

INTERSECTION AND SIGN ILLUMINATION
FOR HIGHWAY SAFETY AND EFFICIENCY

by

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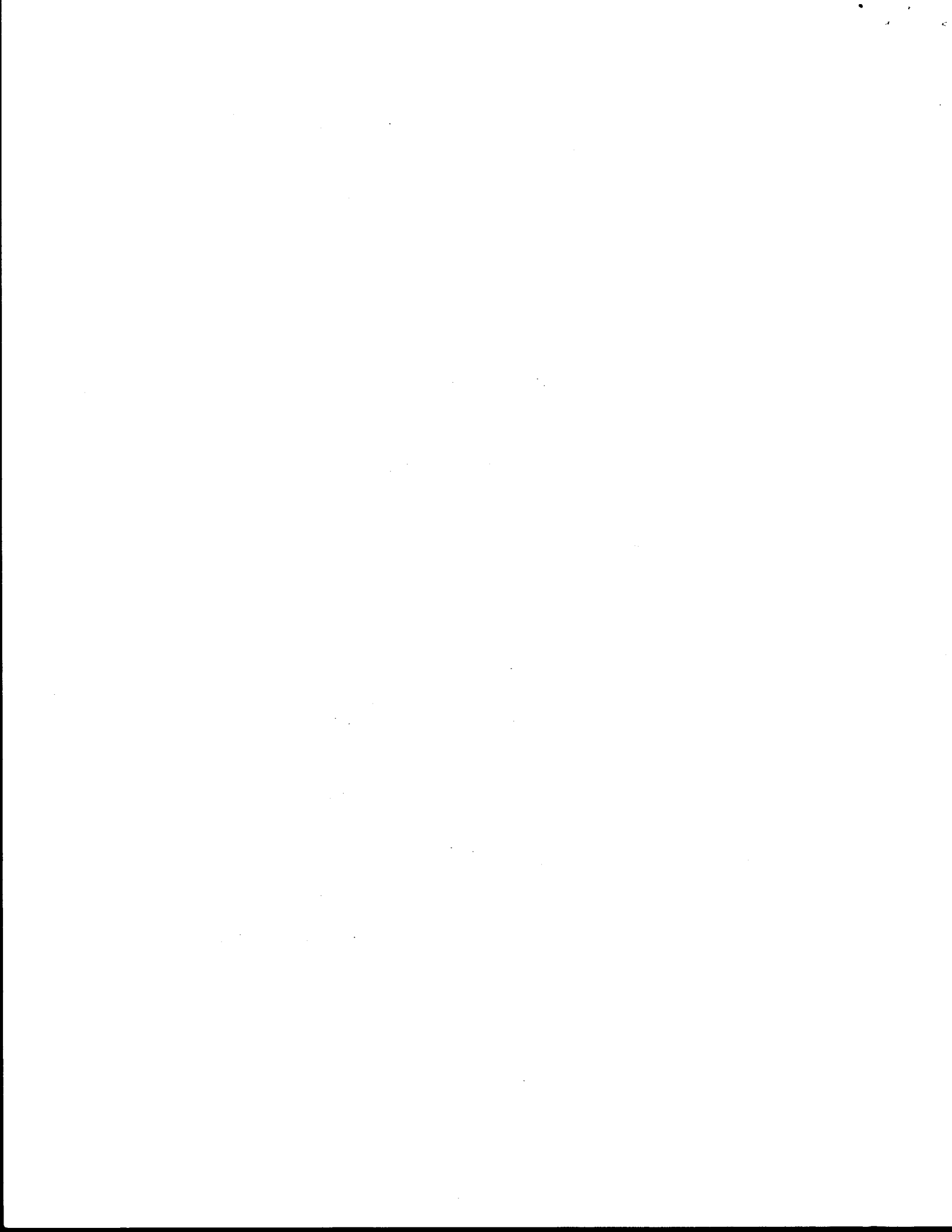
Intersection Illumination
Research Project Number 2-8-57-5

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PREFACE

This final report (Research Report 5-9 Final) summarizes the findings of several years of research on intersection illumination. The research was conducted by the Texas Transportation Institute in cooperation with the Texas Highway Department and the Department of Commerce, Bureau of Public Roads.

The various phases of the work are covered in detail in seven interim reports and an unpublished paper. They are listed as follows:

Research Report 5-1, "Roadside Sign Legibility and Roadway Illumination," by Donald E. Cleveland.

Research Report 5-2, "Lighting Studies at the Texas City Wye," by D. M. Finch.

Research Report 5-3, "Rural Intersection Illumination and Driver Tension Response," by Donald E. Cleveland and Weldon C. Franklin.

Research Report 5-4, "Overhead Signing and Traffic Operations," by S. N. Van Winkle and H. H. Bartel, Jr.

Research Report 5-5, Unpublished paper - "Roadside Sign Studies - II," by S. N. Van Winkle and Donald E. Cleveland.

Research Report 5-6, "Driver Tension Responses and Intersection Illumination," by Weldon C. Franklin and Donald E. Cleveland.

Research Report 5-7, "Traffic Operations - Illumination Studies," by Donald E. Cleveland.

Research Report 5-8, "Overhead Sign - Illumination Relationships," by Donald E. Cleveland.

The unpublished paper has been embodied in this final report and will not be published otherwise. Summaries of the other reports are also contained in its pages. It is hoped the contents of this final reporting on intersection illumination will be useful in highway programs aimed to provide greater safety and convenience for the nighttime motorist.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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N E E D S A N D G O A L S



NEEDS AND GOALS

Keeping America mobile through its road systems is an overwhelming task that keeps growing greater as population increases and the economy advances. Not only must highways be built and maintained, but safely and effectively operated. All this has to be achieved within the realm of practicability and financing available.

Research to enable the highways to meet transportation aims seeks solutions for many types of problems. One of these is that of intersection illumination. Associated with it are the problems of sign legibility and sign illumination.

The further development of the National System of Interstate and Defense Highways has emphasized the importance of adequate lighting at intersections and signs of highest standard so that drivers can recognize and read signs at distances necessary to make transitions smoothly and safely at high speeds. Many parts of the 41,000-mile system will have roadway lighting, particularly at interchanges with important federal and state routes and with major urban streets.

In the illumination field a project was started by the Texas Transportation Institute in November 1957 as RP-11 and continued during 1958-1959 as a part of HPS 1(18), and beginning in November 1959 through August 1960 as a part of HPS 1(21) A. Its latest designation was 2-8-57-5. Its objective was to determine the effects of various types of intersection and sign illumination on traffic performance and safety.

The work was conducted in cooperation with the Texas Highway Department and the Department of Commerce, Bureau of Public Roads, and dealt with (1) the effect of highway safety illumination on operations at typical intersections and (2) the effects of illumination on signs.

In the comprehensive investigation of intersections, human behavior was studied by using galvanic skin response as a measure of driver reaction to various levels of illumination. For, as a driver approaches an intersection or interchange, he is required to make several decisions rapidly, often under traffic conditions which put heavy demands upon his driving skill and his physical senses. Frequently, particularly at night or under adverse weather conditions, he must plan maneuvers into intersection or interchange areas which are well beyond the reach of his headlights, and which are therefore, out of the field of his vision. It is thus obvious that adequate intersection or interchange visibility is a critical factor both to traffic performance and to safety of the individual driver and his passenger.

The experimentation dealing with the intersections also included model scale studies of lighting arrangements and correlation of these with full scale situations and operations.

The sign lighting studies attempted to establish data regarding the effects of relative locations of highway signs and luminaires on nighttime visibility of signs. They were confined to pilot tests on local highways and on a controlled lighting test section on the campus of Texas A&M University.

Two locations were utilized for major field studies of traffic operations at illuminated intersections. The first of these was the Montopolis Intersection in Austin (intersection of U.S. 183 South and S.H. 71 West). The second, at which the most intensive field studies were carried on, was the Texas City Wye (intersection of S.H. 146 and S.H. 3 near Texas City).

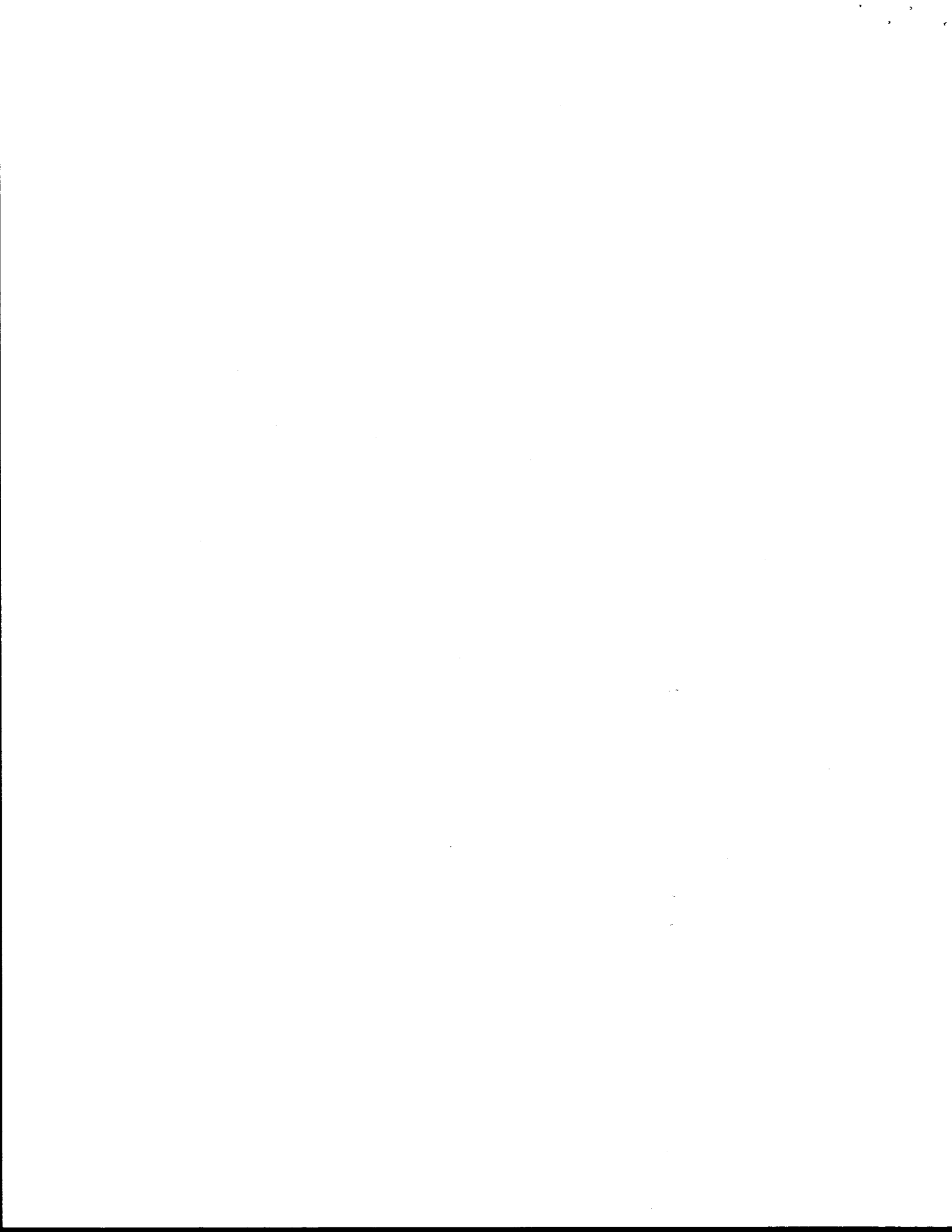
The Montopolis Intersection in Austin was selected because it was a complex intersection involving many conflict points within a limited area. The intersection was scheduled for illumination, and thus offered the potential for a "before-and-after" illumination study. As there were many aspects of night photography to be investigated, the Montopolis Intersection study was designated as a "pilot study" for this project. The chief value to the over-all project on the Montopolis Intersection study was the fact that this pilot study familiarized the researchers with some of the basic and higher-to-unknown problems associated with nighttime traffic research, and enabled the researchers to develop techniques to study and research instruments which were effectively used in the subsequent field studies carried on at the Texas City Wye.

The Texas City Wye was selected because, being in a rural area, it offered more flexibility for research in illumination with fewer conflicting light sources; also, the intersection was sufficiently complex to demand many decisions of each driver.

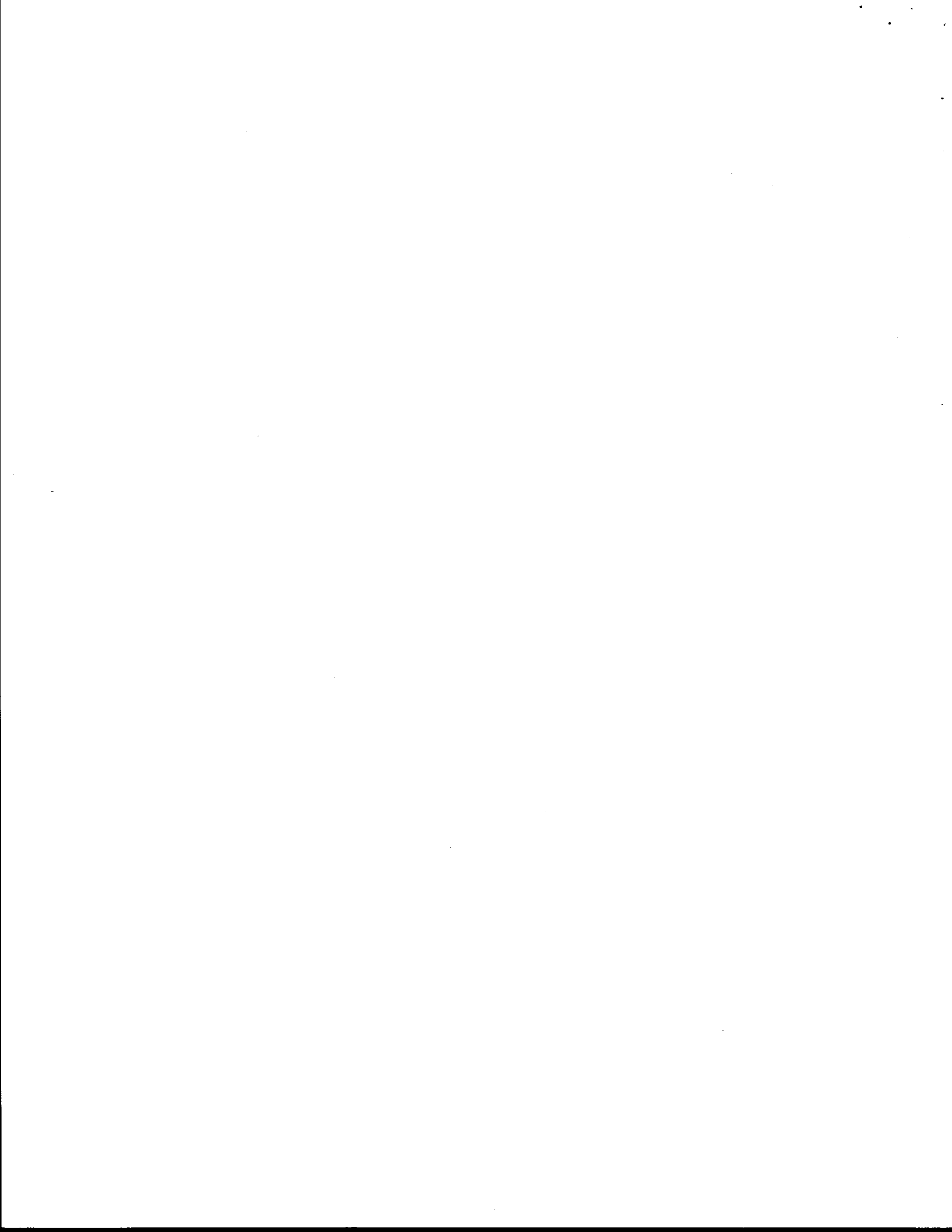
Two other study areas were utilized for brief observations. They were the intersection of S.H. 6 and U.S. 290 north of Hempstead and a recently completed lighting design on U.S. 90 near Vidor, Texas.

No data other than direct observation data were taken at these two field study areas. Observers were chiefly members of the research group and representatives of the Texas Highway Department. In one instance, at the intersection of S.H. 6 and U.S. 290 north of Hempstead, Texas, lighting fixtures were attached to signs, and the operational characteristics of nighttime traffic under these conditions were observed. Also the effect of throwing light on the roadway from low-mount fixtures was observed.

As one phase of the research an exact scale model of the Texas City Wye intersection was constructed. This model intersection afforded the opportunity for tests of various lighting designs, for studies in glare elimination, and for investigation of relative locations of signs and luminaires for maximum signing visibility.



I N T E R S E C T I O N L I G H T I N G S T U D I E S



INTERSECTION LIGHTING STUDIES

LIGHTING AT THE TEXAS CITY WYE

The Texas City Wye intersection on Route 3 from Houston to Galveston was selected as the study site for a comprehensive study of intersection illumination. This intersection of Routes 3, 146 and 197 was experimentally lighted with several arrangements of overhead luminaires so that several combinations of spacing and mounting heights could be employed. The visual effects were appraised for various combinations of lights on two of the approaches to the intersection.

The study considered the potential areas of conflict for a driver when approaching and passing through the intersection from either of two directions, viz., from Galveston or from Texas City. Evaluations were made using three different spacing configurations, referred to as continuous, intermediate and minimum, for luminaires at 30- and 45-foot mounting heights in clear dry weather. Principal data obtained included horizontal and vertical illumination, brightness, visibility and glare. Also, traffic studies were conducted to determine the effects of the various lighting arrangements on traffic operating characteristics and driver reaction.

The Test Site and Conditions

The intersection is shown in plan view in Figure 1. The two approach directions considered in this study are shown by arrows on the above figure and are further designated as locations A (Galveston approach) and B (Texas City approach). All of the lighting units used in the study are numbered sequentially, and the luminaires used in each of the continuous, intermediate and minimum spacing configurations can be determined from the table included in Figure 1. Figures 2 shows the Galveston approach in daytime and Figures 3 and 4 show the same approach at night with the 30-foot continuous and 45-foot intermediate systems in use. Figure 5 shows the Texas City approach in the daytime and Figure 6 and 7 show the 30-foot continuous and the 45-foot intermediate system in use.

The lighting installation was composed of 400-watt, 21,000-lumen mercury vapor clear lamps mounted in type III luminaires with built-in regulator type ballasts.

This particular intersection was selected for study because it was located in a rural area with few conflicting light sources and because it offered considerable

LIGHT NO.	MOUNTING HEIGHT	CONTINUOUS SYSTEM	INTERMEDIATE SYSTEM	MINIMUM SYSTEM
1	30'	✓		
2	30' & 45'	✓	✓	✓
3	30'	✓		
4	30' & 45'	✓	✓	
5	30' & 45'	✓	✓	✓
6	30'	✓		
7	30'	✓		
8	30' & 45'	✓	✓	✓
9	30'	✓		
10	30' & 45'	✓	✓	✓
11	30'	✓		
12	30'	✓		
13	30' & 45'	✓	✓	
14	30'	✓		
15	30' & 45'	✓	✓	
16	30' & 45'	✓	✓	✓

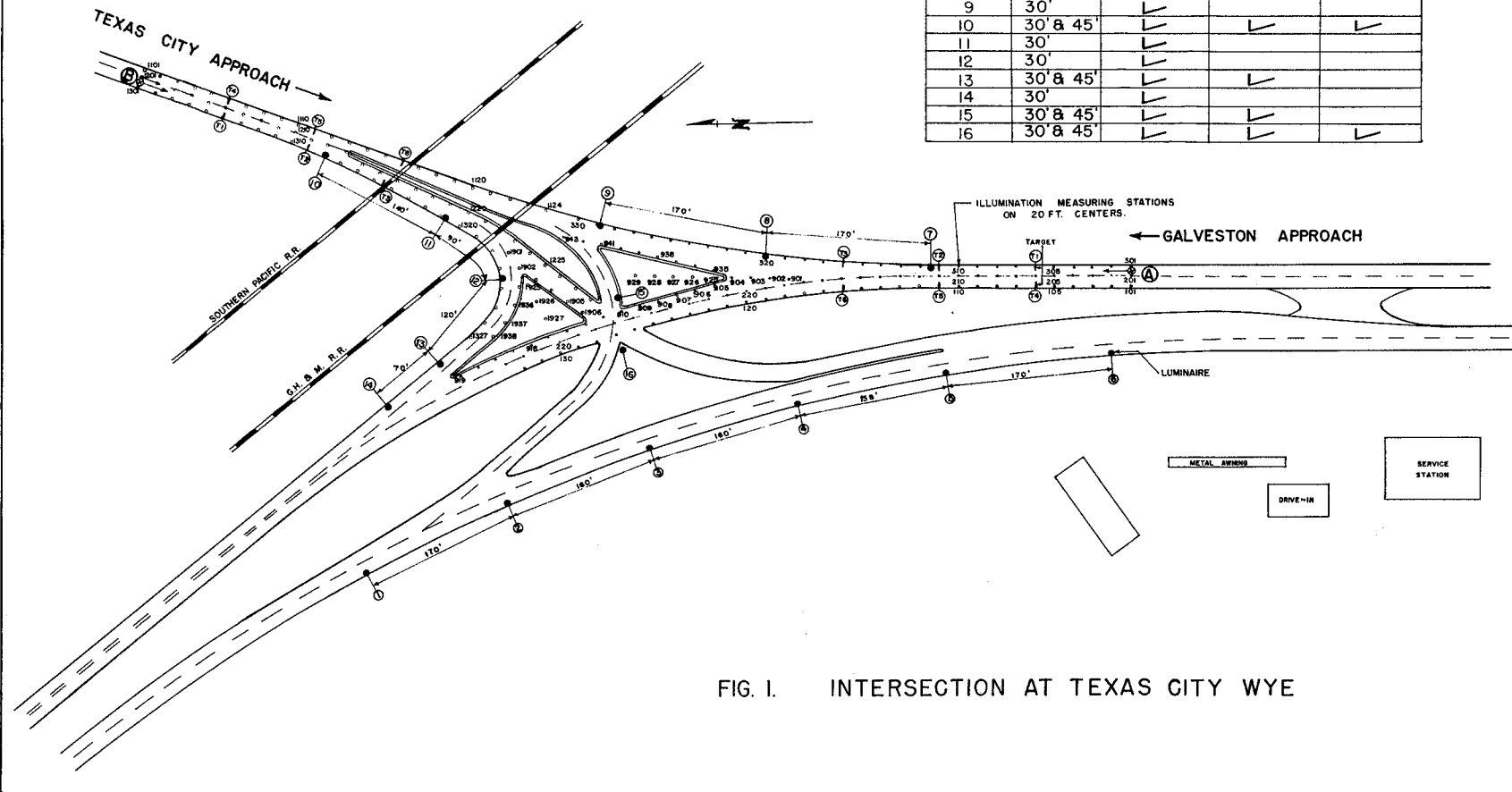


FIG. 1. INTERSECTION AT TEXAS CITY WYE

flexibility for the research in illumination. The area is almost flat and the driver's perspective view of the intersection does not change very rapidly from 700 to 400 feet away. As the distance decreases to less than 400 feet from the divider island, the driver still has several seconds of decision and reaction time available before he has to begin his control operation through the maze of distribution roadways.

The preliminary studies of the intersection both by day and night indicated that most of the significant information necessary for directional guidance should be available to a driver about 300 to 400 feet from the critical area in either approach direction. Most of the vehicles travel at moderate to high speeds, and there are very few slow-moving vehicles. The operating conditions dictated that an observation point should be used that was approximately 200 feet ahead of the first light in both the Galveston and Texas City Wye approach directions which would locate the driver about 300 feet from the critical maneuvering area.

The Galveston approach roadway is paved up to the first railway crossing with an asphaltic concrete. The Texas City approach roadway is paved with Portland cement concrete up to the second railway crossing. Beyond this point the roadway is asphaltic concrete.

The daytime photographs (Figures 2 and 5) show that there is normal contrast between the roadway foreground and the sky. The horizon is primary reference throughout all of the daytime scenes. The other key elements in the visual scene are the skeletal lines forming the edge of the roadway, the edges of the shoulders, the painted lane lines, and the edges of the island as they develop during the approach.

The other elements in the central field are mostly vertical in dimension and contribute little to the guidance pattern. The poles may actually detract since they form a pattern within which the driver must find the information and direction signs and other shapes such as railroad signals.

The shoulders and surrounding areas are sufficiently different in texture and reflectance from the roadway and islands so that good daytime contrast is available even on days having relatively low sky brightness. Surfaces forming the principal shapes are uniform in brightness in the daytime.

The nighttime scene is very different from the daytime scene and can be changed very greatly by the fixed lighting and by vehicle-mounted lights. Aside from the tremendous reduction in the brightness of the principal areas at night there are other distinct differences. For instance, at night the sky brightness reverses from light to dark and the distance horizon disappears. Distances become deceptive because of the lack of perceptible continuity of the surround. The familiar daytime lineal patterns are frequently not distinct at night and may be lost

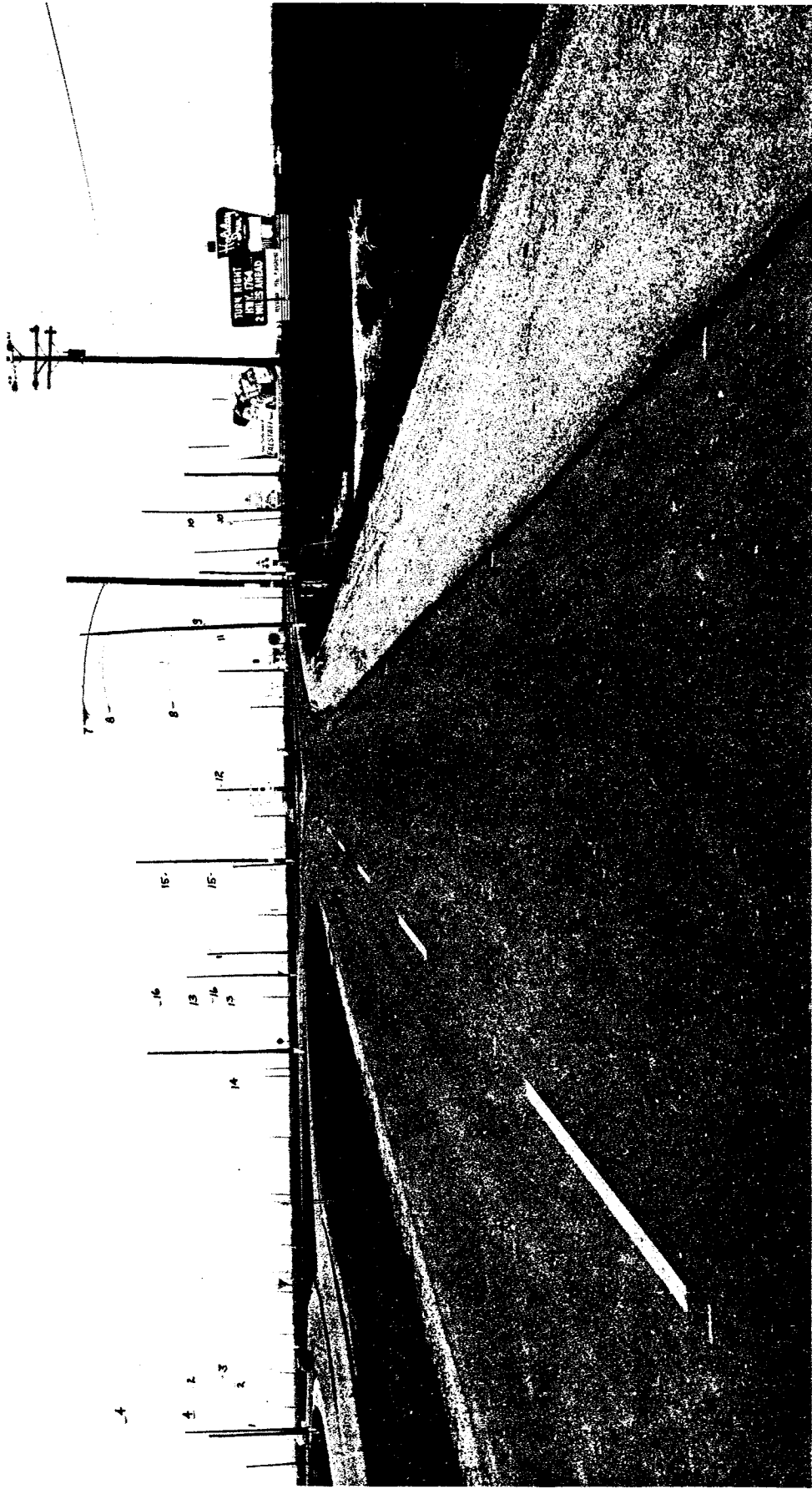


Figure 2. Galveston approach in daytime.

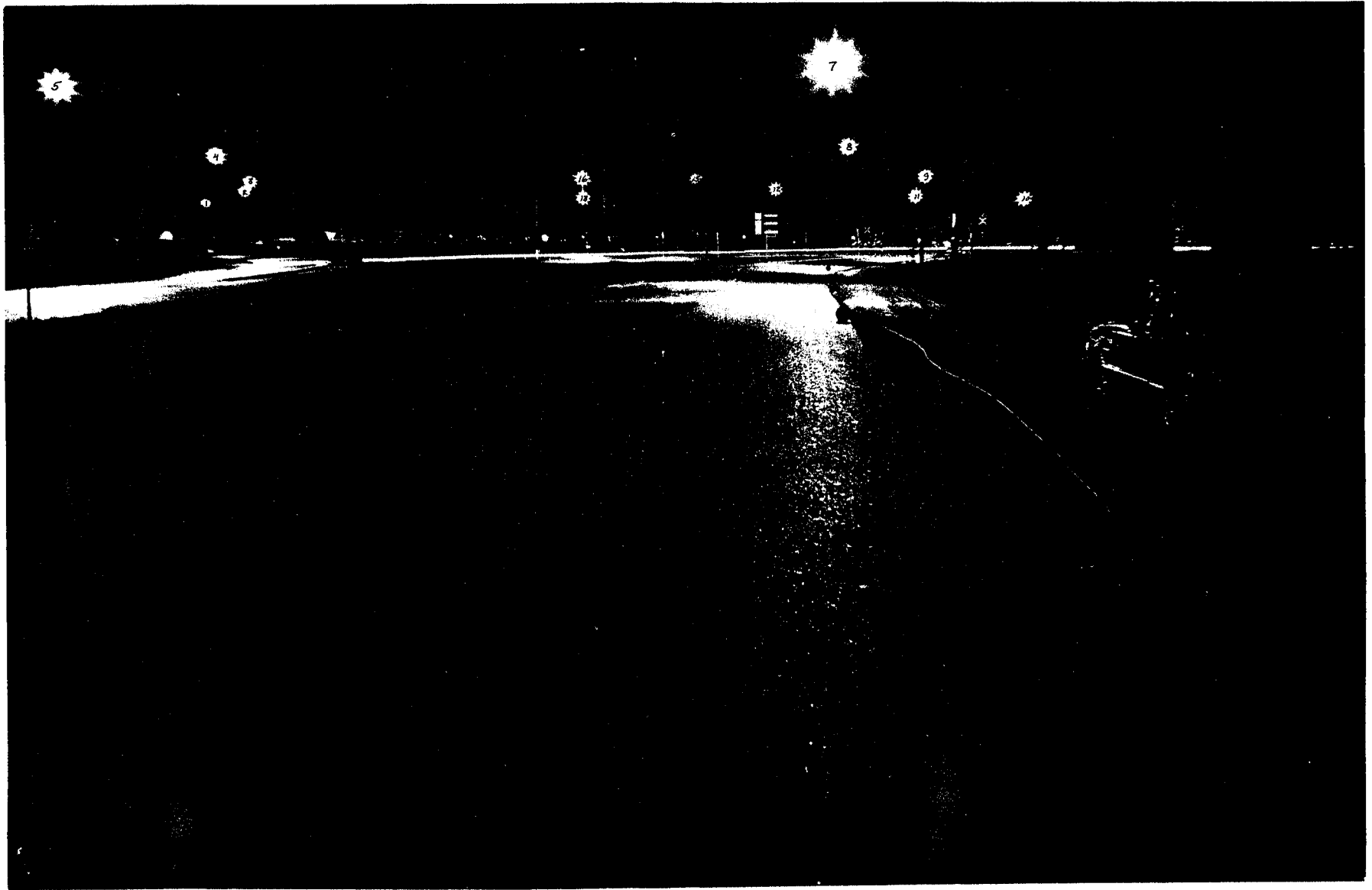


Figure 3. Galveston approach at night with the 30-foot continuous system in use.

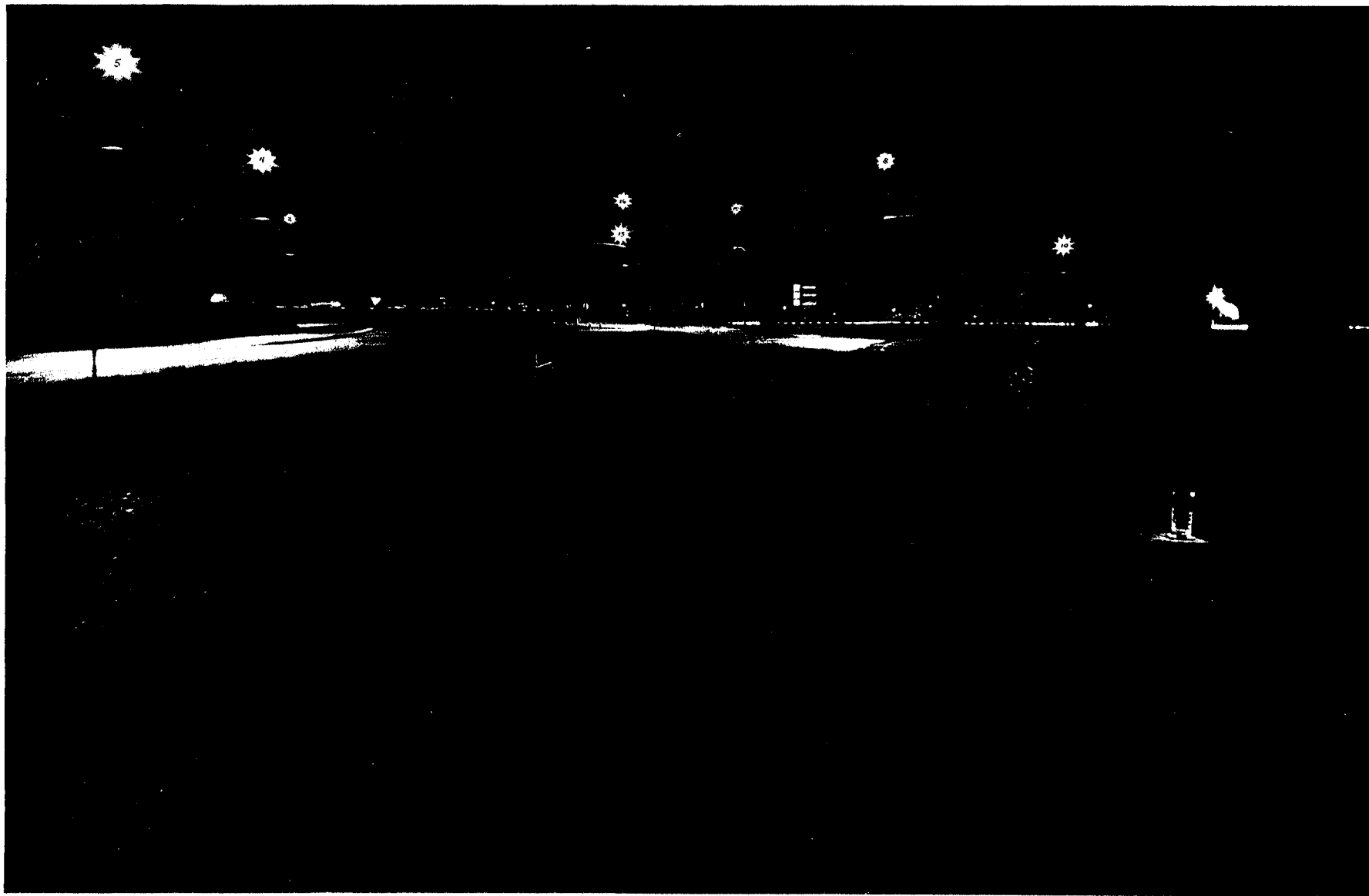


Figure 4. Galveston approach at night with the 45-foot intermediate system in use.



Figure 5. Texas City approach in daytime.

altogether in a series of bright splotches. Almost invariably at night one finds a pattern of extremely bright overhead sources distributed in a very dark surround. These may constitute an annoying and disabling source of glare. The visual differences in pattern between the day and night scene are very apparent.

There is great reduction in the scope of the visual field at night compared to the day scene. Some horizon information is still present at night due to the distant industrial lights, but the extent of the horizon information is greatly reduced. For some lighting conditions, the foreground is not tied in with the more distant background, thus leaving an area of uncertainty and discontinuity. Also where the lighting is not properly distributed, the pools of brightness under each source may not develop a meaningful brightness pattern. In all of the lighting arrangements of the research, the overhead luminaire brightnesses are several thousand times the roadway brightnesses. These bright sources have a seriously deleterious effect on visual conditions on the roadway.

Discussion of Data

Horizontal Illumination - The data on horizontal illumination showed that the individual luminaires acted almost independently in developing the illumination pattern for the 30-foot mounting height units. The spacing along each lane was 5 to 6 times the mounting height for the luminaires mounted at 30 feet, and therefore, adjacent light sources contributed very little beyond the midpoint between luminaires. A comparison of the pattern of the measured values with the manufacturer's reported values for a single luminaire indicated nominal agreement.

The 45-foot mounting height has a more favorable ratio of spacing to mounting height, viz., about 3.5. Therefore, the uniformity was better although the values of horizontal illumination for the 45-foot mounting height were lower than for the corresponding units at 30-foot mounting height.

The average values of horizontal illumination for the continuous systems are brighter than for either the intermediate or the minimum systems. This would be expected since more light is available within a given roadway area. The intermediate and minimum systems differ very little in average horizontal illumination. This is because the intermediate and minimum patterns use practically the same lights to illuminate the approach directions considered in this study. When the system is switched from intermediate to minimum, only two lights are turned off (numbers 13 and 15) and these two are so far away from the roadway areas under consideration that they contribute practically nothing to the horizontal illumination.

The values reported for average horizontal footcandles indicate that the levels are generally lower than the latest recommendations of the IES-ASA Committee on

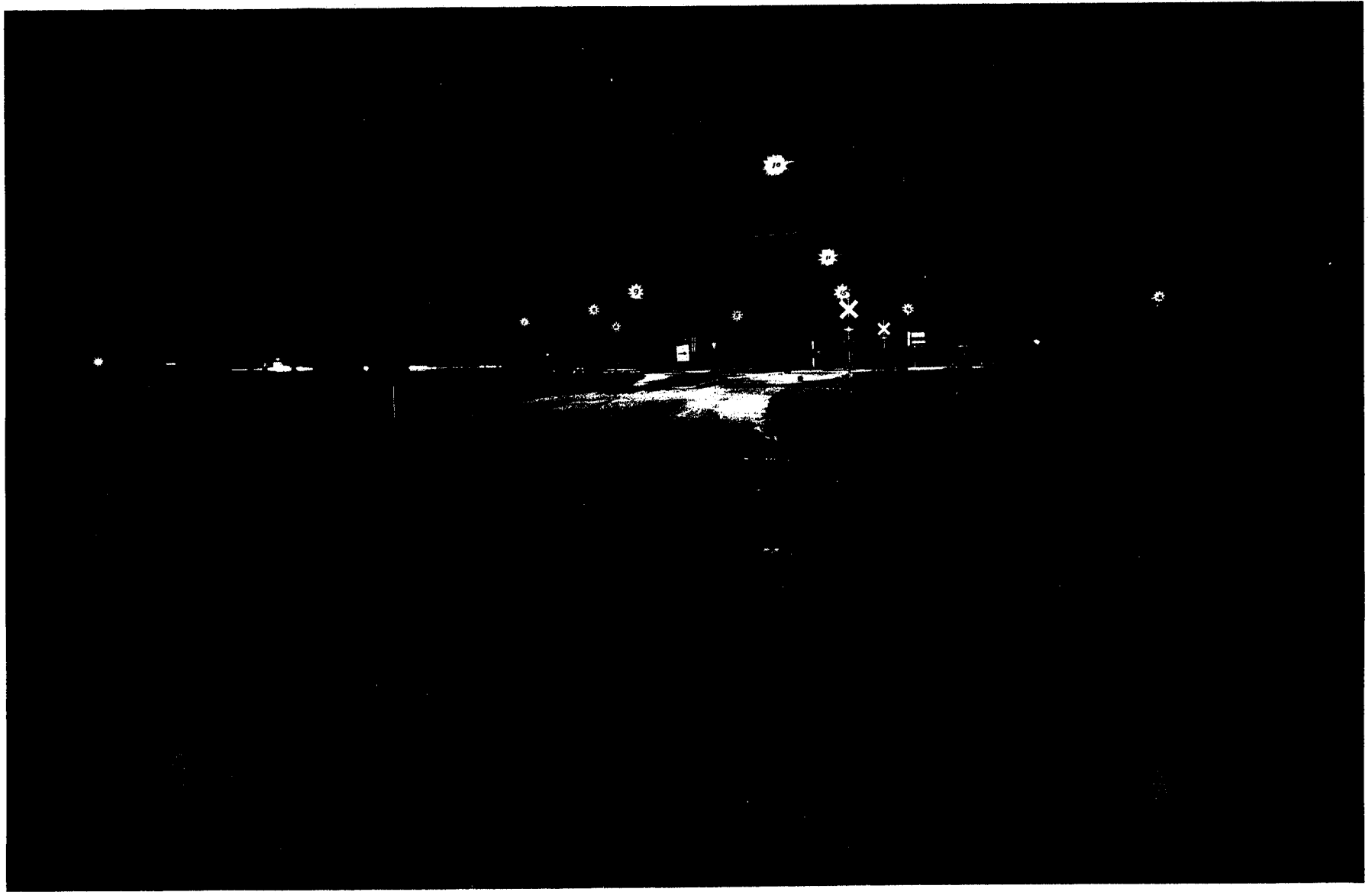


Figure 6. Texas City approach at night with the 30-foot continuous system in use.



Figure 7. Texas City approach at night with the 45-foot intermediate system in use.

Roadway Lighting. In the latest report the above group recommends 1.2 fc (average) for a rural interchange. The method of computing this average is not stated. If the area used to compute the average is restricted to the roadway in the immediate vicinity of the islands, the calculated values of average horizontal illumination would be higher than those reported herein and would be more in line with recommended practice.

Vertical Illumination - The data on the 30-foot intermediate and minimum systems show that direct object visibility can be expected to be poor since the vertical illumination is generally low (average in the traffic direction).

The 30-foot continuous and the 45-foot intermediate systems are better insofar as vertical illumination is concerned, but only the 30-foot continuous system is reasonably satisfactory.

The directional characteristics of the light, as revealed by the modeling factor, show that all systems have a reasonable probability of developing highlights, shadows, form and texture in objects located above the roadway.

The modeling factor should be greater than 1.5 for good object visibility. An object uniformly illuminated from all directions would have a modeling factor of 1.0 and would tend to have a flat two-dimensional appearance.

All of the systems meet the modeling condition, but all except the 30-foot continuous and 45-foot intermediate systems have vertical illumination values that are on the low side.

Brightness - Extensive data on brightness were collected. At the present time there is no standard procedure for analysis nor formula to use to arrive at an over-all appraisal of a brightness pattern. However, there are three basic requirements that must be met by an installation if it is to be satisfactory for drivers of motor vehicles: viz., (1) there shall be adequate guidance information, (2) forms and objects on the roadway should be readily perceived, and (3) the pattern should be understandable, unambiguous and not deleterious to easy, comfortable seeing.

Many factors contribute to these aspects of the visual problem. Among these are incident light effects and directional reflectance as related to characteristics of the roadway. The final result of incident light on surfaces is the brightness pattern as seen by the driver from a point about 300 feet ahead of an area of decision.

The problem here was to examine each brightness pattern and to extract the key information, then to evaluate the over-all scene in terms of the above basic requirements.

Summary of Data and Recommendations

The lighting data for the two approach directions and for the five lighting conditions on each approach direction have been summarized (Table A) with an over-all rating based upon a weighted appraisal of all factors. Roadway brightness, adaptation brightness, visibility index and glare have been considered to have greater weighting than the factors associated directly with illumination quantities.

The research has amassed data that have been used to demonstrate a number of significant lighting design features which are reported by D. M. Finch in a report entitled "Lighting Studies at the Texas City Wye". Some of these are listed below:

1. The complete brightness pattern of the roadway and adjacent area is the all-inclusive concept to keep in mind for design, evaluation or use purposes.
2. The brightness pattern must include elements for orientation and guidance as well as provide the necessary contrasts for form perception and detail visibility.
3. The complete roadway scene for a distance of 400 to 500 feet ahead of the driver should be tied together visually by a meaningful array of continuous lines, areas and shapes, all with adequate contrast well above threshold levels.
4. On the roadway area between the entrance and the exit regions of the intersection, objects on or above the roadway should be visible.
5. The extraneous brightnesses in the field of view such as the overhead lights should be reduced as much as possible to provide relief from discomfort glare.
6. The brightest area in the field of view should be along the line of sight at the roadway level. All entrance and exit directions to the intersections should decrease in brightness away from the central area.
7. The brightness levels within and on the approaches to the intersection should be adjusted in accordance with the driver's adaptation level determined by the roadway brightness and should be two to three times the brightness of the adjacent areas.

The above seven statements are in accordance with the definition of the desired visual conditions as given in the IES Handbook: "Good visibility on roadways at night

TABLE A

GALVESTON APPROACH

Lighting System

Quantity	30 ft	30 ft	30 ft	45 ft	45 ft
	continuous	intermediate	minimum	intermediate	minimum
Horizontal Illumination E_h (average)	0.80 fc	0.44 fc	0.37 fc	0.39 fc	0.30 fc
Ratio $\frac{E_{\text{maximum}} \text{ (horizontal)}}{E_{\text{(average)}}}$ (only)	6.0	8.0	9.2	4.1	4.6
Vertical Illumination, E_v (average)	0.29 fc	0.13 fc	0.12 fc	0.19 fc	0.15 fc
Modeling (vertical illumin-) Factor (ation ratio)	1.8	3.1	2.7	1.5	1.7
Adaptation Brightness, B_a	3.1 fl	1.5 fl	1.2 fl	2.1 fl	1.5 fl
Average Roadway Brightness, B_r	0.18 fl	0.02 fl	0.01 fl	0.03 fl	0.02 fl
Ratio $\frac{B_r \text{ (maximum)}}{B_r \text{ (average)}}$	14.3	65.5	131.0	23.3	26.0
Transition Brightness	Good	Poor	Poor	Fair	Fair
Object Contrast	Good	Poor	Poor	Fair	Fair
Visibility Index	Good	Poor	Poor	Fair	Fair
Glare Rating	Poor	Poor	Poor	Poor	Poor
Overall Rating	Fair	Poor	Poor	Fair	Poor

TABLE A (continued)

TEXAS CITY APPROACH

Lighting System

Quantity	30 ft	30 ft	30 ft	45 ft	45 ft
	continuous	intermediate	minimum	intermediate	minimum
Horizontal Illumination E_h (average)	0.84 fc	0.46 fc	0.43 fc	0.30 fc	0.30 fc
Ratio $\frac{E_{\text{maximum}} \text{ (horizontal)}}{E_{\text{average}} \text{ (vertical)}}$	5.6	9.9	10.5	3.7	3.7
Vertical Illumination, E_v (average)	0.39	0.20	0.18	0.28	9.27
Modeling Factor (vertical) (illumination ratio)	6.8	9.0	8.0	19.0	18.0
Adaptation Brightness, B_a	2.3 fl	1.5 fl	1.3 fl	2.2 fl	1.8 fl
Average Roadway Brightness, B_r	0.08 fl	0.06 fl	0.05 fl	0.08 fl	0.06 fl
Ratio $\frac{B_r \text{ (maximum)}}{B_r \text{ (average)}}$	14.8	12.0	14.4	7.9	8.2
Transition Brightness	Good	Poor	Poor	Fair	Fair
Object Contrast	Good	Poor	Poor	Fair	Fair
Visibility Index	Fair	Poor	Poor	Fair	Poor
Glare Rating	Poor	Poor	Poor	Poor	Poor
Overall Rating	Fair	Poor	Poor	Fair	Poor

results from lighting which provides adequate pavement brightness with good uniformity and appropriate illumination of adjacent areas, together with reasonable freedom from glare."

The individual lighting conditions in each approach direction have been examined and compared with the above generalized statements.

The 30-foot continuous system in either approach direction is generally superior to the others except that the glare is highest for this system.

The 45-foot intermediate system is better than the 30-foot continuous system insofar as glare is concerned. It also has more uniform pavement brightness distribution and better brightness transitions, but the brightness pattern does not extend far enough ahead of the intersection.

The other systems are generally inadequate and should not be considered for other areas that are to be lighted in the future.

Recommended Changes - In order to improve the lighting conditions at the intersection, several features could be added and several modifications could be made to the existing installation. A few ideas are listed below for the Galveston approach direction. The same principles could be extended to the other approach directions. Recommendations for the Galveston approach are:

1. Improve the transition zone lighting by adding one luminaire, 100 feet ahead of light number 7. This should have a shielded 175-watt mercury lamp mounted at 25 feet. Use 400-watt mercury lamps mounted at 45 feet in both number 8 and 9 luminaires.
2. Shield all luminaires to cut off the main beam at approximately 3.5 times the mounting height along the roadway.
3. Add reflex reflector roadway delineators on the center lines out to 500 feet from the island. Install where painted lines are now used.
4. Add delineators on the curbs around the islands.

These minor changes plus new signing should greatly improve the Galveston approach direction. The principles established in this report and demonstrated by such a modified system could lead to a set of ground rules that could be applied to other similar areas in the future.

TRAFFIC OPERATIONS - A PILOT STUDY

Before the Texas City Wye was selected as the principal study location for intersection illumination, pilot studies were conducted at the Montopolis intersection in Austin to develop techniques for study of the operational characteristics of traffic passing through the intersection under various conditions of illumination. The conditions of illumination were daylight, dark, spot illumination, and continuous illumination.

Although some manual methods of collection of traffic data were used, the study was conducted primarily to determine the effectiveness of motion picture methods of study in measuring vehicular operation through the intersection. For this study a 16 mm motor driven camera was located atop a 60' aluminum tower located far enough away from the intersection to avoid major distraction to drivers passing through the intersection. Attempts were made to obtain volume, speed, gap, delay, lane use and weaving characteristics from the film.

Since most of the data were to be obtained at night, it was necessary to first develop materials and techniques for night filming. It was found that high-speed films had sufficient sensitivity to make headlights and taillights clearly distinguishable. It was further noted that when illumination was provided, pavement markings and reference markers could be photographed but not clearly enough to record data with the desired precision. However, using infrared lights for markers, and using infrared film in the camera, the difficulty of establishing reference points was overcome.

Reflector markers were also used to establish reference points for the filming operations and subsequent analysis of the films. White reflectorized boards were placed in the median adjacent to the roadway, and small reflectorized geometric shapes were painted in the centerline of the roadway. This technique was fairly satisfactory, particularly when color film was used in the filming operation.

The films were analyzed using a special projector which permits frame-by-frame analysis. The image was projected on the rear of a ground glass on which reference markers, measuring traps, and other pertinent features could be reconstructed. The filmed positions of the vehicle headlights were used to determine the actual positions of the vehicles with respect to the reference features.

It was found that this procedure did not always provide data of the desired accuracy, since a great deal depended on such matters as the position of the lights, the height of vehicle headlights, the camera angle, the distance from the camera to the vehicle, and ultimately the proficiency and judgment of the technicians recording the data from the film.

In this pilot study it was found that direct observation and notation of individual driver behavior under the varying conditions of illumination was the most satisfactory method of obtaining driver behavior data. However, much valuable data can be obtained using motion picture study techniques.

TRAFFIC OPERATIONS AT THE TEXAS CITY WYE

In 1960 and 1961, and again in 1963, studies were conducted at the Texas City Wye to investigate the effects of various conditions of illumination on the characteristics of traffic operation. Methods employed in these studies included the motion picture techniques developed in the Austin study, previously described. In addition, a method of determining vehicle speeds in several sections on each approach was developed and used. This method consisted of roadtubes and pneumatic switches placed at the section boundaries and interconnecting them with an event recorder. Travel times were measured and speeds were computed for each vehicle. This method was satisfactory for low-volume traffic conditions.

Although a considerable amount of data was obtained using both study techniques, it was later found that much of the data was not sufficiently accurate or particularly applicable to a comparison of the various conditions of illumination. The speed data were judged to be of greatest reliability and therefore, constitute the main basis for comparison.

Principally these studies were established to investigate effects of different night visibility conditions on driver performance. It was assumed that driver performance would be reflected by changes in the speed of his vehicle, and the variability in speed of individual vehicles within the traffic stream. These studies involved the three illumination conditions previously described and one additional condition referred to as "point" illumination. In this particular lighting configuration eight luminaires were used to illuminate conflicts or points of decision for the drivers on the various approaches. Also the characteristics of the directional signs directing traffic to Texas City and La Marque from Galveston were varied. In one case a comparison was made between 4" and 7" black letters on a white reflectorized background. The results of these studies showed that there was no practical or statistically significant difference in the observed speeds. The average speed for all the data ranged from approximately 40 to 44 mph.

In another phase of the study an experimental sign with 7" first capitals and appropriately scaled lower case letters was compared with the standard 7" THD D-1A sign, both signs having black letters on a white reflectorized background. In this study only two levels of illumination were used. Again a comparison of the average speeds showed that there was no consistent difference between illumination

levels or types of letter used. The over-all difference in average speed was less than 5 mph, a difference which is not practically or statistically significant. Similarly, the variability in individual speeds through the intersection as measured by the average speed variance displayed no significant improvements in operations for either type of signing or the continuous illumination when compared to the nonlighted conditions.

Further study was conducted during daylight hours to compare the effectiveness of the three sign configurations previously described. The results showed that the average speed through the intersection varied less than 2 mph. The average speed variance through the intersection was greatest but not practically significant for the larger size capital letter.

In the later study an illumination system (see pages 9-23) recommended by D. M. Finch in his report, "Lighting Studies at the Texas City Wye," was installed and an operational study was made to compare the minimum lighting scheme, the continuous 30 lighting scheme and the transitional lighting system recommended by Finch. Although there was some indication that smoother operation was observed using the system recommended by Finch and the continuous lighting system, the difference was very small. It was concluded that the changes in the illumination conditions were not materially reflected in the measurements of traffic speeds, or other operational characteristics of traffic.

HUMAN RESPONSE TO LIGHTING CONDITIONS

Using the galvanic skin response technique of psychologists, experiments were conducted to determine the extent of driver tension on the approaches to the Texas City Wye intersection at night under lighted and unlighted conditions. The general purpose of this work was to further explore and evaluate the possibility of using the GSR to measure the effect of illumination on driver comfort.

The general scope of the experimentation was limited to the following:

- 1) A comparison of driver tension responses as related to conditions of continuous illumination, point illumination, and no illumination;
- 2) A comparison among several drivers to determine if the effects are consistent from driver to driver; and
- 3) An evaluation of the effect of a limited number of curvature geometrics and traffic control conditions.

It was also desired to consider only that part of total tension related to the highway itself, eliminating the effect of other traffic. As a by-product it was hoped that an

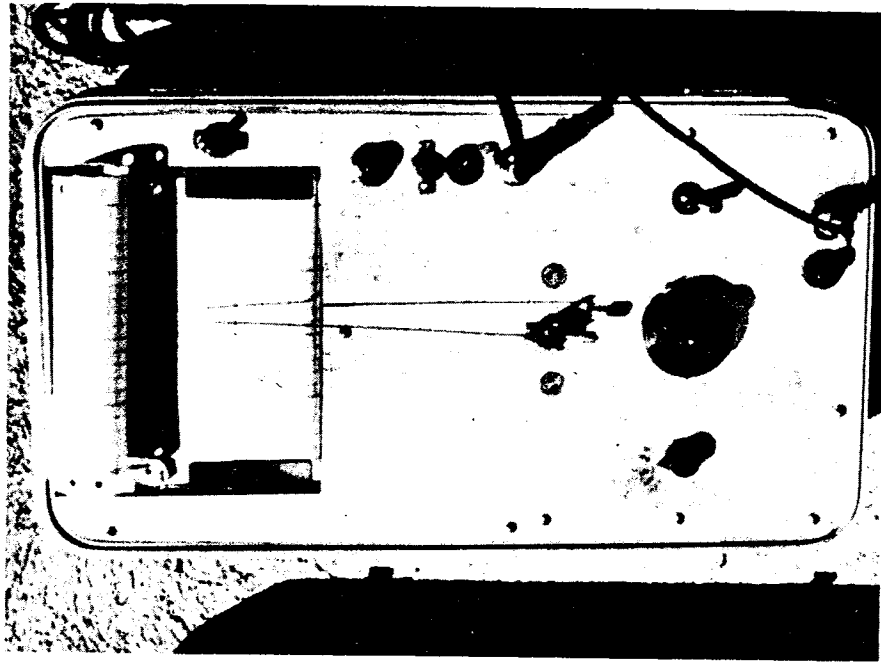
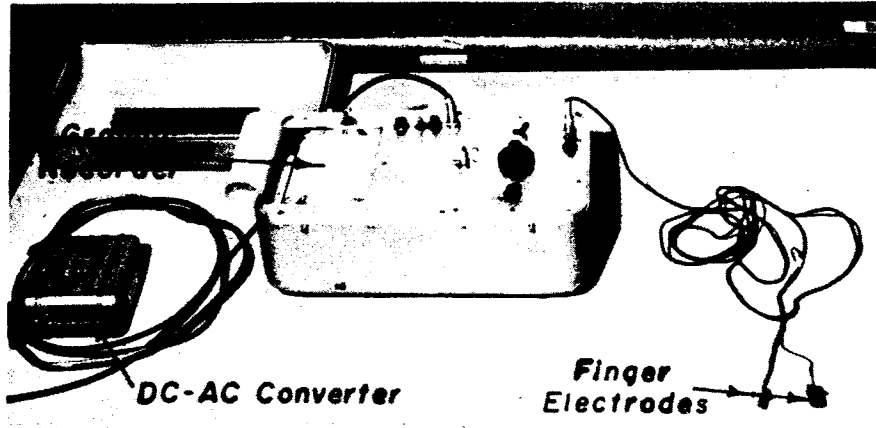


Figure 8. GSR recording instrument.



Figure 9. GSR recording instrument operating position.

estimate of a sample size necessary to discriminate between designs could be determined from the findings of this study. It was recognized that appropriate consideration must be given to the proper measure of the GSR for studies of this type. It was also hoped that the "learning" or adaptation effect to the GSR and stimuli could be investigated for this environment.

The GSR studies of the Texas City Wye were made using ten male driver subjects. Their ages ranged from 21 to 28 years and all had had at least 4 years driving experience. None of the drivers were familiar with the area or had prior knowledge of this study. The test area was approximately 150 miles from the research headquarters and the test drivers were driven to the test area in pairs and remained two nights while the study was being conducted.

A commercially available GSR recording instrument, as shown in Figure 8, was used to measure tension response. The GSR instrument consists of an alternating current Wheatstone bridge, galvanometer, set of electrodes, associated amplifying circuitry and controls, and a single-channel graphic recorder providing a permanent ink record of the time fluctuation in skin resistance.

The GSR recorder measures Galvanic Skin Response in units of the logarithm of conductance (the reciprocal of resistance). This unit of measurement is nearly linearly related to the magnitude of the inducing stimulus and is equivalent to measuring the percentage changes in resistance. The divisions on the ordinate of the graphic record represented equal increments of GSR for this study. The absolute values of these divisions depended upon the setting of the sensitivity scale and were not measured for the various sensitivities used in the study.

At the beginning of a study the electrodes were connected to the first and third fingers of the test driver's left hand as shown in Figure 9. When the driver rested his left hand comfortably on his thigh or lap he was in operating position. A sedan with an automatic transmission was used in the study, allowing the test drivers moderate freedom in operating the vehicle.

With the driver in the operating position for the start of an evening's study the normal resting level of skin resistance was determined. A startle stimulus was used to adjust the sensitivity of the GSR recorder. Full scale deflection with a startle stimulus provides adequate range for severe reactions and detects more of the minor reactions than would some lesser sensitivity setting. This sensitivity setting was not changed for the rest of the evening. Drivers were studied for a period of time ranging from 1 1/2 to 2 hours. All studies were conducted between 8 p.m. and 4 a.m. with most between 10 p.m. and 2 a.m., periods of very light traffic flow. Each driver repeated his study on the second night, generally at the same time of evening. During the studies drivers were observed for signs of fatigue and in the few cases that it appeared necessary, brief rest stops were made.

The study team consisted of four persons: the test driver, the GSR operator, and two assistants. The driver was alone in the front seat and GSR operator and one assistant accompanied him in the rear seat. The other assistant was stationed at the test intersection to control the intersection illumination. The driver was instructed to drive normally, not to speak, and when possible to try to avoid "floating" with other traffic moving in the same direction. He was informed that his driving ability was not being tested.

The GSR recorder operator coded traffic or other unusual occurrences on the graphic record, recorded the beginning and ending of the test sections, and determined travel time over the test course with a stop watch. The assistant in the automobile actuated a multiple-channel event recorder at each of the number of predetermined check points within the study area to provide information on the speed profile through the test area.

The driver subjects were instructed to follow a circuitous route which included a number of similar appearing highways and at least one illuminated intersection very similar in geometrics to the test intersection. The drivers were not informed of the intersection to be studied or other features of the study and after completion of the studies none indicated that they knew the purpose of the test. Apparently they did not notice that the illumination conditions at the test intersection had changed from passage to passage.

A typical study run was conducted as follows. The run was started some distance from the test intersection on the test route. The driver was given instructions well in advance of each intersection as to his designated course. The GSR recorder was turned on approximately 1500 feet in advance of many intersections and turned off after reaching a point 1500 feet past these intersections. This was intended to keep the driver unaware of the study location since operation of the equipment made a little noise detectable by the driver. The actual study route was generally approximately 0.3 mile in length. Travel time through the study area was usually less than 60 seconds and averaged approximately 38 seconds. Once the driver had passed through the intersections he continued on and eventually returned to the intersection according to the experimental scheme.

Illumination Reduces Tension

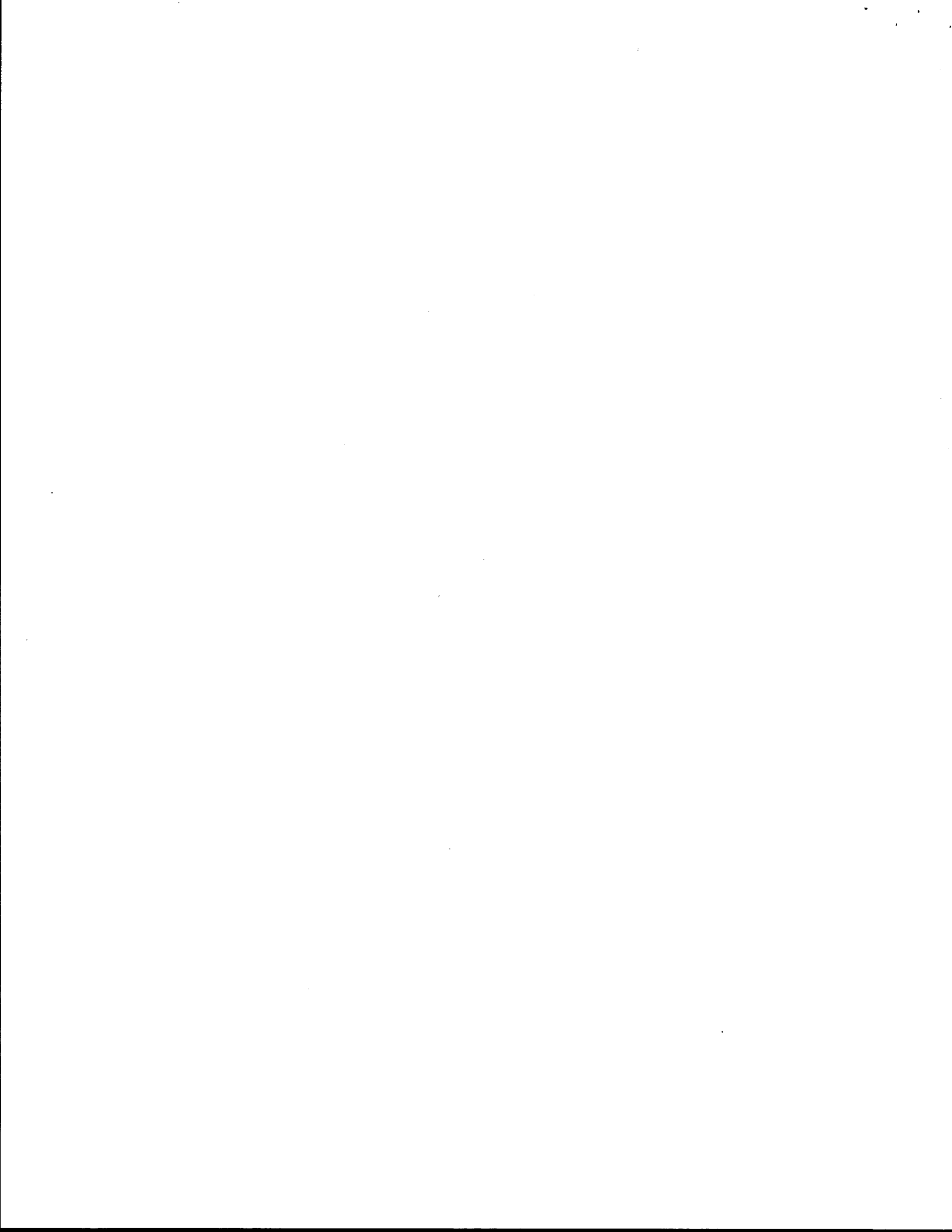
The results of the study indicate that the GSR can be used by trained engineering personnel with selected driver subjects to produce consistent results. The GSR revealed differences between conditions of illumination, producing only 80% as many tension responses under illuminated conditions as when the test intersection was not lighted. Both the number of responses and the

total magnitude of responses for each test as measuring variables showed progressive reduction when darkness was changed to "point" illumination, and then to continuous illumination at the intersection. This effect was similar for the different drivers tested.

The roadway geometry seemed to have some effect on tension responses. Greater tension responses were observed on the more difficult and complex paths through the intersection. Shorter turning radii caused greater responses than smooth flowing turns. Also, it is believed that passing under the individual luminaires produced a response that could be detected in the results.

The results of the study revealed a learning effect, a reduction in the tension responses due to repeated trips through the intersection while it was illuminated. However, the drivers returned to their original tenseness when illumination was eliminated.

Appraisal of the findings indicates that the GSR can be used to obtain a quantitative measure of driver comfort at intersections at night. It is believed that the GSR can be used in obtaining data for the development of design criteria for lighting, and warrants further study and application.



SCALE MODEL STUDIES OF ILLUMINATION



SCALE MODEL STUDIES OF ILLUMINATION

Other attempts to apply bench scale techniques in highway research led to the development of a method of studying illumination of intersections by the use of models.

After an actual highway intersection (the Texas City Wye Intersection) was selected for intensive field studies, construction of a scale model of this intersection was begun. An arbitrary scale of 1" equals 5'-0" was chosen, based on past experience in scale model construction and available laboratory space.

The completed model, shown in Figure 10, was approximately eight feet square, constructed on a plywood base with "Upsom Board" pavements, which could easily be removed and replaced with other materials to simulate different types of highway construction materials. Plaster of paris was used for the "shoulders" of the "highways" and all materials utilized were finished so as to reproduce very closely the light-reflection qualities of the actual intersection conditions, which were simulated through the use of paints, sand, and model landscape moss.

After several observers had worked with the model, it was decided to include the merging area at the south end of the Texas City Wye Intersection in the model. An additional three-foot square section was constructed, and is now a part of the complete model.

Miniature signs were also built to scale and positioned on the model in the same locations and positions as are the signs at the actual intersection. The model signs were hand lettered, and were thus somewhat crude, but they were sufficiently precise in dimensions, letter sizes, and light-reflective qualities for the work.

Because of its widespread use through Texas, a typical 400-watt mercury-vapor street lamp, type III distribution, was selected as the prototype for the development of scale-model luminaires. A light distribution pattern for such lamps was obtained from the manufacturer and was duplicated on a piece of thin board to the same scale as that of the model (1" equals 5'-0"). Small holes were cut into the board at certain points on the light distribution pattern, so that a miniature 1-1/8" diameter cosine-corrected light cell could be inserted to measure the light intensity at the board (or "road") surface. The model lighting system was provided by constructing 30-foot poles with 8-foot mast arms to scale and attaching a 12-volt lamp and reflector system.



Figure 10. Model of the Texas City wye intersection

It was then possible to measure the light distribution resulting from any variation in the detailing of the light bulb and reflector system by making comparisons with the distribution curve of the full-sized lamp previously drawn on the board ("road").

As the intensities of the light produced by the full-sized lamps, and subsequently by the model lamps, were very small, it was necessary to develop an instrument for measuring intensities in low foot-candles (from 1/2 to 3 foot-candles). It was found that through the use of an electronic amplifier and oscillograph recorder, the electromotive force produced by the light falling on the miniature light cell in the "road" surface could be measured. This instrument allows for measurements of light intensities as low as one-tenth of a foot-candle.

The miniature lights and towers were equipped with lead bases and flexible wire leads, so that they could be easily moved about on the model highway intersection. Extension bases were also developed, so that lamps could be raised to a height of 45 feet (to scale). An experimental tower 70 feet high (to scale) was also constructed, in an attempt to develop the capacity of the model to evaluate the characteristics of a single high, large light source, as opposed to numerous low, smaller light sources as potential for intersection lighting.

To aid in the use of the model intersection, a model automobile was equipped with a periscope which allowed an observer to view the "highway" through the model automobile's windshield as the model was pushed along the "highway." Also, several "view boxes" of different designs were developed. Using these boxes, observers could gain views of the intersection similar to those obtainable through the windshield of an automobile passing through the actual intersection.

A number of studies relative to sign placement with respect to light sources, variations of light sources, and relationships between luminaire placement and sign placement were made on the model intersection. Also, observers were called in at different times and asked to place the model luminaires at those locations and in those positions which they felt would effect significant illumination variations. All of the studies and observations revealed interesting facets of the lighting design problem, but it was felt that they were not extensive enough or detailed enough to indicate the complete range of usefulness of the model study system.

The model intersection proved itself as a study tool in comparison of data of a full-scale experimental system of lighting constructed at the site of the Texas City Wye Intersection. Researchers felt that with practice, models could be economically built for intersection studies.



SIGN LEGIBILITY AND ILLUMINATION



SIGN LEGIBILITY AND ILLUMINATION

SUN SHADOW EFFECTS ON SIGNS

Shadows of overhanging projections reduce the legibility of highway signs on sunny days. This frequently causes indecision and misinterpretation with operators of vehicles under the stress of speed and traffic.

Since there are certain daily and seasonal regularities in the sun's movement across the sky for a locality, shadows from a projection can readily be predicted. The factors of latitude, time, and the sun's directional transit and angular position with the earth can be correlated to make this possible.

It stands to reason, therefore, that a procedure for calculating shadow patterns to be encountered for a projection from a sign could be established and would serve to aid designers of signing for highways.

Because the usual projection of a highway sign is the illumination system, research to simplify prediction of shadow patterns has dealt with it. The work centered on determining the limiting conditions for minimization of sun shadows.

Results of the experimentation are twofold: first, an analytical expression has been developed which defines the pattern produced by an over-hanging illuminating system; and second, this analytical expression has been programmed for processing by a digital computer.

Although the analysis is general, certain assumptions and limitations are adopted in this report. These are: (1) the illuminating system is the same width as the sign, (2) sunlight is unobscured during daylight hours, (3) calculations are based on solar time, (4) calculations and data are for 32° north latitude.

Nomenclature

Interference Area (A_i): The portion of the sign subject to shadow at any moment during daylight hours. (See Figure 11(a))

Point P: The point cast in the plane of the sign by the extreme corner points of the lighting system. Point P is located by coordinates (x, y) measured from the upper corners of the sign, and it may fall outside the actual sign.

Overhang Dimension (a): The shortest distance from the sign to the corner points (left or right) of the lighting system (see Figure 11(b)). The dimension "a" is measured normal to the sign's surface and parallel to the horizon.

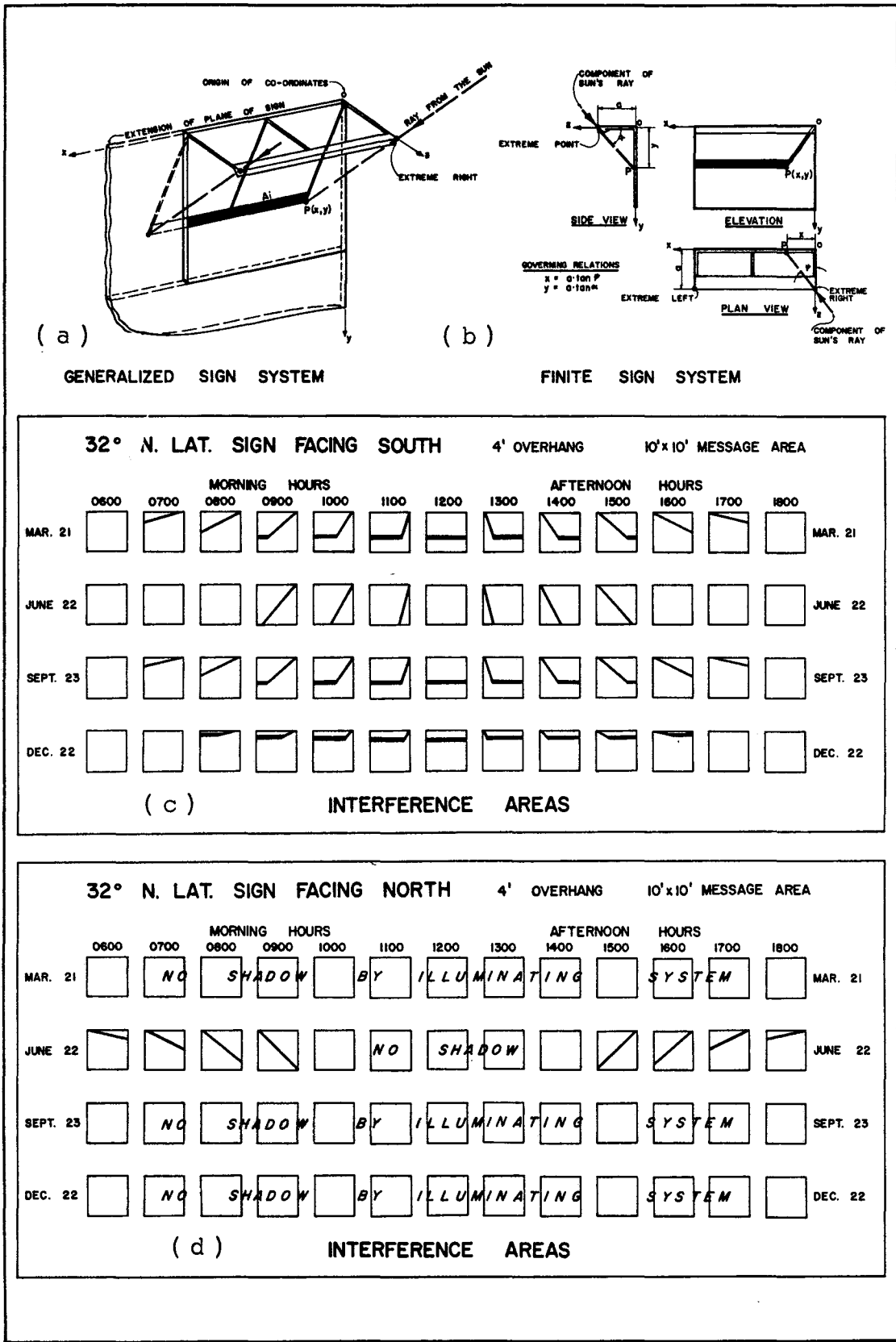


Figure 11.

Profile Angle (α): An angle located in a vertical plane which is perpendicular to the face of the sign; the profile angle is included between a horizontal line and the component of a ray of the sun in the subject plane. (See Figure 11 (b).)

Normal Angle (ψ): An angle located in the horizontal plane; the normal angle is included between a line normal to the message and the horizontal component of a ray of the sun. (See Figure 11 (b).)

Analytical Procedure

It can be shown that the point P (x, y) is a function of the sun's altitude and bearing, the altitude and bearing of the sun being those usually defined in the horizon system widely used by surveyors and navigators. Furthermore, it can be shown that the altitude and bearing of the sun are functions of the latitude of the place where the sign is located, the declination of the sun at the moment of observation, and the meridian angle (or sun's hour angle). These latter variables are those usually defined in the celestial system for locating the sun, or for locating the position of a point on the earth's surface. Based on relationships between these variables the simple equations indicated in Figure 11 (b) are utilized. Computation of the profile angle and the normal angle is tedious, but straightforward. Once this information has been obtained, however, the extent of sun shadow interference is known for any latitude at any moment of time.

The computational investigation consisted of the solution for the location of the point P on a sign located 32° N. Latitude, during daylight hours (6 a.m. to 6 p.m.) on four critical days of the year, March 21 (Vernal Equinox), June 22 (Summer Solstice), September 23 (Autumnal Equinox), and December 22 (Winter Solstice), for eight orientations of the sign (viz. sign facing south, southeast, east, northeast, north, northwest, west, and southwest).

Interference areas were calculated and plotted for the twelve daylight hours on each of the four days considered and for the eight sign orientations selected. A typical set of interference areas is shown in Figure 11 (c), in which the message area was arbitrarily chosen to be $10' \times 10'$ and the overhang dimension was selected arbitrarily as $4'$. The interference areas plotted in Figure 11(c) are for the south orientation and those in Figure 11 (d) are for the north orientation.

Discussion of the Procedure

A careful examination of the interference areas indicated that the message area of a highway sign is subject to sun shadow interference during almost every day in the year. The greatest interference occurs on signs facing south; the least interference is encountered on signs facing north. A predictable continuous regularity on interference exists for all sign orientations between these extremes.

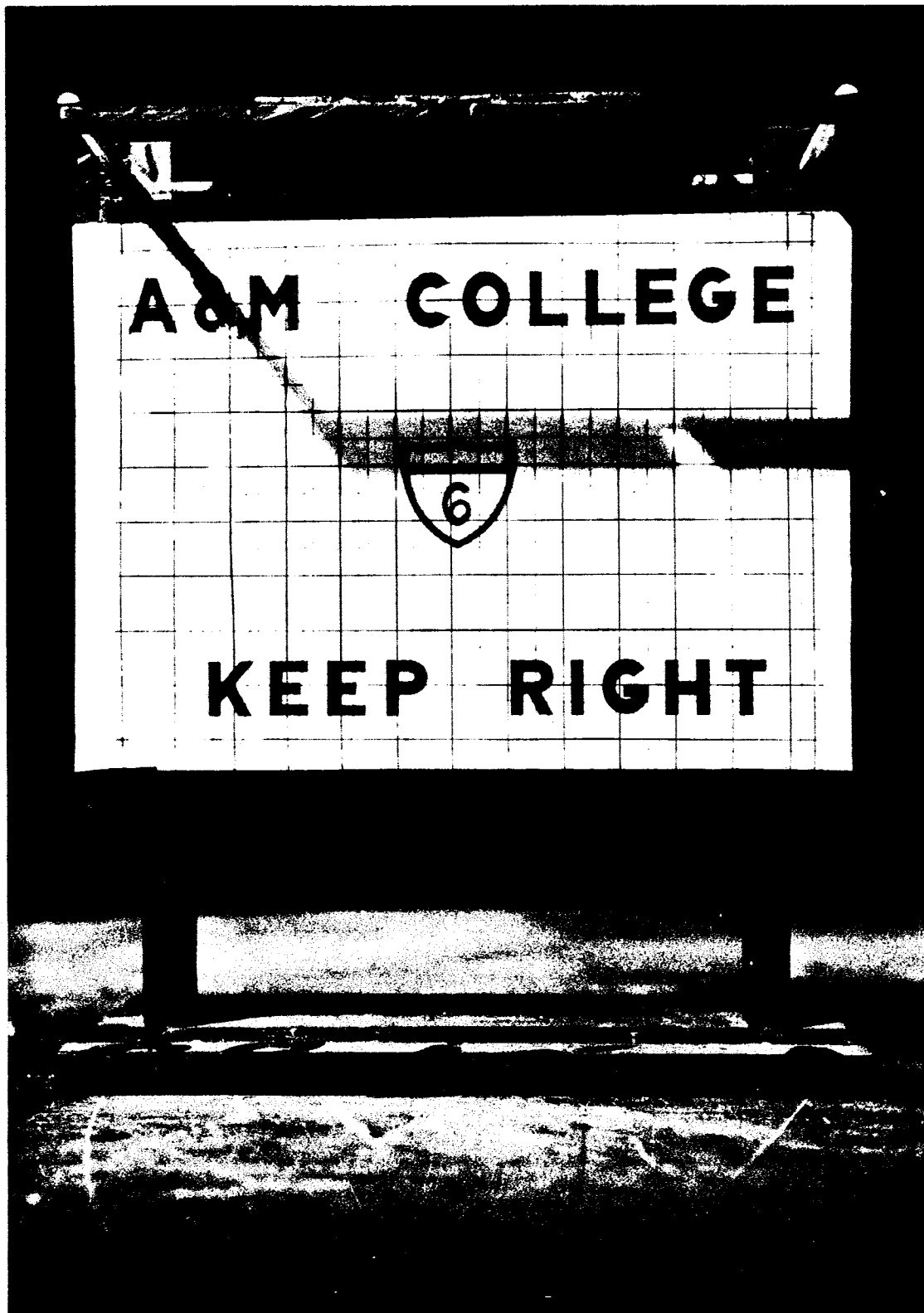


Figure 12. Simulated lighting fixture on model sign casts a sun shadow.

It is further apparent that the equinoctial sun shadow patterns are identical. However, the sun shadow patterns at the solstices are not identical. Thus any analysis used for design purposes must consider the sun shadow transit across the sign's message for the entire year.

A definite regularity is observed for sign orientations which are located 180° from each other. This is to say, for each orientation the sun is directed at the back of a sign during a part of the day for every nonequinoctial day.

Every vertical highway sign is subject to a sun shadow pattern of some shape at some time during the year. The shape of shadow is variable, however. Examination of Figure 11 (c), for example, indicates that the sun shadow pattern consists of three general shapes: (1) triangular, (2) trapezoidal, and (3) rectangular. The triangular-shaped pattern is composed of the shadow of the member supporting the illuminating system. The trapezoidal-shaped pattern is composed of the shadow of the supporting member and the shadow of the illumination fixture. The rectangular-shaped pattern consists of the shadow of the illumination fixture only.

These three sun shadow shapes are of considerable significance. The horizontal pattern cast by the illumination fixture causes greater interference than does the oblique portion cast by the smaller cantilever overhead arm.

Closer observation of Figure 11 (c) leads to the conclusion that the horizontal portion of the sun shadow pattern transits from a "starting" position at the Vernal Equinox downward beyond the limits of the sign at the Summer Solstice, then transits upward until it reaches the "starting" position at the Autumnal Equinox. The horizontal portion then continues to transit upwards until it reaches an upper portion at the Winter Solstice. During the annual transit the horizontal portion of the sun shadow pattern traverses the entire vertical dimension of the message.

These observations made for a sign facing south may be extended to the other orientations and can be useful in selecting illumination fixture dimensions and other design parameters for minimizing the effect of sun shadows.

Minimization of Shadow Area

The analytical procedure described above furnished basic information. With this basic information the opportunities for designing sign illuminating systems so as to minimize sun shadow interferences are limited only by the required illumination intensity, structural requirements, economic feasibility, and the design engineer's ingenuity.

In more northern latitudes the patterns are different in extent from those shown, and this fact may be utilized in design. Investigation of climatological data might reveal that cloud cover is extensive during the winter months. Thus, the probability of interference with the message may be minimized.

Since it is not possible to eliminate completely the sun shadow from the face of a sign, another approach might be made to the design problem. For example, the shadow cast by the overhead illuminating system might be combined with side overhangs to produce complete shadow during daylight hours. Such an approach would also protect the sign surface materials, and structural design advantages might accrue to permit savings in weight and material.

Well known, predictable, and widely used sun-time relations have been adopted to develop a computer program which will produce values which make extremely simple calculations for sun shadow patterns possible. The program will furnish precise data for any latitude and sign surface orientation. The results of this study are general, but may be easily extended to embrace various design parameters. In addition, statistical data concerning cloud cover and other climatological data may be readily incorporated into the input data for the program.

It is apparent that sun shadows on highway signs cannot be entirely eliminated. It is possible, however, to minimize the effect of these shadows or to put the shadows to use.

LEGIBILITY OF OVERHEAD SIGNS

A comprehensive controlled study of the legibility distance of overhead signs under various conditions of illumination was conducted at a specially constructed test area on the Texas A&M University campus. Overhead signs with several types of commonly used background materials were used in combination with several types of reflectorized letters for the study. Also, an internally illuminated overhead sign was included to facilitate a direct comparison with externally illuminated and reflectorized signs. The results of this study which are summarized herein, were presented in greater detail in Research Report 5-8, "Overhead Sign - Illumination Relationships."

The purpose of this investigation was to examine the relationships between the legibility of overhead signs and the brightness configurations which can result when various vehicle, sign, and roadway lighting conditions exist for a number of commonly used high-type sign materials. The effects of the variables have been evaluated to enable the designer to compare the relative improvements in legibility for various sign-illumination systems. The specific variables in lighting included: (1) the longitudinal positioning of one and two luminaires with respect to the sign, (2) two different types of fixtures for external sign illumination and one condition of internal illumination, (3) the two-headlamp and four-headlamp automobile lighting systems, and (4) high-beam and low-beam operation.

The roadway luminaires used in this investigation were standard 400-watt mercury vapor units mounted 30 feet above the pavement edge. Four luminaires were used and they were positioned longitudinally 10 feet and 75 feet in front of the sign, and 5 feet and 90 feet behind the sign. This configuration permitted a study of the effects of the lighting system if the sign was located either immediately in front of or behind a single luminaire, or approximately midway between two luminaires.

Two types of fluorescent sign lighting fixtures were used in the study. One unit, referred to as the standard unit, was developed by the California Division of Highways and adopted by the Texas Highway Department. The other unit was designated as a Fluoroflood fixture. Both fixtures were mounted on the signs, and were tested in positions above and below the sign.

The overhead signs used in the experiment were 4 feet high and 12 feet in length. Six different signs were used, each having different combinations of background materials and letter materials. The combinations were as follows:

- (1) Reflex reflector letters on porcelain enamel background.
- (2) Reflex reflector letters on exposed lens reflective background.
- (3) "Signal" letters on reflective sheeting background.

- (4) Cut-out reflective sheeting letters on reflective sheeting background.
- (5) "Signal" letters on exposed lens reflective background.
- (6) Internally illuminated sign.

The letter spacings in the legends were those recommended by the manufacturers, and the test words were six-letter pronounceable place names such as BEAVER, BAXTER, etc. All letters were standard interstate sign letters, 16-inch capitals and 12-inch lower case letters.

The signs were evaluated by observers riding in slow moving vehicles. The test record was the distance at which the legend on the sign could be read, a measure of "pure legibility." The study was conducted with the test vehicle moving at a speed of approximately 15 miles per hour. This speed was considered satisfactory in representing the dynamic situation, and made it possible to record legibility distance more accurately.

Results

For sign number 1, the reflex reflector letters on a porcelain enamel background, there was only small variation in legibility distances for tests involving the four-headlamp automotive lighting system. Legibility distance was not improved by switching from low to high beams with the four-headlamp system. For the two-headlamp lighting system there was a substantial improvement in legibility distance in switching from low-beam to high-beam operation.

When the sign was illuminated using the sign lighting fixtures, no change in legibility distance was noted except in the case of the two-headlamp automobile lighting system displaying low-beam operation. In this particular case it was observed that addition of the sign illumination increased the legibility distance to compare with the two-headlamp system on high-beam operation and the four-headlamp system on both low and high-beam operation. When additional illumination was provided using the roadway luminaires, some improvement in legibility distance was observed, but mainly in the case where the two-headlamp automotive lighting system was on low-beam operation. It is believed that this improvement was due to illumination from the luminaires in front of sign.

In general, there was no difference in legibility distance when the standard fluorescent sign lighting fixture was compared to the commercial Fluoroflood unit. Similarly there was no difference in legibility distance due to mounting the fixture above or below the sign.

For sign number 2, composed of reflex reflector letters on an exposed lens reflectorized background, legibility distance was lowest when low-beam operation of the two-headlamp automobile lighting system was the only illumination source. Otherwise, there were no significant differences in legibility distance regardless of the conditions of illumination.

For sign number 3, composed of "signal" letters on reflective sheeting background, the shortest legibility distance was observed using the two-headlamp system operating on low-beam with no other illumination on the sign. In general, the legibility distances were lower for low-beam operation of both headlamp systems and with the sign lighting fixture off. However, these differences were not considered to be of any practical significance.

For sign number 4, which was composed of cut-out reflective sheeting letters on a reflective sheeting background, noticeable results were obtained with illumination by the standard sign lighting fixture. For the two-headlamp system operating on low-beam and with the sign lighting fixture off, the placement of a luminaire in front of the sign increased legibility by more than 20%. This improvement was not realized when the luminaire was placed behind the sign. An improvement of over 10% was noted for the four-headlamp system on high-beam operation and with the sign lighting fixture off.

For sign number 5, composed of "signal" letters on an exposed lens reflectorized background, a roadway luminaire in front of the sign improved the legibility distance for the two-headlamp system operating on low-beam with the sign lighting fixture off. For high-beam conditions, placing the luminaire in front of and near the sign resulted in a substantial improvement in legibility. In general, placing a luminaire behind the sign reduced its legibility.

For the internally illuminated sign, the total range in average legibility distance was only 75 feet regardless of the configuration of roadway luminaires and for both high- and low-beam headlamp operation. These differences have no practical significance.

The following average legibility distances for each of the sign configurations will permit a relative comparison.

(1) Reflex reflector letters on a porcelain enamel background	983 feet
(2) Reflex reflector letters on an exposed lens reflective background	938 feet
(3) Signal letters on a reflective sheeting background	862 feet

- | | |
|---|----------|
| (4) Signal letters on an exposed lens reflective background | 835 feet |
| (5) Cut-out reflective sheeting letters on a reflective sheeting background | 738 feet |
| (6) Internally illuminated sign | 651 feet |

Conclusions

Under rural conditions it is possible to use several methods of improving the legibility of overhead signs that are not internally illuminated. It was found that the legibility distance of various high type signing materials under generally dark surrounding conditions varied as much as 20 per cent as the external illumination of the sign varied. Sign fixtures, high beam operation and roadway luminaires will each make a contribution. The effects are not additive and the use of any one of the above makes the need for the other two less apparent. Also, it is apparent that differences in illumination result in meaningful differences in legibility and that this should be taken into account in design. This is an individual problem and very difficult to standardize. From a legibility point of view, it is concluded that satisfactory legibility can be achieved under many conditions without the use of overhead sign lighting fixtures.

LEGIBILITY OF ROADSIDE SIGNS

Studies were conducted to determine the effect on nighttime sign visibility of the placement of roadside signs in relation to luminaires. Two types of signs were mounted at various locations in relation to one 400-watt mercury vapor luminaire mounted 30 feet above the pavement edge. In the first phase of this research a Texas Highway Department standard destination sign with 7-inch black letters on a 1' by 7' white reflectorized background was used. In these tests, ten observer subjects were used to determine recognition and legibility distances for the sign located in various longitudinal positions in front of and behind the luminaire and in transverse positions of 2-, 14-, and 26-foot distances from the edge of the pavement over which the luminaire was installed. Tests were conducted with the test vehicle displaying both low- and high-beam headlamps and with and without an opposing vehicle located 300 feet behind the sign and in the adjacent opposite lane.

The observers were front seat passengers of the test vehicle which was driven at 30 mph for the sign recognition test and at 10 mph for the sign legibility test.

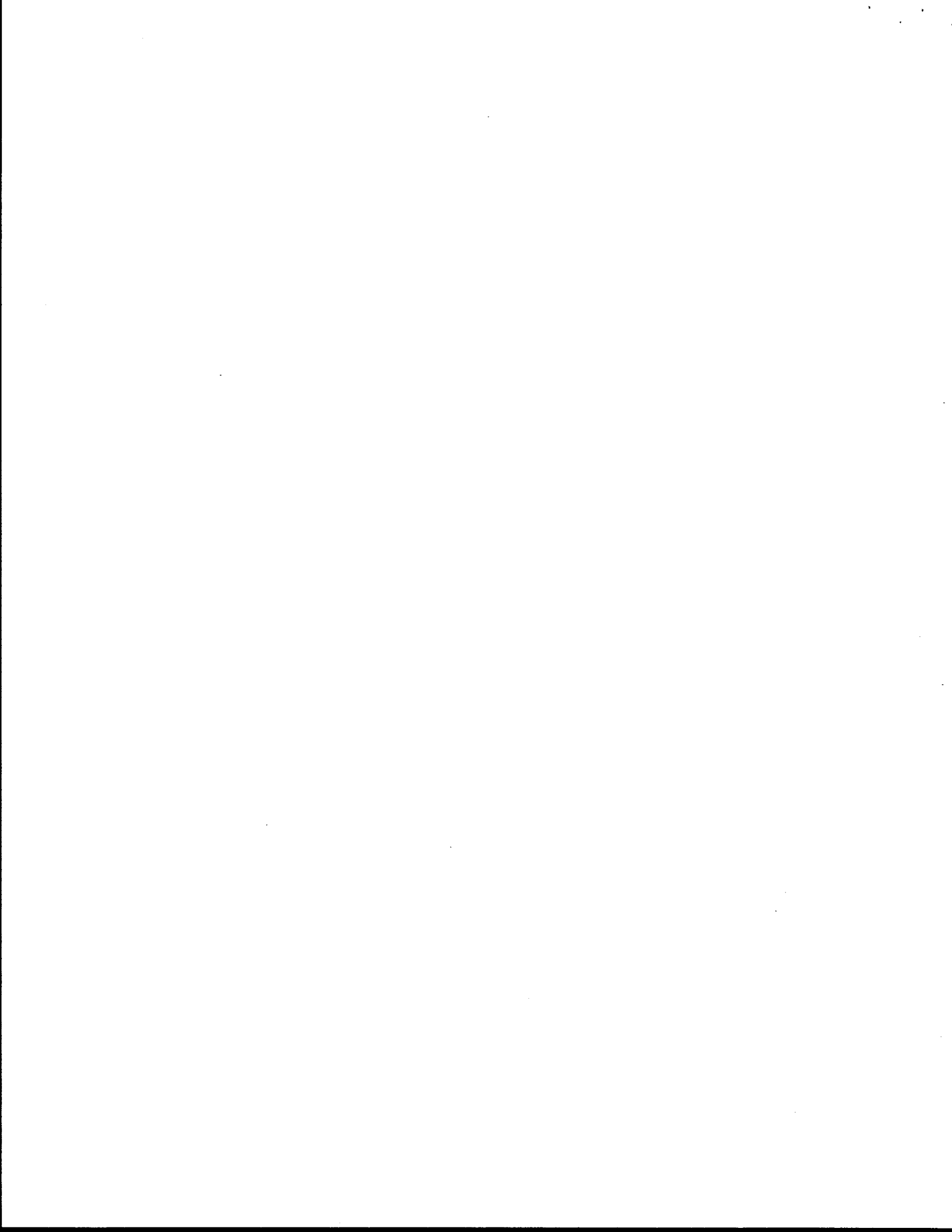
From these tests it was concluded that real and substantial improvements in night sign legibility will result when roadside sign location and luminaire location are coordinated at the design stage. Signs should be placed from 25 to 75 feet beyond the

luminaire for maximum legibility. The lateral location of signs is not as critical as the longitudinal position, but the optimum placement is approximately 10 feet to the right of the luminaire.

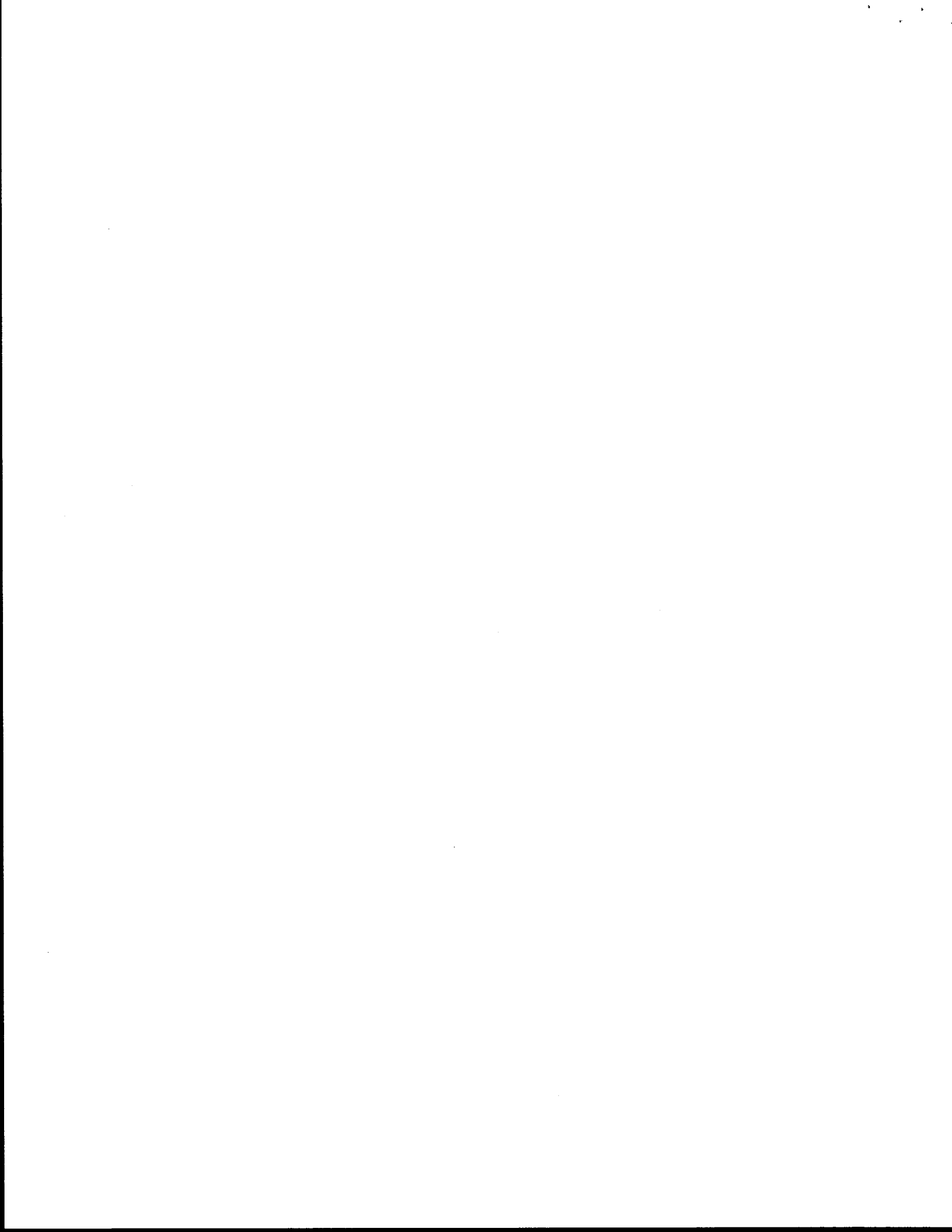
The second phase of the research was conducted to compare the above results with a sign composed of 8-inch reflex reflector letters on a black background. Because the effect to opposing headlights was negligible in the first phase, this variable was not included in this study. All other conditions of the tests were the same in both studies.

Analysis of the data showed that the longitudinal effect, which was so apparent in the previous study was quite irregular and of no significance in this study. Bright headlights gave no better results than did low-beams. The lateral positioning effect, although not significant showed the same pattern as found in the first phase.

The results of this study and the previous study indicate that the effect of roadway illumination on roadside sign position varies with the type of reflective materials used in sign construction. The reflex reflector letters on a black background were just as easily read with low-beam headlights as they were with bright headlights, and the sign location was not important, while the standard material was sensitive to both of these characteristics.



CONCLUSIONS



CONCLUSIONS

The research to determine the effects of various types of intersection and sign illumination on traffic performance and safety provided a number of conclusions. These were drawn from field studies of operations at several intersections, model studies, and sign illumination studies.

The operational studies of the Austin intersection in daytime and at night, with darkness, spot illumination and full illumination conditions, revealed that accurate data on driver behavior were difficult to obtain. However, they showed also that motion picture and instrumentation techniques provided valuable data for evaluation.

Studies with an eight-by-eight-foot table-top model of the Texas City Wye built to a scale of 1" = 5' gave evidence that lighting problems of an intersection can be visualized and solved in the design room before full-scale construction at the site. The model, which duplicated the intersection in miniature, was equipped with small lights which simulated the distribution pattern of mercury vapor lamps and were adjustable per scale to represent both the 30-foot and 45-foot heights. Although the model technique proved itself in correlation of the miniature and full-scale data, more studies need to be conducted to determine its range of utility in highway research and planning.

Studies at the Texas City Wye showed that operational conditions of the traffic stream were not appreciably affected by the range of illumination conditions subjected to experimentation. In accordance with the definition of desired visibility by the IES Handbook, D. M. Finch believed that the 30-foot continuous system of lighting of experiments at the Texas City Wye was superior to other intersection systems, except that glare was a greater problem.

Galvanic skin reflex (GSR), which measures changes in conductivity of the skin, proved to be an effective means of determining driver reaction to different illumination and geometric conditions at intersections. Nighttime use of different drivers and comparison of their tension patterns as recorded by the GSR instrument showed that increase in illumination brought decrease in tension responses and that greatest tension occurred with no illumination. Also, complexity of the intersection caused increase in tension responses. Although the drivers reacted differently to the various intersection situations, their over-all response patterns were similar and familiarity with situations brought reduced tension.

An analytical expression which can define the sun shadow patterns to be expected across highway signs from overhanging projections such as lighting fixtures has been developed and programmed for a digital computer. It makes use of such factors as

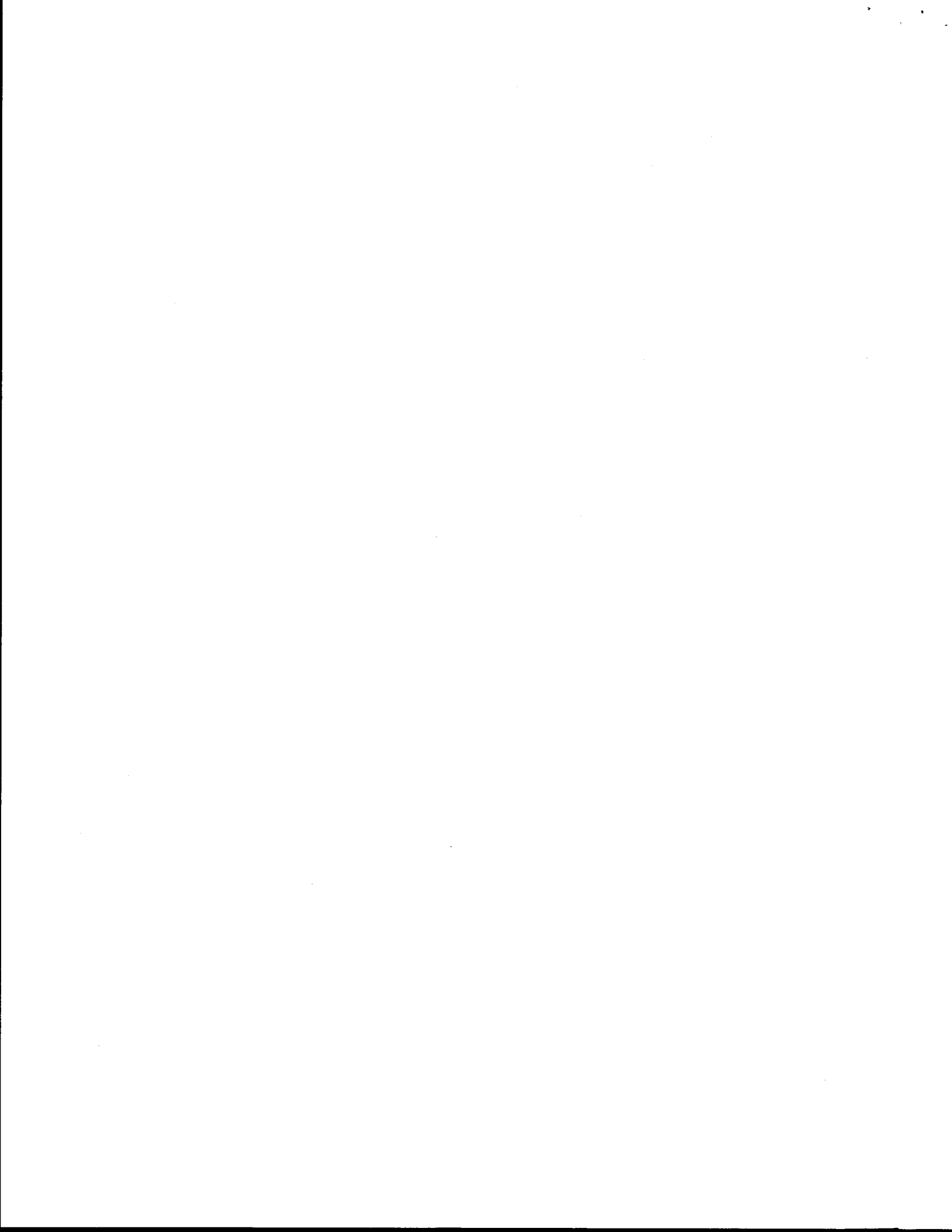
latitude, time, and the sun's directional data. The expression can be used by planners of signing from not only the interest of avoiding or reducing shadows but also that of utilizing them to reduce reflected glare of the sun for good legibility of the sign's message.

Several conclusions were reached in the legibility study of reflectorized signing. It was found that the legibility distance of various high type signing materials under generally dark surrounding conditions varied as much as 20 per cent as the external illumination of the sign varied. Headlamp systems, low or high beams, special sign fixture luminaires, and roadway luminaire placement all individually affect legibility distance for letter sizes commonly used in overhead signing applications. In very few cases was there an additive effect when more than one of these illuminating situations existed.

Findings of legibility studies involving sign positioning showed that roadside sign location and luminaire location should be coordinated at the design stage. They revealed that signs placed 25 to 75 feet behind a luminaire have legibility for a greater distance than signs placed ahead of a luminaire. They also showed that in lateral placement, signs located approximately 10 feet on the right or "house" side of the luminaire give best readability.

An over-all conclusion reached was that intersection illumination, intersection signing, and intersection design must be coordinated for maximum efficiency.

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Project 2-8-57-5

Intersection Illumination

1. Research Report 5-1, "Roadside Sign Legibility and Roadway Illumination," by Donald E. Cleveland.
2. Research Report 5-2, "Lighting Studies at the Texas City Wye," by D. M. Finch.
3. Research Report 5-3, "Rural Intersection Illumination and Driver Tension Response," by Donald E. Cleveland and Weldon C. Franklin.
4. Research Report 5-4, "Overhead Signing and Traffic Operations," by S. N. Van Winkle and H. H. Bartel, Jr.
5. Research Report 5-5, Unpublished paper - "Roadside Sign Studies - II," by S. N. Van Winkle and Donald E. Cleveland.
6. Research Report 5-6, "Driver Tension Responses and Intersection Illumination," by Weldon C. Franklin and Donald E. Cleveland.
7. Research Report 5-7, "Traffic Operations - Illumination Studies," by Donald E. Cleveland.
8. Research Report 5-8, "Overhead Sign - Illumination Relationships," by Donald E. Cleveland.
9. Research Report 5-9, "Intersection and Sign Illumination for Highway Safety and Efficiency," by Charles J. Keese and Donald E. Cleveland.

