EVALUATION OF THE TELEVISION SURVEILLANCE SYSTEM FOR THE BAYTOWN-LAPORTE TUNNEL

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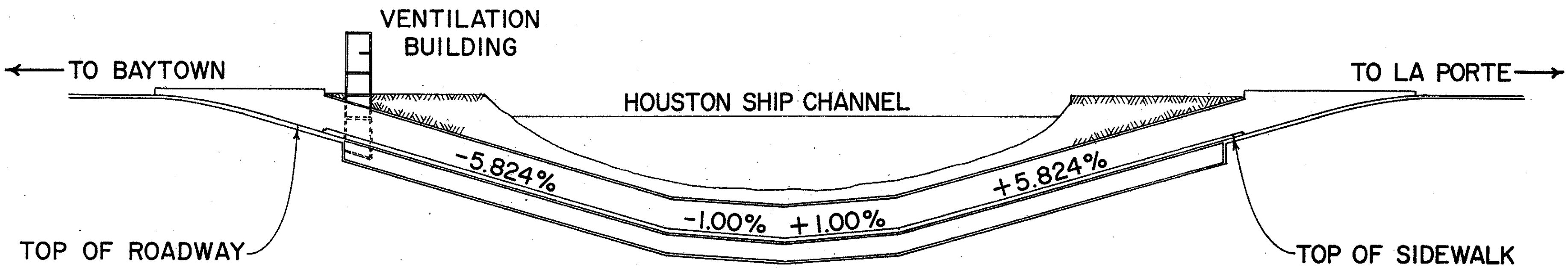
INTRODUCTION

The Baytown-LaPorte Tunnel was constructed and is maintained by the Texas Highway Department. It is 3000.1 feet in length with a ±5.824 percent grade on each end which intersects a ± 1.0 percent grade through the center (Figure 1). The Baytown-La Porte Tunnel is a toll-free facility under the Houston Ship Channel and connects Baytown and LaPorte Texas on a state highway route. It is located three miles south of Baytown and five miles north of LaPorte (Figure 2).

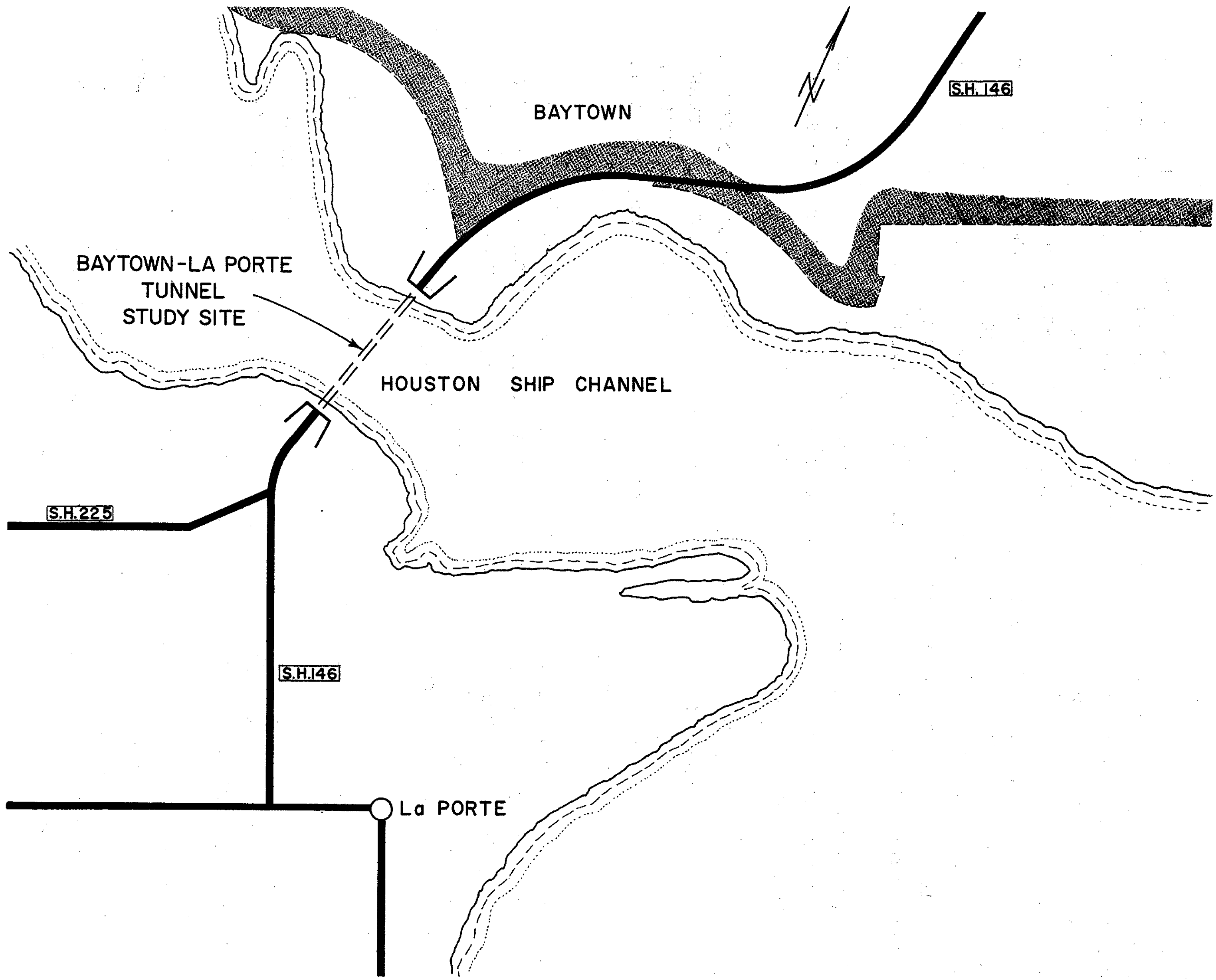
It is a recognized fact that the maintenance of orderly traffic movement through a tunnel and over bridges requires some type of continual surveillance of traffic flow in order that appropriate traffic control measures can be put into effect when needed. A closed circuit television system appears to have the flexibility of providing the necessary information to assure that the proper traffic control can be imposed and to enable an evaluation to be made of the over-all effect of the control on the entire system. With the increasing demand that automobiles are placing on tunnels as well as freeways, television appears to be a very effective tool for maintaining desired levels of service.

In April of 1963 the Texas Transportation Institute initiated a cooperative research project with the Texas Highway Department and the U. S. Department of Commerce, Bureau of Public Roads, to evaluate the use of television as a surveillance system for the Baytown-LaPorte tunnel. A two-year research program was developed to study uses of the television medium. During the first year of this two-year program, most of the work was concentrated towards evaluating the then existing manual surveillance system as a basis for comparing operation with a closed circuit television survellance system.



PROFILE BAYTOWN—LA PORTE TUNNEL

FIGURE I



LOCATION OF STUDY SITE

FIGURE 2

OBJECTIVES

The inflexibility of tunnels and bridge facilities with regard to re-routing traffic during times of a lane stoppage requires that continual surveillance of traffic flow on such travel ways be provided so that traffic control measures can be put into effect as soon as stoppages are observed. Freeways assume the same characteristics during peak-periods. In the Baytown Tunnel a 24-hour surveillance was initially accomplished by guards stationed at two locations in the tunnel. It was proposed that a closed circuit television surveillance system be installed that would cover the entire length of the tunnel and the approaches to the tunnel entrance. The following specific project objectives were planned in connection with this installation.

1. To investigate the feasibility of using the television installation for traffic surveillance in tunnels and othertraffic facilities with similar physical restrictions to traffic movements.

2. To evaluate television equipment and accessories in order to determine the optimum design of a television installation for conducting traffic studies and surveillance. This would include determination of the relationship of mounting heights, camera spacings, and lens selection for various types of studies.

3. To develop equipment and techniques for recording traffic data by filming and television monitors. This would consider the use of a complex data reduction procedure which would require the time motion method of viewing the study area, even though many of the studies might be made directly from observing traffic flow on the monitors.

4. To conduct operational studies to determine the effectiveness of the tunnel traffic control system. In addition to the new signal controls outlined in the plans and specifications, various other control devices, such as variable speed limit signs and advance warning signs and signals were used.

5. To analyze traffic flow characteristics obtained from data recorded from the television monitors. To be included in these studies were the effect of the traffic control devices (mentioned in 4 above) on the traffic flow, experiments in car following, and the evaluation of other measures of traffic flow characteristics.

TUNNEL OPERATION

Manual Surveillance

From the time of the completion of the Baytown-LaPorte Tunnel in the Spring of 1953, until the installation of the closed circuit television system, the staff assigned to the manual surveillance system consisted of the following:

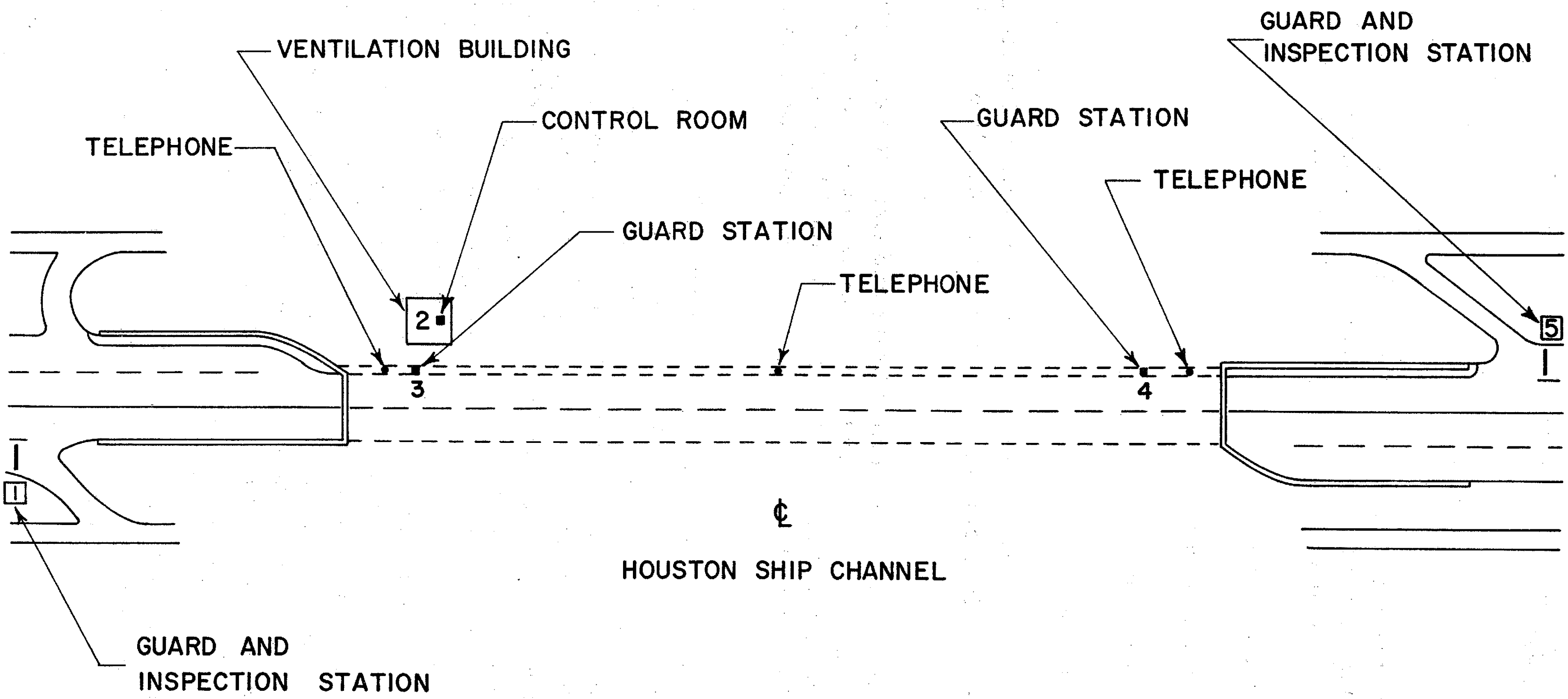
1. Four control room operators.
2. Three sergeants of the guard.
3. Twelve privates of the guard.
4. Twelve maintenance men.

Of the above personnel, twenty-one men were required to operate five stations 24 hours per day (Figure 3). This did not include or make any allowance for vacation or sick leave.

The maintenance men worked on an hourly basis and were primarily concerned with the maintenance of the equipment, lawns, roadsides, buildings, and tunnel washing. However, some of the maintenance men were used to complete shifts and others worked as relief men when the surveillance personnel were on vacation or sick leave.

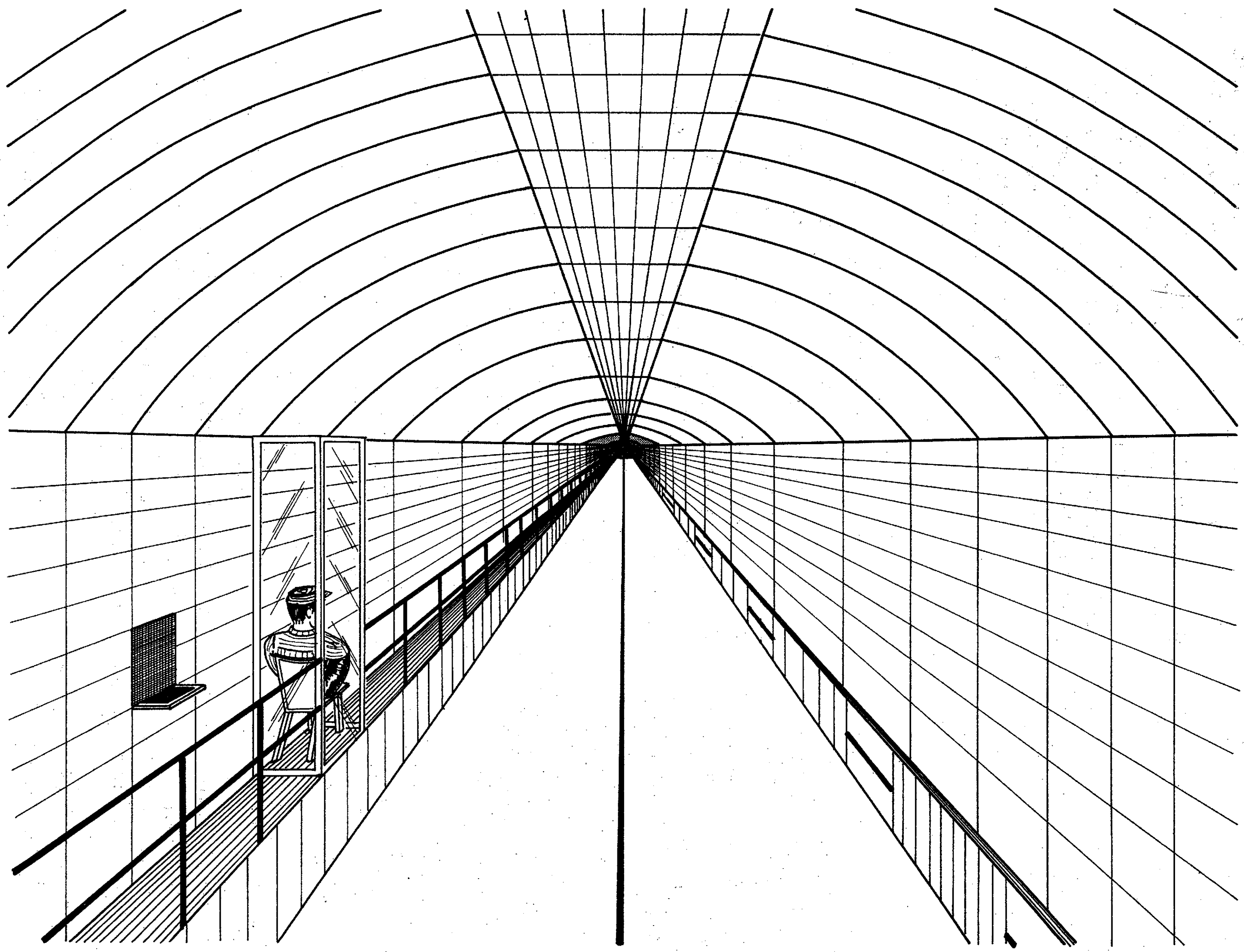
The twelve privates of the guard worked on alternating 8-hour shifts and were stationed at locations 3, 4, and 5 (see Figure 3). Locations 3 and 4 were approximately 150 feet from each end of the tunnel and location 5 was on the south approach to the tunnel. Locations 3 and 4 were selected as guard stations because the guards could observe one-half of the tunnel operation and have access to a telephone when a stoppage occurred. The telephones were located approximately 60 feet from each end of the tunnel and at the center of the tunnel. When a stoppage occurred, the guard nearest the stoppage immediately reported the incident via phone to the control room operator. The guards at locations 3 and 4 (Figure 3) then proceeded to change the traffic signals inside the tunnel from green to amber. All of the traffic lights inside the tunnel were controlled by the guards stationed on each end of the tunnel (locations 3 and 4). The guard at location 3 assisted the auto car operator in clearing stoppages. Immediately after the stoppage was cleared, the guards switched the lights in the tunnel from amber to green for normal tunnel operation. The guards then resumed their position in a booth on the cat-walk as shown in Figure 4.

The four control room operators worked on alternating 8-hour shifts and received all calls from the guards stationed inside the tunnel. As stated previously when a stoppage occurred it was reported to the control room operator



LOCATIONS OF MANUAL SURVEILLANCE STAFF

FIGURE 3



MANUAL TUNNEL SURVEILLANCE

FIGURE 4

and he in turn reported the stoppage to the guards on each approach to the tunnel (locations 1 and 5). The control room was located on the second floor of the ventilation building and the auto car or wrecker used in removing disabled vehicles was parked next door. When a stoppage was reported by the guards inside the tunnel (locations 3 and 4) the control room operator notified the guards on each approach (locations 1 and 5) (Figure 3) and then operated the auto car throughout the clearing procedure. During a stoppage the control room was unoccupied. In utilizing the existing system for clearing stoppages the control room operator was assisted by the guard at location 3 (Figure 3) in the clearing task. Immediately after the stoppage was cleared, the auto car was parked and the control room operator returned to the control room. The guards at locations 1, 3, 4, and 5 were then advised of the clearing and the amber signal lights were then changed to green and the advisory signs removed from the roadway.

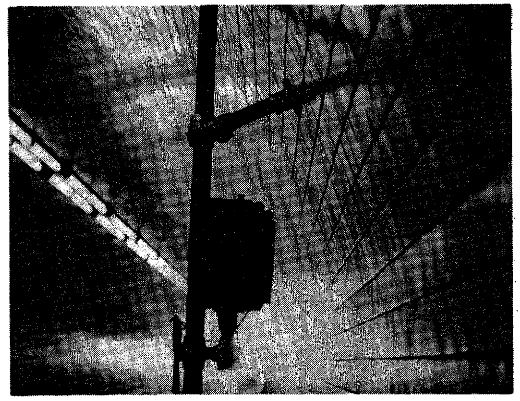
In addition to operating the auto car the control room operator kept a daily log of all stoppages which occurred in the tunnel. The control room operator also had to keep a constant watch on the carbon monoxide analyzer located in the control room. Since the carbon monoxide analyzer was not automatic, the operator had to manually control the switch which increased the flow of fresh air into the tunnel when a pre-determined carbon monoxide level was reached. Relief personnel for the control room operators were obtained from the qualified tunnel staff as needed.

Guards were also located on each approach to the tunnel (locations 1 and 5) (Figure 3). The three sergeants of the guard worked on alternating 8-hour shifts with the privates of the guard serving as relief men. The three sergeants of the guard always worked from location 1 (Figure 3) because this location was considered the most critical. The guards at locations 1 and 5 assisted in clearing stoppages by placing advisory signing in the roadway and by changing the traffic signal on each approach when a stoppage occurred. In addition to assisting in clearing tunnel stoppages, the guards on each approach inspected each truck for explosives, over heights, over widths, and each vehicle pulling a trailer for a safety chain.

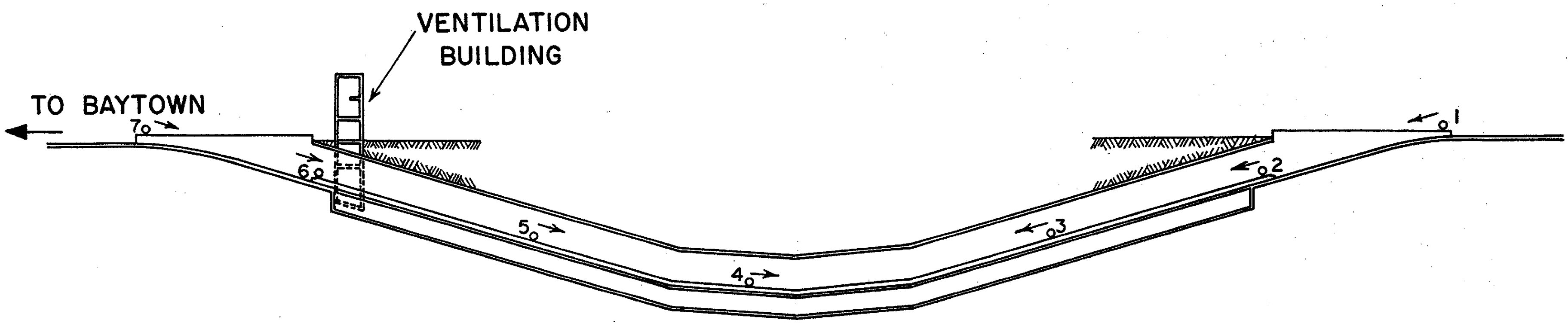
Television Surveillance

The closed circuit television system for the Baytown-La Porte Tunnel was formally accepted by the Texas Highway Department on May 26, 1964. The closed circuit television system included five random interlace cameras inside the tunnel and 1 random interlace camera on each approach.

The five random interlace cameras inside the tunnel were mounted on vertical poles which were attached to the wall of the tunnel at the top and the cat-walk at the bottom. A weatherproof camera housing suitable for outdoor use, was used to protect the camera from the environment. The camera locations, housing, and type of installation are shown in Figure 5.



CAMERA HOUSING & TYPE OF MOUNT



CAMERA LOCATIONS

FIGURE 5

Eight 14-inch monitors were mounted in the console cabinet located in the ventilation building. The monitor arrangement is shown in Figure 6. One monitor was used for each camera and an auxiliary monitor was provided in case of monitor failure.

In addition to the closed circuit television system in the Baytown-LaPorte Tunnel, new traffic signals were installed on each approach to the tunnel and the signals inside the tunnel were rewired to place the controls in the control room. The procedure used in clearing a stoppage in the tunnel utilizing television surveillance was essentially the same method as that used before the closed circuit television system was installed. The only exception to the procedure used in the manual surveillance was that the guards at locations 3 and 4 were eliminated (Figure 3) and one man was added to the control room staff to assist the control room operator when a stoppage occurred. It was decided to have one maintenance man work the same shift as each control room operator and his duties would be confined to the ventilation building where he was available to help the control room operator in clearing stoppages.

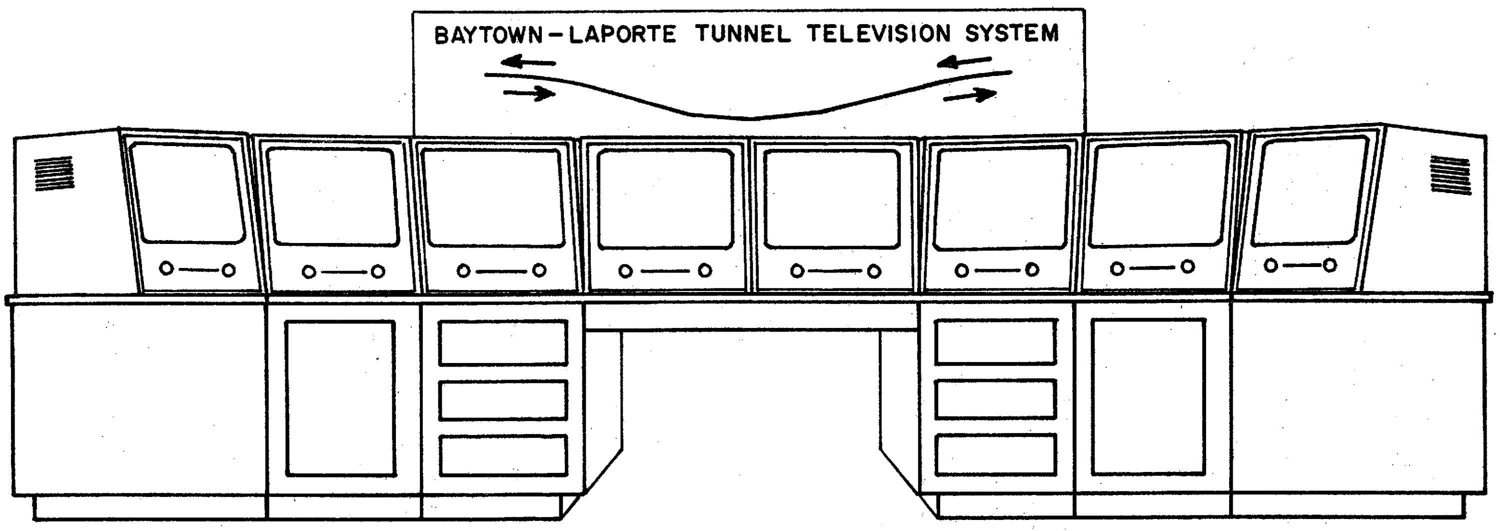
As a result the staff of the television surveillance system consisted of the following:

a. Four control room operators.

b. Three sergeants of the guard.

c. Six privates of the guard.

d. Four maintenance men.



MONITOR ARRANGEMENT

FIGURE 6

INSTALLATION OF CLOSED CIRCUIT TELEVISION SYSTEM

Specifications

Plans and specifications for the revision of the existing traffic signal system, illumination system, and installation of closed circuit television system at the Baytown-La Porte Tunnel were prepared by the Texas Highway Department. The closed circuit television system consisted of five cameras inside the tunnel and one camera on each approach, Figure 5. The exact locations of the television cameras and lens to be used were to be determined utilizing an experimental camera at the time of installation. After the bid was awarded, the camera locations were determined experimentally by locating a camera at one end of the tunnel and then varying the lens sizes until the optimum picture could be obtained considering the field of view. This automatically determined the next camera location. It was decided that 3-inch lenses would be used at locations 2, 3, and 6 (Figure 5) and 2-inch lenses would be used at all other locations. The mounting heights were limited by the vertical clearance in the tunnel and the camera spacings and the lens selections were dictated by the roadway grades. Additional studies on mounting heights, camera spacings, and lens selection for various types of studies were conducted as an integral part of Project 2-8-61-24.

Technology concerning the application of closed circuit television equipment to traffic engineering was limited at the time this project was initiated. As a result, a very careful investigation was conducted between purchasing and leasing the specified system. From the investigation, it was concluded that it would be more advantageous for the Texas Highway Department to lease the proposed closed circuit television system.

The installation of the closed circuit television system was performed in two parts: (1) work to be performed by the lessee and (2) work to be performed by the lessor. The lessee provided a 120 volt - 60 cycle single phase AC outlet at each camera location and six outlets at the console location, revised all traffic signals, and installed a remote cable from each controller located in the tunnel to the proposed console location, and connected all wiring from the traffic system to the terminal strip in the console. The lessor installed the basic system of seven television cameras, eight television monitors in a console housing, and all connecting cables and/or wiring. The console cabinet was to have a working space in the front of the monitors at approximately desk height. A special video selector switch was to be provided by the lessor so that any video line in the console could be switched to the spare monitor.

Results of Bidding

The closed circuit television system for the Baytown-La Porte Tunnel was submitted for competitive bidding in October of 1963. Bidders were asked to submit bids on several alternatives. The results of this bidding are shown in Table 1.

TABLE 1

COMPILATION OF BID PRICES

	Random	Positive	Random	Random	Random
*Purchase	$18,071.00	24,937.00	25,978.00	28,220.00	32,596.00
**Cost in Two Yrs.	$24,071.00	30,937.00	31,978.00	34,220.00	38,596.00
Cost in Four Yrs.	$30,071.00	36,937.00	37,978.00	40,220.00	44,596.00
***Lease Two Yrs. Alternate No. 1	$13,368.00	18,308.00	40,877.00	33,000.00	48,200.00
***Lease Two Yrs. Alternate No. 2	$13,920.00	18,900.00	40,877.00	33,000.00	48,200.00
Lease Two Yrs. and Purchase as is	$17,080.00	24,879.00	46,196.00	42,900.00	58,200.00
Lease Two Yrs. and Purchase Like New	$19,741.00	27,622.00	49,148.00	***** 42,900.00	63,200.00
****Lease Four Yrs.	$20,016.00	27,324.00	52,893.00	42,900.00	63,200.00

*Includes $2,700 for work to be done by State forces.

**Includes $3,000 per year maintenance cost.

***Lessor must furnish additional equipment and labor totaling $2,700.

****At end of four-year period additional lease time or purchase must be negotiated.

*****Price to restore system like new $42,900 plus time and material. No figure given for time and material value

Each bid was evaluated independently on the basis of: (1) type of equipment bid, i.e., whether positive or random interlace cameras; (2) the ability of each bidder to perform the desired functions; and (3) the total price, both purchase price and lease price. After careful evaluation of each bid it was decided that it would be more advantageous to lease a closed circuit television system for a two-year period with the option to renew the lease provided that the lessor and lessee agree on the terms of the renewal. The bid was awarded to company A, Table 1, for the random interlace camera.

Under the terms of the lease agreement, the successful bidder was required to maintain, service, and make all necessary repairs to the leased equipment and at the lessor's expense. The maintenance of the equipment would begin within eight hours after notification of a malfunction of the equipment and sufficient spare parts would be warehoused by the lessor so that the complete system would not be out of order more than 24 hours. The standard retma resolution chart, Figure 7, would be the basis of determining the performance of the system and equipment. The minimum acceptable performance of the system and equipment would be 500 lines of horizontal resolution, and a corner resolution of 400 lines with a minimum of two foot-candles of scene illumination. The closed circuit television system would be at the minimum acceptable standards when these conditions were satisfied and the resolution chart was placed at a proper distance from each television camera determined by the focal length of the lens on the television camera.

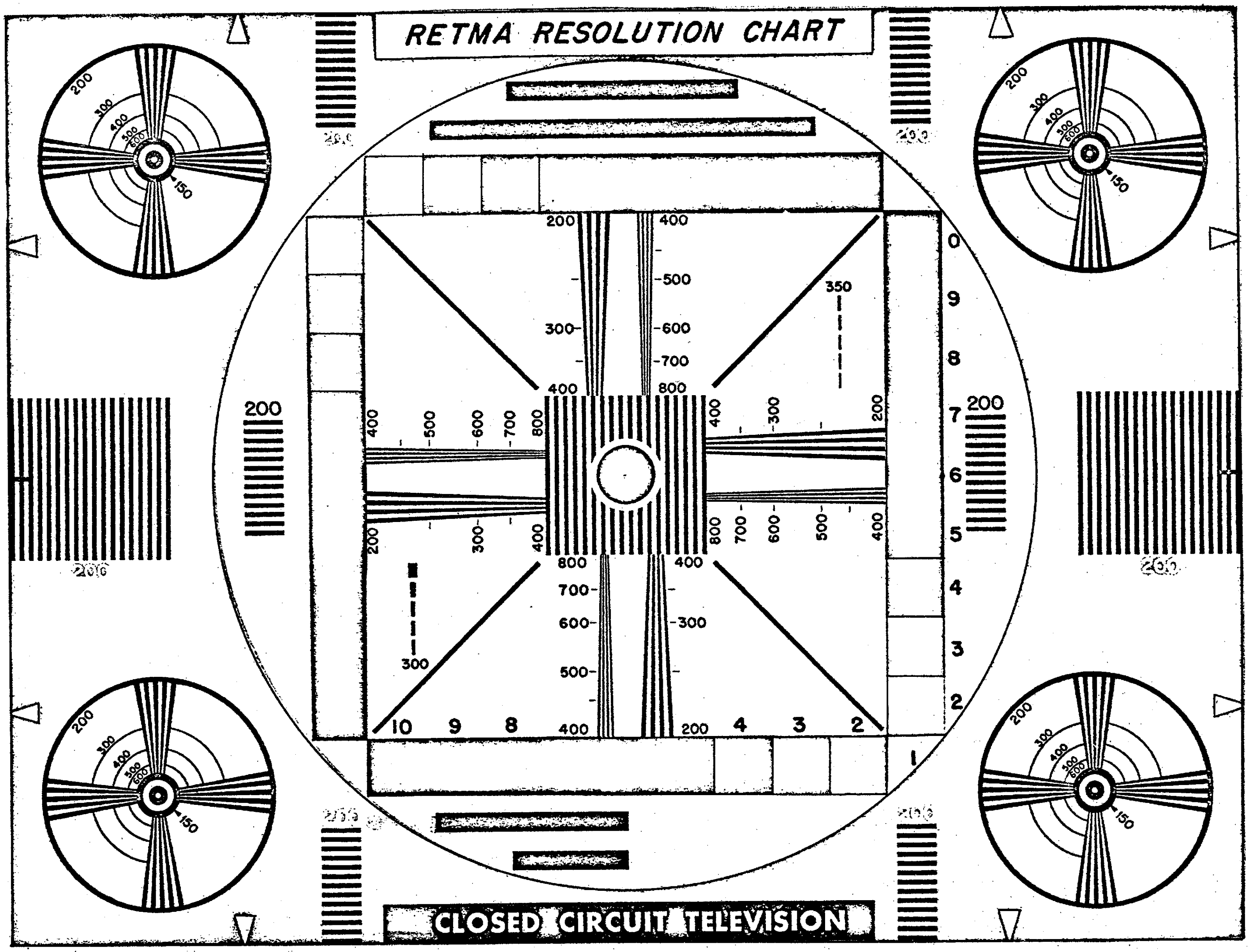


FIGURE 7

EVALUATION OF TELEVISION SURVEILLANCE SYSTEM

Cost Comparison

The total costs of operation for the Baytown-LaPorte Tunnel were investigated for both the manual observation by guards stationed in the tunnel and the closed circuit television system. The procedure utilized for reporting and clearing stoppages before the closed circuit television system was installed was used as a basis for comparing the cost of operation of the two systems.

The total costs of surveillance could be computed utilizing any of the following methods: (1) an annual cost based on man-hours of surveillance, (2) an annual cost based on employee monthly wage rate, and (3) an annual cost based on total number of men required. It was decided that total man-hours of surveillance would be the best method to be used for this cost comparison study since the relief men were employed by the hour and portions of their time were used for surveillance if they were needed.

Twenty-four-hour surveillance annually for five locations (Figure 3) required a total of 45,360 man hours of surveillance. This included two weeks or 10 working days for vacation for each man. However, it didn't include sick leave since there was no positive way to accurately predict annual sick leave for each employee. With the installation of the closed circuit television system, two guard stations (locations 3 and 4) (Figure 3) were eliminated but one employee had to be added to location 2 to assist the control room operator in clearing stoppages. This reduced the total annual man-hours of surveillance from 45,360 man-hours to 34,944 man-hours. This difference of 10,416 man-hours represents a substantial savings in labor alone amounting to $18,731.20 per year. The closed circuit television system rental was $580.00 per month or $6960. per year, which when subtracted from the total annual labor savings, results in a net annual savings of $11,651.20 or a monthly savings of $970.93. It should be noted that the above savings were based on the 1963-64 wage rate schedule as paid by the Texas Highway Department to the tunnel personnel. Since the maintenance cost of the closed circuit television system was covered under the terms of the lease agreement, the net annual savings represents only the surveillance staff salaries and equipment rental. It is believed that the maintenance costs figure will probably affect the total annual savings in the future, but at the present time there are no maintenance cost figures available.

Tunnel Stoppages

One of the objectives of this research project was to investigate and compare the costs of operation and the efficiency of two surveillance systems

(1) manual observation of guards stationed inside the tunnel and (2) the proposed closed circuit television system). In order that some measure of efficiency of operation could be obtained, it was decided that an accurate record would be maintained on the tunnel operation with specific emphasis on the number and type of stoppages and the total time to clear each stoppage. A form, Figure 8, was developed for use by the control room operator and was put into service approximately six months prior to the television installation. The data forms were simplified as much as possible to minimize the time required to complete the form and still obtain accurate and complete information on each stoppage. The stoppage log was kept in the control room and when a call was received from the guards stationed inside the tunnel reporting a stoppage the exact time was obtained from a clock on the control room wall and entered in the log. After the stoppage was cleared and the control room operator had returned to the control room the time was again recorded. The time the control room operator reached the stalled vehicle was an estimate in many cases. In some cases the control room operator checked his wrist watch when he reached the stalled vehicle. A complete description of the incident was given in the remarks column following each incident. The same procedure for reporting stoppages was used following the installation of the closed circuit television system.

A review of the tunnel stoppages reports revealed that there were two major causes of vehicle stoppages in the tunnel: (1) vehicle out of fuel and (2) flat tires. A comparison of the two systems (manual surveillance and television surveillance) indicates that the average time to clear a stoppage was 11.4 minutes for the manual system and 10.4 min. for the television system.

Equipment Operation

After the closed circuit television system was formally accepted by the Texas Highway Department the form shown in Figure 9 was introduced to facilitate the evaluation of the reliability of the television system and equipment. The form shown in Figure 9 was completed by each control room operator during his regular working shift. To supplement the records kept by the control room operators, the lessor was requested to supply a monthly statement concerning all maintenance and repairs performed to the television equipment and transmission system. However, the lessor was not willing to supply these records but elected to have his field engineer make some notes on the control room operator's reports regarding the nature of the repairs made. These notes were not made each time a service call was made and the statements that were entered on the control room operator's reports were rather incomplete. As a result, the maintenance records do not indicate possible trouble points or equipment parts which were more likely to fail through continual use.

DATE	TIME RECEIVED CALL	TIME REACHED VEHICLE	TIME OPERATION RESTORED	CAUSE OF STOPPAGE				DIRECTION VEHICLE TRAVELING		REMARKS
				ACCIDENT	STALL	FLAT TIRE	OTHER	N	S	
	A.M. P.M.	A.M. P.M.	A.M. P.M.							
	A.M. P.M.	A.M. P.M.	A.M. P.M.							
	A.M. P.M.	A.M. P.M.	A.M. P.M.							
	A.M. P.M.	A.M. P.M.	A.M. P.M.							
	A.M. P.M.	A.M. P.M.	A.M. P.M.							
	A.M. P.M.	A.M. P.M.	A.M. P.M.							
	A.M. P.M.	A.M. P.M.	A.M. P.M.							
	A.M. P.M.	A.M. P.M.	A.M. P.M.							
	A.M. P.M.	A.M. P.M.	A.M. P.M.							

DAILY LOG OF STOPPAGES IN BAYTOWN-LA PORTE TUNNEL

FIGURE 8

MONITORS DATE TIME FROM TO

MONITOR NO. (LT. TO RT.)								TIME OF FAILURE	TIME REPORTED	TYPE OF FAILURE				TIME SERVICE RESTORED	REMARKS
1	2	3	4	5	6	7	SPARE			NO PICTURE	DISTORTED PICTURE	POOR PICTURE	OTHER		
								A.M. P.M.	A.M. P.M.					A.M. P.M.	
								A.M. P.M.	A.M. P.M.					A.M. P.M.	
								A.M. P.M.	A.M. P.M.					A.M. P.M.	
								A.M. P.M.	A.M. P.M.					A.M. P.M.	
								A.M. P.M.	A.M. P.M.					A.M. P.M.	

BRIEF DESCRIPTION OF OPERATION

CAMERAS

CAMERA LOCATION							TIME OF FAILURE	TIME REPORTED	TYPE OF FAILURE	CAMERA REPLACED WITH	TIME SERVICE RESTORED	REMARKS
1	2	3	4	5	6	7						
							A.M. P.M.	A.M. P.M.			A.M. P.M.	
							A.M. P.M.	A.M. P.M.			A.M. P.M.	
							A.M. P.M.	A.M. P.M.			A.M. P.M.	
							A.M. P.M.	A.M. P.M.			A.M. P.M.	

BRIEF DESCRIPTION OF OPERATION

OPERATOR'S SIGNATURE ______________

TELEVISION EQUIPMENT PERFORMANCE REPORT

FIGURE 9

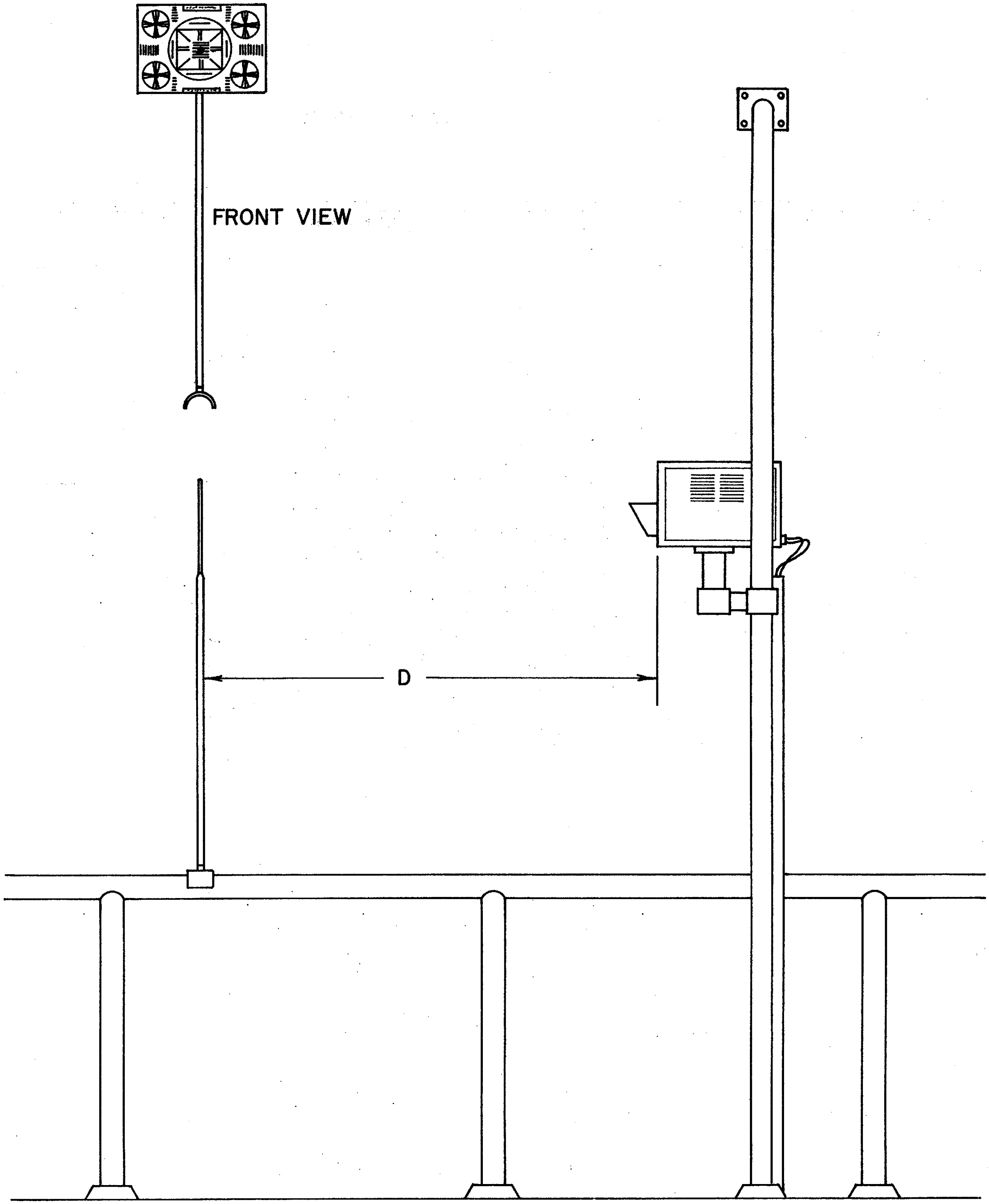
The control room operator's report on the operation of the television monitors and cameras was very helpful in evaluating the over-all operation of the closed circuit television system and the length of time that a particular piece of equipment was out of operation. A review of the records indicates that the picture quality was very poor and the lessor was not very prompt in providing the needed maintenance service. The records also indicate that the picture quality appeared to deteriorate through continual use and this was verified through the horizontal resolution readings which were made on the television cameras.

Horizontal resolution checks were made periodically throughout the study period on the five television cameras located inside the tunnel. The standard retma resolution chart, Figure 7, was placed on a rigid rod and positioned at a proper distance from the television camera, Figure 10. The distance D between the retma resolution chart and the television camera was determined by the size and focal length of the lens on the television camera. With the resolution chart on a rigid rod as shown in Figure 10 the resolution checks would be made without removing the camera from the camera housing.

In order to make a horizontal resolution check it was necessary to have a communication link between the camera location and the monitor room. In this particular installation communication was not provided at each camera location. As a result, communication at each camera location was obtained by running an 18 gauge two conductor cable from the control room through the tunnel and utilizing sound powered hand phones. Three men were used to make the horizontal resolution checks: one man at the camera to make adjustments, one man holding the resolution chart and one man in the control room to read the lines of resolution.

One of the major problems associated with taking horizontal resolution readings was that the chart had to be perfectly still and at the exact distance from the television camera.

The initial horizontal resolution check was made by the lessor at the time the closed circuit television system was formally accepted by the Texas Highway Department. The lines of horizontal resolution were checked both at the camera site and in the control room. There was no difference in the two readings. The succeeding horizontal resolution checks were made by staff of the Texas Transportation Institute. The results of these horizontal resolution studies showed a decline in the lines of horizontal resolution that could be read (Table 2). This depreciation in picture quality might be attributed to such things as varying voltage, inferior parts and the quality of the entire television system. Another factor which contributed to the inferior picture quality was the carbon monoxide from the vehicles collecting on the window of the camera housings. As a result, frequent cleaning was necessary.



EXAMPLE OF RECORDING HORIZONTAL RESOLUTION

FIGURE 10

TABLE 2

HORIZONTAL RESOLUTION READINGS

MONTH	LINES READ	MONITOR 1	2	3	4	5	6	7
May (initial)	H	550	525	550	575	550	600	400
	V	350	400	350	425	350	375	300
Sept.	H		550	525	450	275	575	
	V		375	350	250	200	400	
Oct.	H		500	500	550	450	525	
	V		300	300	200	250	300	
Nov.	H		400	425	425	400	525	
	V		200	300	250	250	300	
April	H		325	Too bad to read	400	475	525	
	V		200	"	200	250	350	

It was also noted that the camera housings needed frequent adjustments. This could be attributed to the vibration from the passing vehicles or from being touched by the tunnel personnel during the tunnel washing process.

Conclusions

The technology of the television industry appears to be applicable to traffic engineering, both as a research and a surveillance tool. From a surveillance standpoint, the closed circuit television system in the Baytown-LaPorte Tunnel greatly increased the efficiency of the tunnel staff. However, this system posed several problems which must be viewed closely if a closed circuit television system is to be used for research purposes only.

One of the major problems associated with this particular installation was that it was very difficult to maintain a satisfactory picture of sufficient quality that traffic measurements could be recorded. The picture quality of each monitor varied from day to day and as a result the study locations were dictated by the quality of the television picture rather than the desired study locations. The maintenance of television equipment and the associated transmission system is a major problem and should be considered very carefully. Provisions should be set up to keep the entire system at a minimum standard and a severe penalty assessed when the system or any part of the system fails below this minimum acceptable standard.

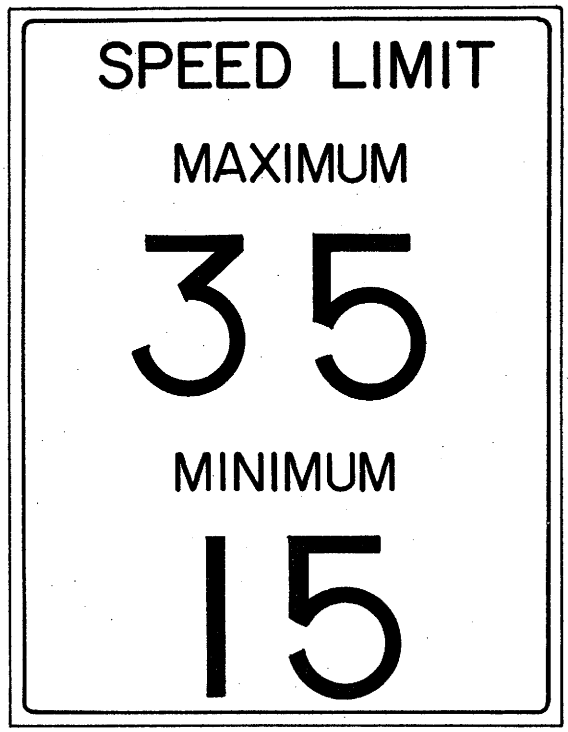
OPERATIONAL STUDIES

Advisory Signing

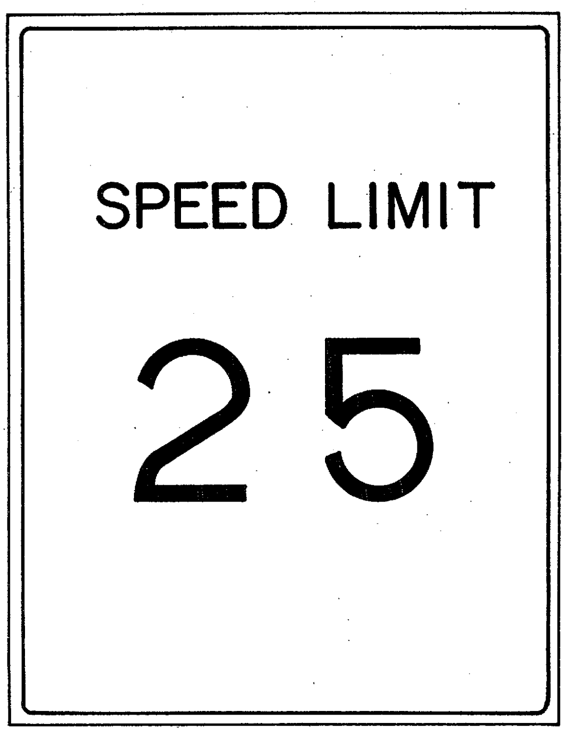
Driver compliance to advisory signing is a very difficult parameter to try to measure because of the many roadway and human factors that influence individual drivers. The major factor being the inability to explain the action of the individual drivers. Because of the many human factors that cannot be evaluated, it was felt desirable to treat all of the drivers in each study as a group rather than as individuals.

In order to try to evaluate the degree of compliance of the drivers to advisory signs, the posted speed limit sign on the approach to the tunnel, Figure 11, was changed and a new speed limit was placed on signs with white, amber and red backgrounds. As can be seen in Figure 11 the existing speed sign was a maximum speed of 35 mph and a minimum speed of 15 mph. This was changed to read Speed Limit 25 mph. A radar speed meter and recorder were used to record the individual speeds of each driver under both normal and controlled conditions. The radar machine was located approximately 300 feet from the entrance to the tunnel and approximately 800 feet from the speed sign. The new speed signs were attached to the existing sign and the individual speeds were recorded at the same location as before. Since the traffic volume was predominantly repeat traffic, it was felt desirable to move the speed sign to a new location and then try to evaluate the effects of the move. This was accomplished by covering the existing posted speed sign and moving the new sign to the entrance of the tunnel. The speed studies were conducted in two parts: (1) on consecutive days and (2) at periodic intervals.

Standard statistical methods and a high speed electronic computer were used to analyze the data. Table 3 shows the results of this analysis. The average speed per minute throughout the study period was computed and plotted against time (Figures 12, 13, and 14) for each type of sign. The average speed of the original condition was superimposed on each graph. It can be seen that by changing the speed limit and keeping the color of the sign the same there was virtually no change in the average speed during the entire study period. (Figure 12) This was verified by analysis of variance using the standard F test. The fact that there was no appreciable reduction in speed might be attributed to the fact that the researchers dealt with repeat drivers and perhaps they did not see the sign. It should be noted that the volumes were about the same for each study condition. It can be seen from Figure 13, black letters on amber background, that the average speed throughout the study period was reduced. Since the study conditions were almost



EXISTING SPEED SIGN



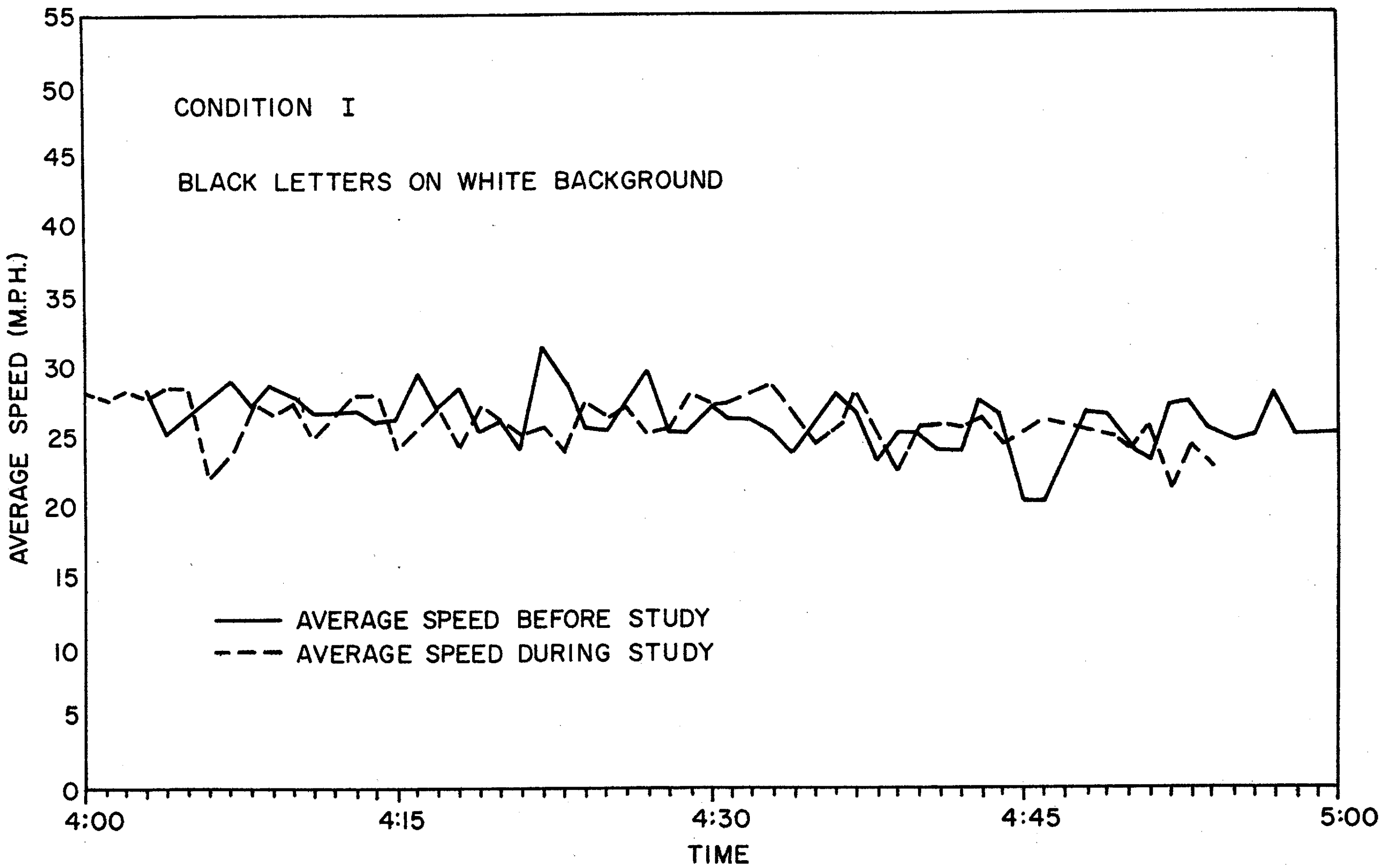
POSTED SPEED SIGN

SPEED SIGNS UTILIZED IN STUDY

FIGURE II

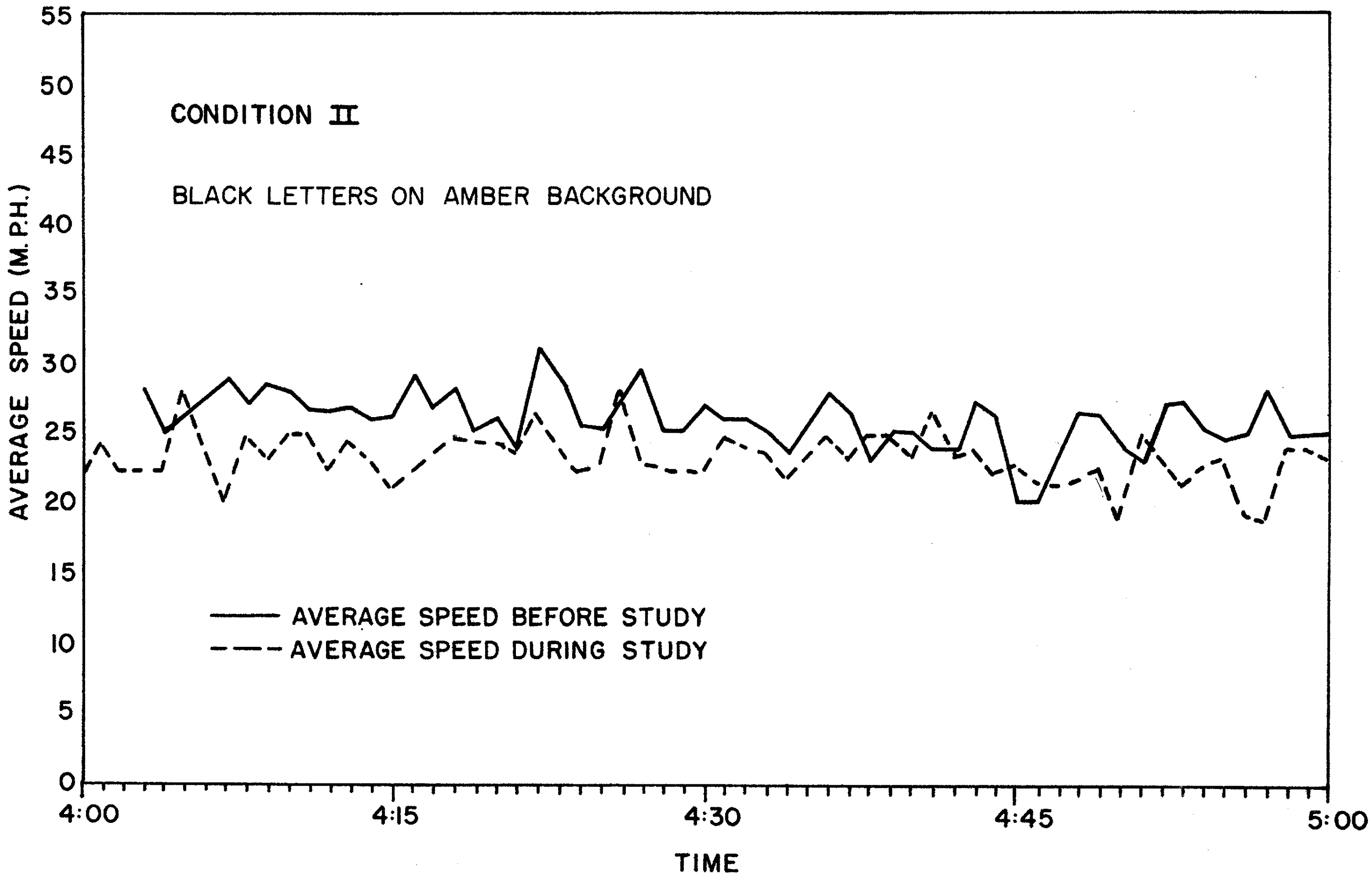
TABLE 3

SIGN CONDITION	SPEED PERCENTILES 15	50	85	MEAN SPEED	STANDARD DEVIATION
Original	20.5	24.4	27.7	25.67	3.6968
White Over Original	21.0	24.2	27.5	25.47	3.5703
Amber Over Original	17.2	21.2	24.8	22.93	3.6489
Red Over Original	12.1	16.5	18.9	17.86	2.9008
White at New Location	18.7	24.3	29.2	25.86	4.2362
Amber at New Location	17.6	22.2	26.6	24.01	4.2530
Red at New Location	16.5	20.0	23.5	22.33	3.6642



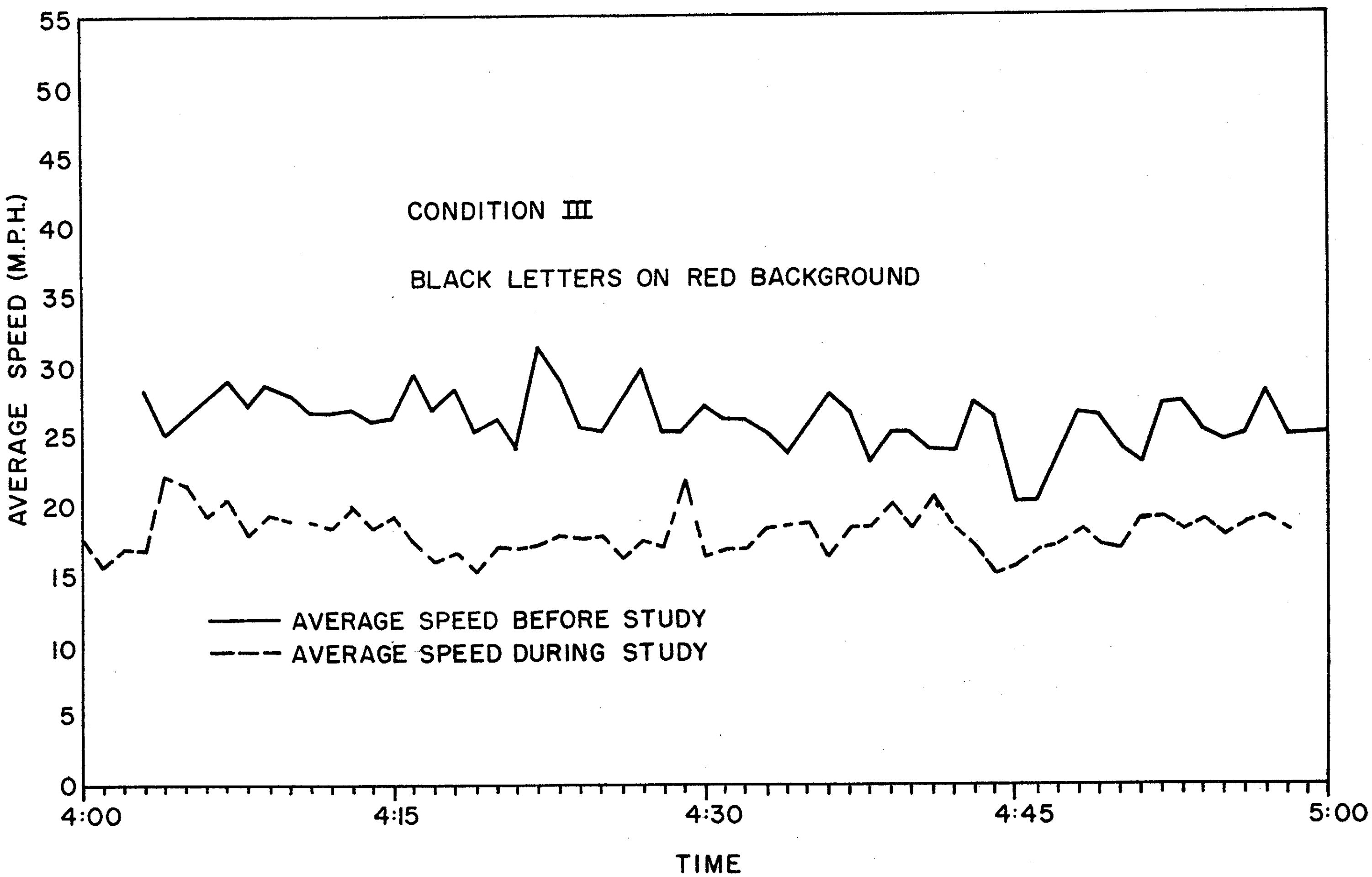
VARIATIONS IN TRAFFIC SPEEDS

FIGURE 12



VARIATIONS IN TRAFFIC SPEEDS

FIGURE 13



VARIATIONS IN TRAFFIC SPEEDS

FIGURE 14

constant and the volumes almost equal, the sign condition must have had some effect on the individual drivers. Here again the original average speed was superimposed on the graph so that the change in speed could be detected. The standard statistical tests revealed that there was a relationship between the new sign and the existing sign. By examining Figure 14 which is the black letters on the red background, it can be seen that there was a significant reduction in speed throughout the study period. Here again the study conditions were held constant as before and it was concluded that the sign color made the difference and this was verified in the statistical analysis.

It should be noted that the colors selected for the speed signs did not totally conform to the standard highway signs. However, from the results of this study it can be concluded that to attract the attention of the repeat driver, the engineer must resort to unusual techniques if any degree of compliance is to be expected. The exact trend was detected when the existing sign was covered and the new speed sign was placed in a new location (Appendix I, II, and III).

The tunnel geometrics are a consideration in an evaluation of this nature, however, it was felt that any effect from the plus and minus 5.824% grade would be the same in all study conditions and as a result could be neglected.

Detector Studies

Two types of vehicle detectors were reviewed in connection with the research studies conducted in the Baytown-LaPorte Tunnel: an ultra sonic and a special pressure sensitive detector which was built and installed by the Texas Highway Department. Since many previous studies have evaluated the accuracy of the sonic type detector most of the research studies were concentrated toward evaluating the accuracy of the Texas Highway Department detector. Traffic counts were used to evaluate the accuracy of both types of detectors.

An event recorder was used to record the vehicles as they were detected by the Texas Highway Department detector. Special counts were made by placing trained personnel along side the detector. The results of the two counts were compared. Traffic counts were also made from the television monitor in the control room at the same time and location and the results compared with the counts from the detector.

The accuracy of the Texas Highway Department detector was checked periodically throughout the research period by both short term counts and long term counts. The study conditions were fairly constant throughout the study period. As a result, this detector evaluation study did not include the effects resulting from varying temperatures. It should be noted that the Texas Highway

Department detector counted axles rather than vehicles. It was concluded that the accuracy of the Texas Highway Department detector was very good.

The Texas Highway Department detector appears to be a great step forward in assisting the detector industry in producing a relatively cheap detector that is very sensitive and quite accurate. It was found that once the detector was installed and adjusted it remained in adjustment. On the other hand it was found that the ultra-sonic detector had to be adjusted periodically to insure that both large and small vehicles would be detected. It was also concluded from this very limited study that the THD detector showed no signs of deterioration through constant use. The detectors were evaluated periodically over a nine-month study period. It should be noted that the 24-hour annual average daily traffic through the tunnel was approximately 12,000 vehicles and perhaps under more rigid use the detector could be evaluated in greater detail.

DATA RECORDING

Motion Picture Filming

Various recording techniques were investigated as a part of this research. These included motion picture camera, video tape recorder and kinescope recordings all of which will be discussed in detail in the following paragraphs.

The motion picture technique was investigated using a positive interlace camera and a monitor located in a portable trailer where the lighting conditions could be controlled. Various camera speeds were investigated ranging from 10 frames per second to to 32 frames per second. The light condition was held constant and the camera F stop was varied from F 1.9 to F 22. One of the major problems associated with the filming of the television monitor was that it was very difficult to obtain synchronization between the television monitor and camera. If the two were not synchronized, a roll bar appeared in the developed film and the roll bar became more objectionable as the shutter speed was increased. It was observed from this film study that the 10 frames per second shutter speed and the F stop of 1.9 were most desirable. The roll bar was detected at this speed but it was not objectionable. Time lapse photography and a synchronous motor mounted to the motion picture camera were also used in this study.

Video Tape

Video tape appeared to be an excellent way to record if needs required instant replay. However, these tapes were very expensive at the time of the research and would not be economically feasible for recording traffic operations unless a long term lease arrangement could be made. Another objection to the video tape recorder was the poor picture quality that resulted when the motion was stopped at any instant of time to record traffic measurements. Poor picture quality appeared to be only a temporary problem. The rapidly advancing technology and new equipment being developed in the video tape field promises a solution to this problem. Listed in Table 4 are the monthly rental rates existing at the time of the study, for a video tape machine. One way of increasing the quality of the picture when the action was stopped was to transfer the recorded data on tape to a kinescope recording. This allowed the action to be stopped and traffic measurements to be made at any instant of time. However, this did not alleviate the problem of original video tape cost, costs of processing, the stock film, cost of labor, reel and cans. The total cost of producing a film from video tape was approximately $10. per 100 feet.

TABLE 4

VIDEO TAPE RECORDER RENTAL RATES

TIME (HRS.)	*COST PER HOUR MONTHLY (SEPARATE DAYS)	TIME (HRS.)	*COST PER HOUR MONTHLY (SEPARATE DAYS)
8 - 12	$25.00	8 - 12	$50.00**
12 - 15	22.50	12 - 15	44.00**
15 - 28	20.00	15 - 18	38.00**
18 - 21	18.00	18 - 21	32.00**
over 21	15.00	over 21	25.00**

*Monthly rental rate for portable videotape machine only for recording or playback of sight and sound.

**Includes:

A. Camera and zoom lens
B. Cable and Auxiliary Attachments
C. Audio equipment
D. Reception monitor
E. 1 experienced cameraman
F. 1 program coordinator

There were two types of video tape recorders available: (1) a recorder with broadcast quality and (2) a recorder with nonbroadcast quality. It was recommended that the nonbroadcast recorder be used for a closed circuit television system. The nonbroadcast video tape recorder has one video channel and two audio channels. The purchase prices of the broadcast and nonbroadcast video tape recorders were obtained from several companies. The purchase prices of the nonbroadcasting and broadcasting video tape recorders were $11,500 and $14,000, respectively. These appeared to be standard prices for video tape recorders.

TRAFFIC FLOW CHARACTERISTICS

G. R. S. Study

Studies of traffic flow in the tunnel were made using an automatic traffic computer type ES-100-VOS which was made available to the Texas Highway Department by the General Railway Signal Company. Traffic volumes and lane occupancies were recorded directly from the automatic traffic computer and the results compared with those obtained directly from the television monitor as recorded on motion picture film. Three ultrasonic detectors were located over one lane of a two-lane roadway; one located at each portal, 3,000 feet apart; and one located at the center of the tunnel, Figure 15. Each of the detectors was connected to a VOS computer.

The type ES-100-VOS Volume - Occupancy - Speed Computer receives information from ultrasonic detectors and computes running averages of volume, lane occupancy and speed. Since the principles involved in the computations of all three quantities are similar, a description of the occupancy computation will be included in this report.

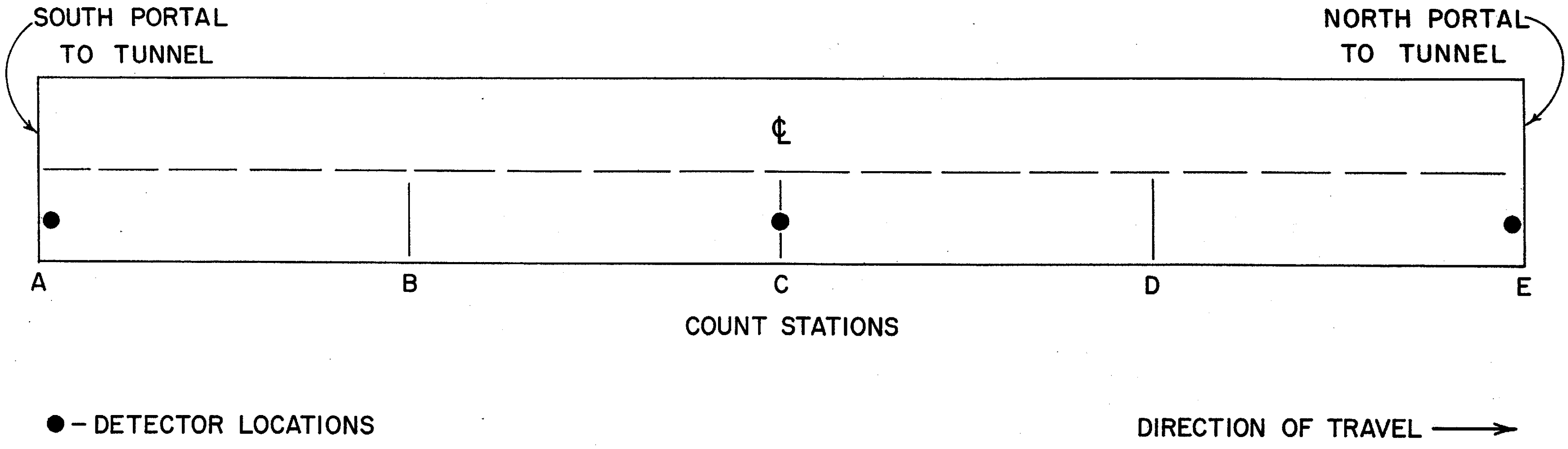
Starting with an occupancy indication at any time - t, the occupancy indication at a slightly later time $t + \Delta t$ may be expressed as follows:

$$0_{(t+\Delta t)} = 0_t - \frac{\Delta t}{t} 0_t + \frac{\Delta t}{t} 0_{\Delta t}$$

where: 0 = occupancy in percent
T = selected time constant in seconds and represents the time interval over which volume is being averaged
Δt = incremental time in seconds between computations and is no larger than 0.1T
$0_{\Delta t}$ = average occupancy during time Δt

The time interval over which the averages are taken is controlled by the the response time switch. Nominal values of averaging time interval for the various switch positions are as follows:

Switch Position	Averaging time Interval
1	1/8 minute
2	1/4 "
3	1/2 "
4	1 "



DETECTOR LOCATION AND VEHICLE COUNT STATIONS

FIGURE 15

The objective of the studies was to determine the relationship of the computer readings of percent occupancy and volume parameters to manual measurements of traffic density and volume for four of the five levels of response time. Data were recorded from the automatic traffic computer on response times one through four. The study period was from 3:30 P.M. to 5:30 P.M., Monday through Friday. In order to relate point measurements to measurements over a section, the tunnel was divided into four sections and five count stations were established as shown in Figure 15. Trained personnel were positioned in front of the monitors and traffic counts were made and recorded in one-minute intervals throughout the study period. Lane occupancy and volumes were recorded from each G.R.S. computer simultaneously in a similar manner. The speed feature of the volume-occupancy-speed computer was not used in this investigation. There appeared to be a malfunction within the speed computation section of the computer which would not permit the speed readings to be made. It was not possible to correct this malfunction through normal calibration procedures. The study period was started by an observer driving a test vehicle through the test sections. As the test vehicle approached the detectors the test vehicle was picked up on the television monitor and the G.R.S. equipment was zeroed prior to the test vehicle's passing the detectors. Manual counts were started as the test vehicle passed each count station. The study was closed in a similar manner.

The total volume of traffic on the one lane studied during the two-hour period was approximately 1500 vehicles with one hour flow of 1000 vehicles and a five-minute rate of flow of 1200 vehicles.

It was possible to conduct an input-output type study for each subsystem or group of subsystems. The term system is defined here as the area under study between any two points. For example system A-C (Figure 15) would include the single lane roadway between points A and C. The density in each system or combination of systems was plotted against the percent occupancy from two detector locations for each response time. Since the values shown on the computer dial are an indication of the traffic that has passed the detector, it was decided to plot the density of each system against the occupancy read at detector locations A and C only (Figure 15). An analysis was performed using the standard t and F test and a high speed computer. For each of the computer response times and each system, a regression analysis was performed and an equation of a straight line which best describes the data points was computed. Appendix IV presents the results of the regression analysis. The equation for each section and response time was compared.

As stated earlier, the volumes were low and as a result an attempt was made to obtain higher volumes. The traffic was stopped on the approach and held for 3 to 4 minutes. A queue was built up but it dissipated about the time the computer had time to respond to the change. As a result the percent occupancy obtained under normal peak period operation was around 12 to 17 percent.

It was concluded from the analysis that there is a relationship between percent occupancy and density for each system that was investigated. The correlation coefficient in most cases ranged from .70 to .98 for each subsystem; however, there was no trend detected as the computer response time was changed. Appendix V presents the results of this analysis.

Speed Studies

Individual vehicle speeds were recorded from the television monitors on motion picture film. Reference marks were placed on the pavement at several locations in the tunnel. A white stepdown plastic material 4" x 4' was used for the reference marks and placed 44 and 88 feet apart. A test vehicle was driven through the tunnel at various speeds which were compared with those obtained from the motion picture film. Observers with stop watches were also placed between the reference marks and in front of the monitors to record the travel time between two reference marks. Speeds were later computed and compared with those obtained from the test vehicle and from the motion picture film. The field measurements and the manual measurements from the monitors were within 2 to 3 mph of each other. They also compared favorably with the speeds obtained from the motion picture film. However, in most cases the film speeds were closer to the actual speeds as would be expected because of the human error involved.

An input-output type study was also conducted from the television monitors and recorded on motion picture film. This was accomplished by filming two monitors covering the desired system. This appears to be an excellent way of recording data.

CONCLUSIONS

The following conclusions have been drawn from the results of this research:

1. Closed circuit television is an effective tool for traffic surveillance. The system in the Baytown-LaPorte tunnel reduced the total annual man-hours of surveillance by 10,416 hours and the overall time for reporting and clearing a stoppage was reduced thus reducing cost and increasing efficiency. From a research standpoint, this installation did not provide the desired picture quality for continuously measuring various traffic parameters through the research period. Good equipment and a regular maintenance program is necessary to the provision of desirable picture quality.

2. The tunnel geometrics greatly reduced the ability to study various mounting heights, camera spacings, and lens selection. Studies in connection with this objective were conducted on the Gulf Freeway and utilized to develop the plans and specification for the closed circuit television system to be utilized on the Level of Service project.

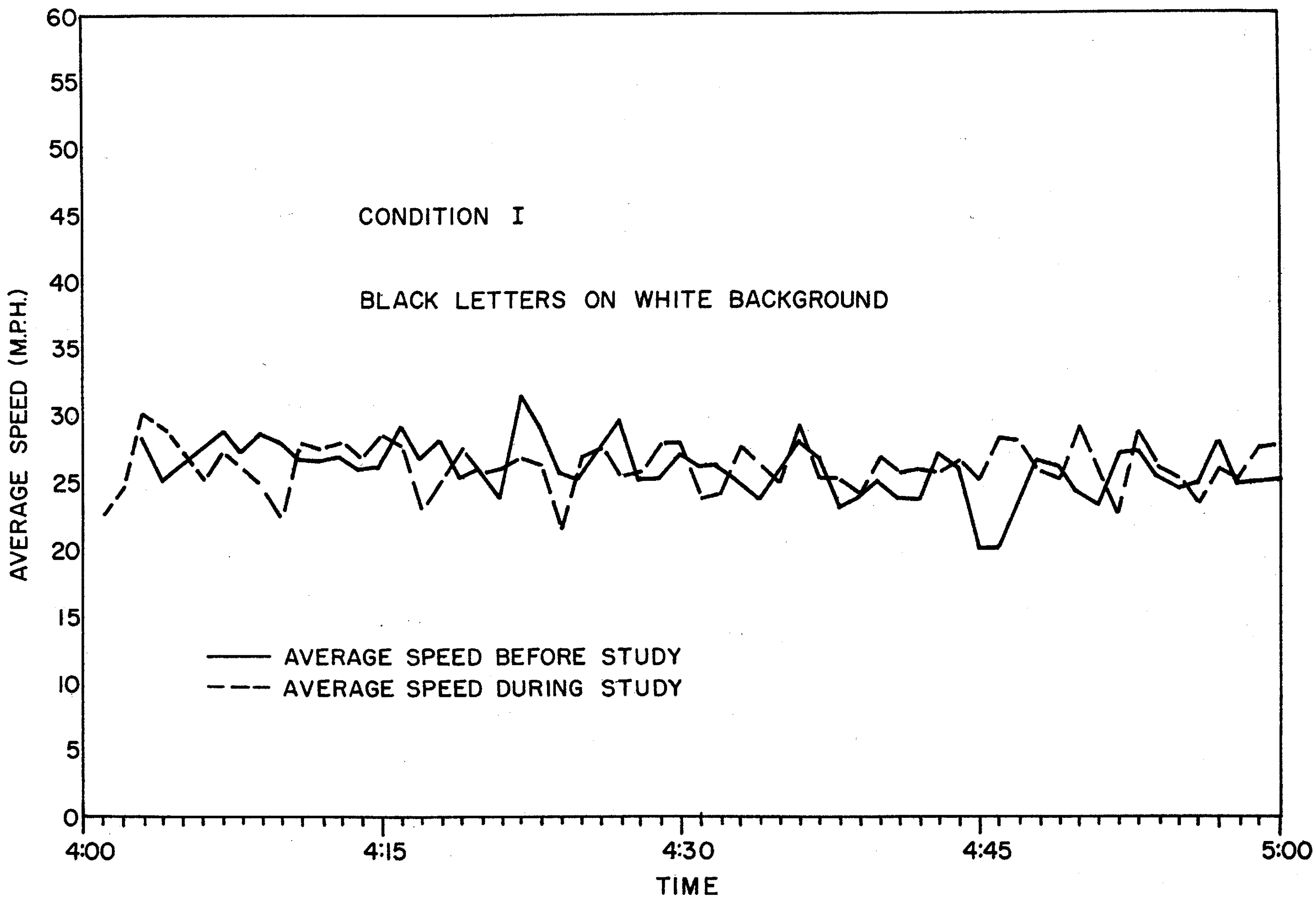
3. Studies of data recording techniques indicated that the video tape recorder was very expensive and did not provide enough flexibility at any time of this investigation to be an economically feasible method of recording data. Also, when the action was stopped, the picture quality was not good enough to accurately measure the desired parameters. The video tape recording can be transferred to a kinescope recording which would permit the action to be stopped. However, this does not alleviate the expense involved. It was concluded that if a minimum of 550 lines of horizontal resolution is maintained on similar installations, data can be recorded from a television by the use of a 16 mm motion picture camera. This method is inexpensive as compared to other techniques and is satisfactory for data analysis.

4. It was concluded from speed studies that when it is desired to control repeat drivers (as drivers on freeways and through tunnels during peak traffic periods) unusual techniques and devices must be employed if any degree of compliance is to be obtained. A posted speed of 25 mph was used with three colors of background materials. Of the three colors, white, amber, and red, the red background produced the greatest speed reduction, the amber less reduction in speed, and the white almost no reduction in speed. This was verified through standard statistical tests.

5. Traffic flow studies were conducted in the tunnel using a combination of automatic sensing devices and manual observation of the television monitors for a data collection method. These studies sought to evaluate the relationship between point measurements (automatic sensor) and actual conditions (as obtained from the television monitors). Some relationships were found but the overall study was inconclusive due to a lack of tunnel traffic which would have permitted observation of higher volume levels.

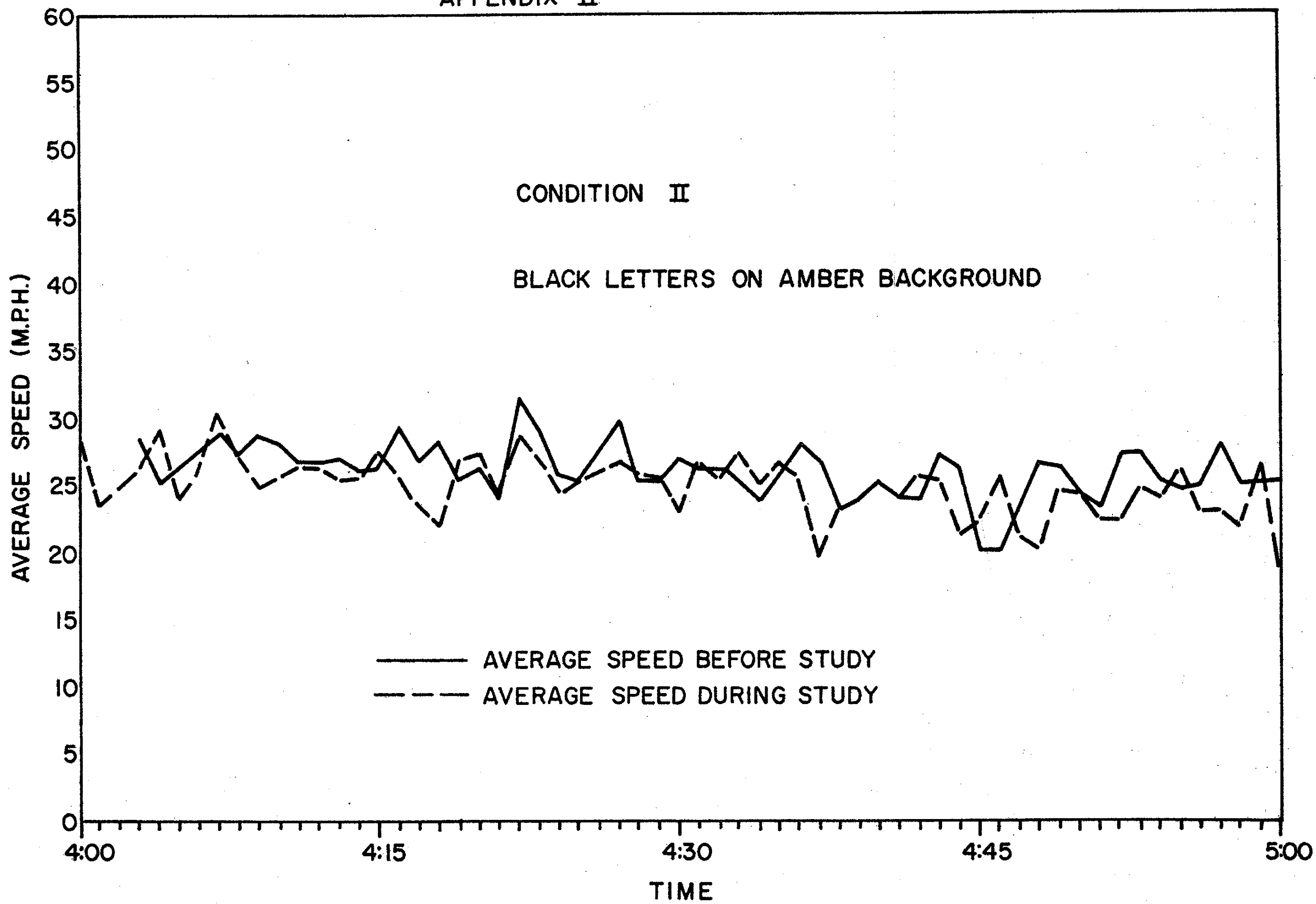
6. It was concluded from studies that the detector developed by the Texas Highway Department is a very sensitive detector which counts axles very accurately. The Texas Highway Department detector did not show any signs of deterioration through continual use over an eleven-month study period with traffic volumes of approximately 12,000 vehicles per day.

APPENDIX I



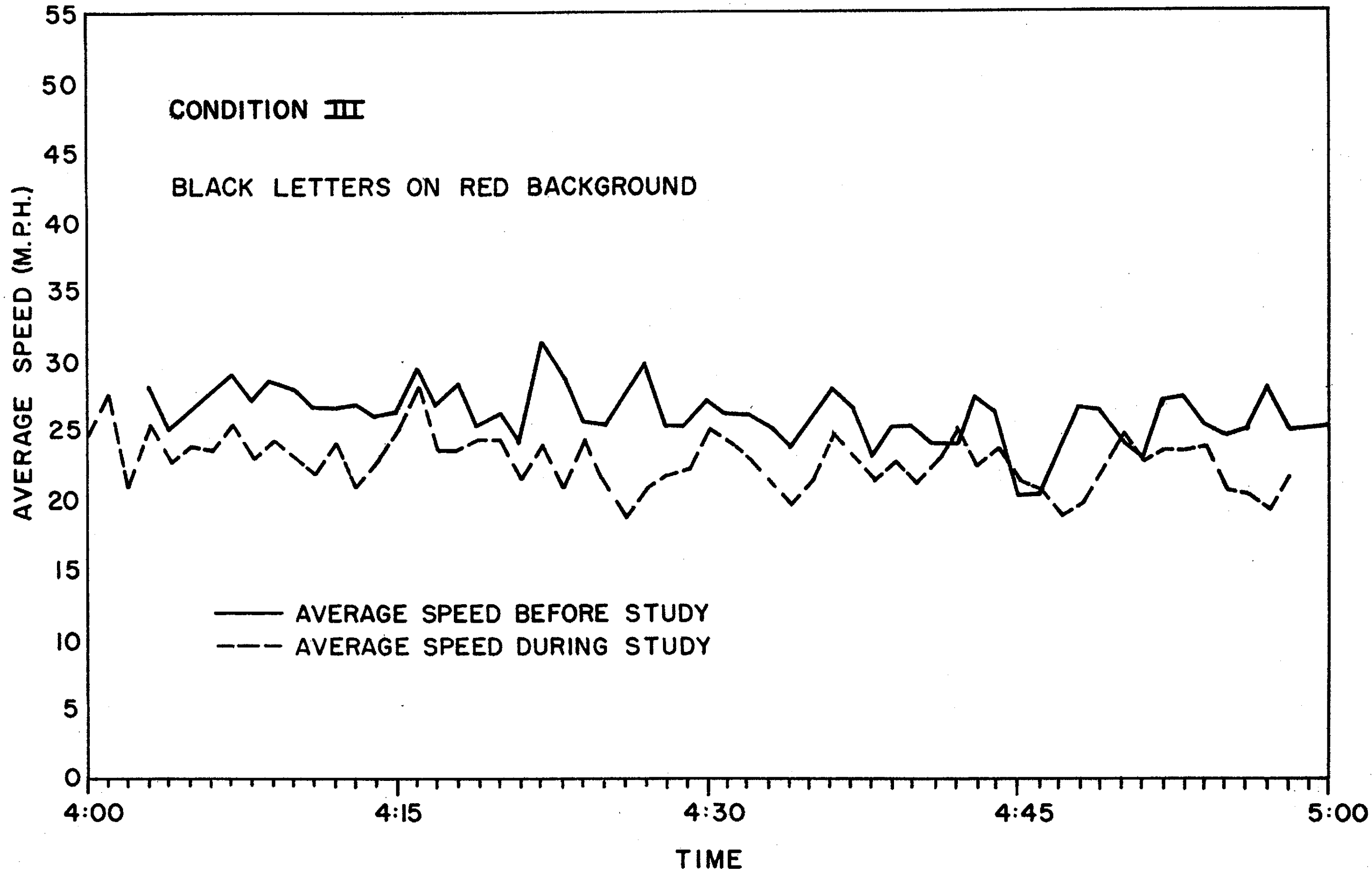
VARIATIONS IN TRAFFIC SPEEDS

APPENDIX II



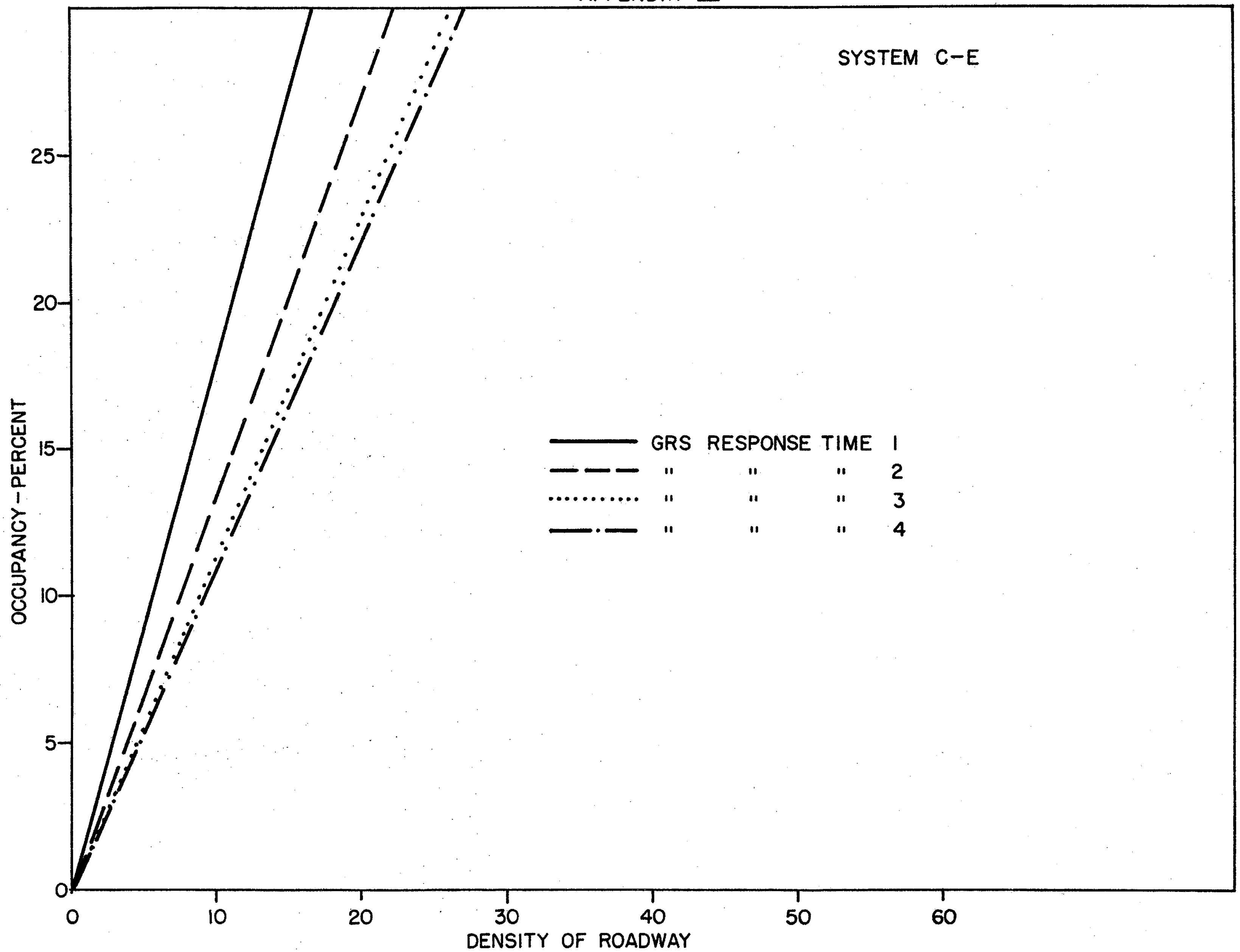
VARIATIONS IN TRAFFIC SPEEDS

APPENDIX III



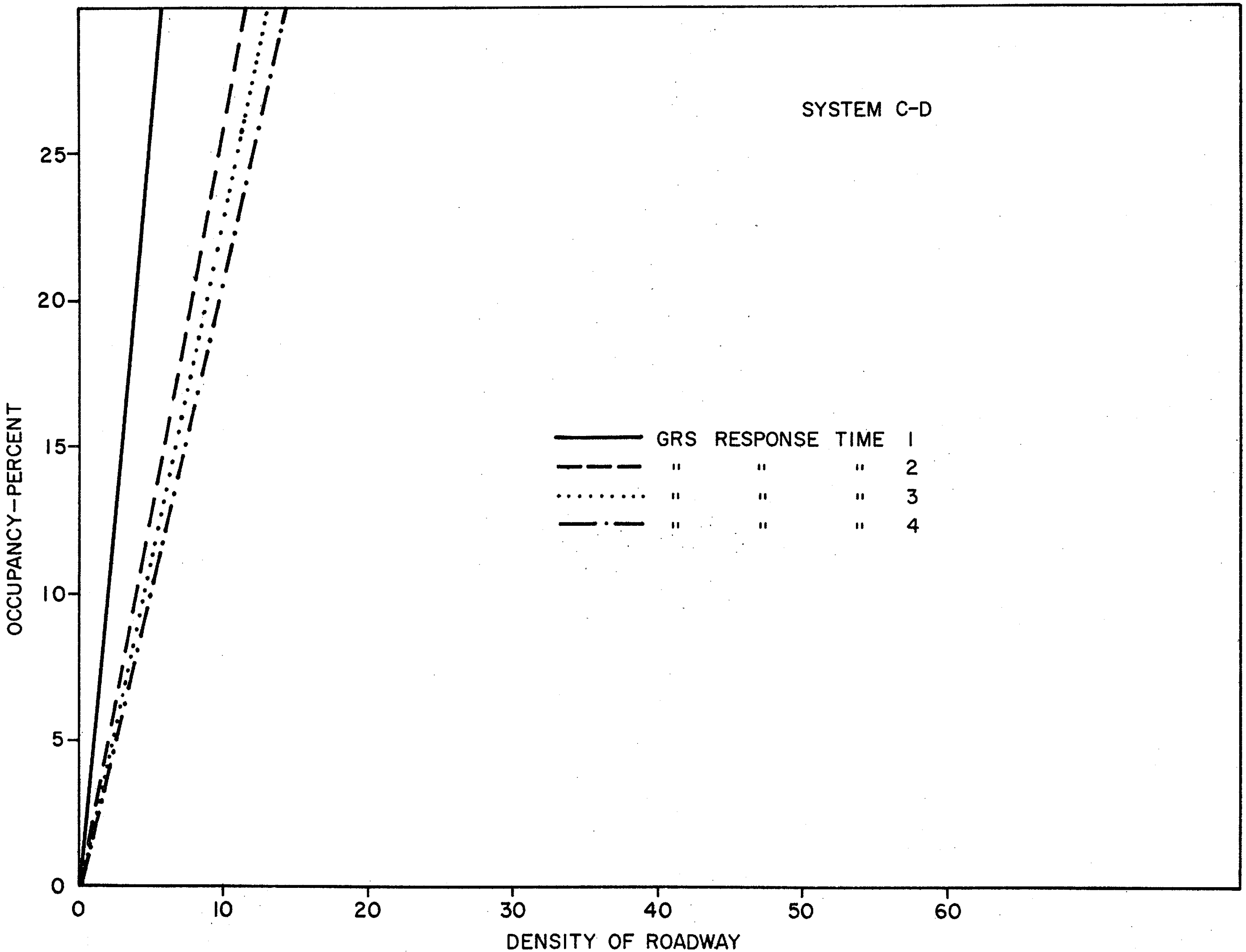
VARIATIONS IN TRAFFIC SPEEDS

APPENDIX IV

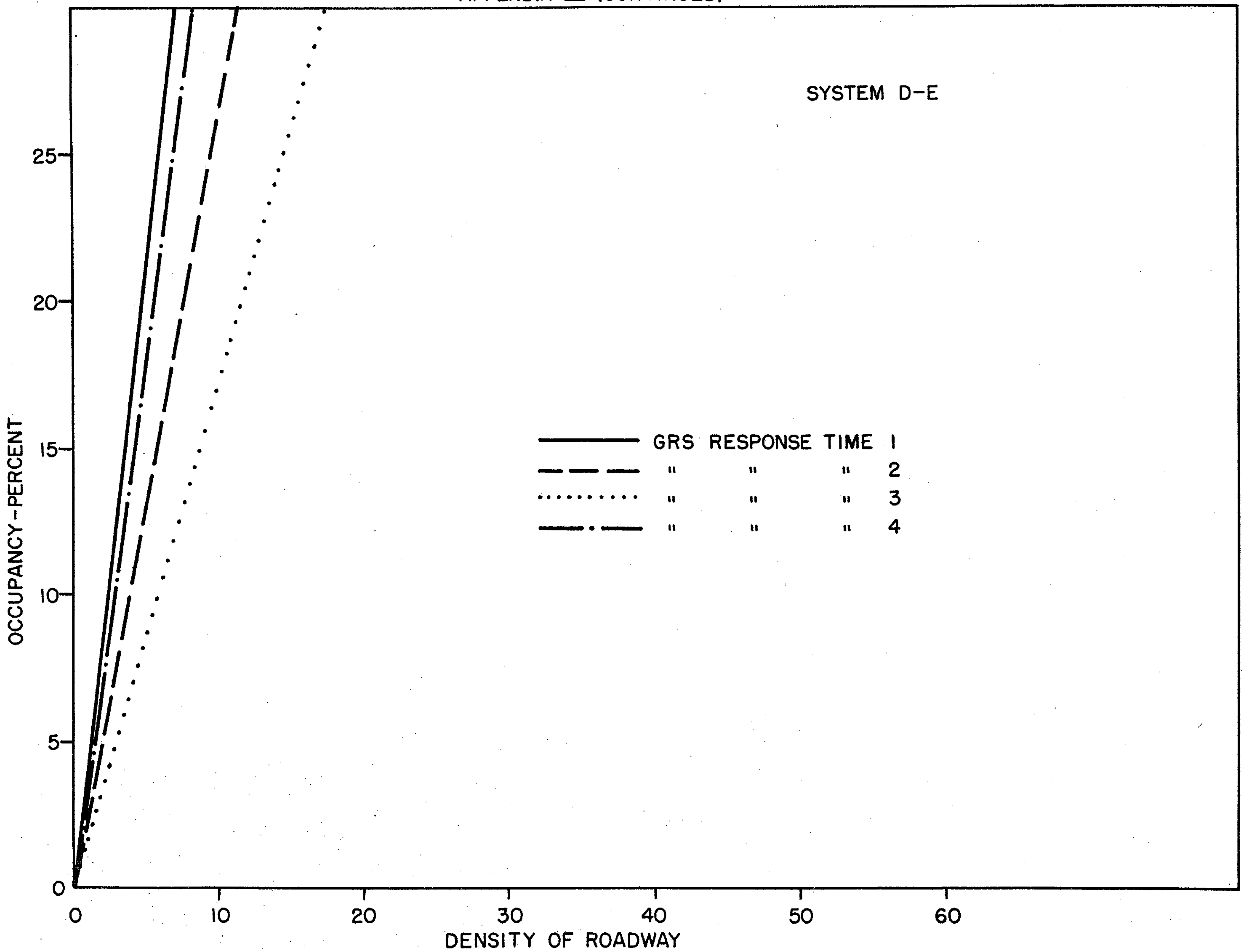


RESULTS OF REGRESSION ANALYSIS

APPENDIX IV (CONTINUED)

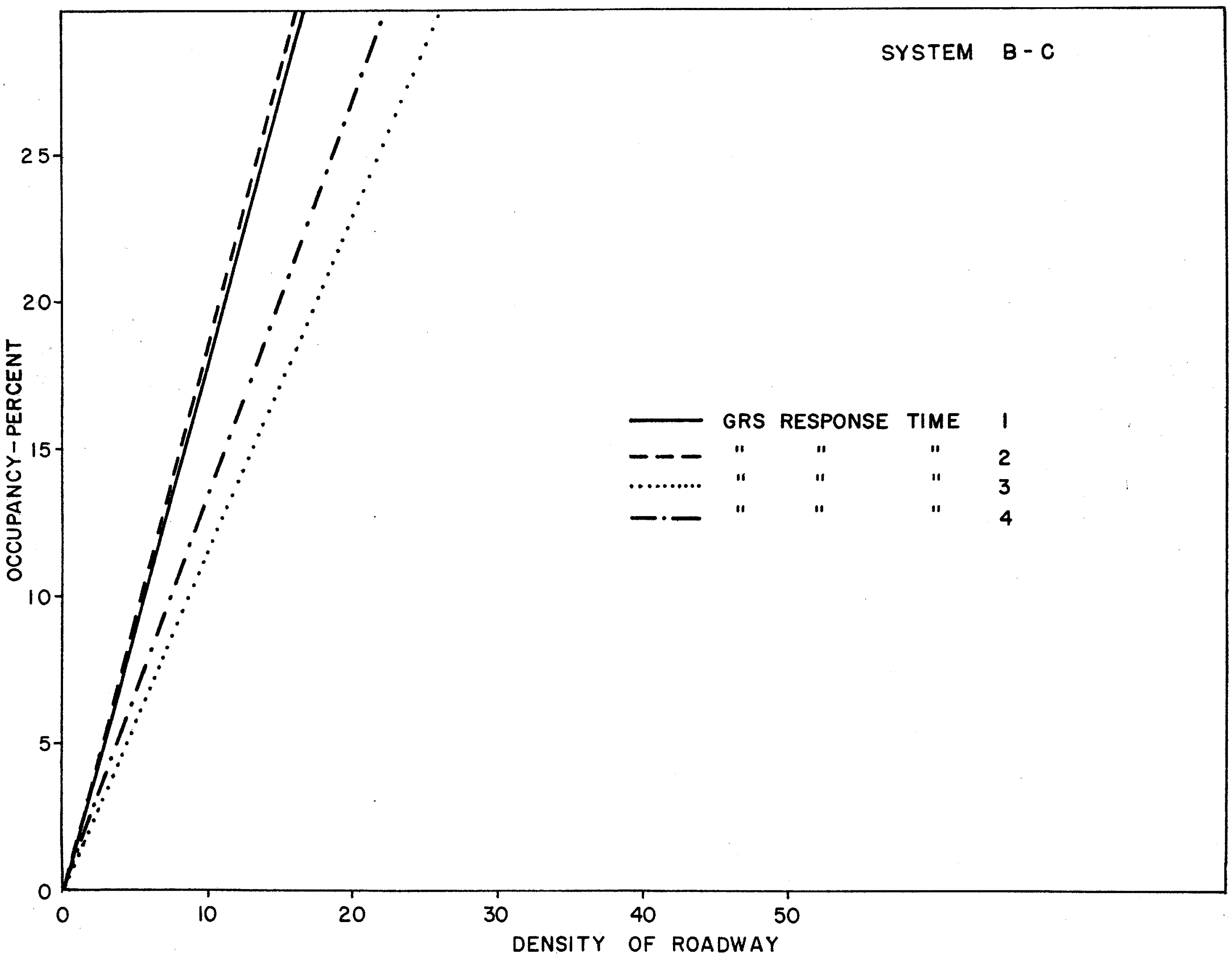


RESULTS OF REGRESSION ANALYSIS

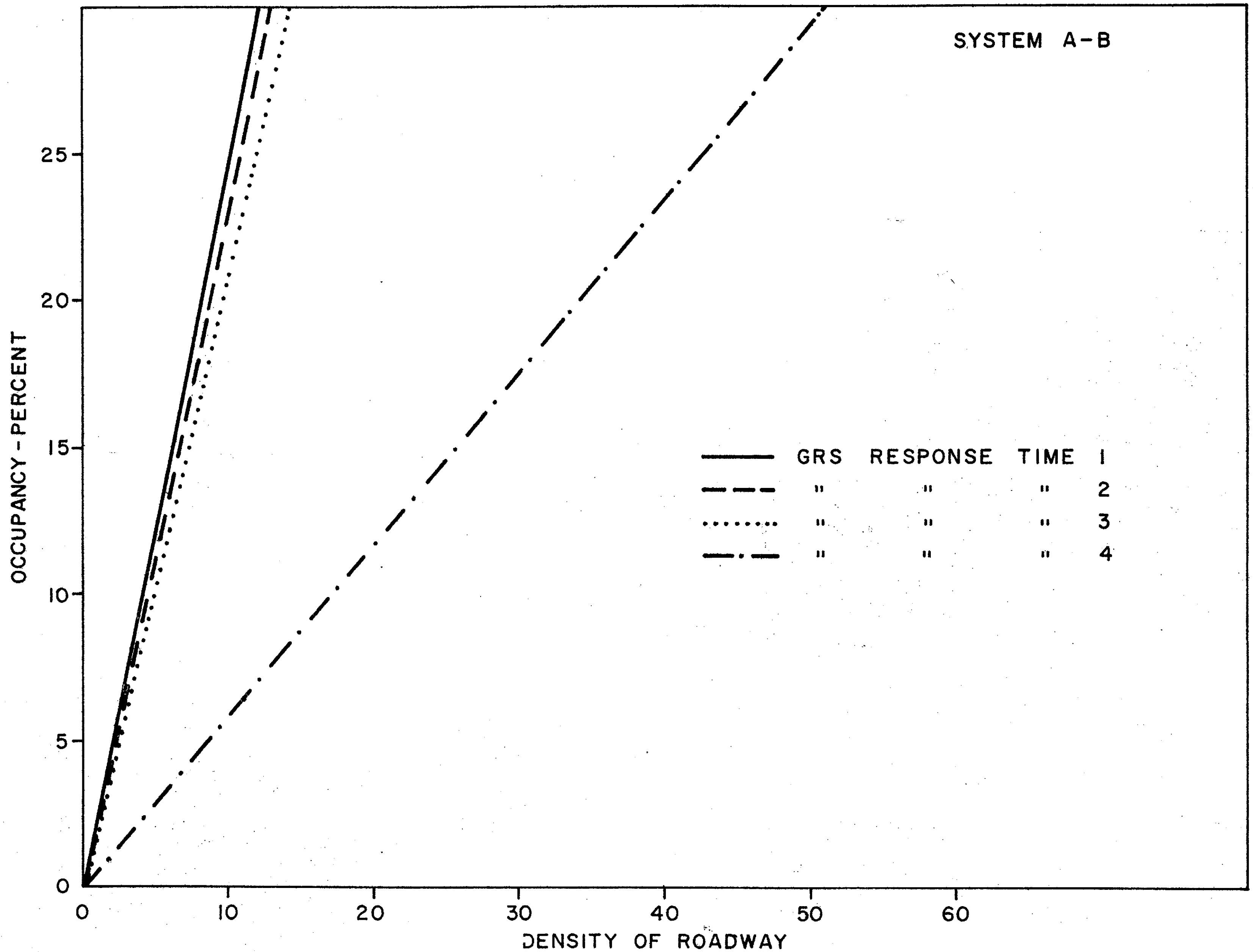


RESULTS OF REGRESSION ANALYSIS

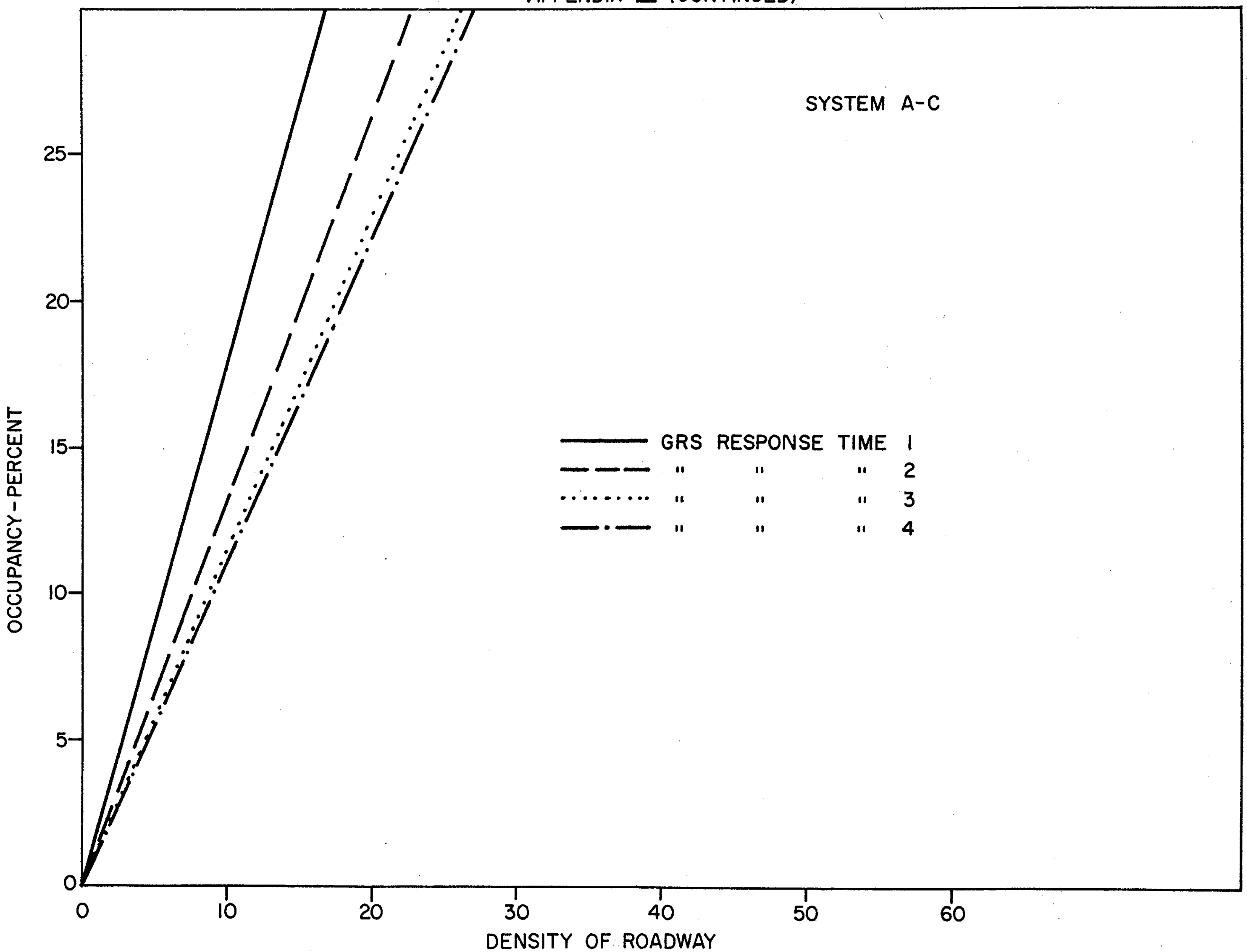
APPENDIX IV (CONTINUED)



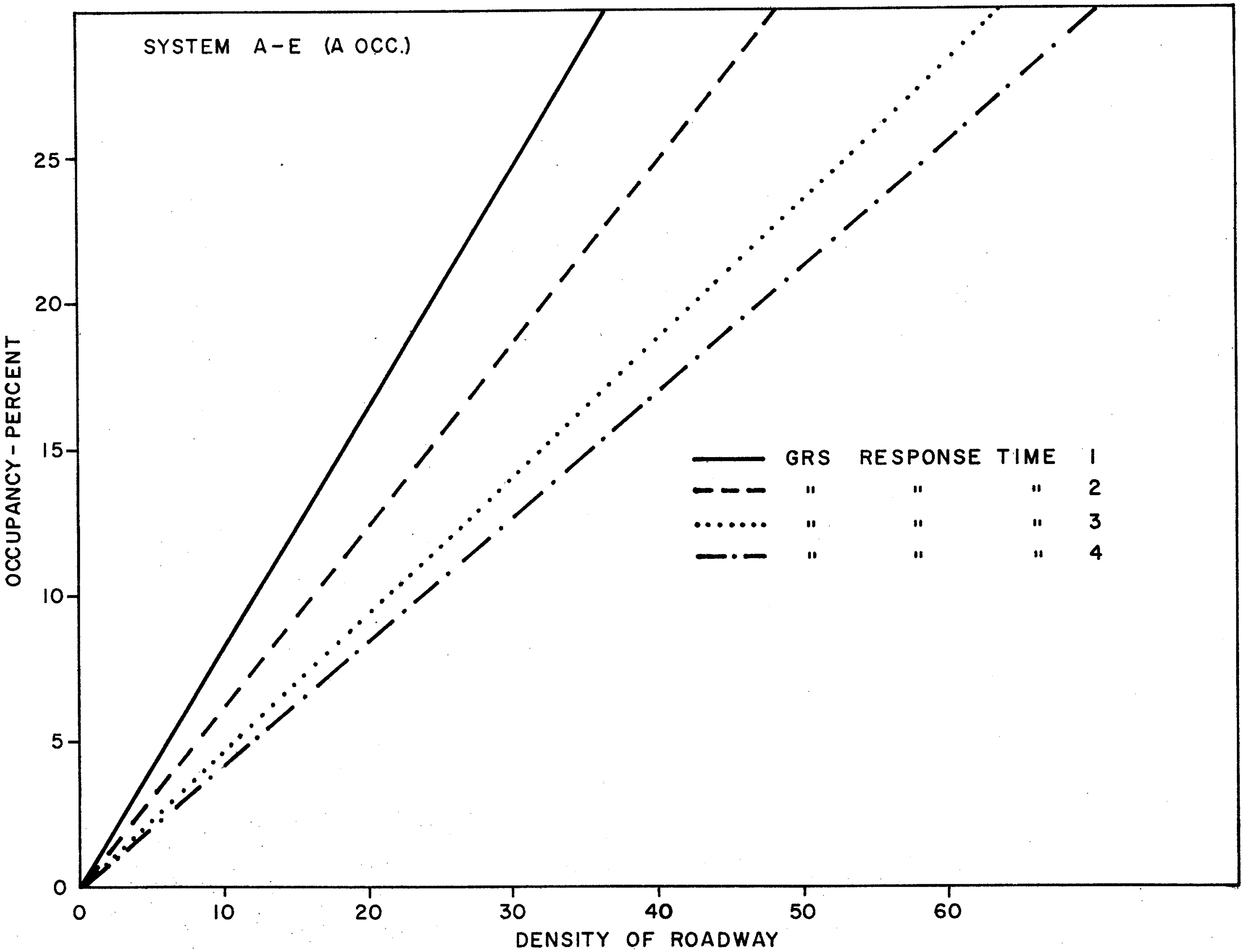
RESULTS OF REGRESSION ANALYSIS



RESULTS OF REGRESSION ANALYSIS

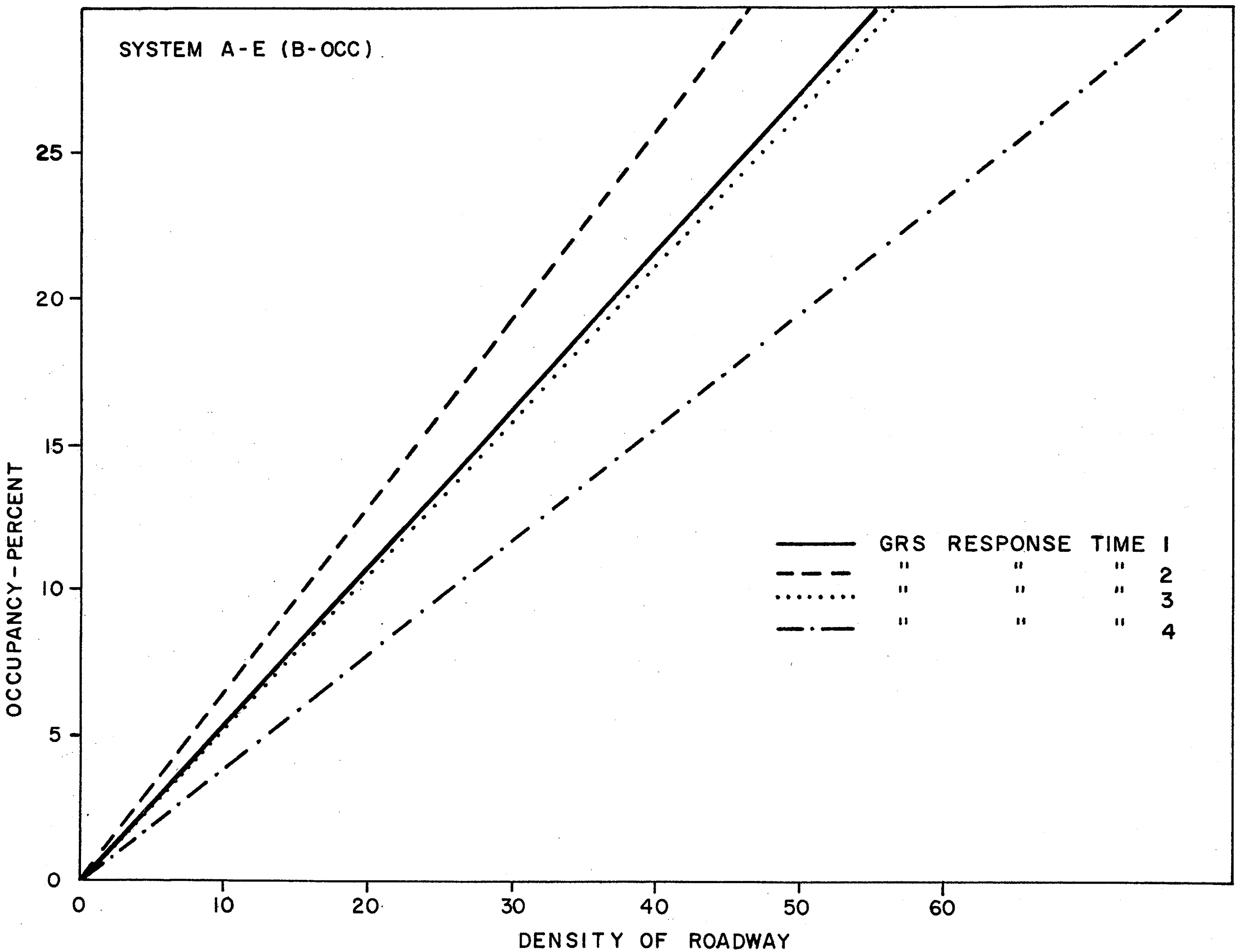


RESULTS OF REGRESSION ANALYSIS



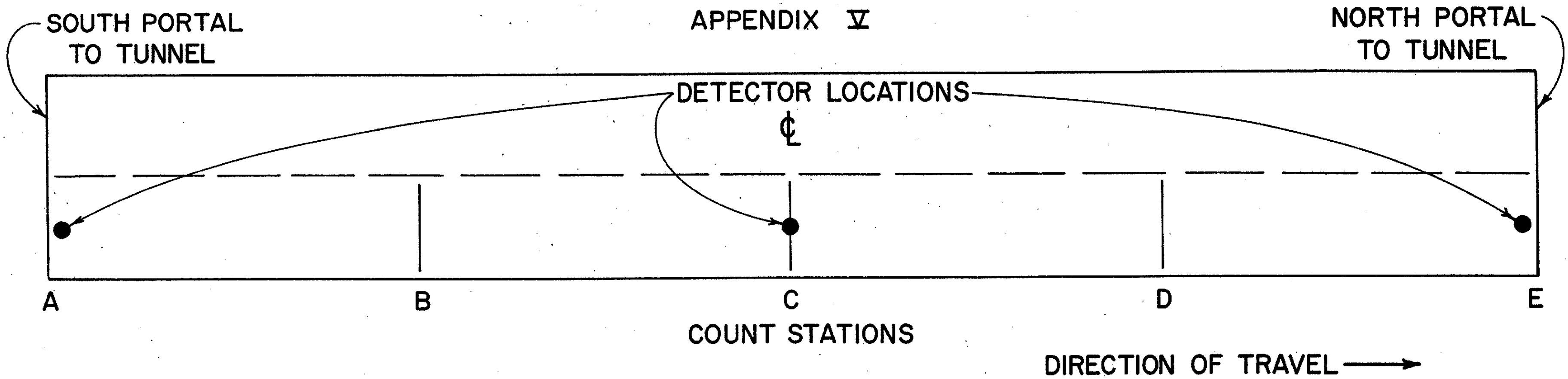
RESULTS OF REGRESSION ANALYSIS

APPENDIX IV (CONTINUED)



RESULTS OF REGRESSION ANALYSIS

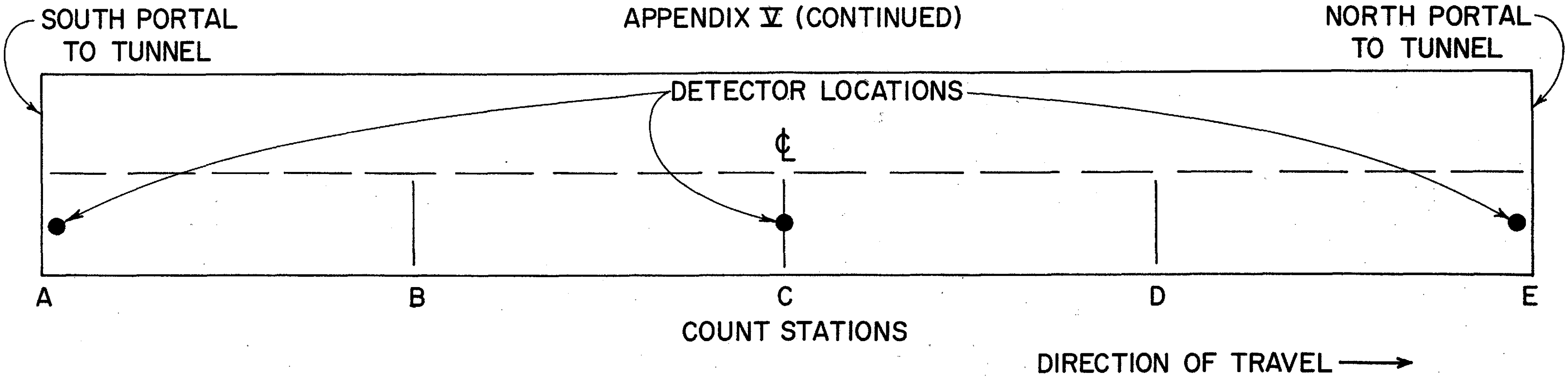
APPENDIX V



SYSTEM	OCCUPANCY READ AT	CORRELATION COEFFICIENT "R"	RESPONSE TIME	ANALYSIS OF VARIANCE-F TEST
A-B	A	0.5633	1	0.5995×10^2
A-C	A	0.6505	1	0.8655×10^2
A-E	A	0.7468	1	0.1614×10^3
A-E	C	0.8735	1	0.4120×10^3
B-C	A	0.6723	1	0.1055×10^3
C-D	C	0.6636	1	0.1007×10^3
C-E	C	0.8643	1	0.3513×10^3
D-E	C	0.6639	1	0.9300×10^2

RESULTS OF ANALYSIS OF VARIANCE

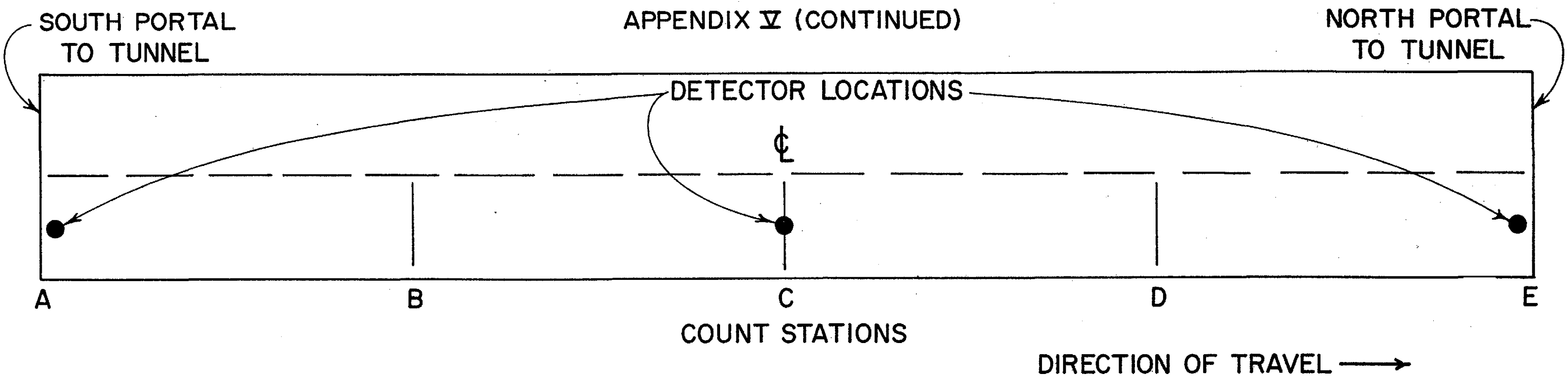
APPENDIX V (CONTINUED)



SYSTEM	OCCUPANCY READ AT	CORRELATION COEFFICIENT "R"	RESPONSE TIME	ANALYSIS OF VARIANCE-F TEST
A-B	A	0.8446	2	0.2911×10^3
A-C	A	0.9447	2	0.9708×10^3
A-E	A	0.9446	2	0.9684×10^3
A-E	C	0.9141	2	0.5942×10^3
B-C	A	0.8948	2	0.4738×10^3
C-D	C	0.8494	2	0.6654×10^3
C-E	C	0.9446	2	0.9774×10^3
D-E	C	0.8041	2	0.2159×10^3

RESULTS OF ANALYSIS OF VARIANCE

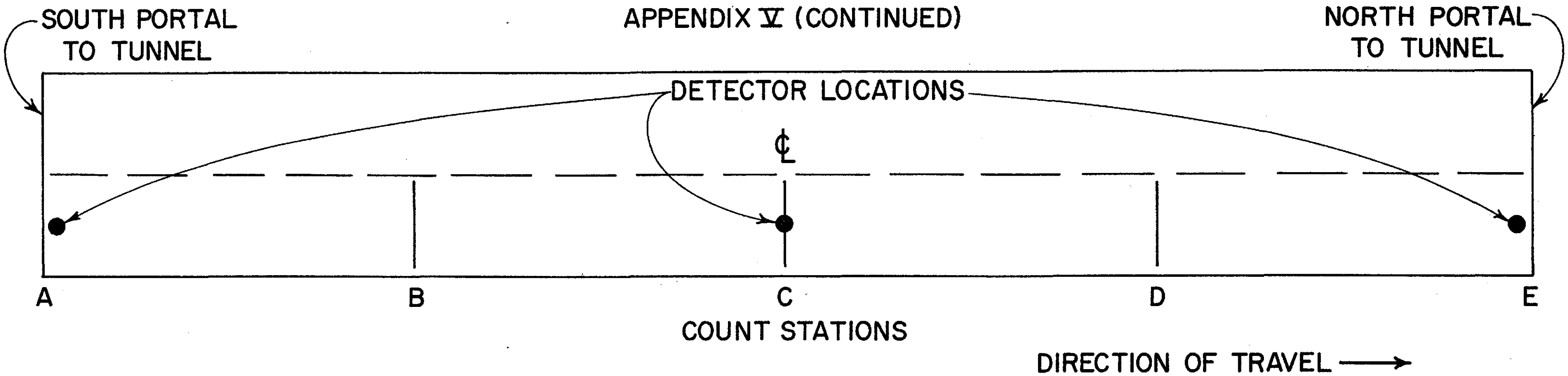
APPENDIX V (CONTINUED)



SYSTEM	OCCUPANCY READ AT	CORRELATION COEFFICIENT "R"	RESPONSE TIME	ANALYSIS OF VARIANCE-F TEST
A-B	A	0.8895	3	0.3488×10^3
A-C	A	0.9635	3	0.1191×10^4
A-E	A	0.9399	3	0.6981×10^3
A-E	C	0.9276	3	0.5678×10^3
B-C	A	0.9296	3	0.5859×10^3
C-D	C	0.8631	3	0.2687×10^3
C-E	C	0.9238	3	0.5360×10^3
D-E	C	0.8752	3	0.3013×10^3

RESULTS OF ANALYSIS OF VARIANCE

APPENDIX V (CONTINUED)



SYSTEM	OCCUPANCY READ AT	CORRELATION COEFFICIENT "R"	RESPONSE TIME	ANALYSIS OF VARIANCE-F TEST
A-B	A	0.3297	4	0.5609×10^2
A-C	A	0.8138	4	0.2216×10^3
A-E	A	0.8942	4	0.4550×10^3
A-E	C	0.8796	4	0.3900×10^3
B-C	A	0.9114	4	0.5595×10^3
C-D	C	0.8758	4	0.3752×10^3
C-E	C	0.9230	4	0.6559×10^3
D-E	C	0.6265	4	0.7365×10^2

RESULTS OF ANALYSIS OF VARIANCE