Final Report

FREEWAY CONTROL AND INFORMATION SYSTEMS

by

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Freeway Control and Information Systems

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A B S T R A C T

A study of urban traffic operations was conducted on the Gulf Freeway in Houston. The study investigated those areas which give greatest promise for immediate implementation to relieve traffic congestion and to improve safety for the largest number of urban motorists. The major areas of study were: traffic control, detection and clearance of disabled vehicles, and driver communications. Although not all objectives were completed, a review of the accomplishments of the studies is presented, with references to the 13 reports, 5 papers, and other material prepared during the course of the project.

Key Words: Freeway control, traffic surveillance, driver communication systems, disabled vehicle detection and clearance, wrong-way driving, arterial street control.

D I S C L A I M E R

The opinions, findings, and conclusions expressed or implied in this report are those of the research agency and not necessarily those of the Texas Highway Department or the Federal Highway Administration.

SUMMARY

Three years of research on the development of surveillance, communications, and control systems for urban vehicular traffic have been completed. An assessment of the progress of the research efforts indicates that the anticipated schedule for achieving the 12 stated objectives has not been maintained. An analysis of the problems encountered in the research program is presented in the interest of promoting change in Texas Highway Department policies and procedures to facilitate research and to encourage implementation of research findings in this field. A review of the accomplishments of the research program is presented with the description of reports, papers, and other supporting materials that were prepared for documentation of the studies.

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INTRODUCTION

Statement of the Problem

During the decade of the sixties, several significant developments in traffic engineering took place in the field of traffic surveillance and control: it was proven that the application of signal control to urban freeway traffic improves both operational characteristics and safety (1,2); indications are that area wide surveillance and control systems operated from a centralized location will be the next form of urban traffic control system; (3,4,5) a logical extension of the use of data collected by the surveillance systems for the traffic control system is to activate real-time motorist information systems. There has been a general acceptance of the validity of these control concepts, and research and demonstration projects are producing results which confirm the feasibility of the systems. However, there has been a reluctance on the part of the operating agencies to undertake implementation projects until more information on the design, operation, and management of these traffic systems is known. The cautiousness of the agencies is understandable because the equipment and personnel costs to operate and maintain a large network of traffic facilities will be high. However, this hesitancy on the part of the cities and states presents a problem since much of the information can only be answered by the agency which assumes the responsibility for day to day operations. Until an agency establishes programs and sets priorities for the development of these systems, personnel will not be assigned to those tasks of planning and design; and many of the questions pertaining to operational and management requirements will remain unanswered.

The research program being conducted by the Urban Transportation Systems Program of the Texas Transportation Institute is designed to provide some of the information and to develop some of the questions that should be resolved by the operating agencies. Some decision matrixes giving alternatives and consequences can be developed for the technical aspects of implementation, but matters which concern legal interpretations, intergovernmental relationships, management policies, personnel, and funding are beyond the scope of the current research program.

The statement of the problem, then, is to provide sufficient information about these traffic systems to justify the establishment of a department that has as its goals and objectives the planning, design, operation, and management of urban traffic surveillance, communication, and control systems.

Statement of Purpose

In September, 1968, an ambitious program of research on the development, implementation, operation, and evaluation of freeway surveillance control and driver informational systems was begun in Houston. Twelve objectives were outlined for study which were later modified by the deletion of one at the request of the Federal Highway Administration and the addition of another at the request of the Texas Highway Department. This report contains summary statements on the status of each of the twelve objectives and references to the research project reports, papers, and other pertinent documentation which provide the technical details of study.

This final report of three years of research will not restate the technical and theoretical development of the several studies. Rather, it is the purpose of this report to review the accomplishments and research findings, to discuss the status of the research program in achieving certain goals, and to outline the future work to be undertaken by the research program.

Objectives of Study

The general objective of this research program is to determine the functional requirements for the detection, communications, and control systems for an urban freeway which will respond automatically to traffic conditions at any time and will result in safer and more efficient operations. Specific objectives were defined to accomplish this goal:

1. To develop and test a completely automatic freeway control system for the Gulf Freeway Ramp Control System which will initiate and terminate the system as traffic conditions warrant.
2. To develop and test traffic flow parameters that will best define major reductions in roadway capacity for use in real-time freeway control programs.
3. To develop a communications system that will inform the motorists at freeway entrance ramps, on the freeway through lanes, and on arterial streets near the freeway of traffic conditions.
4. To develop a Freeway Control System that will control demand on the freeway lanes.

5. To evaluate the effects of special controls for commercial vehicles.
6. To develop a detection, communications and control system for wrong-way operation on freeway exit ramps and main lanes.
7. To provide technical assistance in the development of plans and specifications of other freeway control system installations in the State of Texas.
8. To develop, test, and evaluate procedures that will minimize the time that freeway traffic is affected by disabled vehicles on the section of the Gulf Freeway under television surveillance.
9. To develop an educational program for motorists on emergency procedures for freeway driving. (Deleted in 1968-69 at the request of the FHWA).
10. To develop functional requirements for a freeway communications system.
11. To develop and test prototypes of communications devices for use at:
    a. Freeway entrance ramps
    b. Freeway through lanes
    c. Arterial streets approaching the freeway.
12. To investigate the application of commercial radio to freeway communications.
13. To investigate the application of closed circuit television (or other transmission systems) in the design, calibration and

evaluation of operational systems of freeway surveillance, communications and control. (Added in 1969-70 at the request of the THD.)

In addition to the research objectives, the research staff performs other functions that are important and necessary in an operational environment:

1. Operating the surveillance and control systems every day and monitoring traffic operations, equipment operations, and computer software. The detection of malfunctions in any of these areas requires immediate corrective measures.
2. Receiving visitors to the project - A demonstration project such as this serves an important role in providing an opportunity for engineers, technicians, administrators, and laymen to view the facilities and to discuss questions of system design, operation and maintenance.
3. Providing assistance to the Texas Highway Department and the City of Houston to improve traffic operations - Problems which come to the attention of the research staff in the course of normal research activities are recorded and transmitted to the appropriate operating agency with any recommendations for possible solutions. Examples are: a proposal to provide outbound control on the Gulf Freeway; a suggestion to reverse the Pierce Street entrance ramp to the outbound Gulf Freeway; a recommendation to extend the ramp metering project to the interchange signals along the Gulf Freeway.

The objectives of the research were directed to the functional requirements of the systems to be developed; however, testing and evaluating operational systems under realistic conditions require some consideration as to the design and operation of the hardware systems. Therefore, the research staff has specified and evaluated hardware systems to accomplish the planned research. Having the research project responsible for the hardware studies may be the best approach to research of this type. If this is true, proposals for other studies should reflect this activity in more definitive terms than those used in the research objectives for this project.

Implementation Statement

This study has produced some implementation projects of results as part of the testing and evaluation phases of the research. This report discusses these as well as other aspects of the implementation process of freeway control and information systems.

Generally, the development of plans and specifications and the exercise of the procurement process followed standard Texas Highway Department procedures. As it happens in so many instances, the projects were completed, but the time requirements were much too long. Also, those installations that require supervision by a technical staff during the operational stages were, and still are being manned by research personnel.

Therefore, it should be the goal of future research studies to continue to define the requirements for the development of facilities and personnel to design, install, operate and maintain these traffic surveillance and control systems.

APPROACH TO RESEARCH

Conducting Research on Operating Systems

The research program of the Texas Transportation Institute concentrates on the practical problems of today. Whenever possible, this research is conducted on real situations with the ultimate goal to implement successful research findings. The Urban Transportation Systems Program of the Institute has been operating under actual field conditions throughout the course of this study. The type of facilities that are present in Houston have been extremely important. These facilities have been made possible through the fine support of the operating agencies, District 12 of the Texas Highway Department, and the City of Houston. (Table 1)

A research study being conducted under actual operating conditions in the field has disadvantages that must also be considered. The first is that the research activities must compete with operational activities for priority of time schedules and funding support. Secondly, there are many tasks performed by the research personnel which do not directly contribute to the accomplishment of the research objectives, but which are necessary for the development and advancement of the research program. Finally, there are restrictions imposed on the research work plan because the studies directly affect the motoring public. The following discussions are presented to explain these situations in more detail with the obvious intent to improve the status of the research program. The remarks presented in this section are not to be taken as criticism because these agencies have provided invaluable assistance

TABLE 1

GULF FREEWAY SURVEILLANCE AND CONTROL FACILITIES

Existing

- 14 Camera Closed Circuit Television Systems
- 50 pair Control and Data Transmission Cable
- Channel Multiplexing System for Data Transmission
- 8 Ramp Metering Systems
- Detector Surveillance System
- 8 Analog Controllers for Ramp Metering System
- IBM 1800 Digital Computer System for Signal Control and Data Analysis
- Datamate Model 16 Mini-Computer for Signal Control and Data Analysis
- Control Center Office Facilities
- Accident Investigation Site System

Proposed for 1972

- 1 Television Camera Microwave System
- 3 Advanced Warning Communications Signs
- 3 Changeable Message Matrix Signs
- 6 Arterial Intersection Signal Control Systems by Digital Computer
- 3 Ramp Closure Gates
- 1 Freeway Lane Closure System

to the Institute in its research program for many years.

Research Versus Operational Time Schedules

The principal problem facing the research program is the proposed time schedule for accomplishing the objectives. There does not appear to be any reason why all of the objectives can not be satisfied, but the time schedule which was proposed in 1968 was not met. The primary reason for the delay is the procurement of equipment and facilities. The persons responsible for the delay represent both the research and the operating agencies. There is no willful intent to delay progress on the research program by anyone, but rather it is the nature of the procurement procedures which require many persons to review and approve plans, specifications, and estimates of new or unique installations and equipment. Also, there are differences of opinion related to the assignment of project priorities of projects by the research agency and the operating agency.

It was known at the beginning of the project that the accomplishment of several of the objectives outlined in the research proposal would require the following:

1. Purchase of new experimental equipment by the Texas Highway Department.
2. Hardware development by the City of Houston, Texas Highway Department and the Texas Transportation Institute.
3. Purchase of equipment by the City of Houston.
4. Construction and installation of new and innovative systems by the City of Houston and the Texas Highway Department.

The representatives of the research agency noted these requirements but did not urge a change in procedures since there appeared to be adequate time allocated: nor did the research agency attempt to improve the priority of the research projects until the second year of the study. Also, the operating agencies did not want to alter or circumvent standard procedures that have been proven successful in their operations.

It has become more obvious that research projects of this type do require special attention if proposed time schedules are to be met, or research project time schedules will have to be adjusted for the possibilities of delays. Special attention by the operating agencies does not have to involve changes in due process, but should include those activities which affect the amount of time required to complete the project.

Work Tasks Outside the Research Proposal

During the transitional stage from research to operations, the research staff must function in many capacities that are not defined in the research proposal. The Texas Highway Department does not have sufficient personnel to assign tasks created by the research program. For example; the responsibility for the development of plans and specifications, the review of bid proposals and the conduct of acceptance tests for some of the equipment purchased by the State for the research study is shared by the Department and the Institute. The time spent on these activities by the research staff can become significant.

The operation of the control systems is a responsibility of the Department, but the time required for this task is shared by the research staff of the Institute.

Finally, the responsibility for the reception and handling of visitors to the control center is shared by the research and operational staffs of the center.

It is understood that many of these tasks will continue even after the assignment of additional operational personnel, because there is a need for the research staff to remain informed of operational conditions and to assist the operating agencies with technical developments and with the briefing of visitors.

Restrictions to the Research Work Plan

Research studies which directly affect the motoring public can not use certain of those techniques which are normally used in the controlled testing conditions of a laboratory because of the following reasons: It is important to obtain and to retain the cooperation of the public; techniques which might confuse and endanger the public must be avoided; and finally, techniques which are found to be successful and beneficial to the public may be continued indefinitely as part of the operational system.

In the field of traffic control, all of these limitations prevail. For example, in ramp control studies the effectiveness of the system can best be determined by comparisons with no control conditions. However, since the control system has been proven beneficial to the public, the option to shut down the control system is no longer available to the research program.

In instances where the traffic conditions on the freeway lanes warrant the use of very low metering rates on entrance ramps, it is not

always possible to achieve this control because of excessive delays to a small number of drivers who use the ramps.

Studies which result in the diversion of traffic from normally developed travel patterns must include adequate public relations activities to advise motorists of the reasons for the study, the options available to them, and the time schedule for termination of the study. Changes in the schedule or the research plan are difficult to make once the study is under way.

Summary

The use of the real world as a research laboratory has its limitations, but the advantages of actual demonstrations of the effectiveness and feasibility of the various traffic control measures are many. The results obtained in this manner can be used to substantiate the findings developed through the more classic forms of research in the laboratory and through computer simulations. The opportunity for administrators and managers to see these systems in operation should improve the implementation of similar projects.

RESULTS OF THE STUDY

Status of the Objectives

A brief review of the status of the twelve objectives is presented below. The results of the three years of work related to the objectives will be discussed in the next section entitled Statement of Accomplishments.

Objective 1 - Automatic Freeway Control System. This objective has been satisfied in its basic interpretation, but the scope has been expanded to include the study of mini-computer applications, automatic ramp closures, and traffic control of frontage road traffic signals.

A computer program has been written for the IBM 1800 computer which controls the eight ramp signals on a traffic-actuated, traffic-responsive basis for ramp queues, ramp demands, merge blockage, freeway speeds, traffic flow, lane occupancy, and measured gaps in the merge lane. Computer programs are available for evaluation of traffic operations, automatic initiation and termination of the control program, and equipment calibration.

A mini-computer has been purchased from Datamate Corporation of Big Spring, Texas. The programs for controlling the ramp metering system have been written but have not been field tested. The evaluation programs have not been completed.

The study of digital computer control of a small network of arterial street and frontage road traffic signals is under way. The design of the surveillance and control system to operate six (6) signal controllers

with the IBM 1800 has been completed. The installation of the detectors and controller interface will be completed in 1971. A control program has been written, but field tests have not been conducted. A display for the detectors and traffic signal indications has been constructed for tests and confirmation of the control and evaluation programs. Evaluation of the operation should be completed in 1972.

A study of the effects of entrance ramp closure on freeway and frontage road operations was conducted. More studies are proposed to evaluate techniques of closure, as well as traffic operations during closure, so that the control can be automatic.

Objective 2 - Incident Detection. This objective has been partially satisfied.

Twenty-seven loop detectors were installed on the freeway lanes to provide additional speed, flow, and lane occupancy measurement. A computer program has been written for the IBM 1800 computer that senses the change in traffic conditions upstream and downstream of three overpasses on the Gulf Freeway. The program will be used to activate the Pilot Driver Warning System to be installed at these three overpasses in 1972. Furthermore, testing to evaluate and validate the computer program will be conducted for one year following the installation of the signs.

Objective 3 - Driver Communication Systems. This objective has been partially satisfied.

A questionnaire survey was conducted with 500 Texas motorists to determine the requirements for motorist information systems. The results

of this survey have been applied to succeeding studies of prototype design.

A pilot installation of a freeway warning system has been designed and will be installed in 1972. The design requirements for the signs, signals, and controls were determined from the questionnaire survey and comparative evaluations of prototype installations at the Texas A&M Research Annex.

Plans and specifications for changeable message signs for use on the freeway lanes, frontage roads, and entrance ramps have been prepared. The installation and evaluation of three signs will be completed in 1972.

Studies on the effectiveness of radio communication of traffic conditions were conducted. Proposals for the improvement of existing systems and for new configurations of radio transmission have been drafted and will be submitted for consideration in 1972.

Further testing to evaluate the effectiveness of the driver communications systems will be conducted for one year following the completion of the installations.

Objective 4 - On-Freeway Control. This objective has been partially satisfied.

A two-week study of on-freeway control in the form of lane closure in a freeway-to-freeway interchange was conducted. Additional evaluations are proposed as part of the new driver communications project to evaluate techniques of lane closure, driver comprehension and acceptance, and traffic operations and safety.

Objective 5 - Commercial Bus Operation. This objective has been satisfied.

A proposal was prepared and submitted to the Texas Highway Department for a plan to provide a bypass for buses using S.H. 35 entrance ramp during peak periods. This plan would save five minutes travel time per bus, but the number of buses was too small to be considered at this time. No future work is scheduled for this objective as part of the freeway surveillance, communications, and control project on the Gulf Freeway.

Objective 6 - Wrong-Way Operation. This objective has been satisfied.

A literature search was conducted on the subject of wrong-way operation to determine the state-of-the-art in special design and traffic operation systems used to combat this problem.

A survey was conducted of traffic engineers, as well as state and local enforcement officials, to determine the severity of the problem in Texas and the course of action being taken to eliminate or to reduce incidents of wrong-way driving.

Reports of these studies have been prepared. No further work on this subject is scheduled as part of the freeway surveillance, communications, and control project on the Gulf Freeway.

Objective 7 - Technical Assistance to THD for Preparation of Plans and Specifications of Freeway Control Systems. This objective has been satisfied.

The staff of the Houston Surveillance and Control Project has met with representatives of five districts of the Texas Highway Department

to discuss the design requirements of ramp metering systems. Since the beginning of this project and the establishment of Objective 7, HPR Study 501 entitled, "Freeway Control Demonstration" has been initiated and has the responsibility to provide technical assistance for the design and operation of demonstration metering projects. Therefore, no further action will be taken by the Houston Project.

Objective 8 - Disabled Vehicle Studies. This objective has been partially satisfied.

A proposal for the installation of accident reporting sites along the Gulf Freeway was prepared by the research staff. The Texas Highway Department and the City of Houston have installed the sites, and the Houston Police Department has been directed to use the sites as much as possible. An evaluation study on the design and usage of the sites is underway. One year of experience will be the basis of the evaluation.

Objective 10 - Functional Requirements for Freeway Communications System. This objective has been satisfied.

The analysis of the questionnaire survey revealed some of the basic needs of the motorists for real-time information. The subjective evaluations of the prototypes at the Research Annex provided some detail for design. Finally, conferences with sign manufacturers provided information on equipment and techniques available for communication by changeable message signs. From these data a report on driver communications requirements for the Gulf Freeway Corridor has been prepared. Continual updating of requirements for the communications systems will be necessary

as data from evaluation phases become available.

Objective 11 - Development and Testing of Prototype Devices. This objective has been partially satisfied.

Plans and specifications for three types of changeable message signs were prepared. The Texas Highway Department recommended that the matrix type signs be used in the field tests on the Gulf Freeway. Three signs will be installed in 1972 for operational tests and evaluation.

Objective 12 - Application of Commercial Radio to Driver Communications. This objective has been satisfied.

Studies were conducted on the current practices used by three Houston radio stations to provide traffic information. A report was prepared on the timeliness, reliability, and accuracy of the information broadcasted by the radio stations. Also, the use of aerial surveillance in broadcasting traffic reports was analyzed with the same type of information.

A proposal for improving the use of both commercial and inductive radio broadcasts will be prepared as a result of these studies.

Objective 13 - Traffic Surveillance by Closed Circuit Television (CCTV). This objective has been partially satisfied.

A report on the application of CCTV for traffic surveillance in Texas has been prepared. Four different designs are presented with discussions of operation and maintenance experience. A single camera system utilizing a microwave transmission system has been purchased by the research project for application to the study of changeable message signs and the arterial street signal control.

Statement and Discussion of Accomplishments

A review of the accomplishments of the research as they relate to the twelve objectives is presented in this section. A brief discussion of the significance of the work is included.

Ramp Control

The development and modification of traffic control programs is never completed. There are always variations of control strategies and levels of control parameters to be tested in an attempt to develop a better control program which is more responsive and more efficient. The Houston Project has developed a freeway surveillance and control program for the IBM 1800 computer which, in its basic structure, has operated satisfactorily for several months. The program incorporates the following features:

1. Traffic-actuated operation based on the sensing of ramp queue lengths, ramp traffic demand, and blockage of the merge area.
2. Traffic responsive operation which utilizes: the measurement of traffic flow, speed and lane occupancy for the selection of metering rates; the detection and projection of gaps in the merging lane on the freeway for the determination of ramp vehicle release times.
3. System evaluation of traffic operations, based on the closed system input-output analysis of traffic flow.
4. Ramp operation evaluation, based on merge flow, lane occupancy, acceptance of gaps, and the compliance to

traffic signal operations.

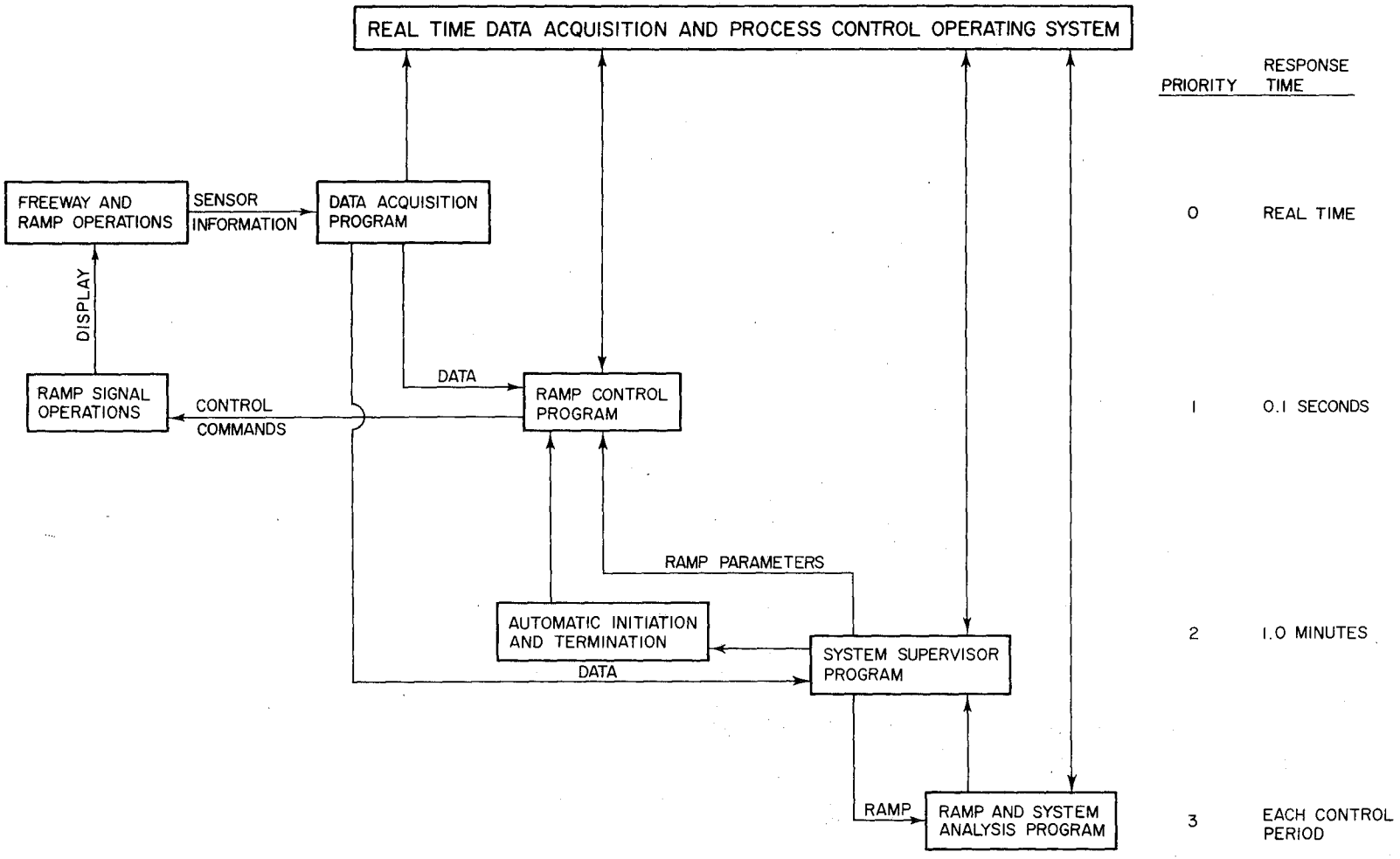
5. Automatic initiation and termination of ramp control, based on conditions of traffic flow, speed, and lane occupancy at critical freeway locations.

A symbolic representation of the computer subroutines to accomplish these operations is shown in Figure 1. There are other computer routines which monitor and calibrate the input data, adjust speed detectors by software tuning, and delete malfunctioning detectors which provide flow and lane occupancy data for control decisions.

The programs are written in assembler language and require 24K storage, an MPX System, and a complement of computer peripheral equipment.

A mini-computer, Model 16, has been purchased from Datamate Corporation by the Texas Highway Department to replace the IBM 1800 as the ramp metering system controller. The 1800 control programs have been converted for use with the mini-computer, but different evaluation programs will be written to compensate for the limited capability of the I/O device which is an ASR-33 Teletype. Evaluation of the effectiveness of the small computer as the control unit will be conducted in subsequent research projects.

A proposal to extend the ramp control system to the outbound Gulf Freeway has been submitted to the Texas Highway Department for review. The mini-computer is designed to accommodate the surveillance and control systems for both directions.



FLOW DIAGRAM OF RAMP CONTROL PROGRAMS

FIGURE 1

Discussion - The conclusions drawn from three years of developing and operating ramp control programs on the Gulf Freeway substantiate the results of other studies across the country; that is, the application of control to urban freeways is a feasible and cost effective solution to improving operational efficiency during periods of heavy traffic demand. The development by this project of digital computer programs to initiate and terminate control, to monitor the system for equipment failures, and to calibrate detector inputs will reduce the dependency of future systems on human operators. Finally, the installation and operation of the mini-computer as the control unit enhances the cost effectiveness relationships of ramp control systems.

Details on the computer programs are contained in Research Report 139-12 entitled "Documentation of Computer Control of the Ramp Metering System on the Gulf Freeway."

Digital Computer Control of Wayside - Telephone Network

A proposal to control traffic signals at two diamond intersections and two arterial street intersections was developed in 1969. The purpose of the study was to coordinate the control strategies of the ramp control system with the arterial street systems. Then, when freeway conditions warranted the diversion of traffic to the frontage roads, adjustment in the frontage road capacities at the interchanges would be made in a way to avoid significant restriction to other traffic movements on the cross streets.

The project was significant in that the City of Houston, the Texas Highway Department (THD), and the Texas Transportation Institute (TTI) each had a part in the installation. The progress has been slow due to delays by the City of Houston to receive shipment of detectors.

The THD has installed the time division multiplexing equipment to expand the data transmission capability of the central control cable. The TTI has installed the computer interface and the display board. The system will be completed when the City of Houston installs the controller interface and 33 detectors.

Computer programs have been written to drive the signal controllers. Tests were conducted to determine the reliability of the controller interface, the data transmission system, and the computer program. The final tests simulated five days of continuous control without an error in the hardware or software.

Computer programs have been written to adjust the signal cycle and phase lengths according to traffic volumes and lane occupancies on the approaches to the intersections. Special subroutines that introduce

false data to the frontage road approaches will be used when preferential treatment for freeway diversions is requested. The programs have not been tested with the network display.

Operation of the network of signals will begin 30 days after the completion of the system by the City of Houston, which is expected to be in the fall of 1971.

Discussion - Ramp control of freeways has developed from the experimental to the operational stages. The same can be said of the control of intersection signals by digital computer because the San Jose, Wichita Falls, Austin, and other computer control systems have been in operation for several years. However, the development of the control logic and strategy for all traffic signal networks is still in the embryonic stages. The Dallas and Houston Projects are the only research studies under way at this time which take into consideration the integration of the freeway control systems with the adjacent arterial street control system. This work is of considerable importance to states which include parallel frontage roads in the design of urban freeways. The development of driver information systems and ramp closure controls dictates a greater use of these roadways for movement of traffic. The changes in traffic patterns will be predictable, and the traffic signals supervised by the control computer can be adjusted accordingly to reduce delay at the intersections of cross streets.

Telephone Road Entrance Ramp Closure

There are times when entrance ramps to freeways should be closed to traffic: (1) hazardous roadway conditions; (2) traffic congestion on freeway lanes; (3) maintenance or construction activities in the area; (4) policy decisions to maintain a high level of service on the freeway. A two-week study was conducted to determine the effects on the Gulf Freeway and on ramp traffic when the inbound Telephone entrance ramp was closed for one hour during peak flow. Even though the timing of the study was not the best because it coincided with the start of Daylight Saving Time, the results were favorable enough to warrant continuation of the investigations of procedures and equipment to automatically close entrance ramps under heavy traffic conditions.

The results of the study indicated the following:

1. The conditions on the freeway did not change significantly. Speeds at some locations increased; at other locations, speeds decreased, and traffic volumes decreased slightly.
2. Normal shock wave action due to downstream congestion was not observed during the time of closure. This is a very significant finding.
3. Delay to the diverted motorist was very small, and no complaints were received in the Gulf Freeway Control Center.

The conclusion is that ramp closures under traffic are feasible from the standpoint of acceptance by the diverted traffic and from the beneficial effects on freeway traffic operations. Proposals will be prepared for the study of closures on other ramps and the study of techniques for

accomplishing the closures automatically under traffic. The study is discussed in Research Report 139-9 entitled "The Effects of Entrance Ramp Closure on Freeway Operation During Morning Peak Period."

Discussion - The closure of entrance ramps to improve traffic operations on the main lanes of the freeway has been studied for many years. The benefits to the operation of a freeway will vary with location, time, and length of closures, but there is no question that it will improve traffic flow on the freeway. The effects of the diversion to alternate routes will depend on existing traffic conditions and available capacity on the street system.

The studies which are under way on the Gulf Freeway are designed to evaluate the technique and effectiveness of closing ramps at unspecified times and for varying lengths of time based on existing traffic conditions. The parameters used to initiate and terminate the closure control will be measured from alternate routes as well as from freeway main lanes.

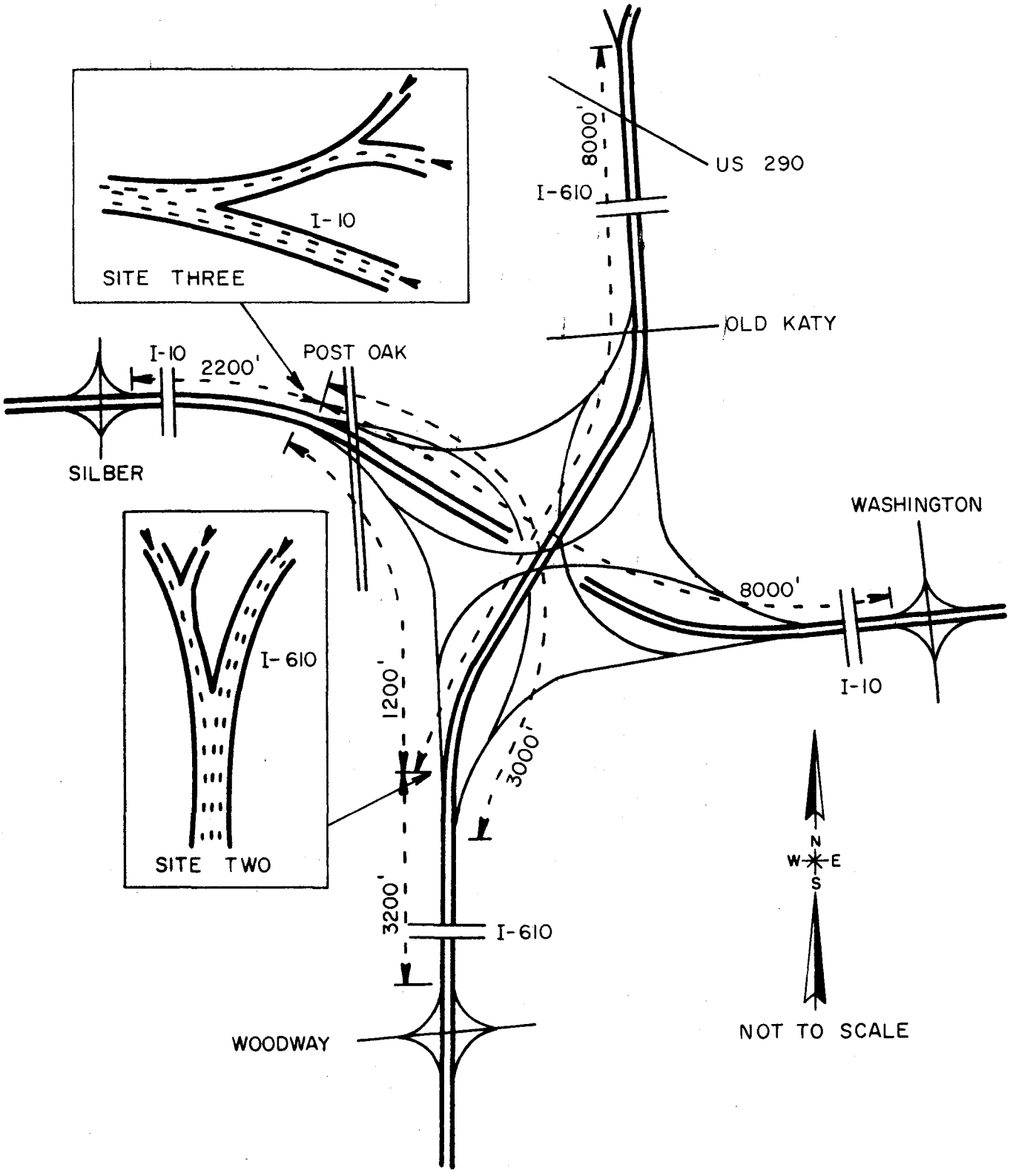
The technique of closure most often suggested is a ramp gate of a design similar to railroad crossings and entrances to automated parking lots. Advanced signals and signs and a vehicle detection system are used to warn motorists of impending closure and, therefore, to reduce the element of surprise. Another favorable characteristic of the ramp gate is that special vehicles, such as buses, police cars, fire trucks, etc., can be equipped to open the gate either by controls in the vehicle or by special vehicle detectors on the ramps.

On-Freeway Control

There are times when the safety and operational efficiency of a roadway system can be improved by the controlled reduction of capacity using lane closure. Certainly, there are times when there are no alternatives to the closure of a freeway lane, such as construction and maintenance activities, roadway failure, environmental factors, vehicle accidents, and stalls. But the lane closures discussed in these studies are those designed to respond to normal traffic demands and roadway capacities. The reduction of capacity at one location causes a reduction of the traffic flow at downstream locations. If the downstream location is a bottleneck section, control of the traffic flow may improve the travel characteristics for the total roadway system.

An example of this concept is the major interchanges of two freeways. The connections of two roadways usually have more lanes entering the interchange area than leaving the interchange; therefore, one or more lane drops must take place on the roadway connection. Most of the time, traffic demand on these roadway connections is low, and the reduction of capacity caused by the lane drop has no major effect on traffic flow. However, during peak periods, traffic demands increase to the degree that queues form on the connecting roadways. Frequently, these queues become long enough to interfere with traffic flow on other roadways in the interchange. A reduction in the number of lanes entering the interchange can improve the merging characteristics and can shift capacity from one to the other connecting roadway (Figure 2).

A study on I 610 and I 10 interchange in Houston demonstrated the



Site Selection Area

Figure 2

effectiveness of control by closure of one lane by traffic cones during the peak periods for two weeks. This study indicated the need for effective advanced information signs since the length of time the lane should be closed will vary from day to day as traffic conditions change. There was good acceptance by the public for this type of control, but the technique of manually closing the lane with traffic cones is not acceptable for long-range operation. Lane closed signs, signals, and information signs will be tested in the future for their effectiveness as a voluntary lane closure method. However, it is the opinion of the research staff that these devices will have to be supplemented with some other form of deterrent, such as police enforcement and/or semi-barrier devices. This study is discussed in Research Report 139-10 entitled "Evaluation of On-Freeway Traffic Control at an Interchange."

Discussion - It is an unusual situation when the closure of a moving lane during peak periods can improve traffic operations, but the extreme traffic pressures which major freeway interchanges are subjected to on the outer freeway loops of the urban areas illustrate the problem. The traffic patterns through the interchange have changed so drastically from the design values that only major geometric design modifications can accommodate the existing traffic. Often, this requires a very costly bridge structure. The funds for these types of betterment projects may not be available for several years and, by that time, the traffic patterns may have shifted again to make the geometric design change less critical.

Traffic control systems, although not as effective as an additional

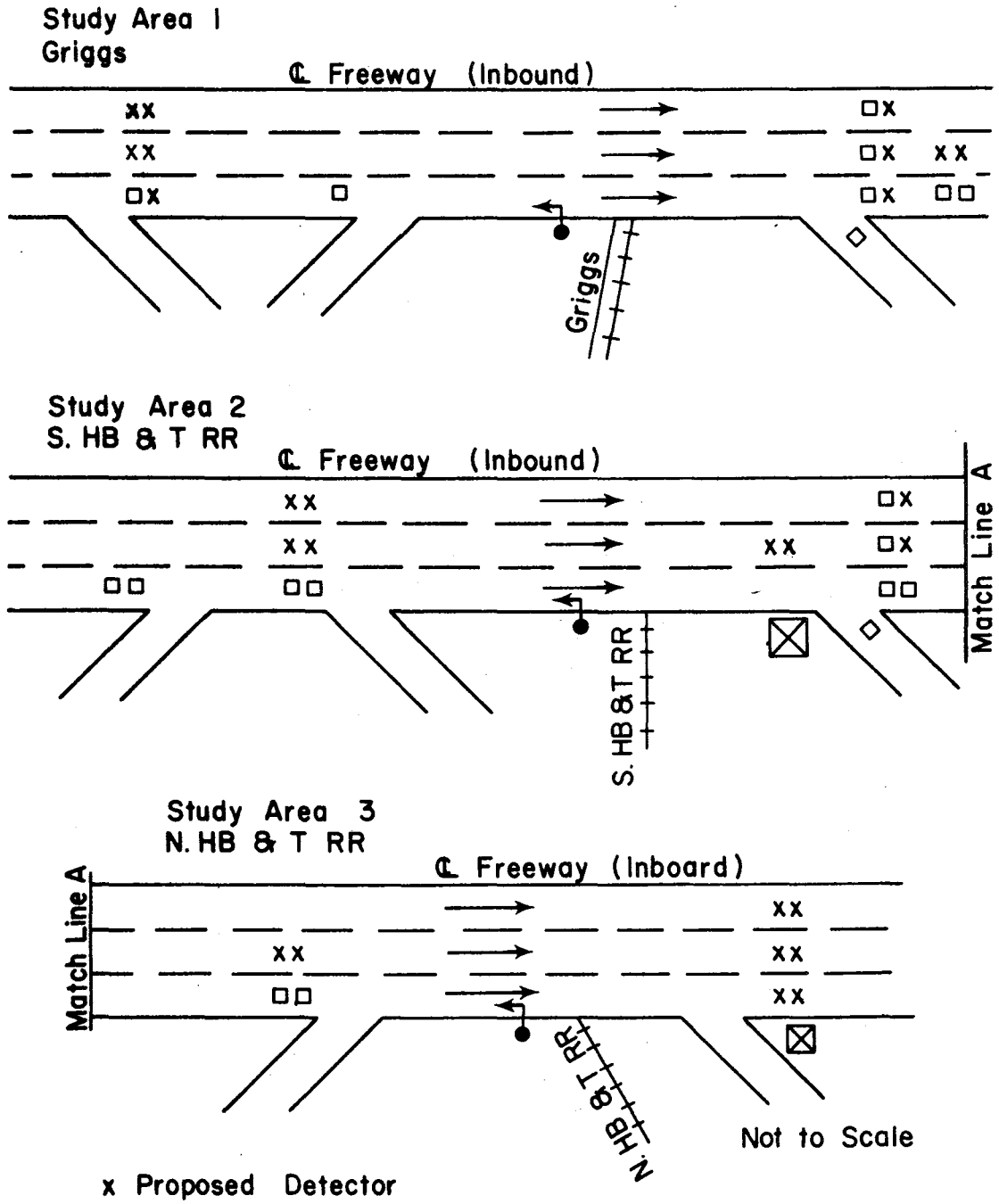
lane of through capacity, have the advantages of: less expense, greater flexibility, and adequate effectiveness. A partial solution is better than no solution at all.

Incident Detection

Twenty-seven detectors were added to the surveillance system on the Gulf Freeway to provide more data on traffic conditions upstream and downstream of three overpasses as shown in Figure 3. Extensive studies have been under way for over a year to measure and calculate many different traffic parameters with these detectors and the IBM 1800 computer. These data were then compared with the results of visual surveillance measurements taken from video tapes of the same traffic. The studies provided information for the development of a computer program which will activate warning devices placed along the roadway. The program must be designed to activate the warning devices quickly, but not so sensitive as to produce false calls. Different time bases for data analysis were examined for various parameters. Studies of false call errors and errors of ommission were made from video tape data.

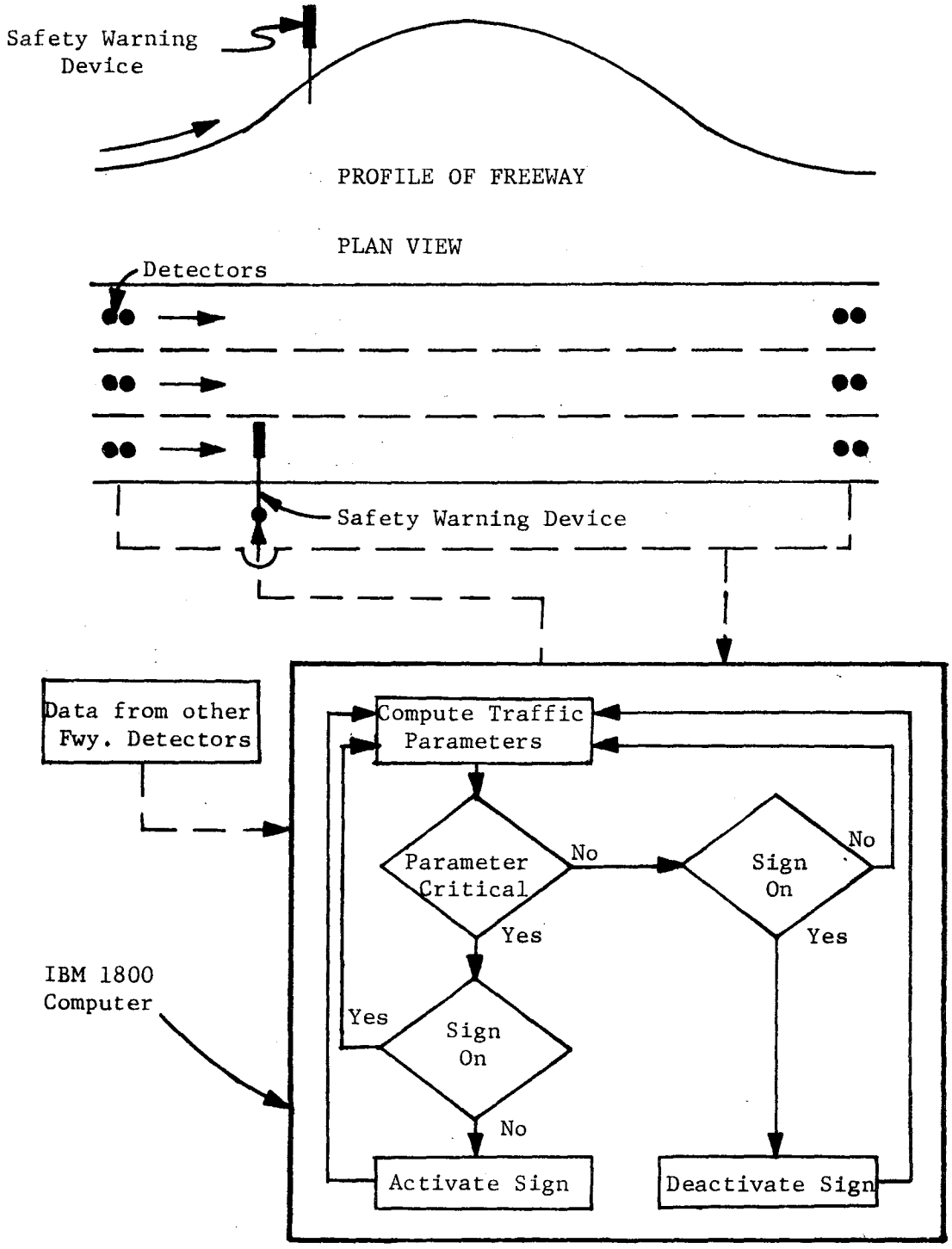
A computer program has been written and will be tested with a simulated warning device located in the television control room. The television operators note when the simulated warning device is actuated and record the cause of disturbance and the degree of sensitivity. The program uses a 30-second time base and measures the change in energy of a traffic stream. The differential energy measurements upstream and downstream of the freeway overpass determine when the warning device should be activated and deactivated (Figure 4). Preliminary results show a performance level of greater than 95 percent of the time, with a response time of less than 30 seconds.

More data will be collected to calibrate and verify the program.



Detector Locations

Figure 3



Control Schematic

Figure 4

Some modification of the program or the detection system will be necessary if the system is to be used for Level of Service A as defined in the Capacity Manual.

Discussion - Incident detection has the potential of having the highest cost effectiveness relationship of all of the surveillance and control systems. The prevention of an incident can save hundreds of vehicle hours for each event as well as the cost of the accident. Early notification of incident location can reduce the effect on freeway operations which, in turn, reduces the number of incidents. The costs will not be excessive since the elements of the system are shared by ramp control and other operating systems. The displays which may be attached to the output of the incident detection system are simple, two-position devices to signify the existence of congestion.

Incident detection is probably the most pressing problem in freeway operation. The use of electronic detection as the primary surveillance system appears to be the most promising; however, there are several technical and legal questions that have not been resolved which relate to the design and application of the surveillance system. For example, to be effective, the surveillance system must have many vehicle detectors transmitting data to a central office. Experience of similar systems has shown that a large amount of maintenance will be required to keep the system operating properly.

The installation of an incident detection system implies that there are responsive systems. The form which this responsive, or service system, takes will vary from no action to immediate action. The most

common response is the dispatch of a patrol unit to investigate an area in which there is evidence that an incident has occurred. The patrol may be a special purpose vehicle, such as a freeway patrol vehicle, or a traffic surveillance helicopter; or, it may be a general purpose vehicle such as a police patrol car.

The next reponse may be to notify motorists in the area of the possibility of traffic congestion. This is being done through radio broadcasts but usually only after the incident has been located and identified with greater detail. Another communication area that is being developed would use special purpose signs along the freeway to alert the traffic in the area. This approach is conceptionally more appealing to the transportation engineer since it communicates quickly with those persons immediately affected by the event.

When these devices are employed, there is a certain amount of responsibility that must be assumed in its operation. Those devices project a more positive image than do the remote and infrequent broadcasts. Also, an inactive sign with no messages shown implies no problems ahead. Therefore, the question of liability for false information relative to the legal and moral obligations of the agency operating the devices is of considerable importance.

The accuracy and reliability of devices which involve the motorist is important from several points of view: (1) legal responsibility; (2) safety; (3) acceptance and adherance; and (4) respect. These areas will have to be explored more fully before extensive systems of signs will be employed, but the studies should and will be conducted under controlled field conditions.

Accident Investigation Sites

In June, 1971, a system of accident investigation sites on the Gulf Freeway was opened by the Texas Highway Department for use by the Houston Police Department. The system consists of six sites constructed on the freeway right-of-way and ten sites designated and signed on the city street system adjacent to the freeway.

The Police Department was given forms to be filled out by the investigating officers to provide data on usage rates, as well as design and operational deficiencies of the sites. Preliminary results from these data indicated a lower usage rate than anticipated, but the reasons for the low usage rate could not be determined from the information supplied on the forms.

Therefore, a conference was held with the Police Department to provide the opportunity to revise the forms and to renew the interest of the project with those persons responsible for accident investigations. Data will be collected for one year, and an analysis of the benefits will be prepared for publication. Results to date indicate that more than 50 per cent of the accidents reported on the Gulf Freeway are being moved to the accident investigation sites or other off-freeway sites by the police.

Discussion - It has long been recognized that any distraction along a roadway creates an unsafe and inefficient condition for traffic operations. Any procedure which eliminates or reduces those events which distract the attention of the motorists is beneficial. Also, a high percentage of fatalities on the freeways involves pedestrians outside

their disabled vehicles. Consequently, the establishment and use of accident investigation sites out of view of the freeway main lanes should be encouraged by all persons and agencies responsible for urban traffic safety and operation.

Therefore, it is surprising to see the apparent disinterest in this endeavor by some representatives of law enforcement agencies, insurance companies, highway and traffic engineering departments, as well as the motoring public. It appears that strong leadership must come from the top administrative offices responsible for the safe operation of the freeways to obtain the degree of cooperation and compliance which these safety procedures warrant. The cost for establishing these sites is minimal; the cost for operating and using the sites is negligible; the benefits from the use of the sites are very great. An analysis of the time required to remove accidents was presented in Research Report 139-1 entitled, "Accident Reporting and Clearance Procedures on the Gulf Freeway." Cost benefit analyses conducted on the effect of total travel during the times these accidents occur will be presented in the report which includes a study of the accident investigation sites.

Driver Information Systems

The development of a real-time driver information system is a difficult and complex task. There must be an adequate surveillance system to detect significant events; a comprehensive system of displays or audio transmissions to convey the information to the motorist; and, finally, motorists who can comprehend the messages and who will take the appropriate action. Work was initiated in Houston on the development of an information system for freeways since the surveillance system of the Gulf Freeway is sufficient to detect most incidents on the inbound lanes.

A comprehensive questionnaire study was made of motorists in Houston and Dallas. The survey indicated that motorists wanted a real-time information system. Radio announcements and changeable message signs were the preferred media for receiving the information before entering the freeway, and information most requested was the location, length, and severity of congestion.

The questionnaire survey also provided information on the design of the sign displays. The motorists preferred the simple designs which contained words and color indications to describe traffic conditions, rather than diagrams with symbols. There was no consensus on the word descriptors to be used for the various conditions. This is true of traffic engineers as well as laymen. For example, should the peak period condition that exists every work day be described as "Normal" or "Congestion," if, in fact, it is normal for the roadway to be congested? These problems will have to be worked out as experience and usage of the system grow.

Discussion - The key factors in the success of driver information systems are validity and reliability. The other technical factors of prototype design, message composition, and driver comprehension are also important and must be resolved, however, unless the motorist believes in the system, all else is insignificant. Therefore, before a driver information system is installed, all conditions of operation should be reviewed carefully, and a decision matrix should be developed. As in all of the urban freeway surveillance, communications and control projects, the comprehensiveness of the detection and data transmission systems is the vital design element.

Two research reports were prepared on the investigations of the need for a driver information system: Research Report 139-2, entitled "State-of-the-Art Related to Real-Time Traffic Information for Urban Freeways," and Research Report 139-4, entitled "Real-Time Information Needs for Urban Freeway Drivers."

Changeable Message Signs

To validate the findings of driver attitudes and opinions taken from the questionnaire survey, the development of prototype devices was initiated by the research project. Two problem areas were defined: first, the use of informational devices to warn drivers of hazardous conditions ahead; and second, the application of informational devices to describe these conditions for motorists.

The warning system consists of three fixed message signs with flashing amber lights which are activated by the digital computer program. The computer program automatically detects incidents which cause traffic congestion. Tests at the Texas A&M Research Annex were conducted to determine sign size, letter design, and flasher operational specifications. The sign will be 12 feet by 6 feet with 12-inch black lettering, with a yellow non-reflectorized background. These signs will be placed in operation in early 1972 on three overpasses on the Gulf Freeway.

The second problem area was the design and operation of signs to convey several different messages to the motorists. After conferences with several sign manufacturers, plans and specifications were developed for three types of signs: matrix, using incandescent lights to compose the characters; rotating drum, using two or more lines of copy attached to sign panels which can rotate two or more positions to formulate different messages; and a scroll sign which operates as a window shade with several messages written in total on sections of the canvas. The rotating drum and scroll signs are new to the industry and, although tested under extreme environmental conditions by the manufacturers, have

had little field experience to date. The Texas Highway Department decided that studies in driver comprehension and acceptance of changeable message signs would best be accomplished with the matrix signs. Therefore, these matrix signs have been ordered for installation and testing on the Gulf Freeway. The operation of these signs should begin in the summer of 1972.

Discussion - Because of the detection system required for a freeway ramp control system, the freeway is the best location to provide driver information signs. The implementation of an on-off type display to alert freeway motorists of impending hazardous operating conditions appears to be a simple system, but the surveillance equipment and computer software is complex because of the conflicting requirements of a short response time and a high degree of accuracy. This type display also raises questions concerning the legal implications of providing false information. However, it is felt that the public interest will be better served by a device which works well for greater than 90 percent of the time, than by the absence of a warning system.

The effectiveness of the message signs which advise motorists of traffic and roadway conditions and of alternate routes of travel will not easily be measured. Observations over long periods of time under many different circumstances will have to be made. Again, it seems that some additional information would be better than no information, but the determination of the benefits, both positive and negative, will be difficult to define. However, the limited studies conducted to date indicate a desire and a need for this information by the motorists, and it remains to be determined in what manner this information should be provided.

Radio Communications

In the questionnaire survey, the use of commercial radio for the reporting of traffic conditions and incidents was rated very high. Therefore, a study was undertaken to determine the quality and quantity of information being given by radio broadcasts to the motorists in the Houston area. Three radio stations which were broadcasting traffic reports were monitored. The accuracy of the information was varified by video surveillance of incidents on the Gulf Freeway.

The results were not very encouraging. Only 48 percent of the accidents were reported by all the stations combined, and only 3 percent of the stalled vehicle incidents was reported. The average time between the incident occurrence and the radio report was approximately 25 minutes. Finally, there were no follow-up reports to indicate the clearance of the incident.

A second study was made when one of the radio stations began traffic surveillance and traffic reporting from a light plane. The station's reporting improved considerably, the percentage of accidents and stalls reported by this station increased from 35 percent and 5 percent to 80 percent and 70 percent, respectively. Eighty percent of the incidents were reported at least twice. The reports were given more frequently and included meaningful information to motorists as to the length of congestion, as well as possible alternate routes.

Discussion - Radio has the distinct advantages of being available to almost all motorists at a low cost. Often the cost of air time is donated in the interest of public service. These same advantages can be viewed

as disadvantages as well. A report of an accident in the southwest section of the city should not affect the traffic in all other sections. The lack of control of the time, frequency, and content of the reports presented by the stations is an important factor also.

Some of these disadvantages can be eliminated if an official agency could, either by voluntary agreement or by contract negotiations, exert more control over the reports. Purchasing air time that could be scheduled as the needs dictate could solve the response and frequency problems of reporting.

It has also been suggested that a commercial frequency be assigned for public service uses only and that traffic reports be issued on a regular basis during peak hours, as well as on an "as-need" basis throughout the day. This type of programming becomes boring very quickly and does not hold the attention of the motorist for long. The California Division of Highways has suggested that changeable message signs on the roadway could be used to notify motorists that a bulletin which is of particular importance to that section is being broadcasted on that frequency.

The use of induction radio or very low-powered radio broadcasts to limit the transmission to a small area is being tested in special situations, such as airports and other large parking areas. This type of broadcast, which has many other applications throughout the street network, should be given careful study and consideration in the design of future motorist information systems.

Two research reports were prepared on the investigation of the need for and the application of commercial radio to motorist information

systems: Research Report 139-3 entitled, "Application of Commercial Radio to Freeway Communications - A Study of Driver Attitudes," and Research Report 139-8 "A Study of Freeway Traffic Information Reported via Commercial Radio."

Documentation of Research

During the three years of the study, there have been twelve interim reports and one final report. Five papers have been prepared for presentation at the Annual Highway Research Board Meetings in Washington, D.C.

In addition to the three annual Project proposals, several special study proposals were prepared for submission to District 12, Texas Highway Department approval and implementation. All of these documents are listed in Appendix A.

Plans and specifications have been prepared for the purchase of the mini-computer, changeable message signs, microwave television, pilot freeway warning system, and the construction of the accident investigation sites.

Many of the activities begun during this study will be reported at the conclusion of the evaluation phase as part of a new HPR study entitled "Development of Urban Traffic Management and Control Systems."

CONCLUSION

Discussion of Results

Specific discussions on the status of the research objectives and the accomplishments of the studies have been presented in the preceding chapters of this report. More detail descriptions and discussions of the studies are available in the research reports listed in Appendix A. The following statements are made in reference to the total research program of traffic surveillance and control.

Technical Advances - The results of this project are very positive and the accomplishments very significant, in that these systems are cost effective, as well as operationally effective. The delays encountered in the research program which prevented completion of all studies are regretable, but they represent the real-world conditions and thus serve to demonstrate the problems which must be solved. This program has illustrated that there is equipment available in "off the shelf design" that can be applied to our existing traffic problems. There are control techniques that should be tested with an operational system. These are communication concepts which must be evaluated by and with the urban motorists.

There are many more questions than answers, but there is sufficient reason to begin to assemble the resources necessary to find the answers. All new projects will be susceptible to hindsight reviews and critique, but, unlike many other traffic facilities, the surveillance and control equipment is relatively portable and salvageable. Computer systems can

be updated or exchanged. Signal hardware can be removed. Finally, the control strategy in the form of computer programs can and will be continually modified to meet changing traffic requirements and advancement in control theory.

Acceptance of Research Results by Operating Agencies - The acceptance and adoption of a totally new concept in traffic control is difficult to achieve. For example, there is still a strong feeling by many highway engineers that improvements in traffic operations and safety on freeways can best be made through changes in geometric design. This report does not argue the point that significant improvements can be accomplished by widening freeway roadways, redesigning and relocating entrance and exit ramps. But these solutions often require several years to implement, during which time traffic conditions may have changed sufficiently to warrant different design modifications. Also, the competition for construction funds is heavily biased by a desire to complete new roadways, rather than to redesign old ones.

The application of control where none existed before is sometimes hard to accept. The ramp metering systems invariably meet with some public resistance initially, but acceptance comes with time; and no operational system has been terminated because of public criticism. The application of computer control of arterial signals has yet to receive widespread acceptance, primarily because it requires money to provide a signal system which overlays an existing signal system. An effective public relations program is needed to provide the facts on costs and benefits to the public officials as well as to the public in general.

Finally, the motorist information systems appear to many to be a luxury item. The benefits for these systems must be well documented before large-scale funding will be available. Also, a comprehensive surveillance system must be in operation before effective control of informational devices can be achieved.

The progress in the study, development, and implementation of these large and complex systems of surveillance, communications, and control is much slower than anticipated at the beginning of this project in 1968. This is true in other parts of the State of Texas and throughout the nation. The apparent reasons for the slowness to adopt these new concepts are many: money, personnel, priority of other projects, to name only a few. The principal cause for the delays to achieve implementation of proven systems is the lack of an organizational structure with definitive goals or responsibilities in the field of Urban Traffic Operations. It is hoped that the State Highway Organizations across the country will provide the leadership necessary to develop these organizations.

Recommendations for Continuation of the Research Program

At this time there is no other research project in the country that is as suitably equipped and supported by their highway department as the Gulf Freeway Surveillance and Control Project in Houston. The Texas Highway Department has again demonstrated its support of the research program by approving the first of a three-year study designed to carry on the work in freeway control and driver communications. The first phase will complete the work outlined in the objectives of this report. The second phase will pursue implementation projects of the successful results. Finally, the research program will serve as a sounding board to assist in the planning processes for the development and structuring of an organization which, with the help of the Texas Highway Department, will have the primary responsibility for traffic surveillance, communications, and control systems.

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1. McCasland, William R. Freeway Ramp Control System. Texas Transportation Institute, Research Report 24-26, 1969.

2. Moskowitz, Karl and Roy Jorgensen and Associates. Analysis and Projection of Research on Traffic Surveillance, Communications and Control. National Cooperative Highway Research Program Report 84, 1970.

3. Hillier, J. A. Glasgow's Experiment in Area Traffic Control. The Engineer, May 1967.

4. San Jose Traffic Control Project Final Report, IBM Document No. 320-0959-0.

5. System Analysis Methodology in Urban Traffic Control Systems - Project Final Report, TRW Document No. 11644-H014-R0-00, June 30, 1969.

APPENDIX A

RESEARCH REPORTS

Research Report 139-1 "Accident Reporting and Clearance Procedures on the Gulf Freeway," by Merrell E. Goolsby.

Research Report 139-2 "State of the Art Related to Real-Time Traffic Information for Urban Freeways," by Conrad L. Dudek.

Research Report 139-3 "Application of Commercial Radio to Freeway Communications - A Study of Driver Attitudes," by Conrad L. Dudek and Dannie Cummings.

Research Report 139-4 "Real-Time Information Needs for Urban Freeway Drivers," by Conrad L. Dudek and Hal B. Jones.

Research Report 139-5 "A Systems Analysis for a Real-Time Freeway Traffic Information System for the Inbound Gulf Freeway Corridor," by Carroll J. Messer, Conrad L. Dudek, and Roy C. Loutzenheiser.

Research Report 139-6 "A Qualitative Analysis of Wrong-Way Driving in Texas," by Carroll J. Messer, John D. Friebele, and Conrad L. Dudek.

Research Report 139-7 "State-of-the-Art of Wrong-Way Driving on Freeways and Expressways," by John D. Friebele, Carroll J. Messer, and Conrad L. Dudek

Research Report 139-8 "A Study of Freeway Traffic Information Reported via Commercial Radio," by Conrad L. Dudek, John D. Friebele, and Roy C. Loutzenheiser.

Research Report 139-9 "The Effects of Entrance Ramp Closure on Freeway Operation During Morning Peak Period," by Roy C. Loutzenheiser.

Research Report 139-10 "Evaluation of On-Freeway Traffic Control at an Interchange," by Roy C. Loutzenheiser.

Research Report 139-11 "Application of Closed Circuit Television for Traffic Surveillance in Texas," by William R. McCasland and Raymond G. Biggs.

Research Report 139-12 "Documentation of Computer Control of the Ramp Metering System on the Gulf Freeway," by Gene P. Ritch.

Research Report 139-F "Final Report - Freeway Control and Information System" by William R. McCasland.

HIGHWAY RESEARCH BOARD PAPERS

1. "A Study of Design Considerations for Real-Time Freeway Information Systems" by Conrad L. Dudek, Carroll J. Messer, and Hal B. Jones.

2. "Evaluation of Real-Time Visual Information Displays for Urban Freeways" by Conrad L. Dudek and Hal B. Jones.

3. "Cost Effectiveness of Freeway Merging Control" by Conrad L. Dudek and William R. McCasland

4. "Influence of Incidents on Freeway Quality of Service" by Merrell E. Goolsby.

5. "Reducing Imbalance of Intersecting Freeways by On-Freeway Control" by Roy C. Loutzenheiser and Donald M. Henderson.

ASCE PAPER

1. "Toward the Development of a Real-Time Freeway Information System" by Conrad L. Dudek and Carroll J. Messer.

PROPOSALS FOR RESEARCH STUDIES

1. Installation of Accident Investigation Sites
2. Real-Time Freeway Driver Communication System - A Pilot Study
3. Lane Control in Major Interchange of Two Freeways
4. Ramp Closure of Telephone Entrance Ramp
5. Preferential Treatment of City Buses Using the Gulf Freeway Control System
6. Ramp Control for Outbound Gulf Freeway