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FINAL REPORT
DESIGN AND EVALUATION OF FREEWAY
SURVEILLANCE AND TRAFFIC CONTROL SYSTEMS

by

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Research Report Number 202-3F

Design and Evaluation of Freeway
Surveillance and Traffic Control Systems

Research Study Number 2-18-75-202

Sponsored by
The State Department of Highways and Public Transportation
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ABSTRACT

Studies of urban traffic operations were conducted on the freeways of Texas to determine the design and effectiveness of traffic control and surveillance systems; to relieve peak period congestion; to lessen the impact of disabled vehicles on the operation and safety of the freeways; and reduce the incidents of overhead structure damage by overheight vehicles. The research study uses demonstration installations to test the implementation requirements as well as to evaluate the operational theory.

DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Key Words: On-freeway control, lane use control, surveillance and control, overheight detection, cost-benefit analysis, incident detection.

SUMMARY

This study is the continuation of research in the development and evaluation of traffic surveillance and control on urban freeways. Two designs of on-freeway control were considered: lane use control in an interchange and total freeway control approaching a congested section of freeway.

The total freeway control study has progressed through the preliminary designs and has been approved for demonstration and evaluation when funds are available.

The lane use control study has been concluded and the results indicate that the control was effective in closing a lane approaching a merge area, that the control was cost effective in the reduction of total delay in the intersection and that extensive traffic enforcement is essential for this type of control. The study was conducted on I.H. 10 (Katy Freeway) at I.H. 610 in Houston.

Three projects involving the design and evaluation of traffic surveillance systems were included in this study: detection of overheight vehicles, design of CCTV systems for incident identification and incident management, and evaluation of detectors for applications in traffic surveillance and control.

The study of the detection and warning of overheight trucks was conducted on an experimental installation on I.H. 45 (North Freeway) in Houston. The results indicated that the photoelectric detection system was effective in detecting loads that could damage a low clearance structure. There was inconclusive proof that the activations of the warning caused trucks of legal or illegal heights to divert from the freeway, but studies did indicate that

the warning system did not have a detrimental effect on the safety or operation of the total traffic flow.

The study of the design and application of closed circuit television systems in urban traffic management continues. Camera locations were examined with respect to area coverage and resolution problems. Low light level cameras were demonstrated for applications in 24-hour surveillance and produced excellent quality pictures for traffic surveillance under average nighttime conditions. Research efforts will be continued to test the equipment under extreme light and environmental conditions.

The effectiveness of vehicle detectors for an automatic incident detection system is being evaluated on the old Gulf Freeway surveillance system and on a new installation on I.H. 610 North Loop in Houston. Redundant equipment designs and computer software logic will be used to compensate for the errors in detection due to equipment malfunctions, vehicle placement, and vehicle detection characteristics. This effort will be continued in fiscal year 1976.

The basic evaluation of the effectiveness of transportation facilities is the benefit-cost ratio analysis. A review of literature indicated that only a limited amount of data was available that considered current conditions. This study developed costs to update that basic data and the benefit-cost analysis procedures. An analysis was made of the effects of energy shortages and temporary mandatory controls that affect the supply, demand, and price resources. Data on air and noise pollution and other highway impact data were assembled and an analytical procedure was recommended for use in determining the economic feasibility of a project and in determining which project best accomplishes a particular goal or set of goals.

Technical assistance to the State was provided through the study for those activities that closely related to the implementation of results of the research. Two such activities were concluded in this study: the surveillance design for the elevated section of I.H. 35 in Austin and the operational analysis of a high accident location on U.S. 59 in Houston. It is the interchange of knowledge and experience between the operations and the research programs of the State Department of Highways and Public Transportation that determines the success of both.

Implementation

All of the systems described in this study are operating now or planned to be operational in the near future. There is no indication as a result of this research that any of these systems should be discontinued. Implementation of similar systems will require detailed justification studies as did each of these demonstrations.

Recommendations for Further Research

1. Those systems not completed in this study should be continued. These include on-freeway control - total freeway control, low volume incident detection, low light level CCTV demonstration studies.
2. Every effort should be made to investigate the applications of these systems to priority treatment operations for transit and high occupancy vehicles.

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INTRODUCTION

Background

The Texas State Department of Highways and Public Transportation (SDHPT) has supported research on traffic operations on urban freeways since 1955. The continuity of the research program has enabled the SDHPT to apply the results of the past to the development and conduct of the new studies. It has also enabled the researchers to extend and continue studies beyond work plan schedules when delays in the procurement and the installation of equipment were encountered. Such is the case with the major efforts of this research study: the study of on-freeway control systems was begun in 1973 and will be completed in 1976 while the study of low volume incident detection which includes the objectives on closed circuit television systems and detector accuracy, was proposed in 1972 and will be completed in 1976.

These statements on delays to the research program emphasize the problems and realities of conducting research under field conditions and the need for the patient support which has been provided by the SDHPT during these two decades.

The justification for this support of research in surveillance and control is becoming more evident as the SDHPT directs its attention to energy and resource conservation, to public transportation development, and to optimization of existing transportation facilities. The basic goal in the development of surveillance and control systems has been the effective management of traffic, which must also be the prerequisite for many of the transit and car pooling incentive programs now being proposed.

Statement of the Problem

Urban freeways carry almost 40 percent of the vehicle miles of travel in the urban areas. The freeway network is only two percent of the total street network. Twenty to twenty-five percent of freeway travel occurs during the two peak periods, which constitute 10 to 15 percent of the total 24 hours. These statistics may vary from day-to-day, city-to-city, state-to-state, but the importance of the freeway system to urban transportation is constantly increasing. The current trends in the development and installation of bus priority systems on urban freeways to increase the people-carrying capacity of these roadways emphasizes the necessity for maintaining an acceptable level of service.

The definition of an acceptable level of service has not been established, because it must reflect local conditions and local transportation goals and objectives. However, traffic congestion and stop-and-go operations that prevail on most freeways during peak periods, maintenance operations, or incident occurrences are not acceptable to any motorist or transportation agency.

Many freeways are instrumented with ramp metering systems that have improved traffic operations, but many ramp systems cannot exert sufficient control to eliminate congestion brought on by increasing traffic demands. On-freeway control systems are proposed in this study to supplement ramp metering and to provide a sufficient amount of control of traffic demand.

Disabled vehicles and accidents cause more disruptions to traffic operations than any other factor. Many freeways have some form of surveillance system to locate and identify disabled vehicles. Visual surveillance with closed circuit television and electronic detection with detector-computer monitoring systems are being investigated in this study for

application to this serious problem.

Transportation agencies must consider any system, procedure, or operation that improves the efficiency of the existing streets and freeways, and must weigh the costs and benefits of the various alternatives. Inflation, energy shortages, and governmental controls have affected transportation supply and demand relationships. The cost analysis evaluation procedures for transportation alternatives have been reviewed and revised in this study.

Goals and Objectives of the Study

The goals of the research program are to develop, test, and evaluate traffic surveillance, control, and communications systems that reduce the frequency and severity of recurrent and non-recurrent congestion on urban freeways.

The specific objectives of this research study are:

1. To evaluate an on-freeway control system that meters traffic flow on the main lanes of the freeway when traffic densities downstream exceed critical levels.
2. To evaluate an on-freeway control system that restricts the use of one freeway lane upstream of the merge area of another freeway lane.
3. To evaluate a detection and warning system to divert trucks with overheight loads from freeways with height restrictions.
4. To develop a design for an urban-wide closed circuit television system with a cost effectiveness evaluation for use in incident identification and incident management.
5. To evaluate the effectiveness of detectors for applications in traffic surveillance, driver communications, and control systems.

6. To determine a cost-benefit analysis that reassesses the priorities of time, vehicle operating costs, and air pollution values to compensate for energy shortages, the Environmental Protection Agency's transportation regulations and other nondescript economic factors.
7. To provide technical assistance to the SDHPT for development of goals and objectives for implementation of research results.

RESULTS OF THE STUDY

Status of the Objectives

A review of the status of the seven objectives is presented below. The results of the study related to each of the objectives are discussed in the following sections of the report.

Objective 1 - On-freeway control to meter freeway traffic flow.

This objective has been partially satisfied. The design, operational procedures, and measures of effectiveness have been developed and identified. The installation and evaluation of a test facility have been delayed until approval from the Federal Highway Administration for an experimental project is secured.

Objective 2 - On-freeway control of one lane upstream of a merge area. The signal system to control one of the three westbound lanes of I.H. 10 Freeway at the interchange of I.H. 610 Freeway in Houston became operational on November 20, 1974. Preliminary results of the control study are discussed in this report. A final research report on the study will be written after data from one year of operation have been collected and evaluated.

Objective 3 - High load detection system. The study of the high load detection and warning system of I.H. 45 North Freeway at the interchange of I.H. 10 Freeway in Houston has been completed and documented in Research Report 202-1.

Objective 4 - Design of urban-wide CCTV system for traffic surveillance. This study has concentrated on the evaluation of low light level television cameras for night-time surveillance. Demonstrations of television cameras from several companies were conducted and technical requirements for night-time surveillance were identified. A one-camera system has been leased and a six-month study of field installation requirements will be conducted in 1976. A research report will be written on the results of these studies.

Objective 5 - Effectiveness of detectors for application in traffic surveillance, driver communications, and control systems. This objective has been partially satisfied by the study of the existing detection system on the Gulf Freeway (I.H. 45 in Houston). The study will be completed with the evaluation of a low volume incident detection system to be installed on I.H. 610 North Loop Freeway in Houston in 1976. The installation will have three-loop detector speed traps to determine if the speed and volume measurements can be made more accurately with redundant detection systems. A research report will be prepared in 1976 documenting the results of the studies for this objective.

Objective 6 - Benefit-cost analysis with consideration for current conditions. This objective has been satisfied by the review of current literature and economic conditions and the revision of

the benefit-cost analysis for transportation facility evaluations. Results of the study were documented in Research Study 202-2.

Objective 7 - Technical assistance to the Texas State Department of Highways and Public Transportation. This objective has been satisfied by the conduct of two studies: the evaluation of a high accident location on U.S. 59 Southwest Freeway in Houston and the design of the surveillance and communications system for the evaluated section of I.H. 35 Freeway in Austin. Results of these two studies are discussed in the following sections of this report.

Discussion of Accomplishments

A review of the status of the objectives of the research indicates that some of the activities scheduled for completion during this study have been delayed because of the length of time required to receive approval and to complete the installation of test facilities. Some objections were raised to the proposals to control the main lanes of freeways to improve urban transportation because the acceptability of the control systems by the public and the safety of operation were unknown. Yet, these are the same questions that the research program proposes to answer through demonstration under real world conditions. Even though it takes time to contact all offices responsible for the review and approval of demonstration and experimental projects and to answer their questions on the merits of the study, considerable progress has been made on the objectives in this study that fall in this category. Progress reports on the development and evaluation of these demonstration projects are included in the following sections.

On-Freeway Control - Total Roadway - "As I look at the solutions that people offer for various problems facing us, I notice that

they all have a feature in common. Whenever one can identify some aspect of the problem that is holding back progress (that is, whenever one can isolate a bottleneck), the universal conclusion seems to be that the bottleneck should be eliminated, and then all will be right.

Unfortunately, whether one is talking about traffic or whatever, it does not work that way.

When one bottleneck is eliminated, several others suddenly spring into existence. I would like to argue that the automatic assumption that bottlenecks are bad is a false and most dangerous premise.

Indeed, I wish to make the heretical assertion that a much more effective way for solving many of our problems might be to insert a few well-chosen bottlenecks into the system.**

Ramp metering is an accepted operational system of applying bottlenecks for controlling traffic demands entering on urban freeways, but control strategies usually depend on certain traffic demand patterns for exiting traffic. When these exiting demands do not reach expected levels, the ramp metering controls will be less effective in eliminating and reducing freeway congestion. Similar situations exist when lane blockages and other capacity-reducing events occur.

Research in traffic control of freeways in the operations of special controlled access facilities indicates that more restrictive control of demand is required if peak operational efficiency is to be achieved and if the level of service of the freeway is to be controlled. The control

* Dr. William H. Huggins, John Hopkins University, quoted from the "Wall Street Journal," March 14, 1974. Dr. Huggins is a professor in Electrical Engineering, specializing in circuit and system theory.

of a freeway by the level of service strategy becomes more meaningful as the development of public transportation priority systems for urban freeways becomes a necessity. The research on more restrictive control of freeway demand is being conducted at two locations with the control of one lane and with the control of a total roadway to provide the answers to the design and operational requirements.

Theory of Control - The concept of controlling traffic on the main lanes of a freeway is based on the same theory used on entrance ramps, that is, to control traffic demand at less than roadway capacity to improve operating conditions at downstream bottleneck sections. Most of the ramp control systems use a strategy of maximizing the through-put of a bottleneck in terms of vehicles per hour. The ramp control systems often fail to achieve total success because of several factors. First, there is a short delay in sensing variations in traffic flow. When operating at or near capacity, this delay is very critical and can result in the development of congestion due to normal variations in traffic flow. Second, even if the change in traffic flow characteristics is sensed immediately, the amount of control that can be applied to entrance ramp demand may be insufficient to eliminate the development of congestion. Third, once congestion has developed, most ramp control systems do not exert enough control on demand to return the traffic flow on the freeway to optimum conditions. This can only be done by a reduction in freeway demand.

Therefore, if ramp control systems cannot achieve total success when the objective is to maximize flow rates, there is less chance of success when the objective is to maintain a high level of service. There are several alternatives for improving the effectiveness of freeway

control regardless of the objective.

First, the ramp control system can be expanded and level of control can be more restrictive. This alternative has several disadvantages that make it unacceptable. The expansion of ramp metering will extend into sections of freeways that have no operational problems. Experience has shown this control to be unacceptable to the public and thus ineffective because of high violation rates of the metering signals. The costs for providing this control are greater than other alternatives. The increase in level of control is economical, since the system is already installed, but the very restrictive control rates are unacceptable to the public and may cause problems on adjacent streets that parallel and cross the freeway. Even though field experiments have proven ramp closures to be very effective, only a few locations have been equipped with ramp closure gates. Completely denying access to freeways by local traffic is difficult to achieve, even for the short time periods during peak flows.

A second alternative is to divert traffic from the freeway to other routes or other modes of transportation. Systems for promoting voluntary diversions from the freeway have not been successful. Only when conditions on the freeway are known to be much worse than alternate routes can significant voluntary diversion be expected. Systems promoting diversion to other modes of travel have had limited success, and should be encouraged. The development of park and ride facilities, car pool, and van pool programs and other transit incentives are to be supported, but their impact on total traffic demand will be small for many years.

The third alternative is to control traffic demand on the main lanes of a freeway. This approach is direct and effective in controlling the level of service downstream of the control point. It is this approach

that is the subject of this research study.

Method of Control - The control system must be capable of reducing the capacity of the roadway. Theoretically, this can be done by controlling the speed of vehicles, but that method is impractical on an urban freeway. Freeway motorists drive at a speed they consider practical and safe, which is usually at or near the speed limit. The freeway roadway width can be restricted by narrowing the lanes or reducing the number of lanes. Narrowing the lanes is unacceptable at high speeds and provides less control of the demand rates passing the control station. Reducing the number of lanes is a practical solution which has been applied on urban freeways, though usually for the objective of improving a downstream merging area. The assignment of one lane to priority vehicles could also have the effect of reducing traffic flow. Another approach, which is to be investigated in this study is the control by traffic signals of all freeway lanes at the control site. The installation would resemble in theory a mid-block traffic signal on an arterial street (Figure 1). The signals would rest in green until control of demand was required. The signals would be activated, changing the signals to yellow, followed by a red indication. Depending on the condition of traffic downstream, the signal cycle would be split to reduce the freeway flow by 25, 50, or 75 percent. The green phase will be short (15-20 seconds) so that speeds at the signal will be low.

The major concern, expressed by those who proposed as well as those who reviewed the study, is for the safety of motorists approaching the signal. Every effort will be made in the design and operation of the signal to minimize the probability of accidents. Advanced warning signs and flashers will be prominently displayed (Figure 2). Fail-safe circuits

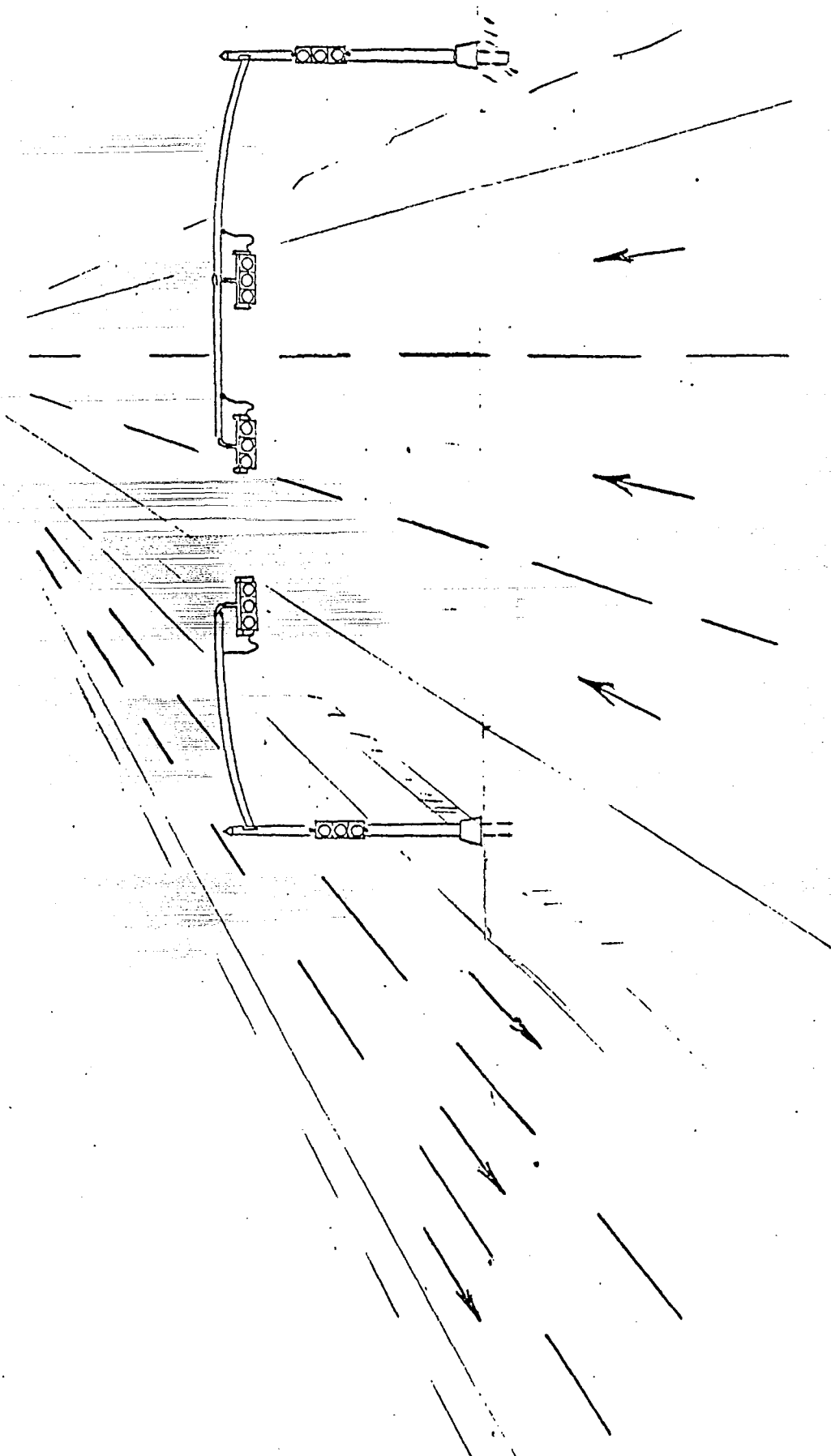


Figure 1. On-Freeway Traffic Control Signals

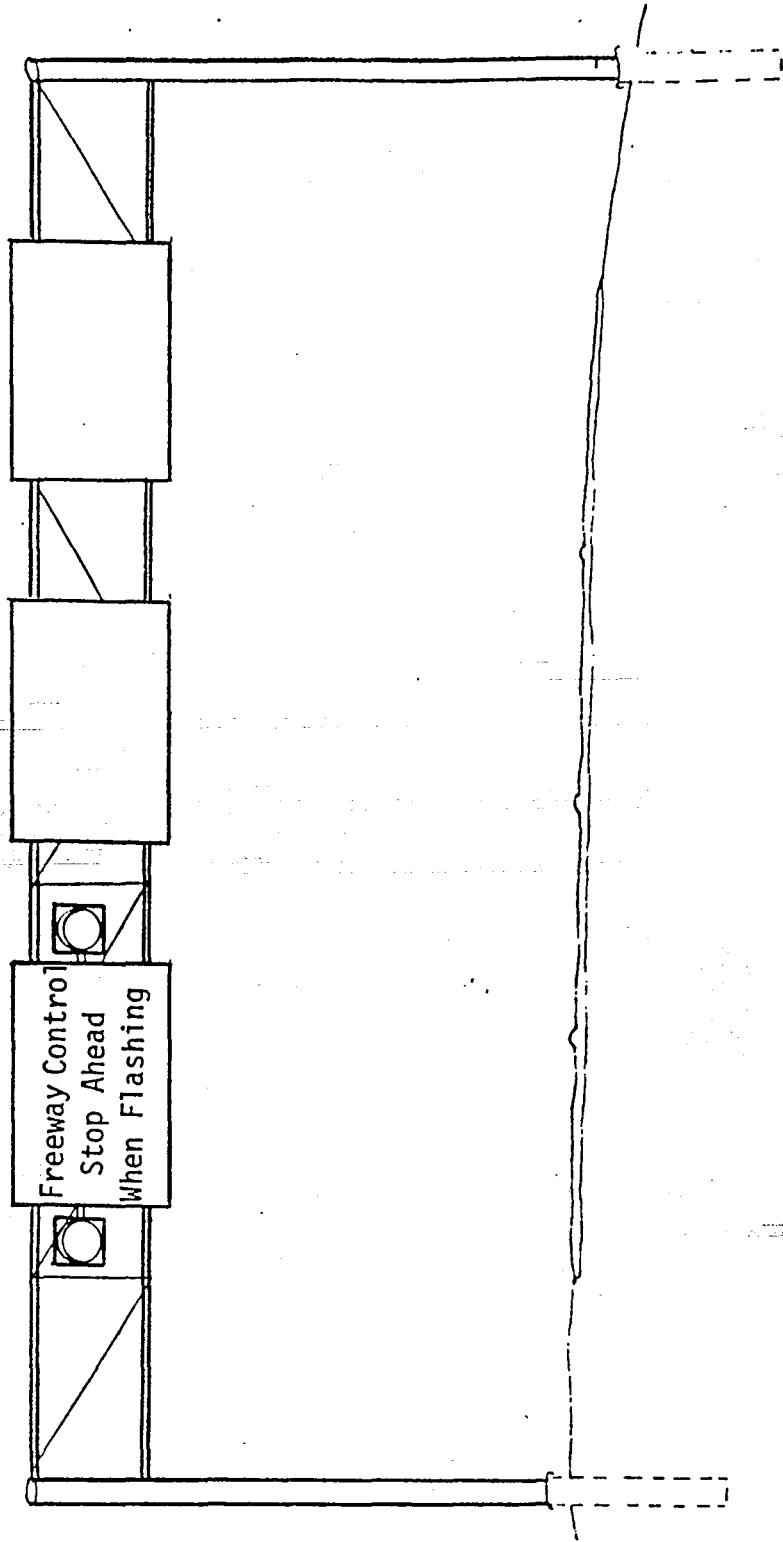


Figure 2. Advanced Warning Signs and Flashers for On-Freeway Traffic Control Signals

will be provided to minimize the effect of equipment malfunctions, and the operation of the signals will be closely monitored.

Benefits of Control - The primary benefit of an on-freeway control system will be the achievement of the level of operation required for the selected control strategy of the freeway. The on-freeway control will enable the operators of the freeway to more equitably distribute the effects of control between local and suburban users of the freeway. The control system can be used to promote usage of high occupancy vehicles by providing priority entry of one freeway lane and/or providing a higher level of service downstream of the control site.

There are other potential benefits that depend on the existing traffic demands, environmental conditions and alternate facilities. For example, the reduction in freeway demand will tend to increase the traffic flows on downstream entrance ramps and interchanges. It is possible that total traffic delay along the freeway corridor will be reduced if queues at the entrance ramps have blocked the movement of crossing traffic. Secondly, the relocation of standing queues from the ramps and freeway lanes inside the control site to the main lanes upstream of the control site may result in improved air quality by distributing exhaust emissions over a larger and less populated area. Finally, the establishment of controls at the outer limits of an urban area may encourage the following: the use of other roadways that are not fully utilized; the change in trip starting times to avoid the control; and the change to other forms of transportation that receive priority operations at and beyond the control site. All of these potential results are improvements in maximizing the use of existing facilities.

On-Freeway Control - One Lane - Most freeway to freeway interchanges

are of a balanced design with the same number of freeway lanes entering and exiting the interchange area. Within the interchange, the connecting roadways diverge from the major roadways, add one or more lanes, then merge one with another and finally merge with the major roadway. It is possible, for example, to have six lanes of demand within the interchange destined for the exiting roadway that has a four lane capacity. When traffic demand peaks on all six lanes at the same time, queueing within and without the interchange takes place and other traffic movements are adversely affected. This study examines one solution to this problem that adds capacity to the traffic that forms the long queues that affect other traffic movements.

Installation - The study site is at the merge of I.H. 10 Westbound at I.H. 610 North Loop Freeways in Houston. In Figure 3, the connecting roadways (1) and (2) from I.H. 610 that merge with roadway (5) of I.H. 10 have long queues that block one of the through lanes of roadways (3) and (4) on I.H. 610. Capacity is added to the connecting roadways by closing the outside lane of I.H. 10 (5). This is accomplished by overhead lane use signals shown in Figures 4 and 5. The first two signals use a green arrow and a yellow 'X' and the last two signals use a green arrow, yellow 'X' and red 'X' to affect the lane closure. The lane closure signals rest in green and the advanced flashers at the warning signs rest in dark when control is not in operation. When traffic conditions warrant the application of control, an operator presses a switch which starts the advance flashers and changes the green arrow signals over the right lane to a yellow 'X'. After 30 seconds, the operator presses the switch a second time, changing the lane closure signals on the last two mast arms from a yellow to a red 'X'. When the operator determines that control has been as effective as possible, within the limits of

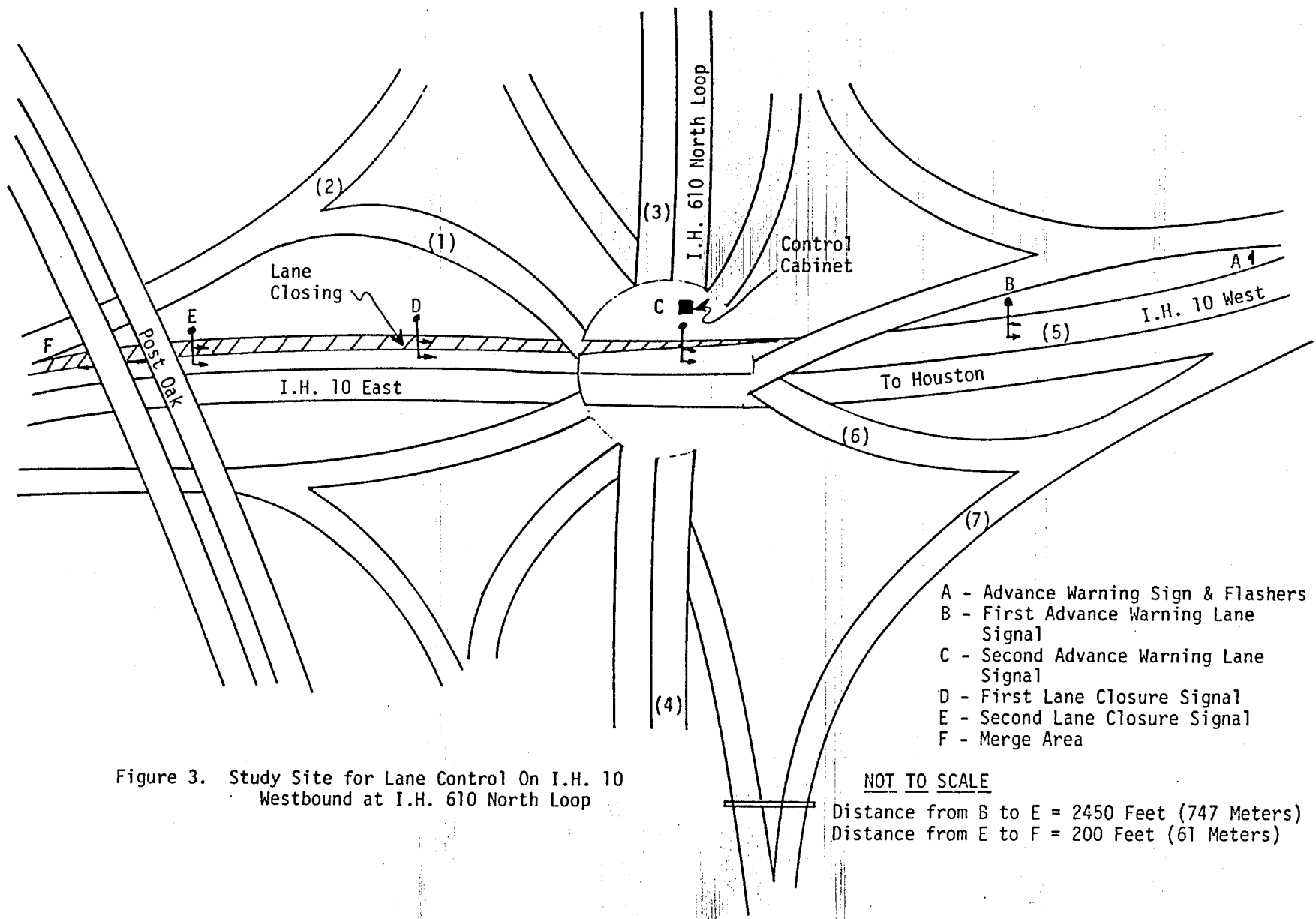


Figure 3. Study Site for Lane Control On I.H. 10 Westbound at I.H. 610 North Loop

NOT TO SCALE

Distance from B to E = 2450 Feet (747 Meters)
 Distance from E to F = 200 Feet (61 Meters)

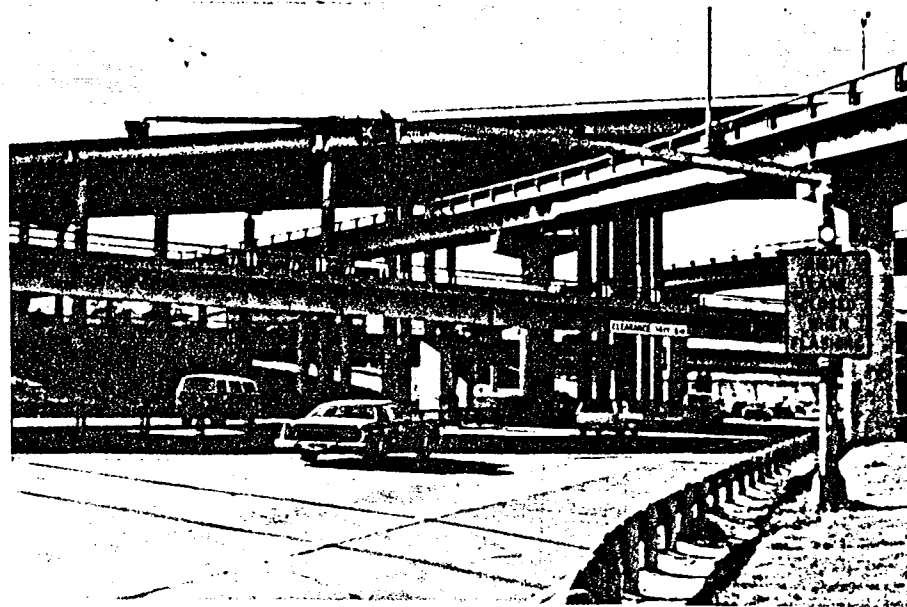
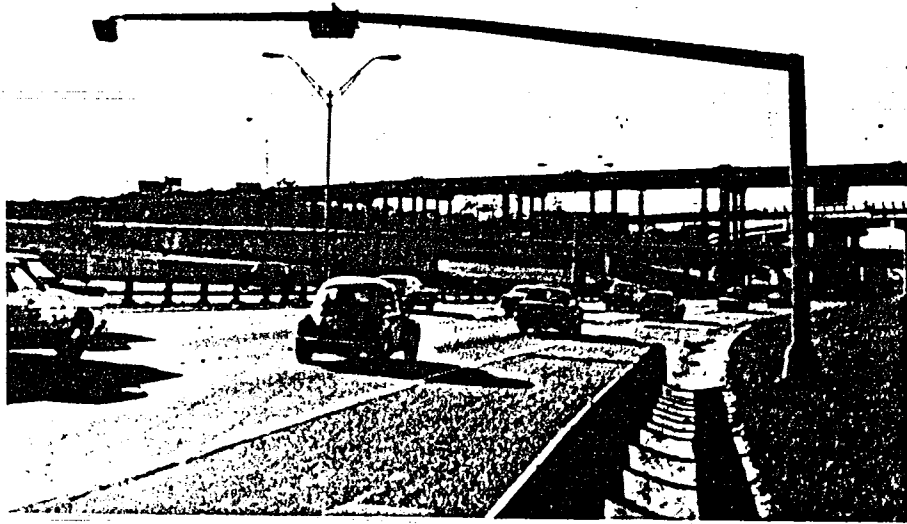


Figure 4. Overhead Lane Use Signals - Lane Closure Warning with Yellow 'X'

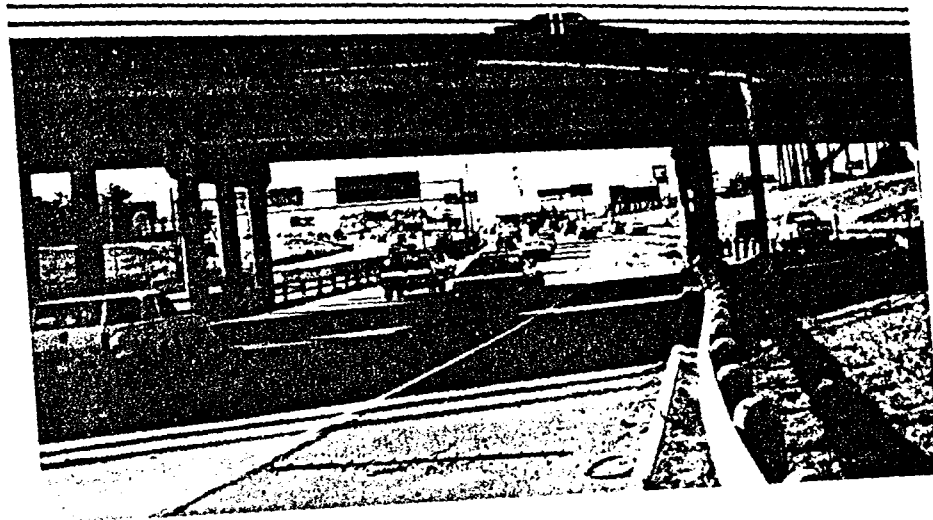
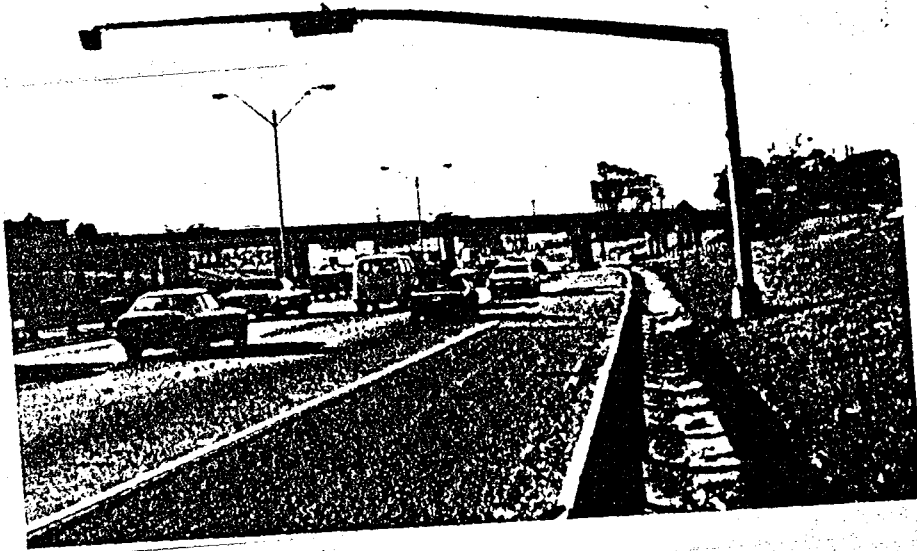


Figure 5. Overhead Lane Use Signals - Lane Closure Control with Yellow and Red 'X's

the control strategy, he presses the switch once more, which returns the lane signals to the green arrow and the advance flashers to a dark state.

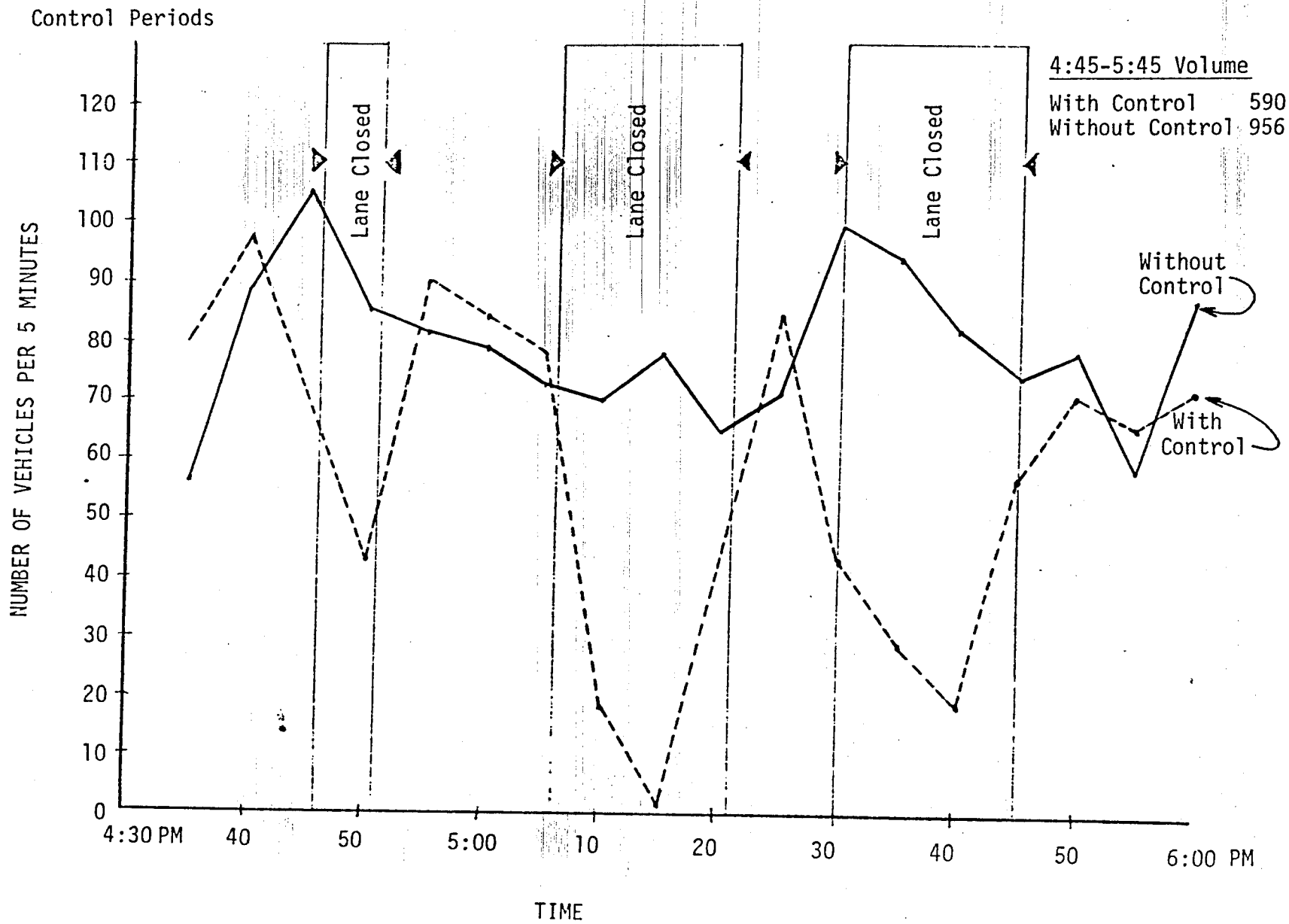
Results of Control - There are several ways to measure the effectiveness of the lane control system: first, does it accomplish the objective of shifting capacity from one roadway to another; second, do the motorists understand and comply with the control signals; third, is it a safe operation; fourth, what effect does the control have on the total operations in the area; and fifth, is the system cost effective.

Data are to be collected during one year of operation and a final report will document the results. The following sections of this report will present the interim findings of operation.

Effectiveness of Lane Control in Shifting Capacity Between Roadways - Flow rates at the merge point confirm that the lane signals effectively close the outside lane to I.H. 10 traffic flow and give priority entry to I.H. 610 traffic. Figure 6 illustrates the change in flow for the controlled lane before and during control. The extent to which the capacity is shifted is directly affected by the length of the control period. For example, for 35 minutes of control, the hourly volume in the outside lane at the last control signal was reduced from 956 to 590 vehicles per hour. Thus, a 58 percent reduction in capacity resulted in a 38 percent reduction in volume. The difference of 20 percent is accountable in the violation rate and increased flow rates in the two open lanes.

Motorist Compliance - From the first day of operation, it was evident that the meaning of the green arrow and yellow and red 'X' signals were understood by the motorists. Publicity and police enforcement

Figure 6. Volume Comparison - Outside Lane
With and Without Lane Use Control



assisted in getting the meaning of the signals across to those who might not have understood, but the major factor contributing to the understanding of the signals by the motorists was the compliance by the majority of the drivers. The actions taken by most drivers to immediately clear the control lane was in sharp contrast to those who ignored the signals indicating that violations of the signals for the most part are intentional.

To measure the voluntary compliance of the signals, lane closure compliance rates are computed for each period of control. A compliance rate is the percent of motorists who comply with the red 'X' phase of the lane closure light. The data are collected by the operator after the outside lane of traffic has had sufficient time to merge into the middle lane. The operator counts traffic in the outside (closed) lane for three minutes. The count is made at the last closure signal just upstream of the merge point. When this control period ends, the operator makes another count for the same amount of time when the lane is open. The two counts are compared to determine the percentage of motorists who violated the red 'X' signal during the control period. These compliance rates, which estimate the motorists' acceptance of the lane closure system, have averaged approximately 85 percent under normal traffic conditions. There are four factors that influence the level of compliance:

Severity of Congestion significantly reduces motorist compliance to the lane closure system. When a motorist has been delayed in a queue for a period longer than he feels is normal, he is more likely to violate the lane closure signal in an effort to decrease his delay. Violations usually occur in groups; i.e. one or two consecutive violators will attract other violators.

Weather, because of its relationship to congestion, also affects compliance rates. Rain, wet pavement, hazy overcast conditions adversely affecting visibility, cause an increase in congestion and a decrease in compliance rates.

Motorist familiarity with the system may have an effect on compliance rates. The greater percent of traffic during the control periods is repeat drivers who, after several runs through the system, may begin to violate the closure.

Enforcement by the police results in an increase in compliance. Police usually patrol the area one or two days a week. Motorcycle policemen are stationed at the first advance warning light and the second lane closure light. Their presence raises the compliance rates to almost 100 percent. Occasionally they issue tickets to violators or verbally warn them of the necessity for their compliance with the closure light.

Figure 7 shows the average compliance rates for the first 120 days of control with notations when police were present. Figure 8 indicates the high, low, and average compliance rates for an average month of control. This indicates the extreme range of compliance particularly during the peak period.

Safety of operation - Of utmost concern was the effect that control of main lane traffic on a freeway would have on safety. If the initiation and operation of the signals were proven to be a hazard to traffic, the system would be removed.

Fortunately, data indicate that the lane closure has no adverse effect on the safety conditions in the area two miles upstream and two miles downstream of the control site. When accident experience for the

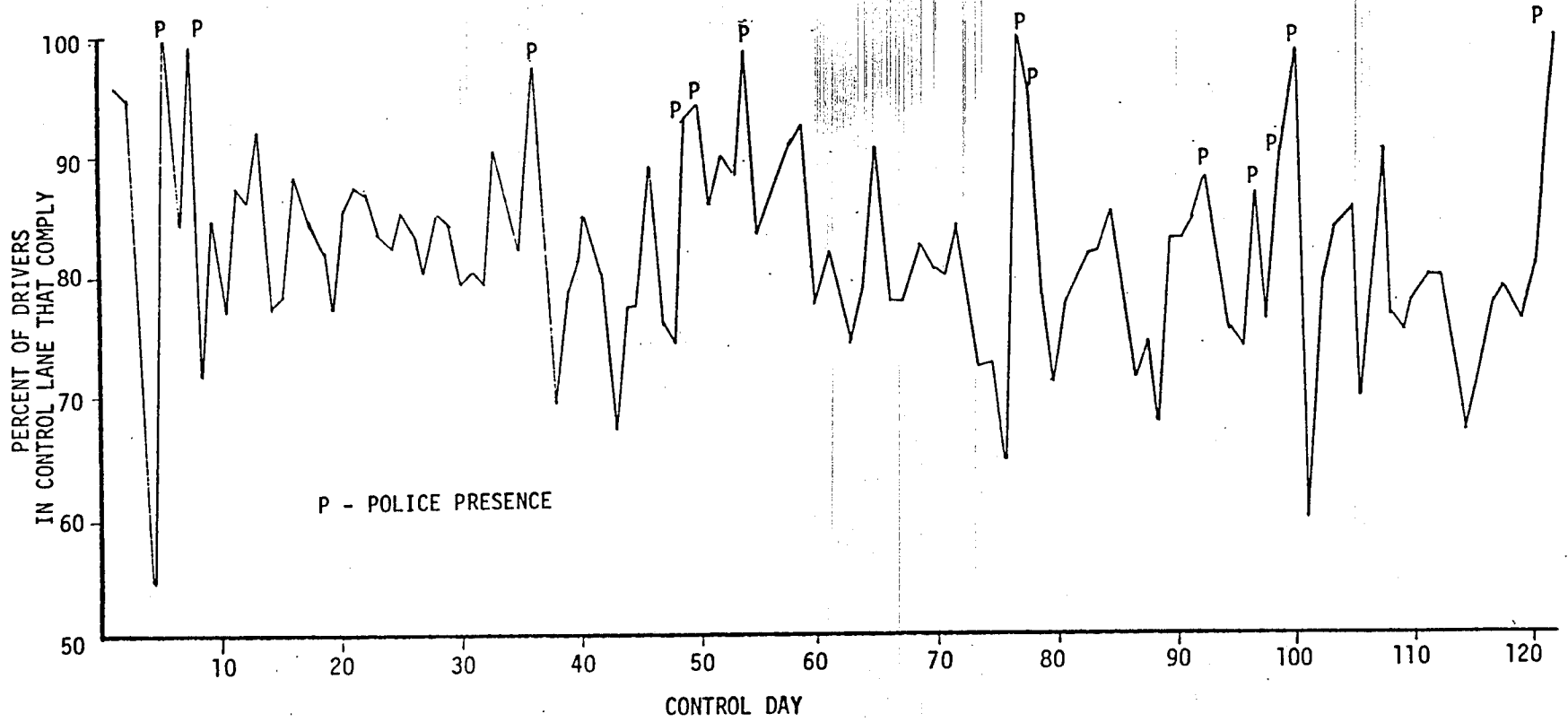


Figure 7. Average Daily Signal Compliance Rates

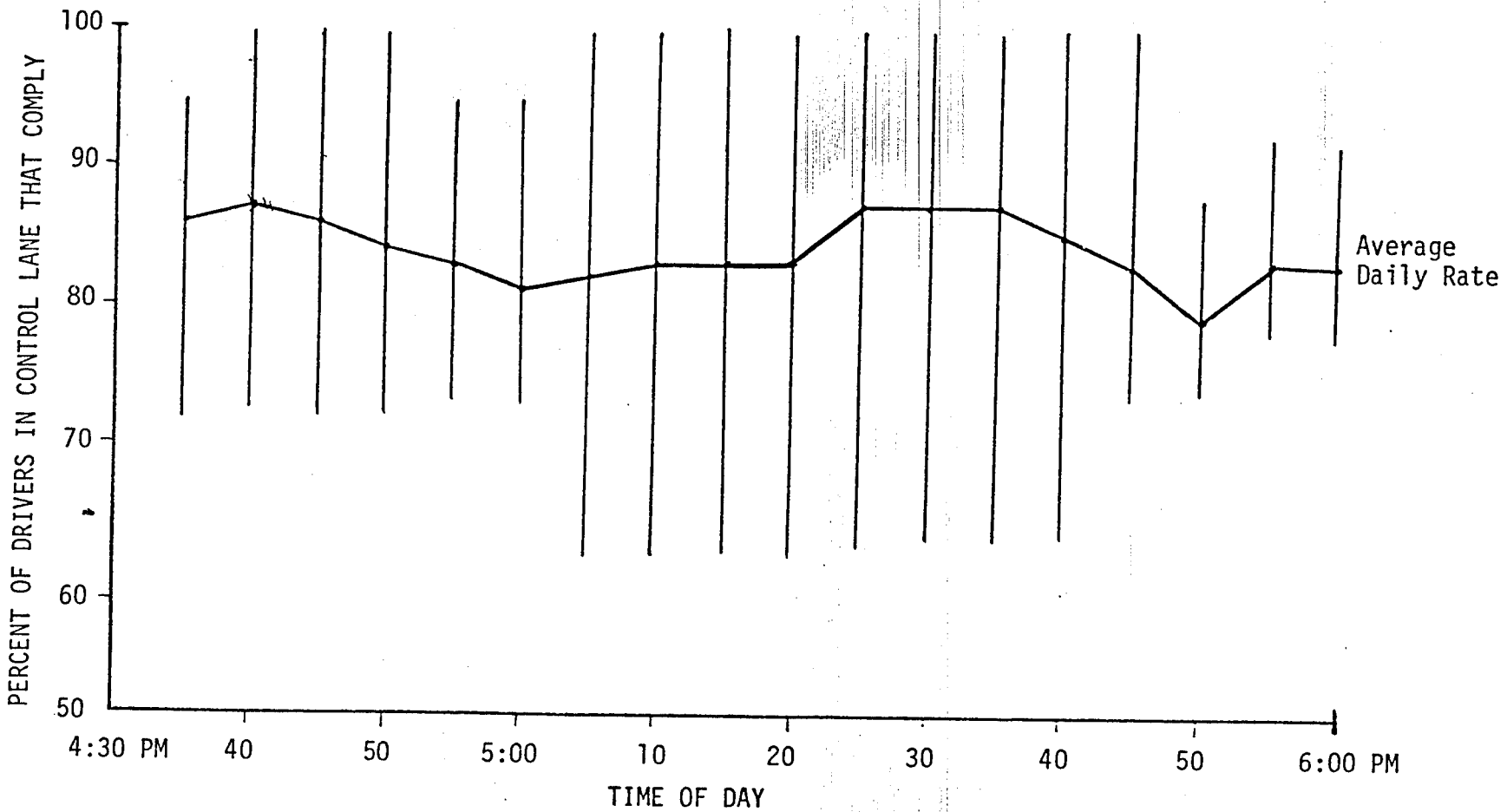


Figure 8. Range of Signal (rates

first four months of 1975 is compared with that of the same period during the previous year (non-control), records show a 57 percent decrease in the combined outbound and inbound incidents (Table 1). When considering only the section of outbound freeway that is directly affected by control operations, the reduction of accidents is 80 percent. Table 1 was compiled from the computerized records of the SDHPT.

These results can not be directly attributed to the operation of the signals, since the time of comparisons is so short. Still they do present a strong argument that the signals are not a traffic hazard. Data for the full year of operation will be collected and further analyses will be made in the final report.

Effect of Lane Control on Traffic Operations - There are three sections of roadway that can be affected by the lane closure control system: I.H. 10 Westbound, downstream of the control site; I.H. 10 Westbound, upstream of the control site; and I.H. 610 connecting roadways and approaches from the South and East. Each of these roadways has been monitored and measurements of traffic characteristics on each indicate the following:

Traffic Flow Downstream of Control - The control system does not change the capacity of the merge area, but simply shifts the priority flow from one approach to another. If there is adequate demand on both approaches, the total output of the merge area remains the same. This is the case with the I.H. 10-I.H. 610 merge area. The total flow on I.H. 10 Westbound from the interchange has not been significantly changed.

Even if the lane control could exert some influence on the flow at this point, the two bottleneck sections downstream (the weaving section at Silber and the lane drop at Wirt) would still control the throughput of the freeway.

TABLE 1
 ACCIDENT DATA COMPARISON
 FROM WASHINGTON TO CAMPBELL
 INTERCHANGES ON I.H. 10 FREEWAY

	4:00-6:00 p.m.		24 Hours	
	<u>I.B.</u>	<u>O.B.</u>	I.B.	<u>O.B.</u>
<u>Non-Control</u> (Jan.-Apr. 1974)	1	14	42	35
<u>Control</u> (Jan.-Apr. 1975)	3	3	18	15

To confirm the thesis that downstream conditions were not affected, observations, counts, and speed measurements were taken at Wirt and Campbell. The comparisons of typical days before and during the control show no appreciable difference in the operation characteristics (Figures 9 and 10).

of delay and congestion will vary from day to day with the length and times of lane control and the demand pattern on the approach lanes.

Some typical curves were constructed to illustrate the effects of moderate and very restrictive control days (Figures 11 and 12).

These two curves indicate that the added delay caused by the lane control can be expressed in the following manner: For moderate restrictive control, the maximum additional delay encountered by a motorist from 5:30 to 6:00 p.m. would be 5 minutes and the average additional delay would be approximately 3 minutes. The queue length would be increased by approximately 100 vehicles per lane, which would move the end of the queue upstream for approximately one mile. For very restrictive control, the maximum additional delay would be 10 minutes and the queue would be 150 vehicles per lane, or 1.5 miles longer than usual. The average additional delay would be approximately 5 minutes.

As bad as these figures seem to be, the fact is that the total delay to motorists using I.H. 10-I.H. 610 interchange has been reduced. This is explained in the following section.

Traffic Flow in I.H. 610 Approaches to I.H. 10 - Since the lane control provides more capacity to the connecting roadways from I.H. 610,

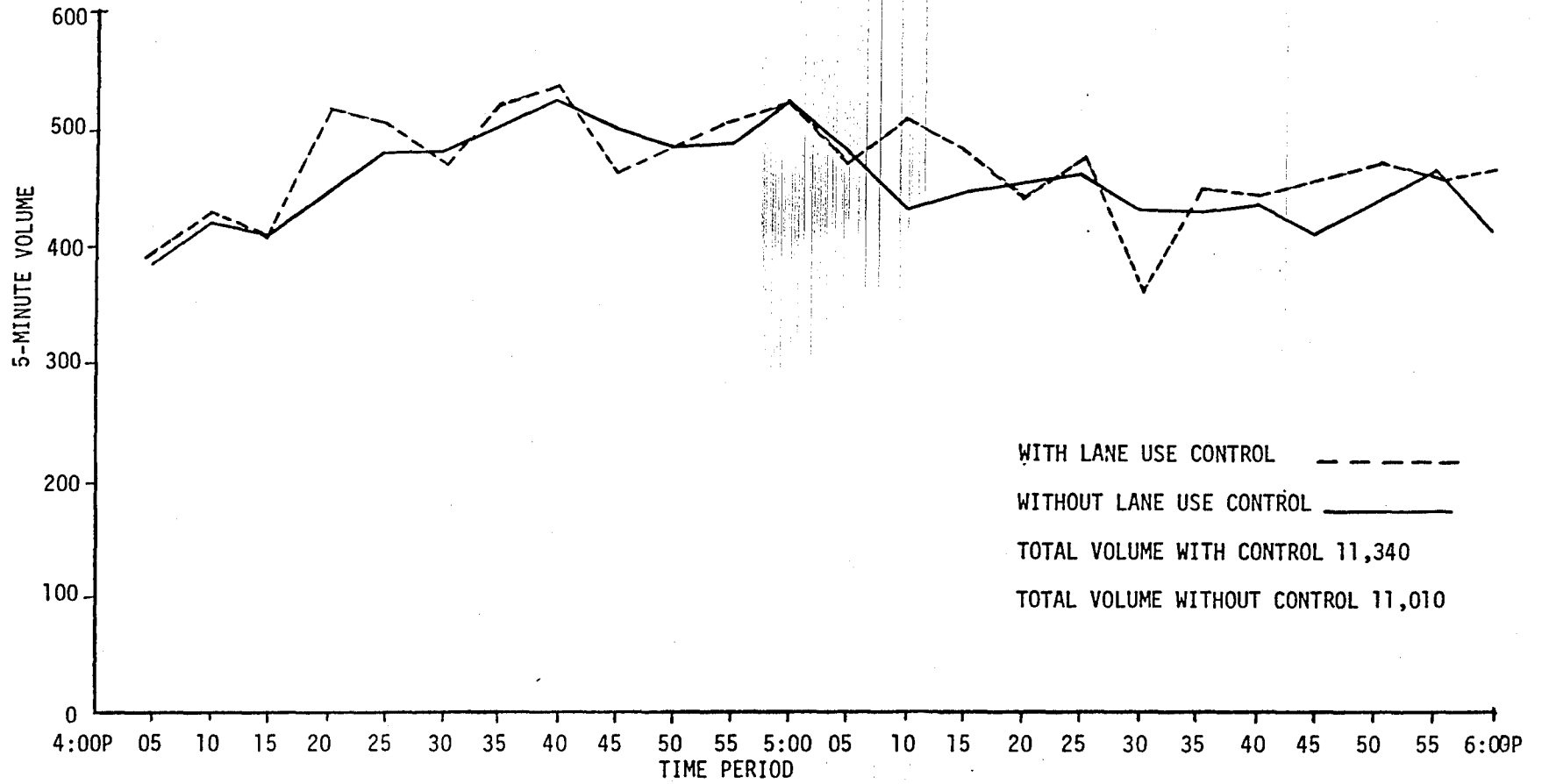


Figure 9. Five-Minute Flow Rates
at I.H. 10 Westbound at Wirt Road

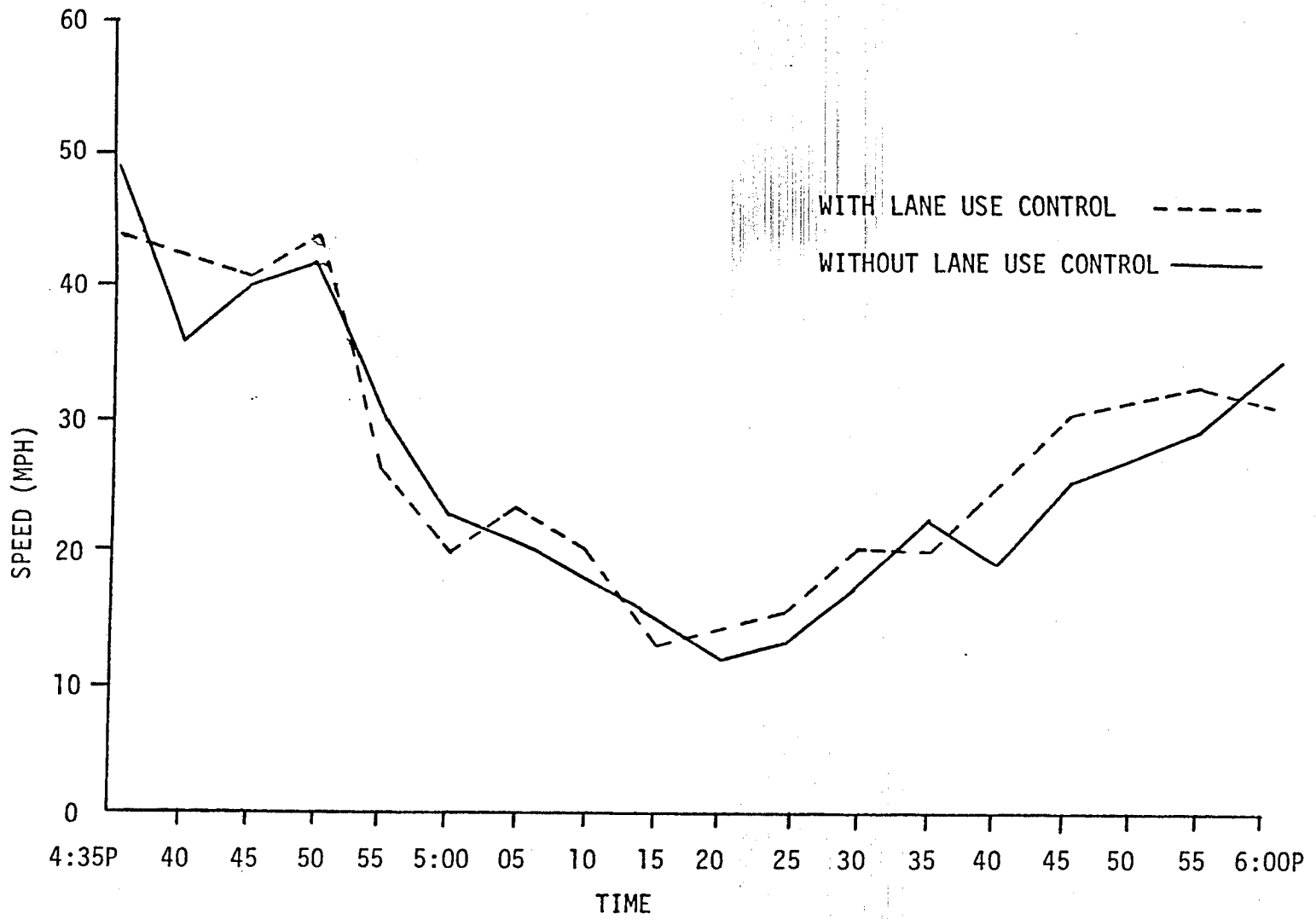
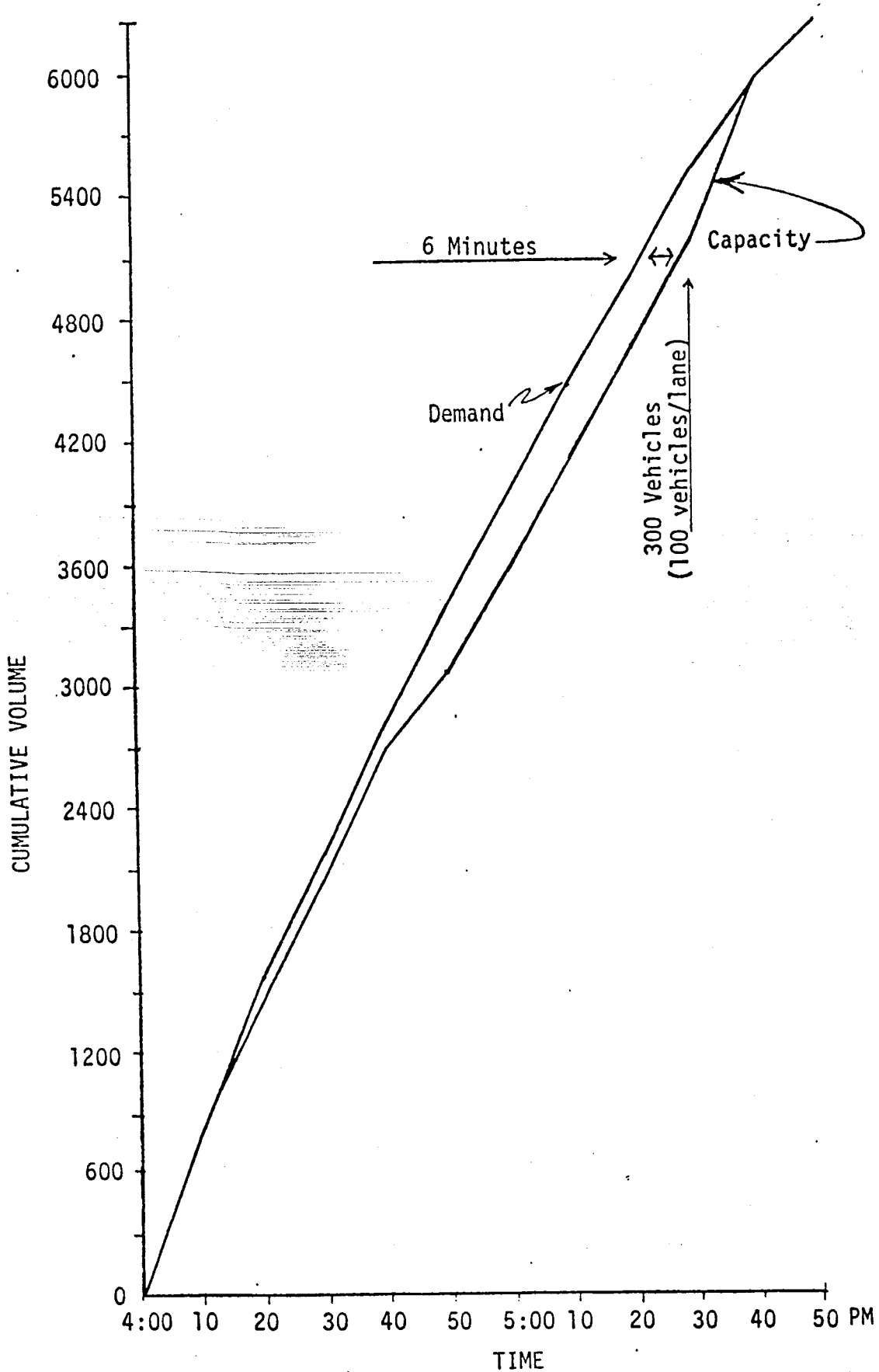
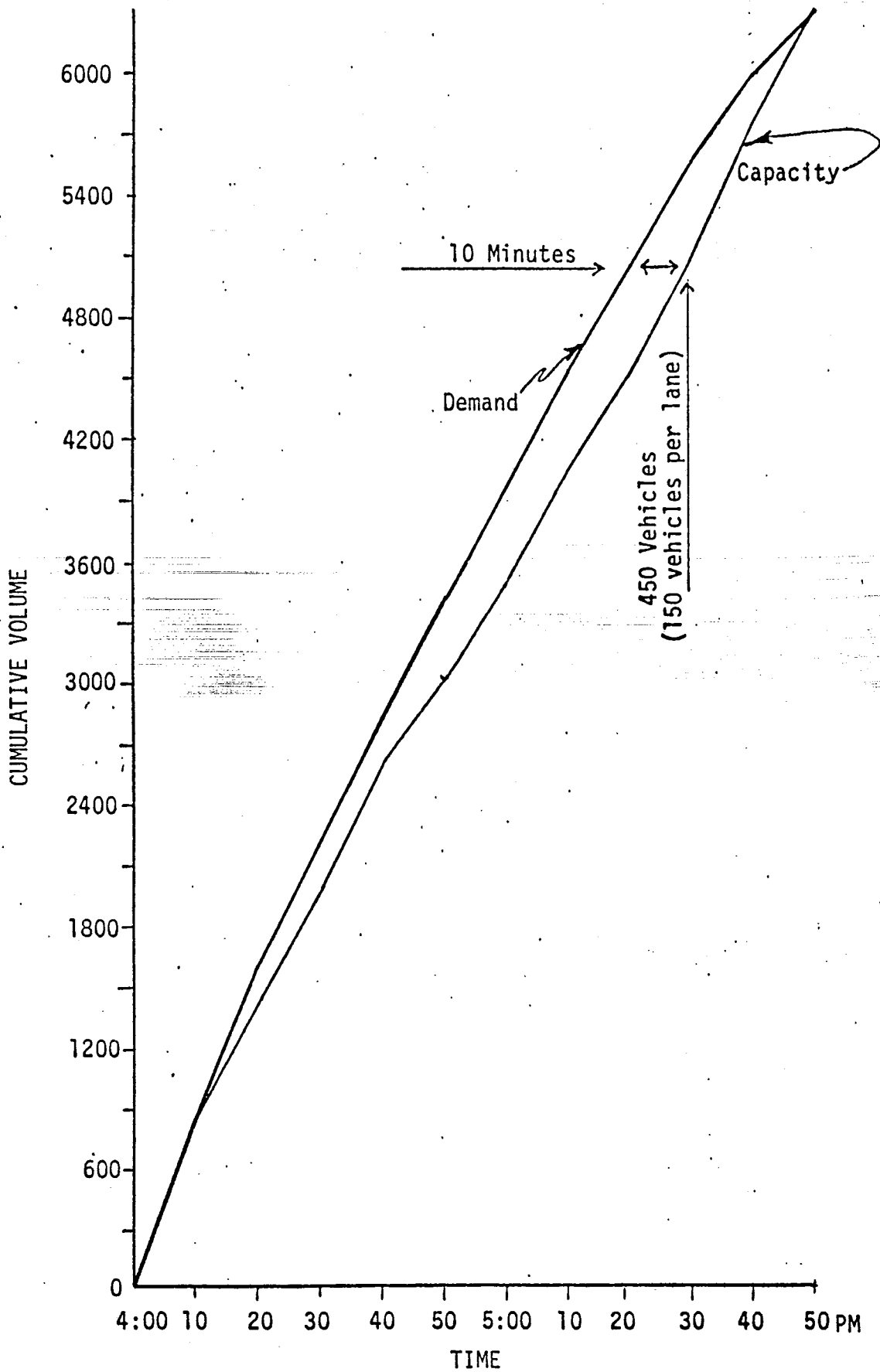


Figure 10. Five-Minute Average Speeds at I.H. 10 Westbound at Wirt Road



(40 Minutes of Control)

Figure 11. Typical Capacity - Demand Curves for I.H. 10 Westbound with a Moderate Restrictive Lane Use Control Strategy



(65 Minutes of Control)
 Figure 12. Typical Capacity - Demand Curves for I.H. 10
 Westbound with Very Restrictive Lane Use Control Strategy

the flow rates are higher and the queues are shorter on these ramps.

The objective of the control at this particular interchange was to keep the queue lengths on the ramps from extending back to the main lanes on I.H. 610. In most instances, the control was successful. Please refer to Figure 13 for the following discussion of delay in the I.H. 10-I.H. 610 interchange.

The reduction in delay on the two connecting ramps from I.H. 610 was equal to the increase in delay to the I.H. 10 approach. This is proven by the fact that the downstream capacity of I.H. 10 has not been changed and that total upstream demands have not been affected by control. (See Locations (1) and (2) in Figure 13.) Therefore the total delay to traffic destined for I.H. 10 Westbound has not changed.

The reduction of queue lengths of the I.H. 610 ramps (Location 3) has improved the throughput of the I.H. 610 roadway from the West Loop to the North Loop (Location 4). Delay studies on the 3-lane section of freeway crossing over I.H. 10 indicated a savings of approximately 13-vehicle hours of travel time on one typical day of control or 2,416-vehicle hours per year (Location 5). This savings would increase with an increase in traffic demand on I.H. 610.

Benefit-Cost Analysis - The operation of lane control has several obvious benefits: the reduction of conflicts in the merging area; the reduction in total travel time through the interchange; and possibly, the reduction of accidents in the area. There are also operations that may be considered as disadvantages: the increase in delay to I.H. 10 traffic, even though it is offset by improvements to I.H. 610 traffic delay; the increased difficulty for I.H. 10 traffic to weave to the right to exit at the first ramp (Silber) downstream of the control section, and the frustrations of facing additional controls on the urban roadway system.

The only factor that can objectively be evaluated at this time is

(2) I.H. 610 and I.H. 10 Demand
for I.H. 10 Westbound
Unchanged.

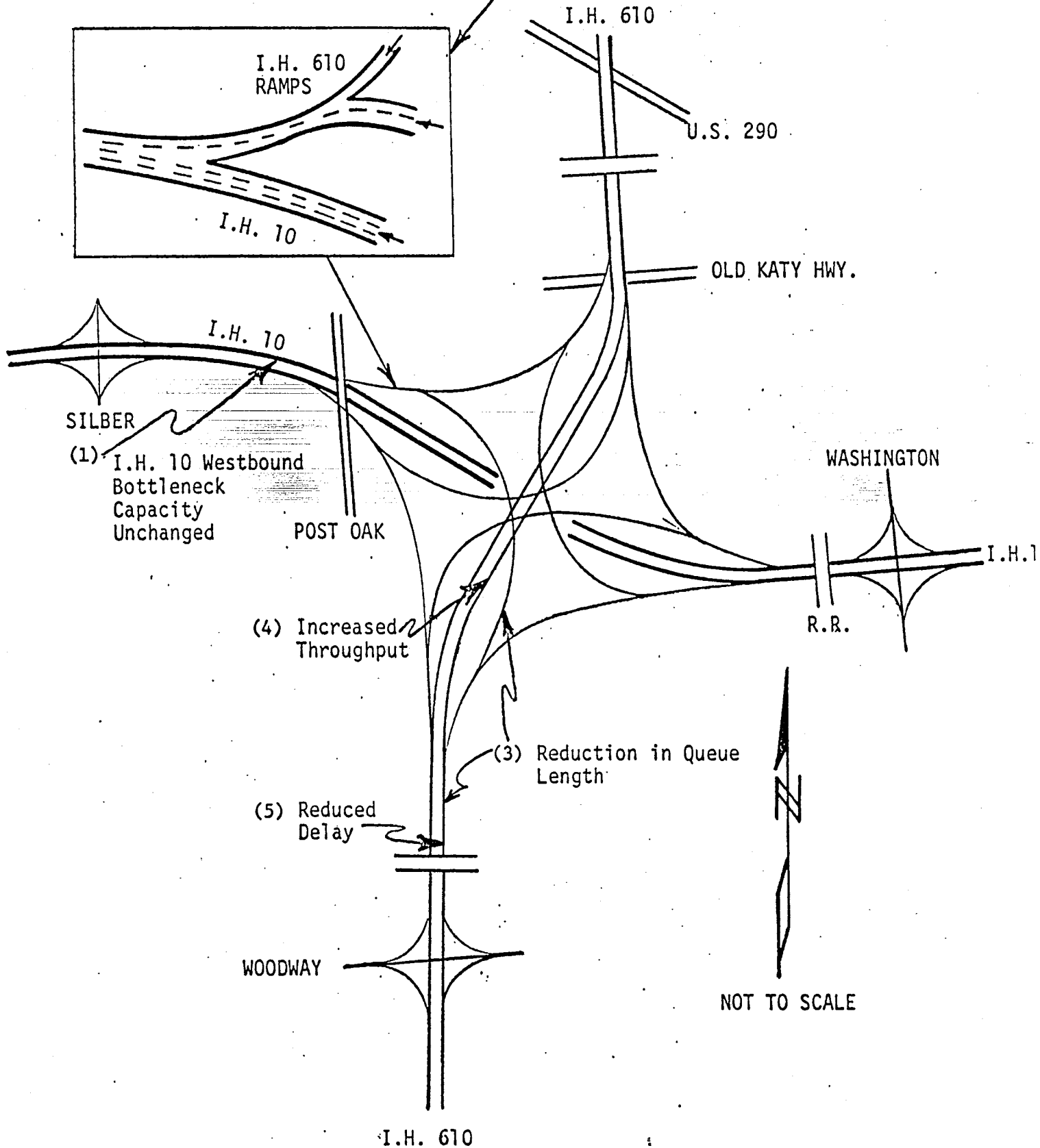


Figure 13. Capacity, Demand, Delay Relationships
In the I.H. 10-I.H. 610 Interchange

the reduction in delay compared to the cost of installation, operation, and maintenance of the signal system.

From available accident records for the first four months of 1974 and 1975, from Washington to Wirt Road interchanges, a projected accident reduction of 16 vehicles per year was obtained by comparing accident frequencies of 1974 and 1975 in this area. An average two-vehicle rear-end involvement with no human injury is estimated at \$418. This results in a yearly savings of \$6,688 in motorists' personal property damage.

Elimination of these 16 accidents also results in an additional savings to the motorists for delay. Studies have shown that the average accident directly affects traffic flow for approximately 41 minutes, resulting in a 51 percent decrease in flow for three lanes. For a four-lane section of freeway, the reduction of flow would be in the 25-40 percent range.

But because of the difficulty in relating the change in accident experience to the lane control, these benefits are not included in the analysis.

Therefore, total annual cost for this system is computed to be \$8,600 and the total annual benefit is \$17,500, yielding a benefit-cost ratio of approximately 2.0 (Table 2).

High Load Detection System - An Overheight Load Detection and Warning System was implemented by District 12 of the State Department of Highways and Public Transportation on I.H. 45 near the I.H. 10 exit just north of the Houston Central Business District. The system was to function by detecting objects passing through a continuous light beam 14 feet above the Northbound I.H. 45 roadway and operating a series of yellow flashing lamps on static message signs in advance of the Hogan

TABLE 2

BENEFIT-COST ANALYSIS FOR THE
ON-FREEWAY LANE USE CONTROL SYSTEM
ON I.H. 10

Part I

Costs (Manual Operation)	Annual	Initial cost
<u>Cost of System</u>		\$29,600
10 years @ 10%		
$\frac{R(1+R)^N}{(1+R)^N - 1} \times P = Y$		
$\frac{.1(1.1)^{10}}{(1.1)^{10} - 1} \times \$29,600 = \frac{7677.47768}{1.59374246} =$	\$4,800	
R = Interest Rate		
N = Number of Years		
P = Principal		
Y = Yearly Capital Recovery Cost		
<u>Annual Operating Costs (Signal Operator Expenses)</u>		
Maximum 240 days/year		
Control time 4:00-6:30 for 240 days = 600 hours		
600 hours @ \$3/hour = \$1,800		
6,240 miles @ 16¢/mile = \$998 travel expenses		
Total	2,800	
<u>Annual Maintenance Costs</u>	<u>1,000</u>	
Total Annual Cost	\$8,600	

Part II

Costs (Automatic Operation)	Annual	Initial Cost
Cost of System		\$29,600
Cost of Automation		<u>8,150</u>
Total Installation Cost		\$37,750

TABLE 2 (Continued)

10 years @ 10%

$$\frac{R(1+R)^N}{(1+R)^N - 1} \times P = Y$$

$$\frac{.1(1.1)^{10}}{(1.1)^{10} - 1} \times \$37,750 = \frac{9791.37778}{1.59374246} = \$6,145$$

Annual Maintenance Costs	<u>1,500</u>
Total Annual Cost	\$7,545

Part III

Benefits

Vehicle hours savings per typical day	13
Number of days operation per typical year	240
Total Yearly savings in vehicle hours	3,120

Average cost per vehicle hour computed
for an occupancy of 1.3 persons per
vehicle

5.56

Total annual savings

\$17,500

Benefit Cost Ratio

Manual Operation	2:1
Automatic Operation	2.3:1

Street Overpass. The static messages alerted the drivers of a possible overheight vehicle and indicated the diversion route to the Westbound I.H. 10 roadway (Figures 14, 15, and 16). Preliminary tests were conducted at the study site by recording traffic operations on 8-mm film each time the system was activated. This study approach was unacceptable because of numerous false actuations of the detection system and the expense of photographic equipment and supplies. An alternate approach of controlled studies was used at the study site to collect the traffic data on volumes, speeds, and brake light applications at five time periods over three days. Each of 11 studies for each time period was composed of nine minutes of data; 1) 3 minutes immediately before the warning system was manually activated, 2) 3 minutes while the warning system was operating, and 3) 3 minutes immediately after the warning system had ceased operations. Analysis of the volume and speed data indicated that the operations of the warning system did not significantly affect the normal traffic operations in the study section. The brake light data analysis did show that the system was significantly noticeable by the driver in three of the five time periods over the three-day period. Only one overheight load was observed during the studies and was diverted to I.H. 10 Westbound exit by the sign-signal system.

Extensive tests conducted on the photoelectric detection system indicated that an object one inch in diameter was the minimum detectable size, if the object is less than 20 feet from the detector. Tables were developed for various lamp source-to-detector distances and detectable object sizes. Test results indicated light diffraction around objects close to the light source inhibited detection. Also, no detection was noted when the speed of the object's shadow between the photoelectric

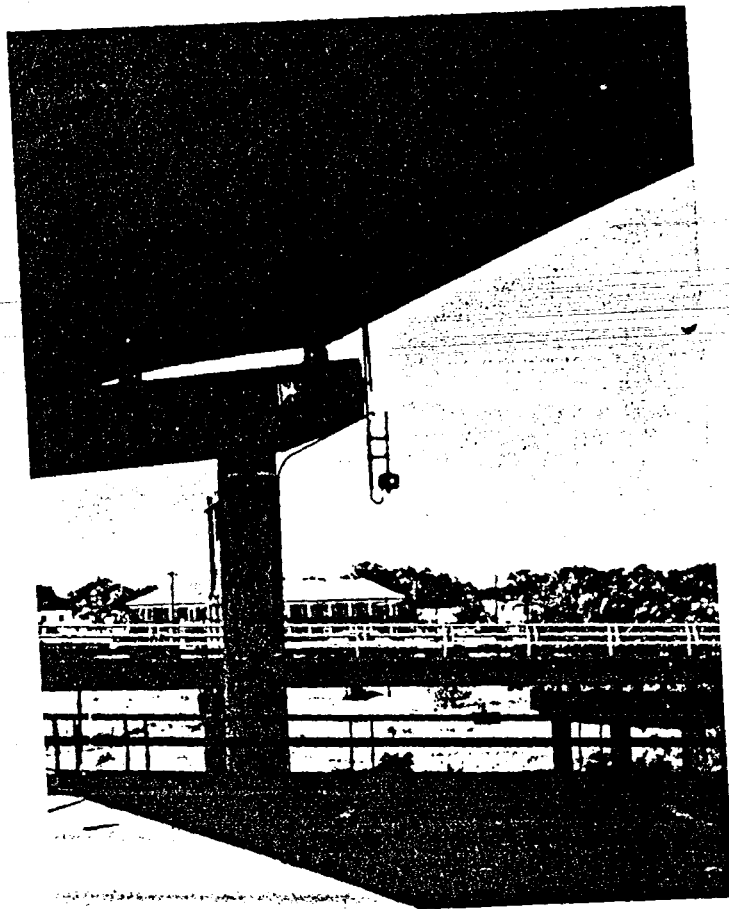


Figure 14. Light Source for Photo
Electric Detector for
High Load Detection



Figure 15. Advance Warning Signs and Flashers

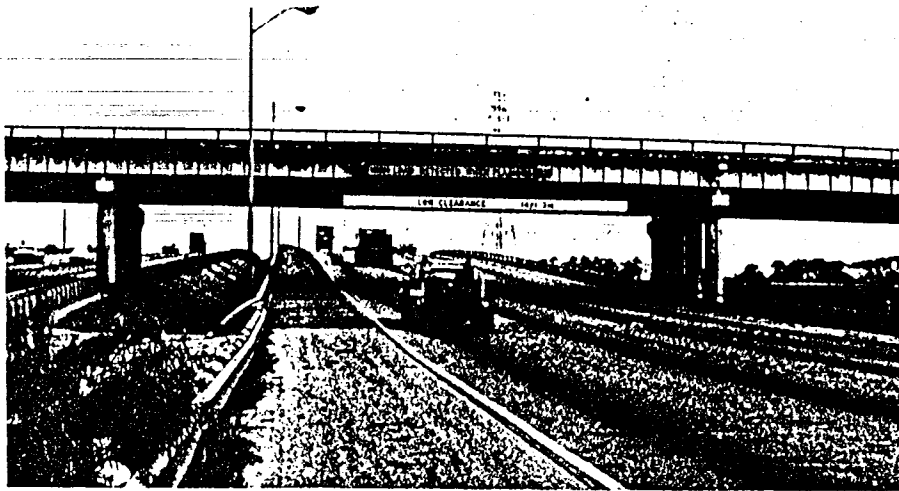


Figure 16. Signs and Signals at the Low Clearance Structure

cells was greater than 450 MPH or was slower than 2 MPH.

These studies prove that the system does not detect all overheight loads. In fact, skid plates welded by District 12 State Forces under the Hogan Street Overpass have paint scratches that prove that not every high load diverts to I.H. 10. Further study did not reveal whether the detection and warning system functioned properly when contact with the skid plates was made by the overheight loads. However, the detection system was proven in the laboratory to be effective in detecting large objects and the fact that no significant damage to the bridge has been reported since the installation of the warning system is supportive of the conclusion that the warning system is effective.

The results of the study are discussed in more detail in the Research Report 202-1 entitled "Evaluation of the High Load Detection and Warning System on I.H. 45 in Houston."

Design of Urban Wide CCTV System for Traffic Surveillance

There is continued interest in the design and application of closed circuit television for traffic surveillance, even though there have been studies of television systems since the first installation in the early 1960's. The reasons for this are: the need for visual surveillance has increased; the development of automatic electronic surveillance systems has been slow; the television industry continues to provide better quality cameras with greater capability for 24-hour surveillance.

Need for Visual Surveillance - Urban highway transportation systems are required to provide the desired mobility but with constraints that limit the expansion of the transportation network. To accomplish the goals of mobility under these conditions, transportation agencies are investigating all alternatives for making the best use of the existing facilities,

for encouraging the development and use of public transportation systems, and for increasing the efficiency of private transportation. These alternatives can be stated another way: better management of traffic operations, priority operation of high occupancy vehicles, incentive programs for use of public transportation, and car pools. Most of the techniques, procedures, and systems that are being proposed involve traffic surveillance, motorist communications, and traffic control systems. In some instances, intensive enforcement of traffic controls is required. Current information on the status of traffic conditions, roadway conditions, capacity reducing events, traffic control devices is essential to all of these alternatives.

Visual surveillance is one of the best methods for obtaining information, and television surveillance is one of the best means of providing visual coverage of miles of freeway. Freeway patrolling is another form of visual surveillance that is very effective, except for the time required to cover many miles of freeway, particularly during periods of heavy traffic congestion. If used together, patrols and CCTV can provide an excellent visual surveillance system, with that most important extra benefit of improved response time to incidents.

On most freeway and major arterials of the urban areas of the United States, visual surveillance from passing motorists, arterial traffic watchers, official patrol units, or other on-site persons are the only systems now in use. If the need for surveillance is increasing, then the need for better systems of surveillance is increasing.

Development of Automatic Electronic Surveillance - Electronic surveillance systems use vehicle detectors that provide basic traffic data to a traffic analyzer that computes traffic parameters which are applied to

control strategies or to other decision making processes. Since the first vehicle detector was placed at an intersection to make the signal control responsive to traffic, engineers have continued to develop new and better ways to apply the real time traffic data to control and communications systems. And with the application of digital computers to traffic control, the number of traffic algorithms has increased dramatically.

However, progress in the development of an automatic electronic surveillance system has been slow because the hardware systems for detection and transmission of data cannot perform at accuracies that are expected and required. Attempts to obtain the required accuracy and reliability often resulted in designs that were considered to be economically infeasible, but the equipment manufacturers continue to try to develop the perfect detector and the traffic control managers continue to try to develop computer programs that compensate for the inaccuracies, variations, and reliability of operation of current hardware.

Development of CCTV Equipment - Experience in the development of equipment for industry, military, and the space agencies has enabled the CCTV industry to greatly improve the quality and costs of the equipment. Improvements in camera tubes have lowered the light requirements such that nighttime visibility is adequate for traffic surveillance. Developments in the quality of electronic circuits and environmental housings have improved the reliability of equipment housed in the field.

Research Accomplishments - The research was conducted on two subjects: the state-of-the-development of the television cameras with low light level capability and the state-of-the-development for towers capable of providing a mounting platform for the video equipment in the field.

Suppliers of CCTV equipment were invited to demonstrate their lines

of low light level cameras for the research staff and representatives of the State Department of Highways and Public Transportation. Six companies responded and five demonstrated their equipment (Table 3). Two cameras provided excellent pictures of traffic and roadway geometrics at night: COHU Model 2855 - Silicon Intensified Target Camera; and the General Electric Camera. COHU Model 2856 - Intensified Silicon Intensified Target Camera - demonstrated greater sensitivity to light than Model 2855 in a closed light box, but was not used in field trials. Diamond Electric successfully demonstrated its low light level camera to SDHPT, but the research staff was unable to attend.

Based on the results of these limited demonstrations, it was determined that the camera should be able to produce a usable picture with less than 10^{-3} foot candles (FT-c) illumination on the face plate of the camera. Those cameras that, according to their specifications, can satisfy the requirements are noted in Table 3.

The demonstration of these cameras did not answer all the questions on design. The angle between the camera and the headlights was an apparent critical factor, indicating the need to specify mounting heights and limits of the usable field of view for various lighting and climatic conditions. Tests to determine these relationships will be conducted on a COHU Model 2855 that was obtained on a six-month lease (Figure 17). Those tests will define the practical limits of surveillance at night.

Camera Mounts* - Since the first installations of cameras for traffic surveillance in the United States, the mounting heights have been getting higher and the spacing between cameras, longer. Detroit Lodge Freeway had

*Dr. Neilon J. Rowan, recognized authority in highway illumination, is the contributing author to the following section on camera mounts.

TABLE 3
 LIST OF SUPPLIERS OF
 LOW LIGHT LEVEL (LLL) CCTV
 EQUIPMENT*

Company	Model	Remarks
COHU, Inc.	2855	Silicon Intensified Target Vidicon
COHU, Inc.	2856	Intensified Silicon Intensified Target Vidicon
Diamond Electric	LL1 LL2 LL55	
General Electric	4TE 36A	Nite Guard Electron- In-Epicon
Panasonic	WV-260T	Silicon Target Vidicon
Venus Scientific, Inc.	NV1	LLL CCTV
Venus Scientific, Inc.	NV2	Intensified LLL CCTV

*Exclusion of any camera or manufacturer in this study does not constitute an opinion on the unacceptability of the equipment or supplier.

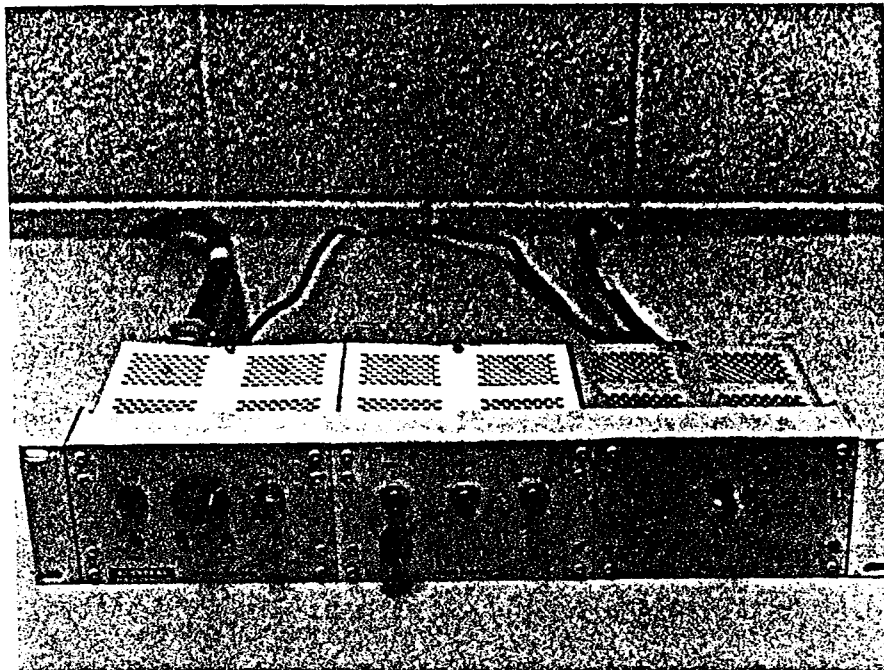
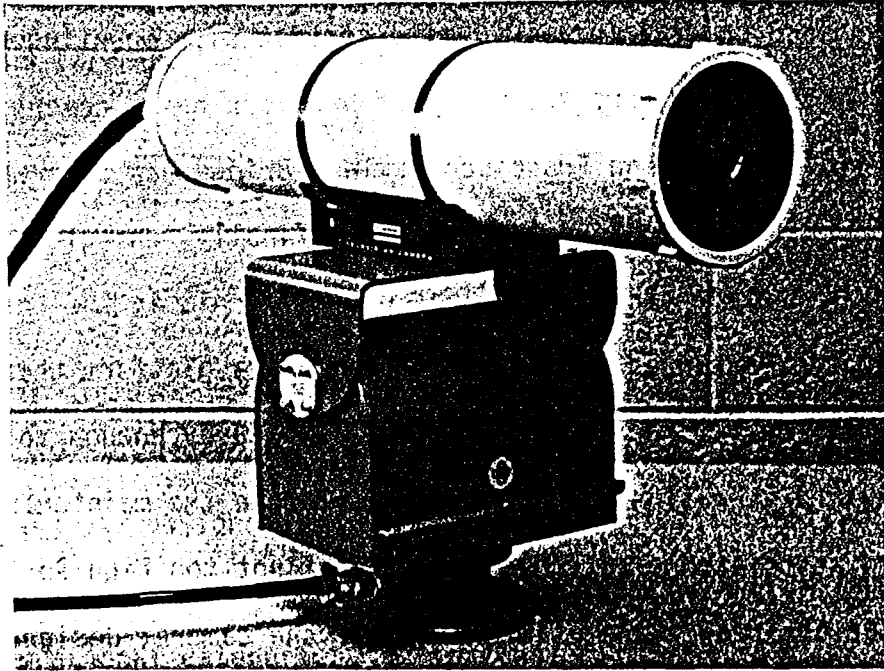


Figure 17. Low Light Level CCTV Camera, Pan and Tilt, and Control Unit

14 cameras in a 3.2-mile section with mounting heights of 30 feet. Houston Gulf Freeway had 14 cameras in a 6.5-mile section with some mounting heights of 60 feet. Dallas has 8 cameras in a 10.0-mile section with mounting heights from 50 feet to 120 feet. The Port Authority of New York has a camera on the 35th floor of a building. The San Francisco Oakland Bridge has cameras mounted on the bridge towers 125 feet above the roadway. Finally, the ultimate in camera installations is the airborne camera used by California in the Los Angeles area.

So the search continues for an effective camera platform that is high enough to permit longer spacing between cameras; sturdy enough to prevent excessive sway and vibration; designed to facilitate the maintenance of the camera and associated electronic components; not too high so that climatic conditions reduce the usable range of the camera; designed to be aesthetically acceptable; and economically feasible. Several alternatives have been investigated:

Standard Highway Luminaire Poles - Current designs use 50-foot poles for continuous highway lighting. Experience of several operating systems is that this mounting height is very good for daylight viewing for distances of 2,000 to 3,000 feet. Good resolution is possible for viewing distance up to 5,000 feet in clear weather.

Sign Bridge Towers - Poles attached to the top of sign bridges have been tested and proven to be acceptable platforms for towers with mounting heights comparable to the luminaire pole.

High Mast Lighting - Several factors have prompted the consideration of CCTV systems with existing and planned high mast lighting systems. These include:

1. It is desirable to mount TV cameras at substantial heights to gain a better perspective view of transportation facilities and to increase the area of coverage.
2. The clear line of sight required for microwave transmission

necessitates the installation of antennas to substantial heights to avoid the interference of urban development and terrain.

3. It is desirable to make maximum use of all elements of the highway system to improve safety and economics.

For these reasons, a preliminary analysis was made of the feasibility of installing CCTV systems on existing high mast lighting systems. This analysis was based on previous experience with high mast lighting systems, a review of current standard plans for high mast lighting hardware, and discussions with designers of high mast lighting systems.

High mast lighting systems generally conform to one of the general operational categories, as follows:

1. The luminaires are fixed at the top of the mast, and access for service and maintenance is accomplished by service personnel climbing the towers.
2. The luminaires are fixed at the top of the mast and access for service and maintenance is achieved by a personnel carrier that travels along the mast.
3. The luminaires are mounted on a ring assembly that can be lowered to near ground level for service and maintenance.

Except for the very early installations, Texas has utilized the third alternative, that is, providing for the lighting assembly to be lowered for service and maintenance. Thus, a typical high mast assembly consists of a mast from 150 feet to 175 feet in height, a ring assembly with 6 to 15 luminaires mounted on it, and the necessary winch and electrical gear for operation of the system.

To facilitate lowering of the lighting assembly, the luminaires are

mounted on a ring
is suspended on the
system of pulleys
which is attached
the winch, the light

The mast is ge
at the joints. The
base to approximate
the electrical conduc

Because the ring
on the mast due to win
transmission equipment
alternative is to moun
lighting assembly or on
number of factors that

1. The camera cou
below the light
luminaires would
Although it has
pated that the s
low light level c

Another majo
attracted to the
numbers, and they
accumulation on the
CCTV lens.

2. The use of microwav

assembly would be questionable. Even though the light ring can be made to fit the mast with low tolerance, the mast is not designed to satisfy the allowable deflection requirements of microwave transmission. Typically, lighting masts deflect several feet under normal wind loads.

3. Because of the extensive deflections observed, the acceptability of CCTV camera mounting on a lighting mast is questionable. It is possible that the deflections would result in seasickness effects and problems in maintaining the viewing target under long distance viewing conditions.
4. Using a coaxial cable for signal transmission from a lighting mast would require modification of the mounting assembly. It would be necessary to route the coaxial cable through the top of the mast and over a pulley in the same manner as the electrical conductor is installed. This could be accomplished quite easily on new installations, but would be quite costly on existing installations.

In view of the fact that most factors relating to the installation of CCTV equipment on high mast lighting supports are negative, it was concluded that this alternative was not feasible. Therefore, effort to identify suitable support equipment was directed in two areas: a review of the CCTV microwave system used on the Houston Ship Channel and a review of commercially available support systems.

Towers - Early in 1975, the U.S. Coast Guard began operation of the Houston-Galveston Vessel Traffic System. This system is a combination of the previously established voice radio network on which vessels report their intentions and movements to the Vessel Traffic Center, and a CCTV

system on which Coast Guard personnel in the center can visually observe traffic at critical bends along the channel. This CCTV system consists of several towers which support cameras at 30- and 75-foot heights and microwave reflector boards at 150-foot heights.

The towers used in the Coast Guard system are typical three-legged, self-supporting communication towers, commercially available as catalog items. From inspection, it appears that the Coast Guard towers may have been purchased from the Rohn Tower Company of Peoria, Illinois.

The Rohn Tower Company was contacted for information relating to the availability and general design details of communication towers applicable to CCTV microwave transmission. A general catalog was provided, giving tower descriptions for various applications. The heavy-duty self-supporting tower series offered by Rohn is available in 20-foot sections up to a mounting height of 320 feet. If shorter mounting heights are required, then only the sections required to satisfy the deflection requirements are specified. For example, it appears that the Coast Guard towers on the Houston Ship Channel were made up of the eight (8) bottom sections of the heavy-duty series, giving a total tower height of 160 feet and reflector board mounting height of 150 feet. As an indication of the size of structure, it is estimated that the base dimension of the tower is approximately 25 feet and the top dimension is about $8\frac{1}{2}$ feet along the side of the triangular section. It should be noted that these towers are designed on the basis of limiting deflections for microwave transmission. The Rohn catalog makes reference to Electronics Industries Association (EIA) specification RS 222-A for the twist and deflections.

Also available for microwave transmission are several series of guyed towers. The limitations on the use of such towers would be the

area in which they are to be installed. If the towers are to be installed within close proximity to the roadway, they would be of the self-supporting type with protective devices to prevent vehicle impacts with the tower. It is important to note, however, that the guyed towers are considerably cheaper than self-supporting towers because the rigidity for microwave transmission is provided by the guy wire system. Preliminary recommendations on camera platforms are as follows:

1. CCTV systems should be mounted on towers installed for that specific purpose. The towers should be of a frame-work type to achieve maximum rigidity for the least cost.
2. Towers should be self-supporting except in special cases where the guy wire system can be installed without danger of being damaged by traffic or maintenance operations.
3. The tower design should be developed on the basis of signal transmission methods. Allowable deflections are far more liberal for camera mounting than for the mounting of reflectors or antennas for a microwave system.
4. Microwave transmission systems should take advantage of buildings and other rigid structures where practical.
5. Towers designed for microwave transmission should be designed in accordance with Electronic Industries Association specification RS 222. This specification may be obtained from the following source:

Electronics Industries Association
Engineering Department
2001 I Street, NW
Washington, D.C. 20006

Driver Communications, and Control Systems - The development of automatic traffic surveillance, driver communications, and control systems depends directly on the accuracy and reliability of vehicle detectors. Research studies during the last few years have measured wide variations in the operation of detectors used on the Gulf Freeway Surveillance Project. Because the computer system and computer programmers were available to the research staff, the variations in detector operation could be lessened by software programs to improve the accuracy of the data. However, a better understanding of the detection problem is necessary so that implementation projects, that do not have the staff or computer capabilities of a research project, will not be disabled by high incidence of hardware malfunctions.

Preliminary studies were conducted on the Gulf Freeway with the existing system. A procedure for recording malfunctions of detectors and the detection system was established. Two detection stations 850 feet apart, with two loop detectors per lane were studied with the following results:

1. Each loop yields different occupancy (vehicle time-over-the-loop) times for the same vehicle type at the same speed and lane position.
2. The range of occupancy readings for each detector for the same vehicle type, excluding tractor-trailer combinations, is predictable.
3. The accuracy of vehicle counts for all types, excluding tractor-trailer combinations, was acceptable.
4. The mean occupancy value for a loop detector is directly related to the loop amplifier used.
5. The mean trap time (time between the lead and lag detector actuations) for the same vehicle type is related to both

the loop detectors characteristics and loop amplifier type.

6. Temperature change caused a change in both loop detector and amplifier characteristics resulting in change in mean occupancy and speed trap volumes. Twelve loop amplifier models from six different manufacturers were used in the detector study.

Computer programming was used to compensate for the above occupancy and speed variances. The installation of three-loop speed traps on Loop I.H. 610 at U.S. 59 will be investigated next year to determine if the speed trap accuracies can be increased by using redundant systems. The effects of telephone line data communications facilities on detector measurements will be analyzed as opposed to the present direct wire communications.

Updating Benefit-Cost Analysis Procedures - A review of literature on transportation costs related to highways, traffic characteristics, and exhaust and noise pollution indicated that only a limited amount of data was available that considered current conditions. This study developed costs to update the basic data and the benefit-cost analysis procedures. An analysis was made of the effects of energy shortages and temporary mandatory controls that affect the supply, demand, and prices of resources. The full presentation of the user costs and analysis procedure is contained in Research Report 202-2, entitled "Benefit-Cost Analysis: Updated Unit Costs and Procedures."

Current Highway User Costs - The updated highway user costs are presented with the value of time costs, vehicle running costs, and highway accident costs that reflect those costs existing in Texas during early 1975.

The vehicle running costs are given by vehicle type and average running speed for six levels of service that might exist on Texas freeways. Also, vehicle running costs are given by vehicle type, uniform speed, and speed cycle change on city streets.

The values of time are given by vehicle type and average running speed for vehicles with driver only and for vehicles with passengers.

Highway accident costs are given that reflect the average direct costs for vehicles involved in an accident by vehicle type and type of accident in urban areas. Separate costs are given for vehicles with fatal injuries, nonfatal injuries, and property damage only. Also, costs due to loss of future earnings for persons killed in accidents are presented separately according to sex.

Impact of Energy Shortage - An analysis was made of the impact of the energy shortage on the relative costs that are used in conventional benefit-cost or cost-effectiveness analyses of highway projects.

This analysis indicates that there has been a change in the relationship between real income (value of time) and real vehicle running costs, caused primarily by the fuel shortage. A literature search reveals no procedure for discounting time cost savings in relation to other user cost savings that could be incorporated in benefit-cost analyses.

Recommended Analytical Procedure - An analytical procedure that uses the benefit-cost or cost-effectiveness approach and considers user and non-user benefits and costs of a highway project and the data requirements of the procedure were developed in this study. In addition to the updated values of time, vehicle running costs, and accident costs, other data are presented which will assist in the measurement of the effects of air and noise pollution generated by highway users and the effects of traffic

generation characteristics on land use activities directly affecting land values.

By comparing annualized dollar benefits and costs, discounted to present value, for a year prior to implementation and one or more years after implementation, a benefit-cost ratio can be generated and the economic feasibility of a project can be partially determined. The full economic feasibility of a project can be determined if due weight is given to all measurable benefits and costs (in dollars and other units) attributable to it. Various weighting schemes can be employed with the benefit-cost ratio to arrive at an implementation decision. If the cost-effectiveness approach is used, the benefits and costs can be considered in other measurable quantities in addition to dollars, but no weighting scheme is employed to arrive at a decision.

The procedure is useful in selecting the most economically feasible or cost-effective project from among several alternative projects which could accomplish one or more goals. This is accomplished through the use of a value matrix technique composed of weights assigned to each goal and to each project. The technique is fairly flexible, and the most difficult task is assigning weights to the goals. But, this technique is necessary to arrive at a decision between alternative projects and goals.

Summary and Recommendations - The following results have been obtained from the study:

1. Highway user costs have been updated to 1975 conditions in the urban areas of Texas.
2. Data on air and noise pollution and other highway impact data have been assembled in a usable manner.

3. An analysis has been made of the impact of the energy shortage on the relative costs that are used in the conventional benefit-cost or cost-effectiveness analysis.
4. An analytical procedure has been recommended for use in determining the economic feasibility of a project and in determining which project best accomplishes a particular goal or set of goals.

It is recommended that the analytical procedure be tested on pilot freeway projects to further define data requirements and limitations so that alterations and refinements can be made.

Surveillance Design for Elevated Freeway in Austin - System design considerations for a closed circuit television system for the new elevated freeway section of I.H. 35 in Austin were developed by the research study and presented to the Austin District Office. The results of the low light level camera demonstrations reported in Objective 4 were applied at this location because of the requirement for 24-hour surveillance of the roadway.

A final design of the camera locations and mounting heights will be developed following tests with the camera system leased by HPR Study 173 and further demonstrations of the camera system at the site.

A system design of the driver information system to be used to warn approaching traffic of congestion or accidents on the elevated freeway was proposed to the Austin District. Matrix signs using one or more candidate messages were proposed for the freeway approaches. The ramp approaches were considered less critical because of lower volumes and slower speeds. Fixed message signs with flashers and fold-out message signs were suggested for these locations.

Operational Analysis of High Accident Locations on U.S. 59 in

Houston - Film studies were made of the erratic maneuvers approaching a major diverging area of U.S. 59 in Houston. The accident experience at this location was high despite the good geometric design and adequate roadway capacity.

The film studies revealed the extent of the problem. Of the 70,000 vehicles that used this section of the freeway, 2 percent (1,400) of the vehicles weaved from one diverging roadway to the other within a few hundred feet of the Vehicle Impact Attenuator (VIA) installation. At the speeds of operation and the flow rates, these maneuvers were considered hazardous, and the site was unsafe as evidenced by the high accident experience since the opening of the diverge area in October 1974.

The site and the approach to the diverge of the roadway were studied by several engineers. The results of the subjective evaluations were:

1. The approach signing should be improved to align the motorists in the correct lanes.
2. The Vehicle Impact Attenuation installation needed to be more visible to the motorists, especially at night.
3. The approach striping should be enhanced to improve the alignment of the approaching traffic.

Several changes were suggested by the research study and the participating engineers from the Houston District Urban Office and Austin Office of the State Department of Highways and Public Transportation. The recommendations for changes and the actions taken by the Department were as follows:

1. Improve the advance signing to clearly identify through routes and the left-hand exit to the downtown distribution system.

Response - The Department has drafted plans for advance signing changes which will be made in the near future.

2. Improve the visibility of the gore area by increasing the back-drop signing.

Response - A standard EXIT sign with upward sloping arrow was placed above the Cross Hatched Backboard to denote the left-hand roadway was the exit to the street system.

3. Improve the visibility of the gore area by adding spot lighting.

Response - Lighting will be installed at the same time as the new advanced signing mentioned in Item No. 1.

4. Improve the visibility of the gore area by painting the crash barrels.

Response - The barrels were painted Highway Yellow.

5. Improve the visibility by adding yellow flashers and delineators to the gore area.

Response - Delineators have been added to the gore area to increase the effective distance from the VIA to the decision point. Plans have been developed for installing the yellow flashers in the gore area in 1976.

6. Improve the alignment of the approaching traffic by adding accentuated lane lines to discourage lane changing across the center lane.

Response - 1,300 feet of 12-inch white Thermoplastic Pavement Markings were added to the lane lines delineating the middle lane passed the gore area.

7. Improve the approaching traffic by minor changes to existing advanced signing.

Response - Several modifications were made to signs just in advance of the gore area.

After several of the modifications were made to the gore area, additional film studies were made. The results of the weaving studies indicated no significant change in the number of weavers, but a perceptible reduction in severe (i.e., close to the gore area) maneuvers.

The accident experience to date is very limited, but encouraging. In the 8 months from October 1974 to June 1975, there were 14 impacts of the Vehicle Impact Attenuator. After the modifications to the signs and striping, there was only one impact in the next 5 months.

Further analysis of this area will be made as the other modifications are put in effect.

DOCUMENTATION OF RESULTS

Three research reports were written for the one-year period entitled "Design and Evaluation of Freeway Surveillance and Traffic Control Systems:"

Research Report Number 202-1, "The Evaluation of the High Load Detection and Warning System on I.H. 45 in Houston," by Gene P. Ritch.

Research Report Number 202-2, "Benefit-Cost Analysis: Updated Unit Costs and Procedures," by Jesse L. Buffington and William F. McFarland.

Research Report Number 202-3F, "Final Report of Design and Evaluation of Freeway Surveillance and Traffic Control Systems," by William R. McCasland.

Several studies initiated under this project will be completed and documented in research reports for Study Number 2-18-76-173, entitled "Development and Evaluation of On-Freeway Traffic Control Systems and Surveillance Techniques." These include: On-Freeway Control - Total Roadway; On-Freeway Control - One Lane; and Low Light Level CCTV Demonstration Testing.

CLOSURE

This study has continued the State's research program in the development and implementation of traffic control and surveillance systems for the improvement in the efficiency and safety of existing urban freeway networks. Progress in the application of new technology and innovative transportation strategies cannot be measured by the results of one year.

That on-freeway control for one lane is operational and on-freeway control for the total roadway has been approved for installation and evaluation is the culmination of over three years of work in the research program.

The CCTV surveillance system for I.H. 35 in Austin will be the second to be installed as an operational system in Texas, since the Baytown Tunnel System in 1963. Research systems were installed on the Gulf Freeway in 1965 and the North Central Expressway in Dallas in 1969. Development of the low light level cameras now permits designs for 24-hour surveillance.

The application of vehicle detection hardware to more complex and demanding tasks, such as incident detection and high load detection, will result in better equipment and improved computer logic. The process has not run its course, but the detection deficiencies are becoming better known and the requirements for detection better defined.

The most significant progress that this study can report for this year of research is the continued relationship between the research program and the State's operational programs. The objective of providing technical assistance to the State is a means used to assist in implementation of research results when appropriate. That the Austin District, Houston District, and Houston Urban Office did request and receive this assistance is the best indication of progress in the research program.

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