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16. Abstract

Studies of urban traffic operations were conducted on the freeways of Houston as part of a research program to develop traffic surveillance, motorist communications and services, and traffic control systems for the improvement of the level of service of existing urban street and highway facilities. The research study concentrates on facilities, equipment, procedures and practices that are available for immediate implementation. Not all of the objectives of the three-year study were completed, but documentation of the project is summarized in this report.

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Final Report

# DEVELOPMENT OF URBAN TRAFFIC MANAGEMENT AND CONTROL SYSTEMS

BY

William R. McCasland
Research Engineer

Research Report Number 165-18F

Development of Urban Traffic Management and Control Systems

Research Study Number 2-18-72-165

Sponsored by
The Texas Highway Department
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University
College Station, Texas

October 1974

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# INTRODUCTION

## BACKGROUND

This report presents the status of the Texas Highway Department's research program on urban traffic problems. Early studies dealt with determining the traffic characteristics of freeway operations and at-grade intersections, geometric design, and limited traffic control studies. In 1963, a systems approach to the problem of urban freeway congestion was adopted with the five-year Level of Service Project that produced the freeway surveillance and ramp control systems on the Gulf Freeway. This work was followed by the expansion in range and scope of the traffic control systems and by investigations of the need to communicate with the urban motorists. The three-year research project, Freeway Control and Information Systems, dealt with ramp closures, intersection signal control and dynamic motorist communication systems that respond to the constantly changing traffic conditions.

In 1971, the on-going research program was restated with emphasis given to the concept of managing urban traffic. The three-year project, The Development of Urban Traffic Management and Control, continued the work in driver communications, expanded the application of traffic control to include on-freeway traffic and pursued the goal to keep roadways clear of capacity reducing incidents. All objectives not completed in this study will be continued in future research studies. There have been significant findings that are implementable at the present time. These and other accomplishments of the Research Study 165 are discussed in this report.

## STATEMENT OF THE PROBLEM

Urban freeways continue to experience severe congestion of traffic during hours of commuter traffic. The length of time of congestion continues to expand and the level of traffic flow during other times of the day increases as travel demands continue to rise. The result is that any incident that significantly reduces the capacity of a roadway causes congestion and large traffic delays. Unscheduled incidents; such as accidents, stalls, spilled loads, debris, snow or ice, must be cleared as quickly as possible if an acceptable level of service is to be achieved. Maintenance and construction activities must be carefully scheduled with appropriate traffic control and diversion routing if congestion is to be minimized.

There are many candidate solutions to ease and perhaps to eliminate the traffic congestion that plagues the freeways and major arterials of an urban area. These can be grouped into three categories; increase the capacity of the transportation system, reduce the demand of vehicular traffic, and optimize the existing transportation system.

In the first case, increasing the capacity has been the objective of cities and highway departments during the last two decades; but social, political, and financial considerations issue a warning that expansion of streets and highways in urban areas will not be continued at rates that will be necessary to match the rate of travel demands.

In the second case, reducing the demand of vehicular traffic, while continuing to provide sufficient transportation to satisfy travel demands is an admirable goal and may be the long range solution of urban transportation. The development and promotion of public transportation is receiving an increasing amount of attention and financial support. However, the immediate needs in public transportation can only be fulfilled by systems that use facilities in mixed mode with private transportation.

Thus, buses and car pools suffer the same consequences in heavy traffic as the private vehicle unless priority systems can be implemented.

Finally, optimizing the operation of streets and highways seems to be an appropriate solution, even if one or both of the first two cases are implemented. Making the best use of existing facilities under existing traffic and roadway conditions is a sound engineering decision. This is the direction taken in the development of systems to manage and control urban traffic.

## OBJECTIVES OF STUDY

The three-year research program had six major objectives:

1. To evaluate operational systems developed and implemented by the research study.
2. To develop and test detection, communication and display systems to automatically detect and locate disabled vehicles on the travel lanes of an urban freeway.
3. To prepare hardware and software requirements for a digital computer to control a small network of traffic signals.
4. To develop and test information and control systems for a network of arterial streets, urban freeways, and major traffic generators.
5. To develop the functional and operational requirements for an urban traffic control center.
6. To assist District 15 in the preparation of an evaluation study report as outlined in Research Report 24-26F.

The many studies and reports that partially fulfill the objectives are discussed in another section of the report.

## IMPLEMENTATION STATEMENT

It is the goal of this research study to provide information on systems and procedures involved with urban traffic management that are immediately implementable. However, it is apparent that implementation will not be accomplished quickly. The major problems facing the state highway departments are money and time. This is compounded by the lack of adequate manpower and facilities for taking the responsibility of implementation, operation, and maintenance of these systems. Also, these systems must involve several agencies and must require interagency agreements, which take time to develop.

However, progress has been made in several areas of Texas, as well as other parts of the Country: ramp metering control is now operational in 4 Texas cities; ramp closure control has been installed in Dallas; lane control is operational in Houston as part of the research study; accident investigation sites; safety warning signs; and changeable message signs are operational on the Gulf Freeway Surveillance and Control Project. Also, many Texas Highway Districts are in the process of making studies and developing plans for installing many of these systems.

## RESULTS OF THE STUDY

### STATUS OF THE OBJECTIVES

A review of the status of the six 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 and Discussion of Accomplishments.

Objective 1 - To evaluate operational systems developed and implemented by the research study. This objective has been partially satisfied. There are 10 separate systems to be evaluated. Six systems have been completed and documented; accident investigation sites, minicomputer control, arterial intersection control, CCTV by microwave transmission, ramp closure control, and motorist warning systems. Two have been installed, but have not been operated long enough to be evaluated; changeable message signs and lane control at interchanges. One is scheduled for installation in 1975; low volume incident detection system. One has not been approved for installation; on-freeway control.

Objective 2 - To develop and test systems to automatically detect and locate disabled vehicles. Much work has been accomplished in the detection of incidents under moderate to high volumes of traffic. Plans for the installation of a detection system to study the requirements for the situation of low volumes of traffic have been developed and will be installed in 1975. The principal problem in this area is detector reliability which though studied and reported in this research study remains the weak element of most surveillance systems.

Objective 3 - To prepare hardware and software requirements for a digital computer to control a small network of traffic signals. Two areas of research have been completed in this objective. The documentation of the Wayside-Telephone network provides information on the hardware aspects of the problem, and the progression model and operations handbook for the PASSER model provides software for the design and evaluation of signal timings along an arterial street. More effort will be put into this area of work in 1975 in Research Study 203 which will study platoon dispersion and level of service of intersections. PASSER is discussed in more detail on Page 27.

Objective 4 - To develop and test information and control systems for a network of arterial streets, urban freeways and major traffic generators. Considerable study remains to be done in driver communications. The work in early warning systems on freeways show that low cost systems can be provided for that function. The study of diversion requirements remain to be done and is scheduled for study in the completion of the evaluation of the changeable message sign in Houston and in related research studies of the Institute in the Federally Cooperative Program of the Federal Highway Administration.

Objective 5 - To develop the functional and operational requirements for an urban traffic control center - This objective has been partially satisfied by reports on the various hardware systems that compose an urban traffic control system. Discussion of the operational requirements have been presented, but must be qualified according to the designated goals and objectives of an operational organization.

Objective 6 - To assist District 15 in the preparation of an evaluation study report as outlined in Report 24-26F. This objective has been satisfied by the report on the ramp metering installation on IH 10 in San Antonio.

## STATEMENT AND DISCUSSION OF ACCOMPLISHMENTS

One of the major accomplishments of this research study is the assistance given District 12 in continuing the operations of the Gulf Freeway Surveillance and Control Project for three more years. The operational experience, so necessary for the implementation of other projects, has been developed through the Texas Highway Department's support of both research and operations of the freeway surveillance and control systems since 1963. Texas Highway Department policies for delineating the responsibility and degree of participation in urban traffic control systems are being developed as a result of the work of the Gulf Freeway Project.

The many other accomplishments are the results of the research studies documented in 17 research reports and summarized in this final report. That many studies are incomplete emphasizes the difficulty of implementation, even in a temporary demonstration basis.

### Freeway Control

For over ten years, ramp metering has been accepted as an operational system (1). In most installations, the results have been consistent; that is, an increase in operating efficiency and a reduction in accident experience. However, many freeways with ramp control systems continue to experience traffic congestion during peak traffic demands. In many cases, ramp metering alone cannot control the level of service of a freeway, but can only delay the development of congestion and shorten the length of congestion.

Research in traffic control of freeways indicates that more restrictive control of demand is required if peak efficiency is to be maintained and the level of service to be controlled. Three approaches to providing more stringent control of freeway demand were considered in this research study; entrance ramp closure, freeway lane closure, and on-freeway control. Each control system was traffic responsive to existing freeway traffic conditions.

Entrance Ramp Closure Control Based on Traffic Conditions - Experiments and studies on the effects of ramp closure have been conducted many times during the last twenty years (2). The results indicate that entrance ramp closures improve the level of service more than metering, but the closure of ramps should not be used when good alternate routes are not available and when the political consequences are unfavorable.

Ramp closures may not be as efficient as metering in improving overall traffic operations unless they are responsive to changing traffic conditions on freeways and arterial streets. Also, ramp closures that are responsive to changing conditions will not be consistent in time of day or length of control, a type of operation which may be unacceptable to the public.

A study, using manual closure of four ramps on the inbound Gulf Freeway in Houston, was conducted to demonstrate the effectiveness of the traffic responsive control and to test the acceptance by the public (Research Report 165-11). The ramps were closed for 15 to 20 minutes between 6:45 and 8:15 a.m. Traffic was diverted along parallel frontage roads to downstream entrance ramps that remained open. The decisions to open and close the ramps were based on observations from closed circuit television and evaluation of freeway parameters taken from an electronic surveillance system.

Before and after studies showed significant improvements in freeway flow rates, a 20 percent increase in freeway speeds, and a reduction of stop-and-go operations. The total volume of traffic served by the freeway was not significantly changed by the diversion control.

The acceptance by the public was generally good, with compliments offsetting the complaints. The study proved that ramp closure with good alternate routes is an acceptable and beneficial control strategy when applied with consideration of existing traffic conditions.

Freeway Lane Closure Control Based on Traffic Conditions - Due to an imbalance of traffic demand during peak hours and to a lane reduction at merge areas, major interchanges of urban freeways have become bottlenecks in the freeway system. Queues of vehicles form on one or more approaches to the interchange and create hazardous conditions and increased delay to motorists who are not a part of the interchange movements.

There are three candidate solutions to this problem:

(1) Add a lane in the merge area;

(2) Reduce the traffic demand approaching the merge area; and

(3) Reduce the number of lanes approaching the merge area.

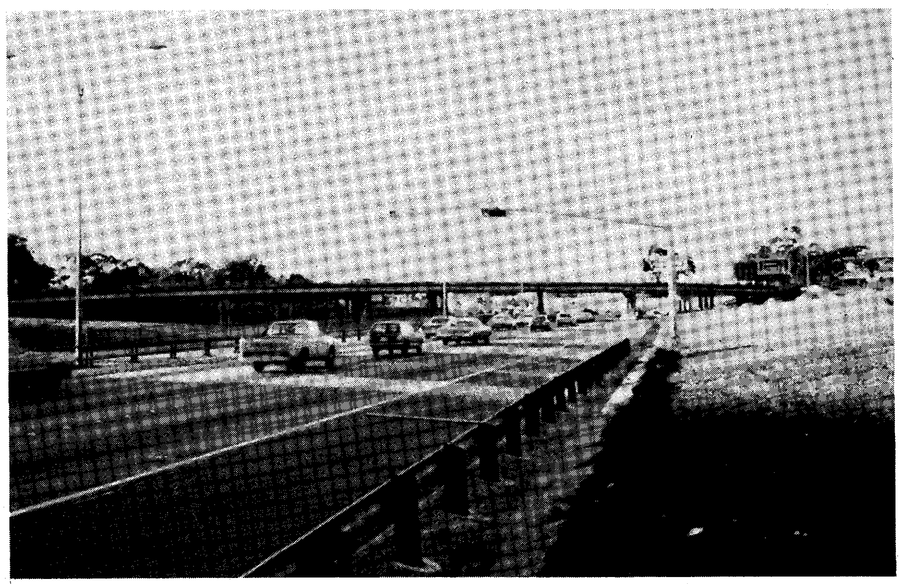
The addition of capacity in the merge area is the best solution for improving operations, if the added lane can be carried to a downstream exit ramp. However, it may be very expensive if right-of-way is limited, or if the expansion of highway structures is required. The temporary use of roadway shoulders is an inexpensive physical modification that has been used successfully in several locations to expand roadways for travel.

The reduction of traffic demand on the approaches to the merge area may be feasible. Ramp metering, which has proven to be a successful traffic control system for entrance ramps to freeways, may be deployed on the interchange roadways, so that traffic demands could be coordinated from several different directions to the merge area by bulk metering.

The reduction of the number of lanes approaching the merge area will not change the capacity of the freeway since the number of lanes leaving the interchange remains the same. The total travel characteristics of the freeway system will improve if there is a shift of capacity to a roadway in proportion to the demand or to the delay experienced by traffic on that approach. The closure of a lane of freeway under traffic is very difficult. A positive closure with trucks and signs was tested in 1971 and the results were favorable (3).

The manual closure was too costly and too cumbersome to be traffic responsive, so a second method of lane control, using signs and signals to gain voluntary compliance by the motorists, has been proposed, approved, and installed by the Texas Highway Department. The installation of the system, completed in 1974, will be tested and reported in 1975 (Figure 1).

On-Freeway Control Based on Traffic Conditions - Freeway control strategies have been the subjects of discussions since the first ramp metering system was installed. Can the improvement of the merging maneuver at one or several entrance ramps have any effect on the total operation of the freeway? Can the control of demand at one or several entrance ramps eliminate traffic congestion? Is the control of downstream entrance ramps with the objective to maintain good freeway operations upstream discriminatory to local traffic? What strategy should a freeway control system use to provide the best service to the motoring public? These and many other questions must be answered when considering the design of a freeway control system. There is no single answer because each freeway has different conditions and each location may have different priorities, goals, and objectives.



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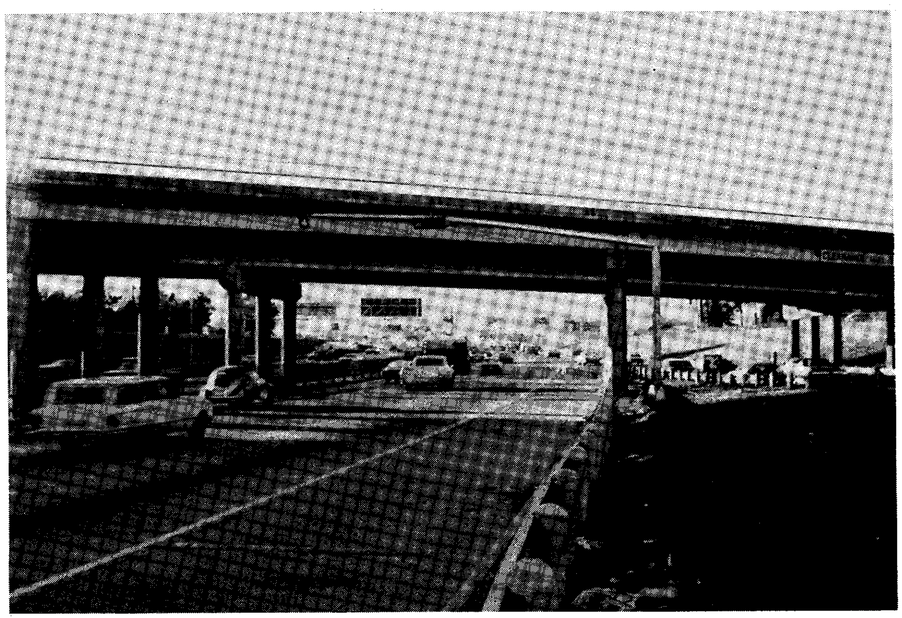

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Figure 1. Lane Control on IH 10 at the Interchange of IH 610

However, in many of the freeway control systems that are now in operation, there is an opinion that the control system should be capable of operating on a level of service basis. This is, the control should be capable of establishing a desired level of operation, regardless of the traffic demand. To accomplish this, the control must be closed system; that is, traffic control must be applied to the main lanes of the freeway. This concept has been tested on special controlled access facilities such as tunnels, bridges, and toll roads (4).

The study of an on-freeway control system was proposed in January 1973 and included in the work plan for fiscal year 1974. A system of traffic signals was to be installed on the Gulf Freeway at SH 225 to control freeway demand when downstream conditions exceeded predetermined limits. However, the plans for the signals and the study were not approved by the Federal Highway Administration, because they violated the policy of no traffic control on the Interstate System.

Therefore, this study has been postponed until a suitable site is located. The Central Expressway in Dallas is now being studied and a proposal is to be submitted to the Texas Highway Department and the Federal Highway Administration in 1975.

The need to control freeways on a level of service basis is greater now that there is a need to promote the use of buses and car pools on freeways. The on-freeway control enables the controlling agency to provide priority level of service to these high occupancy vehicles.

### Incident Detection and Response

One of the most pressing problems in operating urban freeways is keeping the roadway cleared for moving traffic. The occurrence of any incident, regardless of how small or seemingly insignificant, causes a reduction in capacity of the roadway. If the reduction of capacity occurs at a critical location, at a critical time, or for an extended length of time, severe traffic congestion can develop. For example, a study has shown that a minor accident blocking one lane of a three-lane roadway reduces capacity by 50 percent, and that an accident blocking two lanes of a three-lane roadway reduces the capacity by 75 percent (5). The same study determined that the accident vehicles moved to the shoulder had an effect of reducing capacity by 33 percent even though all main lanes were clear.

There are many different problems and many possible solutions for keeping the roadways operating at capacity. This research study has examined several approaches to the problem with the goal of developing systems and procedures that are implementable at a reasonable cost with a large payoff in benefits to the public.

Accident Investigation Site (AIS) System - Studies of accident investigations on urban freeways have determined that an average time of 25 minutes is spent in police investigation following the detection and removal of vehicles from the main lanes. If the investigation is conducted on the shoulder of the freeway, the length of time required to return the freeway operation to normal flow will be increased because of the reduced capacity of the freeway section. In 1969, a report by Goolsby on "Accident Reporting and Clearance Procedures on the Gulf Freeway"[5] recommended the designation and construction of accident investigation sites along the freeway at which the police officer could complete the investigation with all vehicles and passengers out of view of main lane traffic. Thus, the capacity of the freeway would be increased and the time of disturbance caused by the accident would be reduced. The recommendation was approved for implementation and study. Sixteen accident investigation sites were designated along six miles of the Gulf Freeway at locations that were easily accessible from the Freeway and were out of the direct view of freeway motorists. Six sites were constructed on the freeway right-of-way under bridge structures (Figure 2). Ten sites were designated parking areas on the city streets in the area. Signs on the freeway service roads were placed to direct vehicles to the sites. The signs also identified the sites by number. The costs to construct and sign the sites were $3,200 for construction for each of the six special sites, $115 for signs for each of the 16 sites, and $2,800 for lighting of five sites.

The Houston Police Department was issued booklets locating the sites and supplementary freeway accident report forms for recording study data on site usage and time requirements for accident investigation. Over 2,000 forms have been received for analysis since July 12, 1971, when the sites were opened.

The results of this three-year study were that the police conducted 33 percent of the investigations in view of the freeway motorists, 49 percent of the investigations were conducted at one of the 16 designated sites, and 18 percent were conducted at other sites out of view of the freeway motorists (Research Report 165-1).

An analysis of the 33 percent of the total accidents not moved to off-freeway sites revealed a number of explanations:

(1) Lack of towing facilities;

(2) Inaccessibility to a site;

(3) Difficulty in traffic management;

(4) Major accident requiring more detailed reporting; and

(5) Investigation officer's decision.



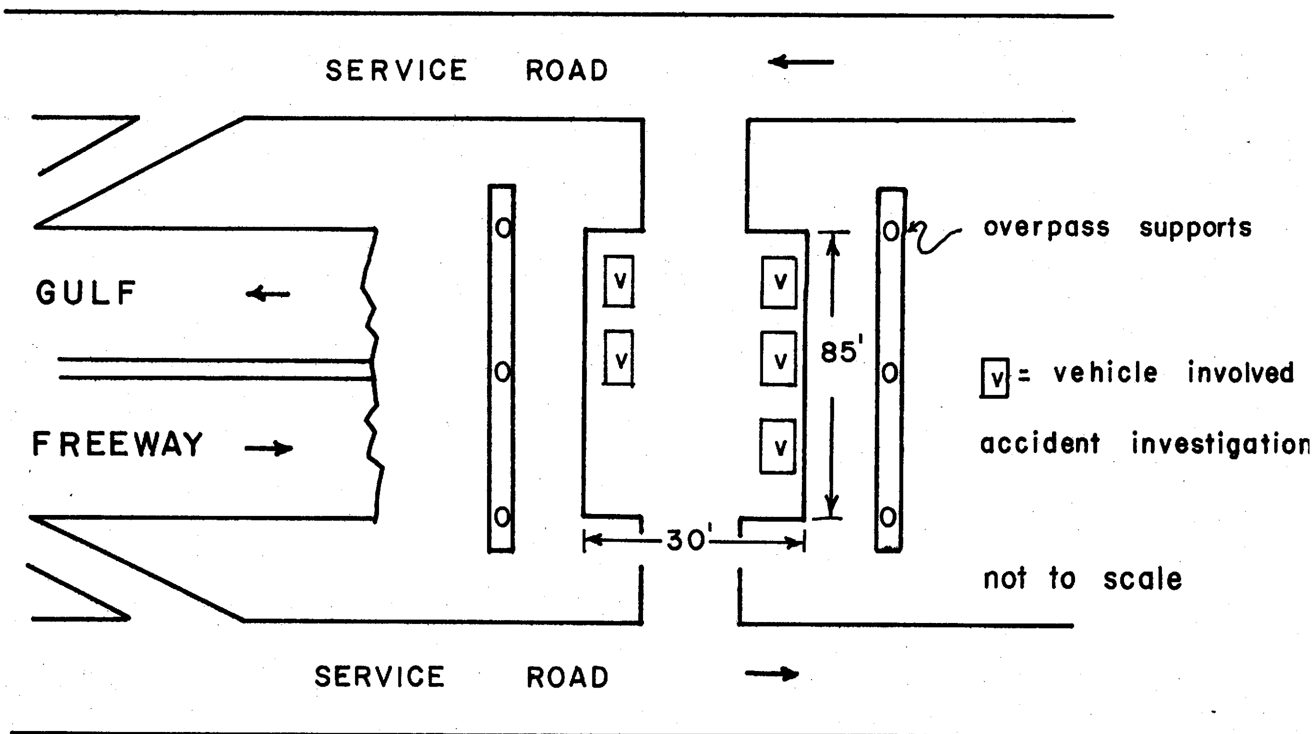




Figure 2. Design of accident investigation site on unused land under a freeway overpass

This analysis determined that only 15 percent of the accidents should not have been moved to off-freeway sites.

The benefits relating to the saving in time to the freeway motorist and the reduction in secondary accidents amounted to $228,000 per year; and the annual cost for the system, using a 10-year, 10 percent capital recovery factor, was $8,000; and the benefit-cost ratio was 28.5 to 1.0.

Studies of the individual sites indicated some changes in design and location were justified. Other techniques for concealment of the accident scene will be developed for other freeways.

The Gulf Freeway Accident Investigation Site System has proven to be very successful. Greater cooperation by the accident investigators can increase the usage factor by 25 percent, which will significantly increase the benefit-cost ratio above the 28.5 value for the study period. Because of the very great potential for improvements in safety and operational efficiency of urban freeways, accident investigation sites are being recommended for all urban freeways.

A motion picture film describing the uses and the benefits of the AIS System was developed for use in police training courses and in continuing education application with transportation agencies.

Incident Detection - Shock Wave Detection and Safety Warning System Operation - The majority of accidents on freeways are rear-end collisions, caused by following too close for conditions. The condition may be the rapid deceleration of vehicles caused by traffic congestion or roadway conditions. Usually, the deceleration of a traffic stream on an urban freeway is an orderly and safe operation, but with geometric or traffic conditions that restrict sight distances, the hazards and probability of rear-end collisions increases.

Considerable research has been devoted to the detection and measurement of traffic conditions on urban freeways for the application to control entrance ramps. This study examined the surveillance system for the Gulf Freeway ramp metering system and determined the design modifications necessary to provide the capability of detecting stoppage waves in freeway traffic at three locations with restricted sight distances at crest vertical curves. A surveillance system was designed for the measurement and calculation of speeds by speed traps, lane occupancies, volumes, and energy at both upstream and downstream locations of the crest vertical curves in all lanes. Tests of the system, verified by visual observations from a CCTV system, determined the system to be effective in the detection of stoppage waves at a time resolution of 30 seconds (Research Reports 165-5 and 165-6).

Studies of the type of display to be used in communicating with the motorists were conducted at the Research Annex in Bryan, Texas. A combination of static signing and flashing beacons were determined to be very effective since it was an extension of the application of the type of signs used on the approaches to traffic signals and railroad crossings (Research Report 165-4).

An experimental safety warning system was installed at three overpasses on the Gulf Freeway in Houston in April 1972. The static signs display the message "Caution - Slow Traffic When Flashing" (Figure 3). Two alternately flashing yellow beacons were located on the sign, and one flashing beacon at the crest of the overpass for maximum viewing range (Figure 4). Studies in the evaluation of the system used accident experience and motorists' subjective responses to questionnaires to measure the effectiveness of the systems. Results of these studies indicate the prototype system on

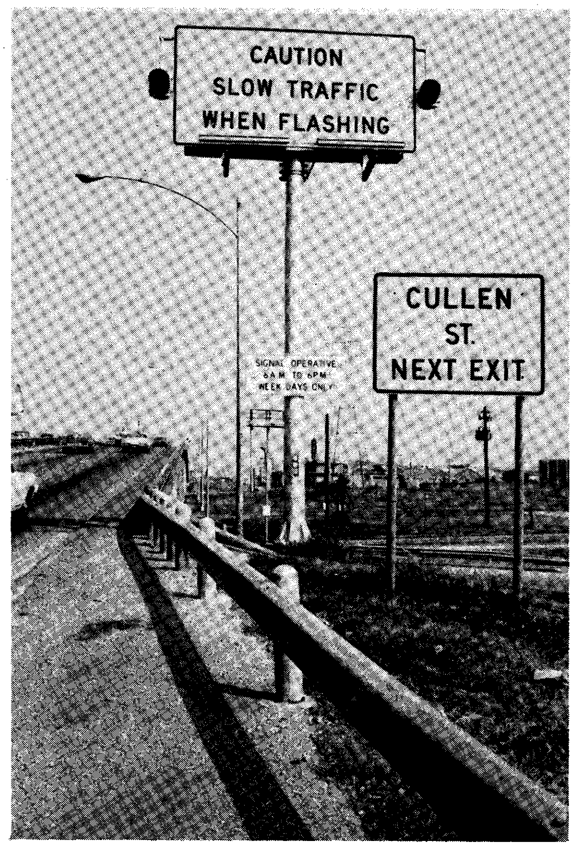



Figure 3. Warning Sign with Flashers

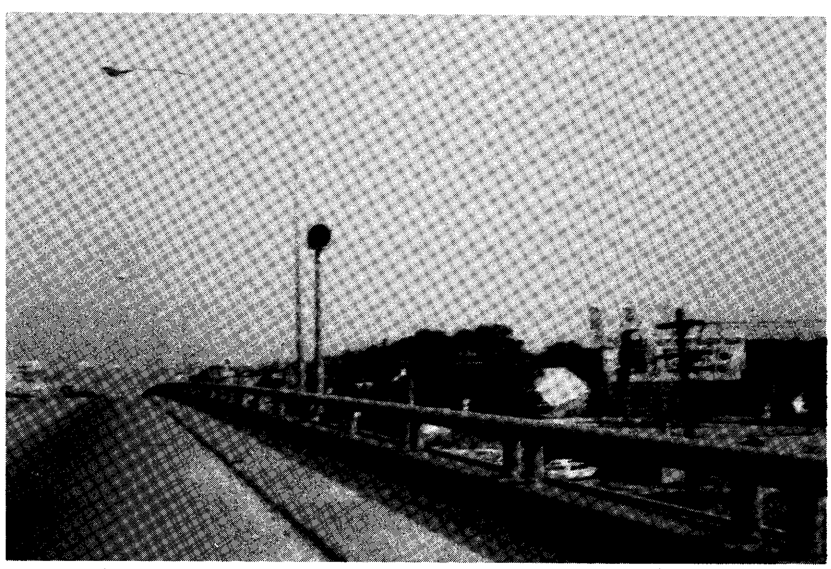


Figure 4. Flasher Unit at Crest of Overpass

the Gulf Freeway was cost effective in the reduction of accidents and the resulting traffic delays. Accidents in the study area were reduced 50 percent over a nine-month period, while accidents in comparable sections outside the study area were reduced only 5 percent (Research Report 165-13).

The results of the questionnaire study indicated that the motorists, observing the sign in operation, believed the sign to be useful, to be readily noticed, and the message to be generally understood. The respondents reacted to it appropriately and confirmed that the message displayed was verified later by traffic observed.

The sign was especially effective and accepted during the off-peak conditions when motorists were traveling at higher speeds and approached an incident not visible to them. Likewise, the greatest skepticism regarding the usefulness of the signs came from motorists traveling during the peak traffic when slow speeds and stoppages were expected. The drivers resented the operation of the sign when traffic operation was in a stop-and-go condition. Some changes to the detection system by adding traffic sensors upstream of the signs, but as close to the overpass as possible, will permit the signs to be turned off as quickly as possible when the shock wave passes over the overpass crest.

The results of the questionnaire verified the flashing beacons to be effective and to have an excellent target value. Small changes in the fix message sign were suggested to provide information on the limits of the sign's applicability.

The system was shown to be a cost effective operation and is being considered for implementation on other freeways with traffic volumes comparable to the Gulf Freeway test site. The system is to be considered for implementation at vertical curves and other sites that have restricted sight distances and high frequency of rear-end accidents.

Incident Detection - Travel Time Prediction - To reduce the frequency of incidents and the severity of congestion, variable message signs and other motorist communications systems to divert traffic from the freeway to alternate routes are being investigated. Travel times on the freeway and alternate routes are one measure that would be considered in the information displayed to the motorists.

A model was developed for the Gulf Freeway Surveillance Project which predicts the time required by a motorist to travel from any selected freeway location to the end of the freeway system during freeway incident situations. The model computes the estimate of a motorist's travel time if the motorist were to enter the freeway several minutes in the future. Freeway speeds, volumes, and shock wave speeds are also predicted.

The mathematic model of freeway incident conditions was developed by following the kinematic wave theory of Lighthill and Whitham (6).

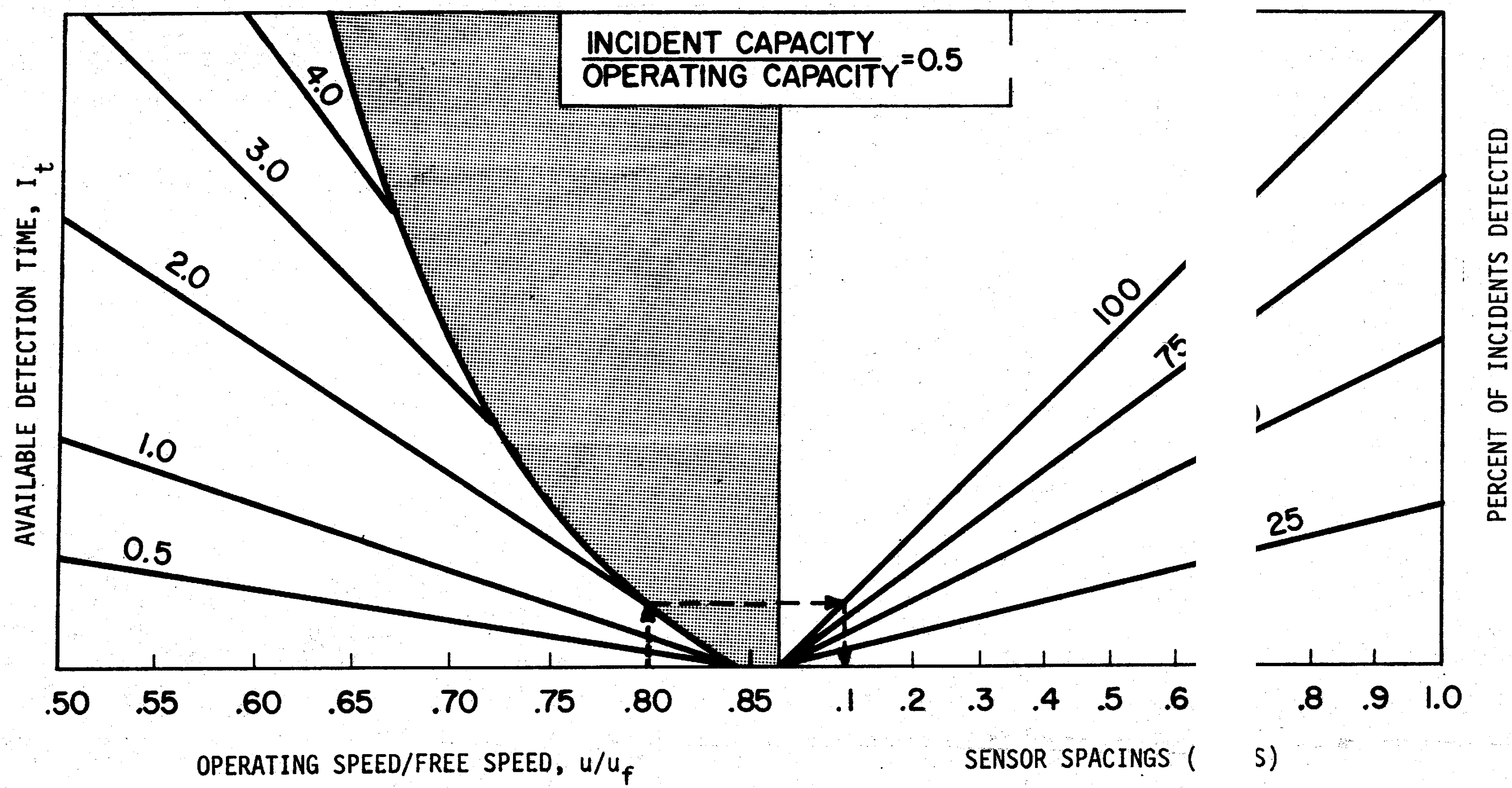
A computer program was written to compute the desired travel times when the initial freeway conditions and the characteristics of the incident were known. Four incidents were studied to determine the accuracy of the model when all conditions were known. The model was calibrated to these data with an error in travel time of no greater than 15 percent for 85 percent of the time (Research Report 165-8).

The model in its present form may be used to predict the effects of a lane closure in terms of lengths of queue back-ups and delays. The theory of the model has already been helpful in describing more effective incident detection systems. Prior to its use as a real time element of an operational information and diversion system, the model must be further refined by tests with more incidents under wider variations of conditions.

Disabled Vehicle Detection - Low Volume Conditions - The incident detection and shock wave detection programs being used to operate the safety warning signs and provide information for the changeable message signs are effective only when freeway volumes are moderate to heavy. Recommendations and requirements for sensor spacing relative to the duration of incidents to be detected and to the required response time to the incident were developed for immediate implementation (Research Report 165-12) (Figure 5).

Mathematical models for automatic detection of vehicular incidents under low volume conditions were also developed, and additional detectors are being installed on a new section at IH 610 with which to test and evaluate these algorithms. The biggest problem in this study is to obtain 100 percent vehicle count accuracy with off-the-shelf detectors. Therefore, redundant detectors are being evaluated, and computer software is being developed to compensate for the inefficiencies of existing hardware (Research Report 165-7).

The two computer algorithms for automatic freeway detection under low volume conditions differ in that one utilizes a time scan process, and the other operates on an event scan principle. Computer simulations produced a family of curves for determining sensor spacing requirements for an operational system using the event scan algorithm. The results indicate that 1000 feet detector spacings would provide adequate response to incidents for volumes up to 500 vph on a three-lane freeway section, and at volumes of 1000 vph, a detector spacing of 500 feet would be




$I_t$ = [Required Detection Time ($D_t$)] - [Computer Algorithm Response Time )]

Figure 5. Sensor Spacings for an Incident Duration of Two Minutes or More

desirable. The evaluation and validation of these models will begin immediately after the completion of the detector system in 1975.

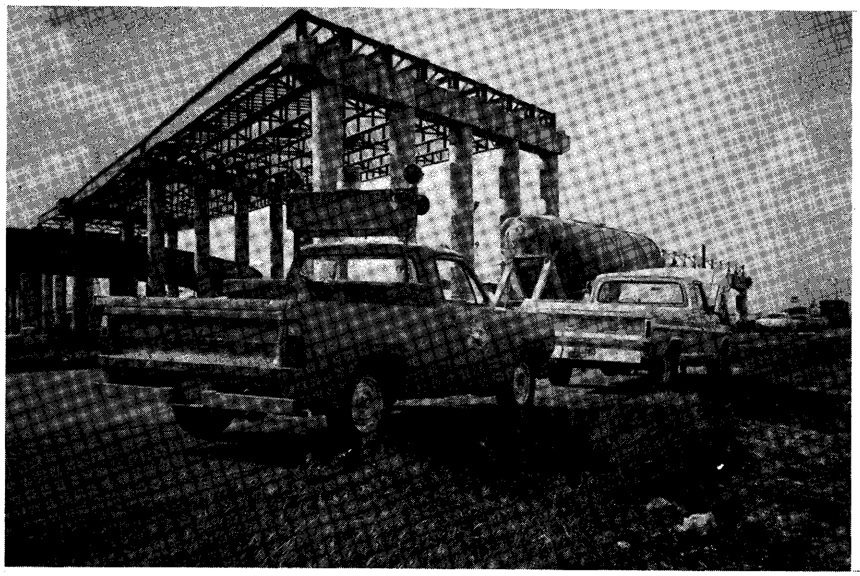
Incident Response - Changeable Message Sign Operation - Three variable bulb matrix signs were installed on the Gulf Freeway in 1974. The study of the operation of these signs has not been completed. Questionnaire surveys and traffic characteristics studies were being conducted in 1974 to determine the effectiveness of the signs to advise motorists of traffic conditions ahead and to affect diversion of traffic away from the freeway.

Incident Detection and Response by Freeway Patrols - The freeway service patrol serves two functions: surveillance and response. The Texas Highway Department operates patrols in two urban areas: Fort Worth and Houston. This research study investigated the operation of the patrols in Houston by District 12 to determine if they were cost effective and if changes in procedures would be warranted to improve the efficiency (Research Report 165-16).

The patrol system consists of two pickup trucks equipped with appropriate emergency materials such as gasoline, water, fire extinguishers, flares, tools, etc., (Figure 6). There are two men riding in each truck over sixty-four (64) miles of freeway within the IH 610 Loop from 4:00 pm to 8:00 am on weekdays and twenty-four (24) hours on weekends.

The evaluation of the patrol was done in two parts: First, responses to a questionnaire given motorists who were helped by the patrol were evaluated. The second phase of the analysis compared the benefits due to the operation of the patrol to costs necessary to provide them.

In 1973, the patrol performed 12,328 services. Of these, 4,605 services benefited the motorists in need of aid; 1,961 services benefited



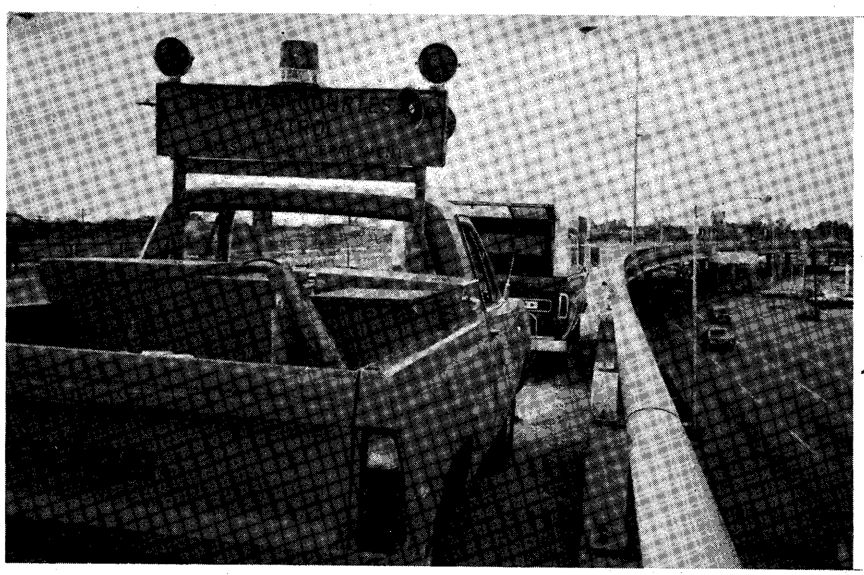


Figure 6. Freeway Courtesy Patrol Trucks
of the Houston District of the
Texas Highway Department

the other motorists; 1,571 services benefited the Houston Police Department; and 4,191 services benefited other members of the Texas Highway Department. A total of 1,429 questionnaires were received from the motorists who received aid. Results from this survey were greatly in favor of the freeway patrol.

The costs of operating the patrol were determined to be $229,400 per year. This is based on 12-man years of labor, and $37,000 in equipment costs. The vehicles travel over 400,000 miles per year.

The annual benefits of the patrol system were determined to be approximately $477,000. The benefits consisted of savings to the motorists receiving aid, reduction of delay to all motorists, savings to Texas Highway Department personnel, and reduction in accidents. There were many other benefits related to the patrols, such as security to motorists, public relations for the Texas Highway Department and reduction of work load for the Police Department. These were not included in the analysis since they were 'non-priceable' benefits.

Therefore, the resulting benefit-cost ratio of 2 is a conservative estimate of the worth of the patrol system. Efficient development and use of personnel and equipment and reasonable values, assigned to the 'non-priceable' benefits, can significantly improve the benefits to costs comparisons.

Traffic Signals - Frontage Road and Arterial Street Control

The control of entrance ramps and the diversion by driver communication and control of freeway traffic to the adjacent street system places a greater burden on the arterial streets and freeway frontage roads to accommodate traffic flow. It is important that the signal system on the surface street network can be adjusted to meet these changes in demands. The study of computer controlled signals for diamond interchanges on the frontage roads and adjacent arterial intersections has provided some information on the hardware and software system designs and the control strategies in the development of a coordinated signal control system for a freeway corridor.

Frontage Road - Freeway Control Coordination - The network of six intersections on O.S.T., Wayside Drive, and Telephone Road at the Gulf Freeway, which were placed under control by an IBM 1800 computer in 1971, has been studied and reported (Research Report 165-3). Although there were other control strategies that were to be tested at this location, the computer control was discontinued in 1973 because of freeway construction activities, detector maintenance difficulties, and other project scheduling problems associated with the changeable message signs.

However, the primary objectives of the study, which were to implement computer control and to compare the performances of progressive pretimed and progressive traffic responsive control with the present isolated pretimed control, were satisfied. Also, this study provided the impetus for a continuing research program in computer controls of traffic signals, and specifically the development of a real time diamond interchange analysis, scheduled for completion in 1974-75.

Arterial Progression Program - A new arterial signal progression optimization program was developed through the work of the staff of this project and the Dallas Corridor Project on the North Central Expressway. The computer program is designed to assist the traffic engineer in developing optimal signal timings for progression through signals having more than one arterial signal phase. The multiphase progression program, named PASSER II - Progression Analysis and Signal System Evaluation Routine, has been adapted to the Texas Highway Department Computer System in Austin (Research Report 165-14).

The program uses much of the same input data required of current signal programs; intersection distances, progression speeds, allowable cycle lengths, turning movement volumes, saturation capacity flow rates, etc. In addition, a particular arterial phase sequence at one or a set of intersections can be specified and each analyzed to determine which one gives the best progression. Platoon dispersions, speed variations, and non-overlap signal phase sequences are a few of the special features of the program. The program calculates green timings, phase sequences, optimal offsets, and resulting movement volume to capacity ratios (Figure 7). Time-space diagrams can be plotted. The cooperative effort of the research staff and the Division of Automation and Maintenance Operations of the Texas Highway Department in Austin has resulted in the development of an operating program and a users manual. Improvements will be made to the program as research into traffic signal control progresses.

Signal Interconnect Study - There is a renewed interest in the subject of network definition for traffic signals. Guidelines have been developed for determining whether a group of signals along an arterial should be operated independently of each other or interconnected to operate as a system. But with the increasing use of computer control and with the development of new analysis programs, such as PASSER II, further studies to develop new or refine old guidelines and procedures are required. The platoon dispersion models, developed during this study, will be validated in a signal system in Texas in 1975. The signal system evaluation routine section of PASSER II will then be modified to calculate overall arterial delays. Finally, the total

MULTIPHASE ARTERIAL PROGRESSION PROGRAM - PASSER II

COLLEGE STAT SH 6 DIST 17 6/27/74 RUN NO. 1

***** BEST SOLUTION *****

55 SECOND CYCLE , BAND A = 16 SECONDS , BAND B = 15 SECONDS 0.29 EFFICIENCY 0.98 ATT
AVERAGE SPEED THRU SYSTEM BAND A SPEED = 41. BAND B SPEED = 41.

**** INTERSECTION 1 0.0 SECONDS OFFSET ARTERIAL PHASE SEQUENCE IS LE.. ..RNS FIRST
N ROSEMARY

| | ARTERIAL | | | | CROSS STREET | | | |
|---|---|---|---|---|---|---|---|---|
| MOVEMENTS | 2 + 4 | 1 + 4 | 1 + 3 | TOTAL MAJOR ST | 5+7 | 5+8 | 6+7 | TOTAL MINOR ST |
| GREEN TIME SECS | 27.2 | 13.8 | 0.0 | 41.0 | 0.0 | 0.0 | 14.0 | 14.0 |

| MOVEMENTS | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| VOLUME TO CAPACITY RATIO | 0.126 | 0.112 | 0.0 | 0.078 | 0.0 | 0.038 | 0.0 |

**** INTERSECTION 2 34.3 SECONDS OFFSET ARTERIAL PHASE SEQUENCE IS LEADING GREEN
FM 60

| | ARTERIAL | | | | CROSS STREET | | | |
|---|---|---|---|---|---|---|---|---|
| MOVEMENTS | 1 + 4 | 2 + 4 | 2 + 3 | TOTAL MAJOR ST | 5+7 | 5+8 | 6+7 | TOTAL MINOR ST |
| GREEN TIME SECS | 12.0 | 4.0 | 13.0 | 29.0 | 12.0 | 0.0 | 0.0 | 26.0 |

| MOVEMENTS | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| VOLUME TO CAPACITY RATIO | 0.137 | 0.681 | 0.726 | 0.643 | 0.950 | 0.374 | 0.356 |

**** INTERSECTION 3 5.5 SECONDS OFFSET ARTERIAL PHASE SEQUENCE IS LAGGING GREEN
WALTON DR

| | ARTERIAL | | | | CROSS STREET | | | |
|---|---|---|---|---|---|---|---|---|
| MOVEMENTS | 2 + 3 | 2 + 4 | 1 + 4 | TOTAL MAJOR ST | 5+7 | 5+8 | 6+7 | TOTAL MINOR ST |
| GREEN TIME SECS | 12.0 | 7.0 | 12.0 | 31.0 | 0.0 | 12.0 | 12.0 | 24.0 |

| MOVEMENTS | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| VOLUME TO CAPACITY RATIO | 0.065 | 0.531 | 0.433 | 0.670 | 0.459 | 0.236 | 0.085 |

Figure 7. Computer Results of the PASSER II Multiphase Progression Program

analysis program will be tested and the findings will be incorporated into a report on Isolated Versus Progression System Modes of Control.

Implementation of Freeway Control Systems

As a result of Research Study 2-8-61-24, entitled Level of Service, techniques for improving the operating characteristics and the safety of urban freeways through the use of ramp control were developed. In 1970, Research Study 1-8-71-501, entitled Freeway Control Demonstration, was initiated with the objectives to develop a ramp control system in each of the three urban areas of Fort Worth, San Antonio, and Austin and to develop a knowledge and understanding of the process of ramp control within the Texas Highway Department. In 1972, Study 501 was terminated, and the objectives were added to Study 165.

The goal of this demonstration project was to facilitate implementation by giving 'hands on' training to the operational personnel at the district level of the Highway Department. It was not difficult to interest the traffic engineers in the theory of ramp control, but it takes time to get projects funded, designed, installed, and operating. At present, there are three operating ramp control systems (single ramp) as a result of this activity by the research agency and the Highway Department, and there are several ramp control systems in the planning stages.

San Antonio - Ramp Metering - The Texas Highway Department developed plans and specifications for a signal controller to meter a freeway entrance ramp based on the concentration of freeway traffic flow and traffic characteristics on the ramp. The controller, the signal hardware, and vehicle detectors were installed by the San Antonio District Office personnel at the Culebra entrance ramp on Southbound IH 10 in San Antonio on May 1, 1973, (Research Report 165-15).

The controller operated in accordance with the functional specifications established for ramp control, although there were numerous problems with the hardware during the check-out period. The deficiencies were summarized by the San Antonio District Office in the results of the study.

The effects of ramp control on freeway operations were mininal since adjacent ramps were uncontrolled. Accident experience was improved on the entrance and the freeway lanes. The freeway volumes, average speeds, and travel times were not changed significantly. The degree of acceptance of ramp control was 90 to 94 percent, which is consistent with the results of other control systems in the Country. The study has shown that as a rule more than one ramp along a section of freeway should be controlled to achieve significant improvement in freeway operation.

The study satisfied the objectives of the project by the examination of a remote ramp controller for metering freeway traffic and by the establishment of a demonstration installation for gaining experience and information for applications to future control systems. Specific plans have been made to expand the control system to the four ramps on IH 10 adjacent to the Culebra ramp. The traffic engineering staff of the San Antonio District has received valuable experience in freeway surveillance and control.

Houston - Ramp Metering - The Texas Highway Department, using the same specifications as those for the San Antonio ramp metering controller, designed an installation of a ramp metering system for the inbound Cullen entrance ramp on the Gulf Freeway. The requirements and conditions were similar to the San Antonio installation, except this ramp was part of a ramp control system that extended 4 miles upstream. The operation of the ramp controller could be monitored by the closed circuit television system and by an electronic surveillance system.

In May 1973, a controller of different design and manufacturer than the San Antonio system was installed. The controller operated in accordance with the functional specifications and with few hardware problems. The difference in the two systems seemed to be the experience of the contractors. The Houston controller was constructed by a signal equipment manufacturer and the San Antonio controller was constructed by an electronics firm with no prior experience in traffic control hardware. However, it must be pointed out that after a period of adjustment and modification, the San Antonio controller operated satisfactorily.

The effects of the ramp metering in Houston on traffic operations was similar to other systems: Ramp traffic was encouraged to divert to acceptable alternate routes, volumes and speeds in the merge area of the ramp were improved, and accident experience was reduced. The primary finding of this demonstration installation was that a traffic responsive local controller is effective if all ramps in an area are controlled. The next freeway system to be installed in Houston in 1974-75 will use the local control concept on 20 ramps and phase the installation so that a centralized controller (digital computer) can be added later.

Fort Worth - Ramp Control - The Fort Worth District Office developed plans and specifications for a three-ramp control system on IH 30 Westbound with local controllers for metering traffic and, at one location, for closing the ramp. This project is only one of several that the Fort Worth District has undertaken to improve freeway operations.

Through the assitance of the research study, data on the status of traffic conditions on the entire freeway system of Fort Worth were collected with an instrumented vehicle. Data on peak period operations on IH 820 were collected and analyzed to determine the feasibility of installing ramp control and early warning systems to relieve congestion and reduce accidents. A film study was made of the weaving area at the interchange of IH 35 and IH 20 for analysis by District personnel.

All of these activities related to the comprehensive proposal developed by the Fort Worth District Office in May 1973 for the purpose of establishing a Freeway Operations Section and defining its objectives, the basic one being; "To provide better, safer, and more cost effective transportation."

## URBAN CONTROL CENTER DESIGN

The design of an urban traffic control center is greatly dependent on the goals and objectives to be defined by the operating agency and the resulting system designs for the surveillance, communications, and control elements. For example, if incident detection and response is to be a major requirement, then personnel, space, and facilities for incident surveillance and identification must be provided. Electronic surveillance and closed circuit television systems must be manned by observers to respond to an incident and to assist in incident management. If control of entrance ramps is to be accomplished by local remote controllers, the need for digital computers and computer personnel will be reduced.

These and many other possibilities exist which can affect the control center design. Therefore, the following sections discuss the facilities and personnel requirements with the basic assumption that they are in compliance with the goals and objectives of the responsible operating agency.

Urban Traffic Control Concept

The capacity of the urban roadway system may not be significantly increased in the future, but the demand for urban mobility will continue to grow. The need for public transportation systems is increasing, but the provision for the acceptance of these forms of travel will take time. Thus, there is an ever increasing need to make the best use of the existing roadway system. This goal can best be achieved if there is an organization with facilities to supervise, manage, and coordinate all activities that affect the safety and efficiency of the transportation system in an urban area. In the large urban areas, the freeway system is the most important, yet least controlled network of roadways, but results of research studies and years of experience have shown that this situation must be changed to improve the efficiency and safety of freeway travel. Also, freeways cannot be considered independent of arterial streets in an urban area, because the effects and consequences of control systems, traffic accidents, roadway repairs, etc., affects all roadways in the vicinity.

Therefore, the most effective solution would be one traffic control center under the direction of one organization to supervise and control traffic in an urban area. However, the establishment of this type of control center will take time because there are many governmental agencies, and departments of these agencies, who are responsible for parts of urban transportation. But the size, magnitude, and complexity of the jurisdictional problem should not cause any transportation agency to reduce its efforts to improve the quality of transportation.

There are many approaches to the solution of urban transportation problems:

(1) Reduce the peak traffic demands;

(2) Reduce the daytime off-peak traffic demand;

(3) Maintain high flow rates on all roadways under normal operating conditions;

(4) Reduce the effects of momentary traffic interruptions;

(5) Schedule maintenance and construction for time of low traffic flow or provide additional capacity on alternate routes; and

(6) Advise motorists of environmental and traffic conditions.

The implementation of these solutions is difficult, but vital to the economic growth of urban areas and the maintenance of the desired life style of its citizens. Many of the solutions to the urban traffic problems are voluntary in character. A person may reduce the effects of his travel demands by using public transportation, car pooling, or moving closer to work. The solution may be semi-voluntary in that working hours can be adjusted, motor fuel may not be readily available, or the route normally driven is bypassed because of poor driving conditions. Many other solutions are regimented or mandatory in structure, such as the schedule of maintenance activities; the assignment of right-of-way with traffic control devices; and the assignment of facilities to high priority vehicles.

Therefore, implementation requires:

(1) Public awareness of the problem and the possible solutions;

(2) Institutional cooperation and participation;

(3) Facilities for surveillance of traffic and roadway conditions; and

(4) Facilities for the issuance of traffic controls and traffic advisories.

The implementation must be fairly applied urban wide, or the problems that were evident with the stage construction of the urban freeway system will develop. Urban traffic problems do not recognize jurisdictional boundaries.

The urban traffic control concept is to systematically attack the problems of urban traffic congestion from all approaches by coordinating the many public organizations involved in urban transportation, by working with private and public institutions to solicit their participation and by providing the private citizen with as much information as possible to assist him in his travel in the urban area.

Traffic Control Center

Putting the urban traffic control concept into operation requires facilities and people. This section will discuss the functional requirements of the center without regard to political and jurisdictional responsibilities.

Control Center Space - Since urban traffic control affects so many organizations, a separate, distinct unit with separate and well defined facilities should be provided.

Location - The location of a control center building, or office space, would be determined from an analysis of the following:

(1) Availability of utilities, power and communications to operate computers, radios, television systems, etc.;

(2) Access to all control and surveillance systems in the area; and

(3) Access to maintenance facilities.

The primary determinant will be the cost of the space and costs to install and maintain communications lines.

Size of Building - The amount of office space required to operate an urban traffic control system will depend on the number and types of activities to be conducted. The following statements are guidelines for determining the space requirements:

(1) Control Room - Space for visual displays, computer terminals, television monitors, radio communications, and at least three operators.

(2) Computer Equipment and Data Communications Interface Equipment- The size and complexity of a computer system can vary from a simple minicomputer and teletype to a large process control computer with printer, card reader, etc.

(3) Communications Equipment - If the control center is to provide a communications center for highway, police, wrecker, and other services, space for one operator and equipment should be provided separate but adjoining the control room.

(4) Personnel - Office space should be provided for full-time staff members of the center. The staff should be composed of but not limited to the following:

a. Director

b. Traffic Operations Engineer

c. Computer Programmer - Systems Analyst

d. Computer Operator

e. Systems Operator

f. Communications Operator

g. Enforcement Representative

Other personnel would be required if other functions were added, such as planning and design of new systems, maintenance of equipment, operation of service patrol systems. There may be a need to add representation from other governmental agencies or departments, such as state highway patrol, city transit, suburban cities.

(5) Administrative Functions - Office space should be provided for reception and clerical staff, conference or meering rooms, equipment, and supply storage areas.

In summarizing the space requirements, separate rooms should be provided for the control, computing, and communications functions. Office space for personnel will depend on the type of operation to be conducted by the center. Finally, the building or leased space should be designed to be expandable when additional activities and people are assigned to the center.

Special Design Features - The office space should provide adequate air conditioning, air filtration, and vibration-free structures to permit the operation of delicate electrical equipment. It may be necessary to make provisions for public viewing of the facilities. Provisions for adding new communication lines or computing and control equipment should be considered in the designs of conduits, doors, elevators, etc. The space must be secure and special precautions may be necessary to discourage the entry of unauthorized personnel. The computer area should be separated from the communications and control room.

Traffic Control Center Personnel - The personnel requirements are directly tied to the functions to be performed by the Control Center. The following positions are described in terms of responsibilities.

It is possible that more than one position can be held by one man but it is also possible that the demands of the operation will require more than one man per position.

(1) Director - There must be one man in charge of the operation. If many organizations are involved, he may report to a council or committee, but for day-to-day operations of the Center, he must be in charge of the staff.

(2) Traffic Operations Engineer - The development of traffic control strategies or traffic handling procedures is the responsibility of this staff member. He must be aware of the technical operations of the Center and make recommendations that might involve policy decisions to the Director.

(3) Computer Programmer - Systems Analyst - The design and operation of the computer system is the responsibility of the Systems Analyst. If there are continuing demands for program development, other computer programmers would be added to the staff. The Systems Analyst and Traffic Engineer share in the responsibility for the total design of the systems.

(4) Computer Operator - If the daily operations of the Center involve the processing of many computer programs and the analysis and logging of traffic data, a staff member with the responsibility of operating the computer system should be provided. This position will improve the security of control programs residing in the computers.

(5) Systems Operator - Most surveillance and communications require manual intervention to respond with appropriate

action. Also, most systems require some monitoring to improve the accuracy and reliability of the hardware. Eventually, many of these functions will be programmed in the computer. But, until that time, a staff position will be required.

(6) Communications Operator - Initially, the Systems Operator may also assume the responsibilities of the Communications Operator. As the Control Center develops, the function of communications center for the many operating agencies will become more important and radio communications with emergency vehicles, police, maintenance crews, freeway service patrols, etc., will demand more time for the operators.

(7) Enforcement Agencies Representatives - The agencies responsible for the handling of traffic in and around incidents, should have a representative to direct or assist in the direction of operations from the Center. The function may be handled on an as needed basis.

Supporting staff will be added to meet the needs of the Center. Whether they are a part of the Control Center staff, or assigned from other departments, the functions of planning and design of new systems, field crews for operating patrols, collecting data, and maintaining equipment must be coordinated through the Director of the Center.

Transit Operations

At the beginning of the project, it was recognized that urban traffic surveillance and control systems could be designed to recognize transit operations and their influence on the total transportation problem. Although the Gulf Freeway was not suitable for a demonstration project because of the lack of transit services, all studies involving the control of traffic considered how preferential treatment could be offered buses. Because the North Central Expressway in Dallas was suitable for a transit demonstration project, the development of the project in that area was reviewed by this Study. Also a comprehensive study into the state-of-the-art of bus use on highways in the nation was reviewed (7).

Ramp Control - There are several ways for ramp control to contribute to a higher level of service for bus operations on freeways.

(1) Raise the level of service of all vehicles on the freeway lanes - A very restrictive ramp control strategy can be implemented that will improve the level of service for all vehicles on the freeway. The control strategy may require the closure of some ramps during peak traffic demand.

(2) Priority entry for transit vehicles at controlled ramps - The objective of reducing delay to transit vehicles at the entrance ramp can be accomplished in several ways: Provide a bypass lane, provide a bypass ramp, increase the metering rate, allow buses to enter on ramps that are closed to private vehicles. All of these systems are feasible and will be operational in a few months.

On-Freeway Control -

(1) Lane Assignment to transit vehicles - The use of exclusive bus lanes on urban freeways has been used sparingly because the volume of buses has seldom been large enough. This is especially true when a lane is taken away from the total traffic in the peak direction. The use of contra-flow

lanes may offer a better solution for traffic operations, but requires greater expense to convert a roadway and operate the system. Reversible lanes offer greater potential for transit use, but there are few roadways with this type of design.

The most promising application of lane assignment is to share the use with high occupancy private vehicles. Car pools can make the exclusive lane more productive while relieving the congestion in the other lanes.

(2) On-freeway control of main lane traffic - The application of traffic control to the main lanes of a freeway was discussed in an earlier section of the report as a means for controlling the level of service of the freeway. This like ramp control, is advantageous to the buses on the main lanes downstream of the signal installation. The control can be more effective if the signal installation is strategically located near park and ride facilities.

Another technique that improves the effectiveness of the on-freeway control system is to provide a bypass lane for buses and possible car pools to reduce their delay upstream of the signal.

This application of traffic control to freeway traffic has not been approved at this time, but planning is underway for a test installation in Dallas and the evaluation of the operation is included in a research study for 1975.

<u>Traffic Surveillance</u> -

(1) Transit vehicle location system - Many controls can be applied

in favor of buses if the controller can recognize the presence of a bus. For example, the closure of an entrance ramp by a gate can be interrupted to allow the passage of a bus; a traffic signal on a ramp, at an intersection, or on a freeway lane can operate in a manner to give priority control to buses. Transponders affixed to buses can be sensed by a detection system and the data transmitted to the controller. These systems are in operation on city streets, and soon will be a part of the freeway surveillance system.

## DOCUMENTATION OF RESULTS

During the three years of the study, there have been seventeen interim reports and one final research report (Appendix A). Nine papers have been presented at the Annual Transportation Research Board Meetings in Washington, D. C. (Appendix A). A 12-minute motion picture film on the design, implementation, and utilization of accident investigation site systems was prepared for the Texas Highway Department for use by the cities of Texas.

# CLOSURE

The conclusion drawn from the results of this program of research on urban traffic management and control systems is that freeways can be made safer and more efficient by the proper application of traffic surveillance, motorist communications, and traffic control; by the improvement of procedures of handling capacity reducing events; and by the application of modern technology in computers, displays, and traffic sensors. There is still much work to be done in the development of the control strategies and the design of the hardware and software systems, but with the continued support of the research program by the Texas Highway Department, progress is being made. But the true test of the success of a research program is the implementation of the proven results. In the field of urban traffic management, implementation is a very serious matter of concern, both to the researcher and the operating agency. There are many difficult policy decisions to be made on the problems of; defining multijurisdictional responsibilities, providing for facility and personnel needs, and satisfying the operational and maintenance requirements. These are problems that administrators at all levels must face and resolve if the systems and procedures advocated by these research studies are to be provided to the public.

This report has touched on the many studies that have been conducted as part of this research effort. The detailed discussions and results of these studies are found in the seventeen research reports listed in Appendix A. Copies of these reports can be obtained from the Planning and Research Division of the Texas Highway Department in Austin.

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5. Goolsby, M. E. ACCIDENT REPORTING AND CLEARANCE PROCEDURES ON THE GULF FREEWAY, Texas Transportation Institute Research Report 139-1.
6. Lighthill, M. J. and Whitham, G. C. ON KINEMATIC WAVES, II: A THEORY OF TRAFFIC FLOW ON LONG CROWDED ROADS, Proc. Inst. of Civil Engineers, London, Sec. A, Vol. 229, May 1955, pp. 317-345.
7. National Cooperative Highway Research Program BUS USE OF HIGHWAYS, Report No. 143, 1973.

APPENDIX A

DOCUMENTATION FOR

STUDY NUMBER 165

DEVELOPMENT OF URBAN TRAFFIC MANAGEMENT

AND CONTROL SYSTEMS

Reports being Reviewed

Research Report 165-1 "A Study of Accident Investigation Sites on the Gulf Freeway," by Mary Ann Pittman.

Research Report 165-2 "Evaluation of the Datamate Model 16 as a Traffic Controller," by Gene P. Ritch.

Research Report 165-3 "Computer Control of the Wayside-Telephone Arterial Street Network," by Carroll J. Messer and Jim L. Gibbs.

Research Report 165-4 "Design of a Safety Warning System Prototype for the Gulf Freeway," by Conrad L. Dudek and Raymond G. Biggs.

Research Report 165-5 "Development of a Technique for Digital Computer Control of a Safety Warning System for Urban Freeways," by Conrad L. Dudek.

Research Report 165-6 "Investigation of Lane Occupancy as a Control Variable for a Safety Warning System for Urban Freeways," by Conrad L. Dudek, Carroll J. Messer and John D. Friebele.

Research Report 165-7 "A Study of Detector Reliability for a Safety Warning System on the Gulf Freeway," by Conrad L. Dudek, Amitabh Dutt and Carroll J. Messer.

Research Report 165-8 "Development of a Model for Predicting Travel Time on an Urban Freeway," by Carroll J. Messer.

Research Report 165-9 "A Study of the Application of CCTV Utilizing Microwave Television Transmission for Traffic Surveillance," by William R. McCasland and Raymond G. Biggs.

Research Report 165-10 "Investigation of a Computer Operating System for Use in Urban Traffic Control Systems," by Jim L. Gibbs (Unpublished).

Research Report 165-11 "Study of Traffic Responsive Ramp Closure Control," by William R. McCasland and Joseph H. Ibanez.

Research Report 165-12 "Automatic Detection of Urban Freeway Incidents," by Nelson B. Nuckles, Conrad. L. Dudek, and Carroll J. Messer.

Research Report 165-13 "Evaluation of a Prototype Safety Warning System on the Gulf Freeway," by Conrad L. Dudek, R. Dale Hutchinson. and Gene P. Ritch.

Research Report 165-14 "Users Manual for Progression Analysis and Signal System Evaluation Routine - PASSER II," by Carroll J. Messer.

Research Report 165-15 "Study of Local Ramp Control at Culebra Entrance Ramp on the Southbound IH 10 Freeway in San Antonio," by William R. McCasland.

Research Report 165-16 "Cost Effectiveness Evaluation of Freeway Courtesy Patrols in Houston," by Conrad L. Dudek and Daniel B. Fambro.

Research Report 165-17 "State-of-the-Art of Motorist Aid Systems," by Gene P. Ritch.

Research Report 165-18F "Development of Urban Traffic Management and Control Systems," by William R. McCasland.

## PRESENTATIONS TO THE TRANSPORTATION RESEARCH BOARD


1. "Reduction in Freeway Congestion by Usage of Accident Investigation Sites," by Mary Ann Pittman and Roy C. Loutzenheiser, January 1973.
2. "A Method for Predicting Travel Time and Other Operational Measures in Real-Time During Freeway Incident Conditions," by C. J. Messer, C. L. Dudek, and J. D. Friebele, January 1973.
3. "A Variable Sequence Multiphase Progression Optimization Program," by C. J. Messer, R. H. Whitson, C. L. Dudek, and E. J. Romano, January 1973.
4. "Detection Stoppage Waves for Freeway Control," by C. L. Dudek and C. J. Messer, January 1973.
5. "An Approach for Incident Detection on Urban Freeways," by C. L. Dudek, N. B. Nuckles, and C. J. Messer, January 1974.
6. "A Study of Detector Reliability for a Motorist Information System on The Gulf Freeway," by C. L. Dudek, A. Dutt, and C. J. Messer, January 1974.
7. "A Real-Time Frontage Road Progression Analysis and Control Strategy," by C. J. Messer, J. D. Carvell, R. H. Whitson, January 1974.
8. "Preferential Traffic Control for High Occupancy Vehicles," by W. R. McCasland, January 1974.
9. "Detecting Freeway Incidents Under Low Volume Conditions," by C. L. Dudek, G. D. Weaver, G. P. Ritch, and C. J. Messer, January 1975.