FREEWAY OPERATIONS ON THE GULF FREEWAY RAMP CONTROL SYSTEM

by

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PREFACE

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

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INTRODUCTION

The Gulf Freeway Surveillance and Control System had its beginning in 1963 when the Texas Transportation Institute began a research endeavor to investigate means of improving the level of service on urban freeways. The research was sponsored by the Texas Highway Department and U.S. Bureau of Public Roads with the objective of developing criteria for the design and operation of a control system to improve level of service on an over-capacitated urban freeway.

DEVELOPMENTAL STUDIES

Studies of basic freeway characteristics and freeway operation were conducted during the first two years of the research. From these studies, control theories were formulated and validated through ramp metering and ramp closure experiments. The results were so encouraging that a full scale control system was established on a 3.5-mile section of the inbound Gulf Freeway.

Freeway control began on a day-to-day basis on the Gulf Freeway in the summer of 1965 after installation of ramp metering signals on eight inbound entrance ramps. Figure 1 illustrates a typical signal installation. Early control was done manually by personnel stationed near each ramp. Cycle lengths for the ramp signals were determined through a capacity-demand relationship at each ramp.

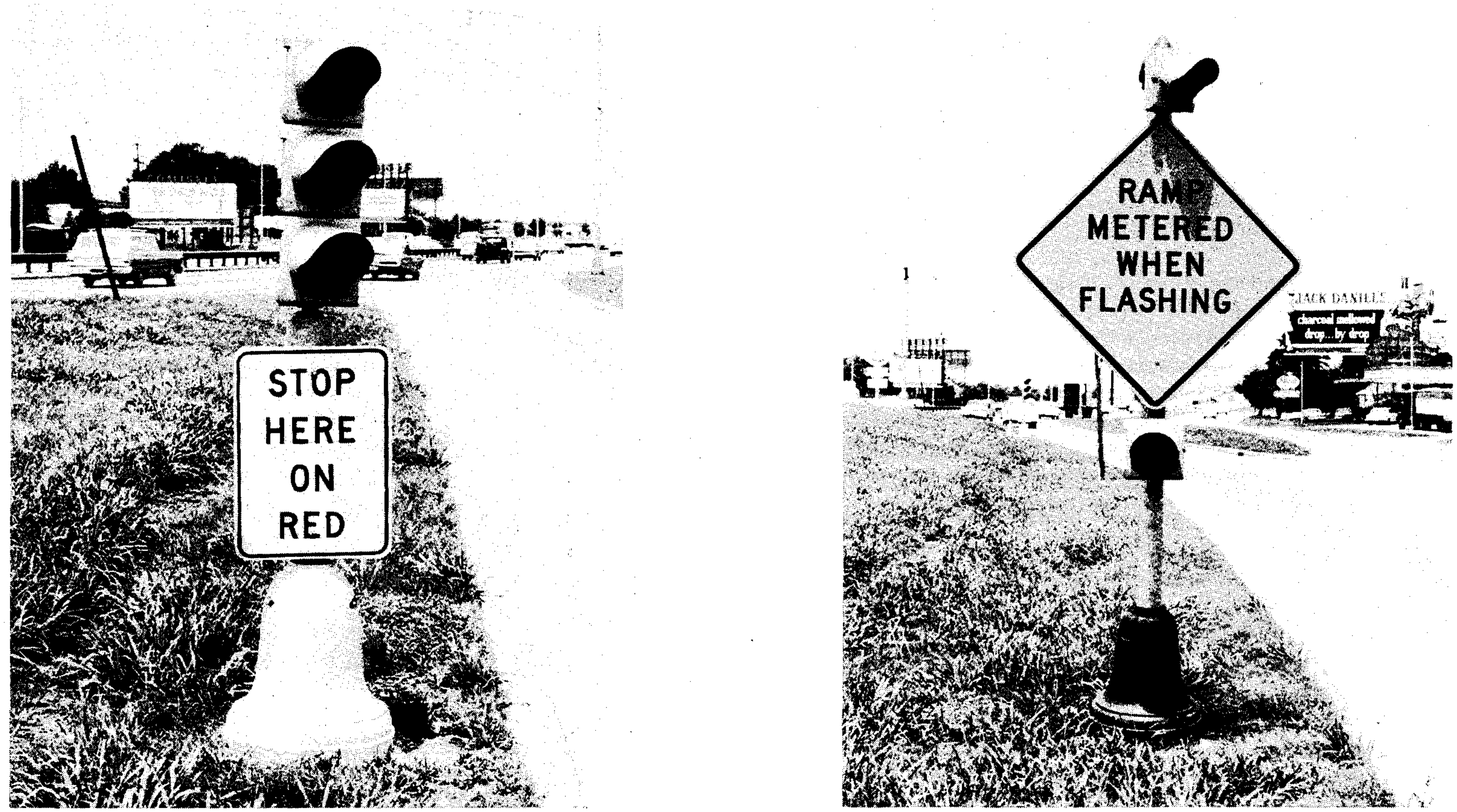

FIGURE 1. RAMP SIGNAL AND ADVANCE WARNING SIGN.

ANALOG CONTROL SYSTEM

Two prototype ramp controllers were installed for study and evaluation in 1966 on the Telephone Entrance ramp. These traffic responsive controllers were designed specifically for freeway ramp control based on the functional requirements of control strategies. Two control strategies studied were the capacity-demand mode and the gap-acceptance mode.

From the experience gained in freeway system control with the prototype controllers and manual ramp metering, an eight-ramp, automatic control system was developed. It included sixty-three loop detectors and the control equipment shown in Figure 2. The equipment consists of a bank of analog devices. This system was installed in late 1967 in a central control center and incorporated both the capacity-demand and the gap-acceptance theories of control.

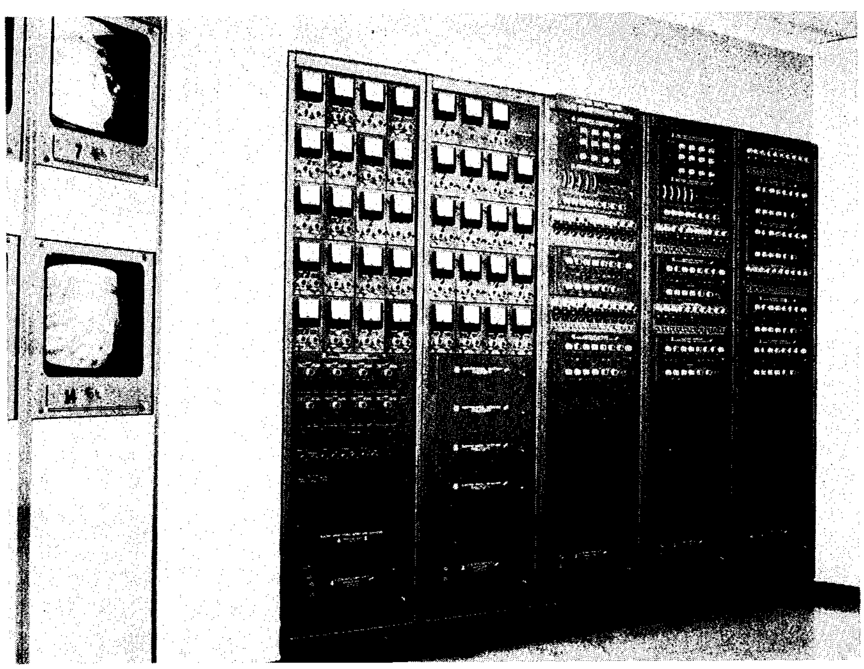

FIGURE 2. ANALOG CONTROL SYSTEM.

TELEVISION SURVEILLANCE SYSTEM

A closed circuit television system was designed and installed in early 1967. This system does not function as part of the control system, but to aid in the research and evaluation of the freeway control system. Its sole function is to provide the visual surveillance necessary in the studies and does not interface with the control logic at any point. The Houston Police Department, at the invitation of the research agencies, uses the television system for detection of freeway incidents and coordination of the removal of these incidents.

The television system consists of fourteen cameras spaced at approximately one-half mile intervals with seventeen monitors located in the control center. Each camera can be operated from the control center to accomplish the following functions: pan, tilt, zoom, focus, and lens opening. Figure 3 shows the television monitors and control console located in the central control center. A buried cable running 6.5 miles along the freeway provides transmission for the television system as well as the detection and control systems.

DIGITAL COMPUTER SYSTEM

In August 1967, a digital computer was installed in conjunction with the research project sponsored by the U.S. Bureau of Public Roads to investigate "Gap Acceptance and Traffic Interaction in the Freeway Merging Process." The computer has the dual capability of freeway control and real-time data acquisition (Figure 4). This makes possible the automatic collection and analysis of data for the evaluation of operations on a routine basis. Studies utilizing the digital computer as a ramp and freeway system con-

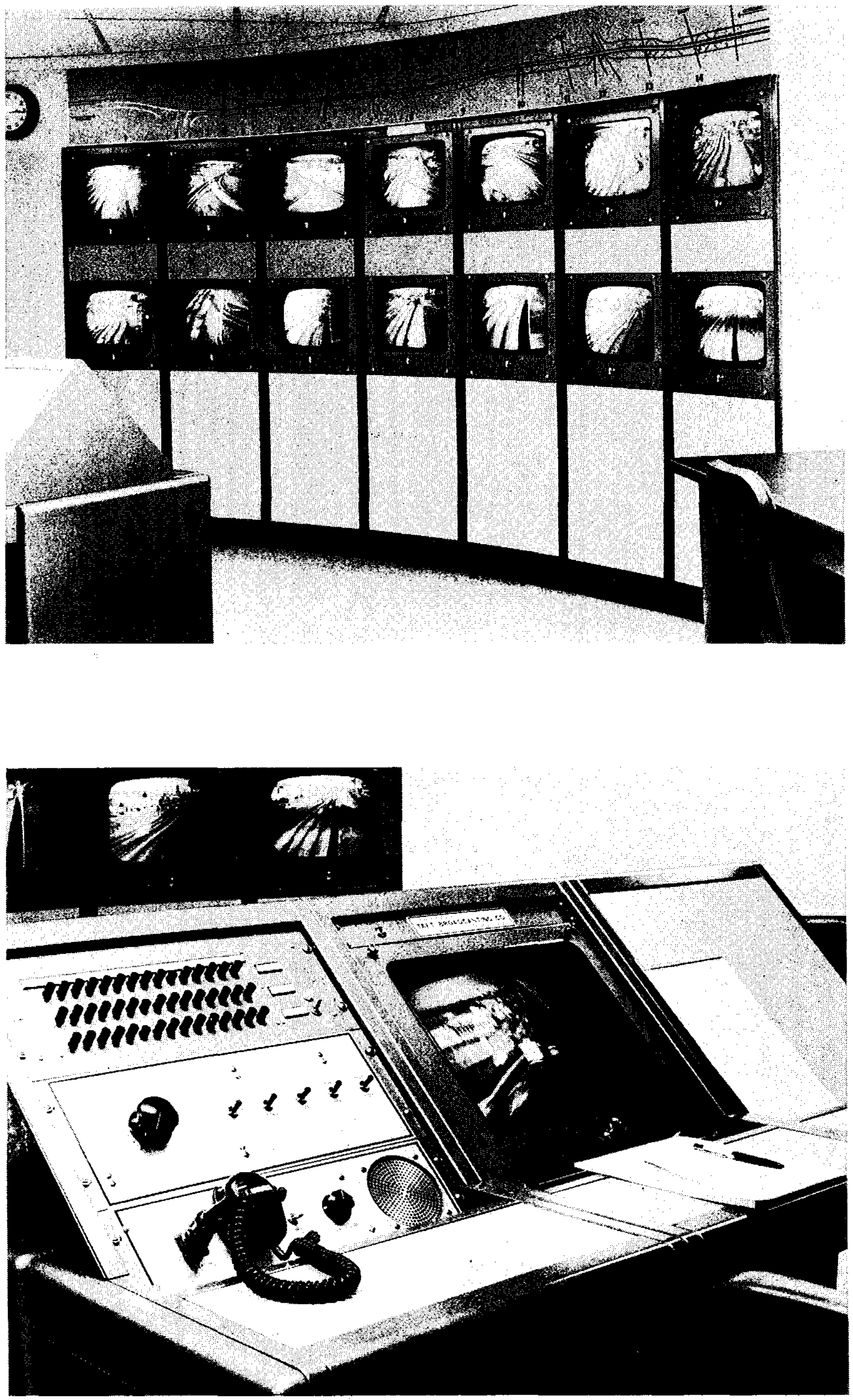

FIGURE 3. TELEVISION MONITORS AND
CONTROL CONSOLE.

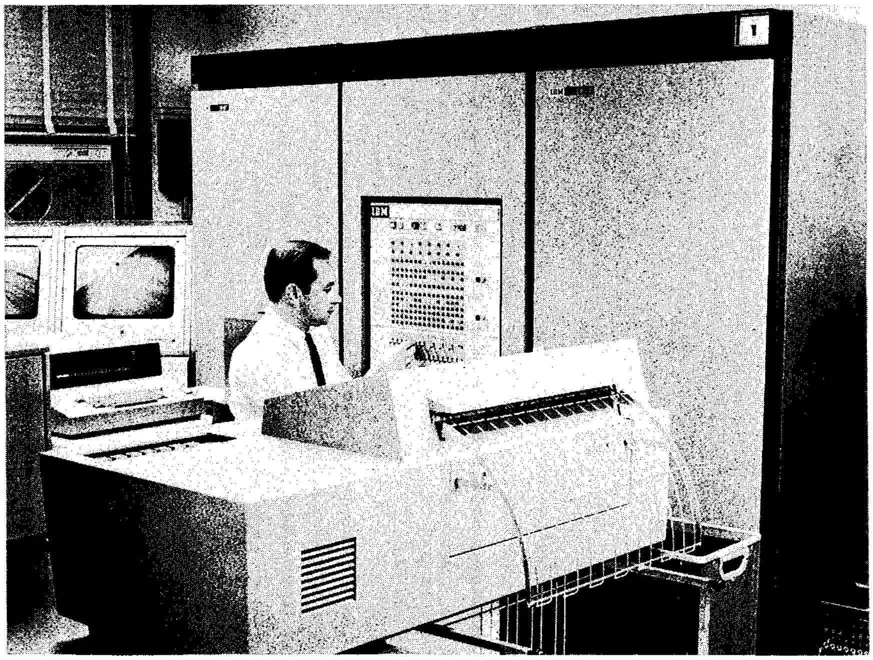

FIGURE 4. DIGITAL COMPUTER DATA ACQUISITION AND CONTROL SYSTEM.

troller were made during 1968-1969. As a result of this developmental work, an operational control system evolved which has been utilized as the primary control on the Gulf Freeway since January 1969. Consequently, the analog system has assumed the role of a "backup" control system.

CURRENT OPERATION

The control strategy presently used is a system-type control employing a digital computer for data acquisition and logic. Freeway detectors provide real time traffic inputs to the computer which processes the data and makes control changes based on the programmed control strategy. Computer control does not operate as eight isolated ramp controllers housed in the same cabinet, but is programmed to make system-wide control changes based on control theory.

The control strategy used is a combination of capacity-demand and gap-acceptance with refinements that provide fast system response to changes in freeway operation. A linear programming model is used to establish the capacity-demand relationship of the system and assign metering rates to the controlled ramps. These rates are converted to appropriate service gap settings for each ramp based on a gap availability-freeway flow relationship. The "service gap" is that gap in the outside freeway lane for which a ramp vehicle is released. Special incident routines are used to adjust control parameters when traffic inputs indicate the occurrence of a capacity-reducing incident.

MEASUREMENT OF PRESENT OPERATION

Documentation of traffic characteristics on the inbound Gulf Freeway has been extensive since the beginning of the research project. The principal objective of this report is to present the characteristics of the present operation. Comparisons of many of these parameters are made between present operation and operations without control.

System parameters are now collected and analyzed routinely through the data acquisition feature of the digital computer. The vehicle detection system extends from the State Highway 225 overpass to the Dumble Street entrance ramp.

Current traffic patterns on the inbound freeway are shown in Figures 5 and 6. The period 6:30-8:30 AM is used because it normally includes the entire morning peak traffic demand while the 7:00-8:00 AM period generally encompasses the control period. Figure 7 illustrates the flow pattern for the inbound frontage road.

Freeway inputs are a significant parameter in evaluating the effects of control. Tables 1 and 2 compare the present freeway inputs to those measured before control began.

The Griggs overpass is a critical bottleneck of the inbound freeway. Flow through this bottleneck is a good indicator of the success of freeway operation. For this reason, flow data at this location have been maintained since control began. Figure 8 shows the five-minute flow rates between 6:30 and 8:30 AM. The peak period of flow is clearly evident. Figure 9 and Table 3 give an indication of the flow patterns for an entire year at the Griggs overpass. Table 3 contains gross averages of all control days and includes data for all environmental and traffic conditions experienced during the year.

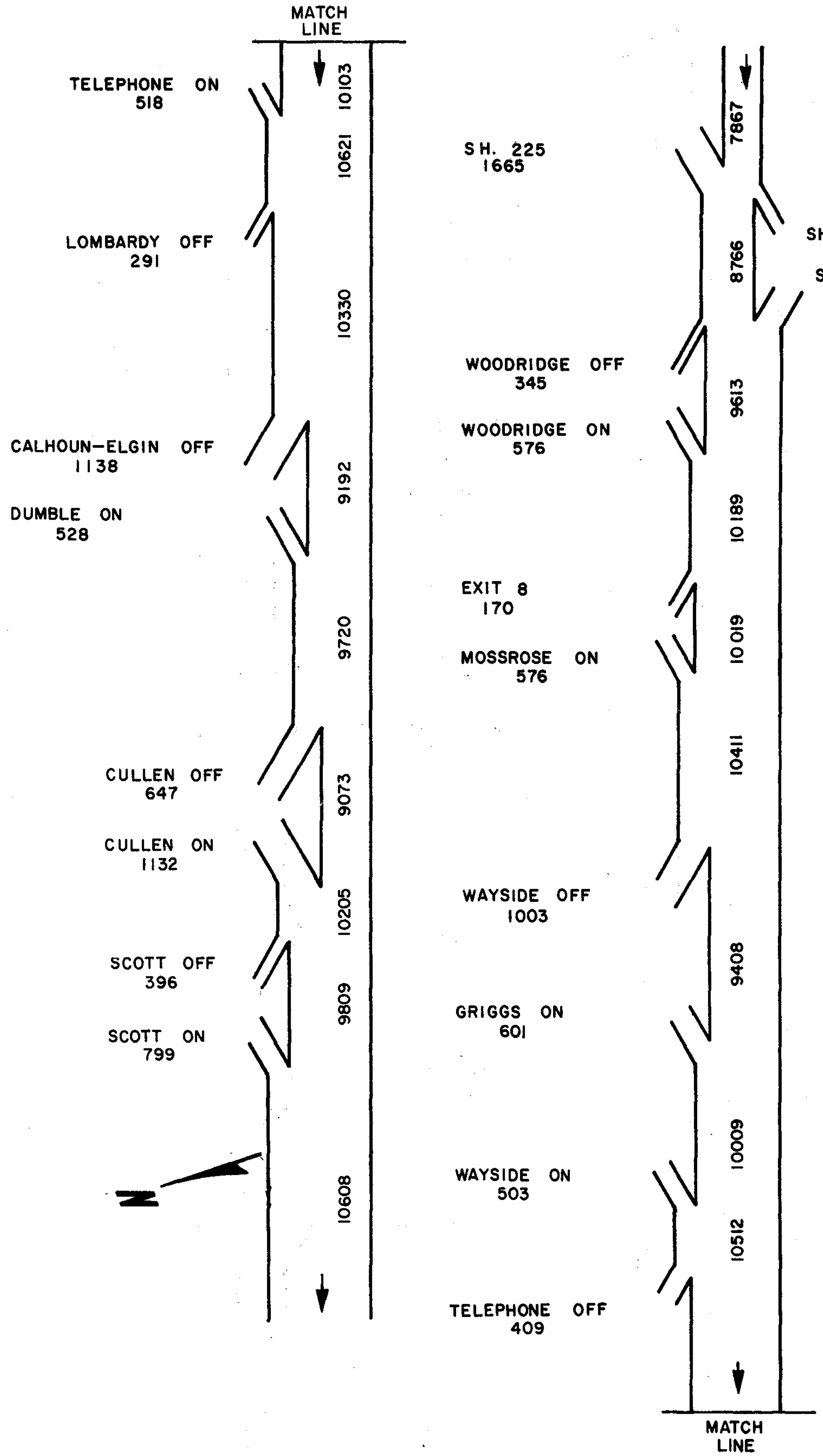

FIGURE 5. VOLUME FLOW MAP— INBOUND GULF FREEWAY—6:30-8:30 A.M., JULY 1969.

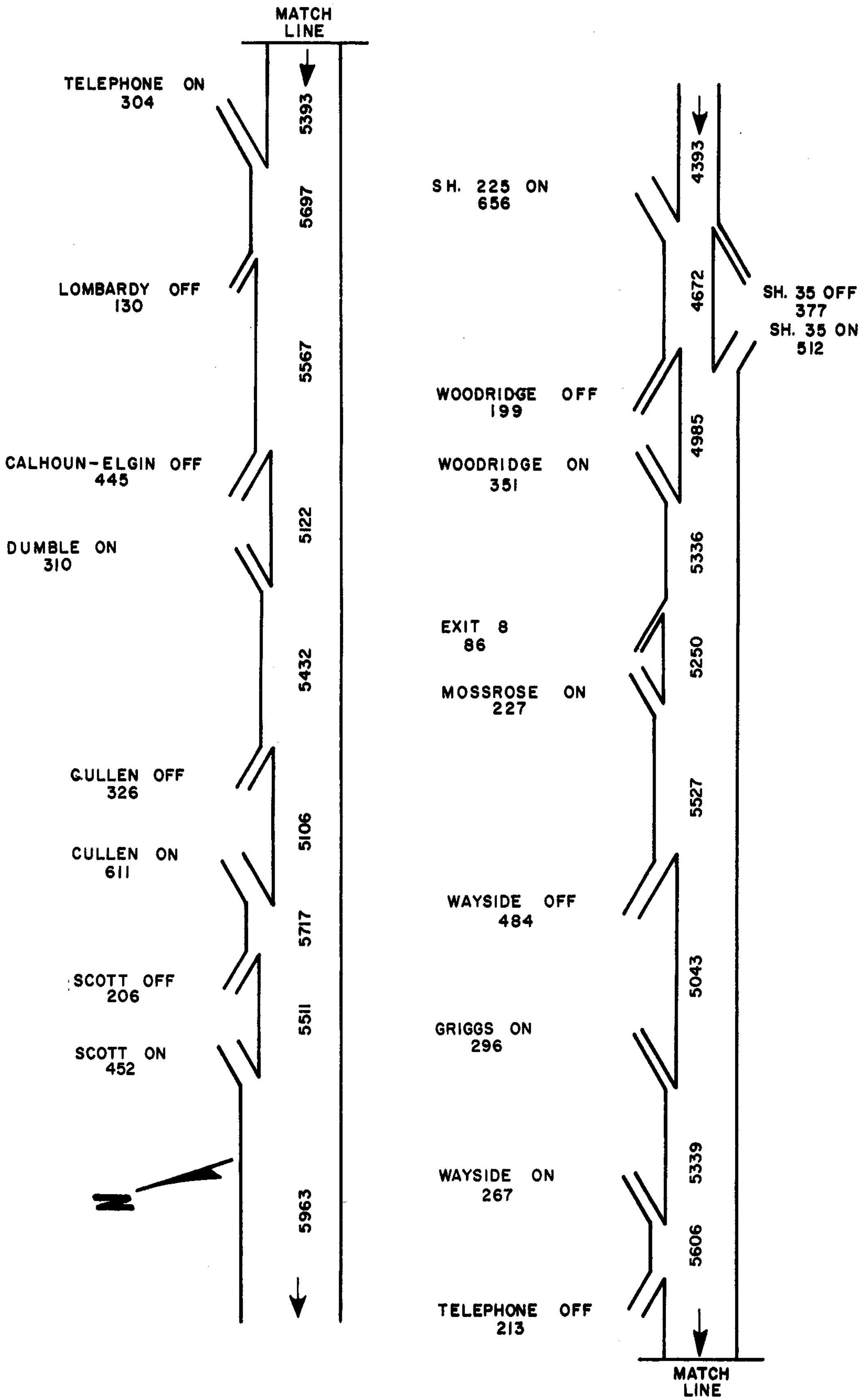

FIGURE 6. VOLUME FLOW MAP – INBOUND GULF FREEWAY—7:00–8:00 A.M., JULY 1969.

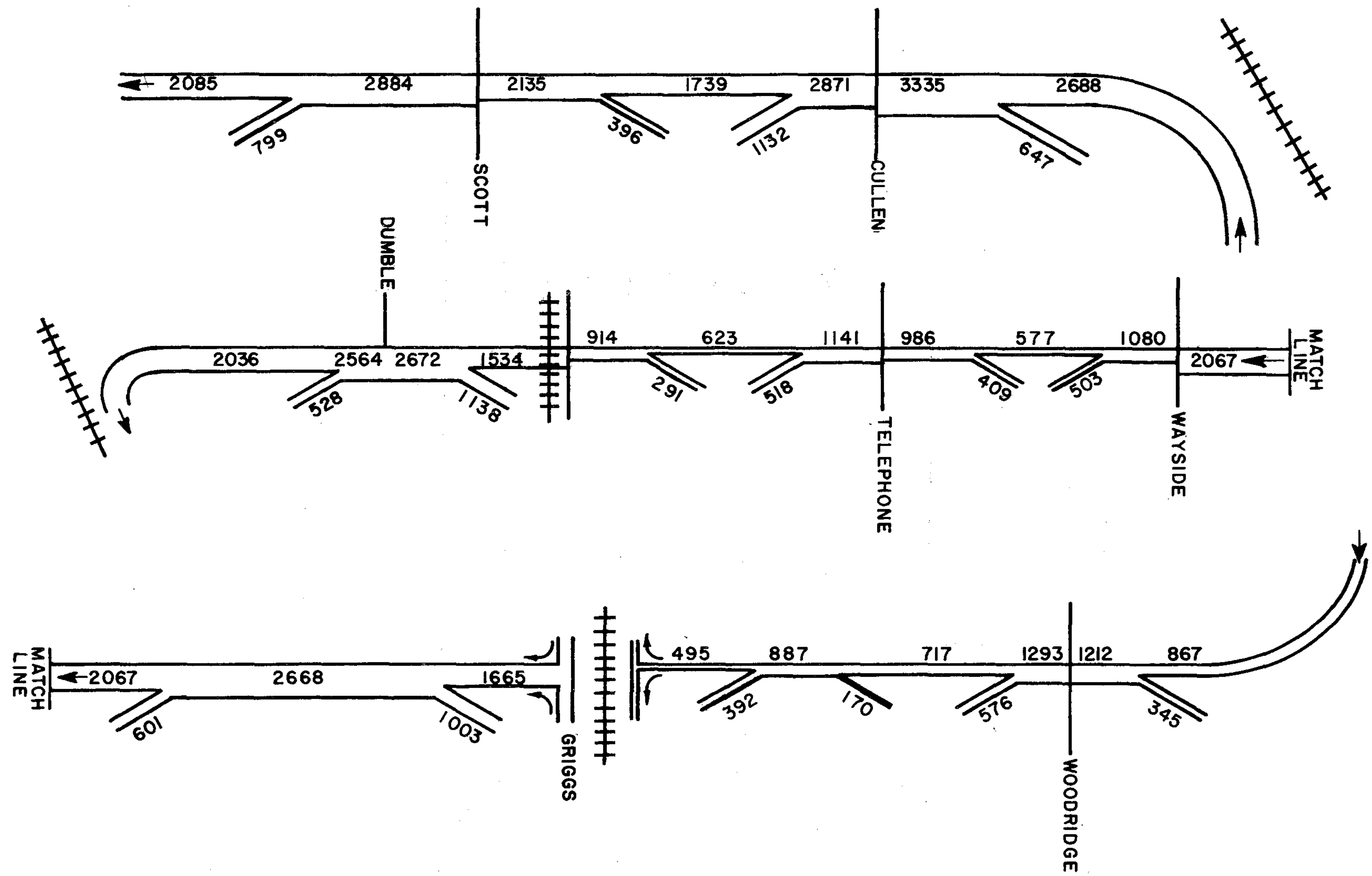

FIGURE 7. FRONTAGE ROAD FLOW, INBOUND—6:30-8:30 A.M., JULY 1969.

TABLE 1

AVERAGE 7-8 AM INPUTS TO THE FREEWAY

Entrance to System	Before Control (January 1964)	During Control (July 1969)	Difference
Freeway Near Broadway	2831	4355	+1524
*Detroit On Ramp	218	217	- 1
SH 225 On Ramp	559	656	+ 97
SH 35 On Ramp	818	512	- 306
Woodridge On Ramp	426	351	- 75
Mossrose On Ramp	643	277	- 366
Griggs On Ramp	683	296	- 387
Wayside On Ramp	335	267	- 68
Telephone On Ramp	413	302	- 111
Dumble On Ramp	345	310	- 35
*Cullen On Ramp	574	611	+ 37
*Scott On Ramp	63	452	+ 389
TOTAL	7908	8606	+ 698

*Ramps not controlled.

TABLE 2

AVERAGE 6:30-8:30 AM INPUTS TO THE FREEWAY

Entrance to System	Before Control (January 1964)	During Control (July 1969)	Difference
Freeway Near Broadway	6330	7824	+1494
*Detroit On Ramp	405	318	- 87
SH 225 On Ramp	1300	1665	+ 365
SH 35 On Ramp	1540	1182	- 358
Woodridge On Ramp	500	576	+ 76
Mossrose On Ramp	840	392	- 448
Griggs On Ramp	1220	602	- 618
Wayside On Ramp	550	504	- 46
Telephone On Ramp	650	516	- 134
Dumble On Ramp	590	528	- 62
*Cullen On Ramp	760	1132	+ 372
*Scott On Ramp	132	799	+ 667
TOTAL	14817	16038	+1221

*Ramps not controlled.

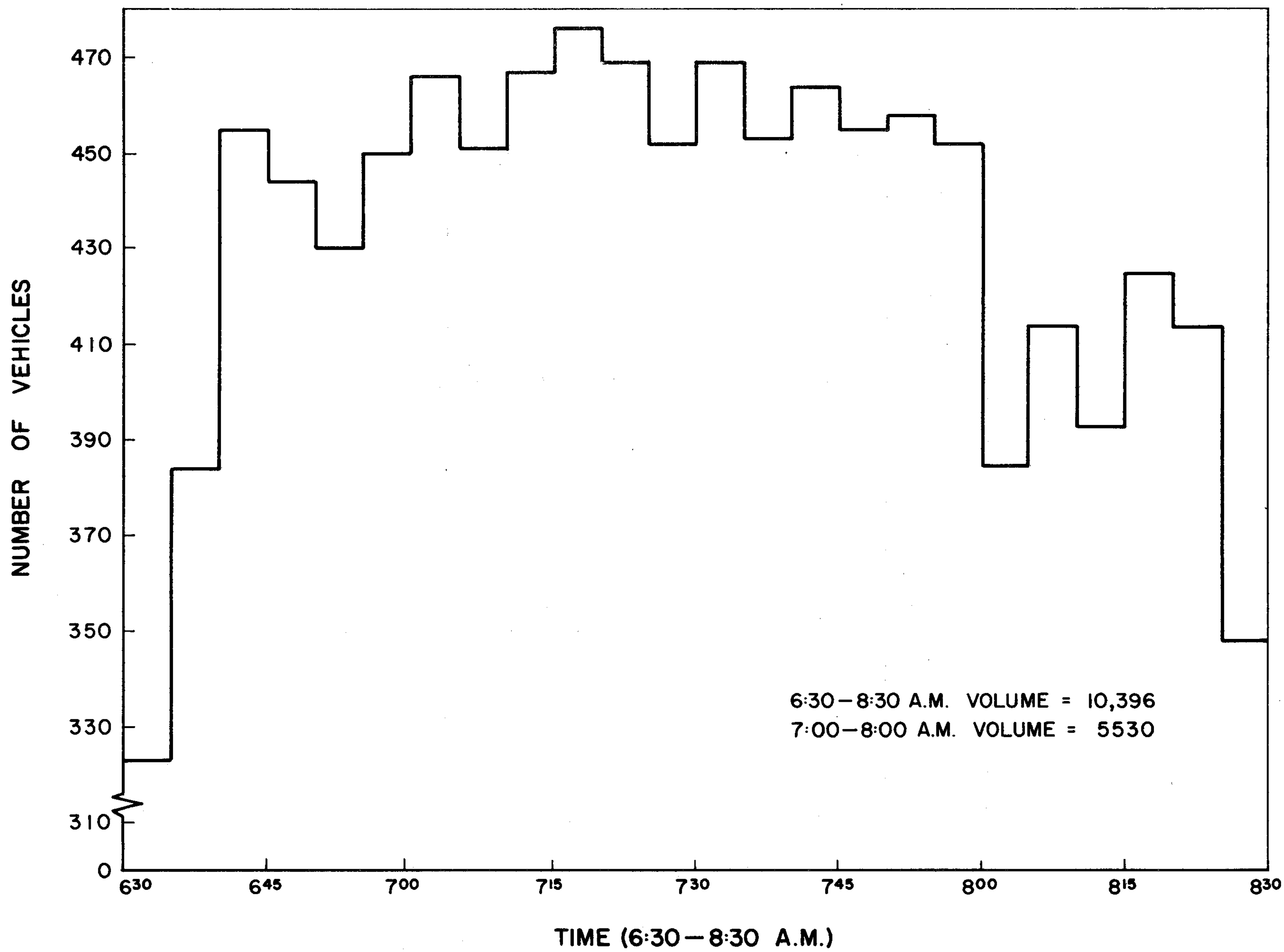

FIG. 8. FIVE-MINUTE VOLUMES ON GULF FREEWAY AT GRIGGS.

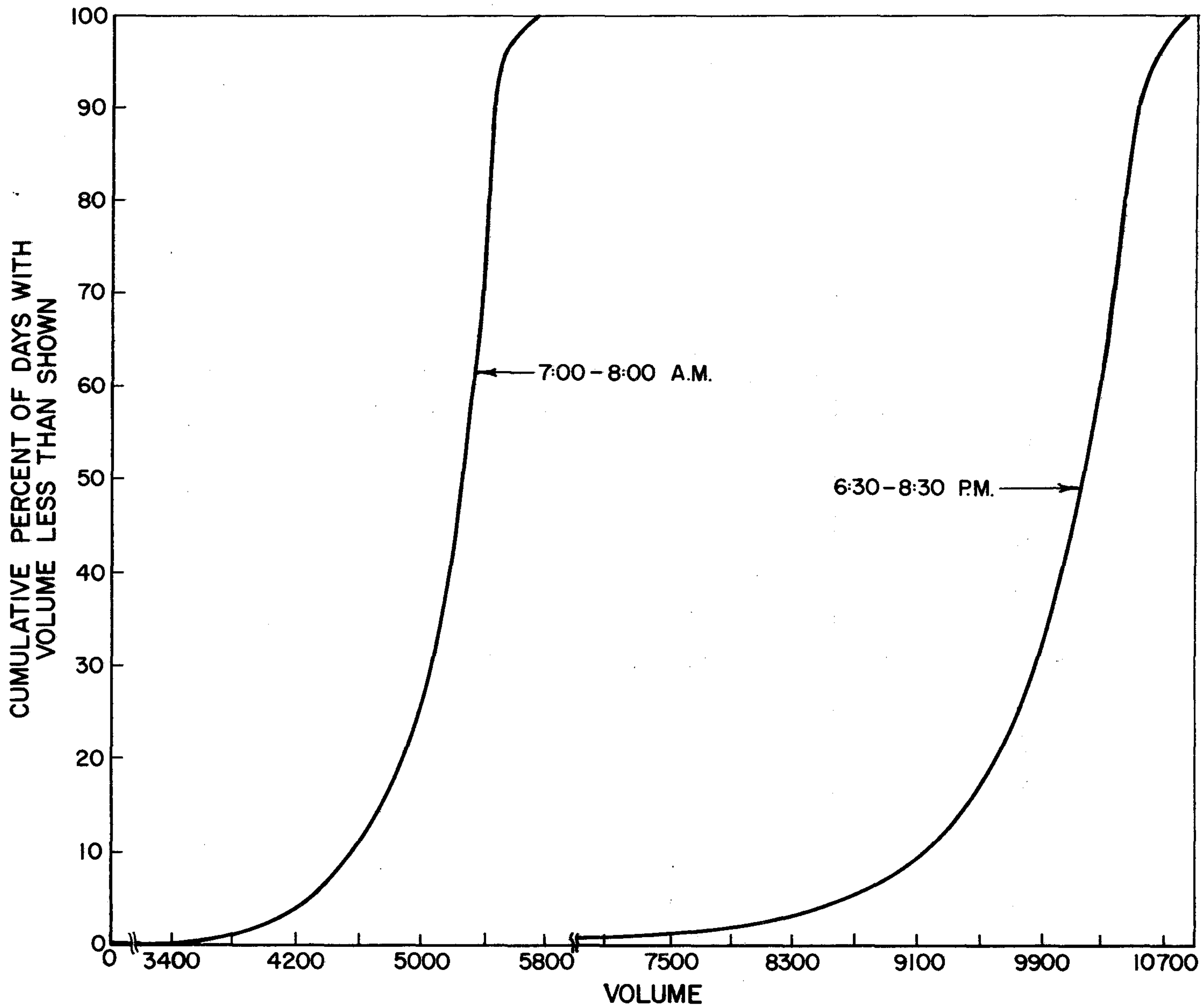

FIG. 9. CUMULATIVE DISTRIBUTION OF VOLUME FREQUENCY AT GRIGGS.

TABLE 3

AVERAGE MONTHLY 6:30-8:30 AM VOLUMES
AT GRIGGS

1968-1969

Month	6:30-8:30 Volume	7:00-8:00 Volume
January, 1969	9,481	4,878
February, 1969	9,609	4,876
March, 1969	10,015	5,241
April, 1969	10,338	5,446
May, 1969	10,041	5,313
June, 1969	10,189	5,258
July, 1968	10,348	5,286
August, 1968	10,157	5,305
September, 1968	10,021	5,144
October, 1968	9,910	4,947
November, 1968	10,097	5,158
December, 1968	9,818	5,084

The system measures of total travel, total travel time, and speed yield the best indications of freeway operation since they reflect both quantity and quality of traffic flow. System data are presented in Tables 4 through 9. The value of freeway control is evident in these before and after comparisons.

Individual vehicle travel times are routinely sampled using television surveillance during the peak period. Figure 10 is a compilation of this information in the form of travel time contours for the period 6:30-8:30 AM.

The mode of freeway control used on the Gulf Freeway requires the stopping of all vehicles entering the freeway on ramps. This creates delays at entrance ramps. Table 10 illustrates the magnitude of the delay experienced on the controlled ramps. The delay on the ramps has been shown to be more than offset by the decrease in delay in the total freeway system.

Ramp signals, like any traffic control device, are not obeyed by all motorists. Table 11 reflects the ramp signal violations as a percent of the traffic volume during control. These violations must be considered in light of the fact that no enforcement of the signal has been attempted since installation of the control system.

The improvement in the peak period level of service has fostered a significant reduction in accidents. Figure 11 shows the accident record on the inbound Gulf Freeway and service road for weekdays. The accident experience is essentially the same for the before and after control years, when considering the 24-hour day. This figure is presented for comparison with Figure 12 which shows accidents during the control period. Installation of a control system has resulted in a reduction in control period accidents of twenty-seven percent.

TABLE 4

VEHICLE MILES OF TRAVEL
IN FREEWAY SUBSYSTEMS
6:30-8:30 AM

Subsystem	Vehicle-Miles (January 1964)	Vehicle-Miles (July 1969)
Broadway to SH 225	5760	6136
SH 225 to Woodridge	3757	4760
Woodridge to Griggs	8496	9990
Griggs to Telephone	8033	8034
Telephone to SHB&T	9487	10223
SHB&T to Dowling	15802	17183
TOTAL	51335	56316

TABLE 5

VEHICLE MILES OF TRAVEL
IN FREEWAY SUBSYSTEMS
7:00-8:00 AM

Subsystem	Vehicle-Miles (January 1964)	Vehicle-Miles (July 1969)
Broadway to SH 225	2532	3394
SH 225 to Woodridge	1630	2517
Woodridge to Griggs	4675	5258
Griggs to Telephone	4309	4307
Telephone to SHB&T	4147	5489
SHB&T to Dowling	9061	9605
TOTAL	26354	30570

TABLE 6

SYSTEM DATA FOR FREEWAY SUBSYSTEMS
6:30-8:30 AM
July 1969

	Total Travel (veh-mi)	Total Travel Time (veh-hr)	Average Speed (MPH)
Broadway to SH 225	6126	141	43.4
SH 225 to Woodridge	4760	188	25.3
Woodridge to Griggs	9990	251	39.8
Griggs to Telephone	8034	225	35.7
Telephone to SHB&T	10223	275	37.2
SHB&T to Dowling	17183	507	33.8
TOTAL	56316	1587	35.5

TABLE 7

SYSTEM DATA FOR FREEWAY SUBSYSTEMS
7:00-8:00 AM
July 1969

	Total Travel (veh-mi)	Total Travel Time (veh-hr)	Average Speed (MPH)
Broadway to SH 225	3394	83	40.8
SH 225 to Woodridge	2517	120	21.0
Woodridge to Griggs	5258	151	34.8
Griggs to Telephone	4307	129	33.4
Telephone to SHB&T	5489	163	33.7
SHB&T to Dowling	9605	292	32.9
TOTAL	30570	938	32.6

TABLE 8

EFFECT OF CONTROL ON SYSTEM
TOTAL TRAVEL TIME
(Vehicle-Hours)
7:00-8:00 AM

Subsystem	Before Control January 1964	During Control July 1969	Difference
Broadway to Griggs	575	354	-221 (-38%)
Griggs to SHB&T	367	292	- 75 (-20%)
SHB&T to Dowling	302	292	- 10 (03%)
TOTAL	1244	938	-306 (-25%)

TABLE 9

EFFECT OF CONTROL IN
BROADWAY-GRIGGS SUBSYSTEM
7:00-8:00 AM

Parameter	Before Control 1964	During Control 1969	Difference
Total Travel (vehicle-miles)	7990	11169.0	+3179 (+40%)
Total Travel Time (vehicle-hours)	575	354.0	- 221 (-38%)
Average Speed (miles/hour)	14	31.6	+17.6 (+126%)

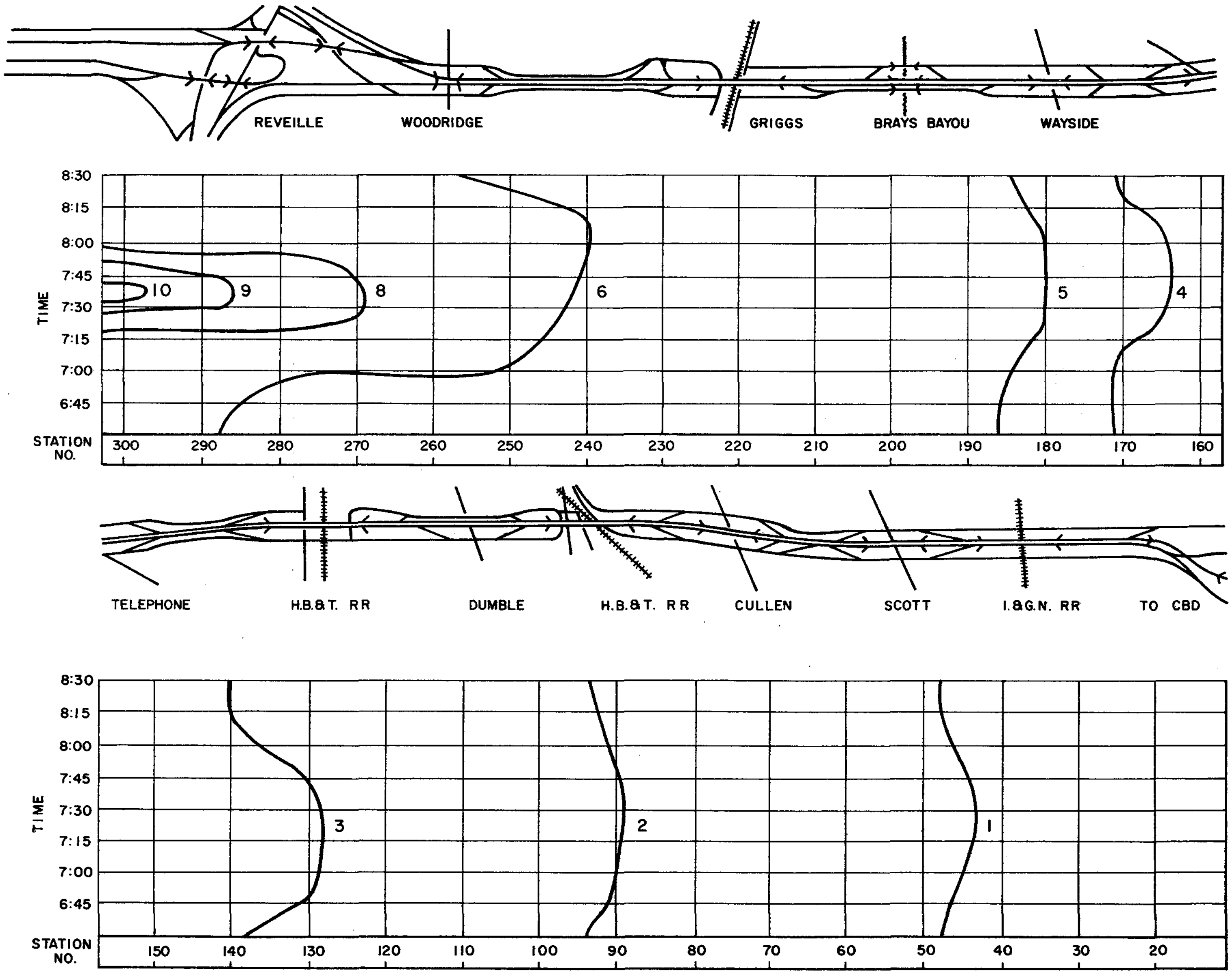

FIG. 10. TRAVEL TIME CONTOUR MAP, JULY 1969.

TABLE 10

RAMP TRAVEL TIME ON
CONTROLLED ENTRANCE RAMPS
July 1969

	Total Travel Time 6:30-8:30 (veh-hrs)	Total Travel Time During Control (veh-hrs)	Delay/Vehicle During Control (min)
SH 225	38.9	38.0	3.0
SH 35	46.3	40.2	2.2
Woodridge	18.7	18.7	2.1
Mossrose	15.4	15.4	2.4
Griggs	18.0	17.8	2.2
Wayside	11.3	11.1	1.3
Telephone	9.7	9.6	1.1
Dumble	4.9	4.9	0.7
TOTAL	163.2	155.7	

TABLE 11

SIGNAL VIOLATIONS ON
CONTROLLED ENTRANCE RAMPS

July 1969

Ramp	Percent Violations
SH 225	13.1
SH 35	1.1
Woodridge	6.5
Mossrose	6.8
Griggs	3.5
Wayside	9.7
Telephone	8.2
Dumble	9.2

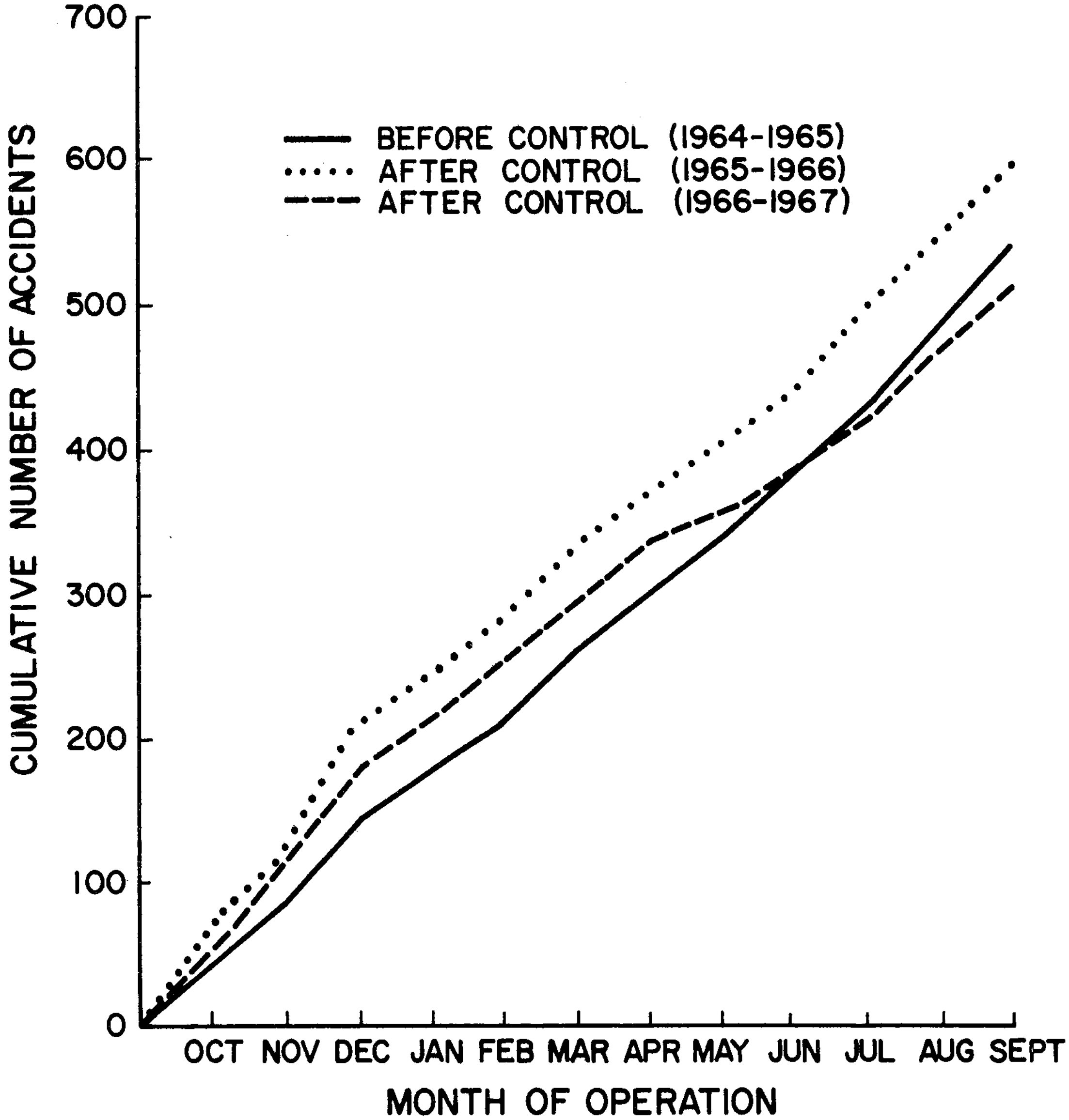

FIG. 11. CUMULATIVE 24-HOUR WEEKDAY ACCIDENTS INBOUND FREEWAY AND SERVICE ROAD.

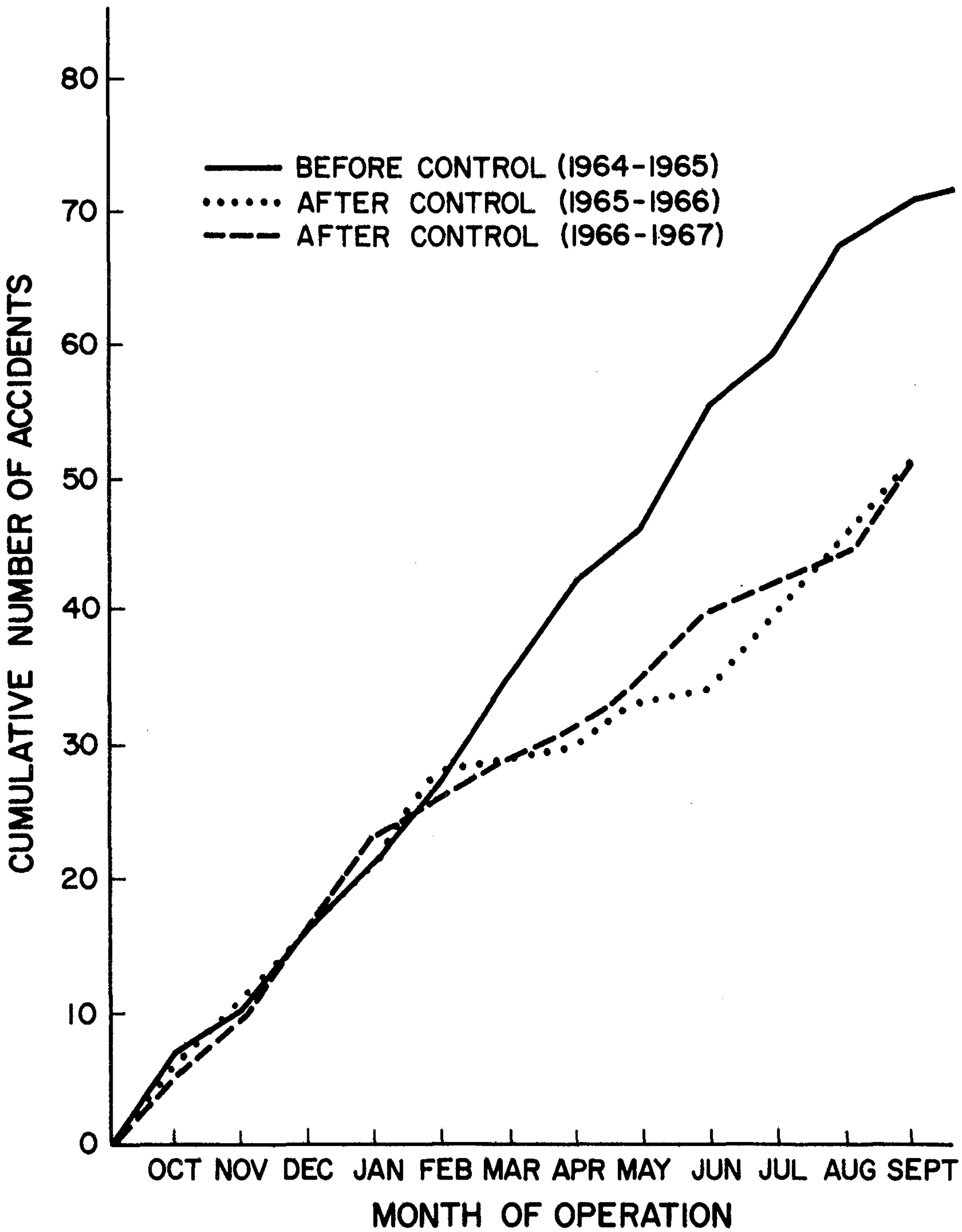

FIG. 12. CUMULATIVE 7-8 A.M. WEEKDAY ACCIDENTS INBOUND FREEWAY AND SERVICE ROAD.

SUMMARY

This report has provided a description of the Gulf Freeway Surveillance and Control project as it operates in 1969. The equipment configuration, control strategy used, and operational measures of effectiveness have been presented and compared to "before control" conditions. Following are some of the significant results of control:

1. Total travel increased by 10% during 6:30-8:30 AM period and 16% during 7:00-8:00 AM period.
2. Average speed during control period increased 12.2 mph to 32.6 mph.
3. Accidents during control decreased 27%.
4. Violation of ramp signals ranged from 1% to 13%.

PUBLICATIONS
Project 2-8-61-24

FREEWAY SURVEILLANCE AND CONTROL

1. Research Report 24-1, "Theoretical Approaches to the Study and Control of Freeway Congestion" by Donald R. Drew.

2. Research Report 24-2, "Optimum Distribution of Traffic Over a Capacitated Street Network" by Charles Pinnell.

3. Research Report 24-3, "Freeway Level of Service as Influenced by Volume Capacity Characteristics" by Donald R. Drew and Charles J. Keese.

4. Research Report 24-4, "Deterministic Aspects of Freeway Operations and Control" by Donald R. Drew.

5. Research Report 24-5, "Stochastic Considerations in Freeway Operations and Control" by Donald R. Drew.

6. Research Report 24-6, "Some Considerations of Vehicular Density on Urban Freeways" by John J. Haynes.

7. Research Report 24-7, "Traffic Characteristics of the Freeway Interchange Traffic of the Inbound Gulf Freeway" by William R. McCasland.

8. Research Report 24-8, "System Demand-Capacity Analysis on the Inbound Gulf Freeway" by Joseph A. Wattleworth.

9. Research Report 24-9, "Capacity-Demand Analysis of the Wayside Interchange on the Gulf Freeway" by William R. McCasland.

10. Research Report 24-10, "Inbound Gulf Freeway Ramp Control Study, I" by Charles Pinnell, Donald R. Drew, William R. McCasland, and Joseph A. Wattleworth.

11. Research Report 24-11, "Investigation of an Internal Energy Model for Evaluating Freeway Level of Service" by Donald R. Drew and Conrad L. Dudek.

12. Research Report 24-12, "Gap Acceptance Characteristics for Ramp Freeway Surveillance and Control" by Donald R. Drew.

13. Research Report 24-13, "Inbound Gulf Freeway Ramp Control Study, II" by Charles Pinnell, Donald R. Drew, William R. McCasland, and Joseph A. Wattleworth.

14. Research Report 24-15, "Peak-Period Analysis and Control of a Freeway System" by Joseph A. Wattleworth.

15. Research Report 24-16, "An Investigation of the Feasibility of Improving Freeway Operation by Staggering Working Hours" by Gary Lee Santerre.

16. Research Report 24-17, "Freeway Surveillance and Control Project-Gulf Freeway-Houston, Texas" by Donald R. Drew.

17. Research Report 24-18, "Considerations for the Installation of U-Turns at Freeway Interchanges" by Sammy L. Wilson.

18. Research Report 24-19, "The Development of an Automatic Freeway Merging Control System" by Donald R. Drew, William R. McCasland, Charles Pinnell, and Joseph A. Wattleworth.

19. Research Report 24-21, "Freeway Ramp Control Reduces Frequency of Rear-end Accidents" by Milton L. Radke.

20. Research Report 24-22, "Evaluation of the Benefits of Traffic Surveillance and Control on the Gulf Freeway" by W. R. McFarland, W. G. Adkins, and W. R. McCasland.

21. Research Report 24-23, "Effect of Rain of Freeway Capacity" by E. Roy Jones and Merrell E. Goolsby.

22. Research Report 24-24, "Cost Effectiveness Analysis of Freeway Ramp Control" by Conrad L. Dudek and William R. McCasland.

23. Research Report 24-25, "Freeway Operations on the Gulf Freeway Ramp Control System" by Merrell E. Goolsby and William R. McCasland.

24. Research Report 24-26 (Final) "Freeway Ramp Control System" by William R. McCasland.