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A STUDY OF ON-FREEWAY LANE CLOSURE IN
THE MERGE AREA OF TWO FREEWAYS

by

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Research Report Number 173-2

Development and Evaluation of On-Freeway
Traffic Control Systems and Surveillance Techniques

Research Study Number 2-18-76-173

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Texas Transportation Institute
Texas A&M University
College Station, Texas

March 1976

PLATE 10
THE GREAT WALL

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ABSTRACT

An On-Freeway Lane Closure to adjust the capacity of two roadways to a merge point in order to improve the efficiency of operation of the total I.H. 10-I.H. 610 interchange in Houston is evaluated. Delay studies conducted on I.H. 610 northbound show that closing the outside lane of I.H. 10 facilitates merge operations which result in a savings of approximately 13 vehicle-hours of travel time on a typical day of control. Daily motorist compliance rates were taken, indicating a majority of drivers voluntarily comply with the lane closure signals. Volume and speed studies were conducted and accident data collected which show that the lane closure has no adverse effect on operations in the control area.

Key Words: Lane Closure, On-Freeway Control, Merging Operations, Delay Savings.

DISCLAIMER

The contents of this report reflect the views of the authors who are 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.

SUMMARY

A voluntary On-Freeway Control System was implemented by District 12 of the State Department of Highways and Public Transportation at the I.H. 10-I.H. 610 interchange in Houston. The purpose of the on-freeway control system was to adjust the capacity of two roadways to a merge point to improve the efficiency of operation of the total I.H. 10-I.H. 610 interchange.

Flow rates at the merge point confirm that the lane signals effectively close the outside lane to I.H. 10 enabling a shift in capacity to facilitate traffic flow by giving priority entry to I.H. 610 traffic. This shift in capacity results in a 13-vehicle-hour savings per typical day of control on I.H. 610 northbound.

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 as it does on the I.H. 10-I.H. 610 merge.

Since the lane control provides more capacity to the connecting roadways from I.H. 610, the flow rates are higher and the queues are shorter. 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 of I.H. 610. In most instances, the control was successful.

The operation of lane control was found to have several obvious benefits: The reduction of conflicts in the merge area; the reduction in total travel time through the interchange; and possibly the reduction of accidents in the area. Even by considering the only measureable benefit to be the reduction in delay on I.H. 610, the system was found to have a benefit cost ratio of 2:1 for manual operation and 2.3:1 for automatic operation.

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INTRODUCTION

Purpose of Control

The purpose of on-freeway control is to adjust the capacity of two roadways to a merge point to improve the efficiency of operation of the total interchange. On-freeway control increases delay on one approach and reduces delay on two other approaches. On-freeway control is beneficial when traffic demand at a merge point is greater than the downstream capacity, and the resulting stop-and-go operations and queues reduce traffic flow.

At the I.H. 610 West Loop interchange with I.H. 10 Katy Freeway, traffic in six approach lanes merges into four lanes to exit the interchange. When traffic flows are high on all approach lanes, traffic flow becomes constricted in the merge area and traffic backs up through the interchange. Traffic on the interchange ramps queues into the I.H. 610 North and South main lanes, resulting in a general slowdown of the through traffic of I.H. 610.

In addition to the overloaded condition at the merge area of I.H. 610 with I.H. 10 West, traffic flow is severely restricted downstream of the interchange by a drop of I.H. 10 at the Wirt exit from four lanes to three lanes. Also, a critical weaving area, caused by a major exit ramp 2,200 feet (670 meters) downstream of the merge point, creates operational disturbances.

Application of on-freeway control at this interchange reduces the total delay of traffic traveling through the interchange, but has no effect on improving flow through the downstream bottleneck and the weaving section. The control does improve the merging operation by

reducing the severity and frequency of traffic conflicts.

Previous Work

Literature on the development of on-freeway control concepts is considerably more extensive than documentation of field implementation of those concepts. Furthermore, results of on-freeway control implementation are conflicting although positive results have been obtained in cases where relevant parameters were applied to traffic. On-freeway control has been applied in three ways: (1) changeable message signs on which variable speeds are posted, (2) lane closure signals, and (3) roadway metering signals.

Variable speed signs were installed on a 3.2-mile section of Detroit's Lodge Freeway beginning in 1962.⁽¹⁾ Evaluation of the effectiveness of the signs indicated that motorists did not decrease their speed to comply with the posted speed unless there was an obvious reason to do so, and that throughput at critical bottlenecks was not increased.

On-freeway control of the second type was also developed in Detroit in 1962.⁽¹⁾ Signals displaying a green arrow under normal conditions were suspended above each lane. If a lane was closed due to maintenance operations, the arrow was replaced by a red "X". When freeway demand was considerably less than capacity, motorists appeared to obey the "X" signal by exiting the closed lane. However, as demand approached and exceeded capacity, the control signal appeared to have little or no effect on traffic flow at the bottleneck.⁽²⁾ Since the signals could be expected to produce significant benefits only during high demand periods, the program was declared unsuccessful and terminated in 1970.

More favorable results have been obtained by San Francisco's Bay Bridge Toll Plaza Metering System.⁽³⁾ The system was designed to correct

the following deficiencies in a previously used priority lane operation: (1) inefficient use of roadway space at the critical location and (2) a "squeeze" situation where cars merge from 17 lanes to 5 lanes in order to enter the bridge. This produced a potential accident hazard resulting from traffic violators merging into priority lanes downstream of the toll booths. The accident hazard was alleviated by revising the priority lane concept from one of an exclusive lane for buses and car pools to one of giving them priority entry.

The system operates in the metering mode during that portion of the morning peak when traffic demand exceeds the capacity of the bridge. Work is underway to prepare the system for use in incident management during off-peak periods.

Favorable results were also obtained in a lane closure experiment conducted at the I.H. 610 West Loop interchange in Houston.⁽⁴⁾ The difficulty of a merging operation during peak periods caused queueing on the merging lanes to extend back into their respective main lane traffic. Preliminary data indicated that the peak period traffic flow on I.H. 10 could be handled as well by two lanes. A trial solution was to manually close the right-hand lane of I.H. 10 with traffic cones, so that the difficulty of the merging operation was reduced. Evaluation of the experiment was favorable, and the manual cone closure has since been replaced by the voluntary lane closure system, using suspended signals similar to those used in Detroit. The study of the effectiveness of this system is the subject of this report.

Description of Installation

Control Hardware - The lane closure site consists of one advance warning sign with yellow flashers, four overhead signal lights on mast

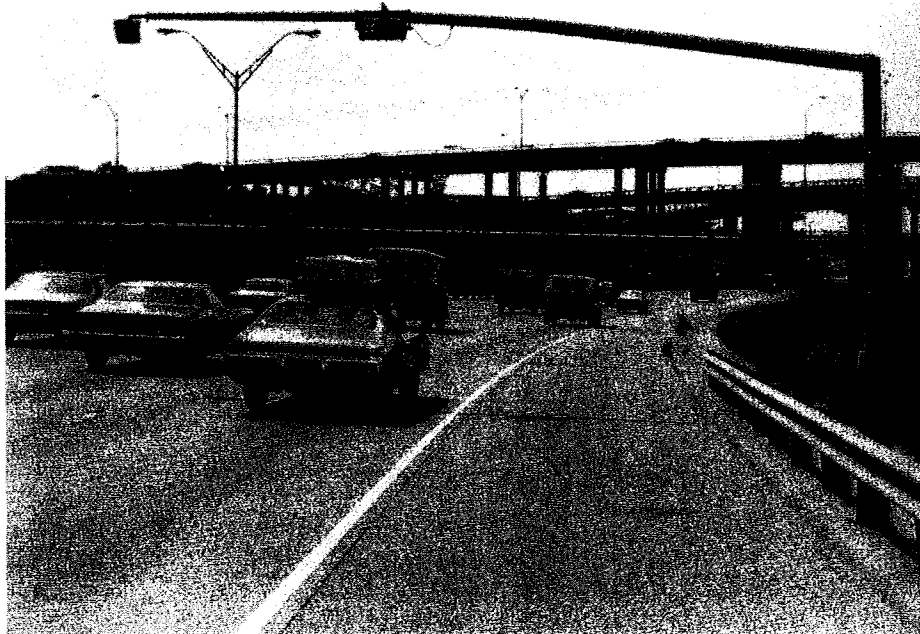
arms, and a central control unit located under the I.H. 610 main lanes (Figures 1 and 2). These components were placed along Westbound I.H. 10.

The controller is a Crouse Hinds PCE-3000 series pre-timed traffic controller, housed in a fabricated sheet aluminum cabinet with a natural finish. Access to the manual control is by a police door in the front of the cabinet. If a malfunction should occur, the main cabinet can be opened and power to the cabinet and signals can be turned off.

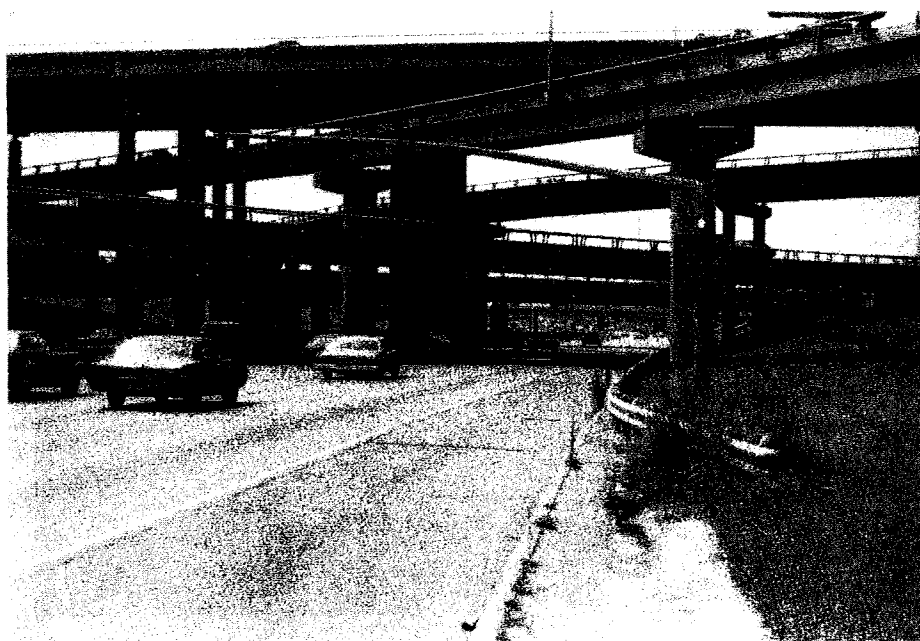
The distance from the advance warning flashers to the last lane closure light is 2,450 feet (747 meters) and to the merge point is 2,650 feet (808 meters).

At this time the signals are controlled manually by an operator, who is stationed at a vantage point where he can observe the operation of the lane signals, as well as traffic operations on the I.H. 610 ramps and their merge with I.H. 10. From this position, he is able to see the queueing on the north and south ramps and on I.H. 10 upstream of the lane closure (Figure 3). The observation area is located in a grassy area bounded by three ramps: I.H. 610 to I.H. 10 and I.H. 610 North and South to I.H. 10 Westbound. A more complete control strategy could be used if the signal operator could see the total queueing upstream of the lane closure on I.H. 10, but the geometrics of the area make it impossible to observe queueing for more than 1,200 feet (366 meters) upstream of the advance warning flasher.

Signal Operation - The lane closure signals rest in green and the advanced flashers rest in dark when control is not in operation. As the afternoon peak traffic develops, volumes on the I.H. 610 North and South ramps increase and queues threaten to interfere with main lane traffic. When the queues reach critical lengths, lane closure is

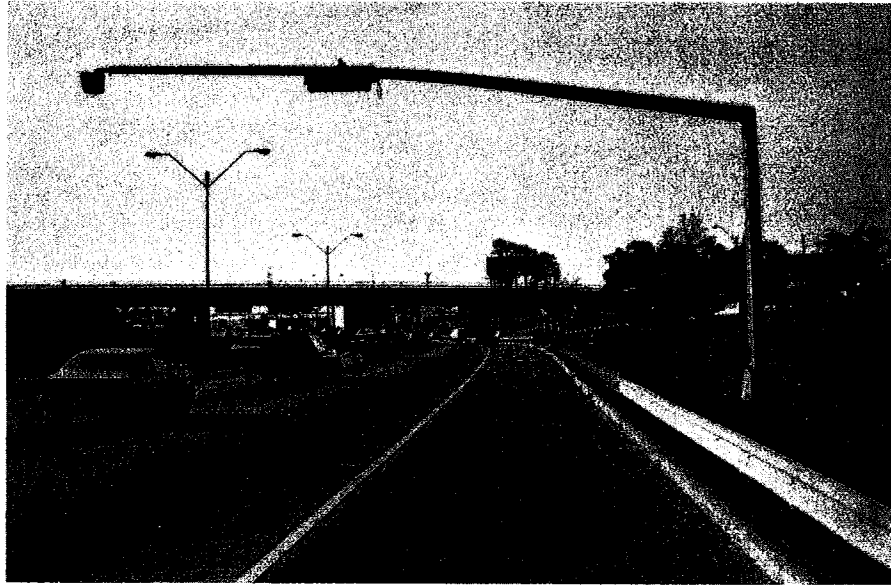


First Overhead Mast
Resting in Amber 'X'



Second Overhead Mast Resting in Amber 'X'

Figure 1. Overhead Lane Use Signals - Lane
Closure Warning With Yellow 'X'



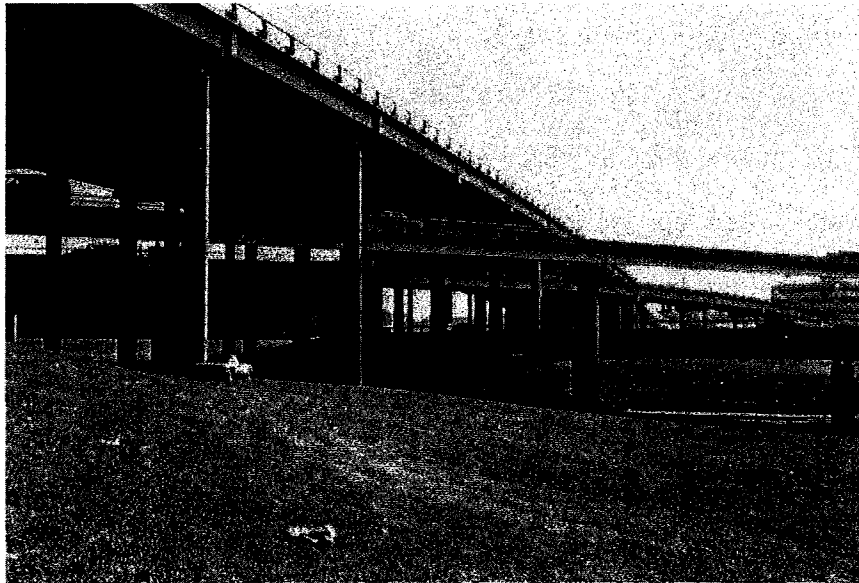
Third Overhead Mast Resting in Red 'X'



Fourth Overhead Mast Resting in Red 'X'

Figure 2. Overhead Lane Use Signals -- Lane Closure Control with Yellow and Red 'X'

I.H. 610 Northbound to
I.H. 610 Westbound



I.H. 10 Roadway

Figure 3. Observation and Control Vantage Point
Showing the I.H. 610 North
to I.H. 10 Outbound Ramp

initiated by the operator who 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 again presses the switch, changing the lane closure signals on the last two mask arms from a yellow to a red "X". A motorist driving through the system will encounter first the advance flasher, then two consecutive warning signals in the amber "X" phase and two closure signals in the red "X" phase. In accordance with the MUTCD, there is a steady green arrow displayed over the lane adjacent to the controlled lane at all times.⁽⁵⁾ When the operator determines that control has been as effective as possible, within limits of the control strategy, he presses the switch once, which returns the lane signals to green arrows and the advance flashers to a dark state.

The controls are operational only during the PM peak and when traffic conditions on the critical sections of the interchange warrant a reduction of traffic demand on I.H. 10.

Geometric Description

The I.H. 610 West Loop interchange has three freeway lanes approaching the merge area; a one-lane ramp and a two-lane ramp merging into a single two-lane ramp; and the combined two-lane ramp and the three I.H. 10 freeway lanes merging into four lanes. Heavy ramp movement from I.H. 610 Northbound crosses over I.H. 10. The ramp is about 3,000 feet (900 meters) in length, and motorists on the ramp have a clear view of the merge area and the I.H. 10 freeway lanes approaching the merge area. An exit ramp is approximately 2,200 feet (670 meters) downstream of the merge area, and the freeway lanes on I.H. 10 are reduced from four to three lanes about 4,400 feet (1,340 meters) downstream of the exit ramp (Figure 4).

Point A to C = 2,650 Feet (808 Meters)

Point A to B = 2,450 Feet (747 Meters)

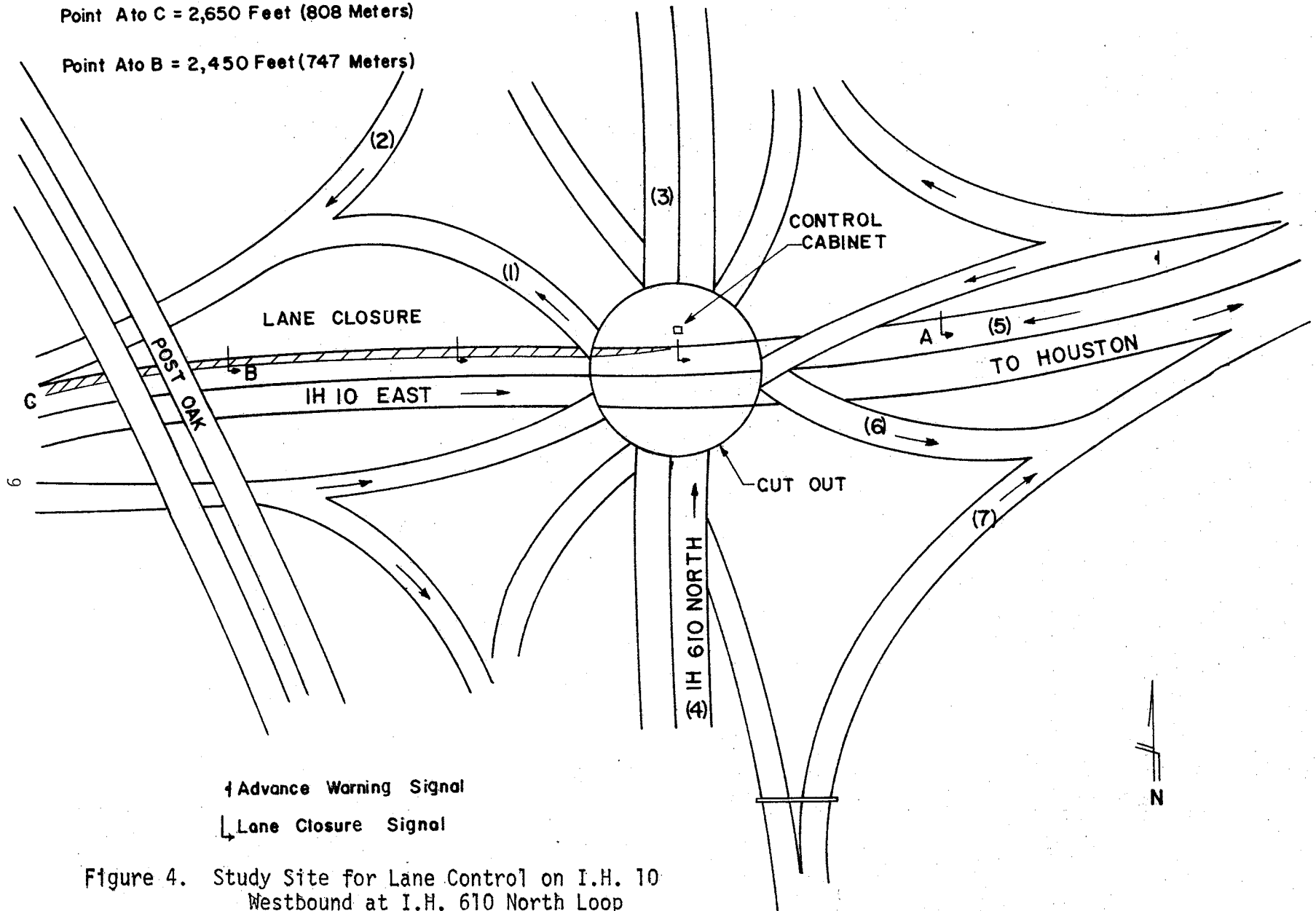


Figure 4. Study Site for Lane Control on I.H. 10 Westbound at I.H. 610 North Loop

CONTROL PROCEDURES

Control Strategy

The lane control signals are operated weekdays from 4:00 p.m. until the afternoon peak period has ended (6:00 to 6:30 p.m.). The exact times for initiating and terminating the control are determined from visual surveillance by an operator who is stationed on an elevated position above the lane closure, so that he can observe traffic conditions, accidents, or other operations. The operator is instructed to remain out of sight of motorists as much as possible and to remain on the site until control is no longer required for that day. When the operator determines that queueing on the I.H. 610 has reached a point where main lane traffic flow is affected, he manually initiates the lane closure, and returns to his observation point away from the view of the freeway motorists until time to terminate control. During the period of control, the operator is responsible for three things:

1. To initiate and terminate control;
2. To watch for accidents and other incidents which might affect operations in the vicinity of the interchange; and
3. To record signal compliance rates.

On Fridays and Mondays traffic demand characteristics make control very difficult. Peaking on all approaches occurs early and congestion remains throughout the control period. On Tuesdays, Wednesdays, and Thursdays traffic demand patterns which can be improved with lane closure, usually develop.

During each peak period, the lane closure may be initiated as many times as necessary to keep the roadways operating effectively. Once lane

closure has begun, it remains on for a minimum of five minutes and a maximum of 15 minutes. These minimum and maximum times were chosen because it was felt that control could not be effective in clearing the outside lane of traffic in less than five minutes. The 15-minute maximum limit was chosen because it was felt that this was a sufficient amount of time to clear the ramps as well as helping to maintain a balanced traffic responsive operation. Control is in operation only as long as necessary to clear the queues on the I.H. 610 ramps. Once control is terminated, it is not resumed for a minimum of five minutes so that motorists approaching the signals will not see the system change from control to no control, back to control.

When the lane closure system was made operational in November 1974, the maximum time for one control period was set at 10 minutes. This was later extended because under the high volume of traffic on the I.H. 610 ramps and I.H. 10, 10 minutes of control was not sufficient to clear the queues on the approaches. If all approaches are completely jammed, control is suspended. If any unusual event occurs on the I.H. 10 roadway that adversely affects traffic flow, control is not applied. The control system is not operated during rain or other adverse weather conditions.

Manual Control

The control system, advance flashers, four overhead traffic signals, and the control unit have not malfunctioned since the first day of control on November 20, 1974. At present, there are no detectors on the ramp or freeway lanes and the control unit has no traffic responsive capability. Control must be manually initiated and terminated for each control period by a human operator. The major problem in this type of operation is the manpower requirements of one man on duty two hours for

each day of control.

While traffic patterns are somewhat consistent, there is a degree of variability caused by traffic incidents, weather conditions, and general traffic characteristics. Because of this, the operator is advised to listen to traffic broadcasts as much as possible and to note any variation in normal traffic patterns on a daily log of control times and compliance rates.

Since the initiation of control calls for a manual evaluation of particular traffic characteristics, it is necessary for consistency in control procedures to limit the number of operators to as few people as possible.

The estimated annual costs for operating the signal system with a human operator at the site is calculated below, assuming that the control was applied each weekday:

5 days/week = 260 days/year

Control time 4:00-6:30 for 240 days = 600 hours

600 hours \$3/hour = \$1,800/year

6,240 miles @ 16¢/mile = \$998.40 travel expenses

Total = \$2,798.40

Of course, this cost is offset by the cost of the data on efficiency of operation collected by the operator.

Automatic Control Design

The next step in the development of lane control on I.H. 10 is the implementation of traffic responsive automatic control. Demand on the main lanes of I.H. 610 Southbound is low so that queues on the ramp to I.H. 10 Westbound do not significantly affect the efficiency of traffic flow. For this reason, detection of the I.H. 610 Southbound ramp traffic

is not necessary for an automatic traffic responsive control system. Therefore the development of an automatic control system will concentrate on detection for the I.H. 610 Northbound ramp.

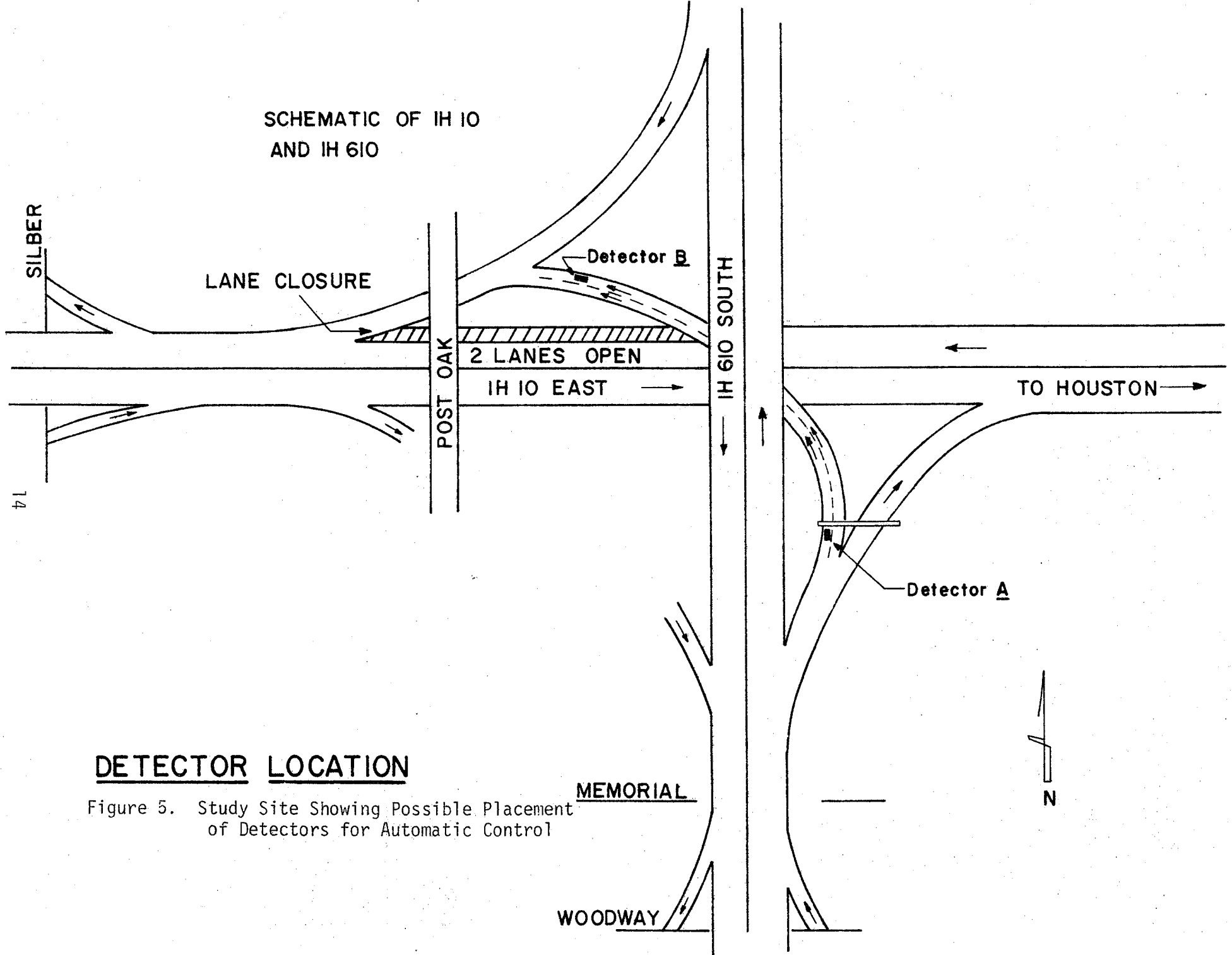
Automatic control can be accomplished by several methods of detection. The simplest method of detection provides for one detector near the merge point of the I.H. 610 North and South ramps and one detector near the diverge point as shown in Figure 5. The inside lane of the I.H. 610 North ramp develops the same traffic characteristics simultaneously with the outside lane. For this reason, one detector could be placed on the inside lane and one on the outside of the two-lane ramp. The distance between the two detectors would be approximately 1,050 feet (320 meters). The total length of the ramp from the diverge point to its merge with I.H. 610 South is approximately 2,000 feet (610 meters). For automatic control, a hard wired logic unit is necessary for making control decisions from traffic data obtained from the two detectors in accordance with time parameters. The components of the logic unit would include: two analogue occupancy averaging modules with relay contact outputs; three interval time delay relays; and one seven-day time clock.

The estimated cost for an automatic detection system is:

2 Detectors - Installation and cost of materials	
@ \$1,000/detector	\$2,000
1,300 linear feet of cable @ \$3/foot	3,900
Amplifier	200
Cabinet material	600
Cabinet installation	200
Logic unit	1,250
	<u>1,250</u>
TOTAL	\$8,150

With the placement of detectors as shown in Figure 5, the logic of control is designed to be more responsive to the ramp traffic characteristics. Lane occupancy measurements from Detector B at the merge can be used to determine if shorter intervals of control can replace the 15-minute periods. This logic would be beneficial during the early portion

SCHEMATIC OF IH 10
AND IH 610



DETECTOR LOCATION

Figure 5. Study Site Showing Possible Placement of Detectors for Automatic Control

of the control period when I.H. 10 flow rates are low, speeds are high, and only short periods of control are required to clear the ramp queues. Detector A at the diverge point would be used to detect the end of the ramp queue under traffic conditions on I.H. 10 that required longer periods of control to clear the ramp.

The final step in implementation of automatic control is the instrumentation of the I.H. 10 westbound roadway. The main advantages in instrumenting I.H. 10 are:

1. When traffic flow is heavy and queues extend too far upstream of the closure on I.H. 10, the time without control could be extended by allowing traffic to queue to the diverge point before initiating control.
2. When traffic flow is light on I.H. 10, the ramp queueing can be reduced by frequent applications of short periods of control.

These two control considerations require instrumentation on I.H. 10 and I.H. 610 to balance and check the flows through the interchange.

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 to evaluate the results of the lane closure were collected during the first year of control. The following sections of this report present

the interim findings after approximately one year of operation.

Effectiveness of Lane Control in Shifting Capacity Between Roadways

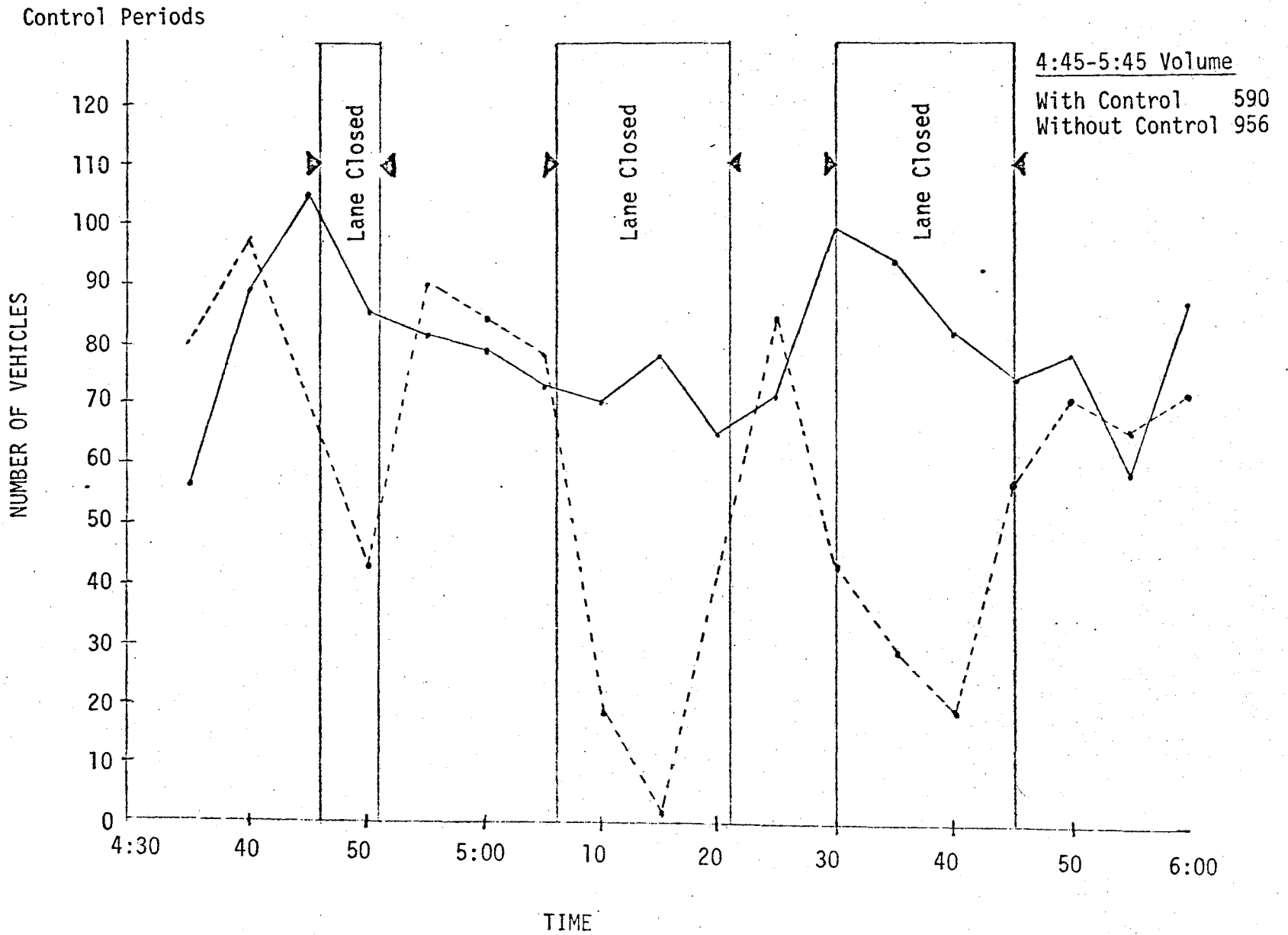
Flow rates at the merge point confirm that the lane signals effectively close the outside lane to I.H. 10 traffic flow and give priority entry to I.H. 610 traffic. Figure 6 illustrates the change in flow for the controlled lane before and after control. The extent to which the capacity is shifted is directly affected by the length of the control period.

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 assisted in getting the meaning of the signals across to those who might not have understood. But the major factor that contributed to the understanding of the signals by nearly all of the motorists was the compliance by the majority of the drivers. For example, it was clear to almost all drivers that the control lane was closed to through movement.

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 lights. The data are collected by the operator after the outside lane of traffic has had sufficient time to merge into the middle lane. He then makes a volume count of traffic in the outside (closed) lane for three minutes. The count is made at the last lane closure signal just upstream of the merge point. When this control period ends, the operator makes another count for the same amount of time. The two counts are compared to determine a percentage of motorists

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



who violated the red "X" signals during the control period. These compliance rates, which estimate the motorists acceptance of the lane closure system, have averaged approximately 80 percent under normal traffic conditions for the first 160 days of control. Four factors that influence the level of compliance are:

The severity of congestion significantly reduces motorist compliance to the lane closure system. When the 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 signals in an effort to decrease his delay. It has been observed that violations usually occur in groups; i.e. one or two consecutive violations will attract other violators from the other lanes.

Weather, because of its relationship to congestion, also affects compliance rates. Although closure is not initiated during rain or other adverse conditions, it is initiated during hazy or overcast conditions as well as after sunset, depending on the time of year. During these conditions, the degree of congestion is increased and compliance rates are lower than the average.

The motorist familiarity with the system may have an effect on compliance rates. The greater percentage of traffic is composed of 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. The policemen, usually on motorcycles, 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 lights.

Figure 7 shows the days when police were at the control site during the first 190 days of control. Figure 8 indicates the high, low, and average compliance rates for an average month of control.

During the month of control, both maximum and minimum compliance rates occurred during peak demand, from 5-6. The low acceptance rate is attributable to high demand and severe congestion during the peak hour which has a direct influence on the compliance. The high compliance occurs during the same time period because police enforcement usually begins at 5:00 p.m. Since this is a composite graph of control days for one month, the fact that police are not present for every control day, accounts for occurrences of both the high and low rates for the same time slot.

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 indicated that the lane closure has no adverse effect on safety conditions in the segment of I.H. 10 directly affected by control operations (Washington to Silber). When accident experience for the period November 20, 1974, to November 20, 1975, is compared with that of the previous 12 months, records show only a 10 percent increase in outbound accidents on this segment of I.H. 10 during the 4:00 p.m. to 6:00 p.m. peak hours. The increase in outbound accidents on other sections of the freeway and during other time periods was significantly greater (Table 1). Table 1 was compiled from the computerized records of the State Department

of Highways and Public Transportation.

Since the time of comparisons is so short, the data are somewhat insufficient to substantially support the conclusion that control operations actually reduce accidents in the affected area. Nevertheless, they support a strong argument that the signals are not a traffic hazard.

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 connecting roadways has been monitored and measurements of traffic 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 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.

To confirm this observation, counts and speed measurements were taken at Wirt and Campbell to determine the effect of lane closure. The comparisons of typical days before and during control show no appreciable difference in the operation characteristics (Figures 9 and 10).

Traffic Flow Upstream of Control - The closure of one through lane

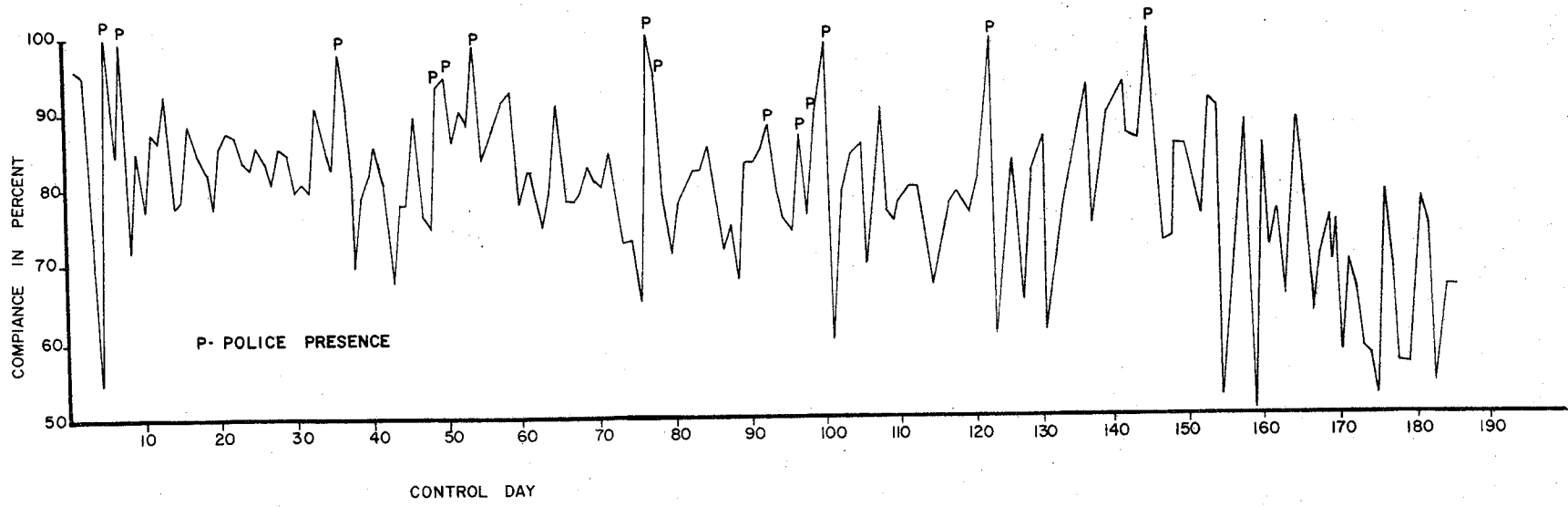


Figure 7. Average Daily Signal Compliance Rates

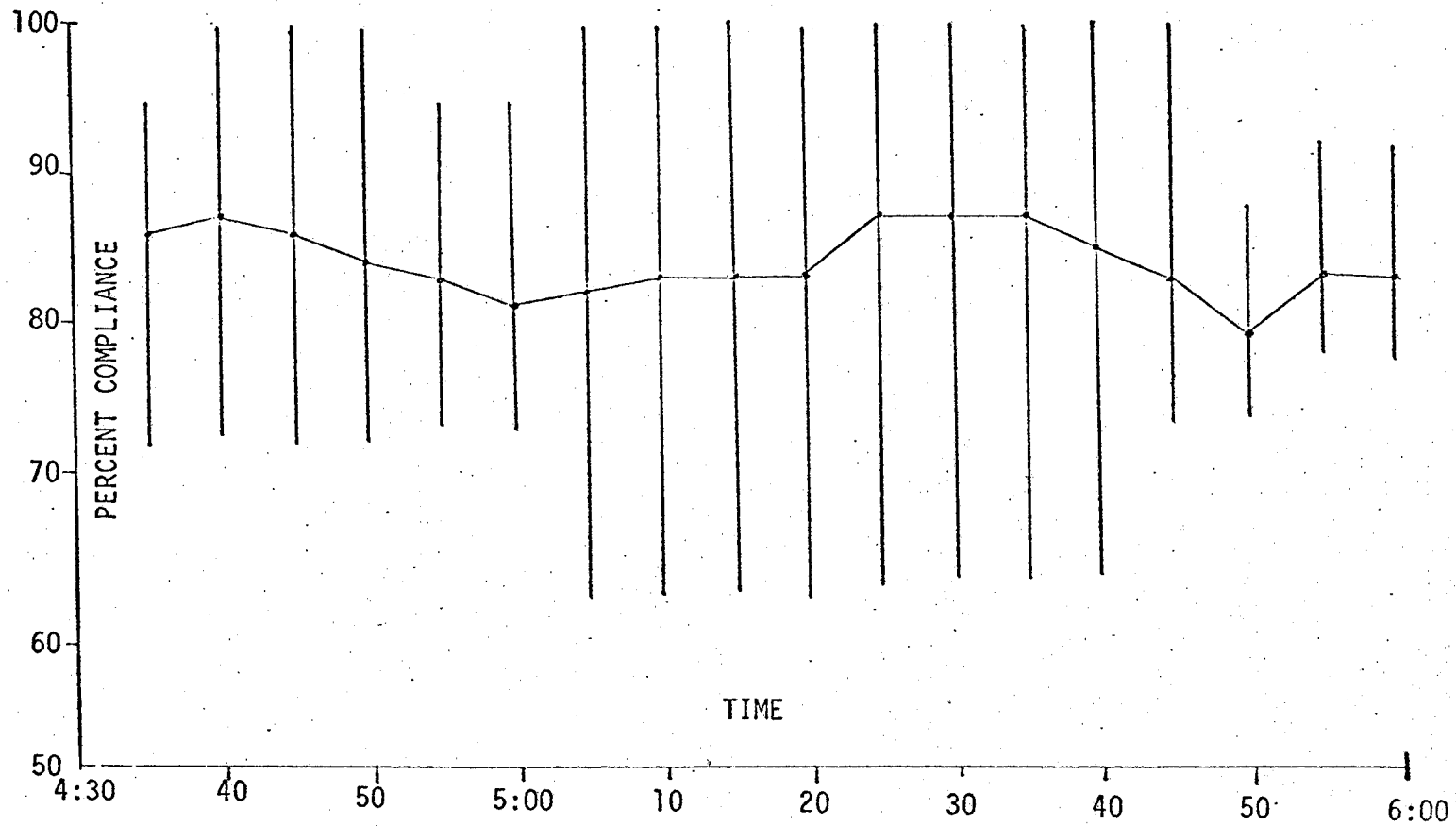


Figure 8. Range of Signal Compliance Rates
March 1975

TABLE 1

I.H. 10 - KATY FREEWAY, ACCIDENT DATA COMPARISON
FROM WASHINGTON TO SILBER

	<u>Non-Control</u> <u>11/15/73-11/15/74</u>		<u>Control</u> <u>11/20/74-11/20/75</u>		<u>Percent Increase</u>	
	<u>IB</u>	<u>OB</u>	<u>IB</u>	<u>OB</u>	<u>IB</u>	<u>OB</u>
7:00-9:00 a.m.	35	20	21	37	-40	85
4:00-6:00 p.m.	13	52	6	57	-54	10
24 Hour	105	188	59	243	-44	29

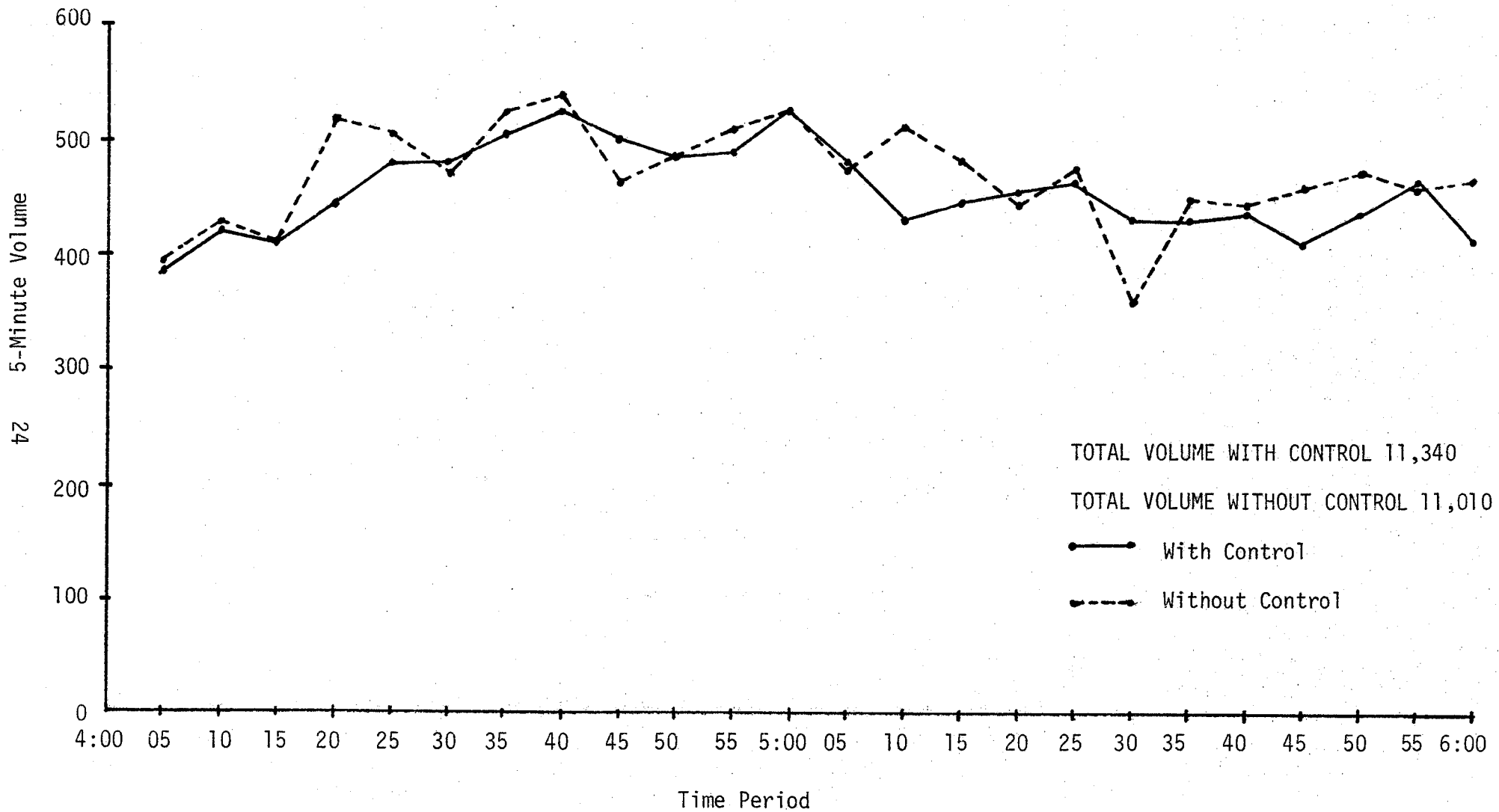


Figure 9. Five-Minute Flow Rates
At I.H. 10 Westbound at Wirt Road

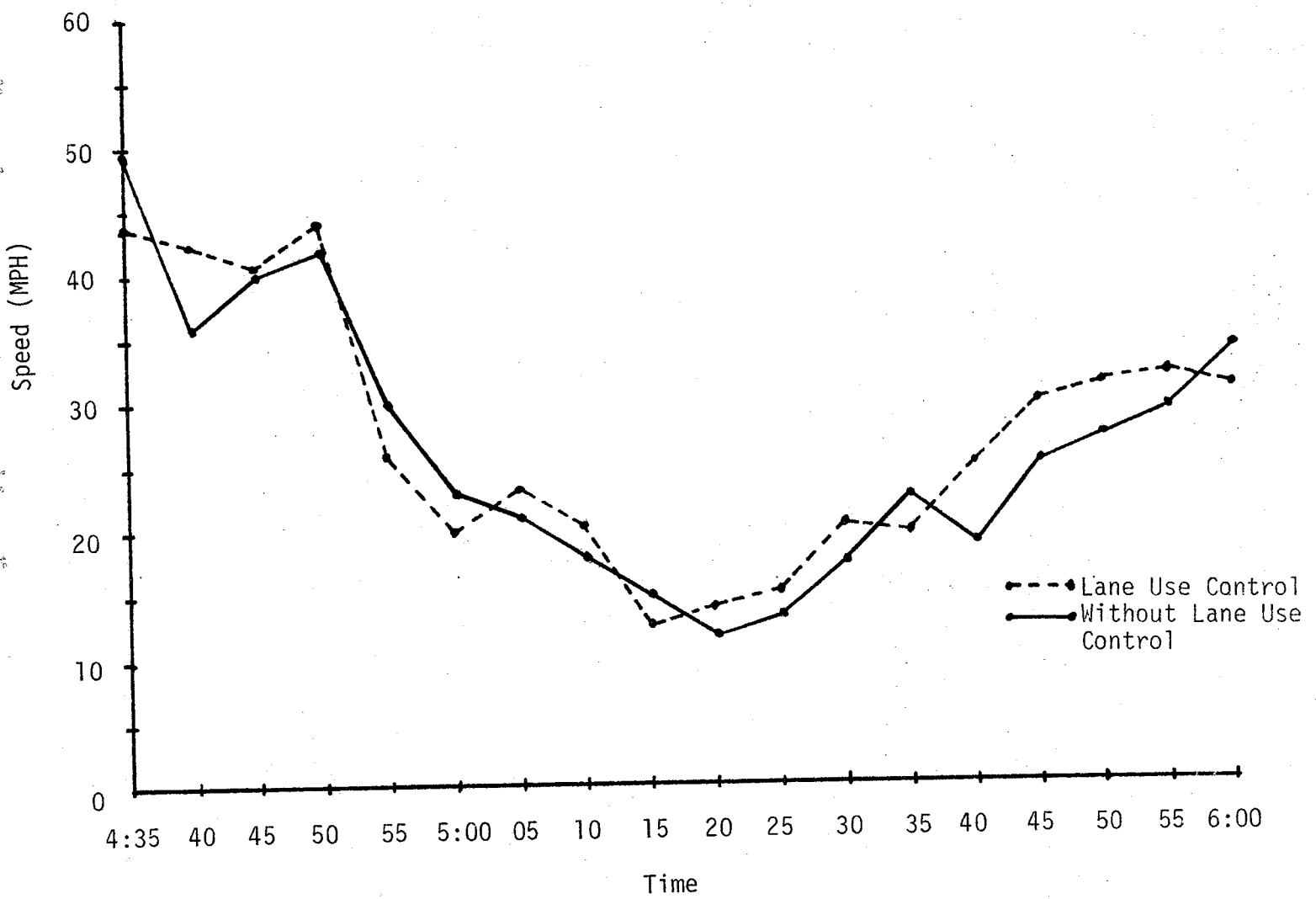


Figure 10. Five-Minute Average Speeds
at I.H. 10 Westbound at Wirt Road

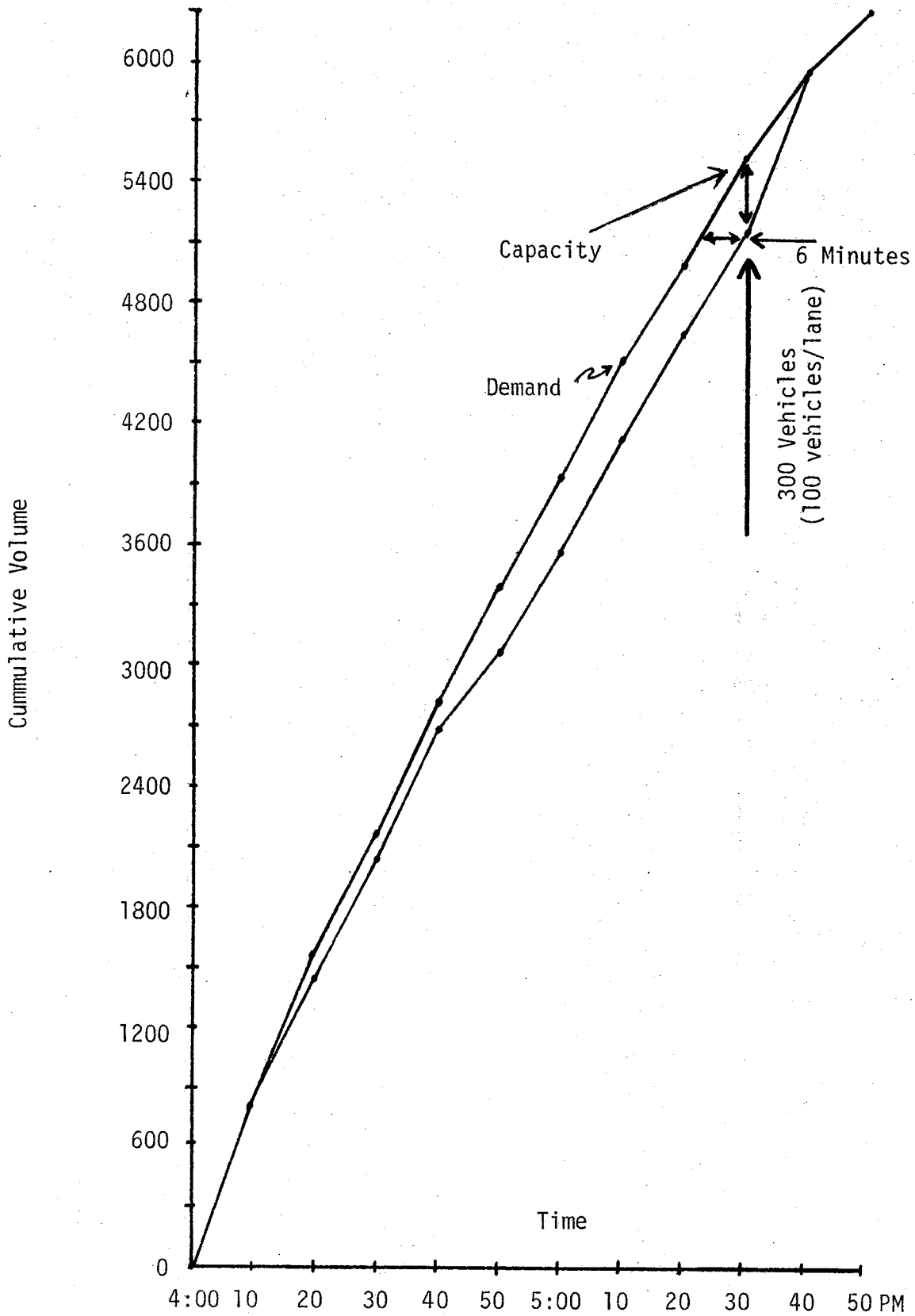


Figure 11. Typical Capacity - Demand Curves for I.H. 10 Westbound with a Moderate Restrictive Lane Use Control Strategy (40 Minutes of Control)

HEAVY CONTROL

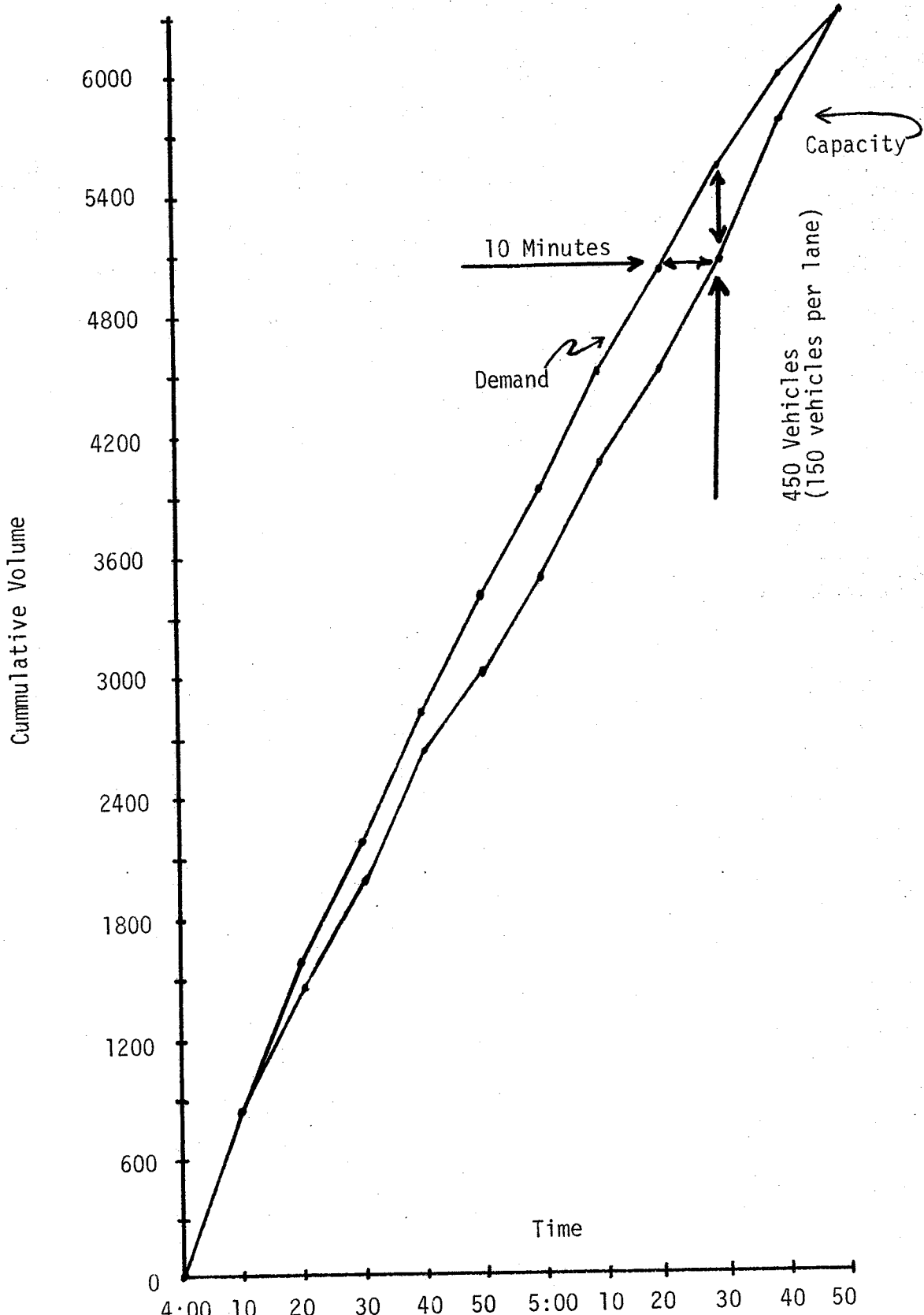


Figure 12. Typical Capacity - Demand Curves for I.H. 10 Westbound with Very Restrictive Lane Use Control Strategy (65 Minutes of Control)

of I.H. 10 caused some additional delay to be encountered by that traffic. The exact amounts 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 heavy 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 control, the maximum additional delay encountered by a motorist would be 6 minutes from 5:30 to 6:00 p.m. The queue length would be increased by approximately 100 vehicles per lane, which would be approximately one mile. Moderate control constitutes approximately 40 minutes of control.

For heavy 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. Heavy control constitutes approximately 65 minutes of control.

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 on I.H. 610 Approaches to I.H. 10 - Since the lane control provides more capacity to the connecting roadways from I.H. 10, the flow rates are higher and the queues are shorter. 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. However, if the output flow rate of I.H. 10 was reduced because of an accident, stalled vehicle, or rain, it was often impossible to prevent large queues from forming in all

directions.

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. 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 has improved the throughput of the I.H. 610 roadway from the West Loop to the North Loop. Delay studies on the three-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 3,120-vehicle hours per year. 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 merge 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 I.H. 610 improvements; the widening of the weaving area from the merge to Silber exit; and the frustrations of facing additional controls on the urban roadway system.

The only factor that can objectively be evaluated at this time is the reduction in delay compared to the cost of installation, operation, and maintenance of the signal system.

While the time of comparisons used in compiling Table 1 are too short to permit an accurate determination of the effect of control

operations on accident rates, still the data suggest an accident reduction of from 0 to 30 vehicles per year in this area. The loss in an average two-vehicle rear-end involvement with no human injury is estimated at \$418. This yields an estimate of yearly savings in motorists' personal property damage of from \$0 to \$12,540.

Elimination of these accidents also indicates an additional savings to the motorists when delay time for these accidents is considered. 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. Accountable costs and benefits are shown in Table 2.

CONCLUSIONS

After one year of operation, the following conclusions can be drawn from the studies of the lane control system.

1. The signals are effective in closing one lane of traffic, thereby giving priority to a merging roadway.
2. Compliance rates average approximately 80 percent. High compliance percentages are achieved during police enforcement, and with operation during light traffic flow and short delays to I.H. 10.
3. There is no evidence that the lane control system is a hazard to traffic operations.

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>	1,000	
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

4. Downstream traffic operations are not significantly affected by the lane control because of the severe bottleneck section at Wirt Road and the weaving section at Silber.
5. Delay to I.H. 10 approach traffic is increased; delay to I.H. 610 approach is reduced; and total delay to traffic entering the I.H. 10-I.H. 610 interchange is reduced.
6. Assuming only reduction in delay as a benefit, the system has a benefit-cost ratio of 2.5.

CLOSING STATEMENT

Voluntary lane control with signs and signals of the design described in this study is a feasible alternative for the closure and/or priority operation of a freeway lane. For the particular application of reducing the queues on the connecting roadway, other alternatives, such as the use of shoulders for travel into and out of the interchange should be explored. It is the opinion of the author that a higher benefit-cost ratio could be achieved with an alternative that adds capacity, requires no man-power for operation, and no additional construction costs for new pavement.

REFERENCES

1. DeRose, F., LODGE FREEWAY SURVEILLANCE AND CONTROL PROJECT. Highway Research Record No. 21, 1963.
2. Wattleworth, J.A.; Courage, K.G.; and Carvell, J.D., AN EVALUATION OF TWO TYPES OF FREEWAY CONTROL SYSTEMS. Report 488-6, Texas Transportation Institute, 1968.
3. Hardin, J.E., MINI-COMPUTER CONTROLS RAMPS, Better Roads, August 1972.
4. Loutzenheiser, R.C. and Henderson, D.M., EVALUATION OF ON-FREEWAY TRAFFIC CONTROL AT AN INTERCHANGE. Report 139-10, Texas Transportation Institute, 1971.
5. TEXAS MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES FOR STREETS AND HIGHWAYS, Volume 1, Texas Highway Department, Division of Maintenance Operations, 1967.