TRAFFIC OPERATIONS - ILLUMINATION STUDIES

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Intersection Illumination
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INTRODUCTION

That our highway systems have not performed as satisfactorily after dark as during daylight hours is evidenced by the night accident rate which is approximately twice the daytime rate. The constantly increasing traffic volume emphasizes the importance of this problem, as more and more people and goods move after dark. Though the personal characteristics and motivations of these night road users pose formidable educational and enforcement problems, the vision problems created by darkness concern the engineer most. He strives to design and equip his facilities with devices that provide for the special problem of seeing after dark. One of the most important tools is highway illumination.

The most critical points in our state systems are rural highway intersections. The highway intersection, long recognized as the point of major traffic conflict and congestion, is the limiting factor in the operational capacity of the highway. As traffic volumes have increased, it has been necessary to increase the complexity of both at-grade and grade-separated intersections. Potentialities for reduction in night accident experience at these centers of conflict, along with increased usage, have stimulated much interest and experimentation on their proper illumination.

These more complex intersections and interchanges require more exacting skills on the part of the driver, who must recognize and react to situations rapidly and accurately. These situations usually must be recognized well in advance of the point at which the maneuver must be made. At even moderate operating speeds, vehicle headlights do not provide adequate visibility for perception of the situation and for the appropriate maneuver to be made safely.

For years, highway and traffic engineers have attempted to improve intersection operations by channelization, signing, and markings. However, because of the complexity of current designs and the adverse visibility conditions frequently encountered, this approach is not entirely adequate.

Engineers naturally have turned to roadway illumination as a means of providing consistently available visibility which can encourage safe and efficient operation at highway intersections. Since the installation and maintenance of illumination systems are a substantial part of capital and operating budgets, strenuous efforts have been made to arrive at adequate designs at minimum cost. Among illumination specialists there is no unanimity of agreement of appropriate designs for the variety of conditions encountered. The development of truly technical approaches to this problem of night visibility is still under way, and many approaches offering promise must be explored.

OBJECTIVE

The objective of this report is to present the results of studies of operational characteristics of highway traffic moving through an intersection at which a number of illumination schemes had been installed. The characteristics reported are related to the ease of operation of the motorist as he passes through the intersection.

PREVIOUS STUDIES

There have been several operational studies of traffic under illumination conditions reported by other investigators. Their findings are of interest and concern to this investigation and are briefly summarized below:

A study was made in 1939 on a one-mile section of lighted highway in Ohio. It was concluded that the average nighttime speed, with or without illumination, was lower than the average daytime speed (3). The average night speeds recorded were slightly less with illumination than when the roadway was unlighted.

A New Jersey study reported in 1944 (4) was made on low volume tangent sections of rural highways. The findings indicated that lighting did not significantly affect travel speeds. However, based on the transverse position and clearance between vehicles, the behavior of drivers at night on lighted highways conformed more nearly to their daytime driving practices than did that of the motorist in unlit sections.

Taragin and Rudy (5) reported on the results of a Connecticut Turnpike study of the effectiveness of highway lighting, delineation, and pavement markings. Effectiveness was measured by speed, lateral placement, headway, lane use, and acceleration and deceleration lane usage. The study was conducted at a freeway interchange. The results showed no significant differences in average vehicle speeds, lateral placements and headways. The use of speed-change lanes improved with increased illumination. The importance of delineation was demonstrated. They commented that other parameters must be studied to evaluate the effect of roadway illumination on traffic operations.

D. E. Cleveland conducted a study in 1960 at the same Texas rural Y-type intersection at which the presently reported studies were made. The objective was to measure the effect of illumination on driver tension. The galvanic skin reflex, or change in electrical skin resistance, was used to discriminate among the conditions of illumination. Only 80 per cent as many tension responses were

produced under illumination as compared to no lighting in the intersection. Average travel time was measured through the intersection, and there was found to be no significant difference between travel times for lighted and unlighted conditions for these test drivers. Later studies gave similar results.

In 1959 Darrell and Dunnette (2) studied driver performance at a cloverleaf interchange in Minnesota under five illuminated study conditions. The drivers tested stated that they were more confident, had less difficulty, and had a better opportunity to do a good job of night driving when visibility was improved by the addition of highway illumination.

In 1962 Christie (1) described a marked user preference for a cut-off as contrasted to a noncut-off lighting system. He conducted a galvanic skin reflex (GSR) experiment and it was found that at night there was remarkably lower GSR in the cut-off installation than in the noncut-off installation. Although no such difference was detected in daylight, it was noted that the subjects drove slightly faster in the cut-off installation at night.

Wright and Oppenlander (7) recently reported on an evaluation of intersection illumination in Indiana. The purpose of the study was to investigate the effects of illumination on certain traffic stream characteristics at two rural intersections. The first part of the study compared the operational and safety characterisitcs of these intersections with and without highway illumination. The second part consisted of an economic analysis at both study locations to determine the economic feasibility of intersection illumination. Comparing these results with earlier studies it was possible to compare no illumination, delineation, and after illumination conditions. Individual vehicles' speeds were measured using radar speed meters with one control station. Nighttime passenger car speeds tended to be slightly higher after delineation while trucks showed no change. Average speeds tended to change very little. The economic analysis indicated that illumination was more justified at one location and that delineation was more justified at the other location.

THE STUDY

In recognition of the fact that at intersections the driver frequently needs better than ordinary visibility of the driving environment, the Texas Highway Department in 1957 authorized the Texas Transportation Institute of Texas A&M University to undertake a research project to investigate the effects of various types of intersection illumination and signing on traffic safety and performance. The Bureau of Public Roads, through the Highway Planning Survey research program, co-sponsored the research in recent years.

The problem of seeing on lighted streets has been very thoroughly studied and many of its aspects are fairly well established. The principal justification for street lighting must be to make roads safer and the final answer must be

measurable in terms of the effect on accident rates. The connection between street lighting and accidents is tenuous and accident statistics can only be crudely related to lighting. Lighting can be used to illuminate the physical features of the roadway and to aid the driver in the driving tasks. When lighting has given the driver all the information he needs there is no more that lighting can do. Approaching the problem, it was believed that the objectives could be attained if the answers to two questions were obtained. These are:

1. What and how well does the driver need to see to pass through an intersection with minimum hazard and with desirable operating characteristics?

2. What illumination approach is needed to provide the required visibility?

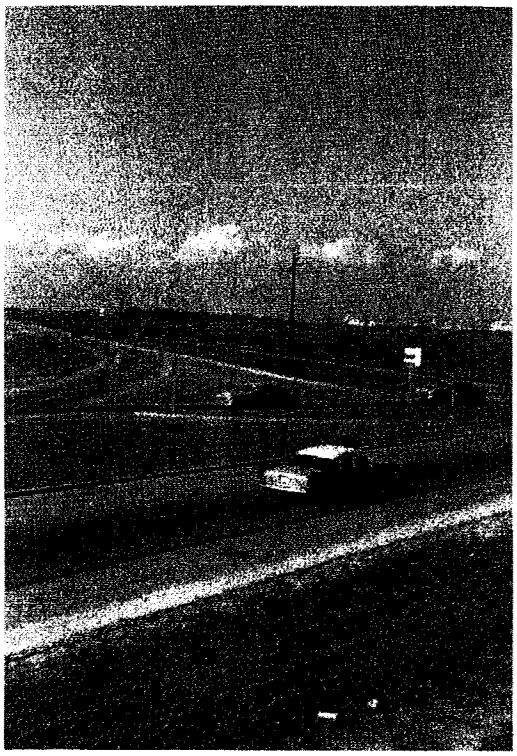
The typical approach to the intersection illumination problem has concentrated on safety experience derived from studies of reported accidents. Even with the best devised reporting systems, however, it is difficult to isolate the level of illumination as direct cause in differential accident experience at intersections. Because of the many contributing factors to accidents and many variables in design, illumination, and operation, it was decided in this study to give minimum emphasis to this aspect. Nevertheless, accident experience at the intersection considered in this investigation was studied but found to be inconclusive.

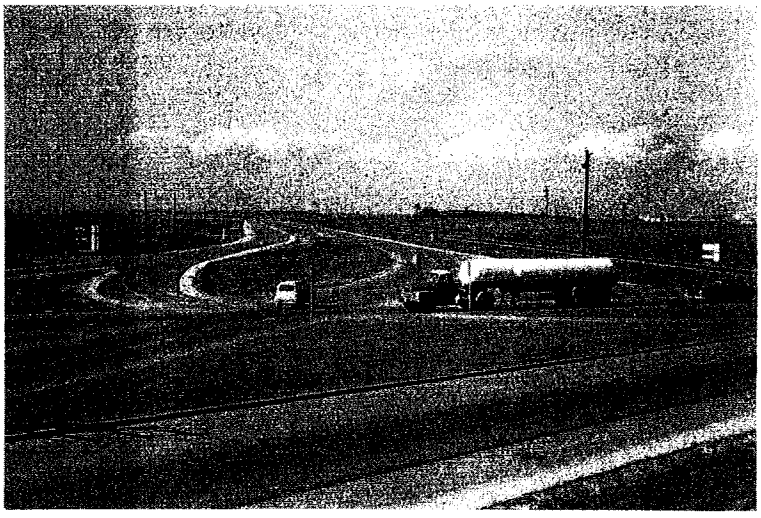
In selecting the approach to the problem, much attention was directed towards providing members of the Project Advisory Committee and Texas Transportation Institute research staff with as much information as possible on intersection illumination alternatives.

The main effort of the study was directed to evaluation of traffic performance in intersection areas. It is reasonable to assume that visibility at the intersection will be reflected in the driver's actions as he approaches and passes through the intersection. It is also reasonable to assume that the smoothness of operation through the intersection at night should be somewhat similar to that achieved in the daytime.

An important part of this research has been devoted to evaluating field installations of highway illumination. Visual evaluation, accident analysis, measurements of vehicle operational characteristics, and measurement of driver behavior have been used to compare alternate approaches to highway illumination.

Major field studies were conducted at two Y-type grade intersections; one near Austin and one near Texas City. Figures 1 and 2 show day and night views at the Texas City Intersection.





PHOTOGRAPHS OF STUDY SITE

FIGURE 1

FIGURE 2

At each intersection, a number of photometric measurements were made to serve as a check on calculated illumination values and also to provide information on illumination characteristics of such geometric figures on the intersection as signs, curbs and medians. Commercially available light meters and brightness meters were used to take the measurements.

In other detailed studies of traffic operations, numerous characteristics were measured. In general, there were reflections of the performance capabilities of the vehicle and the manner in which it was operated by the driver. Those driver characteristics having the most effect on the operation of the vehicle were determined where possible.

Measurement systems were developed for obtaining appropriate information on the following characteristics:

1. Traffic volume and composition.
2. Lane use.
3. Record of position with respect to other traffic.
4. Continuous record of speed through the study area.
5. Stop sign observance and gap acceptance.
6. Merging traffic performance.
7. Familiarity of driver with the intersection.

Since little information was available on the techniques of studying operational characteristics of traffic at night, much effort was devoted to experimenting and evaluating relatively untried techniques. Many of these approaches were based on the use of motion picture photography (used quite successfully in other operational studies by the Texas Transportation Institute). It was found that the motion picture method, supplemented by manual observers and automatic recorders, was effective in measuring the characteristics of vehicular operation through the intersection. In one study, reference markers were placed on the intersection's curbs, medians, or center lines, in positions where the driver's attention would not be distracted from his driving task. In other studies, pneumatic road tubes were used to actuate lights mounted on a panel in the field of view of the camera, or to record on a standard twenty-channel event recorder.

A camera vantage point was located on the Texas Transportation Institute's 60-foot portable tower, near enough to the intersections to allow for good photography, at the same time far enough removed to avoid distracting drivers. Satisfactory techniques for night filming had to be developed. Vehicle headlight and taillights were found to be clearly distinguishable on high-speed film. Further, when roadway illumination was provided, the pavement and the reference markers could be photographed, but not clearly enough to record data with the desired precision. In other tests, infrared lights were used as reference markers and infrared film was used in the data camera. In general, it was found that the nighttime photographic

methods do not always provide data of the accuracy desired, since a great deal depends 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 who record the data from the film.

Concealed radar speed meters equipped with recording units were located some distance from the approaches to the intersection as a supplemental source of speed information.

In order to estimate the effect of familiarity, traffic from an area bounded by the three counties surrounding the test sites was considered as "local" traffic which could be assumed as "repeat" traffic through the intersection. All other traffic was classified as "foreign" traffic.

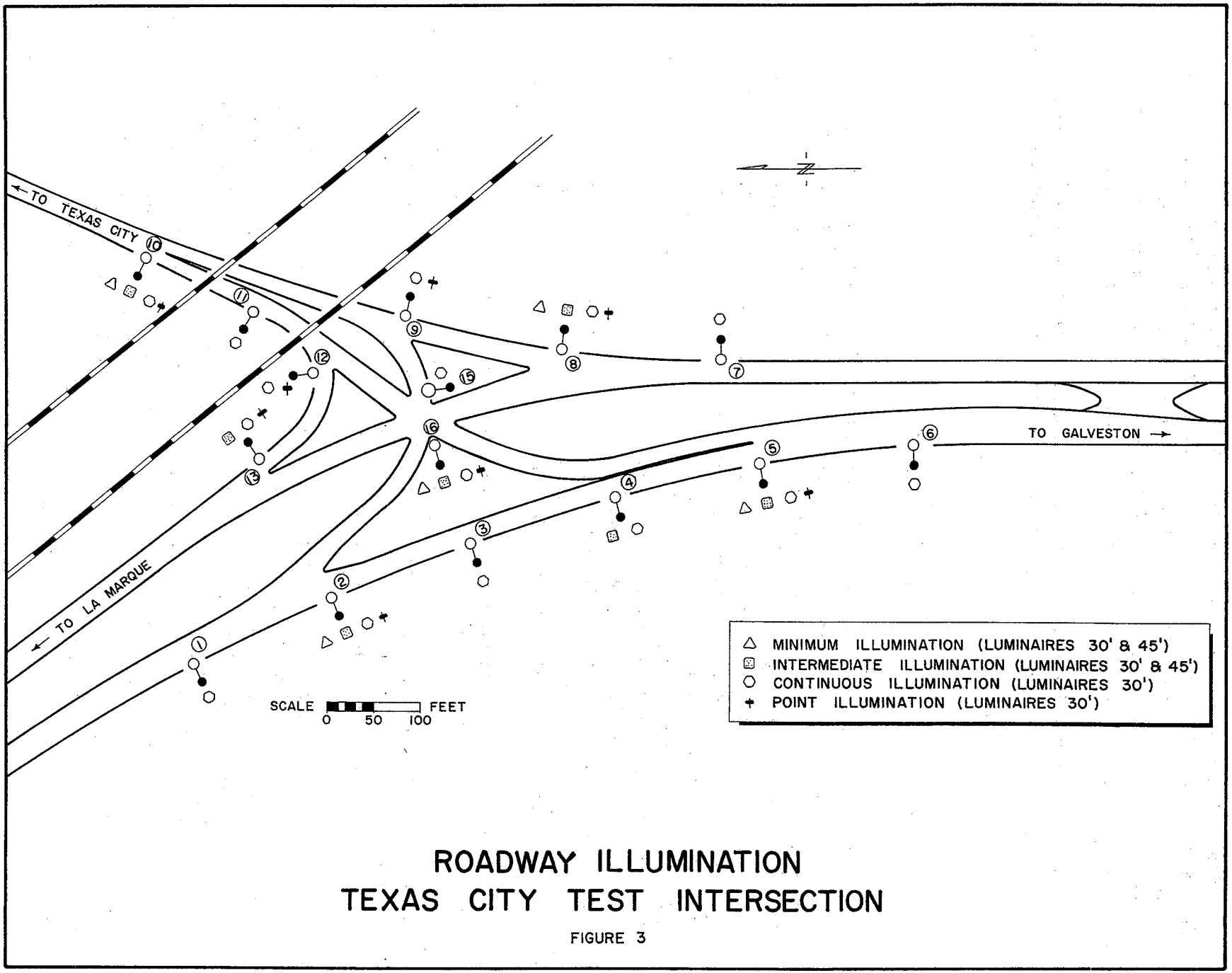
The most intensive field studies were made at the Texas City intersection, selected as a study area because of its complexity and its rural location. A rural area, with few conflicting light sources, offers more flexibility for research in illumination than does an urban area.

DESCRIPTION OF STUDY AREA

The lighting system at the Texas City Wye intersection consisted of Type III luminaires with 400-watt clear mercury vapor lamps with an initial output rating of 21,000 lumens. The luminaires were equipped with integral regulated ballasts.

Figure 3 shows the main illumination configurations used in this study. In addition to these four configurations the transitional illumination system recommended by Finch in his 1963 report to the Texas Highway Department was also installed. The minimum illumination scheme consisted of five luminaires mounted at 30 and 45 feet, respectively, through the intersection area as shown in the figure. Seven luminaires at 30- and 45-foot mounting heights were used in the intermediate illumination system.

A continuous illumination scheme with the luminaires mounted at a 30-foot mounting height required 15 luminaires. This continuous illumination did not extend as far back from the intersection as recommended by manufacturers, but in the intersection area itself it was in accordance with their general recommendations. In addition, a point illumination scheme involving eight luminaires mounted at 30 feet was installed (Figure 3).



ROADWAY ILLUMINATION
TEXAS CITY TEST INTERSECTION

FIGURE 3

The traffic operations studies were designed to reveal possible effects of different night visibility conditions on driver performance. The studies were undertaken during 1960, 1961, and 1963 at the intersection. A variety of experimental conditions of varying visibility were used and driver performance was studied. All studies were conducted between the hours of 7 and 11 p.m.

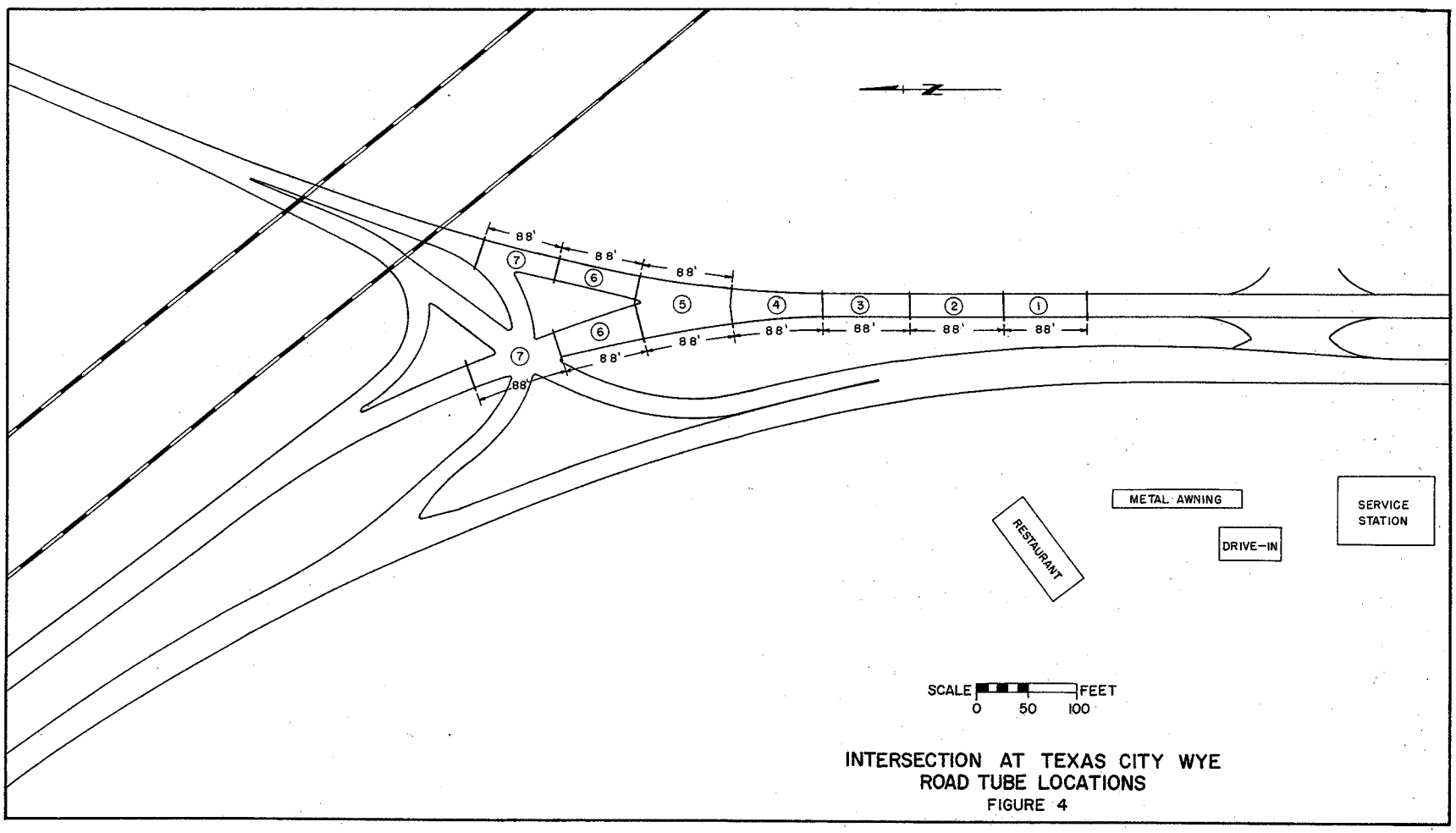
Figure 4 shows the location of road tube measuring positions for measuring the speed fluctuation of individual vehicles as they passed through the intersection.

RESULTS OF STUDIES

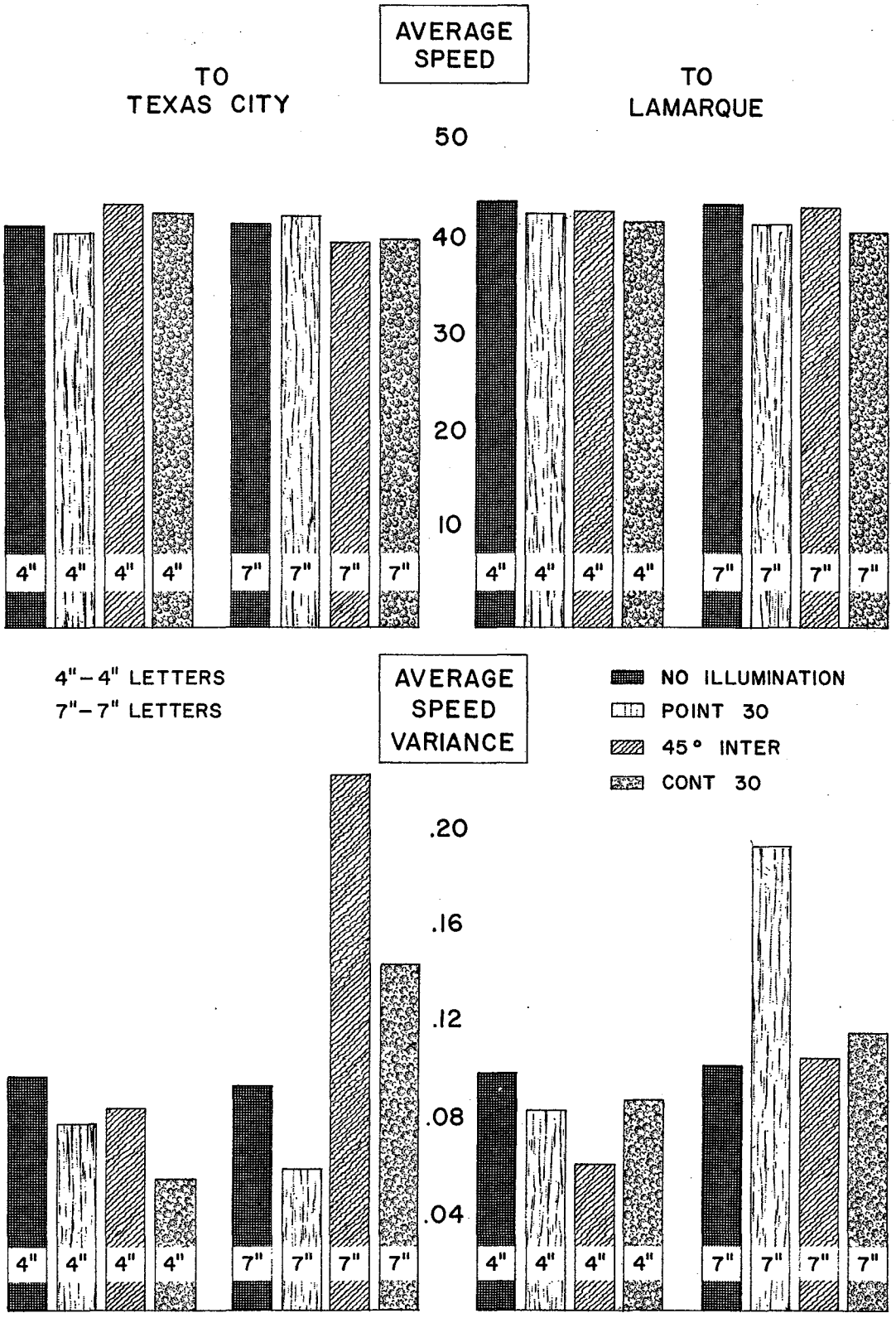
Figures 5, 6, and 7 present a summary of the findings of the 1960 and 1961 studies. Figure 5 shows the average speed and the variance, a measure of the fluctuation in individual speed, as the vehicles passed through the test intersection. The conditions of this study include the four illumination conditions: (1) no illumination, (2) point illumination by luminaires mounted at 30-foot heights, (3) intermediate illumination with luminaires mounted at 45-foot heights, and (4) the continuous illumination system at 30-foot mounting heights. Also, two different sizes of letters were used on the directional signs, directing traffic to Texas City and to La Marque. The average speed for the 16 sets of data ranged from slightly less than 40 mph to less than 44 mph (Figure 5), a variation in speed which even if statistically significant, is of little importance from a practical point of view. There is no apparent difference between the average speeds under the different illumination conditions nor in the different sign letter sizes.

The lower portion of Figure 5 summarizes the variability of the operations of individual drivers as they pass through the intersection. If improved illumination were associated with smoother operations through the intersection, then it would follow that the magnitude of variance would decrease from left to right within a group of identical sign conditions. There appears to be no significant chracteristic which can be concluded from this study of operations based on almost 1000 vehicles.

Additional studies were conducted to determine the effect on traffic speeds of two different types of guide signs in relation to the conditions of continuous illumination and no illumination. One of the signs consisted of 7-inch capital first letters followed by appropriately scaled lower case letters, and the other sign was a standard guide sign composed of 7-inch letters, all capitals. Both signs utilized black letters on a white, beaded background. A comparison of average speeds as shown in Figure 6 does not reveal any consistent difference due to illumination or type of sign legend. The over-all difference in average speeds again was less than 5 mph, a difference which is not practically 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 sign

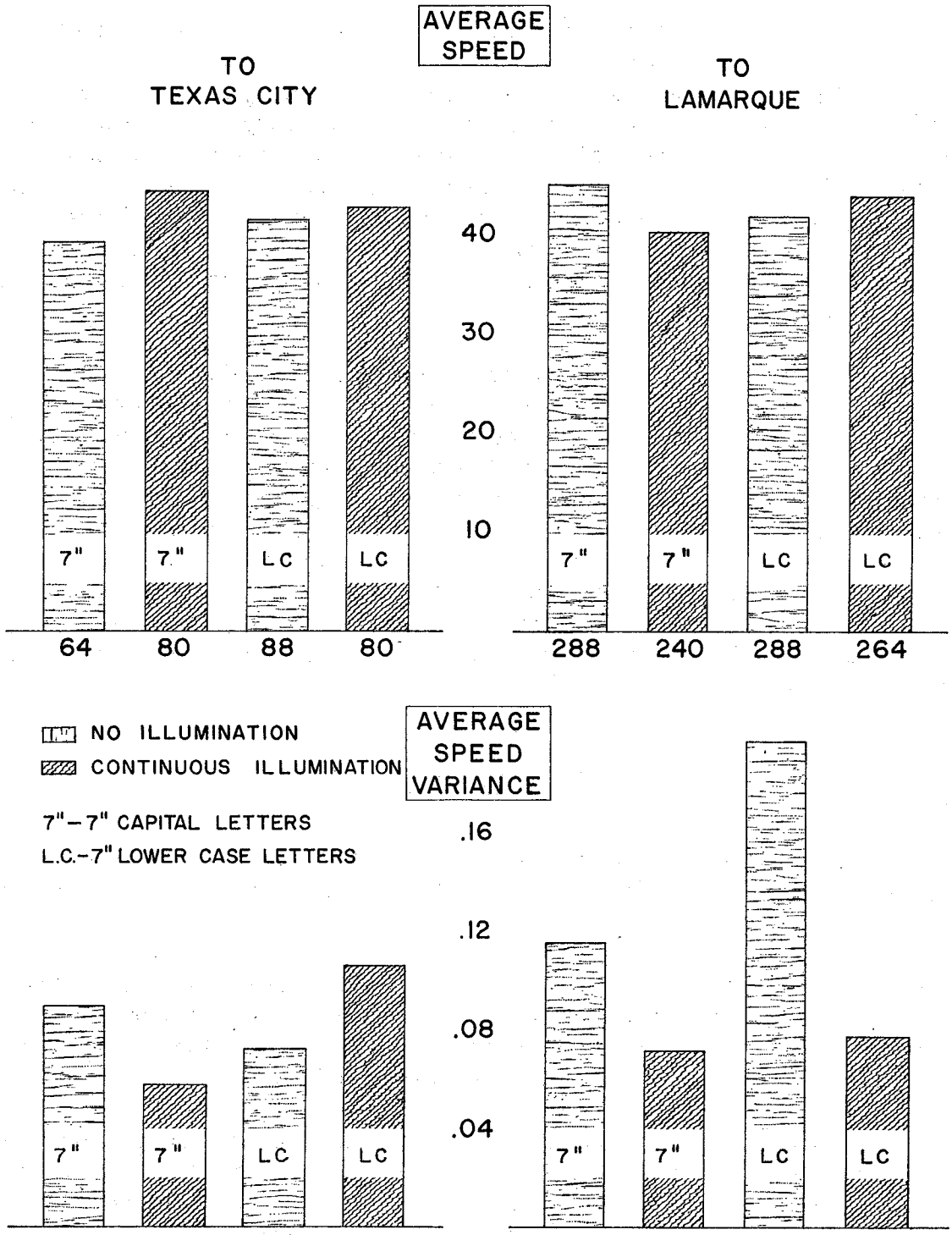


INTERSECTION AT TEXAS CITY WYE
ROAD TUBE LOCATIONS
FIGURE 4



SUMMARY OF NIGHT OPERATIONS

FIGURE 5



EXPERIMENTAL SIGN OPERATIONAL STUDIES

FIGURE 6

or the continuous illumination when compared to the condition of no illumination.

Figure 7 presents the results of a study conducted during daylight hours to compare the effectiveness of the three sign configurations, one with 4-inch capital letters, one with 7-inch capital letters, and an experimental sign with 7-inch first capitals and appropriately sized lower case letters. The average speed through the intersection varied less than two miles per hour. The average speed variance through the intersection was greatest for the larger size capital letter, but the significance is questionable because the high variance was observed on only one of the paths.

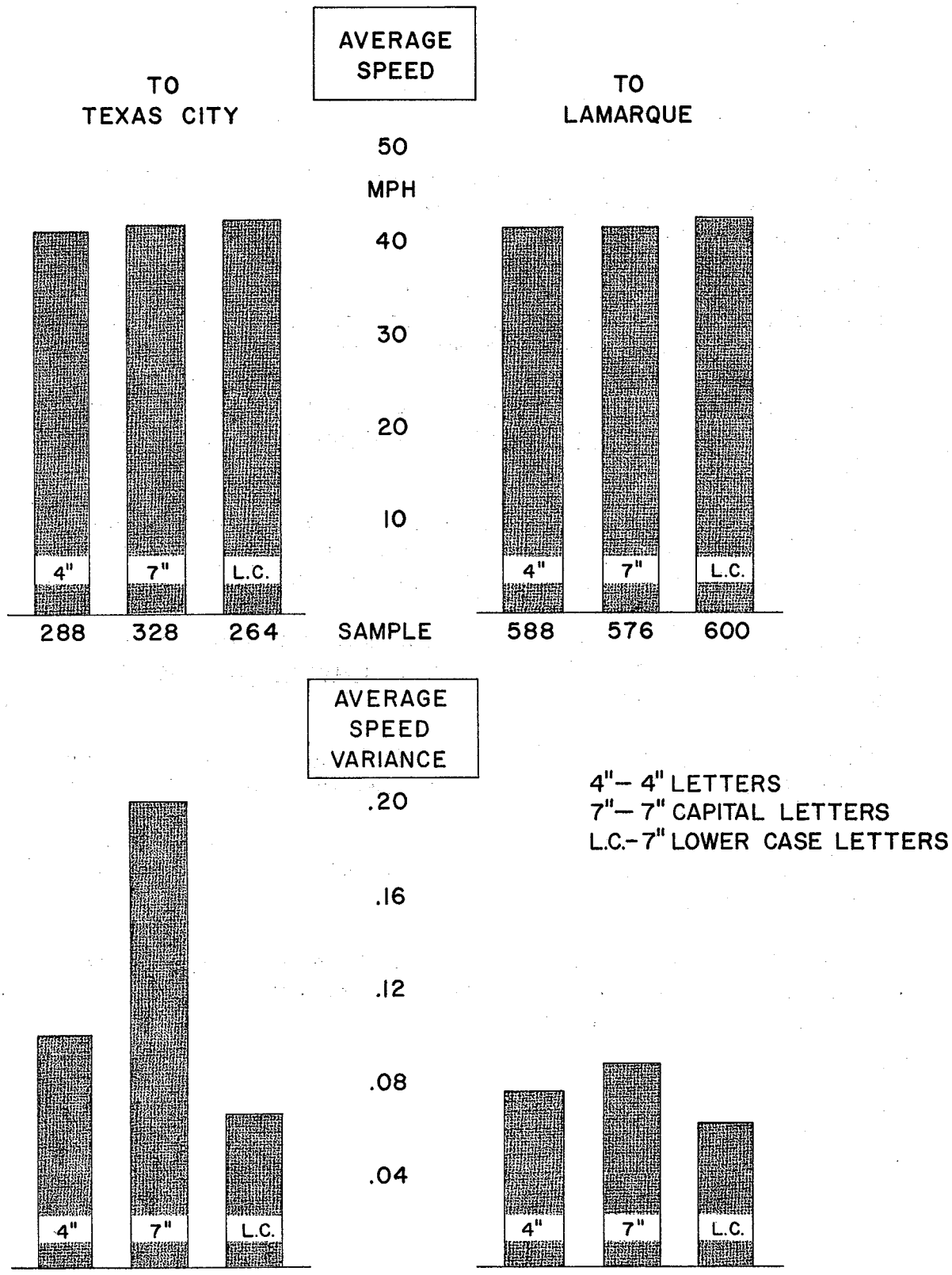
The studies conducted in 1963 were designed primarily to evaluate a transitional lighting system recommended by D. M. Finch in a report to the Texas Transportation Institute entitled "Lighting Studies at the Texas City Wye." In these studies the transitional lighting system was compared to the minimum lighting scheme and the continuous 30-foot lighting scheme as previously described. The comparisons were made on the basis of variability in speed of individual vehicles passing through the intersection as measured by the logarithm of the variance of the time mean speed. The results of this study showed that there was less variability in speeds with the continuous and transition lighting systems than with the minimum lighting systems. This difference in variability, however, was not great.

CONCLUSIONS

It was concluded that the entire range of illumination conditions presented to the drivers studied did not appreciably affect the operational characteristics of the traffic stream.

Even with an elaborate measuring system it was not possible in this research to detect significant reactions of drivers on the highway to a wide range of illumination conditions. In other words, the benefits of illumination are not necessarily reflected in the characteristics of traffic operation.

It is believed that any new research on the problem of night visibility reaction should employ devices which deal directly with the driver such as the acceleration noise meter and the galvanic skin response. Use of such equipment appears to offer the only analytical hope at the present time of evaluating illumination by means of driver reaction.



DAY OPERATIONAL STUDIES

FIGURE 7

REFERENCES

1. Christie, A. W., "Some Investigations Concerning the Lighting of Traffic Routes," Public Lighting Vol. 27, Issue 119, December, 1962, pp. 189-199.

2. Darrell, J. E. P. and Dunnette, M. D., "Driver Performance Related to Interchange Marking and Nighttime Visibility Conditions," Bulletin 255, Highway Research Board, 1960, pp. 128-137.

3. Marsh, B. W., "Report of Committee on Light as Affecting Highway Travel at Night," Proceedings of the Highway Research Board, Vol. 19, 1939, pp. 271-274.

4. Normann, O. K., "Studies of Motor Vehicle Operation on Lighted and Unlighted Rural Highways in New Jersey," Proceedings of the Highway Research Board, Vol. 24, 1944, pp. 513-534.

5. Taragin, A. and Rudy, B., "Traffic Operations as Related to Highway Illumination and Delineation," Bulletin 255, Highway Research Board, 1960, pp. 1-29.

6. Walker, W. D , "Effects of Highway Lighting on Driver Behavior," Public Roads, Vol. 21, No. 10, December 1940, pp. 187-192, 199-200.

7. Wright, J. M. and Oppenlander, J. C., An Evaluation of Intersection Illumination, Joint Highway Research Project, Purdue University, December 1963, pp. 63.

8. Wyatt, F. D. and Lozano, E. "Effect of Street Lighting on Night Traffic Accident Rate," Bulletin 146, Highway Research Board, 1957, pp. 51-55.

PUBLICATIONS

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.