscurity decreases its performance.

Additional findings of these tests were a result of having the ability to look at additional variables. Here we found:

- The less complex a sign is the better it performs.
- Increasing background complexity increases response time and decreases response distance.

Sex was found to be statistically significant in these tests, but as the men were, as a group, older than the women it is believed that the sex difference which was measured was really an age difference.

While all of the above findings are statistically significant, the differences observed were quite small. In fact, all differences were within a one standard deviation range. When the signs were 1/3 obscured or less the differences were almost nonexistent, thus these results should really only be applied to conditions where significant obscurity is present. Even in these cases, however, the differences in response distance will allow less than 1 second of additional response time at 45 mi/h. Because the HYSIM does not require the driver to interact with other vehicles, it was not possible to study the effects of normal interstate traffic volumes when the driver is required to attend to other drivers. The results of the HYSIM study should be viewed with knowledge, as they may represent an optimistic view of driver response.

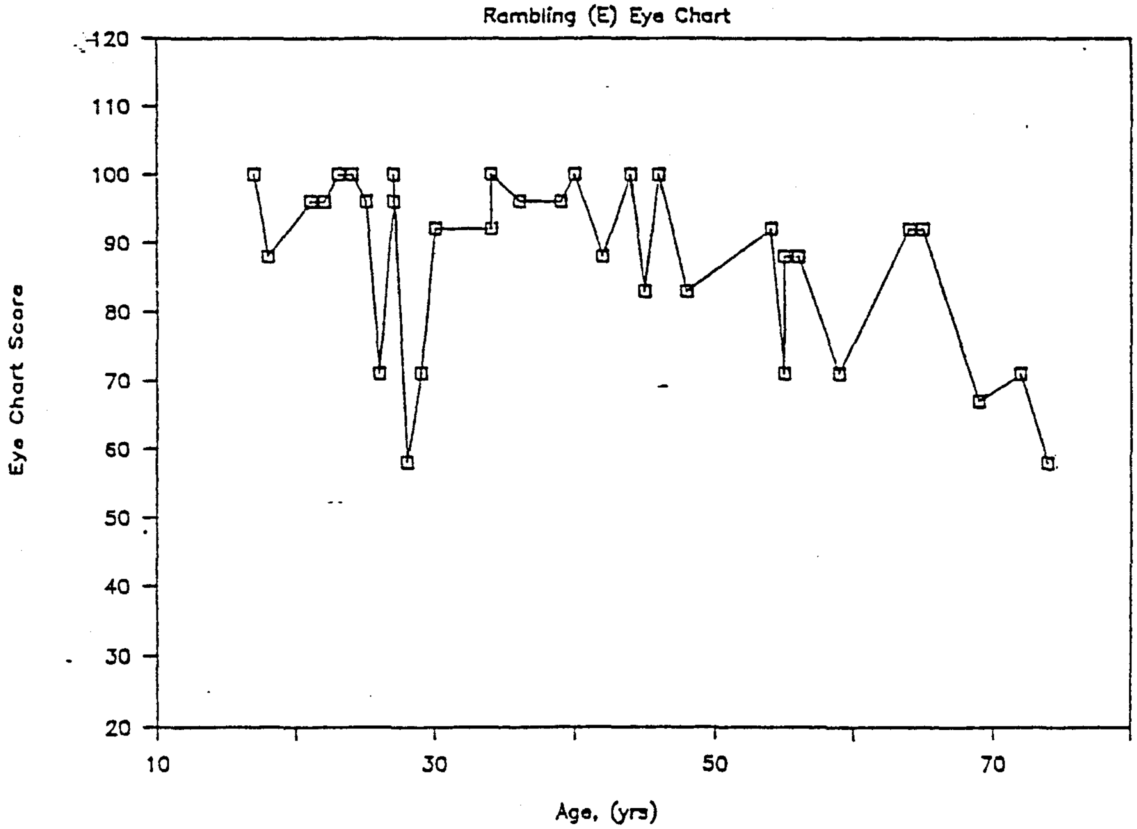


Figure 146. Rambling E eye chart scores.

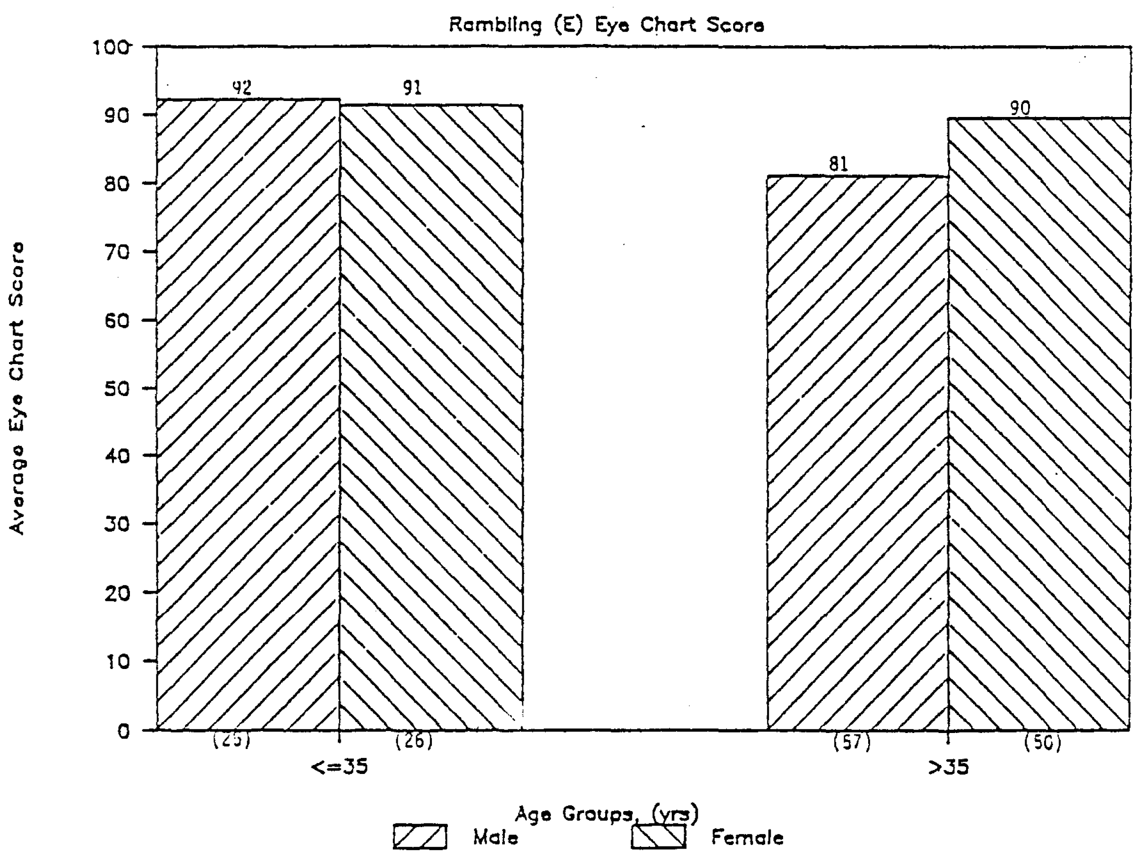


Figure 147. Rambling E eye chart scores divided by sex and age.

Table 10. Contrast sensitivity scores.

CYCLES PER DEGREE			1.5	3	6	12	18
SUBJ #	AGE	SEX	A	B	C	D	E
24	17	1	7	8	7	7	5
36	21	1	6	7	7	7	7
12	22	1	8	8	9	8	9
27	23	1	8	8	8	6	6
31	25	1	7	8	6	4	4
7	28	1	7	8	5	5	4
23	30	1	6	7	5	3	2
25	34	1	7	8	7	7	5
34	34	1	7	7	6	5	5
26	39	1	7	6	6	4	4
16	46	1	8	8	8	8	7
8	48	1	7	7	6	6	4
17	55	1	8	8	7	5	6
43	55	1	7	7	6	5	4
14	59	1	7	7	7	7	7
30	65	1	7	8	8	5	5
18	72	1	7	7	7	7	5
15	74	1	6	6	4	3	3
28	18	2	7	8	8	7	6
42	21	2	7	8	7	7	6
11	23	2	7	7	7	7	6
35	24	2	7	7	7	7	6
10	26	2	6	7	7	6	4
29	27	2	7	8	8	7	7
22	27	2	7	7	6	6	5
20	27	2	6	8	8	7	6
37	29	2	8	8	5	4	5
39	36	2	6	7	7	7	6
5	40	2	7	7	7	7	5
32	42	2	7	7	7	6	5
13	44	2	6	6	7	7	6
33	45	2	6	7	6	4	3
40	54	2	6	8	8	7	6
41	56	2	7	8	7	7	6
21	64	2	7	7	6	6	5
9	69	2	6	7	7	5	4
	OVERALL AVERAGE		6.9	7.4	6.8	6.0	5.3
AVERAGES BY GROUPS	<=35-MALE	—□—	7.0	7.7	6.7	5.8	5.2
	<=35-FEMALE	—○—	6.9	7.6	7.0	6.4	5.7
	>35-MALE	—△—	7.1	7.1	6.6	5.6	5.0
	>35-FEMALE	—▽—	6.4	7.1	6.9	6.2	5.1

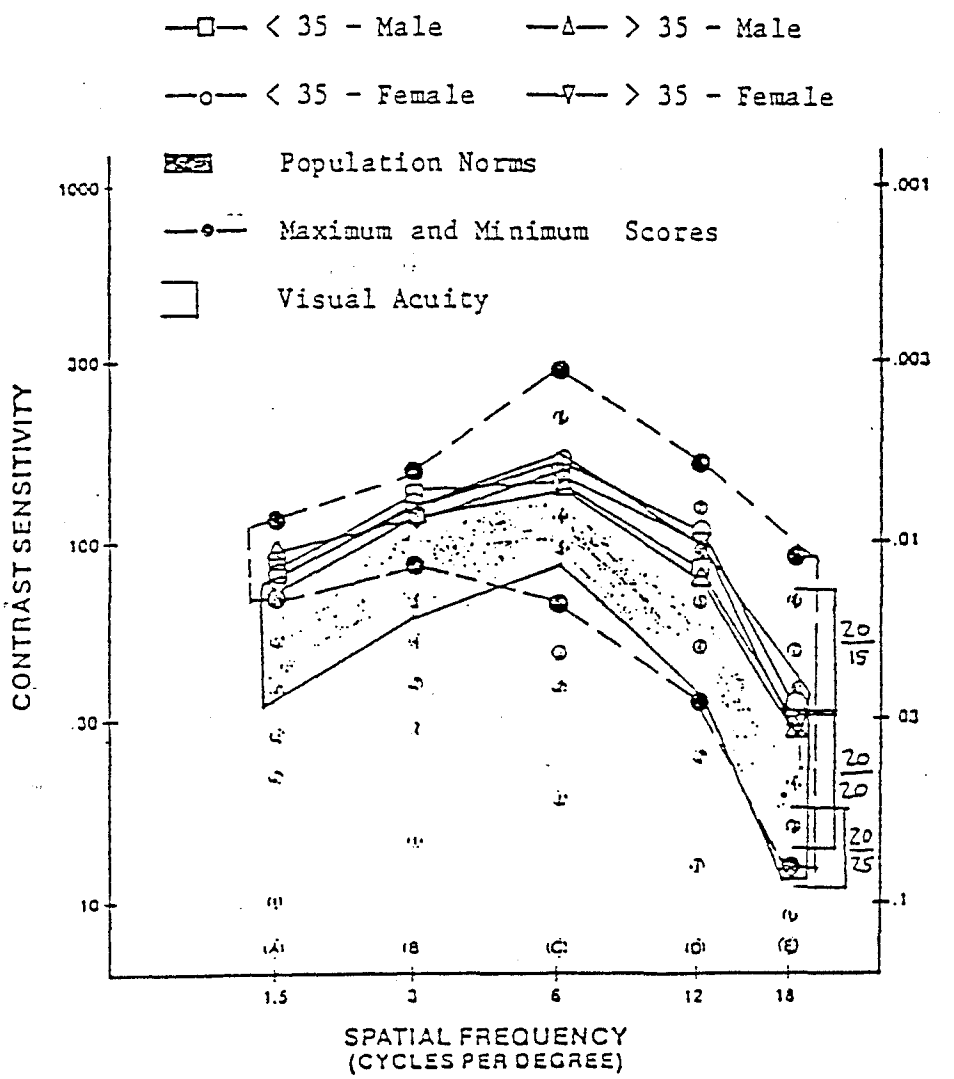
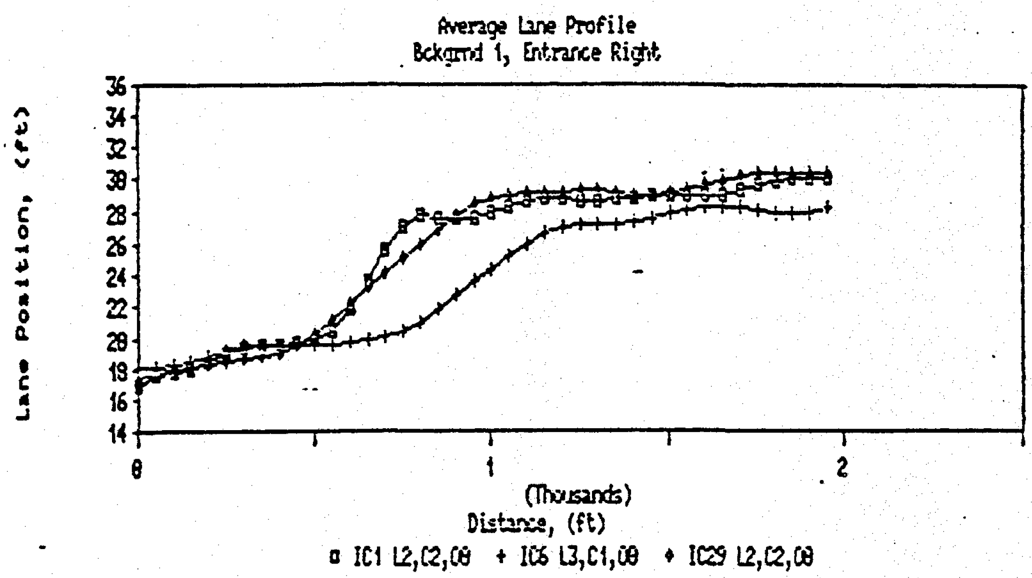


Figure 148. Contrast sensitivity scores contrast evaluation form



IC_X = Interchange Number		
Luminance:	Color:	Obscuration:
L1 = Bright	C1 = Green	0Ø = None
L2 = Medium	C2 = Black	01 = 1/3
L3 = Dim		02 = 2/3

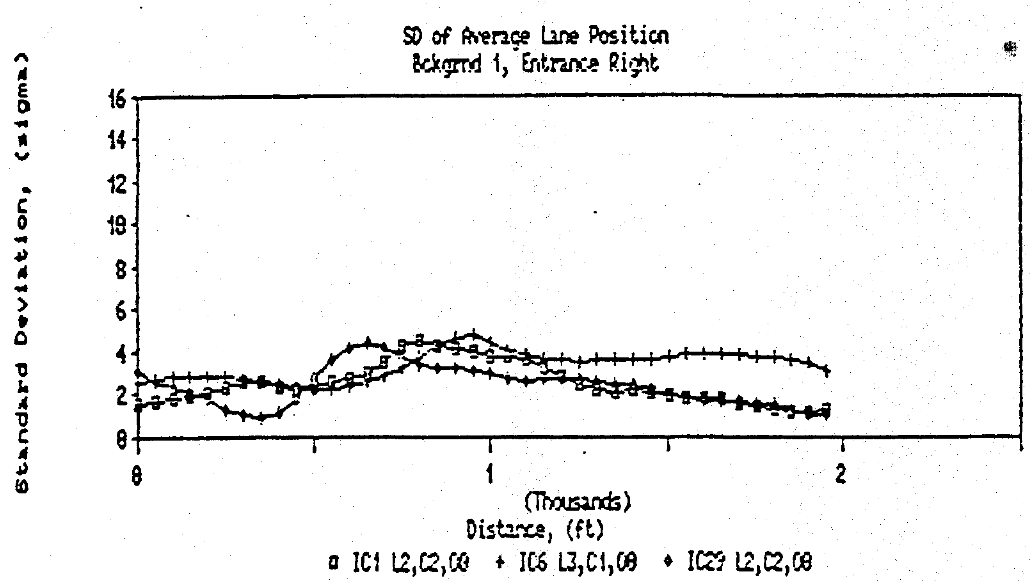
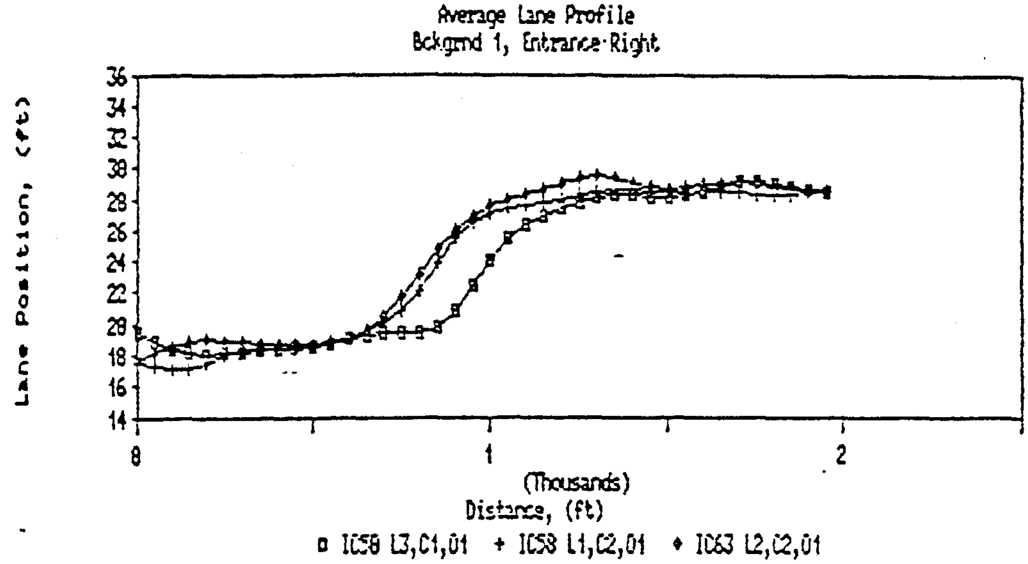


Figure 149. Typical lane change profile data, background 1, no sign obscurity.



ICx = Interchange Number		
Luminance:	Color:	Obscuration:
L1 = Bright L2 = Medium L3 = Dim	C1 = Green C2 = Black	0Ø = None 01 = 1/3 02 = 2/3

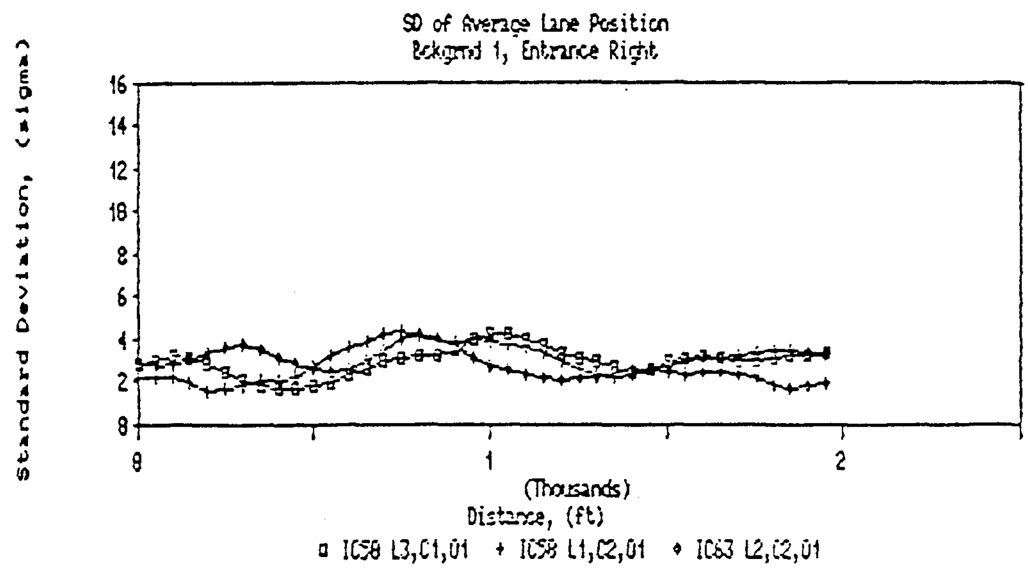
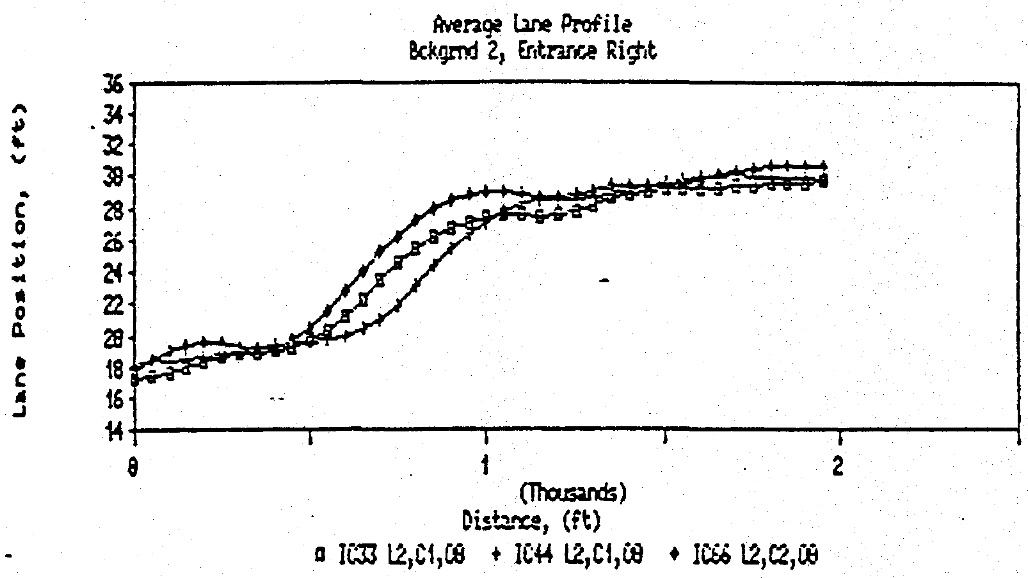


Figure 150. Typical lane change profile data, background 1, 1/3 sign obscurity.



IC_X = Interchange Number		
Luminance:	Color:	Obscuration:
L1 = Bright L2 = Medium L3 = Dim	C1 = Green C2 = Black	00 = None 01 = 1/3 02 = 2/3

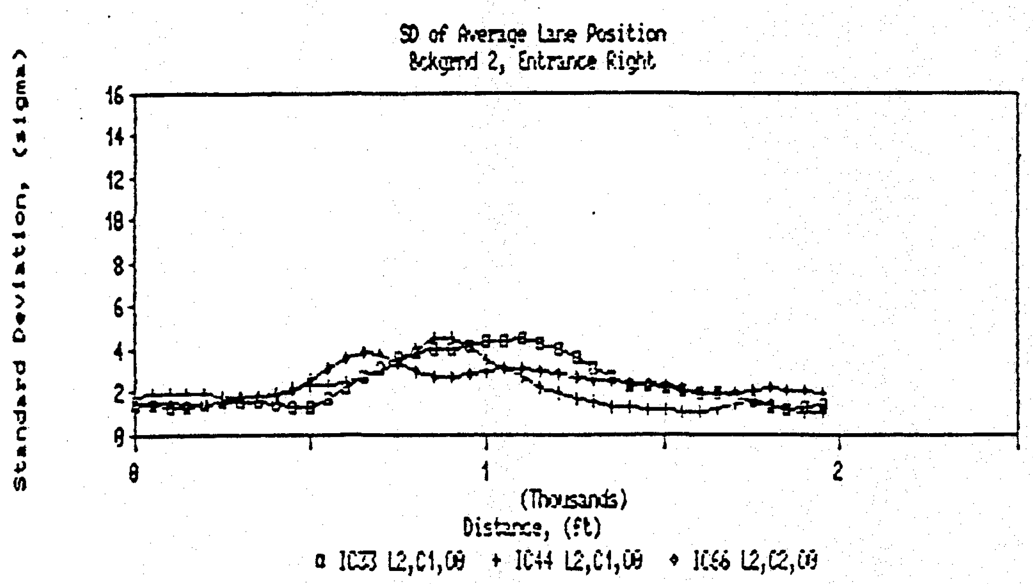
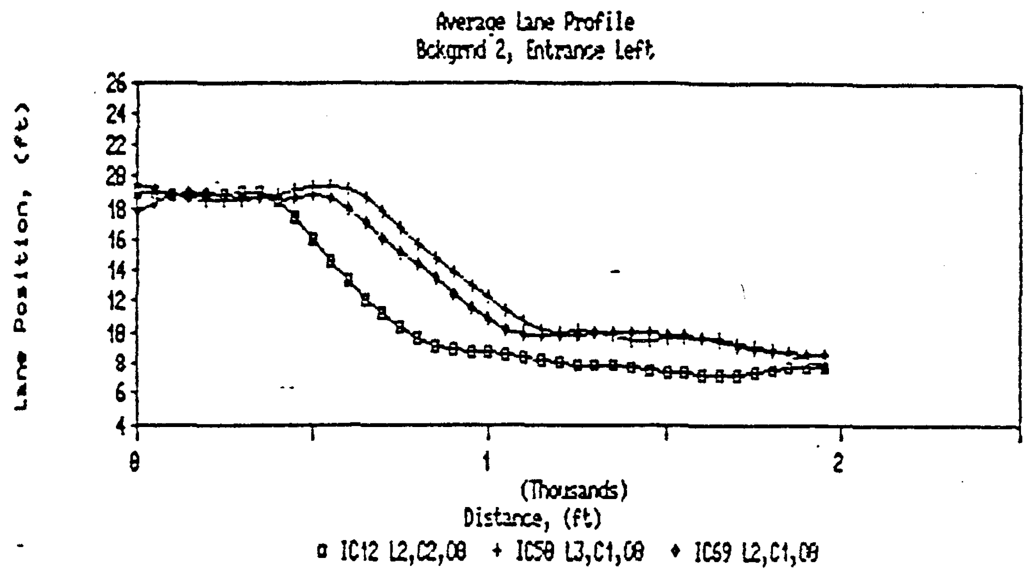


Figure 151. Typical lane change profile data, background 2, no sign obscurity, entrance right.



IC_X = Interchange Number		
Luminance:	Color:	Obscuration:
L1 = Bright L2 = Medium L3 = Dim	C1 = Green C2 = Black	0Ø = None 01 = 1/3 02 = 2/3

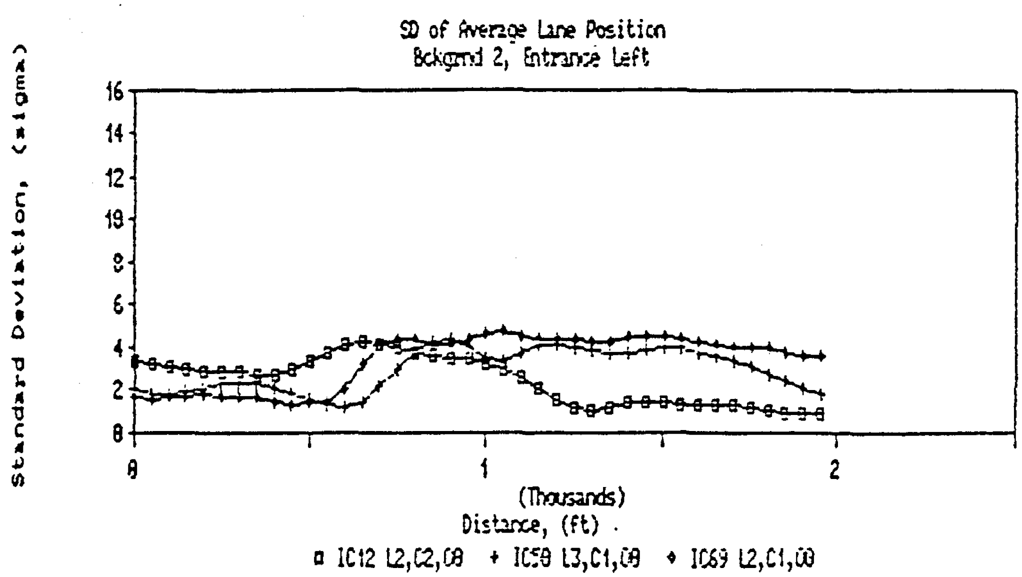
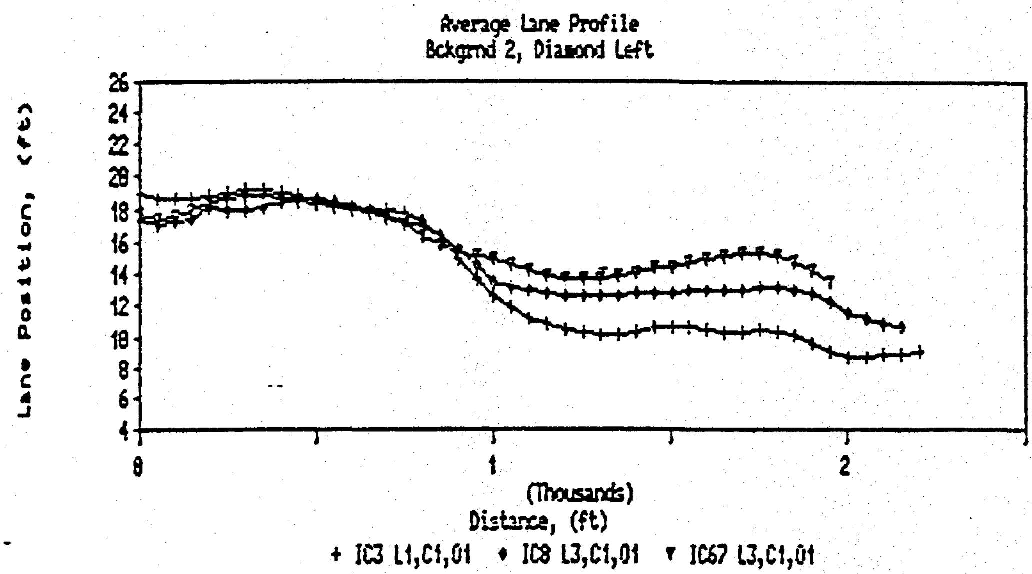


Figure 152. Typical lane change profile data, background 2, no sign obscurity, entrance left.



IC_X = Interchange Number		
Luminance:	Color:	Obscuration:
L1 = Bright L2 = Medium L3 = Dim	C1 = Green C2 = Black	0Ø = None 01 = 1/3 02 = 2/3

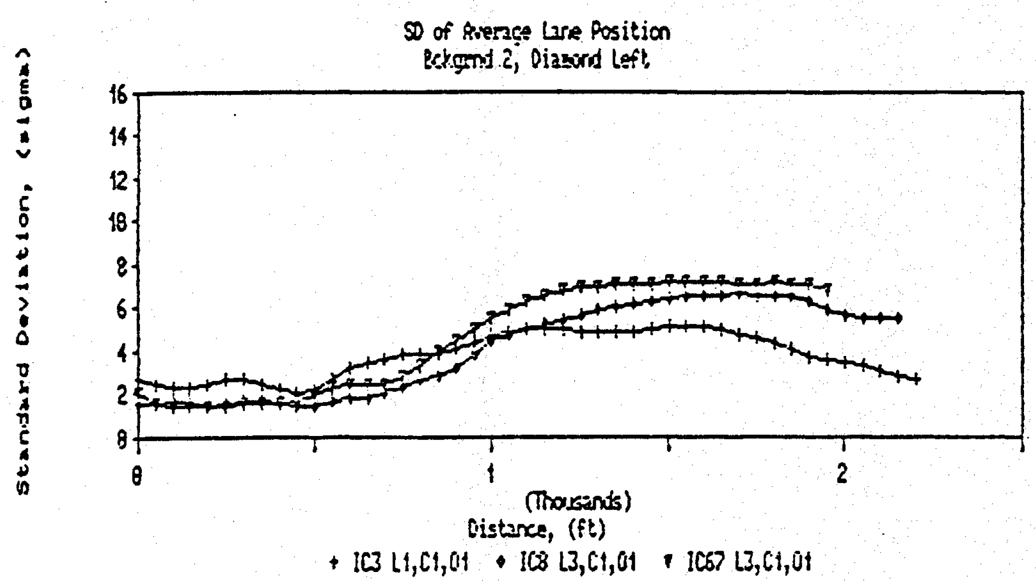
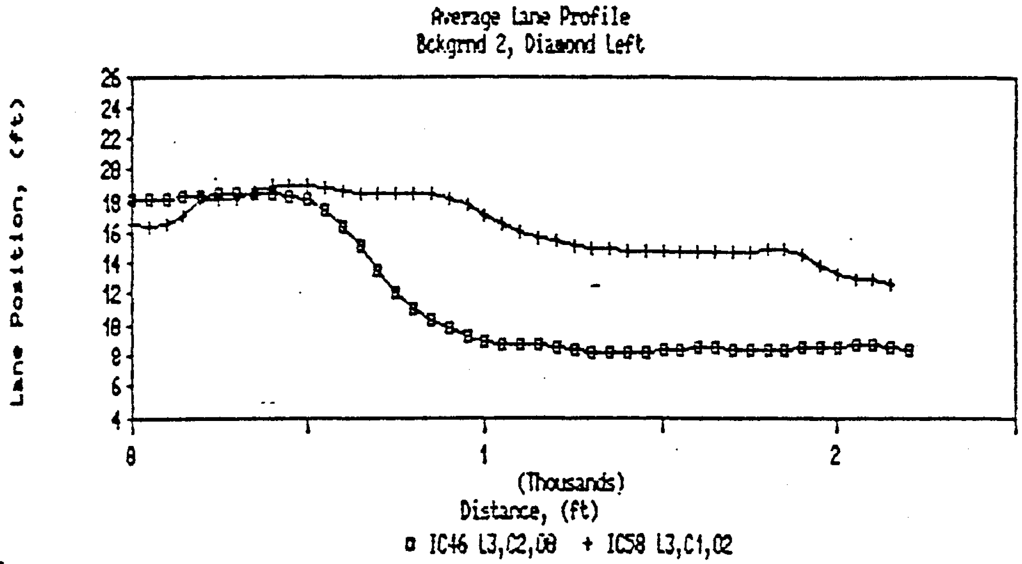


Figure 153. Typical lane change profile data, background 2, 1/3 sign obscurity, diamond left.



IC_X = Interchange Number		
Luminance:	Color:	Obscuration:
L1 = Bright L2 = Medium L3 = Dim	C1 = Green C2 = Black	0Ø = None 01 = 1/3 02 = 2/3

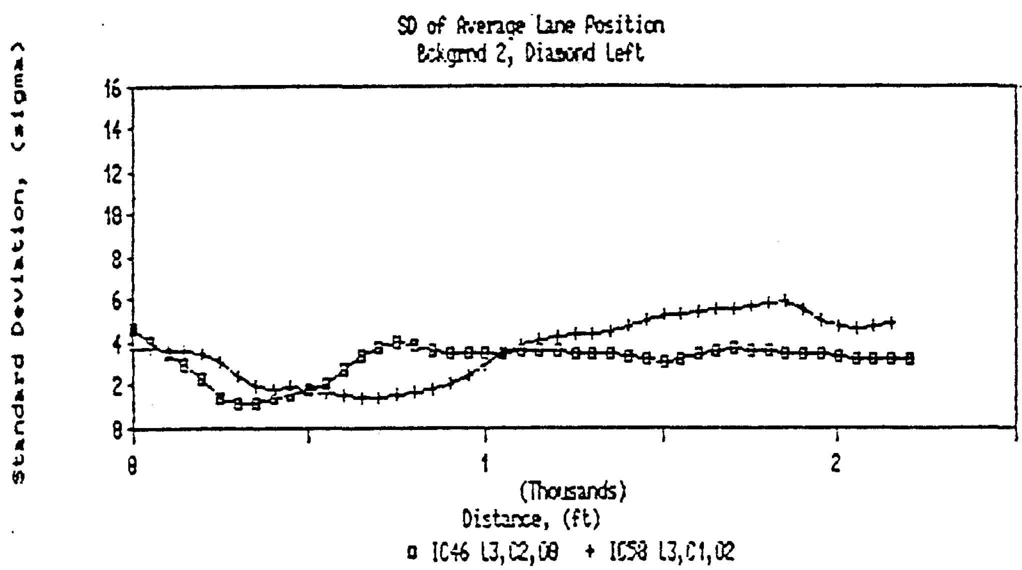


Figure 154. Typical lane change profile data, background 2, diamond left.

Table 11. Analysis of variance and covariance,
dependent variable - reaction distance,
covariate - age,
independent variables obscurity and color/luminance.

SUMMARY OF DESIGN

Name of Data File: D:1209STSC
Dependent variable: 5 missing value code: -9999.000
Covariate: 1 missing value code: -9999.000

Independent variable (A): Var. 10 Codes: 0 1 2
Independent variable (B): Var. 14 Codes: 1 2 3 4 5

A N A L Y S I S O F V A R I A N C E

EFFECT	SS	df	MS	F	p
Covariate	137176.709	1	137176.709	45.273	.000
A	710196.334	2	355098.167	117.195	.000
B	135511.842	4	33877.960	11.181	.000
A x B	107314.895	8	13414.362	4.427	.000
Within	7305303.090	2411	3029.98884		

Table 12. Analysis of variance and covariance,
dependent variable - reaction distance,
covariate - age,
independent variables sign type and color/luminance.

SUMMARY OF DESIGN

Name of Data File: D:1209STSC
Dependent variable: 5 missing value code: -9999.000
Covariate: 1 missing value code: -9999.000

Independent variable (A): Var. 13 Codes: 1 2 3
Independent variable (B): Var. 14 Codes: 1 2 3 4 5

A N A L Y S I S O F V A R I A N C E

EFFECT	SS	df	MS	F	p
Covariate	139114.017	1	139114.017	41.277	.000
A	1610.085	2	805.042	.239	.790
B	105748.931	4	26437.233	7.844	.000
A x B	81278.258	8	10159.782	3.015	.003
Within	8125745.901	2411	3370.28034		

Table 13. Analysis of variance and covariance, dependent variable - reaction distance, covariate - age, independent variables sex, background and obscurity.

SUMMARY OF DESIGN

Name of Data File: D:12098TSC
Dependent variable: 5 missing value code: -9999.000
Covariate: 1 missing value code: -9999.000

Independent variable (A): Var. 2 Codes: 1 2
Independent variable (B): Var. 11 Codes: 1 2
Independent variable (C): Var. 10 Codes: 0 1 2

A N A L Y S I S O F V A R I A N C E

EFFECT	SS	df	MS	F	p
Covariate	109855.329	1	109855.329	36.131	.000
A	110148.101	1	110148.101	36.227	.000
B	54437.894	1	54437.894	17.904	.000
C	812963.351	2	406481.676	133.690	.000
A x B	3733.145	1	3733.145	1.228	.267
A x C	17031.373	2	8515.686	2.801	.059
B x C	25262.099	2	12631.049	4.154	.016
A x B x C	4597.002	2	2298.501	.756	.474
Within	7339723.422	2414	3040.48195		

Table 14. Analysis of variance and covariance,
dependent variable - reaction distance,
covariate - age,
independent variables sex, background and sign type.

SUMMARY OF DESIGN

Name of Data File: D:1209STSC
Dependent variable: 5 missing value code: -9999.000
Covariate: 1 missing value code: -9999.000

Independent variable (A):	Var. 2	Codes:	1 2
Independent variable (B):	Var. 11	Codes:	1 2
Independent variable (C):	Var. 13	Codes:	1 2 3

ANALYSIS OF VARIANCE

EFFECT	SS	df	MS	F	P
Covariate	107465.656	1	107485.656	31.874	.000
A	117378.982	1	117378.982	34.808	.000
B	30641.568	1	30641.568	9.087	.003
C	380.555	2	190.278	.056	.935
A x B	3526.315	1	3526.315	1.046	.307
A x C	5992.392	2	2996.196	.889	.414
B x C	41088.284	2	20544.142	6.092	.003
A x B x C	398.079	2	199.039	.059	.933
Within	8140446.984	2414	3372.18185		

Table 15. Analysis of variance and covariance,
dependent variable - reaction distance,
covariate - age,
independent variables sex, background and luminance/color.

SUMMARY OF DESIGN

Name of Data File: D:1209STSC
Dependent variable: 5 missing value code: -9999.000
Covariate: 1 missing value code: -9999.000

Independent variable (A):	Var.	2	Codes:	1	2				
Independent variable (B):	Var.	11	Codes:	1	2				
Independent variable (C):	Var.	14	Codes:	1	2	3	4	5	

A N A L Y S I S   O F   V A R I A N C E

EFFECT	SS	df	MS	F	p
Covariate	109151.069	1	109151.069	32.675	.000
A	112639.652	1	112639.652	33.720	.000
B	37303.094	1	37303.094	11.167	.001
C	126741.445	4	31685.361	9.485	.000
A x B	4121.402	1	4121.402	1.234	.266
A x C	2883.276	4	720.819	.216	.928
B x C	16158.789	4	4039.697	1.209	.304
A x B x C	4797.190	4	1199.298	.359	.839
Within	8037208.432	2406	3340.48563		

Table 16. Analysis of variance and covariance, dependent variable - reaction time, covariate - age, independent variables obscurity and color/luminance.

SUMMARY OF DESIGN

```
 Name of Data File: D:12098TSC
Dependent variable:   6        missing value code:     -9999.000
         Covariate:   1        missing value code:     -9999.000

Independent variable (A):  Var.   10     Codes:  0  1  2
Independent variable (B):  Var.   14     Codes:  1  2  3  4  5
```

A N A L Y S I S   O F   V A R I A N C E

EFFECT	SS	df	MS	F	P
Covariate	90.365	1	90.365	145.665	.000
A	132.848	2	66.424	107.073	.000
B	21.757	4	5.439	8.768	.000
A x B	22.869	8	2.859	4.608	.000
Within	1495.693	2411	.62036		

Table 17. Analysis of variance and covariance,
dependent variable - reaction time,
covariate - age,
independent variables sign type and color/luminance.

SUMMARY OF DESIGN

```
 Name of Data File: D:12098TSC
Dependent variable:   6       missing value code:     -9999.000
         Covariate:  -1       missing value code:     -9999.000

Independent variable (A):  Var.   13     Codes:  1  2  3
Independent variable (B):  Var.   14     Codes:  1  2  3  4  5
```

A N A L Y S I S   O F   V A R I A N C E

EFFECT	SS	df	MS	F	P
Covariate	91.108	1	91.108	133.272	.000
A	.558	2	.279	.408	.671
B	17.034	4	4.258	6.229	.000
A x B	16.583	8	2.073	3.032	.002
Within	1648.213	2411	.68362		

Table 18. Analysis of variance and covariance,
dependent variable - reaction time,
covariate - age,
independent variables sex, background and obscurity.

SUMMARY OF DESIGN

Name of Data File: D:1209STSC
Dependent variable: 6 missing value code: -9999.000
Covariate: 1 missing value code: -9999.000

Independent variable (A): Var. 2 Codes: 1 2
Independent variable (B): Var. 11 Codes: 1 2
Independent variable (C): Var. 10 Codes: 0 1 2

A N A L Y S I S O F V A R I A N C E

EFFECT	SS	df	MS	F	p
Covariate	81.467	1	81.467	130.753	.000
A	14.337	1	14.337	23.010	.000
B	12.941	1	12.941	20.770	.000
C	152.594	2	76.297	122.455	.000
A x B	1.390	1	1.390	2.231	.131
A x C	3.822	2	1.911	3.067	.045
B x C	4.157	2	2.078	3.336	.035
A x B x C	.657	2	.329	.527	.596
Within	1504.068	2414	.62306		

Table 19. Analysis of variance and covariance,
dependent variable - reaction time,
covariate - age,
independent variables sex, background and sign type.

SUMMARY OF DESIGN

Name of Data File: D:12098TSC
Dependent variable: 6 missing value code: -9999.000
Covariate: 1 missing value code: -9999.000

Independent variable (A): Var. 2 Codes: 1 2
Independent variable (B): Var. 11 Codes: 1 2
Independent variable (C): Var. 13 Codes: 1 2 3

A N A L Y S I S O F V A R I A N C E

EFFECT	SS	df	MS	F	P
Covariate	80.729	1	80.729	117.785	.000
A	16.012	1	16.012	23.361	.000
B	8.261	1	8.261	12.053	.001
C	.846	2	.423	.617	.545
A x B	1.406	1	1.406	2.051	.148
A x C	1.182	2	.591	.862	.423
B x C	6.065	2	3.033	4.425	.012
A x B x C	.226	2	.113	.165	.847
Within	1654.538	2414	.68539		

Table 20. Analysis of variance and covariance,
dependent variable - reaction time,
covariate - age,
independent variables sex, background and luminance/color.

SUMMARY OF DESIGN

Name of Data File: D:1209STSC
Dependent variable: 6 missing value code: -9999.000
Covariate: 1 missing value code: -9999.000

Independent variable (A): Var. 2 Codes: 1 2
Independent variable (B): Var. 11 Codes: 1 2
Independent variable (C): Var. 14 Codes: 1 2 3 4 5

ANALYSIS OF VARIANCE

EFFECT	SS	df	MS	F	p
Covariate	81.211	1	81.211	119.312	.000
A	14.741	1	14.741	21.657	.000
B	9.262	1	9.262	13.608	.000
C	20.387	4	5.097	7.489	.000
A x B	1.487	1	1.487	2.185	.139
A x C	.520	4	.130	.191	.941
B x C	3.254	4	.813	1.195	.310
A x B x C	1.153	4	.288	.423	.794
Within	1637.667	2406	.68066		

Table 21. Analysis of variance and covariance,
dependent variable - correctness,
covariate - age,
independent variables obscurity and color/luminance.

SUMMARY OF DESIGN

Name of Data File: D:1209STSC
Dependent variable: 12 missing value code: -9999.000
Covariate: 11 missing value code: -9999.000

Independent variable (A): Var. 10 Codes: 0 1 2
Independent variable (B): Var. 14 Codes: 1 2 3 4 5

A N A L Y S I S O F V A R I A N C E

EFFECT	SS	df	MS	F	p
Covariate	5.168	1	5.168	93.117	.000
A	.394	2	.197	3.550	.028
B	1.059	4	.265	4.769	.001
A x B	2.711	8	.339	6.105	.000
Within	133.811	2411	.05550		

Table 22. Analysis of variance and covariance,
dependent variable - correctness,
covariate - age,
independent variables sign type and color/luminance.

SUMMARY OF DESIGN

```
 Name of Data File: D:12093TSC
Dependant variable:  12        missing value code:     -9999.000
         Covariate:   1        missing value code:     -9999.000

Independent variable (A):  Var.   13     Codes:  1  2  3
Independent variable (B):  Var.   14     Codes:  1  2  3  4  5
```

A N A L Y S I S   O F   V A R I A N C E

EFFECT	SS	df	MS	F	p
Covariate	5.213	1	5.213	93.264	.000
A	1.765	2	.882	15.788	.000
B	.615	4	.154	2.751	.026
A x B	.410	8	.051	.916	.502
Within	134.756	2411	.05589		

Table 23. Analysis of variance and covariance,
dependent variable - correctness,
covariate - age,
independent variables sex, background and obscurity.

SUMMARY OF DESIGN

Name of Data File: D:1209STSC
Dependent variable: 12 missing value code: -9999.000
Covariate: -1 missing value code: -9999.000

Independent variable (A): Var. 2 Codes: 1 2
Independent variable (B): Var. 11 Codes: 1 2
Independent variable (C): Var. 10 Codes: 0 1 2

A N A L Y S I S O F V A R I A N C E

EFFECT	SS	df	MS	F	p
Covariate	5.201	1	5.201	91.824	.000
A	.003	1	.003	.048	.810
B	.244	1	.244	4.310	.036
C	.549	2	.275	4.848	.008
A x B	.401	1	.401	7.082	.008
A x C	.060	2	.030	.531	.584
B x C	.135	2	.067	1.191	.304
A x B x C	.029	2	.015	.259	.774
Within	136.738	2414	.05664		

Table 24. Analysis of variance and covariance, dependent variable - correctness, covariate - age, independent variables sex, background and sign type.

SUMMARY OF DESIGN

Name of Data File: D:1209STSC
Dependent variable: 12 missing value code: -9999.000
Covariate: 1 missing value code: -9999.000

Independent variable (A):	Var.	2	Codes:	1	2	
Independent variable (B):	Var.	11	Codes:	1	2	
Independent variable (C):	Var.	13	Codes:	1	2	3

A N A L Y S I S   O F   V A R I A N C E

EFFECT	SS	df	MS	F	p
Covariate	5.196	1	5.196	92.873	.000
A	.000	1	.000	.001	.927
B	.355	1	.355	6.341	.011
C	2.069	2	1.034	18.488	.000
A x B	.293	1	.293	5.229	.021
A x C	.034	2	.017	.305	.742
B x C	.223	2	.112	1.997	.134
A x B x C	.099	2	.050	.888	.414
Within	135.049	2414	.05594		

Table 25. Analysis of variance and covariance,
dependent variable - correctness,
covariate - age,
independent variables sex, background and luminance/color.

SUMMARY OF DESIGN

Name of Data File:	D:1209STSC		
Dependent variable:	12	missing value code:	-9999.000
Covariate:	1	missing value code:	-9999.000

Independent variable (A):	Var. 2	Codes:	1 2
Independent variable (B):	Var. 11	Codes:	1 2
Independent variable (C):	Var. 14	Codes:	1 2 3 4 5

A N A L Y S I S O F V A R I A N C E

EFFECT	SS	df	MS	F	p
Covariate	5.174	1	5.174	92.076	.000
A	.000	1	.000	.006	.936
B	.197	1	.197	3.498	.058
C	1.152	4	.288	5.125	.001
A x B	.335	1	.335	5.968	.014
A x C	.150	4	.038	.668	.617
B x C	.821	4	.205	3.655	.006
A x B x C	.171	4	.043	.760	.554
Within	135.189	2406	.05619		

APPENDIX E. PROVIDE COST ESTIMATES FOR OVERHEAD GUIDE SIGN TREATMENTS

Introduction

This report contains an analysis of the costs of signs made from various combinations of background and message materials, and the costs of providing lighting for these signs.

Three types of message materials (enclosed lens reflective sheeting, encapsulated lens reflective sheeting, and button copy) are combined with three types of background materials (opaque enamel, enclosed lens sheeting, and encapsulated lens sheeting); a total of nine combinations. Costs for each of these combinations are developed on a square foot basis, and for a typical sign of 165 ft^2. An examination of the service life of the materials, and the future years when they would have to be replaced, are combined with the cost data of the original sign and replacement overlays to determine a present worth cost of each sign. These costs are presented later in this appendix.

The development of the lighting system costs examines each of the components of this system. One of the major costs involves installing the electrical power system to carry electricity from the existing power lines of the utility company to the structures on which the overhead guide signs are placed. These costs are quite variable because of differences in the cost of construction labor from one region of the country to another, the variety of surface and subsurface conditions that may be encountered, and the distance between the power line and the structure on any particular project. The average costs of the power system presented in later are bracketed with additional estimates at ± 15 percent.

Also found later in the appendix is the estimate of the costs of the original installation of luminaires and lamps. Estimates are provided for three different luminaires and three sizes of mercury vapor lamps (175 watt, 250 watt, and 400 watt), and three sizes of high pressure sodium lamps (70 watt, 150 watt, and 250 watt) that are commonly used for guide sign lighting. The cost per sign is based on two luminaires for the higher wattage bulbs, and for the lower wattage bulb mounted in a luminaire with wide light dispersion capability.

The present worth cost of a series of annual electricity payments for these lamps is then discussed. Also contained is a discussion of the differences in electricity costs around the country, and a discussion of the justification for assuming that electricity prices will remain constant (in terms of constant dollars) in the next 20 years.

Sign maintenance is concerned with lamp and ballast replacement, and other problems that arise on sign lighting systems. The present worth of these replacements is calculated based on a 3-year service life for lamps, and a 12-year service life for ballasts. The "other" costs have been estimated based on adjustments to the detailed maintenance records provided by the California Department of Transportation. These computations follow the present worth cost discussions.

The structural cost of the support systems for the lighting systems is the second major item in determining the cost of providing sign lighting. Lighting support systems which also provide a walkway are very expensive. A variety of lighting support systems, with and without walkways, are reviewed, and detailed estimates are developed for the cost of these systems.

Finally computations contained in the tables presented throughout the Appendix are summarized. The present worth cost of a complete sign lighting system, is presented and the sensitivity of this cost to changes in the costs of the various components contributing to the total are examined.

Summary of Sign System Costs With and Without Lighting

The analysis in this report has tried to answer the question "How much does it cost to provide lighting for overhead guide signs"? As we will show, this is not an easy question to answer because it depends on so many local factors. The summary data illustrates that the present worth costs of providing lighting for a 165 ft^2 sign over a 20-year period (and an interest of 10 percent), is approximately $7,000. The cost of the sign with an opaque enamel background and either button copy or encapsulated lens message for this location is about $4,000, for a total cost of

$11,000. This is equivalent to a uniform annual cost of about $1,300 per sign.

If the operating agency is not concerned about the motorist seeing the background color at night, the same sign(s) described above may be used. The savings will be the cost of the sign lighting, $7,000 in present worth cost, or approximately $825 in uniform annual cost.

If this location is not to be lit and the operating agency wants the background color to be visible, a sign using encapsulated lens sheeting for both the background and the message will have a present worth cost of about $5,300, which is the same as a uniform annual cost of $625. A savings of $5,700 in present worth costs, or $675 in uniform annual costs.

Sign Materials

Introduction

This section discusses the cost of various background and message materials that are used on overhead guide signs. These background materials include enclosed lens and encapsulated lens sheeting, and backgrounds created with opaque enamels. Costs are also shown for three different types of materials used to form sign messages: enclosed lens sheeting, encapsulated lens sheeting, and embossed aluminum characters that contain reflective buttons.

The cost data for each of these nine combinations are shown on the basis of the cost per square foot of signage, and for the total cost of an average overhead guide sign of 165 ft^2. These costs are then compared with the signage costs found in other data sources.

An analysis of the length of the service lives of the materials was used to identify the years when overlays would be required to renew the sign. Separate cost estimates were used for these overlays.

Finally a comparison of the present worth costs of the original sign installation and the necessary overlays for a 20-year period is presented.

Types of Materials

The variety of materials used for sign backgrounds and sign letters are relatively limited. Sign backgrounds may be made with either enclosed lens or encapsulated lens reflective materials, or they may be painted or enameled to provide a background color that is visible only by day. Sign letters may also be made of either type of reflective materials, or they may be formed by a series of retroreflective plastic buttons.

Sign Background Materials

Retroreflective Sheeting

Enclosed lens and encapsulated lens reflective sheeting obtain high levels of light reflectivity through the use of minute glass spheres in the sheeting material. The "1981 Missouri Standard Specifications for Highway Construction" defines these materials as follows:[20]

Enclosed Lens	"... reflective sheeting shall consist of spherical lens elements embedded within a transparent plastic having a smooth, flat outer surface which shall be weather resistant.
Encapsulated Lens	"... reflective sheeting shall consist of spherical lens elements adhered to a synthetic resin and encapsulated by a flexible, transparent, weather resistant plastic having a smooth outer surface."

The primary difference between these two types of reflective sheeting is the amount of light that is reflected back toward the driver's eye. Table 26 shows the retroreflectivity requirement for green enclosed lens and encapsulated lens retroreflective sheeting materials observed from angles of 0.2 and 0.5 degrees with the light entering from angles of -4.0 and +30.0 degrees. As can be seen in this table, encapsulated lens sheeting is at least three times more reflective than enclosed lens sheeting.

Table 26. Minimum specific intensity per unit area (SIA) (candelas per footcandle per square foot).

OBSERVATION ANGLE DEGREES	ENTRANCE ANGLE DEGREE	TYPE II (ENCLOSED LENS)	TYPE III (ENCAPSULATED LENS)
0.2	− 4	70	250
0.2	+30	30	150
0.5	− 4	30	95
0.5	+30	15	65

Opaque Enamel Backgrounds

An Opaque Enamel background is not retroreflective. These painted or enameled backgrounds will appear green during the day when illuminated by sunlight, but background color is not visible at night.

The Missouri specification manual requires that painted signs "... be primed and then painted with two coats of gloss green backing enamel... Each coat of enamel applied at a rate to provide a dry film thickness of not less than 3/4 mil."

Materials for Letters on Signs

Enclosed lens and encapsulated lens sheeting materials may also be used for sign letters. One standard procedure is to cut the characters of the sign message from the sheeting material and directly apply them to the sign background. These are known as directly applied characters.

An alternate procedure is to apply the characters to a flat aluminum sheet that is the same size and shape as the character, and then mount these composite characters on the sign. These sign message characters can be changed without damaging the sign background and are known as demountable characters.

Reflective Buttons

Reflective buttons are prismatic reflectors which use the "corner cube" principal to reflect light back toward its source. The individual faces of these corner cubes are very small (approximately 0.05 in across) and each button is composed of a geometric lattice made of a large number of these faces. The buttons that are used in sign lettering range in diameter from about 1/2 in to 1 and 3/4 in.

When these buttons are installed on new signs that are part of embossed aluminum characters that have holes cut in them for the buttons. These characters are mounted with rivets or screws to the sign surface. The characters are available with baked enamel, or porcelain enamel finishes. Sample characters are shown in figure 155.

Cost of Backgrounds and Messages

The key question to be resolved in this section is the cost difference of the various combinations of sign background and sign letter materials. The objective is to determine the combined cost of each of the three types of backgrounds with each of the three types of letter materials, a total of nine combinations in all.

Cost of Sign Backgrounds

No single source of cost information for overhead sign backgrounds and sign letters could be found. Data from the States might have one or two different combinations of backgrounds and materials, but not enough to establish the entire nine cell matrix of combinations.

The most comprehensive single source of information on various costs of signs was the Hall Sign Company. Although they primarily manufacture smaller signs (Stop signs, warning signs, etc.), it was felt that scaling up a common set of numbers would be more accurate than trying to adjust prices from a variety of different suppliers. The cost per square foot of signs and basic materials provided by the Hall Sign Company are shown below:[(21)]

- Enclosed Lens Message on Enclosed Lens Background = $6.25.
- Encapsulated Lens Message on Encapsulated Lens Background = $9.10.
- Enamel Background (No Message) = $2.15.
- Enclosed Lens Sheeting = $1.25.
- Encapsulated Lens Sheeting = $3.65
- Aluminum Sign Blanks = (0.08 in.) = $1.75.

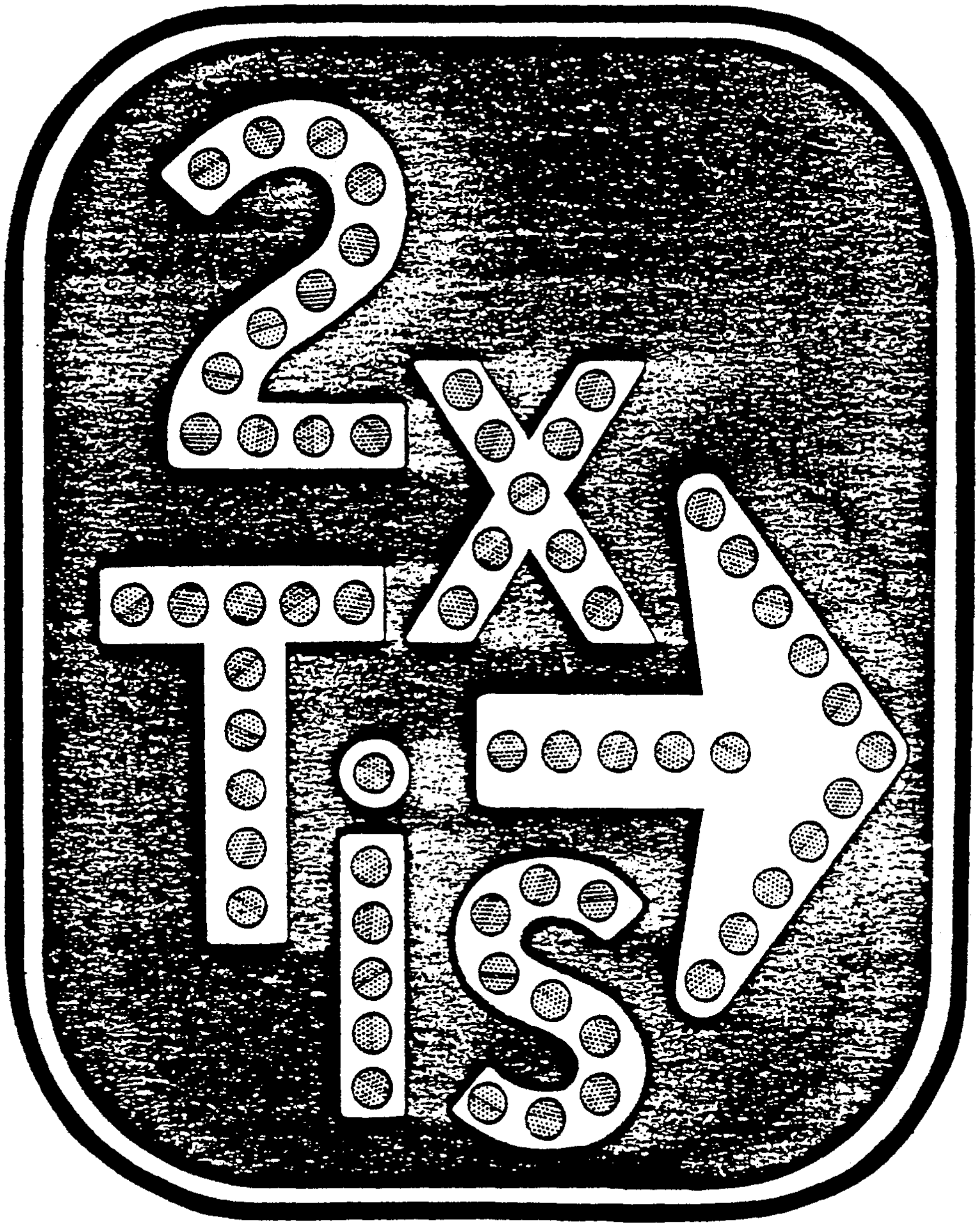


Figure 155. Sample "button copy" characteristics

(These are 1986 prices rounded to the nearest nickel. Sign prices are for order quantities of 10-24 signs, or approximately 160-380 ft^2.)

The effort involved in mounting the message on the sign is considerable. The size of each character must be decided, and reflective materials must be cut from the sheets. In addition, the spacing between characters must be determined, and each line of the message must be centered or otherwise located on the sign panel. Consequently, a decision was made to allocate all of the installation cost to the installation of the sign message.

Thus, for reflective materials, the cost of the sign background was set equal to the cost of the background material plus the sign blank. The cost of the enamel background on the aluminum blank was used as shown above.

The major difference between these small sign and an overhead guide sign is that these signs are mounted on a flat aluminum sheet, while an overhead guide sign is mounted on thicker structural aluminum. After a review of the estimated costs of overhead guide signs provided by Means Site Work Cost Data, a uniform cost of \$6.25 per ft^2 was added to cover the additional materials and fabrication costs associated with the use of a heavier sign blank.[23]

Using these assumptions the costs per square foot for the various sign backgrounds are:

- Enclosed Lens Background = \$ 9.25.
- Encapsulated Lens Background = 11.65.
- Opaque Enamel Background = 8.40.

Cost of Sign Messages

The first step in determining the costs of sign messages was to develop an estimate of the labor costs associated with their installation. A simple equation was used to express the cost of a sign in terms of its major components:

BACKGROUND MATERIAL

\+ message material
\+ installation
\+ sign blank

= Sign Cost.

The amount of materials needed for the message was taken from a report prepared by the Virginia Highway and Transportation Research Council.[23] This source indicated that for each square foot of guide sign, approximately 0.27 ft^2 of reflective material was needed for the message.

Using the material costs and total costs shown previously in the formula above resulted in an installation cost of enclosed lens message on enclosed lens sheeting of $2.90, and an installation cost of the encapsulated lens message on high intensity sheeting of $2.70. The average value of $2.80 per square foot has been used as a common cost for the application of each of the three message materials on any of the three background materials.

One further piece of information that was necessary to compute the costs of the three message types was the cost of the letters formed by the sign buttons. Conversations with the principal manufacturer of these buttons and a review of the specifications of several States revealed that these buttons are installed on new backgrounds as part of an aluminum enamel character.

The manufacturer offers both baked enamel and porcelain enamel characters. The cost of the baked enamel characters in heights from 10 to 16 in ranges between 65 cents and 75 cents per inch of character height. Porcelain enamel characters of the same heights are slightly more expensive at 85 cents to 95 cents per inch of character height.[24] An overall average of 80 cents per character inch has been used here.

The amount of sign message per square foot of sign was taken from a recent sign project in Maryland.[25] Eighteen overhead and bridge-mounted guide signs were included in this project. On each sign the number of characters of each height and the lengths of directional arrows were recorded and the total number of character-inches was calculated. (i.e.: the word EXIT in 12-in letters is 48 character-inches of message.) These signs contained a total of 2,718 ft^2 of signage and 5,765 in of letters, numbers and arrows. Thus, the average sign coverage in this project was 2.1 in of letters (and numbers) per square foot of sign. In addition to the characters, these guide signs contained a white border around the face of the sign. The cost of this border was estimated at $1.00 per square foot based on a computation of 4 in of border per square foot of sign and an average cost of this border material of 25 cents per foot.

The cost of button copy was determined from the manufacturer's price for characters and borders, and the estimate of the amount of characters and length of the border from this Maryland signage project. This was estimated as:

(2.1 in/sq-ft) × ($0.80/in) + $1.00 = $2.68 per square-foot.

A summary of the three costs for sign messages (including installation) rounded to the nearest nickel is shown below:

- Enclosed Lens Message = $3.15
- Encapsulated Lens Message = 3.80
- Button Copy Message = 5.50

Combined Costs of Backgrounds and Messages

The combined costs of the three alternate sign background materials with the three alternate types of message materials are shown in tables 27 and 28. Table 27 shows the individual materials and the costs per square foot for combinations of the materials. Table 28 shows the combined costs for a typical sign of 165 ft^2 rounded to the nearest $50.

As can be seen in these tables the least expensive combination is the opaque enamel background with enclosed lens letters, and the most expensive combination uses encapsulated lens sheeting with button copy. For any particular message material the differences between backgrounds using enclosed lens sheeting and opaque enamel are relatively minor. Similarly, for any given background material the differences between the cost of sign messages made of enclosed lens and encapsulated lens sheeting is relatively small.

Table 27. Overhead guide sign cost per square foot (not including installation costs).

			SIGN BACKGROUND MATERIAL		
			OPAQUE ENAMEL	ENCLOSED LENS	ENCAPSULATED LENS
		COMPONENT COST	$ 8.40	$ 9.25	$11.65
MESSAGE	Enclosed Lens	$ 3.15	11.55	12.40	14.80
	Encapsulated Lens	3.80	12.20	13.05	15.45
	Button Copy	5.50	13.90	14.75	17.15

Table 28. Overhead guide sign cost ($165\ ft^2$ sign not including installation).

		SIGN BACKGROUND MATERIAL		
		OPAQUE ENAMEL	ENCLOSED LENS	ENCAPSULATED LENS
MESSAGE	Enclosed Lens	$ 1900	$ 2050	$ 2450
	Encapsulated Lens	2000	2150	2550
	Button Copy	2300	2450	2850

NOTE: Sign costs are rounded to the nearest $50.00.

The initial cost of the nine combinations shown in table 28 cluster into three groups:

- Lowest Price Group — $1900.00 to $2150.00.
  - Enclosed Lens Message on Enclosed Lens Background.
  - Enclosed Lens Message on Opaque Enamel Background.
  - Encapsulated lens Message on Enclosed Lens Background.
  - Encapsulated lens Message on Opaque Enamel Background.

- Middle Price Group — $2300.00 to $2550.00.
  - Enclosed Lens Message on Encapsulated lens Background.
  - Encapsulated lens Message on Encapsulated lens Background.
  - Button Copy Message on Enclosed Lens Background.
  - Button Copy Message on Opaque Enamel Background.
- High Price Group — $2850.00.
  - Button Copy Message on Encapsulated lens Background.

Installation, Profit, and Overhead Costs

The prices given to this point do not include the costs of installing these signs on the sign structure. The Means Guide shows both an installation cost, and an estimate of the profit and overhead that would be charged by an independent contractor performing this work.[22] The installation cost included in the guide is $4.15 per square foot for both enclosed lens and encapsulated lens signs. Since installation of overhead guide signs is normally performed by a contractor, some provision must be made for this contractor's overhead and profit. The profit and overhead on these signs that is listed in the Means Guide is $2.50 on the enclosed lens sign and $2.85 on the encapsulated lens sign. For purposes of this computation we have added a uniform charge of $7.00 per square foot, or $1150 per sign to cover these installation, profit, and overhead costs in the original installation of the sign.

Comparisons With Other Sources of Cost Data

Bid Summaries of Signage Projects

Table 29 shows the estimated cost of overhead guide signs presented in the bids submitted to five State Highway Departments. (All costs shown in this table are in dollars per square foot of sign.)

As can be seen in table 29 the bids received by the States are full of anomalies. In Massachusetts the bids on two projects all come in at exactly the same price, and in Oregon there is almost a $10.00 difference between the high and low bid.

Table 29. Cost comparison with other sources (in costs per square foot).

MESSAGE/ BACKGROUND	RANGE OF BIDS	YEAR	STATE	COMMENTS
Encapsulated Lens on Encapsulated Lens	$18.00 – $18.00	1984	MA	6 bids on 2 projects All bids identical
Not Indicated	20.00 – 26.00	1985	RI	3 bids on 1 project
Not Indicated	20.97 – 23.30	1983	WS	4 bids on 1 project
Encapsulated Lens on Enclosed Lens <u>or</u> Button Copy on Enclosed Lens	20.11 – 20.58	1984	MO	Avg bids 2 districts
Encapsulated Lens on Opaque Enamel <u>or</u> Button Copy on Opaque Enamel	18.62 – 19.17	1984	MO	Avg bids 2 districts Same as 2 dist.above
Button Copy on Encapsulated Lens	16.97 – 26.90	1984	OR	4 bids on 1 project

NOTE: Prices include installation.

Missouri Data

The Missouri data shown in table 29 are slightly different than the other entries. The values shown for Missouri are from the State's Unit Bid Prices and reflect the average of the bids received for various items in each district on all of the projects put out to bid in a particular year.[26] (In this case 1984.) The bid data are broken down into two classifications of interest: Structural aluminum signs with encapsulated lens reflective sheeting; and Structural aluminum signs with a baked green finish. In each case the letters used on these signs may either be cut from encapsulated lens sheeting, or formed by prismatic reflectors (buttons) mounted in aluminum frames.

Data were available from two districts on sign projects with reflective sheeting, and from eight districts which had conducted sign projects using baked enamel backgrounds. For the two districts that had both types of sign projects the cost differences per square foot were $1.49 and $1.36. These differences are consistent with the differences between the estimates of sign costs shown in table 27.

Care must be exercised in comparing the data from table 27 and the data from an individual State. Generally, the overhead sign data from a State project or Unit Bid Summary will be included in an item entitled "Structural Aluminum Signs." However, this item will usually be the total cost for both the signs and their installation, and will include the contractor's overhead and profit. The item may also be a mix of the costs of both ground mounted and overhead guide signs to further complicate the comparison.

California Guide Sign Reflectorization Project

One of the most interesting sources of comparison data comes from the retrofit program conducted by California in which reflective buttons were applied to existing signs.[27] This series of projects, conducted between 1979 and 1984, applied reflectorized buttons to more than 8000 signs across the State. The actual cost per sign averaged $386.00, or $2.34 per square foot assuming an average sign size of 165 ft^2.[28]

This retrofit cost of $2.34 per square foot cost is considerably less than the cost for button copy of $5.50 shown in table 27. However, there are important differences between the assumptions in this table and the materials and installation procedures used in the California program.

The cost of $5.50 shown in the table consists of a materials cost of $2.70 per square foot for <u>enamel characters containing reflective buttons</u>, and an installation cost of $2.80 per square foot for determining the location of these characters and mounting them on the sign. In the California program <u>reflectorized buttons were glued over the existing message characters</u> in the field.

The materials cost for the buttons used in the California program (estimated at 80 cents per square foot of sign) is considerably less than the cost of $2.70 per square foot of sign for enamel characters containing buttons. Further, the installation of the reflectorized buttons in the California program did not involve the time consuming task of laying out the characters to determine the spacing between the letters and their position on the sign. Thus, it is not possible to use the California data to determine the costs of providing button copy on new signs.

Service Life Analysis

The next step in the analysis was to examine the service life of the background and message materials. These assumptions are based solely on service life, and do not account for replacement due to vandalism, message changes, or accidents. Obviously, these conditions will increase the costs for any of the combinations. The service lives for the various materials used in this analysis were:

- Opaque Enamel – 15 to 20 years
- Enclosed Lens Sheeting (for backgrounds and messages) – 5 to 7 years
- Encapsulated Lens Sheeting (for backgrounds and messages) – 7 1/2 – 10 years
- Button Copy – 15 to 20 years

The renewal times for the combinations were determined by examining the points in time when the service life of the message and background materials was achieved. This was done for a 20-year period. The following assumptions were made regarding the policy of replacing the materials:

- If the service life of the message material was reached and the service life remaining in the background material was less than the service life of the (new) message material, both the message and background will be replaced.

- If the service life of the message material was reached and the service life remaining in the background material was (at least) equal to the service life of the (new) message material, new message materials will be mounted on the old background.

- If the service life of the background was reached and the service life remaining in the message was less than the service life of the (new) background material, both the message and the background will be replaced.

- If the service life of the background was reached and the service life remaining in the message was equal to (or greater than) the service life of the (new) background material, the message would be demounted and remounted on the new background.

- Sign renewals will be made using an "overlay" procedure in which the background and message are mounted on sheet aluminum, rather than structural aluminum as in the original.

- The cost of demounting and remounting messages is equal to the original fabrication cost.

- The cost of installing the overlay is equal to the cost of the original sign installation.

- If new message materials are being installed on an old background the installation cost is reduced by 50 percent.

- Overlays will be installed by the State DOT or operating agency. Hence, the installation cost of these overlays ($4.15/ft^2) does not include the profit and overhead costs.

In the paragraphs below we have summarized the renewal times for the various combinations of backgrounds and message materials.

Engineering Grade Messages on Opaque Enamel Backgrounds

In short service life environments the message will have to be replaced at the end of the 5th year and 10th year. In this environment an overlay with a new background and message will be required a the end of the 15th year. In an environment resulting in long service lives the message will have to be replaced at the end of the 7th and 14th years.

Enclosed Lens Messages on Enclosed Lens Backgrounds

In short service life environments the entire sign will have to be replaced every 5 years. In environments producing a long service life, the sign will have to be replaced every 7 years.

Enclosed Lens on Encapsulated Lens Backgrounds

The service life of the encapsulated lens sheeting is less than twice the service life of the enclosed lens sheeting. It will therefore be necessary to replace both the background and message materials when the message material has reached its service life. In the short service life environment this occurs at the end of years 5, 10, and 15. In the long service life environment complete sign replacement is necessary at the end of years 7 and 14.

Encapsulated Lens Backgrounds on Opaque Enamel Backgrounds

In both the short- and long-term environments, the service life of the message will by 1/2 the service life of the background. At the end of the service life of the message, new message characters must be fabricated and placed on the sign. This occurs at the end of 7 1/2 years in the short service life environment and at the end of the 10th year in the long service life environment. In an environment producing short service lives, both the message and the background will have to be renewed at the end of year 15.

Encapsulated Lens Messages on Enclosed Lens Backgrounds

There will still be useful life in the message material when the background material has reached its full service life. However, there is no way to efficiently reuse the message characters. If they were remounted on the new sign background the message material would reach its service life years before the service life of the new background was reached. Both the sign message and background should be replaced when the sign background has reached its full service life, 5 years in a short service life environment and 7 years in a long service life environment.

Encapsulated Lens Messages on Encapsulated Lens Backgrounds

In this combination the messages and background material are the same, and reach the termination of their service lives at the same time: 7 1/2 years or 10 years depending upon the environment.

Button Copy messages on Opaque Enamel Backgrounds

Both the message and background materials have the same service life. The service life for the entire sign is 15 or 20 years for short and long service life environments respectively.

Button Copy Messages on Enclosed Lens Backgrounds

The message has approximately 3 times the service life of the background. The message will have to be remounted every 5 years in the short service life environment (new message characters will be necessary at the end of the 15th year), and every 7 years in the long service life environment.

Button Copy Messages on Encapsulated Lens Sheeting

In this combination the service life of the message is twice the service life of the background material. When the sign is removed for replacement of the background material, the message characters will have to be carefully removed from the old sign and relocated on the new sign.

Summary

The results of these calculations and the prior analysis have been summarized in tables 30 and 31. Table 30 shows the initial costs, the replacement costs, the year(s) that these replacements should be made over a 20-year period, the present worth of these future replacements (using the 10 percent interest rate recommended by the Office of Management and Budget for analyzing projects), and the total present worth cost of the combinations. The totals for these present worth costs are summarized, for both the short and long service life environments, in table 31.

As can be seen in these tables, the lowest total present worth costs are shown for button copy messages on opaque enamel backgrounds, and the encapsulated lens messages on opaque enamel backgrounds. These costs are close enough to be considered identical.

Table 30. Summary of sign costs during a 20-year analysis period.

MESSAGE	Engineering Grade			High Intensity			Button Copy		
BACKGROUND	Opaque Enamel	Eng'g Grade	High Intensity	Opaque Enamel	Eng'g Grade	High Intensity	Opaque Enamel	Eng'g Grade	High Intensity
INITIAL COST									
Materials	$ 1900	$ 2050	$ 2450	$ 2000	$ 2150	$ 2550	$ 2300	$ 2450	$ 2850
Installation	1150	1150	1150	1150	1150	1150	1150	1150	1150
Subtotal	$ 3050	$ 3200	$ 3600	$ 3150	$ 3300	$ 3700	$ 3450	$ 3600	$ 4000
SHORT SERVICE LIFE									
Overlay #1-year	5	5	5	7.5	5	7.5	15	5	7.5
-cost	850	1700	2100	950	1800	2200	1950	2100	2450
Overlay #2-year	10	10	10	15	10	15		10	15
cost	850	1700	2100	1650	1800	2200		2100	2450
Overlay #3-year	15	15	15		15			15	
cost	1550	1700	2100		1800			2100	
PRESENT WORTH									
Overlay #1	528	1056	1304	465	1118	1076	467	1304	1199
Overlay #2	328	655	810	395	694	527		810	587
Overlay #3	371	407	503		431			503	
Subtotal	$ 1227	$ 2118	$ 2617	$ 860	$ 2243	$ 1603	$ 467	$ 2617	$ 1786
TOTAL COST	$ 4300	$ 5300	$ 6200	$ 4000	$ 5550	$ 5300	$ 3900	$ 6200	$ 5750

Table 30. Summary of sign costs during a 20-year analysis period (Continued).

MESSAGE	Engineering Grade			High Intensity			Button Copy		
BACKGROUND	Opaque Enamel	Eng'g Grade	High Intensity	Opaque Enamel	Eng'g Grade	High Intensity	Opaque Enamel	Eng'g Grade	High Intensity
INITIAL COST									
Materials	$ 1900	$ 2050	$ 2450	$ 2000	$ 2150	$ 2550	$ 2300	$ 2450	$ 2850
Installation	1150	1150	1150	1150	1150	1150	1150	1150	1150
Subtotal	$ 3050	$ 3200	$ 3600	$ 3150	$ 3300	$ 3700	$ 3450	$ 3600	$ 4000
LONG SERVICE LIFE									
Overlay #1-year	7	7	7	10	7	10	--	7	10
-cost	850	1700	2100	950	1800	2200		2100	2450
Overlay #2-year	14	14	14		14			14	
cost	850	1700	2100		1800			2100	
PRESENT WORTH									
Overlay #1	436	872	1078	366	924	848		1078	944
Overlay #2	224	448	553		474			553	
Subtotal	$ 660	$ 1320	$ 1631	$ 366	$ 1398	$ 848	$ 0	$ 1631	$ 944
TOTAL COST	$ 3700	$ 4500	$ 5250	$ 3500	$ 4700	$ 4550	$ 3450	$ 5250	$ 4950

Table 31. Present worth of overhead guide sign costs.

		SIGN BACKGROUND MATERIAL		
		OPAQUE ENAMEL	ENCLOSED LENS	ENCAPSULATED LENS
MESSAGE	Enclosed Lens	$4300/3700	$5300/4500	$6200/5250
	Encapsulated Lens	4000/3500	5550/4700	5300/4550
	Button Copy	3900/3450	6200/5250	5750/4950

NOTES: Date shown are for short/long service life environments.
Sign costs are rounded to the nearest $50.
Costs are based on 165 ft^2 sign

Although the enclosed lens message on the opaque enamel background is initially less expensive than a encapsulated lens message on this background, the shorter service life of the enclosed lens sheeting results in the need for an additional overlay. The cost of this additional overlay produces a 20-year life cycle cost that is higher than the life cycle cost of high intensity messages on opaque enamel backgrounds.

The total present worth costs of signs using enclosed lens or encapsulated lens sheeting for both the message and background are almost the same. This occurs because the shorter service life of the enclosed lens sheeting results in the need for an additional overlay. These costs are about 30 percent higher than the costs for the lowest price combinations.

The costs for encapsulated lens messages on enclosed lens backgrounds, and button copy on encapsulated lens backgrounds are up to 10 percent higher than the costs of the combinations that were described in the preceding paragraph.

The most expensive combinations over the 20-year service life of the sign are for enclosed lens messages on a encapsulated lens background, and button copy on enclosed lens background. These combinations are at least 50 percent more expensive than the two least expensive combinations.

Electrical Power and Lighting Systems

Introduction

This section examines two costs that are only present when sign lighting is provided. These are: the cost of the electrical power system on which electricity is transmitted to the sign; and the cost of the fixtures used to illuminate the sign. The cost of the electrical power system includes the materials and labor that are used in building the power lines that link the fixtures with the existing power lines of the utility company. The major costs of the power system are associated with the point at which the new power lines connect with the existing power lines; the underground duct cable from these locations to the overhead guide sign structures; and the materials and wiring at the sign structure used to switch the sign lighting on and off, and distribute this power to the lighting fixtures.

Electrical power system costs are developed for cities with average, above average, and below average labor and materials costs using data from an actual sign lighting project and standard cost adjustment factors.

The discussion of the illumination systems in this chapter describes the costs of the major components of the illumination system (the ballast, the lamp, and the luminaire), and their service lives. The estimated installation cost for the luminaires is also presented. The chapter concludes with a presentation of low, medium and high priced alternatives for both mercury vapor and high pressure sodium lighting systems.

Electrical Power System

Analysis of Data from a Maryland Signage Project

The Electrical Power System includes all components which transmit electricity from a nearby power source to the luminaire an the cost of their installation. Table 32 from reference 29 is a complete listing of the major conduit and wiring system elements involved in a signing project on a major freeway outside Baltimore, Maryland. In table 33, the major items of interest on this project have been grouped into three subsystems

Table 32. Items specified in a sign lighting project.

ITEM NO.	DESCRIPTION	UNIT	QUANTITY	PRICE (By Winning Bid)
802	Trenching	L.F.	9,000	2.20
803	Duct Cable - 3 Conductor No. 4 AWG, 600V	L.F.	10,000	1.85
804	Cable - 1 Conductor No. 4 AWG, Type USE, 600V	L.F.	2,400	0.65
805	Cable - 1 Conductor No. 10 AWG, Type THWN/THNN, 600V	L.F.	2,600	0.21
806	Bare Copper Ground Wire - No. 4 AWG	L.F.	10,000	0.65
807	3/4" Dia. Rigid Steel Conduit, Schedule 40	L.F.	700	3.70
808	1¼" Dia. Rigid Steel Conduit, Schedule 40	L.F.	350	5.40
809	3/4" Dia Flexible Steel Conduit	L.F.	160	4.00
810	4" Dia Rigid Steel Conduit, Schedule 40 - Driven	L.F.	400	18.70
811	Connector Kit - Type I (see wiring Diag.)	E.A.	30	20.00
812	Connector Kit - Type II "	E.A.	30	21.00
813	Connector Kit - Type III "	E.A.	8	19.50
814	Connector KIt - Type IV "	E.A.	6	22.00
815	Reinforced Concrete Handbox - 30" Dia. x 4' Depth	E.A.	5	740
816	Junction Box - 10" x 10" x 6" (see bridge Struct)	E.A.	7	155
817	Ground Rod - 3/4" Dia. x 10' Length	E.A.	30	73
818	Concrete Cable Marker	E.A.	60	39
843	Elbow Conduit (see sign structure cntrl equip)	E.A.	10	45
860	175 Watt Mercury Sign Luminaire w/Support Bracket	E.A.	23	335
861	250 Watt Mercury Sign Luminaire w/Support Bracket	E.A.	39	333
862	400 Watt Mercury Sign Luminaire w/Support Bracket	E.A.	12	350
863	Sign Structure Electrical Control Equipment	E.A.	18	570
864	Safety Disconnect Switch (mntd onWd pole)	E.A.	7	200
865	30' Wood Pole	E.A.	7	510

NOTE: Source — Ref. 29. This project included 18 structures for overhead guide signs.

Table 33. Electrical power subsystem costs

ITEM	DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	TOTAL PRICE
Tie-In to Existing Power Lines					
865	30' Wood Pole	E.A.	7	$510	$ 3,750
808	1-1/4" Dia. Rigid Steel Conduit[1]	L.F.	250	5.40	1,350
864	Safety Disconnect Switch	E.A.	7	200	1,400
	Power Meter and Socket				
	Subtotal				$ 6,320
Underground Cabling					
802	Trenching	L.F.	9,000	$ 2.20	$19,800
803	Duct Cable – 3 Conductor No. 4	L.F.	10,000	1.85	18,500
806	Bare Copper Ground Wire	L.F.	10,000	0.65	6,500
817	Ground Rod	E.A.	30	73	2,190
815	Reinforced Concrete Handbox	E.A.	5	740	3,700
818	Concrete Cable Marker	E.A.	60	39	2,340
843	Elbow Conduit	E.A.	10	45	450
810	4" Dia. Rigid Steel Conduit	L.F.	400	18.70	7,480
	Subtotal				$60,960
Items at the Structure					
863	Electrical Control Equipment	E.A.	18	$570	$10,260
804	Cable – 1 Conductor No. 1	L.F.	2,400	0.65	1,560
805	Cable – 1 Conductor No. 10	L.F.	2,600	0.21	546
807	3/4" Dia. Rigid Steel Conduit	L.F.	700	3.70	2,590
809	3/4" Dia. Flex. Steel Conduit	L.F.	160	4.00	640
811/814	Connector Kits	E.A.	74	20.51(avg)	1,518
816	Junction Box	E.A.	7	155	1,085
808	1-1/4" Dia. Rigid Steel Conduit[1]	L.F.	100	5.40	540
	Subtotal				$18,739
	GRAND TOTAL				$86,019

Note: [1] Item 808 has been divided between two groups.

that include materials and labor used in: connecting with the utility company's existing power lines; providing underground duct cable from these points to the overhead guide sign structures; and installing the control devices, wiring and other items at the structure itself.

Service Drop

This particular project required bids for several items at the service drop locations where the power system was connected with the utility company's power lines. The specific items required at these locations were: a 30-ft wood pole; 1 1/4-in steel conduit; and safety disconnect switch. Two other components of this subsystem at the service drop locations were the power meter and its socket. These components were not included as cost items because they were (and generally are) supplied by the power company. The power company was also responsible for running the power lines to this pole from their existing lines.

Underground Duct Cable

Power was transmitted from these utility poles to the overhead guide sign structures via underground duct cable. Cost items associated with this part of the power system included: digging trenches; three-conductor duct cable; bare copper ground wire; ground rods; concrete handboxes and cable markers; and elbow conduit. Four-in diameter rigid steel conduit that was suitable for being driven or jacked under the existing roadway was also included.

Items at the Sign Structure

The cost items located at the overhead sign structure consisted of: sign structure electrical control equipment; two sizes of single conductor cable; and 3/4-in flexible and rigid steel conduit. The photo-electric cell, photo-electric controlled relay, miscellaneous wiring to connect these elements, and the relay enclosure were all included as part of this electrical control equipment. Junction boxes and various kinds of connectors are two other items principally located at the sign structure which were included in this subsystem.

Other miscellaneous items that were not included as separate cost items are plastic to steel conduit connectors, "T" and right angle fittings for the 3/4-in conduit, clamps for securing the conduit to the sign structures, and expansion and deflection fittings used at bridge mounted sign supports.

The costs for these three subsystems are summarized in table 34. The cost per sign structure was calculated on the basis of the 18 structures that were part of this project.

As can be seen in this table, the major costs of the electrical power system were associated with underground duct cable. The combined costs of the materials and labor for installing this underground duct cable accounted for 71 percent of the total power system cost. Only 22 percent of the power system costs were due to items that were on the overhead guide sign structure itself. The remaining 7 percent of the costs were linked to items at the point where the electrical wiring was connected to the power lines of the local utility.

Generalized Power System Costs

Caution must be exercised in using these values in other locations. In particular, the underground wiring costs will be very sensitive to local conditions. The values for underground wiring that are shown in the preceding tables were for a freeway in a suburban location where a trench for burying the power lines could be easily dug. These costs could be substantially higher for an urban environment where the utility trench must be dug through asphalt or concrete.

Table 34. **Agated power subsystem costs**

SUBSYSTEM	TOTAL PROJECT COST	COST PER SIGN STRUCTURE	COST PER ....
Utility Service Drop	$ 6,320	$ 400	$ 900/Tie-in point
Underground Duct Cable	60,960	3,400	6.50/Underg'nd ft
Items on Structure	18,739	1,000	
TOTAL	$86,019	$ 4,800	

The length of the excavation is also an important factor. In this project the excavation averaged about 500 ft per sign location. The excavation per location would probably be greater in a rural area and less in an urban setting. For purposes of this analysis we have asssumed that the trade-off of excavation length vs excavation difficulty would hold the cost of the excavation relatively constant. This assumption is discussed further in the analysis of the combined cost elements contained in a later section.

The data presented in tables 32 through 34 is from a specific project located just outside Baltimore, Maryland. Prices for similar projects in other parts of the country will be different.

The method chosen to account for these cost differences was to apply the "City Modifiers" from the Means Electrical Cost Data-1985.[30] This annual publication is widely used to prepare cost estimates on a variety of electrical projects. For each major element of a project it lists the average materials cost, installation costs, overhead and profit. The City modifiers are used to adjust these average costs to the costs in 162 major cities in the United States and Canada.

Rather than pursue the computations with a single average value, we decided to use data for above average and below average cost conditions as well. A review of the City Modifiers for the U.S. Cities revealed that 73 percent of the modifiers for electrical installation were less than 100. The median value of this group was about 85. Similarly, the median value for cities with above average costs was between 10 and 15 points above the average. A city modifier of 115 was chosen for cities with above average costs to maintain the symmetry of the low and high costs and a reasonable difference between the modifiers for the average and high cost conditions.

The Means cost adjustment factor for materials and installation on electrical projects in Baltimore, Maryland is 94.4. To convert the costs from table 34 to cost in areas with below average, average, and above average costs the values in the table must be multiplied by the city modifier for that area and divided by the city modifier for Baltimore. The adjusted power system costs for these three types of areas are shown in table 35.

Table 35. Cost per sign structure for the electrical power system.

SUBSYSTEM AVERAGE	AREA CONSTRUCTION COST BELOW AVERAGE (Modifier=85)	AVERAGE (Modifier=100)	ABOVE AVERAGE (Modifier=115)
Utility Service Drop	$ 300	$ 400	$ 400
Underg'nd Duct Cable	3,100[1]	3,600	4,100
Items on Structure	900	1,100	1,300
TOTAL	$4,300	$5,100	$5,800
Cost per Panel	$3,000	$3,500	$4,100

NOTES: Costs are based on the total project cost shown in Table 34 rounded to the nearest $100.
[1]Underground wiring cost of $3,049 rounded to $3,100 to balance with total.

Since many structures support more than one overhead sign, the cost in tables 34 and 35 must be prorated to arrive at the power system costs for a typical overhead sign. Using the California statewide average of 1.43 signs per structure, the below average, average, and above average power system costs are: $3,000, $3,500, and $4,100 dollars respectively.

Illumination System

The illumination system is made up of three major elements, the ballast, the lamp, and the luminaire. The following sections discuss some of the major characteristics of these elements, their estimated service lives and their costs.

Ballast Characteristics

The ballast matches the power system line voltage to the lamp and ensures proper starting and operation of the lamp. Ballasts for mercury vapor lamps must compensate for changes in the line voltage. Ballasts for high pressure sodium lamps must compensate for changes in line voltage and for changes in the lamp voltage as the bulb ages. In most sign lighting applications each bulb in the lighting system will have an individual ballast selected to match the type and wattage of the lamp being used. Two of the other characteristics that should be considered when a ballast is selected are the line voltage regulation and the power factor.[31]

Line voltage regulation is a measure of the ability of a ballast to control the lamp wattage as the incoming line voltage varies. Public utility commissions normally permit a ±6 percent variation in the line voltage. This 6 percent change could result in a 15 percent change in light output with a nonregulating ballast. Starting problems can also occur with nonregulating ballasts when the line voltage drops below 95 percent of its rated value.

The power factor is a measure of the electrical efficiency of the ballast. It is defined as the ratio of the lamp wattage/(line volts × line amps). A typical high power ballast will have a power factor of at least 90 percent. Ballasts are also available in less expensive, and less efficient, designs where the power factors are 40 percent to 60 percent. For purposes of this analysis we have assumed that all ballasts have a 0.90 power factor.

Lamp Characteristics

Lamps for the illumination of overhead guide signs are available in a variety of different types and wattages. A recent study of lighting systems for overhead guide signs conducted by Arizona State University (ASU) for the Arizona Department of Transportation identified eight different types of lamps. However, in this report we are concerned only with Deluxe Mercury Vapor and clear High Pressure Sodium lamps.[32] Table 36 shows the relative illumination of several different wattages of these lamps. This is not a complete listing of the different sizes that are available in these lamps, but it does include the sizes that are most frequently used in sign lighting.

Table 36. Illumination of mercury vapor and high pressure sodium lamps.

LAMP TYPE AND SIZE	APPROXIMATE LUMENS	
	INITIAL	MEAN
Deluxe Mercury Vapor		
157 Watts	8,600	7,200
250 Watts	12,100	9,800
400 Watts	22,500	12,800
Clear High Pressure Sodium		
70 Watts	5,800	5,220
150 Watts	16,000	14,400
250 Watts	27,500	24,750

Luminaire Characteristics

Three of the major manufactures of luminaires for overhead sign lighting are: Guth Lighting, a unit of the General Signal Company; the General Electric Company; and the Holophane Division of the Manville Corporation.

The Guth SIGNLITER contains a hydroformed aluminum reflector, and a molded borosilicate lens to withstand heat, cold and thermal shock. It comes with an integral ballast and is available for 100, 175, or 250 watt Mercury Vapor lamps; 175 or 250 watt Metal Halide lamps; and 70, 100, 150, or 250 watt High Pressure Sodium lamps.(33)

The sign lighting luminaire manufactured by the General Electric Company is the VERSAFLOOD-II. The luminaire contains an aluminum reflector with a face of clear glass and an activated charcoal filter to maintain internal cleanliness. A unique feature of this luminaire is the ability to adjust the beam by placing the lamp socket in one of the 5 positions that are available. This luminaire also provides an internal ballast. The standard lamps recommended for this luminaire also provides an internal ballast. The standard lamps recommended for this luminaire are 100, 150, or 250 watt high pressure sodium; and 175, or 250 watt mercury vapor.(34)

The Holophane corporation markets several luminaires for highway lighting. The two that have been most frequently used for guide sign lighting are the EXPRESSLITE and the PANEL-VUE.

The Holophane EXPRESSLITE was specifically designed for guide sign and billboard applications. The optical system on this luminaire consists of a specular anodized aluminum primary beam reflector and a glass cover with a prismatic inner surface. An auxiliary retrodispersing reflector is available for retroreflective signs to eliminate the halo of excessive luminance. This luminaire is supplied without a ballast and is available for 150 watt high pressure sodium; 175, 250, or 400 watt metal halide or mercury vapor lamps.(35)

The second luminaire produced by the Holophane Corporation for guide sign lighting is their PANEL-VUE model. This luminaire produces an exceptionally wide beam using a hydroformed aluminum reflector and a pressed prismatic borosilicate glass refractor. The ballast on this unit is built in. It is designed for 175 metal halide, 250, or 400 watt metal halide or super metal halide, 100, 250, or 400 watt mercury vapor, or high pressure sodium, 175 watt mercury vapor; or 150 watt high pressure sodium lamps.(36)

The optical illumination characteristics of these luminaires would of course depend upon the type and size of lamp that was used, and the exact mounting position of the luminaire. The promotional material provided by the manufacturers, and the ASU report has been used to prepare table 37 comparing the illumination characteristics of these fixtures.

As can be seen in this table, two luminaires are required to achieve a maximum foot-candle/minimum foot-candle ratio of 7.5 or less on a 8-ft by 20-ft sign panel. The exception is the Holophane Panel-Vue luminaire which can illuminate this area with a single fixture.

Service Life of the System

The cost analysis presented later in this report is based on a 20-year life cycle. For purposes of this analysis we have estimated that the luminaires will provide useful service for the full 20-year period.

Table 37. Comparison table of luminaire characteristics.

SIGN SIZE (H × W)	GUTH SIGNLITER	GE VERSAFLOOD II	HOLOPHANE EXPRESSLITE	HOLOPHANE PANEL-VUE
9′ × 9′				
No. of lamps	1		1	1
Max/min ratio	3.0		3.2	3.4
9′ × 15′				
No. of lamps	2		2	1
Max/min ratio	2.9		1.9[1]	3.8
8′ × 20′[2]				
No. of lamps	2	2	2	1
Max/min ratio	7.5	6.1	6.5	4.7
9′ × 24′				
No. of lamps	3		3	2
Max/min ratio	2.6		3.7[1]	3.6(1)

NOTES: Max/min data are the ratios of the maximum to minimum illumination levels.
Tests were conducted with 250 watt clear mercury vapor lamps.
[1]These ratios were estimated from the product literature.
[2]These data are from the ASU tests conducted with 175 watt clear Metal Halide lamps.

The ASU estimate of 12 years has been taken as the service life for the ballasts associated with these luminaires.

The useful service life of the lamps is based on both the actual service life, and the standard replacement practice. In order to minimize the number of service calls to replace burnt-out lamps at a particular location, the standard practice of most highway departments is to relamp all the fixtures at an overhead sign when a crew has been sent out to replace any outages at that location. Because of this, it is important to estimate the time from the beginning of service until the first outage occurs.

The General Electric Co. notes, regarding the service life of their lamps, that for lamps rated at 24,000+ hours "...67 percent of lamps are expected to be still burning at 24,000 hours. For cost of light calculations involving these lamps, if an estimated operating time is required at which 50 percent of the lamps will still be burning, a value of 28,500 hours is suggested."[37]

If we assume a linear failure rate based on these two data points, the first lamp in a group would fail at about 15,000 hours. If the lights are on an average of 12 hours per day, this failure would occur after 3.4 years.

Luminaire Installation Costs

Cost estimating sheets from the California Department of Transportation indicate that 2.5 hours is required for the installation of a guide sign luminaire. The ASU report contains an 1.63-hour estimate for the installation time, which is considerably shorter.[32] Although the Means Guide does not have a specific category for luminaires on overhead guide signs, they supply a 3.6-hour estimate for mounting roadway luminaires for 400-watt mercury vapor lamps. In light of these differences we have decided to use the Caltrans estimate for our computations of labor cost. We have used the ASU estimated cost for truck rental of $10.50 per hour.

The average cost of an electrician in the Means Guide is $22.10 per hour. When profit and overhead are added in, which would be the case if this work were performed by an outside contractor, the cost is $31.75 per hour. For the 2.5 hours required to install the luminaire the total labor charge would be about $80. There would be an additional charge of $25 for a truck, bringing the total installation costs for one luminaire to $105.

These calculations assume that the luminaire can be installed when the traffic volume is low, and the control of traffic can be performed with a minimum of manpower and equipment.

Although it would be possible to adjust this installation cost for high and low labor costs, the differences are comparatively minor and would add unwarranted complexity to the overall analysis.

Summary of Costs and Characteristics

Table 38 provides some unit cost estimates for the various luminaires with ballast assemblies, but without lamps. In this table we have included an adjusted cost for the Panel-Vue luminaire because of its capability of lighting an extremely wide area. It should be noted that these costs are for materials only and do not include any installation costs.

The purpose of this study is to examine the costs of providing sign lighting with mercury vapor and high pressure sodium lamps. It is not the intent of this study to try and determine what the most efficient lighting system would be. Consequently, in the analyses that follow, we have estimated the cost for low, medium, and high price mercury vapor and high pressure sodium lighting systems. The actual lighting system utilized by an individual State or municipality will depend upon the size of the sign, number of fixtures, and local preferences that are unique to their particular situation.

In table 39 we have summarized the costs for the illumination system for a typical sign of 165 ft^2. The medium and high costs are based on installing two luminaires with lamp wattages as shown in the table. The low priced system is based on installing a single Panel-Vue type luminaire.

Table 38. Cost of luminaires (with ballasts).

	SIGNLITER	VERSAFLOOD	EXPRESSLITE	PANEL-VUE
Mercury Vapor	260-270	200-210	Not Shown	310
H.P. Sodium	310-340	230-250	340	340

NOTE: Costs do not include the cost of lamps

Table 39. Summary of illumination system costs and characteristics.

	LOW PRICE SYSTEM	MEDIUM PRICE SYSTEM	HIGH PRICE SYSTEM
Mercury Vapor			
Fixture	$310	$210	$210
Lamp	14(175w)	25(250w)	20(400w)
Labor	105	105	105
Initial Cost per Luminaire	$280	$340	$395
Total Cost	$280	$680	$790
Ballasts (ea.)	45(175w)	55(250w)	62(400w)
Annual Total Power Consumption	852(kw)	2,436(kw)	3,896(kw)
High Pressure Sodium			
Fixture	$340	$250	$340
Lamp	44(70w)	47(150w)	50(250w)
Labor	105	105	105
Initial Cost per Luminaire	$490	$400	$495
Total Cost	$490	$800	$990
Ballasts (ea.)	90(70w)	100(150w)	145(250w)
Annual Total Power Consumption	341(kw)	1,462(kw)	2,436(kw)

NOTES: Fixture prices based on retail costs.
Initial Costs are rounded to nearest $5.
Low price cost is based on one Panel-Vue luminaire.
Medium and high price totals are based on two luminaires.
Lamp and ballast costs from Means Electrical Cost Data—1985.[16]
Service Life of lamps based on information from GE.[17]
Kilowatt-hours are calculated from lamp wattage, 365 1/4 days per year, 12 hours of burning time per day, and ballast power factor of 0.90.

Electricity Costs

Introduction

This section discusses the costs of the electricity consumed in providing the lighting for overhead guide signs. This material is divided into three major sections: Current Electricity Costs; Future Electricity Costs; and The Present Worth of Annual Electric Payments.

The first section on Current Electricity Costs describes the process by which electric rates are determined through the regulatory agencies and presents several samples of typical rates. This section also highlights the vast differences in electric rates that exist in different regions of the country.

The possibility of rapidly escalating electricity costs has been of great concern to individuals responsible for providing overhead guide sign lighting. The Future Electricity Cost section contains a discussion of the factors that will limit the growth of electricity cost over the next 10 to 20 years. This section describes how the differences in the mix of energy sources used to produce electricity affect prices in various parts of the country.

In the third and final section of this chapter presents a table containing the present worth of a series of annual electricity payments for the lighting systems that were described in the preceding chapter.

Current Electricity Costs

There are more than 3000 private, Federal, cooperative, and public nonprofit organizations generating and selling power across the United States. Although comparatively few in number, the 236 private investor-owned utilities (IOUs) dominate the electric power industry, accounting for about three-fourths of capacity, generation, number of customers, and sales to ultimate consumer. Historically, these IOUs developed in cities and other large markets where they could produce and distribute electricity efficiently. Since most overhead signs are also located in cities and their suburbs, these IOUs supply the majority of the electricity used in lighting overhead guide signs.

The Regulation of Utility Rates

Although there is Federal regulation of these IOUs, almost none of this regulation is concerned with the rates that these utilities charge their customers. It is the State regulatory authorities that establish retail rates for IOUs. In fact, the major ongoing activity of the State regulatory commissions is to determine how electricity should be priced.

In general, State commissions have attempted to set electricity prices by trying to see that the quantity and price of electric service from the regulated utility come as close as possible to the amounts that a competitive market would produce. The most common method for doing this has been to tie utility revenue and prices to the "cost of service" and to require that all customers have nondiscrimatory access to electric service at a price that covers the cost of providing the service.

This process of determining electricity prices is generally done in three steps: First, revenue requirements are determined; second, the revenues are allocated to different classes of service; and third, the rate structure for each class of service is determined.

The revenue requirement can be viewed as the estimated cost of providing electricity for some future period (i.e.: the next 1 or 2 years). It is equal to the sum of the operating expenses, and the product of the rate of return and the value of the undepreciated portion of the utility's plant and equipment.

Once a commission has determined a utility's revenue requirements, the distribution of the sources of revenues is established. The mix of customer classes and the cost of providing service to each class guide the determination of how much revenue must be collected from each customer class. The primary classifications are residential, commercial, and industrial. However, there are other subsets and classifications, such as street and highway lighting, with distinct rates determined by the cost of furnishing electricity to these users. The utility's rates may also vary by area, reflecting differences in the cost of supplying these areas with service.

Samples of Electricity Rates

Figure 156 is the rate schedule for "Street Lighting," which includes overhead guide signs, for the District of Columbia. In addition to the rate of 3.858 cents per kilowatt-hour (kw-hr), this schedule also indicates that these facilities will be billed on the basis of 4200 hours of burning per year (about 12 hours per day) less a 5.5 percent reduction for monthly outages which reduces the effective rate to 3.646 cents per kilowatt-hour.

Figure 157 shows the rate for "Street Lighting" service in a portion of Maryland served by the same power company. When the fuel adjustment charge of 2.25 cents per kw-hr (figure 158) is added to the monthly rate of 2.35 cents per kw-hr the net result is a rate of 5.51 cents per kilowatt-hour. There is no reduction for normal outages in the Maryland rate schedule. Thus, this Maryland rate is 50 percent higher than the rate in D.C. for similar service.

Nationally, there is a great diversity in the cost of electricity resulting from the variations in the cost of producing electricity, differences in the rates of return allowed by the regulatory agencies, variety of values of the undepreciated portion of the utility plant and equipment, and differences in the allocations to the classes of service.

This diversity of utility costs is reflected in the rates to each group of users. Table 40 is a listing of the retail price of electricity to commercial customers in 24 selected cities during 1985. In 14 of these cities these rates are either 25 percent higher or 25 percent lower than the mean rate. The costs range from a low of 5.23 cents per kilowatt-hour in Minneapolis, Minnesota to 10.60 cents per kilowatt-hour in Newark, New Jersey.

Figure 159 is a map of the 10 Federal regions and a listing of the States in each region. Table 41 shows the price of electricity for sign lighting charged by one IOU in each of the 10 Federal regions. The IOUs

pepco
Potomac Electric Power Company

DC - SL

STREET LIGHTING SERVICE - SCHEDULE "SL"

AVAILABILITY - Available to agencies of Federal, State and Municipal Governments, for street, highway and park lighting purposes in the District of Columbia portion of the Company's service area.

CHARACTER OF SERVICE - Electricity supplied for series lights normally will be sixty hertz, single phase, 2,400 volts delivered to the series lighting transformers.

Electricity supplied to multiple lights normally will be sixty hertz, single phase, 120 volts.

MONTHLY RATE -

For electricity supplied for:

Standard Night Burning street lights..........	3.858¢ per kwhr
24-Hour Burning street lights.................	4.258¢ per kwhr

The energy charge for series street lights will be discounted $0.30 per month per lamp.

The charges under this schedule are for electricity only and do not include furnishing and/or maintaining street lighting equipment.

FUEL ADJUSTMENT CHARGE - The rates stated above include a base fuel cost component of 2.31985¢ per kilowatt-hour including adjustment for losses. Incremental charges for fuel and interchange, computed in accordance with the provisions of "Fuel Adjustment Charge Rider FA", combined with monthly charges under the provisions of this schedule, constitute the total charge for the services which the Company furnishes.

Date of Issue: April 2, 1985 Date Effective: April 2, 1985

Issued by William F. Schmidt, Vice President
1900 Pennsylvania Avenue, N. W.
Washington, D. C. 20068

Figure 156. Rate schedule for street lighting in the District of Columbia

pepco
Potomac Electric Power Company

Electric---P.S.C. Md. No. 1
Twenty-First Revised Page No. 44

MD - SL

STREET LIGHTING SERVICE SCHEDULE "SL"

AVAILABILITY - Available to agencies of Federal, State and Municipal Governments, for street, highway and park lighting purposes in the Maryland portion of the Company's service area.

CHARACTER OF SERVICE - Electricity supplied for series lights normally will be sixty Hertz, single phase, 2,400 volts delivered to the series lighting transformers.

Electricity supplied to multiple lights normally will be sixty Hertz, single phase, 120 volts.

MONTHLY RATE -

For electricity supplied for:

Standard Night Burning street lights. . . . 3.25¢ per kwhr

24-Hour Burning street lights . . . . 2.92¢ per kwhr

The charges under this schedule are for electricity only and do not include furnishing and/or maintaining street lighting equipment.

RIDER NO. "FR" - FUEL RATE - Charges for fuel costs and energy purchases, computed in accordance with the provisions of "Fuel Rate Rider FR", combined with monthly charges under the provisions of this schedule, constitute the total charge for the service which the Company furnishes.

MEASUREMENTS OF ELECTRICITY - Electricity delivered for street lighting is unmetered. Monthly kilowatt-hour consumptions will be computed on the basis of manufacturers' wattage ratings of installed lamps, auxiliary devices where required, and scheduled 4,200 hours of burning time.

Date of Issue: January 17, 1984 Date Effective: January 18, 1984

Issued by William F. Schmidt, Vice President
1900 Pennsylvania Avenue, N. W.
Washington, D. C. 20068

Figure 157. Rate schedule for street lighting in Maryland

MD

FUEL RATE - RIDER "FR"

FUEL-RATE - For monthly billing purposes the following fuel rate shall be applied to bills rendered on and after the effective date of this Rider "FR" in the manner described below:

(1)	Fuel Rate	2.23538¢/kwhr
(2)	Deferred Fuel Amortization Charge	-
(3)	Fuel Billing Rate (1) plus (2)	2.23538¢/kwhr

(4) Conversion of Fuel Billing Rate to various rate schedules to reflect applicable losses:

(a) Applicable to customers under Rate Schedules R, R-TM, SL, GS (except GS-3A, and GS-3B), GT (except GT-3A, and GT-3B), HS, T, OL, and EV:

Fuel Billing Rate x 1.0099

(b) Applicable to customers under Rate Schedules GS-3A, GS-3B, GT-3A, GT-3B and RT:

Fuel Billing Rate x .9813

This Fuel Rate is based upon the weighted average price of fuel and the weighted average generation mix for the periods of three and twelve months respectively, ended March 31, 1986.

Date of Issue: May 15, 1986 Date Effective: June 3, 1986

Issued by William F. Schmidt, Vice President
1900 Pennsylvania Avenue, N. W.
Washington, D. C. 20068

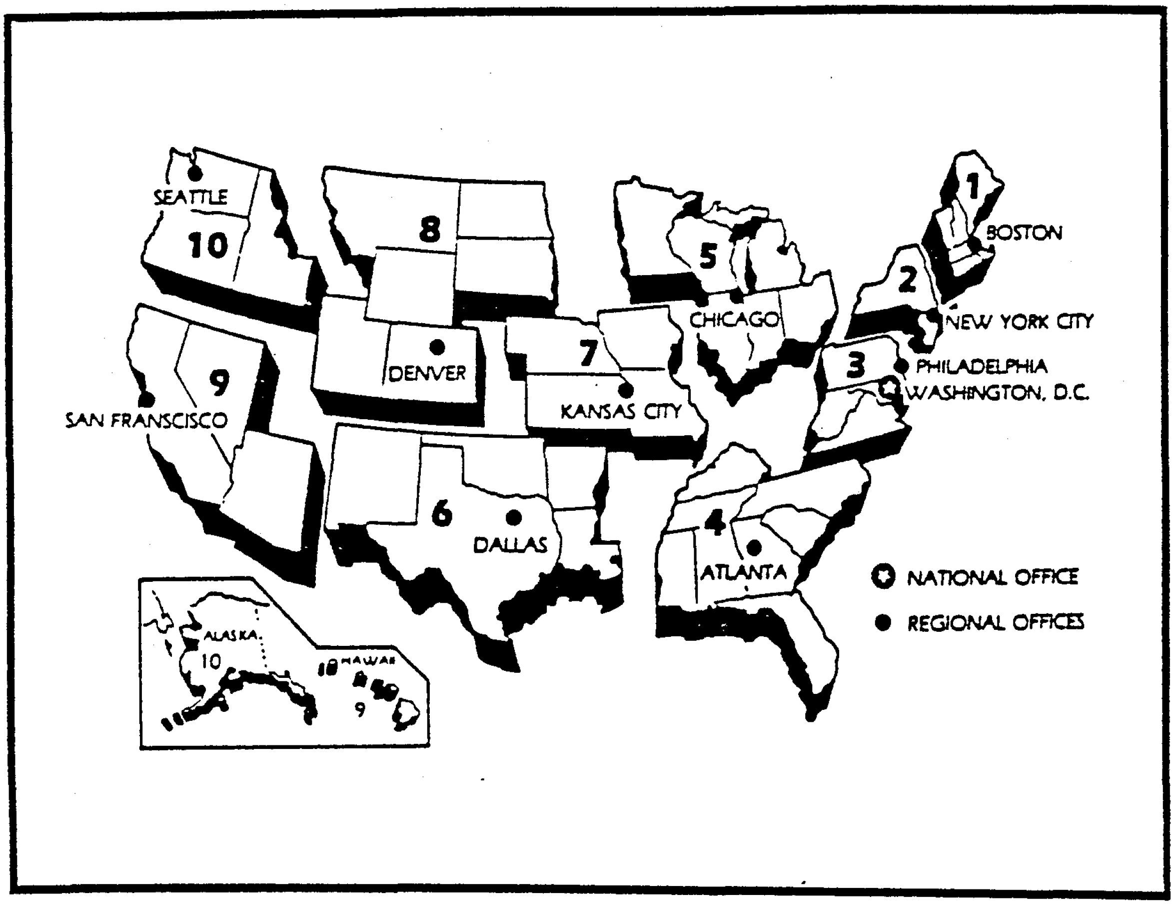
Figure 158. Fuel adjustment for Maryland street lighting rate

Table 40. Retail prices of electricity to commercial customers.

CITY AND STATE	POWER COMPANY	1985 RETAIL PRICE
Atlanta, GA	Georgia Powr Co.	8.58
Baltimore, MD	Baltimore Gas & Electric	7.79
Boston, MA	Boston Edison Co.	10.55
Buffalo, NY	Niagara Mohawk Power Co.	8.51
Chicago, IL	Commonwealth Edison Co.	9.46
Cincinnati, OH	Cincinnati Gas & Electric Co.	8.27
Cleveland, OH*	Cleveland El Illum Co.	9.69
Columbus, OH*	Columbus & So. OH El Co.	7.76
Dallas, TX	Texas Electric Utilities Co.	7.26
Denver, CO	Public Service Co. of Colorado	7.51
Detroit, MI	Detroit Edison Co.	9.11
Fort Worth, TX	Texas Electric Utilities Co.	7.26
Houston, TX	Houston Lighting & Power Co.	8.04
Indianapolis, IN	Indianapolis Power & Light Co.	5.37
Kansas City, MO*	Kansas City Power & Light Co.	8.89
Long Beach, CA	Southern CA Edison Co.	8.81
Los Angeles, CA	Los Angeles (City of)	6.65
Louisville, KY	Lousiville Gas & Electric Co.	6.83
Miami, FL	Florida Power & Light Co.	8.79
Milwaukee, WI	Wisconsin Electric Power Co.	7.16
Minneapolis, MN	No States Power Co. (MN)	5.23
Nashville, TN	Nashville El Serv	10.60
Newark, NJ	Pub Serv El & Gas Co.	7.68
New Orleans, LA	New Orleans Pub Serv Inc.	

NOTE: Based on 10,000 kilowatt-hours at 40-kilowatt demand.

United States Federal Region Map



Region 1 - New England - Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island

Region 2 - New York/ - New York, New Jersey, Puerto Rico, New Jersey Virgin Islands

Region 3 - Mid-Atlantic - Pennsylvania, Maryland, West Virginia, Virginia, District of Columbia, Delaware

Region 4 - South Atlantic - Kentucky, Tennessee, North Carolina, South Carolina, Mississippi, Alabama, Georgia, Florida

Region 5 - Midwest - Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio

Region 6 - Southwest - Texas, New Mexico, Oklahoma, Arkansas, Louisiana

Region 7 - Central - Kansas, Missouri, Iowa, Nebraska

Region 8 - North Central - Montana, North Dakota, South Dakota, Wyoming, Utah, Colorado

Region 9 - West - California, Nevada, Arizona, Hawaii, American Samoa, Guam

Region 10 - Northwest - Washington, Oregon, Idaho, Alaska.

*U.S. GOVERNMENT PRINTING OFFICE: 1985-461-195:20022

Figure 159. Map of the Federal regions

Table 41. Sample of electricity prices for sign lighting.

REGION	POWER COMPANY	1985 RATE
New England	Boston Edison — Massachusetts	.0688
New York, New Jersey	New York State Electric & Gas, NY	.1099
Mid-Atlantic	Potomac Electric Power Co. — DC Potomac Electric Power Co. — MD	.0365 .0551
South-Atlantic	Georgia Power Company, Georgia	.0414
Midwest	Public Service Company of Indiana	.0963
Southwest	Central Power & Light, Texas	.0538
Central	Union Electric, Missouri	.0324
North Central	Public Service Company of Colorado	.0651 [1]
West	Pacific Gas & Electric, San Francisco, California	.08223
Northwest	Pacific Power & Light, Oregon	.0601 [2]

NOTES: Rates are in dollars per kilowatt-hour.
[1] Estimated as 1 cent less than the commercial rate.
[2] Average of winter and summer rates.

shown in this table were randomly selected from the IOUs operating in that region. Although these rates cannot be said to be an average price for electricity in the region, they are sample values and do reflect the variation in price from one region to another.

The lowest rates shown in table 41 were charged by Union Electric (of Missouri) in the Central Region. The highest rates in the table are those of New York State Electric and Gas from New York, New Jersey region. Overall, the sign lighting rates vary from less than 4 cents, to more than 10 cents per kilowatt-hour.

Cost of Electricity for Sign Lighting

Table 42 shows the annual cost of energy for a single luminaire, and for lighting the six luminaire systems contained in table 39. This table is constructed in a matrix format with various types and wattages of lamps down the side and five levels of energy cost across the top. Because of the wide range in electric rates that are charged for sign lighting, the rates that are used in this table vary from 4 cents to 12 cents per kilowatt hour. The kilowatt-hours of energy consumed by each of the six lighting systems are also taken from table 39.

Future Electricity Prices

Figure 160 from reference 38 shows four projections of the price of electricity energy through 1995. As can be seen in this figure only one of these projections shows an increase in the "real" costs of electricity. This estimate of increasing electricity prices was prepared by Electrical World, based on their expert judgement of a consensus of industry analyses.(39) The strong growth in electrical prices reflected in this forecast is predicated on a surge in the new nuclear capacity and reinforced by the increases in prices that occurred between 1979 and 1982. The other three projections show a slight decline in the cost of electricity when measured in constant dollars. (In this case 1984 cents per kilowatt-hour.)

One of these forecasts showing no increase in the real price of electricity was prepared by the Energy Information Administration (EIA) of the U.S. Department of Energy. The EIA produces an annual report containing forecasts of energy prices based on extensive information concerning the supply and demand for electrical power and electrical generating facilities that are in existence and under construction. The material in the remainder of this section draws heavily from their work to explain why the "real" price of electricity is expected to decline under a wide variety of economic conditions. There are, however, major differences in how much the price of energy will decline from one region of the country to another. These differences are primarily based on the source of power used to produce electricity (i.e., hydro, coal, petroleum, etc.). The

Table 42. Annual cost of lighting

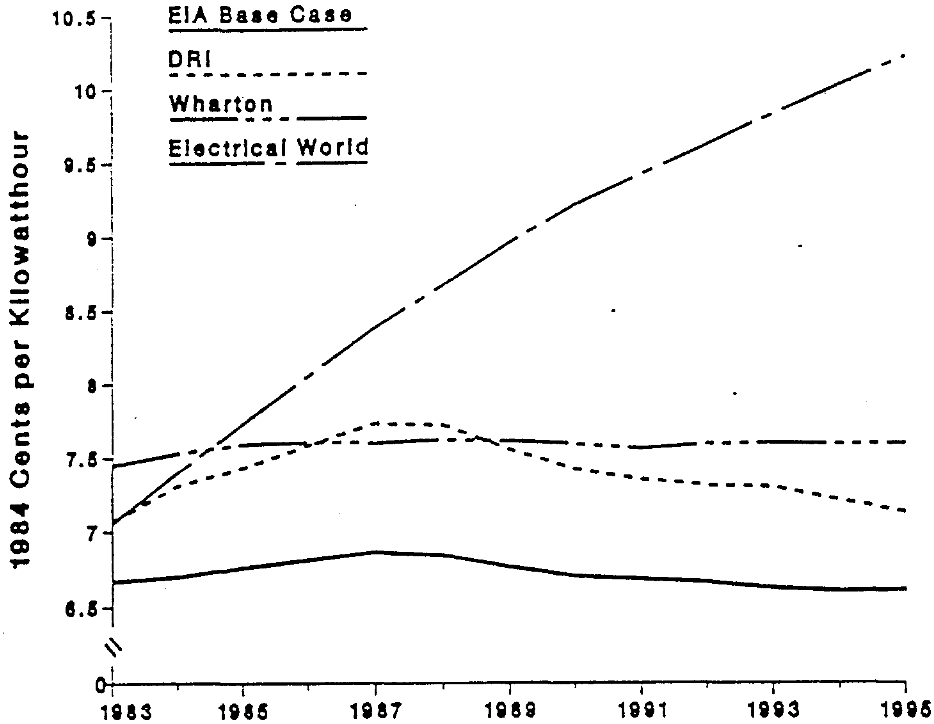
LAMP TYPE, SIZE AND ANNUAL KW-HR	RATE PER KILOWATT HOUR 4 cents	6 cents	8 cents	10 cents	12 cents
Mercury Vapor					
175 w 852 kw-hr	$ 34	$ 51	$ 68	$ 85	$102
250 w 1,218 kw-hr	49	73	97	122	146
400 w 1,948 kw-hr	78	117	156	195	234
System Cost[1]					
Low Price	35	50	70	85	100
Medium Price	100	145	195	245	290
High Price	155	235	310	390	470
High Pressure Sodium					
70 w 341 kw-hr	14	20	27	34	41
150 w 731 kw-hr	29	44	58	73	88
250 w 1,218 kw-hr	49	73	97	122	146
System Cost[1]					
Low Price	15	20	25	35	40
Medium Price	60	90	115	145	175
High Price	100	145	195	245	290

NOTES: For derivation of Kilowatt-hours see table 39.
[1]System costs have been rounded to the nearest $5.

extent to which these differences are reflected in the price of electricity is discussed at the end of the section.

EIA's outlook for electricity prices depends upon several factors, including the overall rate of economic growth, the price and availability of fuels, the price of electricity relative to other energy prices, and the type and rate of growth of new generating capacity.

The forecast in this section is based on material in the "Annual Energy Outlook" 1985 (AEO).[39] Five projection scenarios were covered in the AEO: (1) a base case; (2) a lower-than-base economic growth case;



Sources: Data Resources, Inc. (DRI), *Energy Review* (Lexington, MA, Autumn 1984). Wharton Econometric Forecasting Associates, *Wharton Long-Term Forecast* (Philadelphia, PA, September 1984). *Electrical World*, "35th Annual Electric Utility Industry Forecast" (New York, NY, September 1984).

Figure 160. Comparison of residential electricity price forecasts

(3) a higher-than-base economic growth case; (4) a high electricity demand case; and (5) a reduced capacity growth case. Despite recent sharp drops in world oil prices, this report was based upon a longer term assumption that the real prices of crude oil are likely to come down and stay low the next few years, then recover and resume an upward trend by the end of the decade.

Base Case Analysis

In the base case, U.S. electricity demand (end-use consumption) is expected to grow at a rate slightly less than the overall rate of economic growth. The average rate of growth of electricity demand from all sectors is projected to be 2.7 percent a year, close to the Gross National Product (GNP) growth rate of 2.8 percent a year.

The projected slowdown in electricity demand growth is traced primarily to reduced expectations for industrial electricity demand growth. Growth in the major industries have not fully recovered from the sharp drops of the last recession and also face increased competition from imports. The EIA also assumes that industrial conservation and efficiency improvements made as a result of the rapid energy price increases of the 1970's will continue and expand, reducing the rate of growth of industrial electricity demand. As a result, U.S. industrial electricity demand from the industrial sector is now projected to grow less rapidly than GNP, at less than 2.6 percent a year.

Electricity Prices in the Base Case

Nationwide, electricity prices in the base case (in 1985 dollars) are projected to decline at an average rate of 0.9 percent per year from 1985 to 1995. This projected decrease in electricity's price can be explained in terms of its price components -- fuel, operation and maintenance, and capital.

The fuel components of electricity's price is projected to decline through 1988. After 1988, fuel costs are projected to increase, rising from 33 percent of electricity's price through 1990 to 40 percent in 1995.

The operation and maintenance (O&M) component of electricity's price is projected to increase slightly from 1985 to 1990, and then decline from 1990 to 1995 as it is distributed over more intensively utilized generating facilities, lowering the overall cost per unit of electricity generated. Although the O&M component is projected to decline at an average rate of 0.4 percent a year, its relative share of electricity's price is expected to remain about 25 percent.

The capital component of electricity's price is projected to decrease because of the combined effect of two factors: first, decreases in the size of the rate base and second, increases in the sales base over which the capital costs are distributed.

The rate base is the measure of electric utility investment used by regulators in determining electricity prices. The value of the rate base is projected to decline because of three factors. First, the value of electric plant in service will grow more slowly than in recent years, as new plants are completed and become operational. Second, accumulated depreciation, (which reflects reductions in the value of both existing and new assets over time) is projected to increase substantially. Third, the value of new but incomplete construction allowed in the rate base, is projected to decrease, indicating further slowdowns in new utility investment growth.

Also contributing to a decrease in the capital component of electricity's price is the projected increase in electricity sales. As a result, the value of the decreased rate base is distributed over a larger quantity of electricity sales, further lowering the capital component of electricity's price.

High and Low Economic Growth Cases

World oil prices were assumed to be higher than in the base case for the low economic growth scenario, and they were assumed to be lower than in the base case for the high economic growth and high electricity demand cases. In the low economic growth case, electricity prices nationwide decline slightly more rapidly than in the base case despite higher world oil prices, primarily because oil and natural gas use drops more than enough to offset increases in unit fuel costs. Furthermore, under low economic growth, requirements for new generating capacity also decline, reducing the capital share of electricity's price.

The high economic growth case requires both more extensive oil and natural gas use and additional generating capacity, raising both the fuel and capital components of electricity's price. The overall real electricity price difference between the low and high economic growth cases in 1995 is less than 1 percent.

High Electricity Demand Case

EIA also examined the electricity market effects of economic growth rates higher than assumed in the earlier cases induced by higher industrial electricity demand (and lower-than-base-case world oil prices).

For this analysis EIA examined a scenario in which GNP grows at an average annual rate of 3.6 percent and electricity demand grows at an average annual rate of 3.2 percent.

In this high electricity demand case, electricity prices are projected to decline more slowly than in other cases, at an average annual rate of 0.6 percent. By 1995, real electricity prices are projected to be only slightly above the base case prices, but still below the 1985 price.

Reduced Capacity Additions Case

To examine the effects of further reductions in new generating, capacity EIA assumed that the planned coal-fired and nuclear power plants that were not yet under construction would not be completed before 1995. Nearly 25 gigawatts, or one-fourth of currently anticipated capacity additions, were assumed canceled or postponed under this scenario. Overall, planned coal-fired power plant additions are reduced more than 40 percent. Of currently planned nuclear capability, 5.5 gigawatts are assumed canceled, a decrease of more than 13 percent.

Price patterns vary a great deal across regions in this case, depending upon the relative magnitudes of the capacity reductions, demand for replacement capacity, fuel cost, and quantity and costs of alternate supply sources. In some regions prices remain slightly below projected prices in the base case, as savings in capital costs outweigh increased fuel costs. In other regions, prices are projected to exceed base-case expectations.

Regional Differences for the Five Projections

In the base case analysis electricity prices are expected to fall less rapidly than the national average in the New England, New York/New Jersey, Middle Atlantic, and Western regions because of their dependence on oil and natural gas. In regions that rely more on coal and hydroelectric power, such as the South Atlantic, North Central, Central, and Northwest, electricity prices are projected to drop more rapidly.

The high economic growth case was developed by assuming a price of oil that is less than the price of oil in the base case. Conversely, the low economic growth case was predicated on an increased price of oil that is above its price in the base case. Only in the heavily oil-dependent regions of New England, New York/New Jersey, and Middle Atlantic do the assumed world oil effects predominate over the other factors that determine price. In these regions this predominance results in higher 1995 average electricity prices under conditions of low overall economic growth and lower prices under assumptions of high economic growth.

In this high-electricity-demand case, 1995 prices are projected to be slightly higher than in 1985 in only two regions, the Middle Atlantic and the Southwest, in response to higher fuel costs.

The South Atlantic, Central, Midwest, and Northwest regions are projected to enjoy lower prices and higher demand over the forecast period as a consequence of reduced capacity in the final case that was analyzed. The Southwest, North Central, and Western regions incur increased prices because increased fuel costs outweigh savings in capital costs.

Table 43 presents the Federal regional projections for U.S. electricity prices. This table shows the 1985 price and the 1995 base, low, and high price estimates. These low and high price estimates were drawn from the data for the four variations on the base scenario (low growth, high growth, high demand and reduced capacity) that have been discussed in the preceding paragraphs. All prices are in 1985 cents per kilowatt hour.

Present Worth of Annual Electricity Payments

In the previous section we saw that the forecasts of electricity prices show a steady or declining cost when expressed in constant 1985 cents per kilowatt hour. A uniform Present Worth Factor is used to convert a series of annual payments into a single present worth value. For the 20-year period and 10 percent interest rates that we are using in this analysis, this factor has a value of 8.5136. Based on this factor, and the values in table 42, table 44 shows the total present worth costs of providing lighting for the typical overhead guide sign of 165 ft^2 for a 20-year period.

Table 43. Projections for electric power prices 1985 dollars -- average for all customer classes.

1985 CENTS PER KILOWATT-HOUR REGION	1985	1995 BASE CASE	1995 LOWEST CASE	1995 HIGHEST CASE	PERCENT CHANGE 1985-1995 BASE CASE	PERCENT CHANGE 1985-1995 LOWEST CASE	PERCENT CHANGE 1985-1995 HIGHEST CASE
NEW ENGLAND	8.9	8.3	8.3	8.5	-6.7%	-6.7%	-4.7%
NEW YORK/NEW JERSEY	9.3	9.0	8.9	9.2	-3.2%	-4.3%	-1.1%
MID-ATLANTIC	6.5	6.5	6.4	6.6	0.0%	-1.5%	+1.5%
SOUTH-ATLANTIC	6.0	5.3	5.2	5.3	-11.7%	-13.3%	-11.7%
MID-WEST	6.6	5.9	4.7	6.0	-10.6%	-13.6%	-9.1%
SOUTH-WEST	6.6	6.5	6.4	6.8	-1.5%	-3.0%	+3.0%
CENTRAL	7.1	5.9	5.8	5.9	-16.9%	-18.3%	-16.9%
NORTH CENTRAL	6.1	5.3	5.3	5.6	-13.1%	-13.1%	-8.2%
WEST	7.1	6.6	6.5	6.8	-7.0%	-8.5%	-4.2%
NORTH-WEST	3.3	2.9	2.8	3.2	-12.1%	-15.2%	-3.0%

NOTE: Source — reference 40.

Table 44. Present worth of annual lighting cost

LAMP TYPE, SIZE AND ANNUAL KW-HR	RATE PER KILOWATT HOUR 4 cents	6 cents	8 cents	10 cents	12 cents
Mercury Vapor					
System Cost[1]					
Low Price	$ 300	$ 425	$ 595	$ 725	$ 850
Medium Price	850	1,235	1,660	2,085	2,470
High Price	1,320	2,000	2,640	3,320	4,000
High Pressure Sodium					
System Cost[1]					
Low Price	130	170	215	300	340
Medium Price	510	765	980	1,235	1,490
High Price	850	1,235	1,660	2,085	2,470

NOTES: For derivation of Kilowatt-hours see table 39.
Present worth factor = 8.5136 for i=10 percent, n=20.
[1]System costs have been rounded to the nearest $5.

Annual Maintenance

Introduction

This section reviews the annual costs for sign maintenance. The activities that are included under this heading are relamping and cleaning the fixtures, trouble calls, ballast replacement and other miscellaneous activities. A table summarizing the present worth of these annual maintenance costs appears at the end of the chapter.

These costs are, for the most part, based on data obtained from detailed Caltrans maintenance records. Low, average, and high maintenance estimates were extrapolated from the Caltrans data using cost adjustment factors from Means Electrical Cost Data 1985.

Sign Cleaning

Most of the jurisdictions that were contacted had no regular maintenance program for the cleaning of their overhead guide signs. These jurisdictions indicated that this was dictated by several factors. Some States claimed that the "natural" cleaning actions of periodic rain kept these signs sufficiently clean. Another State indicated that proper cleaning of the sign required the use of chemical cleaning agents that had to be flushed off the sign after their application. Several States admitted that this type of maintenance was such a low priority, when compared to other maintenance activities, that it was never performed.

In 1978 Caltrans reported that "Routine sign washing is not required for overhead signs and the Districts reported little effort in this area...Many of the newer signs are not equipped with the standard gutter required for flushing the sign with water."[11] Less than $3,000 was spent by Caltrans to clean overhead signs in FY 1977/1978.

This rejection of sign cleaning was modified in a 1981 Caltrans study which indicated "During the Fresno observations...(the Review Team) encountered moderate to heavy dew conditions. Droplets of dew, combined with the summer's accumulation of airborne dust and dirt, severely reduced legibility distances." "...adequate legibility distances can be maintained by dry-washing 5 percent of the button-copy signs in a period of 5 years which is equivalent to washing about 1 percent of the nonilluminated overhead guide signs annually."(27)

A conversation with personnel from the Michigan DOT revealed that Michigan had operated a sign cleaning program in the mid 1960s. This procedure involved several steps and they found that it was less expensive to put on a new overlay than to clean the sign.

This analysis has not included any costs for the cleaning of sign faces. To be fully useful the data would have to specify the sign cleaning cost by different combinations of background and message materials. It is reasonable to assume that the differences in the cost of cleaning the nine combinations of background and message materials would not be significant enough to affect the result.

Lighting System Maintenance

Lighting System Maintenance consists of several major activities: periodic relamping, replacement of the ballasts, and other miscellaneous troubling shooting of problems with the electrical system.

One of the "other" problems that creates a maintenance requirement is the periodic replacement of the lighting system due to impacts from below. It would appear that this problem is created by tree limbs or other loose material protruding above the normal truck height limit, or by loose ropes that are used to secure tarpaulins on the top of open trucks. Although the frequency of this type of damage cannot be documented, careful observation of the lighting systems revealed that this is a regular, if infrequent event.

It is interesting to note that new luminaire installations on New York's Long Island Expressway have the luminaires positioned on the top of the sign pointing down, while new installations on the Northern State Parkway (which parallels the LIE but is restricted to passenger cars) utilize the traditional bottom mounted luminaire position.

The following analyses are based on data from the California DOT Maintenance Expenditure Report (41). This computer printout, covering the

12 month period from July 1984 through June 1985, reports the expenditures, by district for very specific maintenance tasks. These expenditures are broken down into the number of person years involved in each task, the percent of support time (i.e.: travel time to the site, and time spent closing lanes), the number of completed production units (for example: number of fixtures relamped, or the number of trouble calls), the total dollar expenditure, and the percentage of this total spent on salaries, equipment, materials, and other. A sample page from this printout is reproduced in figure 161.

Replacement and Cleaning of Luminaires

Most of the Overhead Guide Signs in California are lit by florescent lamps 72 in long. The California computer printouts show an average maintenance time of .54 hours per luminaire for relamping and cleaning. This value includes travel time to the site, any time spent setting up traffic control, and the actual time spent servicing the fixtures.

Since lamp replacement is generally done on a group basis, and most panels utilize more than one luminaire, that actual average time spent per sign will be greater than this value. Unfortunately, there is no data available on the average numbers of luminaires per sign or per structure. We have estimated that there are an average of 4.3 lamps per structure, based on an average sign size of 173 ft^2 (a sign approximately 8 1/2 ft by 20 ft) and 1.43 sign panels per structure as indicated in the 1981 Caltrans report, and the 3 fixture requirement for a 20-ft wide sign listed in the Caltrans Standard Plans.[28,42]

Using this estimate of 4.3 lamps per structure, the labor spent in the replacement and cleaning of luminaires for 1 year would be 2.3 person-hours per structure. This can also be expressed in terms of the total number of panels and structures as an average of .36 person-hours per sign, or .52 person-hours per overhead sign structure.

These cost sheets also provide a breakdown of costs by the percent spent on equipment and materials.

MMS904-E STATEWIDE (DIST 01-11) MAINTENANCE EXPENDITURE REPORT BUSINESS DATE: JUNE 1985 PAGE 28
RUN DATE: 06/05/86
FOR FY 1984-85 (JULY THRU JUNE)

FAMILY PROBLEM	PLANNED PER YRS FY TOTAL	PLANNED PER YRS FYTD	EXPENDED PER YRS FYTD	PCT SUPP	COMPLTD PROD U FYTD	EXPENDED TOT DOLLARS FYTD	EXPENDED <DOLLAR DISTRIBUTION > %SAL	%EQP	%MAT	%OTH	DOLLR/ PROD U	EXPENDED PER YRS JUN 85	EXPENDED DOLLARS JUN 85
43-020 ("Other")													
DIST 01			.04	53	20	2,498	72.6	21.2	6.0		124.93		319
DIST 03			.19	34	47	13,136	57.1	12.1	28.2	2.4	279.49		81
DIST 04			.14	32	47	8,922	62.3	11.5	24.2	1.8	189.84		442
DIST 05			.05	43	5	2,939	80.2	16.1	3.5		587.83		
DIST 06			.05	17	8	3,943	57.2	10.3	32.3		492.96		
DIST 07			.61	35	378	39,003	60.8	22.7	14.5	1.9	103.18	.03	2,356
DIST 08			.15	29	106	7,250	78.6	17.0	4.3		68.40		88
DIST 10			.02	33	20	1,346	71.8	17.9	10.1		67.33		
DIST 11			.18	26	95	10,425	66.1	15.2	18.6		109.74		452
TOTAL			1.46	33	726	89,466	63.4	17.8	17.2	1.3	123.23	.05	3,740
43-021 (Relamping)													
DIST 01				50	1	51	80.6	19.3			51.88		
DIST 02			.01	48	45	815	69.8	13.1	16.9		18.12		
DIST 03			.27	38	1,071	14,300	78.2	21.4	.3		13.35	.13	7,347
DIST 04			.83	29	2,677	42,407	75.5	14.4	9.7	.3	15.83	.02	1,951
DIST 05			.02	27	162	1,303	86.1	13.8			8.04		
DIST 06			.02	27	121	1,653	68.0	7.5	24.4		13.66		
DIST 07			.66	32	2,328	44,587	55.9	23.6	16.9	3.3	19.15		140
DIST 08			.63	45	1,878	29,457	76.8	17.6	5.3	.1	15.68	.01	537
DIST 10			.04	32	128	2,504	65.2	16.7	18.0		19.56		49
DIST 11			.10	32	312	5,646	66.6	13.6	19.6		18.09		
TOTAL			2.62	35	8,723	142,728	69.3	18.5	10.8	1.1	16.36	.17	10,026
43-022 (Trouble Repair)													
DIST 01			.03	41	12	2,298	56.4	25.9	17.5		191.53		
DIST 02			.03	66	23	1,726	76.5	9.6	13.0		75.07		123
DIST 03			.39	43	198	20,319	77.5	17.2	4.8	.3	102.62	.10	4,772
DIST 04			3.65	29	2,129	192,363	74.1	15.4	10.4		90.35	.38	23,356
DIST 05			.10	34	88	8,940	86.4	11.3	2.2		101.59		324
DIST 06			.32	27	202	18,047	67.5	9.4	23.0		66.83		448
DIST 07			3.22	39	1,712	229,968	52.3	25.9	19.2	2.4	134.32	.31	22,193
DIST 08			.87	49	690	42,357	77.4	21.8	.4	.2	61.36	.07	3,640
DIST 09			.01	51	8	936	47.7	10.8		41.4	117.03		
DIST 10			.20	40	258	14,305	56.4	14.3	28.5	.6	55.34	.01	1,255
DIST 11			1.23	33	2,159	75,008	62.6	11.0	25.2	1.1	34.74	.11	5,383
TOTAL			10.10	35	7,559	607,072	64.2	19.1	15.4	1.1	80.30	1.02	61,497

Figure 161. Sample page from CALTRANS' Maintenance Expenditure Report.

Applying the equipment and material as percentages to the average expenditure per fixture relamped provides subtotals of $3.03 for equipment and $1.77 for materials. This average expenditure for materials appears to be distorted by three jurisdictions that had materials costs below the norm. Five of the eight jurisdictions had equipment costs between $3.00 and $3.60 per fixture which appears to be much more consistent with the cost of florescent lamps.

In terms of the total number of sign panels and structures these annual costs are: $2.04 per sign panel, and $2.92 per structure for equipment; and (based on the five districts with replacement lamp costs between $3.00 and $3.60 per fixture) $1.18 per sign panel and $1.68 per structure for materials per year.

Trouble Repair

This category of the Caltrans cost data covers troubleshooting to repair inoperative sign lighting. This would include replacement of lamp sockets, ballasts, and photocells. This category could also include replacement of lamps. There were 7,559 trouble calls during the reporting period.

The average maintenance effort for this category was 2.4 person-hours per trouble call. Expressed in terms of the overall system this was equivalent to 1.4 hours per sign panel per year, or 2.0 hours per sign structure per year.

The annual equipment costs for trouble repair was $15.34 per trouble call. This can also be expressed as $8.95 per sign panel; or $12.83 per structure. The annual materials cost for trouble repair was $12.37 per call. This is the equivalent of $7.21 per sign panel, or $10.35 per sign structure.

Other Sign Lighting Maintenance

A specific charge number is used in the printouts for major damage repairs to sign lighting structures, fixtures, or circuits caused by accidents. It also includes time on apparent false alarm trouble calls, damage by vandalism, trouble calls resulting from utility company power outages and miscellaneous sign lighting maintenance work that is not identified elsewhere. There were a total of 726 calls for maintenance in this category covering the 12,959 sign panels (9035 structures) across the State.

The statewide average for this category of maintenance was 3.6 person-hours per occurrence. However, because of the infrequency of these occurrences the average maintenance for all signs was only .20 person-hours per sign panel and .29 person-hours per sign structure per year.

The annual equipment cost for other sign lighting maintenance was $21.93 per event, or expressed on a per sign or sign structure basis, $1.23 per sign panel per year and $1.76 per sign structure per year. The average annual materials costs for these maintenance calls was $21.19, or $1.18 per sign panel.

Inspection of Sign Lighting

Caltrans reported spending a total of $252,368 inspecting overhead guide sign <u>and</u> freeway lighting during the 12 months ending June 1985. These costs were provided for the 11 California Department of Transportation districts. The costs of these inspections ranged from a low of $13 per structure in the district that includes Los Angeles to a high of $586 dollars per structure in an eastern district that includes Death Valley. As can be seen in these data, the inspection cost per structure is much less in an urban area with many structures than in a rural area with far fewer guide signs. The median costs of lighting inspection are probably better indicators of a typical condition than the average value which tends to be distorted by the urban data. These median costs of $40 per guide sign structure and $30 per guide sign panel are from the California DOT district in a central part of the State in which the major cities are Fresno and Bakersfield.

It should be noted that this cost item can only be considered in an analysis which assumes that there is not roadway lighting.

Comparison With Other Data Sources

Some additional data on maintenance costs was found for Arizona and Virginia. The Arizona data is taken from the 1986 study that has been previously mentioned. The Virginia data is taken from a paper printed in Transportation Research Record #628, 1977.[(43)] Extracts from these sources, and Caltrans printouts are listed in Table 45 for various categories of work on overhead guide signs.

As can be seen in this table, the data sources do not agree well at all. The Arizona data show equal amounts of time for installing luminaires, and relamping and cleaning them. The Virginia data show the labor requirement for the contract that excludes traffic control, to be almost 3 times the labor requirement of the contract that includes traffic control.

Because of these inconsistencies, and the detailed records maintained by Caltrans, we have decided to use the Caltrans data for all maintenance except for the replacement of ballasts where the Arizona data for labor estimates and replacement frequency will be utilized.

Table 45. Estimated labor requirements for work on overhead guide signs (person-hours).

	Caltrans	Arizona	Virginia
Install Luminaire	2.5	1.6	—
Relamp and Clean Luminaire	0.54	1.6	—
Replace Ballast	—	0.8	—
Total Maintenance (per location serviced)	2.5		3.3[1], 9.5[2]

NOTES: [1]Performed under contract — includes traffic control.
[2]Performed under contract — excludes traffic control.

Table 46. Summary of sign lighting maintenance costs.

ITEM	PERSON-HOURS PER		EQUIPMENT COST PER		MATERIAL COST PER	
	PANEL	STRUCTURE	PANEL	STRUCTURE	PANEL	STRUCTURE
Relamping & Cleaning	.36	.52	\$ 2.04	\$ 2.92	\$(2.22*	\$ 3.19*)
Trouble Repair	1.40	2.00	8.95	12.83	7.21	10.35
Other Maint.	.20	.29	1.23	1.76	1.18	1.70
TOTAL	1.96	2.81	\$12.22	\$17.51	\$ 8.99	\$12.05

NOTES: *Based on an estimated materials cost of \$3.30 per lamp replacement.
Due to the differences in the type and cost of lamps, the material cost for lamp replacement has not been used.

Table 47. Adjusted annual maintenance costs (per sign panel).

ITEM	BASIC COST	ADJUSTMENT INDEX[1]	ADJUSTED COST	MULTIPLIER	TOTAL COST
Labor	\$21.37	126.9	\$16.84	1.96[2]	\$33.01
Equipment	12.22	126.9	9.63	1.00	9.63
Subtotal					\$42.64
Materials	8.99	103.5	8.64	1.00	8.69
Total					\$51.33

NOTES: [1]The basic cost is divided by the adjustment index.
[2]The labor requirement is 1.96 person-hours per sign panel.

Present Worth of Maintenance Costs

The present worth of the labor, equipment, and materials costs associated with sign lighting maintenance are summarized in table 48. In this table the costs are shown for the high, medium, and low priced mercury

Table 48. Present worth of annual maintenance costs.

	LOW PRICE SYSTEM	MEDIUM PRICE SYSTEM	HIGH PRICE SYSTEM
Mercury Vapor			
Labor	$435	$435	$435
Lamps	35	125	100
Ballasts	15	35	40
TOTAL	$485	$595	$575
High Pressure Sodium			
Labor	$435	$435	$435
Lamps	110	230	245
Ballasts	30	65	90
TOTAL	$575	$730	$770

NOTES: Labor costs include equipment.
Present worth factor for annual labor costs = 8.5136 for i=10, n=20.
Lamps are replaced at the end of every third year.
Present worth factor for total lamp replacements = 2.4578, i=10%.
Ballasts are replaced at the end of the 12th year.
Present worth factor for ballast replacement = 0.318631, i=10%.
Medium and high price systems require two lamps and ballasts.
Lamp and ballast costs are shown in table 39.
All prices rounded to the nearest $5.

vapor and high pressure sodium lighting systems that were previously discussed. The low price systems use a single luminaire with either a 175 watt mercury vapor, or 70 watt high pressure sodium lamp. The medium price systems utilized two luminaires with either 250 watt mercury vapor or 150 watt high pressure sodium lamps. The high price system uses either two 400 watt mercury vapor or 250 watt high pressure sodium lamps in its luminaires.

In this table we followed the ASU practice of assuming a 4-year life for lamps and a 12-year life for ballasts.

Structural Costs

Introduction

By their very nature overhead guide signs must be supported above the flow of traffic. Three of the basic types of support structures are: sign bridges supported at both ends that span across the entire roadway or from one side of the roadway to the median, cantilevers which provide only one support post and on which the sign is hung from an arm extending out over the roadway, and bridge (or structure) mounts on which the sign support is attached to an overpass that crosses above the roadway.

The components of these support structures that are directly related to the sign lighting support system are: the walkway (catwalk), safety railing, and the structural brackets that support the luminaires and the walkway. Generally speaking, walkways (and safety railings) will only be found on structures that have sign lighting. However, sign lighting is often provided on structures without walkways.

This section presents the structural costs associated with highway guide sign lighting in terms of these two alternatives: for structures with walkways — the costs of walkways, safety railings and walkway/luminaire supports; for structures without walkways — the cost of luminaire supports alone.

Walkways also impose additional loads on the structures that carry them. An analysis was made to determine these additional loads, and the additional steel that is needed to provide the added strength required by the structure. The cost of this additional steel is included in the final summary table for three different types of support structures.

Walkways

Observations of overhead guide signs in various States revealed that the existence of a walkway (catwalk) on the sign support structure was the fundamental difference between the installations. Although the States have a variety of different ways of supporting sign lighting, the most important difference is whether or not these systems are also designed to support a walkway.

Catwalks were much more common in the older fluorescent system (and on structures where fluorescent systems were once used, but have been replaced) because of the long source length. Modern HID source are easier to handle and can be worked on just as easily from a bucket truck, without having to move the bucket back and forth from one end of the luminaire to the other.

The discussions with various highway agencies revealed that these walkways are used only to service the lighting system. There were no reports of overhead guide sign installations where walkways existed without a lighting system, unless a previously installed lighting system had been removed. Although it would be possible to use walkways for the routine cleaning of signs, most of the people that were contacted were quite candid about the lack of maintenance given to overhead guide signs.

Walkways could be used to facilitate the installation of a new overlay on an existing sign, but the usefulness of the walkway would depend upon whether personnel would be able to reach the top of the sign from the walkway. Many of the overhead guide signs are more than 8 ft tall and special equipment would be required to perform an overlay at these installations.

There is no national policy or guidelines on the installation of walkways. The decision to include or exclude them is left to the individual States or operating agency. Several of the States that were contacted have changed their policy toward walkways in recent years, but there is no consensus on the nature of this change. Some States that previously used walkways are not including them on the specifications for new structures. Other States that had not built walkways on their older structures are now including them on their new sign support structures.

The State's preference for the use of a "bucket truck" appears to be the major factor upon which the decision to build or not build walkways is based. Some States like Maryland had been using catwalks but apparently discontinued their use because maintenance crews preferred to service the sign lighting system from the bucket truck. The City of Philadelphia had not been using walkways, but decided that is was preferable to maintain the sign/lighting system from the catwalk rather than a bucket truck because of the high volumes of traffic on the roadway during all hours of the day and night.

Table 49 shows the general policy for providing sign lighting and walkways of some of the States that were contacted.

Because of these differences it is not possible to come up with a typical configuration that can be applied on a national basis. However, walkways are more likely to be found on overhead sign support structures over high speed/high volume roadways. Thus, at a freeway interchange with a cross-road (that is not itself a freeway), walkways are more likely to be found on the structures over the freeway, than on the structures over the cross-road.

Table 49. General sign lighting and walkway policy on new sign bridges.

Partial Listing of States Not Lighting Overhead Guide Sign Structures

Michigan	Massachusetts
Kansas	Washington

Partial Listing of States Providing Lighting Without Walkways

Maryland	Florida
Wyoming	Ohio

Partial Listing of States Providing Lighting and Walkways on New Structures

Nebraska	Missouri
Illinois	Wisconsin
Oregon	California
Virginia	Texas
South California	

Components of the Support Systems

Systems With Walkways

The systems with walkways were divided into three groups of components: the walkway, the safety railing, and the luminaire/walkway support bracketry. The walkway itself is the major element of the walkway component. The safety railing component consists of the pipe or angle iron used for the railing and the vertical supports, and the pivot and latch assembly that maintains the railing in a raised position when the walkway is being utilized. The support bracketry component includes the structural steel that is mounted horizontally to support the walkway, and may also include vertical elements to which the horizontal elements are attached and a reinforcing plate where these horizontal and vertical elements meet.

Walkways

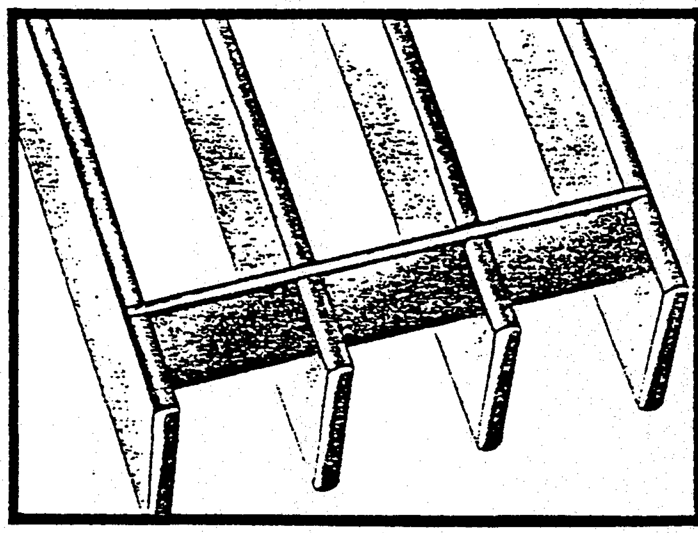
Most walkway gratings used on overhead sign structures are 2 ft wide and extend from the outside edge of the shoulder to the inside edge of the innermost sign.

Figure 162 shows a close-up of a typical walkway grating.[44] The rectangular grids that are formed by the interlocking of the larger bearing bars with the cross bars are 4 in by 1-3/16 in. Although the walkway that is illustrated is made of aluminum, this walkway is also available in galvanized steel.

Safety Railings

Typical safety railings are shown in figures 163 (California), 164 (Nebraska), 165 (Texas), and 166 (Virginia).[42, 45, 46, 47]

The safety railings component is complex because of the need to provide a strong barrier that will keep someone from falling off the structure, that can be folded down out of the driver's line of sight when it is not in use. For purposed of this cost estimate, the safety railing was divided into two parts: the horizontal railings and the support uprights,



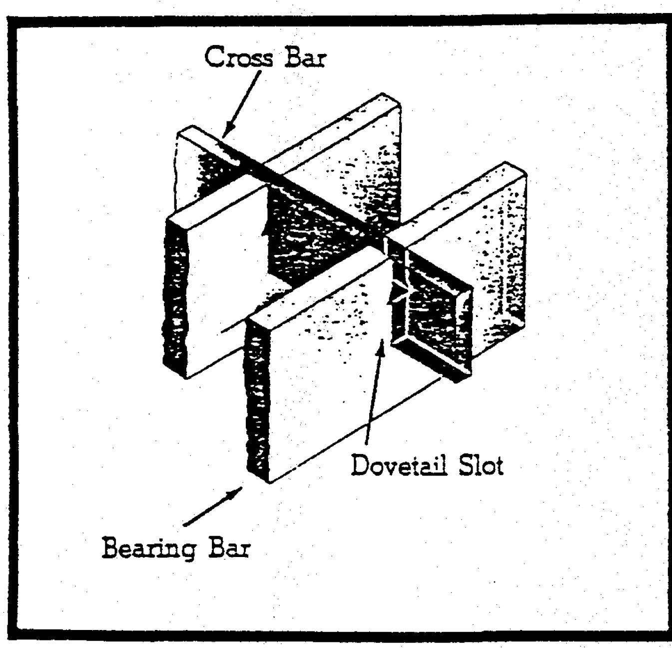


Figure 162. Typical walkway grating

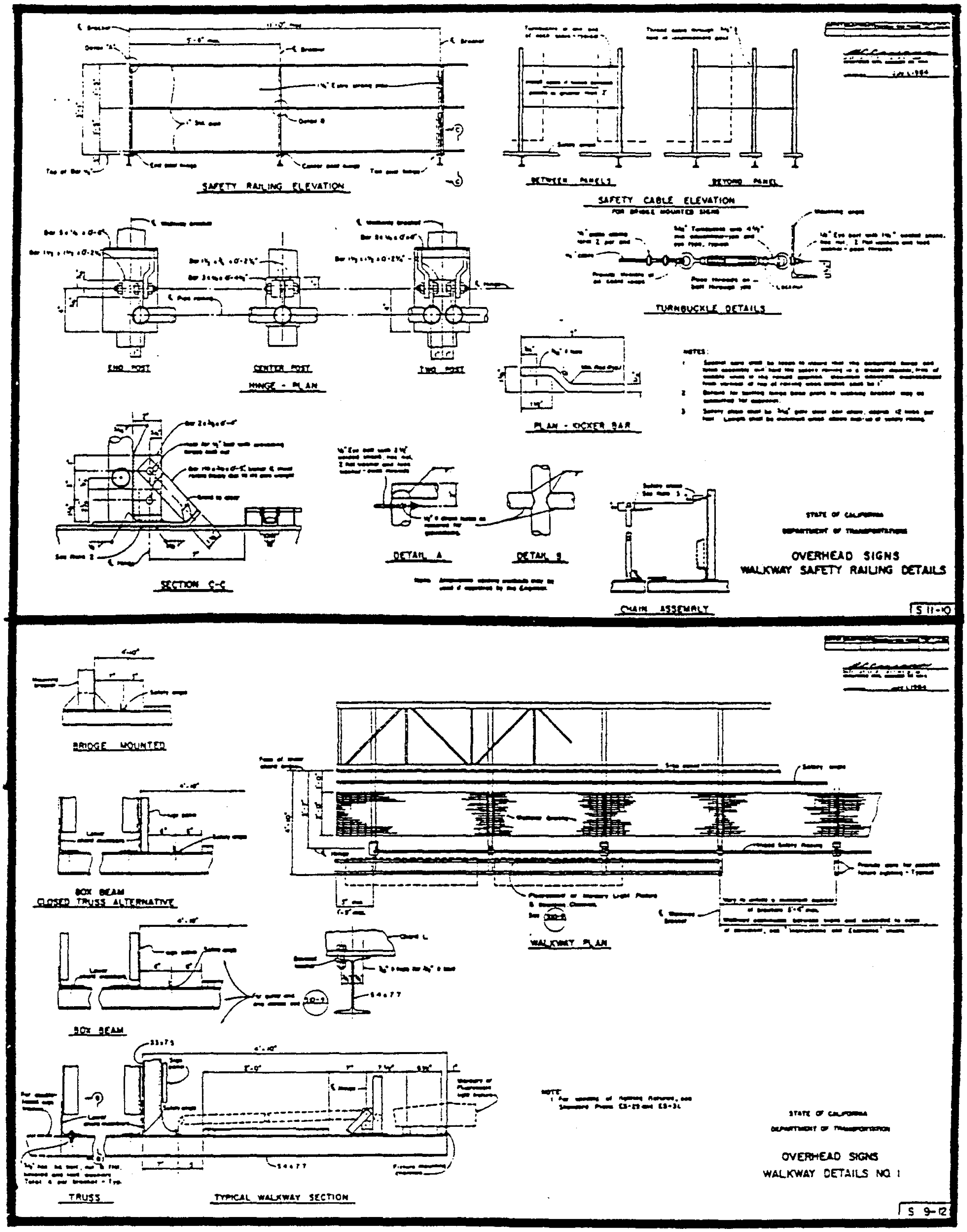


Figure 163. Typical California sign details

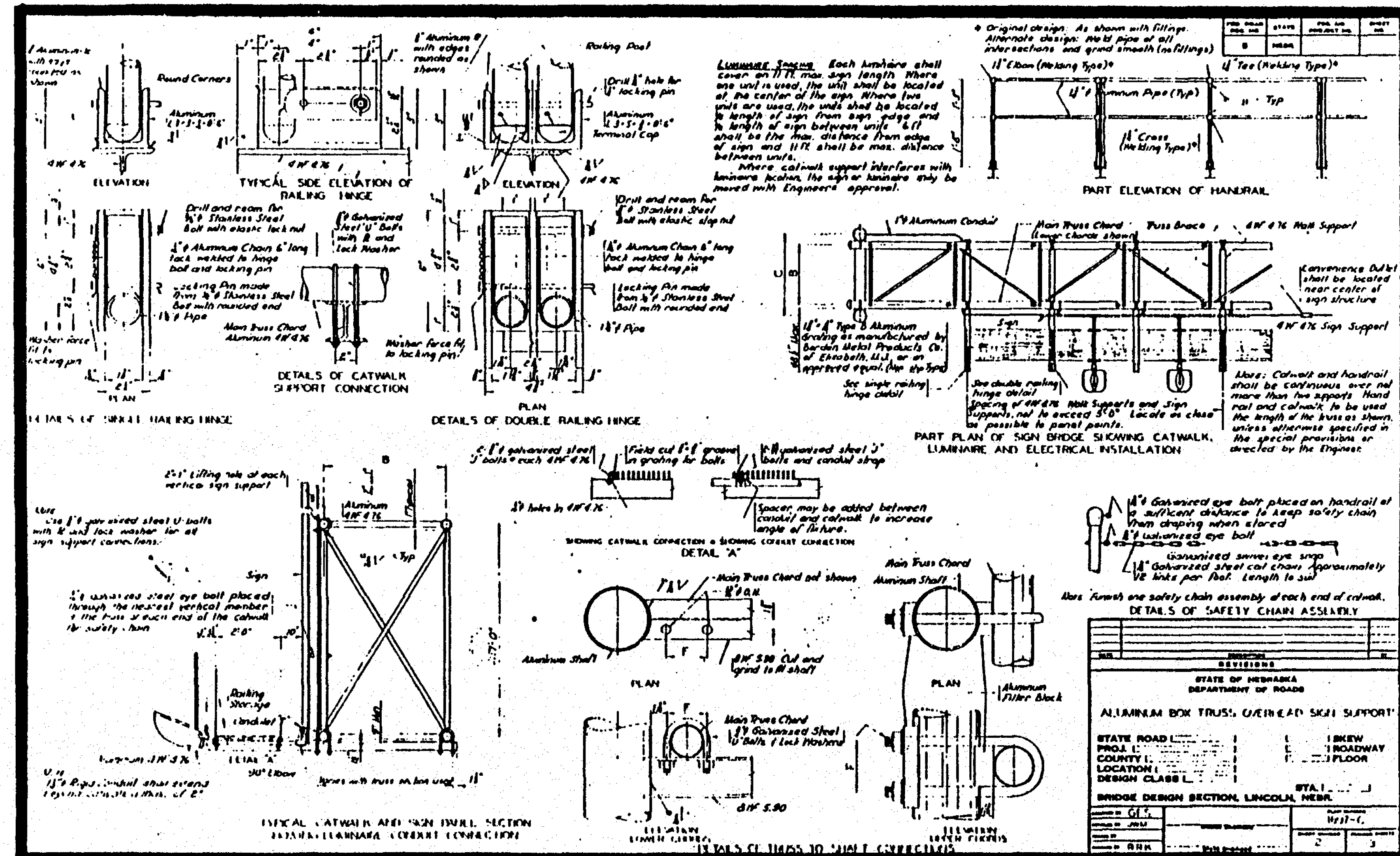


Figure 164. Typical Nebraska sign details

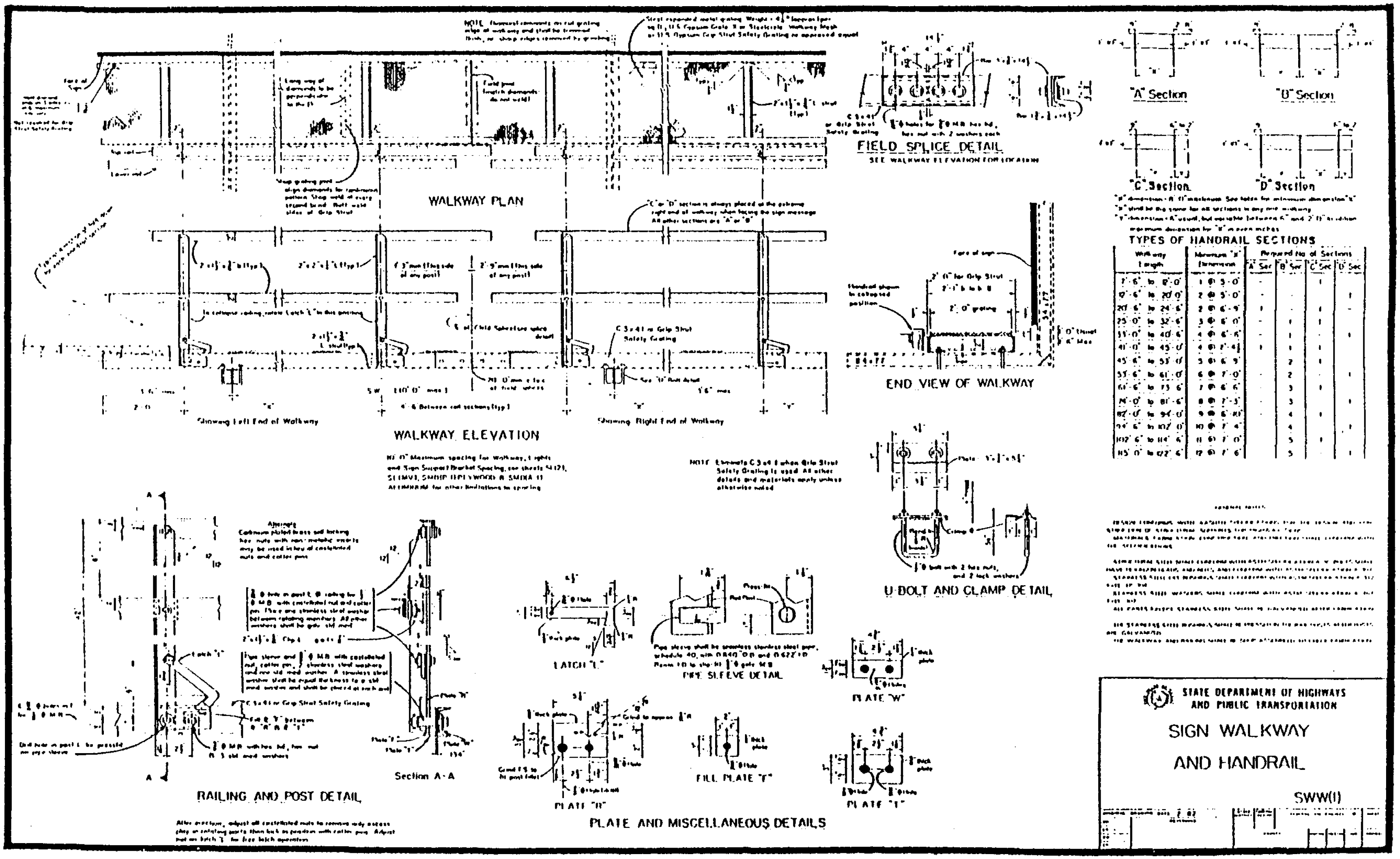


Figure 165. Typical Texas sign details

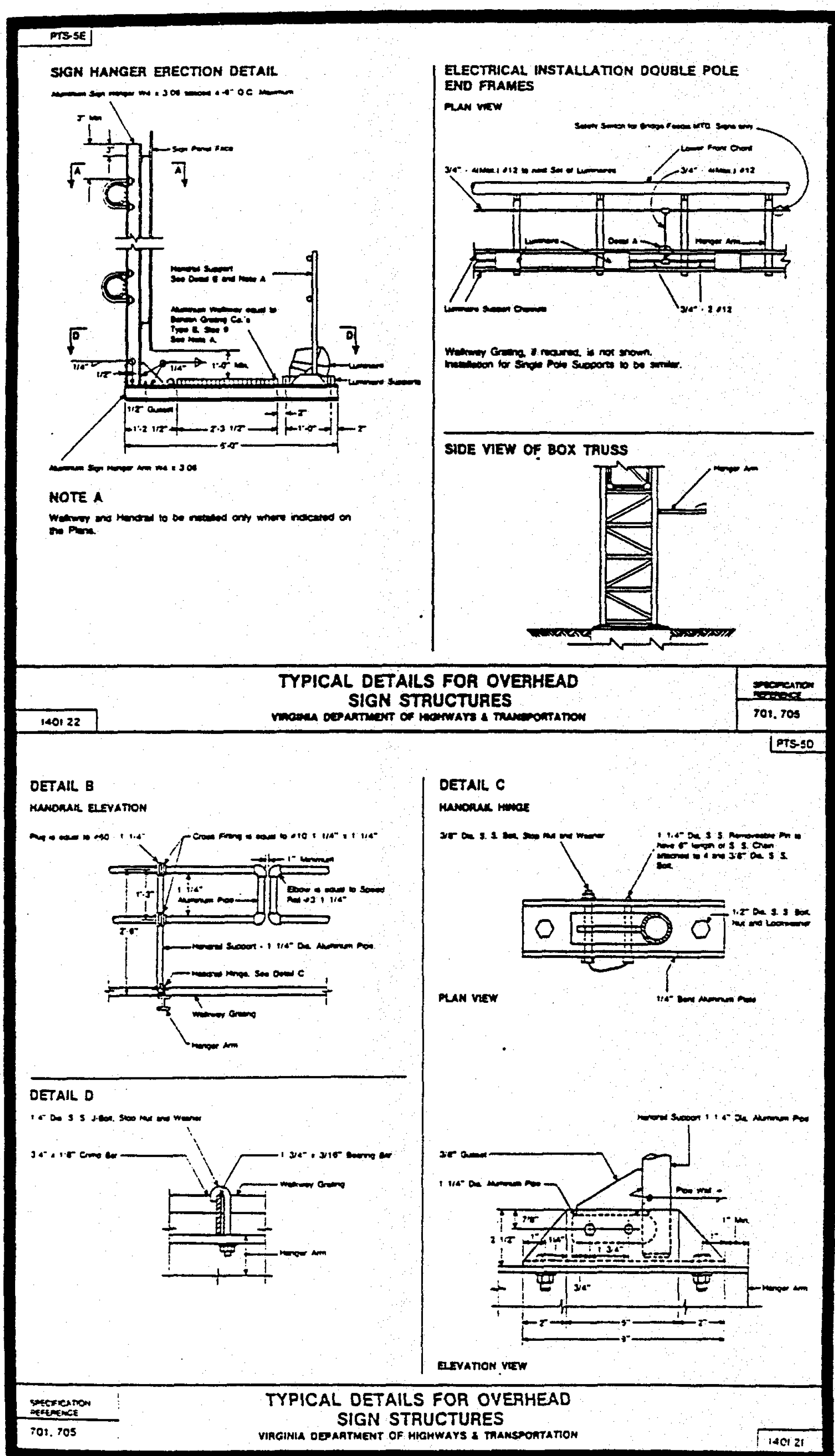


Figure 166. Typical Virginia sign details

and the pivot and latch assembly. Extra attention was paid to estimating the cost of these pivot and latch assemblies because each one is a custom made unit requiring special cutting and welding.

Although there are other miscellaneous parts of the safety railing (such as chain, locking pins, etc), it was felt that the major costs items were included in the elements that were being estimated, and that the estimation of the cost of these miscellaneous pieces would not improve the accuracy of the cost estimate.

Support Brackets of Units with Walkways

There are two major methods of supporting the walkway/luminaires and securing them to the sign support structure. One of these methods is to secure the walkway/luminaire support to the bottom chords of the sign truss itself. This is shown in figures 163 and 164. However, this technique is limited to structures on which there are two bottom chords (or bridge mounts) and is not applicable to a tri-chord sign support structure.

A second mounting technique for the walkway/luminaire supports is to construct an "L" shaped bracket from structural steel (or aluminum) and attach the vertical portion of this "L" to the front of the sign support structure as shown in figures 165 and 166. In this design a supplemental plate is commonly used to reinforce the angle where these horizontal and vertical elements meet.

When an "L" shaped bracket is used the sign is frequently mounted to the vertical element. This is not true in Maryland, and in this estimate the costs of both the vertical and horizontal elements of the bracket were included in the estimate. In all the other estimates the cost estimate of the support bracketry has excluded the cost of these vertical elements.

Systems Without Walkways

The luminaire support is the only major structural component of the support systems without walkways.

Figure 167 shows a "lightweight" installation in California in which the bracketry is only designed for support of luminaires.[42] Some of the differences between the lightweight support bracket shown here and the "heavy" bracketry in figure 163 are the decreased size of the lightweight bracket (the approximate weights are 20 pounds and 60 pounds for a lightweight and heavy bracket respectively), and the maximum spacing between brackets of 9 ft for the lightweight and 5-1/2 ft for the heavy brackets. On a 22-ft wide sign, the total weight of the heavy brackets for a system with walkways would be 240 pounds while the weight of the lightweight brackets for the same sign would be only 60 pounds.

Figure 168 shows the design used by the State of Maryland.[48] This design is very similar to the designs for the support brackets used when there are walkways and includes a very strong (and heavy) horizontal and vertical structural steel element on the bracket. It will be noted that the sign itself is attached to the support structure with a separate sign bracket. The sole function of this vertical element on the support bracket is to provide a strong attachment for the luminaire support.

Figure 169 shows the technique used in Ohio.[49] In this assembly an aluminum tube, projecting in front of the sign, is bolted to piece of steel that runs across the bottom of the sign. An aluminum plate is welded to the front of this tube as a mounting platform for the luminaire.

The Florida DOT design is shown in figure 170.[38] An interesting feature of this design is that it allows the luminaire support to be unlocked from its normal position and rotated out of the way to facilitate maintenance or repair of the sign panel. A similar design has been introduced in New York with the luminaire mounted above the sign.

Costs of Brackets, Safety Railing, and Walkways

The estimated costs of the support systems associated with highway guide sign lighting were estimated using the following procedure.

(1) Selected States were contacted and requests were made for a copy of their standard plans or recent construction drawing that indicated the details of the lighting support system.

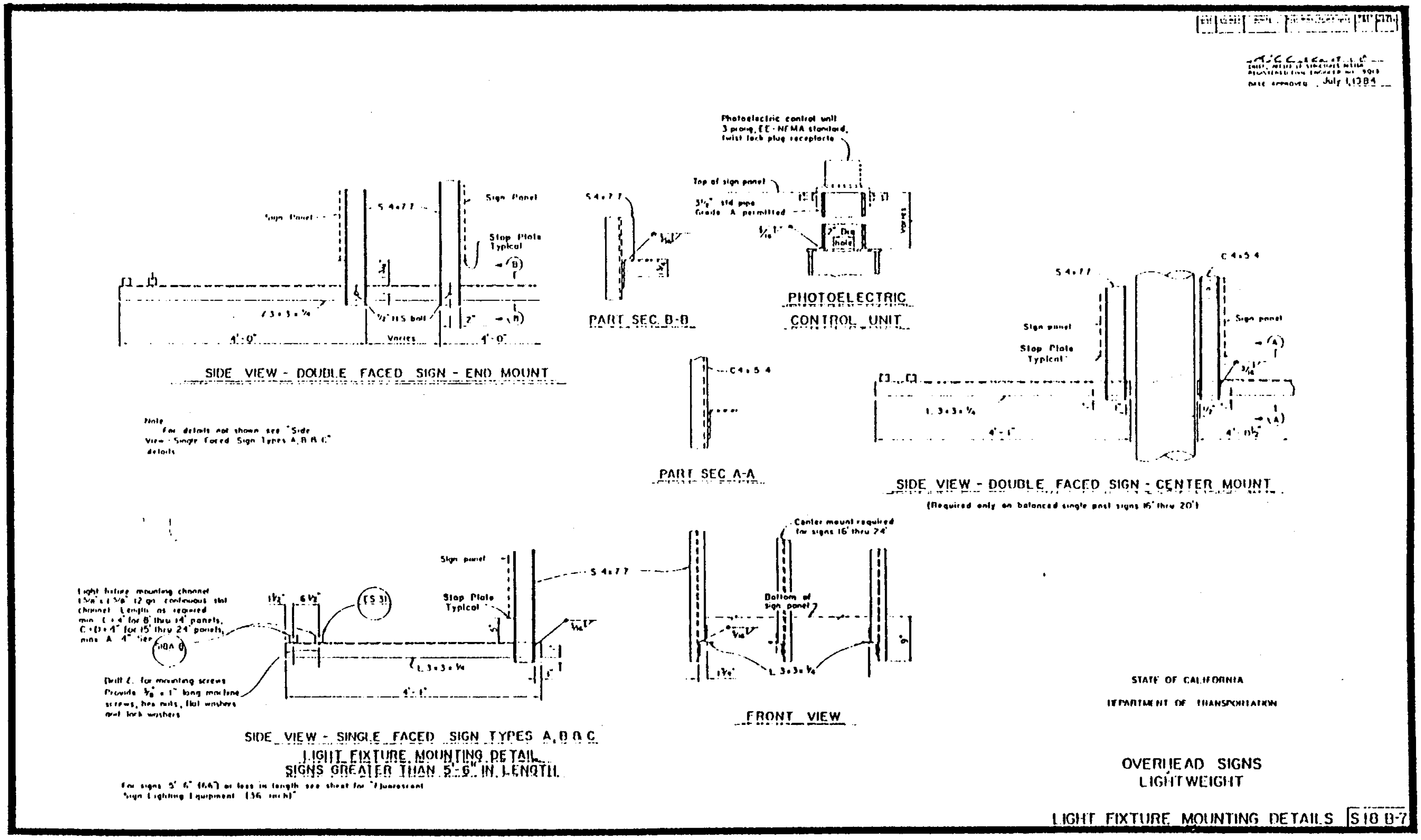


Figure 167. Typical California "lightweight" sign details

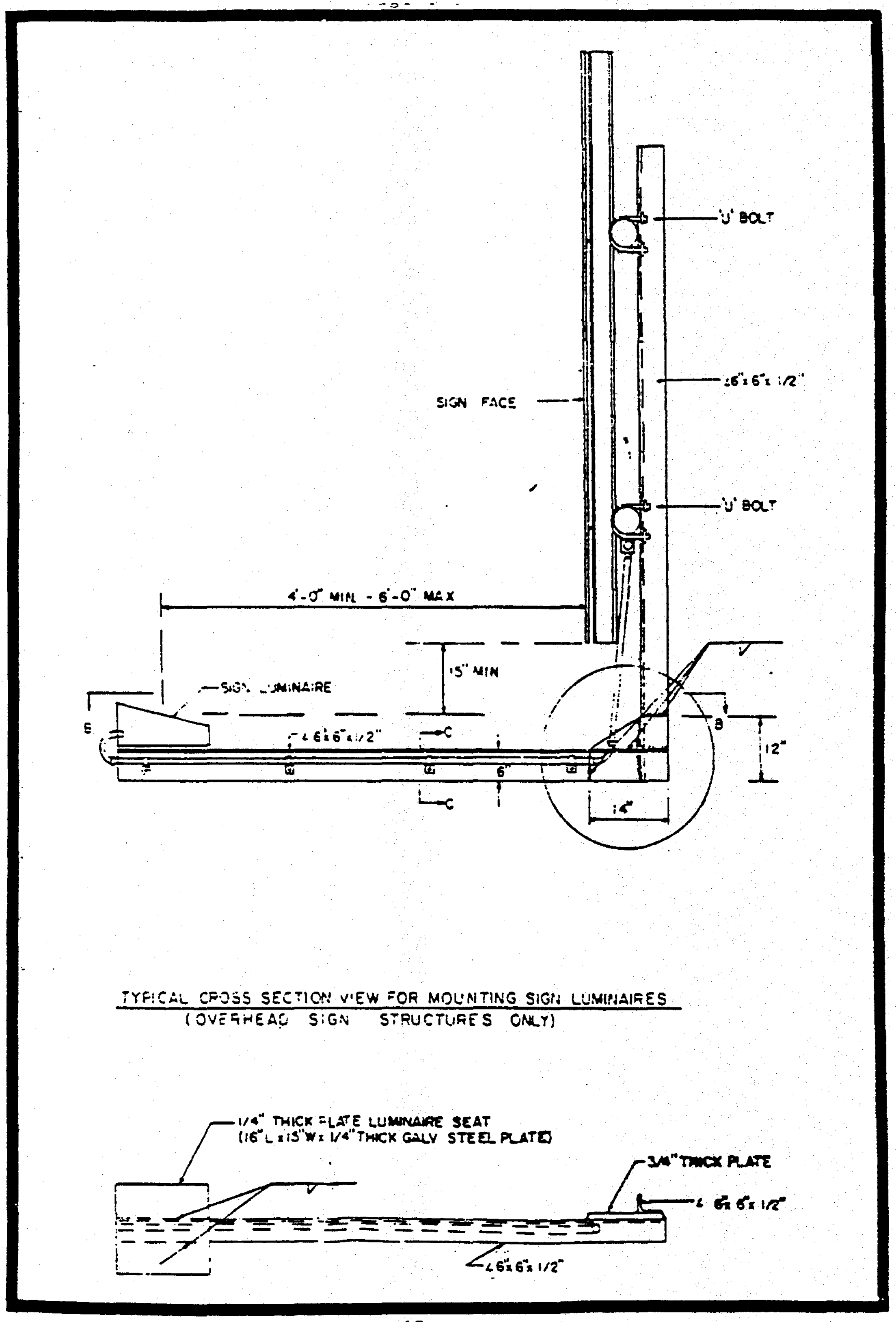


Figure 168. Typical Maryland sign details

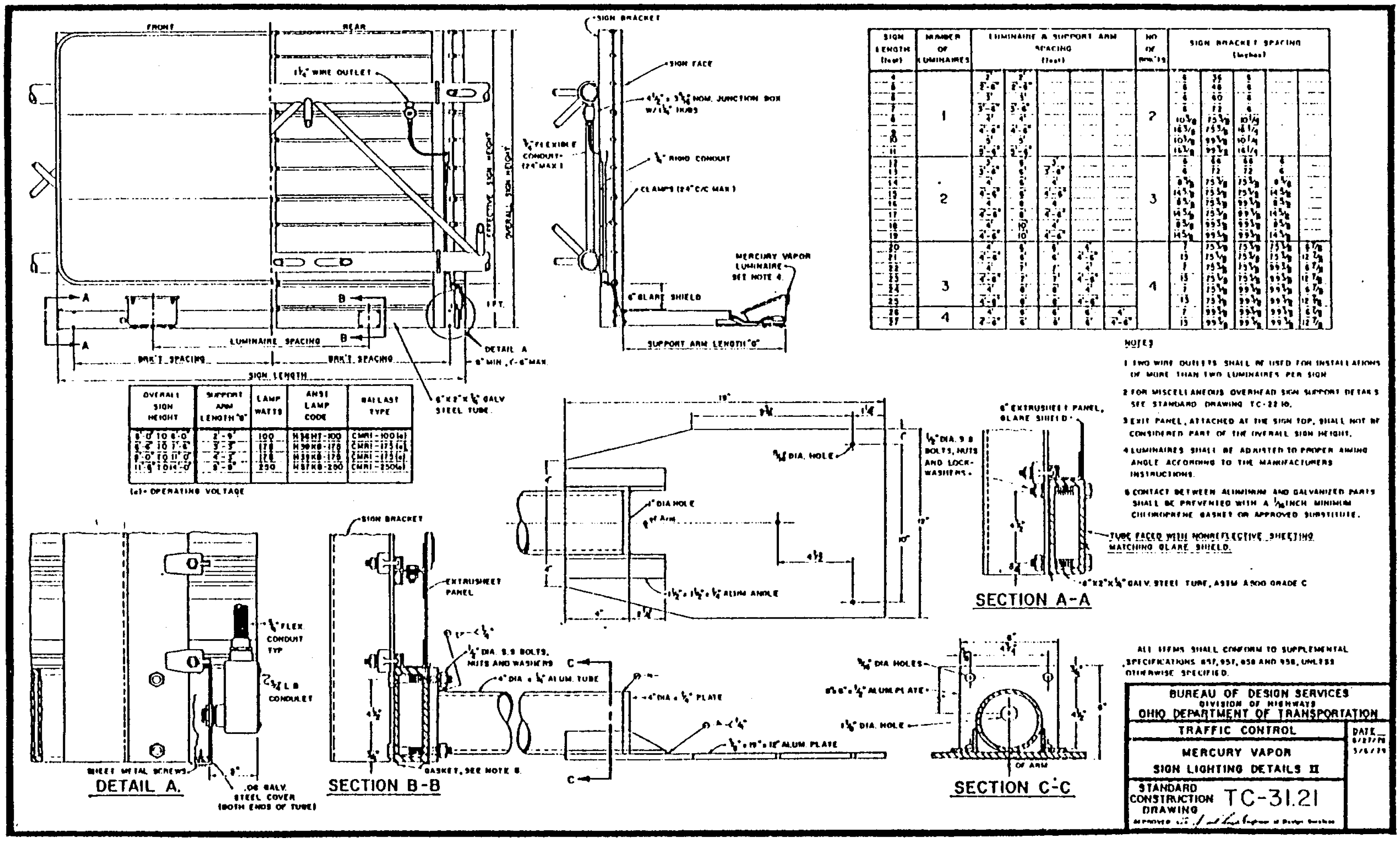


Figure 169. Typical Ohio sign details

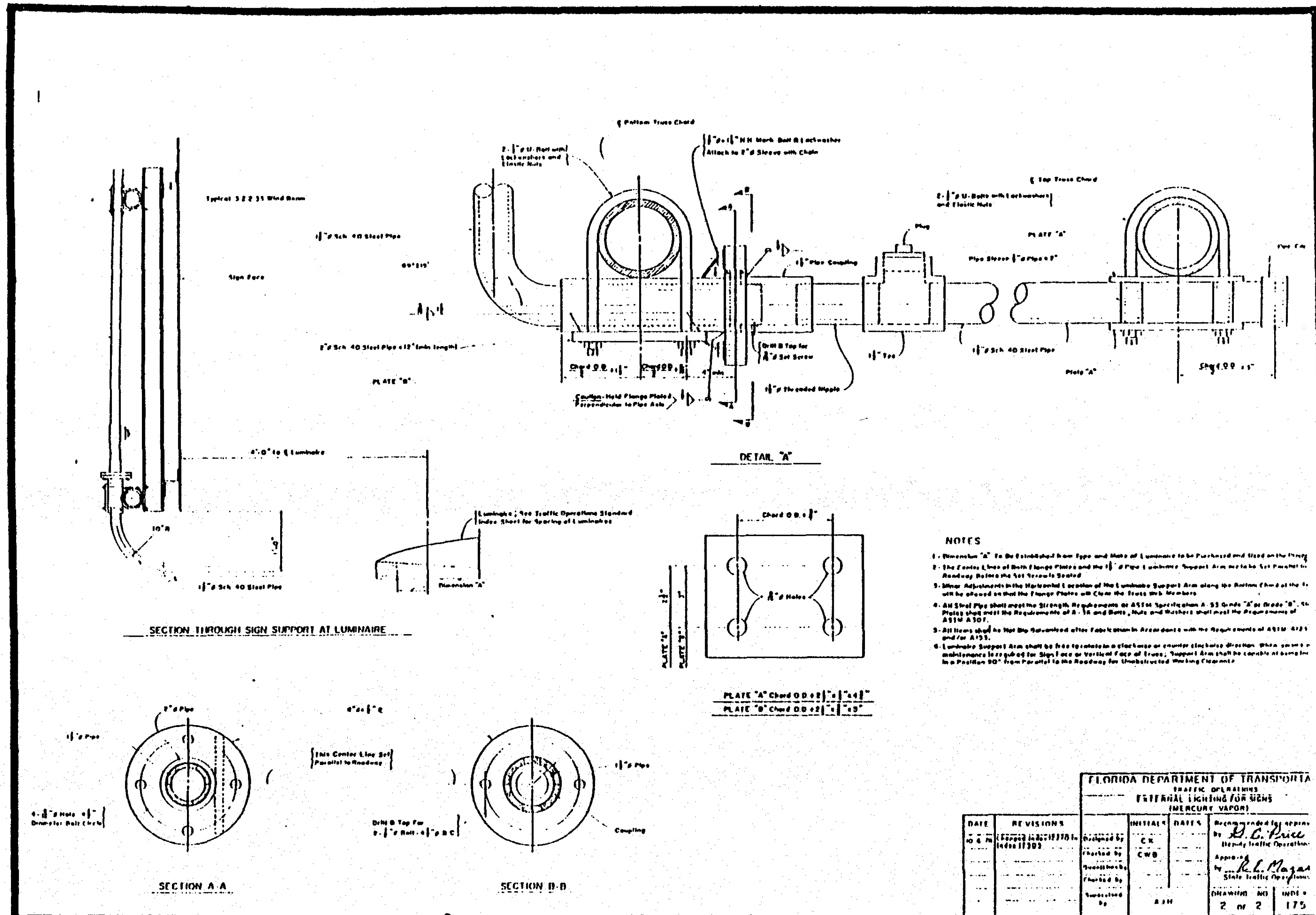


Figure 170. Typical Florida sign details

(2) As previously indicated, the components of the sign lighting support systems were broken into three broad groups: the walkway; the safety railing; and the walkway/luminaire support brackets. In the second step the costs of each of these components was estimated using the guidelines contained in the Richardson General Construction Estimating Standards.(50) Wherever possible, the estimates produced using the Richardson procedure were doublechecked via phone calls to fabricators of overhead sign structures who were familiar with the particular type of structure being estimated.

(3) In the third and final step costs per linear foot were estimated by reviewing the guidelines set by the various states for the distances between sign supports.

It should be noted that the Richardson cost estimation guide did not contain costs associated with construction using aluminum components. Conversion factors from steel to aluminum were obtained through contacts with the publishers office, and a local fabricator dealing in both steel and aluminum products.

The costs that were developed for each of the three component groups include the following items: materials costs (cut to size), welding costs, fabrication costs associated with bending materials and drilling holes, hot dipped galvanizing costs (for steel), and the extra installation cost associated with walkways.

The costs of bolts and other small fasteners were not included. However, since the estimates made without these items were relatively close to the estimated costs provided by the fabricators, this did not seem a significant exclusion.

Differences in the costs of erecting structures with and without sign lighting and walkways could not be documented. The common erection practice for sign bridge is to assemble the entire truss structure (including the walkway, railing and luminaire/walkway supports) on the ground, and then raise it into position as one unit. Since the equipment needed for this process would not change, and there are no activities specifically devoted to the sign lighting support system during this erection process, the assumption that the erection costs will not change seems most reasonable.

The costs associated with these various systems are shown in table 50. This table breaks down these costs into three component groups. The costs for the walkway and safety railing are presented as costs per linear foot. The costs for the support bracketry are presented as costs per linear foot. The costs for these brackets depends on the width of the sign and the maximum spacing allowed in each State. The assumed distance between these brackets was estimated by reviewing these factors and founding the distance up to the nearest foot. (It will be noted the spacing between support brackets is generally less than the maximum spacing.)

The table shows an overall average support system cost for lighting overhead guide signs as $69 per linear foot for systems with walkways, and $29 per linear foot for systems without walkways. Thus, the support system cost associated with sign lighting on a structure with a 36-ft wide sign (or a 24-ft wide sign and a 12-ft wide sign) where the walkway extends over three 12-ft wide travel lanes and a 12-ft wide shoulder is approximately $3,300. If lighting for these signs were provided without the walkway, the cost would be reduced to about $1,050.

The averages shown are reasonable approximations. A first-cut estimate of the support system costs made by a senior member of the Caltrans staff was 69 dollars per linear foot, which is slightly below the estimate for the California system shown in the table.

Extra Strength Requirements for Systems with Walkways

An investigation was also made of the difference in the required "strength" of a sign bridge designed to support a walkway and an identical sign bridge without a walkway.

The structural requirements for sign supports are governed by the Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals published by AASHTO.[51] A review of the structural requirements for sign support structures indicates that they are governed by the Dead Load, Live Load, Ice Load, and Wind Load.

Table 50. Cost of the systems with and without walkways.

STATE	SYSTEM COMPONENT Walkway (cost/ft)	 Safety Railing (cost/ft)	 Support Bracketry (cost per bracket)	ASSUMED SPACING BETWEEN SUPPORTS (feet)	ESTIMATED COST PER LIN. FT.
Systems With Walkways					
California	----------65	(1)--------	73	4	$83
Nebraska	31	14	84	4	66
Texas	----------43	(2)--------	71	8	52
Virginia	40	17	75	4	76
				AVERAGE	$69
Systems Without Walkways					
California (Lightweight)	N/A	N/A	63	6	$11
Florida	N/A	N/A	197	8	25
Maryland	N/A	N/A	390	8	49
Ohio	N/A	N/A	254	8	32
				AVERAGE	$29

(1) Estimated by Sierra Nevada Steel
(2) Estimated by Fallon Steel

The dead load is determined by the weight of the signs, luminaires, walkways, and the support structure. The weight of the support structure is the major contributor to the dead load and it is governed by the type of truss, length of the sign support, and materials used to construct the truss.

The live load is considered only when there is a walkway on which a man (or men) may be standing. For design purposes this live load is considered to be a single load of 500 pounds.

The ice load is taken as 3 pounds per square foot applied around the surface of the horizontal supports and luminaires and one face of the sign panel(s). Although this load need not be considered in the lower and western portions of the "sun belt," it is a consideration in some parts of every State except Florida and Hawaii.

The wind load is created by the pressure of the wind on the horizontal and vertical supports, signs and luminaires. This AASHTO standard contains isotech maps of wind speeds across the country at 30 ft above the ground are available for 10-year, 25-year and 50-year recurrence intervals. As noted in the publication "Wind speeds based on the 50-year mean recurrence interval shall be used...for all overhead sign structures." It is also noted that the isotech maps do not show isolated high wind areas and the designer is cautioned to use sound judgement in selecting wind speeds.

The elimination of luminaires would dispose of the need to consider a portion of these elements of the total load on the structure. The weight of the luminaires, walkways, and handrails could be excluded from the dead load. The live load consideration could be neglected entirely, and the ice load and wind load could also be reduced slightly.

An analysis of the effect of eliminating sign lighting and walkways was conducted by Mr. Robert Mantz, P.E. Mr. Mantz has been active in this field since 1961, and has designed sign support structures for various locations in Massachusetts, Maryland, Virginia, North and South Carolina, and Georgia. Three pairs of "typical" sign support structures analyzed.

Each structure in a pair was identical except for the inclusion or exclusion of a walkway.

The first pair was a 4 chord box truss 125 ft wide with three signs. The signs were 13 and 12 ft in height and totaled 45 ft in width. The design load for the structure with the walkway was calculated to be 331 kips and the total weight of the truss sections was 6,900 points. When the walkway was eliminated the calculated load was reduced to 311 kips and the truss weight reduced to 6716 pounds. Thus, reducing the design load by 20,000 pounds reduced the weight of the structure by about 200 pounds. At an estimated cost of $1.00 per pound for materials, the savings would be $184, or a little less than $1.50 per foot of structure width.

Other calculations of designs with and without walkways were made for a 96-ft wide steel tri-chord, and cantilever support in which the outer edge of the sign extended 40-ft from the support. On the tri-chord the cost reduction was about $2.75 per ft.

A more significant reduction was found in the analysis of the cantilever design with a 40-ft arm. In this design the extra weight of the walkway produces a force that requires a significant strengthening of the support arm and the post. The estimated savings from eliminating a walkway on a cantilever sign support for the design that was analyzed is approximately $10.00 per foot.

The structural computations are summarized in figures 171, 172, and 173.

Summary of Total Structural Costs

The total cost of support brackets, handrail, walkways, and additional steel on structures with sign lighting are presented in table 51. The mean costs shown on table 51 represent the average cost for the three types of support structures shown on the table. It should be carefully noted that on structures without walkways the unit costs per linear foot of signage (with one exception), and on structures with walkways they are per linear foot of walkway. This exception is for the low price system, where we have based the cost of providing sign lighting support on the use

```
JOB: COST STUDY
STEEL BOX-CHORD
DESIGN WIND = 90
SPAN PIPE YIELD = 55000  PSI
END SUPPORT YIELD = 36000  PSI
ANCHOR BOLT YIELD = 55000  PSI
LOCATION NO    1
SPAN LENGTH = 125
NO. OF SIGNS = 3
SIGN:SPACE,WDH,HGT
  1   50   15   13
  2   1    15   14
  3   1    15   12
NO. OF TRUSS SECTNS = 4
TRUSS DEPTH = 4 FEET
SECTN LENGTH
  1    32
  2    32
  3    32
  4    32
LEFT REACTN = 9.93
RGHT REACTN = 12.65
MAX MOMENT = 599.29
MATERIAL
SECTION 1  DESIGN LOAD = 64.63
NO.OF PANELS = 8
CHORDS: 4 O D  .188 WALLX 129
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 164 FEET
SECTION WEIGHT = 1360
SECTION 2  DESIGN LOAD = 101.61
NO.OF PANELS = 8
CHORDS: 4 O D  .318 WALLX 129
FEET
DIAGONALS: 1.66 O.D  .14 WALLX
 168 FEET
SECTION WEIGHT = 1996
SECTION 3  DESIGN LOAD = 91.86
NO.OF PANELS = 8
CHORDS: 4 O D. .318 WALLX 129
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 168 FEET
SECTION WEIGHT = 1996
SECTION 4  DESIGN LOAD = 72.95
NO.OF PANELS = 8
CHORDS: 4 O D  .226 WALLX 129
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 164 FEET
SECTION WEIGHT = 1548

TOTAL DIAGONAL WELD LENGTH =
 1511 INCHES X  .25 IN.
TOTAL SPAN SPLICE BOLTS = 72 @
 .75 DIA.X 3.5 LONG
BOLTS/SPLICE PLATE = 6
TOTAL SPAN SPLICE PLATES = 24 X
 1.25 THK
TOTAL SPAN WEIGHT = 7800
DEAD LOAD DEFLECTION = 4.24
UNLOADED CAMBER = 7.24
```

Walkway

```
JOB: COST STUDY
STEEL BOX-CHORD
DESIGN WIND = 90
SPAN PIPE YIELD = 55000  PSI
END SUPPORT YIELD = 36000  PSI
ANCHOR BOLT YIELD = 55000  PSI
LOCATION NO    1
SPAN LENGTH = 125
NO. OF SIGNS = 3
SIGN:SPACE,WDH,HGT
  1   50   15   13
  2   1    15   13
  3   1    15   12
NO. OF TRUSS SECTNS = 4
TRUSS DEPTH = 4 FEET
SECTN LENGTH
  1    32
  2    32
  3    32
  4    32
LEFT REACTN = 9.48
RGHT REACTN = 12.19
MAX MOMENT = 482.37
MATERIAL
SECTION 1  DESIGN LOAD = 60.58
NO.OF PANELS = 8
CHORDS: 4 O D  .188 WALLX 129
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 165 FEET
SECTION WEIGHT = 1362
SECTION 2  DESIGN LOAD = 95.22
NO.OF PANELS = 8
CHORDS: 4 O D  .318 WALLX 129
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 168 FEET
SECTION WEIGHT = 1996
SECTION 3  DESIGN LOAD = 86.25
NO.OF PANELS = 8
CHORDS: 4 O D  .318 WALLX 129
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 168 FEET
SECTION WEIGHT = 1996
SECTION 4  DESIGN LOAD = 69.07
NO.OF PANELS = 8
CHORDS: 4 O D  .188 WALLX 129
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 165 FEET
SECTION WEIGHT = 1362

TOTAL DIAGONAL WELD LENGTH =
 1511 INCHES X  .25 IN.
TOTAL SPAN SPLICE BOLTS = 72 @
 .75 DIA.X 3.5 LONG
BOLTS/SPLICE PLATE = 6
TOTAL SPAN SPLICE PLATES = 24 X
 1.25 THK
TOTAL SPAN WEIGHT = 6815
DEAD LOAD DEFLECTION = 4.04
UNLOADED CAMBER = 7.04
```

No Walkway

Figure 171. Typical structural computations, example 1

```
JOB: COST STUDY

DESIGN WIND = 90

SPAN PIPE YIELD = 55000  PSI

END SUPPORT YIELD = 36000  PSI

ANCHOR BOLT YIELD = 55000  PSI

LOCATION NO   1

SPAN LENGTH = 96

NO. OF SIGNS = 2
SIGN:SPACE,LGH,HGT
  1    30    15    10
  2    5    20    12

NO. OF TRUSS SECTNS = 3

TRUSS DEPTH = 5 FEET

SECTN LENGTH
  1    33
  2    33
  3    33

LEFT REACTN = 7.59
RIGHT REACTN = 8.6
MAX MOMENT = 274.95

MATERIAL

SECTION 1  DESIGN LOAD = 51.47
NO.OF PANELS = 8
CHORDS: 3.5 O.D. .216 WALLX 100
FEET
DIAGONALS: 1.66 O.D  .14 WALLX
 145 FEET
SECTION WEIGHT = 1088

SECTION 2  DESIGN LOAD = 63.5
NO.OF PANELS = 8
CHORDS: 3.5 O.D. .3 WALLX 100
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 147 FEET
SECTION WEIGHT = 1359

SECTION 3  DESIGN LOAD = 55.71
NO.OF PANELS = 8
CHORDS: 3.5 O.D. .216 WALLX 100
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 145 FEET
SECTION WEIGHT = 1088

TOTAL DIAGONAL WELD LENGTH =
 850 INCHES OF .25 IN.

TOTAL SPAN SPLICE BOLTS = 36 @
 .75 DIA.X 4 " LONG

TOTAL SPAN SPLICE PLATES = 12 X
 1.75 THK

TOTAL SPAN WEIGHT = 3635

DEAD LOAD DEFLECTION = 1.98
UNLOADED CAMBER = 4.28
```

Walkway

```
JOB: COST STUDY

DESIGN WIND = 80

SPAN PIPE YIELD = 55000  PSI

END SUPPORT YIELD = 36000  PSI

ANCHOR BOLT YIELD = 55000  PSI

LOCATION NO   1

SPAN LENGTH = 96

NO. OF SIGNS = 2
SIGN:SPACE,LGH,HGT
  1    30    15    10
  2    5    20    12

NO. OF TRUSS SECTNS = 3

TRUSS DEPTH = 5 FEET

SECTN LENGTH
  1    33
  2    33
  3    33

LEFT REACTN = 7.08
RIGHT REACTN = 7.91
MAX MOMENT = 254.29

MATERIAL

SECTION 1  DESIGN LOAD = 47.72
NO.OF PANELS = 8
CHORDS: 3.5 O.D. .216 WALLX 100
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 145 FEET
SECTION WEIGHT = 1088

SECTION 2  DESIGN LOAD = 58.73
NO.OF PANELS = 8
CHORDS: 3.5 O.D. .216 WALLX 100
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 147 FEET
SECTION WEIGHT = 1092

SECTION 3  DESIGN LOAD = 51.44
NO.OF PANELS = 8
CHORDS: 3.5 O.D. .216 WALLX 100
FEET
DIAGONALS: 1.66 O.D. .14 WALLX
 145 FEET
SECTION WEIGHT = 1088

TOTAL DIAGONAL WELD LENGTH =
 850 INCHES OF .25 IN.

TOTAL SPAN SPLICE BOLTS = 36 @
 .75 DIA.X 4 " LONG

TOTAL SPAN SPLICE PLATES = 12 X
 1.75 THK

TOTAL SPAN WEIGHT = 3368

DEAD LOAD DEFLECTION = 1.91
UNLOADED CAMBER = 4.22
```

No Walkway

Figure 172. Typical structural computations, example 2

```
JOB NAME:COST STUDY

LOCATION#: ?

DESIGN WIND: 90 MPH
ARM PIPE YIELD: 36 KSI
SIDE SUPPORT PIPE
 YIELD: 36 KSI
PLATE YIELD: 36 KSI
ANCHOR BOLT YIELD: 55 KSI
NO.OF SIGNS  1
SIGN,SPAC,WDTH,HGT
 1    20    20    12
WALKWAY SPAC LENGTH
          15      25
***
DESIGN TORQUE= 260.57 K-FT
DESIGN GND MOM= 303 K-FT
ARM TYPE=DOUBLE CHORD
TRUSS DEPTH= 5  FT
ARM CHORD MATERIAL
 18 OD X .25 IN BY 78  FT
BRACING
 2.875 OD X .203 IN BY 93  FT
CSR= .83
ARM CONNCTN BOLTS
QTY= 8
DIA= 1 IN
LNGTH= 4.625 IN
ARM CONNCTN PLATE THK= 2 IN
SIDE SUPPORT CONNCTN PLATE THK=
 1.25 IN
SIDE SUPPORT MATERIAL
 24 OD X .375  IN BY 29  FT
CSR= .99
BASE PLATE THK= 1.75  IN
ANCHOR BOLTS
DIA= 2 IN
QTY= 8
DEAD LOAD DEFL.= 3.73  IN
CAMBER= 8.6  IN
HORIZ WIND DEFL.= 16.59  IN
ARM WEIGHT= 4238 LBS.
SIDE SUPPORT WGT= 2843 LBS.
```

Walkway

```
JOB NAME:COST STUDY

LOCATION#: ?

DESIGN WIND  90 MPH
ARM PIPE YIELD: 36 KSI
SIDE SUPPORT PIPE
 YIELD: 36 KSI
PLATE YIELD  36 KSI
ANCHOR BOLT YIELD: 55 KSI
NO.OF SIGNS  1
SIGN,SPAC,WDTH,HGT
 1    20    20    12
WALKWAY SPAC LENGTH
         0     0
***
DESIGN TORQUE= 243.37 K-FT
DESIGN GND MOM= 262.3 K-FT
ARM TYPE=DOUBLE CHORD
TRUSS DEPTH= 5  FT
ARM CHORD MATERIAL
 16 OD X .25 IN BY 78  FT
BRACING
 2.875 OD X  .203 IN BY 93  FT
CSR= .96
ARM CONNCTN BOLTS
QTY= 8
DIA= 1 IN
LNGTH= 5.125 IN
ARM CONNCTN PLATE THK= 2.25 IN
SIDE SUPPORT CONNCTN PLATE THK=
 1.5 IN
SIDE SUPPORT MATERIAL
 24 OD X .375  IN BY 27.5  FT
CSR= .86
BASE PLATE THK= 1.75  IN
ANCHOR BOLTS
DIA= 2 IN
QTY= 8
DEAD LOAD DEFL.= 2.82  IN
CAMBER= 7.69  IN
HORIZ WIND DEFL.= 17.85  IN
ARM WEIGHT= 3821 LBS.
SIDE SUPPORT WGT= 2702 LBS.
```

No Walkway

Figure 173. Typical structural computations, example 3

Table 51. Summary of structural costs (per sign panel)

	SUPPORT PRICE		
	LOW	AVERAGE	HIGH
<u>Structures Without Walkways</u>			
Cost of Lighting Supports (Unit cost)[1]	($390/bracket)	($29/ft)	($49/ft)
125' box-chord[2]	$ 780	$1,160	$1,960
96' tri-chord[3]	390	580	980
40' cantilever[4]	390	580	980
Mean Cost of lighting supports per panel	$ 390	$ 580	$ 980
<u>Structures With Walkways</u>			
Cost of Walkway Supports (Unit cost)	($52/ft)	($69/ft)	($83/ft)
125' box-chord[5]	$3,250	$4,313	$5,188
96' tri-chord[6]	2,496	3,312	3,984
40' cantilever[7]	2,080	2,760	3,320
Extra Structural Strength Cost			
125' box-chord	184	184	184
96' tri-chord	267	267	267
40' cantilever	417	417	417
Mean Cost of walkway and lighting supports per panel[8]	$2,390	$2,810	$3,340

NOTES: [1]Low price based on cost of Maryland sign bracket from table 50.
[2]40' of sign lighting.
[3]20' of sign lighting.
[4]20' of sign lighting.
[5]62.5' of walkway.
[6]48' of walkway.
[7]40' of walkway.
[8]Mean cost of walkway and lighting supports rounded to nearest $10.

of a single support bracket per sign on which a wide coverage luminaire would be mounted.

Overall Cost Summary

Introduction

This section combines the present worth cost information that has been developed in the preceding chapters. These totals are also expressed as present worth costs for a 20-year analysis period. The uniform annual cost equivalents are also shown.

Sign Materials

The present worth costs for the various combinations of sign and message materials were summarized in table 31. The lowest price signs combine an opaque enamel background with any one of the message materials. The combination of the opaque enamel background with either the encapsulated lens or button copy message are almost identical, and are slightly less expensive than the combination using enclosed lens sheeting for the sign message. The most expensive combinations use either button copy on an enclosed lens background, or an enclosed lens message on an encapsulated lens background.

Sample present worth costs for the 165 ft^2 sign in environments resulting in long and short service lives are shown below. The values in parentheses are the uniform annual costs rounded to the nearest $5.

Inexpensive Signs

Button copy messages on opaque enamel backgrounds	$3,400/$3,900 (405/460)
Encapsulated lens messages on opaque enamel backgrounds	3,500/ 4,000 (410/470)
Enclosed lens messages on opaque enamel backgrounds	3,700/ 4,300 (435/505)

Mid-price range signs

Enclosed lens messages on enclosed lens backgrounds	$4,500/$5,300 (530/625)
Encapsulated lens messages on encapsulated lens backgrounds	4,500/ 5,300 (535/625)
Encapsulated lens messages on enclosed lens backgrounds	4,700/ 5,550 (550/650)
Button copy messages on encapsulated lens backgrounds	4,950/ 5,750 (580/675)

Expensive signs

Enclosed lens messages on encapsulated lens backgrounds	$5,250/$6,200 (615/730)
Button copy messages on encapsulated lens backgrounds	5,250/ 6,200 (615/730)

Lighting System

The present worth costs for the various lighting system components are summarized in table 52. These costs are divided into three groups. The costs shown under the Mercury Vapor heading are all based on the three

Table 52. Summary of present worth costs for lighting system components.

	COST ALTERNATIVES		
	LOW	MEDIUM	HIGH
Mercury Vapor System			
Luminaires	280	680	790
Annual Maintenance	485	595	575
Electricity (@ 8 cents/kw-hr)	595	1,660	2,640
High Pressure Sodium Systems			
Luminaires	490	800	990
Annual Maintenance	575	730	770
Electricity (@ 8 cents/kw-hr)	215	980	1,660
Independent Components			
Power System	3,000	3,500	4,100
Lighting Supports	390	580	980
Walkway and Lighting Supports	2,390	2,810	3,340

mercury vapor luminaire system that were developed in prior chapters. Similarly, the costs listed under the High Pressure Sodium heading are related to the three systems previously discussed for this type of lamp. The costs under these headings cannot be otherwise combined, i.e.: the values shown for low price luminaires cannot be combined with medium price maintenance, and high electricity usage.

The third group of independent components contains the power system cost, lighting support, and lighting and walkway support values. Either the lighting support or the lighting and walkway support costs should be used, depending upon the particular analysis being made. Any of the power system costs can be combined with any of the support costs, and any of the costs sets for the mercury vapor or high pressure sodium lighting systems.

Sample Costs Using the Central Values

The sample cost for a computation using the central values of the ranges for the variables is shown below. As can be seen in this computation about half the cost is attributable to the power system which brings electrical power from the utility line to the overhead guide sign structure.

Mercury Vapor Luminairies (2-250 watt lamps)	$ 680	10%
Annual Maintenance	595	8%
Electricity (@ 8 cents/kw-hr)	1,660	24%
Power System	3,500	50%
Structural Costs (no walkway)	580	8%
Total Present Worth Cost	$7,015	100%
Equivalent Uniform Annual Cost	815	

Sensitivity Analysis

There are 540 combinations of the 6 lighting systems, 3 power systems, 6 support systems, and 5 electric rates that have been developed in this report. It would be extremely difficult to develop a single table containing all of these numbers that would be meaningful to the reader. If the reader want to analyze a particular condition, they should refer to the tables in each chapter for the values that are closest to their specific location.

The following sections present a sensitivity analysis of the items that make up the total present worth cost. The items are varied, one-by-one, and the cost for each combination is compared to the cost for the system based on the central values of each of the items, which was shown in the preceding section.

Type of Light Source

If the system presented above were changed from a mercury vapor to a high pressure sodium system several of the other cost components would also change. The annual maintenance would be increased to $730, and the electricity charges would be reduced to $980. The new total would be a small decrease to $6,590 as shown below.

Luminairies (2-150 watt lamps)	$ 800	12%
Annual Maintenance	730	11%
Electricity (@ 8 cents/kw-hr)	980	15%
Power System	3,500	53%
Structural Costs (no walkway)	580	9%
Total Present Worth Cost	$6,590	100%
Equivalent Uniform Annual Cost	775	
Cost of System with Central Values	$7,015	
Percent Change		-6%

Size of Lamp

If the mercury vapor system is made brighter, two 400 watt lamps will be required. As before, the maintenance and electricity costs will also change. As can be seen, increasing the size of the lamp substantially increases the percentage of the cost that will be spent in paying for electricity. The overall price of this system is $8,085 which is 15 percent higher that the system with central values.

Mercury Vapor Luminairies	$ 790	10%
Annual Maintenance	575	7%
Electricity (@ 8 cents/kw-hr)	2,640	33%
Power System	3,500	43%
Structural Costs (no walkway)	580	7%
Total Present Worth Costs	$8,085	100%
Equivalent Uniform Annual Cost	$ 950	
Cost of System with Central Values	$7,015	
Percent Change		+15%

Low Price System with One Luminaire

In this example we show the price change when a single luminaire with a 175 watt lamp is utilized. This concept of using a single luminaire could also be used with other lamp sizes. In addition to changing the costs for the luminaires, maintenance and electricity, the structural costs must also be changed to reflect the use of a support system with a single bracket holding the luminaire. The data show that this system is 25 percent less expensive than the system bases on the central values.

Mercury Vapor Luminairies (1-175 watt lamp)	$ 280	5%
Annual Maintenance	485	9%
Electricity (@ 8 cents/kw-hr)	595	11%
Power System	3,500	67%
Structural Costs (no walkway)	390	7%
Total Present Worth Cost	$5,250	99%[1]
Equivalent Uniform Annual Cost	$ 615	
Cost of System with Central Values	$7,015	
Percent Change		-25%

[1]Percentages do not add to 100 because of rounding.

Changes in Electricity Costs

The sample costs shown above were computed at electric rates based on 8 cents per kilowatt-hour. Table 44 also shows costs for 4, 6, 10 and 12 cents per kilowatt-hour. Four cents, and 12 cents per kilowatt-hour represent the extreme ends of the scale. The sensitivity analyses shown here will utilize rates of 10 cents per kilowatt-hour for the higher rate, and 6 cents per kilowatt-hour for the lower rate. As can be seen in this calculation the overall cost changes by about 6 percent. Increasing or decreasing the electric rate by another 2 cents per kilowatt-hour will produce an additional 6 percent change in price from the central value cost.

	6 cents/kw-hr		10 cents/kw-hr	
Mercury Vapor Luminairies (2-250 watt lamp)	$ 680	10%	680	9%
Annual Maintenance	595	9%	595	8%
Electricity (@ 8 cents/kw-hr)	1,235	19%	2,085	28%
Power System	3,500	53%	3,500	47%
Structural Costs (no walkway)	580	9%	580	8%
Total Present Worth Cost	$6,590	100%	$7,440	100%
Equivalent Uniform Annual Cost	$ 775		875	
Cost of System with Central Values	$7,015		$7,015	
Percent Change		-6%		+6%

Changes in Power System Costs

The power system is the major cost component of the systems that we have analyzed so far. The low and high priced power systems were based on taking ±15 of the mean value. These 85 percent and 115 percent values are shown here. The reader should bear in mind that particular conditions may result in costs substantially higher than the ones shown here. The difference in cost for these alternatives is a -7 percent of +9 percent change. The difference in the absolute values of these changes is due to the rounding of the power system values.

Mercury Vapor Luminairies (2-250 watt lamp)	$ 680	10%	680	9%
Annual Maintenance	595	9%	595	8%
Electricity (@ 8 cents/kw-hr)	1,660	25%	1,660	22%
Power System	3,000	46%	4,100	54%
Structural Costs (no walkway)	580	9%	580	8%
Total Present Worth Cost	$6,515	99%	$7,615	101%
Equivalent Uniform Annual Cost	$ 765		895	
Cost of System with Central Values	$7,015		$7,015	
Percent Change		-7%		+9%

Percentages do not add to 100 because of rounding.

Cost of Providing Walkways

This final sensitivity analysis examines the effect of going from a lighting support system without a walkway, to a support system that includes a walkway. The values in this computation shown a 32 percent increase in costs when the walkway is included in the system.

Mercury Vapor Luminairies (2-250 watt lamp)	$ 280	7%
Annual Maintenance	595	6%
Electricity (@ 8 cents/kw-hr)	1,660	18%
Power System	3,500	38%
Structural Costs (no walkway)	2,810	30%
Total Present Worth Cost	$9,245	99%
Equivalent Uniform Annual Cost	$1,085	
Cost of System with Central Values	$7,015	
Percent Change		+32%

Percentages do not add to 100 because of rounding.

Comparison of Sign Systems With and Without Lighting

The analysis in this report has tried to answer the question "How much does it cost to provide lighting for overhead guide signs?" As we have tried to show, this is not an easy question to answer because it depends on so many local factors. The data from the Lighting System section, shows that the present worth costs of providing lighting for a 165 ft^2 sign over a 20-year period, is approximately $7,000. The cost of the sign with an opaque enamel background and either button copy or high intensity message for this location is about $4,000, for a total cost of $11,000. This is equivalent to a uniform annual cost of about $1,300.

If the operating agency is not concerned about the motorist seeing the background color at night, the same sign(s) described above may be used. The savings will be in the cost of the sign lighting, $7,000 in present worth cost, or approximately $825 in uniform annual cost.

If this location is not to be lit, and the operating agency wants the background color to be visible, a sign using encapsulated lens sheeting for both the background and the message will cost about $5,300. A savings of $5,700 in present worth costs, or $675 in uniform annual costs.

References - Determine the Value of Color Coding of Highway Signing

1 W.S. Ferguson and K.E. Cook. Virginia Highway Signing Phase 1: Driver Awareness of Sign Colors and Shapes. Charlottesville, VA: 1966, Virginia Highway Research Council.

2 F. Birren. "Safety on the highway: A problem of vision, visibility, and color." Am. J. Ophthalmology, 1957, Vol. 43, No. 2, pp. 265-270.

3 H.R. Blackwell, B.S. Pritchard and R.N. Schwab. "Illumination requirements for roadway visual tasks." Highway Research Board Bulletin 255, 1960, pp. 117-127.

4 T.W. Forbes. "Luminance and contrast for sign legibility and color recognition." Transportation Research Record 611, 1976, pp. 17-24.

5 P.L. Olson and A. Bernstein. "The nighttime legibility of highway signs as a function of their luminance characteristics." Human Factors, 1979, Vol. 21, No. 2, pp. 145-160.

6 Olson, P.L., Sivak, M and Egan, J.C. Variables influencing the nighttime legibility of highway signs. Ann Arbor, MI: 1983, University of Michigan Transportation Research Institute.

7 Raska, J.G. and Jones, J.D. Evaluation of materials for shoulder-mounted signs and sign maintenance management. Austin, TX: 1983, State Department of Highways and Public Safety.

8 Hughes, P.K. and Cole, B.L. "Search and attention conspicuity of road traffic control devices." Australian Road Research, 1984, Vol. 14, No. 1, pp. 1-9.

9 S.E. Jenkins and B.L. Cole. Daytime Conspicuity of Road Traffic Control Devices. Vermont South, Victoria, Australia: 1984, Australian Road Research Board.

10 T.W., Forbes, R.F. Pain, R.P. Joyce and J.P. Fry. Color and Brightness Factors in Simulated and Full Scale Traffic Sign Visibility. Presented at the Annual Meeting of the Highway Research Board Committee on Night Visibility, January 1968.

11 T.W. Forbes. Research on Traffic Sign Requirements, Final Report. East Lansing, MI: 1967, Michigan State University.

12 R.E. Christ. "Review and analysis of color coding research for visual displays." Human Factors, 1975, Vol. 17, No. 6, pp. 542-570.

13 H.L. Woltman, R.H. Stanton and R.A. Stearns. Information Sign Color Evaluation Employing a Video Presentation. St Paul, MN: 1984, 3M Co.

14 H.R. Miller, R.W. Allen and A.C. Stein. Driver Factors, Simulators and Other Instrumented Measurement Approaches. Paper 830563. Warrendale, PA: 1983, Society of Automotive Engineers.