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16. Abstract

The principal goal of this project was to evaluate the operational effectiveness of the CLAS system as an incident management tool to optimize incident management operations in the US 290 Corridor. During incident management, the CLAS system provides for shared turn lane assignments and incident management signal timings at the intersections affected by the freeway mainlane incident. The incident management signal timing plans were developed as part of this project to provide time management by balancing the need to progress additional traffic along the westbound US 290 frontage road with the need to minimize delay along the corridor.

Candidate incidents were documented by the video data collection system and reviewed to assess the impact of incidents on freeway and frontage road operations. Seven incidents (1 AM, 3 mid-day, and 3 PM) were evaluated using FREQ 11 to model freeway operations and Synchro to model frontage road operations. Comparisons were made between results for the actual incident conditions with simulated CLAS incident management conditions. Results indicated a reduction in total (freeway and frontage road network) delay for the three mid-day and three PM peak period incidents analyzed but resulted in increased total network delay during the one AM peak period incident analyzed. Other study measures of effectiveness documented in this report include delay per vehicle, frontage road and cross street levels of service, throughput, and lane use violations.

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EVALUATION OF THE US 290 CHANGEABLE LANE ASSIGNMENT SYSTEM FOR INCIDENT MANAGEMENT

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Project Number 7-2910
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The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the views or policies of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of this project was Merrell E. Goolsby, P.E. #29551.

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INTRODUCTION

The frontage road system is an essential element of design and operation of urban freeways in Texas. Freeways in the Houston Priority Corridor have typically been designed and built with continuous frontage roads over their entire length. These frontage roads are usually two or three lanes wide and signalized at interchanging cross streets. Maintaining acceptable traffic conditions at frontage road intersections that experience varying turning movement volumes can be a significant challenge to transportation agencies in the Houston area and across Texas.

When these interchanges experience high turning movement demands, permitted double turns are often used to maximize traffic throughput. However, traffic demands can have entirely different characteristics between AM, mid-day, and PM peak operations which lead to the need for different lane use controls on a recurring time-of-day basis. In addition to the recurring daily traffic patterns that may need some type of differing lane use control, freeway incidents often impact frontage roads by creating high frontage road traffic demands as freeway mainlane traffic diverts. Lane use information at intersections is typically communicated via pavement markings and static signing. These static traffic control devices cannot accommodate situations where turning movement demands vary significantly over short periods of time (e.g., cyclical variations, during incidents). This shortcoming of static traffic control may significantly impact the efficiency of traffic operations when permitted lane use does not reflect traffic demands.

The use of the changeable lane assignment system (CLAS) on frontage roads addresses both the lane imbalances seen on a time-of-day recurring basis and during freeway incidents. As traffic signals have long been used as a "time management" technique for optimizing traffic operations, CLAS is used as a "space management" technique to add an additional dimension to further optimize traffic operations.

During time-of-day operations, CLAS is intended to more efficiently accommodate variances in turning movement demand that occur throughout the day on a recurring basis. However, during incident management operations, increases in through demand and total approach demand can be expected due to diversion of traffic from the freeway mainlane to the frontage road. When CLAS is activated for incident management, two aspects of the implementation seek to increase frontage road throughput. Throughput is increased through the provision of allowable through movements from all three approach lanes, as well as through the implementation of optimized intersection signal timings to accommodate an increase in outbound frontage road demand. These timings seek to minimize total network delay, including cross streets and inbound frontage road. CLAS incident management signal timing plans primarily provide for increased westbound frontage road green time and cycle length.

OVERVIEW AND BACKGROUND INFORMATION

Development of the CLAS project by the Texas Department of Transportation (TxDOT) included the design, installation, and evaluation of 10 changeable lane assignment control systems that have the capability to alter the permissive double turns at frontage road interchanges based on traffic demands, either on a recurring time-of-day basis or during freeway incident conditions.

The CLAS concept has evolved over several years and was built on the experience of several prototype installations in Dallas and Houston. The fiber optic signing used in the CLAS system was developed and tested by the Texas Transportation Institute (TTI) as a part of Highway Planning and Research (HPR) Project 1232-Task 5.1, Dynamic Lane Assignment Systems, sponsored by TxDOT. The results of this research are documented in TTI Research Report 1232-18 entitled "Space Management: An Application of Dynamic Lane Assignment" (1). The early research was divided into three phases: 1) testing fiber optic sign design features (legibility, target value, etc.); 2) developing 2nd generation signing and testing operations of the signing systems (transition operations, driver understanding and comprehension of the signing) (2); and 3) field evaluation (a static "flip-type" sign at the North Central Expressway at Mockingbird Lane diamond interchange, and a fiber optic installation at the IH-10 and Bingle/Voss diamond interchange in Houston).

Results of the early research indicated that changeable lane assignment systems had the potential to reduce delays and queue lengths during changing traffic volume and turning movement conditions. As a result, the Houston ITS Priority Corridor program implemented the CLAS concept at interchanges along the westbound frontage road of US 290 in northwest Houston and Harris County, as shown in Figure 1. CLAS signing systems were located at intersections where permitted double turns were signed with static signing and pavement markings. The deployment project also updated the signing and controller at the prototype CLAS installation at IH-10 and Bingle/Voss.

Each of the installations consist of two overhead signs located approximately 200 feet upstream of the stopline, and an at-intersection sign across from the stop line. Figure 2 shows a typical layout of the overhead and at-intersection CLAS sign installation. The CLAS system has three basic displays: a double turn display, a transition display, and a shared turn display. Figure 3 illustrates the displays generated by the fiber optic CLAS signs for both double right and left turn intersections.

STUDY OBJECTIVES

The principal goal of this study was to evaluate the operational effectiveness of the CLAS system as an incident management tool to improve operations during incident conditions in the US 290 Corridor (Report 2910-1 evaluated the use of CLAS for recurring time of day changes (4)). This goal was achieved through (and the study methodology based on) the following four objectives:

1. Determine limits for the CLAS incident management evaluation depending on historical accident frequency, and develop a monitoring capability to record incident conditions.
2. Identify measures of effectiveness to evaluate the benefits of using CLAS for incident management.
3. Develop an implementation plan for the use of CLAS for incident management. This plan will assist operators with determining which intersections should be activated for CLAS and incident management signal timings. This plan will consider incident time of day, incident location, degree of blockage, and expected duration.
4. Evaluate traffic operations for actual incidents when CLAS is not engaged for incident management, and simulate traffic operations with CLAS engaged using computer modeling and data from actual incidents.

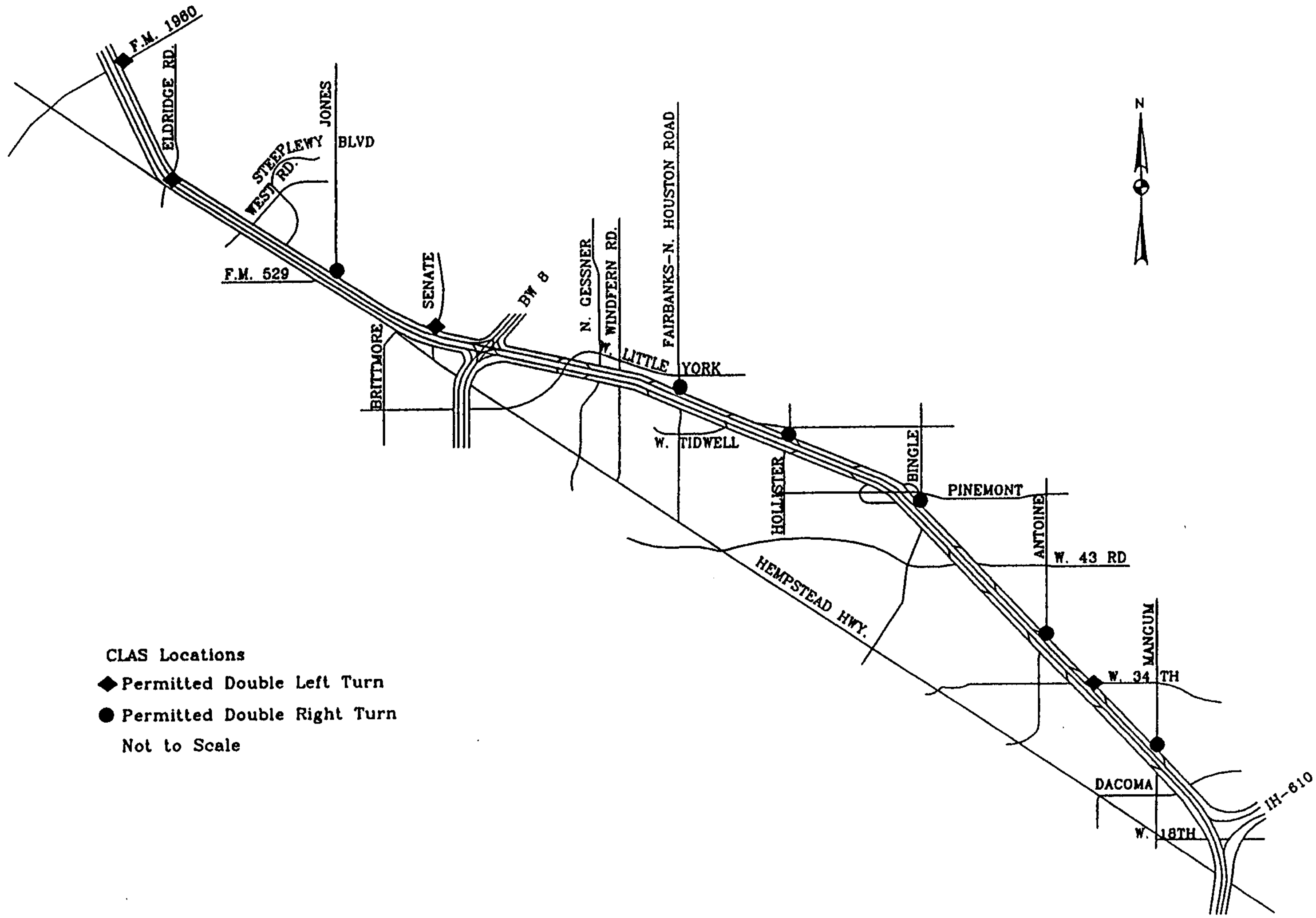


Figure 1. Limits of the US 290 Northwest Freeway Study Corridor

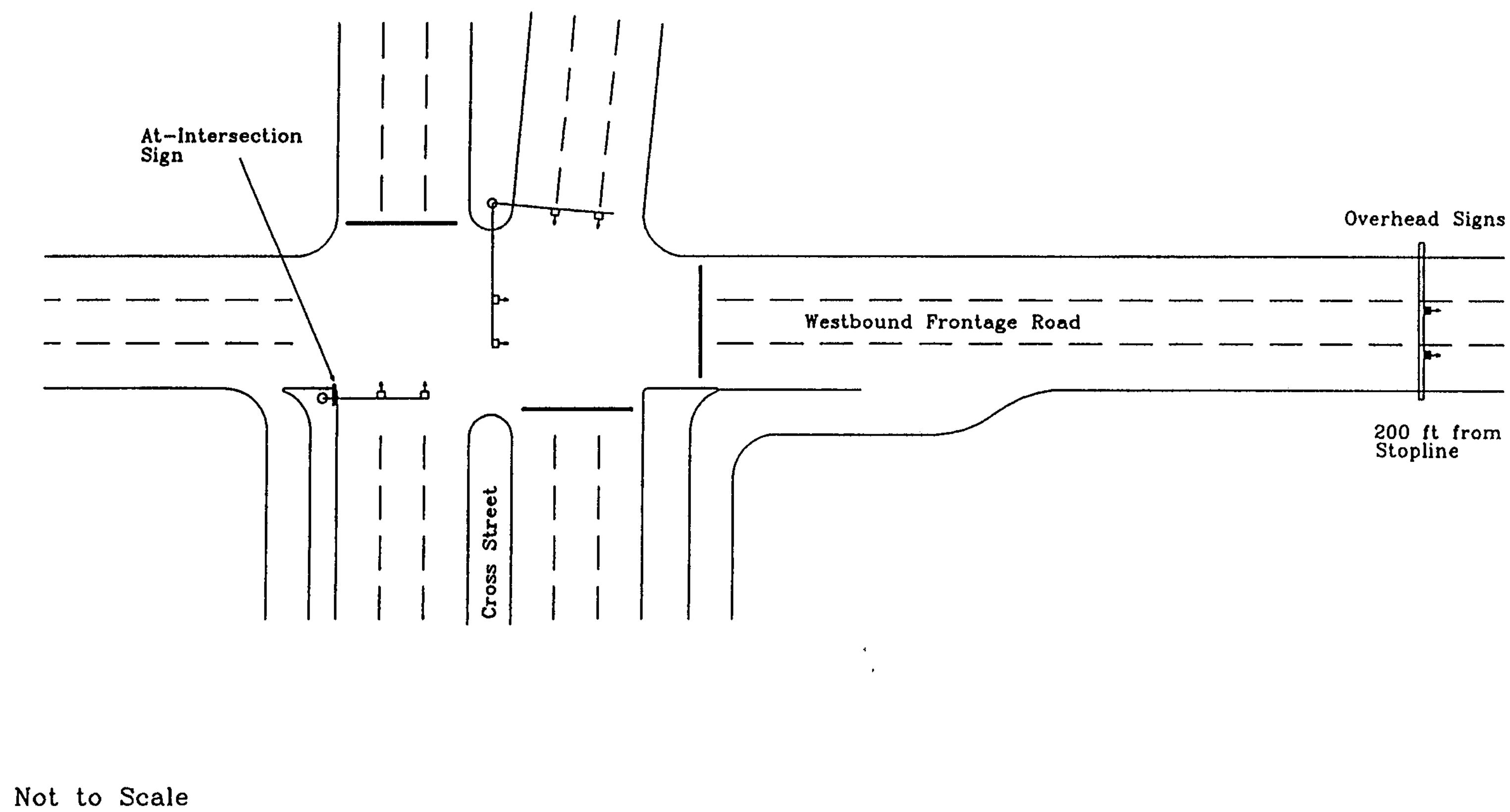


Figure 2. Typical CLAS Installation

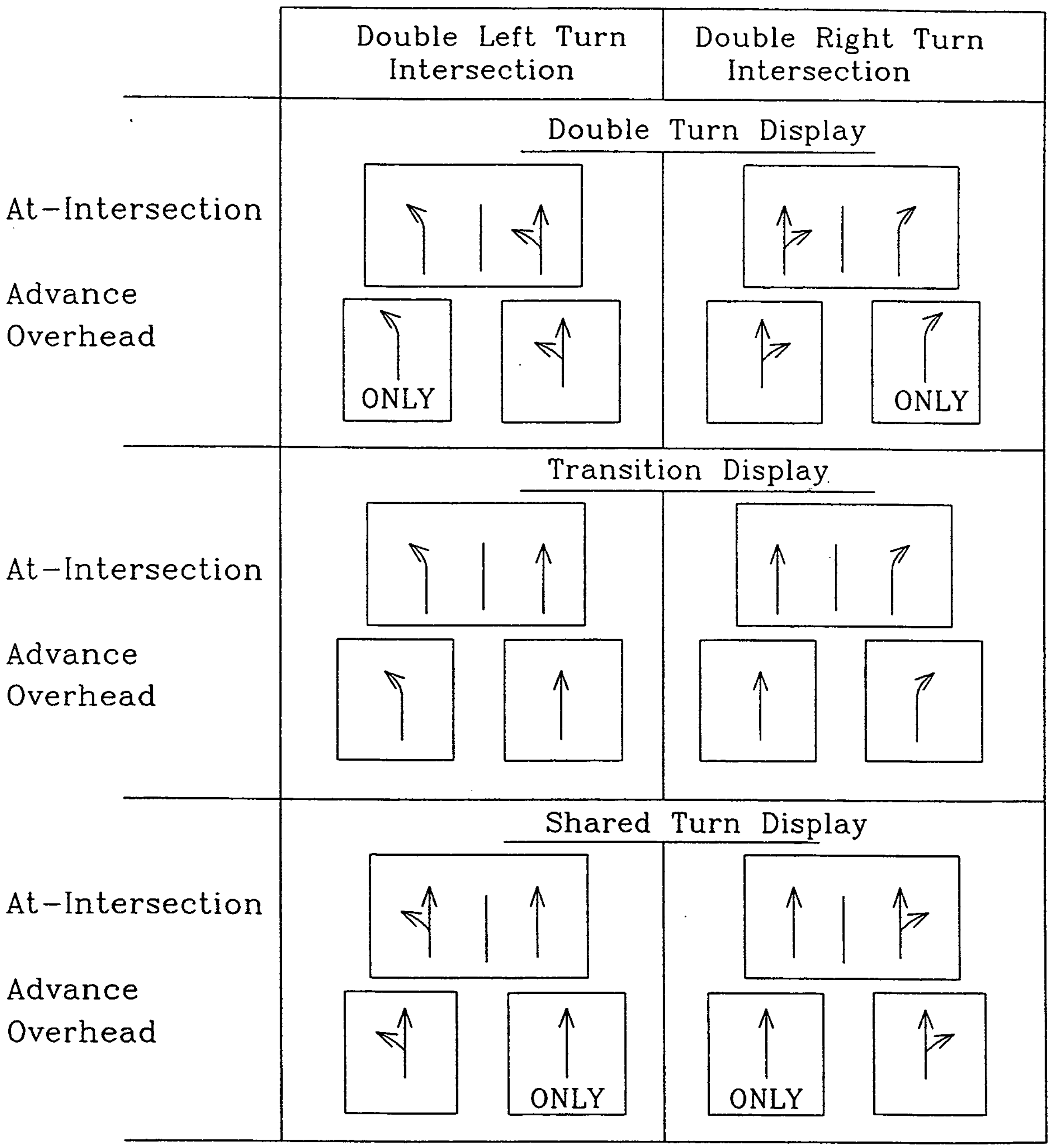


Figure 3. Displays Generated by CLAS Signing

The report is divided into four sections. The first section includes the project problem statement, background information, and the study objectives. The second section presents study methodology, including the development of the CLAS incident management plan, study measures of effectiveness, data collection and reduction procedures, and discussion of computer simulation models used in the evaluation. The third section summarizes the analysis and results, and the fourth section presents findings and conclusions resulting from this study.

STUDY METHODOLOGY

The limits of the study area of the CLAS incident management evaluation are shown in Figure 4. Although CLAS is deployed on the US 290 westbound frontage road approaches, intersections of cross streets from Dacoma to Bingle and the eastbound frontage road were included in the simulated frontage network to capture effects of CLAS during incident management on all frontage road/arterial intersection approaches, on both sides of the freeway, within the study area.

The analysis of the CLAS system for incident management compared simulation results from modeling actual conditions during observed incidents with those results from simulated CLAS incident management. Seven incidents were analyzed in this study. One incident occurred during the AM peak period, three occurred during the mid-day period, and three occurred during the PM peak period. These incidents were recorded with the video data collection system and met the criteria described in this section for implementing CLAS for incident management.

Modeling actual conditions of an incident involved using observed volumes during the incident, time of day lane assignments, and time of day signal timing plans. Modeling simulated CLAS incident management involved using the observed volumes during the actual incident with additional demand due to diversion if applicable, CLAS incident management lane assignments, and signal timings. Saturation flow rates measured for the westbound frontage road approaches at Mangum, West 34th, and Antoine during incident conditions with double turns and shared turns were also incorporated into the models. Implementation procedures presented in this section were used to operate CLAS in incident management mode during each simulated incident.

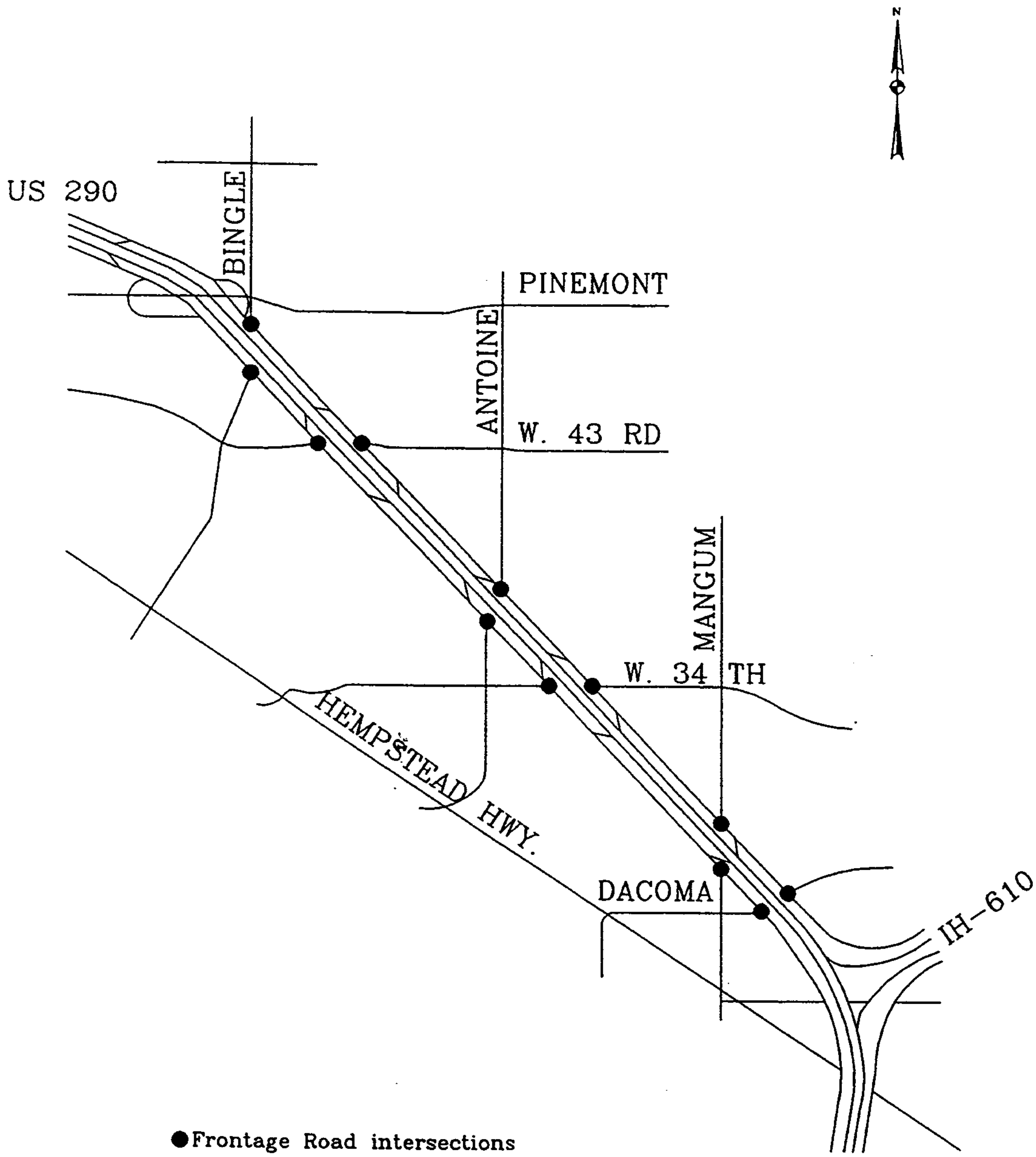
CLAS INCIDENT MANAGEMENT PLAN AND IMPLEMENTATION PROCEDURES

The development of the CLAS incident management plan and implementation procedures included incident management signal timings to optimize frontage road throughput during incidents, establishing guidelines to assist City of Houston (COH) personnel in determining at which locations to activate CLAS lane assignments and incident signal timings, and general procedural relationships among the agencies involved.

Development of Incident Management Signal Timings

Signal timings during CLAS incident management must be changed from regular time-of-day operations to optimize outbound frontage road traffic operations. A set of signal timing plans that provided time management by balancing the need to accommodate additional traffic along the westbound frontage road with the need to minimize delay along the corridor was needed to efficiently handle traffic during incidents on outbound US 290. The steps used to develop these incident management plans follow:

1. Gather volume and geometry data for both the US 290 freeway and adjacent frontage roads. These data were available from existing inventories that TTI collected as part of this project.



●Frontage Road intersections included in simulations

Not to Scale

Figure 4. CLAS Incident Management Evaluation Study Area

2. Use the FREQ 11 macroscopic freeway simulation model to simulate over 180 freeway incidents. The simulations were done with respect to time of day (AM, mid-day, PM), capacity reduction (number of lanes blocked), and expected duration of incident (ranging from 15 minutes to 60+ minutes, in increments of 15 minutes). Incidents were assumed to occur between an exit ramp and the adjacent downstream entry ramp. The FREQ 11 program output included the queue expected due to the capacity reduction caused by an incident, the time to clear that additional queue, and the length of queue.

3. Once the length and duration of the queue was determined for each incident, the frontage road interchanges affected by each incident were identified. The exit ramps located within the queue were then fully loaded (to a capacity of 1900 vph with diverted traffic), and that traffic was added to the normal through movement at each westbound frontage road intersection.

4. PASSER III was used to optimize signal timings at all affected interchanges with the additional through traffic on the westbound frontage road. The resulting timing plans were identified by time period and plan number, and entered into a matrix to allow TranStar operators to easily look up an incident situation (by location, severity or capacity reduction, and expected duration). After a scenario is found in the table the timing plan number and duration can be entered into the CLAS computer on the floor at TranStar.

Tables 1, 2, and 3 present the matrices developed to facilitate CLAS incident management implementation during the AM, mid-day, and PM peak periods, respectively.

TranStar CLAS Incident Management Implementation Strategy

When an incident on US 290 occurs between the hours of 6:00 a.m. and 7:00 p.m., TxDOT personnel on the floor of TranStar contacts COH personnel via telephone or pager. The COH is responsible for the implementation of incident management signal timing plans and lane assignment changes using the CLAS computer. Table 4 summarizes the notification and implementation sequence for the CLAS system during incident management.

General TxDOT CLAS Incident Management Procedures

TxDOT traffic operations personnel were informed about CLAS incident management procedures and given training on the procedures to follow for incidents occurring on outbound US 290 between the Mangum exit and Pinemont entrance between weekday hours of 6 a.m. and 7 p.m.

For any incident verified on outbound US 290, TxDOT personnel immediately contacted the COH representative to activate the CLAS Incident Management Plan. TxDOT personnel were instructed to note the time that COH personnel were contacted (and any other CLAS related incident details) in the comments section of the TranStar incident log.

Table 1. US 290 CLAS Implementation Strategy - AM Period (6am-9am)

Expected Incident Duration	Number of Lanes Blocked	Accident Location				
		between Mangum exit and Mangum entry	between Mangum entry and 34th exit	between 34th exit and Antoine entry	between Antoine entry and 43rd exit	between 43rd exit and Pinemont entry
less than 45 minutes	shoulder	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions
	1	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions	34th, Antoine, 43rd, Bingle	43rd, Bingle
	2	Dacoma, Mangum	Mangum, 34th, Antoine	34th, Antoine	34th, Antoine, 43rd, Bingle	43rd, Bingle
	3	Dacoma, Mangum	Mangum, 34th, Antoine	34th, Antoine	34th, Antoine, 43rd, Bingle	34th, Antoine, 43rd, Bingle
	4	Dacoma, Mangum	Mangum, 34th, Antoine	34th, Antoine	34th, Antoine, 43rd, Bingle	
more than 45 minutes	shoulder	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions
	1	Dacoma, Mangum	check actual traffic conditions	check actual traffic conditions	34th, Antoine, 43rd, Bingle	43rd, Bingle
	2	Dacoma, Mangum	Dacoma, Mangum, 34th, Antoine	Dacoma, Mangum, 34th, Antoine	Dacoma, Mangum, 34th, Antoine, 43rd, Bingle	Dacoma, Mangum, 34th, Antoine, 43rd, Bingle
	3	Dacoma, Mangum	Dacoma, Mangum, 34th, Antoine	Dacoma, Mangum, 34th, Antoine	Dacoma, Mangum, 34th, Antoine, 43rd, Bingle	Dacoma, Mangum, 34th, Antoine, 43rd, Bingle
	4	Dacoma, Mangum	Dacoma, Mangum, 34th, Antoine	Dacoma, Mangum, 34th, Antoine	Dacoma, Mangum, 34th, Antoine, 43rd, Bingle	

Table 2. US 290 CLAS Implementation Strategy - Mid-Day Period (9am-3pm)

Expected Incident Duration	Number of Lanes Blocked	Accident Location				
		between Mangum exit and Mangum entry	between Mangum entry and 34th exit	between 34th exit and Antoine entry	between Antoine entry and 43rd exit	between 43rd exit and Pinemont entry
less than 45 minutes	shoulder	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions
	1	Mangum	Mangum, 34th, Antoine	34th, Antoine	34th, Antoine, 43rd, Bingle	43rd, Bingle
	2	Mangum	Mangum, 34th, Antoine	Mangum, 34th, Antoine	34th, Antoine, 43rd, Bingle	34th, Antoine, 43rd, Bingle
	3	Mangum	Mangum, 34th, Antoine	Mangum, 34th, Antoine	34th, Antoine, 43rd, Bingle	Mangum, 34th, Antoine, 43rd, Bingle
	4	Mangum	Mangum, 34th, Antoine	Mangum, 34th, Antoine	34th, Antoine, 43rd, Bingle	
more than 45 minutes	shoulder	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions
	1	Mangum	Mangum, 34th, Antoine	34th, Antoine	Mangum, 34th, Antoine, 43rd, Bingle	Mangum, 34th, Antoine, 43rd, Bingle
	2	Mangum	Mangum, 34th, Antoine	Mangum, 34th, Antoine	Mangum, 34th, Antoine, 43rd, Bingle	Mangum, 34th, Antoine, 43rd, Bingle
	3	Mangum	Mangum, 34th, Antoine	Mangum, 34th, Antoine	Mangum, 34th, Antoine, 43rd, Bingle	Mangum, 34th, Antoine, 43rd, Bingle
	4	Mangum	Mangum, 34th, Antoine	Mangum, 34th, Antoine	Mangum, 34th, Antoine, 43rd, Bingle	

Table 3. US 290 CLAS Implementation Strategy - PM Period (3pm-8pm)

Expected Incident Duration	Number of Lanes Blocked	Accident Location		
		between Mangum exit and Mangum entry	between Mangum entry and Antoine entry	between Antoine entry and Pinemont entry
less than 45 minutes	shoulder	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions
	1	Mangum	Mangum, 34^{th}, Antoine	34^{th}, Antoine, 43^{rd}, Bingle
	2	Mangum	Mangum, 34^{th}, Antoine	34^{th}, Antoine, 43^{rd}, Bingle
	3	Mangum	Mangum, 34^{th}, Antoine	Mangum, 34^{th}, Antoine, 43^{rd}, Bingle
	4	Mangum	Mangum, 34^{th}, Antoine	
more than 45 minutes	shoulder	check actual traffic conditions	check actual traffic conditions	check actual traffic conditions
	1	Mangum	Mangum, 34^{th}, Antoine	Mangum, 34^{th}, Antoine, 43^{rd}, Bingle
	2	Mangum	Mangum, 34^{th}, Antoine	Mangum, 34^{th}, Antoine, 43^{rd}, Bingle
	3	Mangum	Mangum, 34^{th}, Antoine	Mangum, 34^{th}, Antoine, 43^{rd}, Bingle
	4	Mangum	Mangum, 34^{th}, Antoine	

Table 4. CLAS Notification and Implementation Sequence of Events (Proposed)

Agency	Action
TxDOT	Incident reported on US 290.
TxDOT	Identify incident on outbound US 290 mainlanes between IH-610 and Pinemont.
TxDOT	Call COH CLAS contact on 3rd floor.
COH	COH contact arrives on TranStar floor and confers with TxDOT personnel about incident and expected impact.
COH	COH operator activates CLAS incident management plans on CLAS computer, sets timer or manually holds timings, and logs actions on supplemental CLAS action log.
TxDOT	Notify COH contact that incident clears.
COH	COH operator returns CLAS operation to normal by either letting plans time out or manually changing to normal operations, and logs actions on supplemental CLAS action log.
COH	Contact TTI, informing of CLAS usage, so that TTI can pull video tapes for analysis.

If necessary (to maximize traffic operations), TxDOT personnel were instructed to turn off (remotely from TranStar) one or more flow signals downstream of the incident to improve re-entry of diverting vehicles to the freeway. Once the incident cleared, TxDOT personnel notified the COH contact so that timing plans and CLAS displays could be returned to normal operation.

General City of Houston CLAS Incident Management Procedures (Proposed)

The general procedures COH personnel follow during incident management using CLAS were as follows:

1. The COH operator identifies and begins normal management of an incident on US 290. In addition, operators note location and estimate time to clear based on their judgment and with conference with TxDOT operators.

2. The COH operator refers to the CLAS incident timing plan sheets, selecting a plan based on the following criteria:

   a. time of day (AM, mid-day, or PM period)
   b. location of incident
   c. expected incident duration (using operator judgment)
   d. number of lanes that are (or will be) blocked

Using these four pieces of data, a timing plan and any necessary lane assignment changes are chosen and input into the CLAS computer. A time-out default value is also set so that signal operations will return to normal automatically after a specified time if the operator does not intervene.

3. The COH operators continue managing the incident as normal.

4. If the incident clears sooner than expected or lasts longer than expected, the operator can change the time-out or timing plan number manually. The CLAS computer alerts the operator when the timer reaches a certain value (e.g., 5 minutes), and the operator can extend CLAS incident management manually or automatically transition to normal operation.

Incident Notification System

A notification procedure was implemented to make TTI personnel aware of incidents on outbound US 290 in a timely manner. Beginning in April 1998, TTI relied on TxDOT traffic operations personnel to notify TTI when incidents occurred on outbound US 290. Notification of incidents was made via a phone call from TxDOT personnel to TTI personnel. This manual notification procedure was used for seven months until the TranStar incident logs were made available through computer servers at TTI. Once the TranStar incident database was available in real-time in October 1998, video tapes could be pulled immediately if necessary, providing a detailed record of each incident. Information available in the TranStar incident database includes the nearest cross-street, incident date, time of detection, number of lanes and/or shoulders blocked, and the type of incident (major or minor). Figure 5 shows an example of a query from the TranStar incident database.

MEASURES OF EFFECTIVENESS

The primary goal in using CLAS to improve operations during incident management is to accommodate increased frontage road though demand resulting from freeway diversion. Space management techniques and increased green time for the westbound frontage road movement would be expected to increase throughput of the freeway/frontage road system, and resulting lower total delay.

Researchers identified combined freeway and frontage road network total delay and delay per vehicle as the primary measures of effectiveness for making comparisons between actual conditions observed during incidents and simulated incident management conditions. Frontage road intersection approach level of service (LOS), throughput, and lane use violations were also identified as additional measures of effectiveness.

I-45 Gulf	SCOTT ST	Southbound	Cleared	6/18/99	13:04:00	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	Before	Stall	6/18/99	15:26:52
I-10 Katy	GESSNER DR	Westbound	Cleared	6/18/99	17:31:00	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	At	Stall	6/18/99	17:42:15
I-45 North	ALLEN PKY	Southbound	Cleared	6/18/99	15:49:00	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	At	Stall	6/18/99	15:57.11
I-45 North	ALLEN PKY	Southbound	Cleared	6/18/99	16:30:00	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	At	Minor Accident/Collision	6/18/99	16:56.52
I-45 North	QUITMAN ST	Southbound	Cleared	6/18/99	6:08:00	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	At	Major Accident/Collision, Heavy Truck	6/18/99	7.43:20
I-45 North	CAVALCADE ST	Southbound	Cleared	6/18/99	7:15:00	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	At	Minor Accident/Collision	6/18/99	7:22:58
I-45 North	W PARKER RD	Southbound	Cleared	6/18/99	8:47:00	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	At	Major Accident/Collision	6/18/99	8:53:46
US-290 Northwest	MANGUM RD	Westbound	Cleared	6/18/99	11:18:00	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	At	Major Accident/Collision	6/18/99	12:42:59
US-290 Northwest	W 34TH ST	Westbound	Cleared	6/18/99	16:12:00	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Before	Minor Accident/Collision	6/18/99	16:17:14
US-290 Northwest	W 34TH ST	Westbound	Cleared	6/18/99	16:13:00	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	At	Major Accident/Collision	6/18/99	16:15:41
US-290 Northwest	PINEMONT DR	Eastbound	Cleared	6/18/99	6:50:00	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	At	Minor Accident/Collision	6/18/99	7:12:47
US-290 Northwest	SENATE AVE	Westbound	Cleared	6/18/99	17:49:00	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Before	Major Accident/Collision	6/18/99	18:37:16
US-59 Southwest	EDLOE ST	Northbound	Cleared	6/18/99	12:47:00	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	At	Stall	6/18/99	13:03:18
US-59 Southwest	I-610	Northbound	Cleared	6/18/99	8:25:00	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Before	Minor Accident/Collision	6/18/99	8:46:05
US-59 Southwest	HILLCROFT AVE	Southbound	Cleared	6/18/99	17:06:00	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	At	Stall	6/18/99	17:11:57
US-59 Southwest	BISSONNET ST	Southbound	Cleared	6/18/99	16:34:00	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	At	Minor Accident/Collision	6/18/99	16:44:16
US-59 Southwest	BELTWAY 8	Southbound	Cleared	6/18/99	18:18:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	At	Vehicle on Fire	6/18/99	18:29:38
I-10 East	SAN JACINTO ST	Eastbound	Cleared	6/18/99	17:44:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Before	UNKNOWN	6/18/99	17:46:15
I-610 North Loop	ELLA BLVD	Westbound	Cleared	6/18/99	6:30:00	1	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	At	Major Accident/Collision	6/18/99	7:12:23
I-610 West Loop	US-59	Northbound	Cleared	6/18/99	12:33:00	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	At	Stall	6/18/99	13:03:28

Figure 5. Sample of TranStar Incident Log

DATA COLLECTION AND REDUCTION

Video Data Collection System

Data were collected for the CLAS incident management evaluation with the data collection system shown in Figure 6. TxDOT installed pole-mounted closed circuit television (CCTV) cameras between the mainlanes and the outbound frontage road, downstream of intersections with Mangum, West 34th, and Antoine. The cameras supplied video to video cassette recorders (VCRs) secured in pole mounted cabinets. Two VCRs per cabinet, recording in 12-hour mode, provided continuous 24 hour coverage. The CCTV cameras were positioned to provide a full view of the westbound frontage road approach as well as the westbound US 290 mainlanes. In the event that an incident occurred, researchers retrieved video tapes from the cabinets and inserted blank tapes. Otherwise, VCRs automatically recorded over the previous day's video.

Mainlane, Ramp, and Frontage Road Counts

Mainlane and frontage road counts were conducted from videotapes of the incidents selected for evaluation. The analysis period of each incident was established to capture the duration of the incident as well as any subsequent residual queue dissipation. Mainlane counts were conducted downstream of each incident in five-minute intervals during each incident analysis period. Mangum and West 34th exit ramp counts were also conducted in five-minute intervals during each incident analysis period. Westbound frontage road turning movement counts were conducted by cycle during each incident analysis period. Data for each of these counts were summarized into 15-minute periods. Counts for all other frontage road approaches in the network were obtained from historical 15-minute interval turning movement counts. Counts were also conducted to determine the number of lane use violations at Mangum, West 34th, and Antoine.

Saturation Flow Rate Study

Saturation flow rate is defined as "the equivalent hourly rate at which vehicles can traverse an intersection approach under prevailing conditions, assuming that a green signal is available at all times and no lost times are experienced, in vehicles per hour green or vehicles per hour green per lane" (3). The saturation flow rate is the inverse of the time (in seconds) that it takes to service each vehicle. The Highway Capacity Manual procedure for the calculation of saturation flow rate was followed for the estimation of saturation flow rates during each study period.

Researchers conducted saturation flow studies for the westbound frontage road movement at Mangum, West 34th, and Antoine. These studies were used to determine saturation flow rates during incidents for two prevailing conditions: 1) when lane assignments provided for double turns; and 2) when lane assignments provided for shared turns. Vehicle headways were measured for each vehicle in the queue at the onset of green for each lane at each of the three intersections. The average headway of the fourth vehicle to the last vehicle in queue was calculated, and the inverse of this value was calculated as the saturation flow rate. An example of this calculation is shown in Table 5. This table summarizes the data collected for the middle lane of West 34th on February 10, 1998, for 15 cycles during the PM peak period. Video recordings were used to determine when each

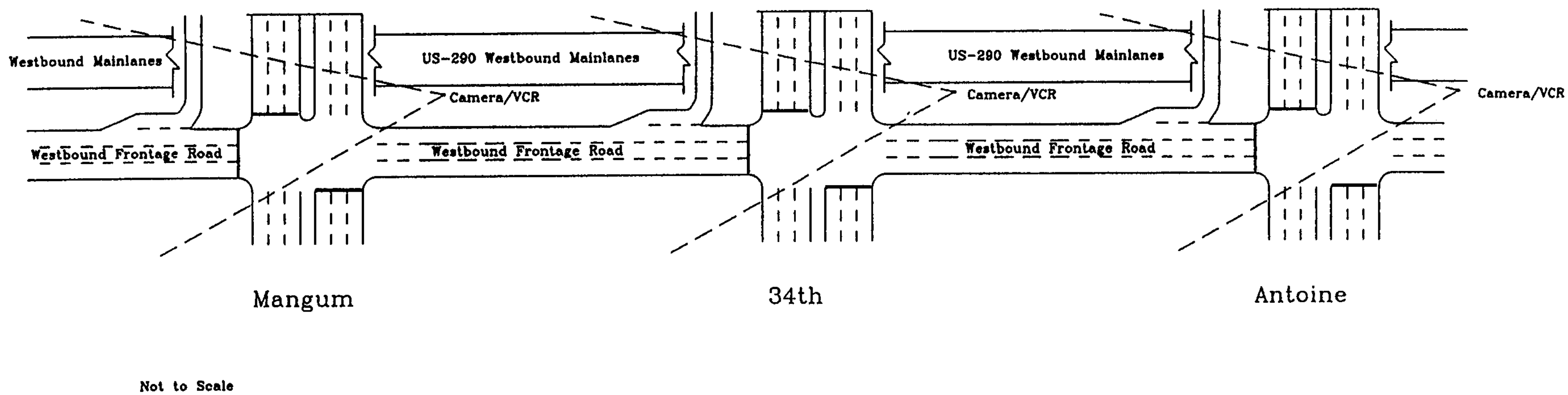


Figure 6. CLAS Video Data Collection System

Table 5. Calculation of Saturation Flow Rates

Vehicle	Headway (secs)														
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11	Cycle 12	Cycle 13	Cycle 14	Cycle 15
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1.98	1.65	2.20	2.69	2.41	1.87	2.69	2.36	2.31	2.03	2.36	2.04	2.03	1.48	2.14
3	1.70	1.48	1.81	2.08	2.04	1.38	2.14	1.81	1.76	2.42	1.76	1.70	1.54	1.65	1.82
4	2.31	1.81	2.31	2.15	1.75	1.53	2.25	1.76	2.47	1.92	1.86	1.59	2.03	2.03	2.14
5	2.36	1.81	2.09	2.25	1.65	1.38	1.21	1.81	1.92	2.20	1.98	1.65	2.96	1.87	1.92
6	2.20	1.76	1.53	4.17	1.38	1.86	1.32	2.03	2.14	1.98	1.65	1.37	1.60	1.75	1.92
7	2.03	1.65	1.65	1.93	1.04	1.87	1.59	1.76	2.25	1.59	1.76	1.54	1.59	1.65	1.70
8	1.16	1.81	2.03	2.25	1.21	1.76	2.14	3.24	3.96	1.32	2.47	1.37	1.65	2.97	1.76
9	1.53	1.59	1.71	1.54	1.21	2.42	1.49	1.92	1.76	1.53	1.70	1.65	1.59	2.58	1.21
10	1.32	1.54	1.53	1.31	1.31	1.64	1.48	1.38	1.97	1.54	1.43	2.36	2.42	2.75	1.92
11	1.21	2.75	1.43	1.82	1.65	2.31	1.65	1.48	1.54	1.32	1.48	1.49	3.35	1.59	1.65
12	1.43	2.42	1.43	1.42	1.27	2.09			1.27	1.76	1.60	1.20	1.04	1.65	1.32
13	2.08		1.87	2.15	1.92	2.25				1.92	1.37	1.54	1.32	1.31	1.32
14	1.32		1.81	1.26	1.43	1.04				1.54	1.54	1.71	2.25	2.81	3.18
15	1.87			1.26	1.37	1.27					1.42	1.42		1.75	2.86
16	1.70			0.94							1.43			1.98	1.37
17	1.38			1.26							1.54				1.43
18	2.03			1.81											1.87
19				1.38											
20															

Middle Lane, US 290 WB Frontage Road at West 34th, PM peak period, 2/11/98

Total Headway = 284.65 seconds

Total Average Headway = 1.77 seconds

Total Vehicles = 161 vehicles

Lane Saturation Flow = 2036 vphgpl

vehicle crossed the stop line at the approach, and a computer-based headway calculation program was used to determine each individual headway.

The average saturation flow rate for each westbound frontage road intersection approach (by lane) for lane assignments with double turns and shared turns is summarized in Table 6. At the time the saturation flow studies were conducted, CLAS had only been implemented for incident management during two incidents. One of the two incidents occurred during rainy weather and was not included in the saturation flow study. Researchers analyzed video from the remaining incident to determine saturation flow rates for incident conditions during shared turns. These data were supplemented with saturation flow rate data at Mangum and West 34th during incidents in which CLAS was operating in shared turn mode during time of day operations. Total approach saturation flow rates for shared turn configurations were 4.2, 5.5, and 5.1 percent higher than saturation flow rates for double turn configurations at Mangum, West 34th, and Antoine, respectively.

Freeway Capacity Under Incident Conditions

In order to model freeway mainlane operations during incidents, it is necessary to know the freeway capacity at the location of the incident. Researchers quantified freeway capacity at each of the incidents evaluated in this study by conducting mainlane counts from videotape provided by the first study CCTV camera downstream of each incident. The counts were summarized into 15-minute periods and input into the computer model as the capacity of the freeway for each 15-minute period.

COMPUTER SIMULATION

Two computer models were used in the CLAS incident management evaluation. The FREQ 11 model was used to model freeway mainlane and entrance/exit ramp operations during simulated incidents. The Synchro model was used to model the frontage road network within the study limits. The frontage road network included westbound and eastbound frontage road intersections with Dacoma, Mangum, West 34th, Antoine, 43rd, and Bingle. Each model was calibrated using data available from videotapes of incidents within the limits of the study. Data not available from incident videotape were provided from historical data.

FREQ 11

FREQ 11 is a macroscopic computer model developed by the Institute of Transportation Studies at the University of California at Berkeley. The model provides for freeway corridor modeling and analysis to assess various design and operational improvements. FREQ 11 allows the user to establish a freeway network composed of numerous subsections and specify the subsection lengths, design speeds, capacities, speed-flow curves, position and capacity of entrance and exit ramps, grades, and number of lanes. Freeway and ramp demand data are supplied in user-defined time slices.

Fifteen-minute time slices (or intervals) were used throughout this evaluation in both the FREQ 11 and Synchro models. Data reduction from videotapes for freeway mainlanes and ramps were summarized in 15-minute time intervals. Historical data for freeway origin demand and

Table 6. Summary of Saturation Flow Study Results

Location	CLAS Mode	Left Lane			Middle Lane			Right Lane		
		Saturation Flow Rate (vph)	Number of Cycles Observed	Number of Vehicles Observed	Saturation Flow Rate (vph)	Number of Cycles Observed	Number of Vehicles Observed	Saturation Flow Rate (vph)	Number of Cycles Observed	Number of Vehicles Observed
Mangum	Double Turns	1816	30	185	2019	30	248	1807	30	179
	Shared Turns	1974	37	221	2071	38	236	1890	45	263
34th	Double Turns	1855	42	251	1990	45	353	1813	45	372
	Shared Turns	1910	53	399	2069	53	547	1976	53	581
Antoine	Double Turns	2134	45	411	1982	45	423	1811	34	247
	Shared Turns	2280	15	159	2019	15	136	1959	15	114

entrance and/or exit ramp demand not covered by study CCTV cameras were available in 15-minute time intervals from previous TTI volume data collection.

The US 290 westbound freeway mainlane model is composed of 500 ft subsections. This increases the accuracy of replicating the placement of the incident location within the model and allows for the development of a general freeway/ramp model of the US 290 westbound mainlanes that could be tailored for each individual incident simulation.

Synchro

Synchro is a microscopic computer model developed to model and optimize network traffic signal timings. Synchro delay calculations are based on the methods of the 1994 Highway Capacity Manual, Chapter 9. Synchro allows the user to establish an analysis network comprised of links and nodes and specify link lengths, number of lanes, allowable movements by lane, volume by movement, saturation flow rate by lane group, and signal timings at each node. Volumes are supplied in equivalent hourly flow rates regardless of simulated time intervals. Fifteen-minute time intervals were used in Synchro simulations of each incident.

Although Synchro does not explicitly handle four-phase diamond operations, it can be manipulated to approximate four-phase operations. Each diamond interchange was defined as a zone with one of the two intersections designated as the master intersection and an offset of approximately nine seconds set for the heaviest internal movement. Because Synchro is a microscopic model, producing slightly different results with each run of the same file, each simulation was run three times and the measures of effectiveness (MOEs) averaged.

Data reduction of westbound frontage road approach volumes was conducted by cycle, summarized into 15-minute volumes, and converted to hourly flow rates. Volumes for all other intersection approaches in the network were obtained from historical turning movement counts. These counts, which were also available in 15-minute time intervals, were converted to hourly flow rates for use in the Synchro model.

Model Calibration

The FREQ 11 and Synchro models were calibrated using actual input information available from videotapes of incidents in the US 290 study area. Historical information was used where information during actual incidents was unavailable. Summaries of the input data for the actual condition simulations and the CLAS incident management simulations for the FREQ 11 and Synchro models are presented in Tables 7 and 8, respectively.

Table 7. Inputs to FREQ Model for Actual and CLAS Incident Management Simulations

Input	Actual Condition Simulation	CLAS Incident Management Simulation
Scaled link-node network	Established from plans in 500 ft sections	Same as actual conditions
Number of lanes per section	Established from plans	Same as actual conditions
Default mainlane capacity (calibrated for time of day)	2100 vphpl - AM and mid-day 2000 vphpl - PM	Same as actual conditions
Mainlane capacity at incident	Measured from mainlane counts of downstream videotape in 15-minute time intervals	Same as actual conditions
Mainlane demand at origin	Historical counts in 15-minute time intervals	Same as actual conditions
Default entrance and exit ramp capacity (calibrated for time of day)	1900 vphpl - AM and mid-day 1800 vphpl - PM	Same as actual conditions
Exit ramp capacity when frontage road queue extends onto ramp	Reduced to observed volume from videotape if continuous or reduced proportionately, if only for portions of the time interval	1900 vphpl
Entrance and exit ramp demand outside of incident area of influence	Historical counts in 15-minute time intervals	Same as actual conditions
Entrance ramp demand upstream of incident location (applies to Mangum entry)	Historical counts in 15-minute time intervals adjusted to reflect reduced demand due to mainlane queue if applicable	Same as actual conditions
Entrance ramp demand downstream of incident location (applies to Mangum or Antoine depending on incident location)	Historical counts in 15-minute time intervals adjusted to reflect increased demand due to diversion vehicles	Same plus additional vehicles assumed to divert to frontage road with additional westbound frontage road green time and increased westbound capacity due to change in lane assignments
Exit ramp demand upstream of incident location (applies to Mangum or West 34th exit ramps or both depending on location of incident and resulting queue)	Video counts of ramp in 15-minute time intervals	Same plus additional vehicles assumed to divert to frontage road with additional westbound frontage road green time and increased westbound capacity due to change in lane assignment (only if resulting queue extends upstream of exit ramp)

Table 8. Inputs to Synchro Model for Actual and CLAS Incident Management Simulations

Input	Actual Condition Simulation	CLAS Incident Management Simulation
Scaled link-node network	Established from plans	Same as actual conditions
Number of approach lanes and allowable turning movements from each lane at each intersection	Established from plans	Established from plans with shared turns at activated CLAS intersections
Saturation flow rates for Mangum, West 34th, and Antoine westbound frontage road approaches	Based on saturation flow studies from video when applicable; TOD lane assignment was in effect.	Based on saturation flow studies from video when shared turn lane assignment was in effect
Saturation flow rates for all other approaches in network	1900 pcphplg	Same as actual conditions
Lane by lane demand for westbound frontage road approaches (may apply to Mangum, West 34th, and Antoine depending on location of incident)	Based on video counts by cycle and summed to 15-minute time intervals	Same plus additional vehicles assumed to divert to frontage road with additional westbound frontage road green time and increased westbound capacity due to change in lane assignments
Lane by lane demand for all other approaches in network	Based on historical turning movement count data	Same as actual conditions
Signal timing plans	Based on time of day signal timing plans in master computer	Based on incident management timing plans in master computer for intersections activated (time of day signal timing plans used for all other intersections)

ANALYSIS AND RESULTS

As outlined in the study methodology, seven incidents that met the criteria for CLAS implementation were documented on videotape and used for the evaluation of CLAS for incident management. Each incident was modeled with FREQ 11 for freeway mainlane and entrance/exit ramp operations and with Synchro for frontage road operations in the 12-intersection network. The effect of CLAS for incident management was determined by comparing the results from computer model simulation of the actual incident under actual conditions with computer model simulation of what would have happened if CLAS had been implemented for incident management. Modeling of actual incident conditions used normal time of day lane assignments with corresponding saturation flow rates and signal timing plans. In simulating CLAS for incident management, shared turn lane assignments with corresponding saturation flow rates, incident management signal timings, and increases in frontage road demand were used at the intersections affected by the incident.

This chapter presents the results of the analysis of CLAS operations during incident management. The results of the simulation of the seven incidents are summarized by time of day, i.e., AM peak period, mid-day period, and PM peak period. The results of a lane use violation study are presented as well.

INCIDENT SIMULATION RESULTS

A summary of results from the simulation of the seven incidents is provided in Table 9. This table provides information on the time of the analysis period (lane blockage plus queue dissipation), number of lanes blocked, duration of blockage, location of blockage, the intersections that would have been activated based on the guidelines presented in Tables 1-3, and the total network (freeway and frontage road system) delay savings (in terms of vehicle-hours) that resulted from modeling of CLAS implementation.

The results of simulating CLAS for incident management suggests that CLAS would have provided benefits for all mid-day and PM peak period incidents that were analyzed. Only the single AM peak period incident simulation produced a disbenefit. A summary of benefits provided by CLAS for the mainlane and frontage road/cross street network is presented in Table 10. Delay savings are quantified in terms of veh-hrs and dollars (assuming an average value of time of $15.50 per hour).

A set of three tables has been prepared for each incident. The first table provides information related to the incident characteristics. The second table provides a summary of frontage road, freeway mainlane, and combined network total delay, and delay per vehicle for the actual condition and simulated CLAS condition. The third table provides delay per vehicle, LOS, and throughput for each facility in the frontage road network (outbound frontage road, inbound frontage road, Dacoma, Mangum, West 34th, Antoine, 43rd, and Bingle) for the actual condition and simulated CLAS condition. LOS was determined using facility delay per vehicle and the HCM.

Table 9. Summary of CLAS Incident Management Simulation Results

Date	Analysis Period	Description of Blockage	Location of Incident	Incident Management Mode Activated at:	Delay Savings from use of CLAS (veh-hr)	Percent Change	Was CLAS in Simulated Incident Management Mode Beneficial?
AM Peak Period							
5/27/98	8:00-8:45	1 lane 30 minutes	westbound between West 34th and Antoine	West 34th, Antoine	-35.4	-8.2%	NO
Mid-day Peak Period							
4/13/98	12:00-13:00	2 lanes 15 minutes	westbound between West 34th and Antoine	West 34th, Antoine	317.7	26.2%	YES
6/1/99	11:45-13:00	2 lanes 45 minutes	westbound between Mangum entrance ramp and West 34th exit ramp	Mangum, West 34th, Antoine	196.5	12.7%	YES
6/18/99	11:00-11:45	2 lanes 30 minutes	westbound between Mangum exit ramp and Mangum	Mangum	82.8	12.8%	YES
PM Peak Period							
6/9/98	18:45-19:30	1 lane 30 minutes	westbound between West 34th and Antoine	Mangum, West 34th, Antoine	108.7	11.1%	YES
10/5/98	17:15-18:15	1 lane 30 minutes	westbound between West 34th exit ramp and West 34th	Mangum, West 34th, Antoine	4.7	0.4%	YES
5/19/98	18:00-18:45	1 lane 30 minutes	westbound between West 34th exit ramp and West 34th	Mangum, West 34th, Antoine	23.0	2.2%	YES

Table 10. Summary of Mainlane, Frontage Road/Cross Street System, and Total Delay Savings

Date	Analysis Period	Description of Blockage	Mainlane Delay Savings		Frontage Road/Cross Street Delay Savings		Total Delay Savings	
			veh-hr	Dollars	veh-hr	Dollars	veh-hr	Dollars
AM Peak Period								
5/27/98	8:00-8:45	1 lane 30 minutes	20.0	$310	-55.4	-$859	-35.4	-$549
Mid-day Peak Period								
4/13/98	12:00-13:00	2 lanes 15 minutes	274.9	$4,261	42.8	$663	317.7	$4,924
6/1/99	11:45-13:00	2 lanes 45 minutes	191.4	$2,967	5.1	$79	196.5	$3,046
6/18/99	11:00-11:45	2 lanes 30 minutes	82.4	$1,277	0.4	$6	82.8	$1,283
PM Peak Period								
6/9/98	18:45-19:30	1 lane 30 minutes	173.2	$2,685	-64.5	-$1,000	108.7	$1,685
10/5/98	17:15-18:15	1 lane 30 minutes	157.0	$2,434	-152.3	-$2,361	4.7	$73
5/19/98	18:00-18:45	1 lane 30 minutes	95.9	$1,486	-72.9	-$1,130	23.0	$357

Note: Dollar values based on a value of time of $15.50 per hour.

AM Peak Period Incident Summary

Only one AM incident (which occurred on 5-27-98) from the pool of candidate incidents was selected for analysis. As the westbound direction is the off peak direction of travel on US 290 during the AM peak period, the majority of the incidents reviewed did not cause any significant delay that would have warranted activating CLAS.

More details related to the 5-27-98 incident simulation are presented in Tables 11-13. The results of this analysis show that activating CLAS could have actually increased total freeway and frontage road network delay by approximately 8 percent. While slight improvements in the westbound frontage road throughput were seen (approximately 2 percent), the adverse impact of CLAS on operations on West 34th and Antoine resulted in an increase in total network delay. The LOS on all other facilities remained unchanged.

Several factors led to increased total delay in this incident. The incident occurred midway between West 34th and Antoine. The resulting queue never reached the Mangum exit ramp and only reached the West 34th exit ramp for a portion of the analysis period. Therefore, significant diversion due to this incident did not occur. Secondly, the incident blocked a single lane for a duration of 30 minutes during a low demand time period. It is possible that CLAS would produce benefits during AM peak period incidents blocking two or more lanes.

Mid-day Period Incident Summaries

Three incidents were analyzed for the mid-day period. Tables 14-16 provide details of the 4-13-98 incident analysis. Details of the 6-1-99 incident analysis are provided in Tables 17-19. Finally, details of the 6-18-99 incident are provided in Tables 20-22. The results of these analyses show that activating CLAS for these incidents could have reduced total freeway and frontage road network delay by approximately 13 to 26 percent. All three of these incidents involved two-lane blockages for durations of 15 to 45 minutes. In the majority of incidents analyzed, freeway mainlane delay savings are partially offset by increases in delay on the frontage road network. With the frontage road network demands existing in the 4-13-98 incident analysis, however, CLAS actually reduced total frontage road network delay by approximately 8 percent in addition to the mainlane delay reduction provided.

The LOS for the westbound frontage road increased in all three incident simulations. Reductions in LOS were seen at Mangum in two incidents and at Antoine in one incident. Throughput increased on four to five of the eight facilities (frontage roads and cross streets) during CLAS incident management simulations for all three incidents. Westbound frontage road throughput increased by 9 to 32 percent.

PM Peak Period Incident Summaries

Three incidents were analyzed for the PM peak period. Details of the 6-9-98 incident analysis are provided in Tables 23-25. Details of the 10-5-98 incident analysis are provided in Tables 26-28. Details of the 5-19-98 incident analysis are provided in Tables 29-31. The results of

Table 11. Incident Description - 5/27/98

Peak Period: AM	Location: westbound between 34th and Antoine	Analysis Period: 8:00 - 8:45
Lanes Blocked: 1	Duration: 30 minutes	Intersections CLAS activated at: 34th, Antoine

Table 12. Results of Incident Simulation - 5/27/98

Measures of Effectiveness	Actual Conditions			Simulated Incident Management Mode			Savings with Simulated Incident Management	Percent Difference
	Frontage Road	Mainlanes	Total	Frontage Road	Mainlanes	Total		
Total Delay (veh-hr)	149.6	282.7	432.3	205.0	262.7	467.7	-35.4	-8.2%
Delay/Vehicle (s)	20.5	79.2	-	28.6	73.2	-	-	-

Table 13. Summary of Frontage Road Incident Simulation - 5/27/98

	Delay/Vehicle (s)				Throughput (vehicles)			
Facility	Actual Condition Delay	Actual Condition LOS	Simulated Incident Management Delay	Simulated Incident Management LOS	Actual Throughput	Simulated Incident Management Throughput	Increase in Throughput	Percent Increase
Outbound Frontage Road	31.4	D	27.2	D	2467	2516	49	2.0
Inbound Frontage Road	33.8	D	39.2	D	2668	2631	-37	-1.4
Dacoma Arterial	7.2	B	7.0	B	1171	1212	41	3.5
Mangum Arterial	18.6	C	19.8	C	1917	1960	43	2.2
West 34th Arterial	13.0	B	47.6	E	1703	1541	-162	-9.5
Antoine Arterial	13.6	B	44.1	E	1957	1781	-176	-9.0
43rd Arterial	12.7	B	13.3	B	1445	1495	50	3.4
Bingle Arterial	15.9	C	15.7	C	2620	2597	-23	-0.9

Table 14. Incident Description - 4/13/98

Peak Period: MID	Location: westbound between 34th and Antoine	Analysis Period: 12:00 - 13:00
Lanes Blocked: 2	Duration: 15 minutes	Intersections CLAS activated at: 34th, Antoine

Table 15. Results of Incident Simulation - 4/13/98

Measures of Effectiveness	Actual Conditions			Simulated Incident Management Mode			Savings with Simulated Incident Management	Percent Difference
	Frontage Road	Mainlanes	Total	Frontage Road	Mainlanes	Total		
Total Delay (veh-hr)	521.9	691.9	1213.8	479.1	417.0	896.1	317.7	26.2%
Delay/Vehicle (s)	38.7	131.3	-	34.3	81.5	-	-	-

Table 16. Summary of Frontage Road Incident Simulation - 4/13/98

	Delay/Vehicle (s)				Throughput (veh/hr)			
Facility	Actual Condition Delay	Actual Condition LOS	Simulated Incident Management Delay	Simulated Incident Management LOS	Actual Throughput	Simulated Incident Management Throughput	Increase in Throughput	Percent Increase
Outbound Frontage Road	49.4	E	27.8	D	3765	4339	574	15.2
Inbound Frontage Road	27.9	D	33.9	D	3348	3322	-26	-0.8
Dacoma Arterial	9.2	B	9.2	B	1447	1433	-14	-1.0
Mangum Arterial	12.6	B	12.6	B	2529	2720	191	7.6
West 34th Arterial	112.1	F	67.6	F	2712	3024	312	11.5
Antoine Arterial	40.4	E	62.5	F	1665	1648	-17	-1.0
43rd Arterial	10.7	B	10.8	B	1533	1586	53	3.5
Bingle Arterial	9.5	B	9.6	B	2142	2206	64	3.0

Table 17. Incident Description - 6/1/99

Peak Period: MID	Location: westbound between Mangum entry and 34th exit	Analysis Period: 11:45 - 13:00
Lanes Blocked: 2	Duration: 45 minutes	Intersections CLAS activated at: Mangum, 34th, Antoine

Table 18. Results of Incident Simulation - 6/1/99

Measures of Effectiveness	Actual Conditions			Simulated Incident Management Mode			Savings with Simulated Incident Management	Percent Difference
	Frontage Road	Mainlanes	Total	Frontage Road	Mainlanes	Total		
Total Delay (veh-hr)	534.5	1011.2	1545.7	529.4	819.8	1349.2	196.5	12.7%
Delay/Vehicle (s)	39.8	203.4	-	35.4	142.8	-	-	-

Table 19. Summary of Frontage Road Incident Simulation - 6/1/99

	Delay/Vehicle (s)				Throughput (vehicles)			
Facility	Actual Condition Delay	Actual Condition LOS	Simulated Incident Management Delay	Simulated Incident Management LOS	Actual Throughput	Simulated Incident Management Throughput	Increase in Throughput	Percent Increase
Outbound Frontage Road	55.5	E	27.4	D	3646	4816	1170	32.1
Inbound Frontage Road	28.0	D	34.2	D	3278	3247	-31	-1.0
Dacoma Arterial	9.4	B	9.4	B	1424	1417	-7	-0.5
Mangum Arterial	12.7	B	50.4	E	2590	2461	-129	-5.0
West 34th Arterial	112.6	F	64.3	F	2599	2961	362	13.9
Antoine Arterial	42.3	E	59.1	E	1771	1789	18	1.0
43rd Arterial	10.9	B	11.3	B	1516	1613	97	6.4
Bingle Arterial	9.7	B	9.8	B	2026	2238	212	10.5

Table 20. Incident Description - 6/18/99

Peak Period: MID	Location: westbound between Mangum exit and Mangum	Analysis Period: 11:00 -11:45
Lanes Blocked: 2	Duration: 30 minutes	Intersections CLAS activated at: Mangum

Table 21. Results of Incident Simulation - 6/18/99

Measures of Effectiveness	Actual Conditions			Simulated Incident Management Mode			Savings with Simulated Incident Management	Percent Difference
	Frontage Road	Mainlanes	Total	Frontage Road	Mainlanes	Total		
Total Delay (veh-hr)	164.9	482.9	647.8	164.5	400.5	565.0	82.8	12.8%
Delay/Vehicle (s)	24.0	219.0	-	23.5	152.4	-	-	-

Table 22. Summary of Frontage Road Incident Simulation - 6/18/99

	Delay/Vehicle (s)				Throughput (vehicles)			
Facility	Actual Condition Delay	Actual Condition LOS	Simulated Incident Management Delay	Simulated Incident Management LOS	Actual Throughput	Simulated Incident Management Throughput	Increase in Throughput	Percent Increase
Outbound Frontage Road	29.1	D	20.0	C	3329	3636	307	9.2
Inbound Frontage Road	30.3	D	31.3	D	2724	2679	-45	-1.7
Dacoma Arterial	9.0	B	8.7	B	1015	992	-23	-2.2
Mangum Arterial	9.4	B	21.1	C	1867	1856	-11	-0.6
West 34th Arterial	48.9	E	48.5	E	2700	2667	-33	-1.2
Antoine Arterial	13.6	B	13.3	B	1740	1747	7	0.4
43rd Arterial	10.5	B	10.2	B	1388	1421	33	2.4
Bingle Arterial	8.6	B	8.5	B	1708	1725	17	1.0

Table 23. Incident Description - 6/9/98

Peak Period: PM	Location: westbound between 34th and Antoine	Analysis Period: 18:45 - 19:30
Lanes Blocked: 1	Duration: 30 minutes	Intersections CLAS activated at: Mangum, 34th, Antoine

Table 24. Results of Incident Simulation - 6/9/98

Measures of Effectiveness	Actual Conditions			Simulated Incident Management Mode			Savings with Simulated Incident Management	Percent Difference
	Frontage Road	Mainlanes	Total	Frontage Road	Mainlanes	Total		
Total Delay (veh-hr)	153.5	822.8	976.3	218.0	649.6	867.6	108.7	11.1%
Delay/Vehicle (s)	20.8	194.4	-	29.6	154.8	-	-	-

Table 25. Summary of Frontage Road Incident Simulation - 6/9/98

	Delay/Vehicle (s)				Throughput (vehicles)			
Facility	Actual Condition Delay	Actual Condition LOS	Simulated Incident Management Delay	Simulated Incident Management LOS	Actual Throughput	Simulated Incident Management Throughput	Increase in Throughput	Percent Increase
Outbound Frontage Road	31.7	D	17.1	C	3712	3765	53	1.4
Inbound Frontage Road	24.2	C	29.5	D	2492	2441	-51	-2.0
Dacoma Arterial	6.1	B	6.1	B	597	616	19	3.1
Mangum Arterial	10.4	B	36.4	D	1860	1803	-57	-3.1
West 34th Arterial	21.9	C	28.5	D	2477	2364	-113	-4.6
Antoine Arterial	10.4	B	66.3	F	2008	1820	-188	-9.4
43rd Arterial	11.3	B	10.6	B	1387	1439	52	3.8
Bingle Arterial	24.8	C	25.2	D	2792	2747	-45	-1.6

Table 26. Incident Description - 10/5/98

Peak Period: PM	Location: westbound between 34th exit and 34th	Analysis Period: 17:15 - 18:15
Lanes Blocked: 1	Duration: 30 minutes	Intersections CLAS activated at: Mangum, 34th, Antoine

Table 27. Results of Incident Simulation - 10/5/98

Measures of Effectiveness	Actual Conditions			Simulated Incident Management Mode			Savings with Simulated Incident Management	Percent Difference
	Frontage Road	Mainlanes	Total	Frontage Road	Mainlanes	Total		
Total Delay (veh-hr)	423.8	862.7	1286.5	576.1	705.7	1281.8	4.7	0.4%
Delay/Vehicle (s)	31.5	138.0	-	44.4	121.0	-	-	-

Table 28. Summary of Frontage Road Incident Simulation - 10/5/98

	Delay/Vehicle (s)				Throughput (veh/hr)			
Facility	Actual Condition Delay	Actual Condition LOS	Simulated Incident Management Delay	Simulated Incident Management LOS	Actual Throughput	Simulated Incident Management Throughput	Increase in Throughput	Percent Increase
Outbound Frontage Road	36.3	D	27.9	D	5483	5546	63	1.1
Inbound Frontage Road	32.9	D	31.7	D	3129	3084	-45	-1.4
Dacoma Arterial	6.8	B	7.1	B	1145	1196	51	4.5
Mangum Arterial	23.3	C	50.7	E	2658	2507	-151	-5.7
West 34th Arterial	35.0	D	55.9	E	2925	2452	-473	-16.2
Antoine Arterial	24.5	C	140.2	F	2653	2006	-647	-24.4
43rd Arterial	13.4	B	13.6	B	1901	1857	-44	-2.3
Bingle Arterial	48.1	E	40.8	E	3350	3371	21	0.6

Table 29. Incident Description - 5/19/98

Peak Period: PM	Location: westbound between 34th exit and 34th	Analysis Period: 18:00 - 18:45
Lanes Blocked: 1	Duration: 30 minutes	Intersections CLAS activated at: Mangum, 34th, Antoine

Table 30. Results of Incident Simulation - 5/19/98

Measures of Effectiveness	Actual Conditions			Simulated Incident Management Mode			Savings with Simulated Incident Management	Percent Difference
	Frontage Road	Mainlanes	Total	Frontage Road	Mainlanes	Total		
Total Delay (veh-hr)	182.2	866.4	1048.6	255.1	770.5	1025.6	23.0	2.2%
Delay/Vehicle (s)	23.6	234.3	-	32.1	188.8	-	-	-

Table 31. Summary of Frontage Road Incident Simulation - 5/19/98

	Delay/Vehicle (s)				Throughput (veh/hr)			
Facility	Actual Condition Delay	Actual Condition LOS	Simulated Incident Management Delay	Simulated Incident Management LOS	Actual Throughput	Simulated Incident Management Throughput	Increase in Throughput	Percent Increase
Outbound Frontage Road	37.1	D	28.3	D	2928	3234	306	10.5
Inbound Frontage Road	27.9	D	29.7	D	1819	1812	-7	-0.4
Dacoma Arterial	5.9	B	6.0	B	432	469	37	8.6
Mangum Arterial	11.5	B	41.3	E	1584	1515	-69	-4.4
West 34th Arterial	22.6	C	30.4	D	1859	1781	-78	-4.2
Antoine Arterial	14.9	B	65.7	F	1537	1380	-157	-10.2
43rd Arterial	11.1	B	10.3	B	1051	1018	-33	-3.1
Bingle Arterial	25.3	D	23.9	C	2051	2013	-38	-1.9

these analyses show that activating CLAS for these incidents could have reduced total freeway and frontage road network delay during these incidents. The magnitude of these reductions, however, is less than the reductions seen in mid-day incident analyses. However, all three incidents evaluated during mid-day involved two lane blockages, while all three of the PM incidents involved single lane closures. Total freeway and frontage road network delay decreased by approximately 11 percent in one PM incident and approximately 0.5 and 2 percent in the other two PM incidents with implementation of CLAS.

The LOS for the westbound frontage road increased in one of the three incident simulations. However, decreases in LOS were seen at Mangum, West 34th, and Antoine during CLAS incident management simulations in all three PM incidents. Changes in LOS at Bingle were mixed, with an increase in LOS seen during one incident and a decrease in LOS seen in another incident. A decrease in the eastbound frontage road LOS was seen in one incident simulation. Throughput increased for the westbound frontage road and Dacoma in all three incident simulations but decreased in all three incident simulations on the eastbound frontage road, Mangum, West 34th, and Antoine. Changes in throughput were mixed at 43rd and Bingle.

Level of Service

The LOS data provided in the summary tables of each incident have been summarized in Table 32 by incident time of day. This table shows where and to what extent CLAS negatively impacts cross street operations. Conditions where facility LOS remained unchanged with simulated CLAS incident management are represented in Table 32 with a dash (-). Increases in LOS are represented by a plus sign followed by a number representing the magnitude of the change in LOS (number of grades increased or decreased by). For example, "+1" would represent a one-grade increase in LOS, e.g., an increase from LOS C to LOS B. Similarly, "-2" would represent a two-grade decrease in LOS, e.g., a decrease from LOS B to LOS D.

It is important to note that the approach demand for all facilities other than the westbound frontage were the same in both the actual condition simulations and the CLAS incident management simulations. The westbound frontage road demands, however, often increased in the CLAS incident management simulation to represent additional diversion that would take place as frontage road operations favored diversion with CLAS lane assignments and signal timings. Thus, even if the LOS remains the same for the westbound frontage road during these simulations, this still implies that more vehicles are being serviced without a reduction in LOS.

As seen in Table 32, CLAS incident management provided increases in westbound frontage road LOS during all three of the mid-day incidents and one PM peak period incident. The LOS on the eastbound frontage road remained constant in six of the seven incidents and decreased during one of the PM incidents.

Decreases in LOS on Mangum, West 34th, and Antoine, as shown in Table 32, correspond to CLAS being activated at those intersections for those incidents. As cycle lengths increase and the frontage road movement green time is increased, it would be reasonable for delay to increase on the

Table 32. Increase/Reduction of Facility LOS Due to Implementation of CLAS

Time of Day	Incident Date	Frontage Road		Cross Street Arterials					
		WB Frontage Road	EB Frontage Road	Dacoma	Mangum	West 34th	Antoine	43rd	Bingle
AM	5-27-98	-	-	-	-	-3	-3	-	-
MID	4-13-98	+1	-	-	-	-	-1	-	-
	6-1-99	+1	-	-	-3	-	-	-	-
	6-18-99	+1	-	-	-1	-	-	-	-
PM	6-9-98	+1	-1	-	-2	-1	-4	-	-1
	10-5-98	-	-	-	-2	-1	-3	-	-
	5-19-98	-	-	-	-3	-1	-4	-	+1

Note: "+1" represents an increase in LOS, e.g., increasing from LOS C to LOS B.
"-2" represents a decrease in LOS, e.g., decreasing from LOS B to LOS D.

affected cross street approaches, especially when the approaches experience high demand during peak periods.

Dacoma, 43rd, and Bingle were essentially unaffected by the activation of CLAS at Mangum, West 34th, or Antoine, since diverting vehicles would be expected to re-enter the freeway either at the Mangum or Antoine entrance ramp. The LOS changes that occurred during two PM incidents at Bingle are a result of minor fluctuations in delay that happened to straddle the 25.0 second delay per vehicle threshold that divides LOS C and LOS D.

Throughput

The effect of CLAS implementation on mainlane and westbound frontage road throughput has been summarized in Table 33. Freeway mainlane throughput remains constant as throughput is limited by the capacity of the freeway at the incident. Increases in westbound frontage road throughput ranged from 49 to 1170 vph depending on the impact of the incident on mainlane operations and extent of mainlane queuing. Increases in westbound frontage road throughput are relatively lower during incidents where mainlane queuing extends past one exit ramp as opposed to incidents where mainlane queuing extends past two exit ramps, allowing more opportunities for diversion.

The relative changes in throughput for the eastbound and westbound frontage roads and six cross street arterials as a result of the implementation of CLAS are provided in Table 34 by incident. Increases in facility throughput are represented by positive percentages, while decreases in facility throughput are represented by negative percentages.

Table 33. Increase in Westbound Mainlane/Frontage Road Facility Throughput Due to Simulated CLAS Incident Management

Time of Day	Incident Date	Actual Throughput (veh/hr)			Simulated Incident Management Throughput (veh/hr)			Increase in Throughput (veh/hr)
		Mainlanes	Frontage Road	Total	Mainlanes	Frontage Road	Total	
AM	5-27-98	3711	2467	6178	3711	2516	6227	49
Mid-Day	4-13-98	4169	3765	7934	4169	4339	8508	574
	6-1-99	4153	3646	7799	4153	4816	8969	1170
	6-18-99	2983	3329	6312	2983	3636	6619	307
PM	6-9-98	4713	3712	8425	4713	3765	8478	53
	10-5-98	4909	5483	10392	4909	5546	10455	63
	5-19-98	4007	2928	6935	4007	3234	7241	306

Table 34. Percent Increase in Facility Throughput Due to Implementation of CLAS

Time of Day	Incident Date	Frontage Road		Cross Street Arterials					
		WB Frontage Road	EB Frontage Road	Dacoma	Mangum	West 34th	Antoine	43rd	Bingle
AM	5-27-98	2.0	-1.4	3.5	2.2	-9.5	-9.0	3.4	-0.9
MID	4-13-98	15.2	-0.8	-1.0	7.6	11.5	-1.0	3.5	3.0
	6-1-99	32.1	-1.0	-0.5	-5.0	13.9	1.0	6.4	10.5
	6-18-99	9.2	-1.7	-2.2	-0.6	-1.2	0.4	2.4	1.0
PM	6-9-98	1.4	-2.0	3.1	-3.1	-4.6	-9.4	3.8	-1.6
	10-5-98	1.1	-1.4	4.5	-5.7	-16.2	-24.4	-2.3	0.6
	5-19-98	10.5	-0.4	8.6	-4.4	-4.2	-10.2	-3.1	-1.9

Increases in westbound frontage road throughput occurred with the implementation of CLAS in all seven incidents. Increases in westbound frontage road throughput ranged from 1.1 to 32.1 percent. The highest increases in westbound frontage road throughput occurred during the mid-day, off-peak hours. The average increase in throughput during these three incidents was 10.2 percent.

Increases in westbound frontage road throughput occurred in all three PM incidents analyzed, but to a lower extent than during off-peak hours. As the CLAS approaches are in the same direction of flow as the PM peak direction of flow, the westbound frontage demands during non-incident conditions are already higher than during off-peak hours for non-incident conditions. Thus, even without the presence of an incident, available capacity at westbound frontage road approaches is lower during the PM peak hours than other times of the day.

Decreases in eastbound frontage road throughput occurred in all seven incidents with the implementation of CLAS. The magnitude of this reduction, however, ranged from 0.4 to 2.0 percent, with an average reduction in throughput of 1.2 percent. The effect of CLAS on cross street arterial throughput was mixed. Decreases in throughput were seen in more than half of the seven incidents on Mangum, West 34th, and Antoine, while increases in throughput were seen in more than half of the seven incidents at Dacoma, 43rd, and Bingle.

LANE USE VIOLATION STUDY RESULTS

A direct comparison of safety at each frontage road approach studied using accident records is not viable given the time lag associated with accident information. However, some insight could be gained from a review of lane use violations during mainlane incident conditions. It is assumed that if lane assignments are not suitable for a given set of traffic conditions, there would be a tendency for some motorists to violate those lane assignments to shorten their individual delay or time in queue. Likewise, if lane assignments are appropriate, motorists will not tend to violate the lane assignment to gain advantage in the queue since a relative balance will occur.

Lane use violation studies were performed during the analysis period of each of the seven incidents at Mangum, West 34th, and Antoine. Figure 7 summarizes lane use violations as a function of display mode: 1) double turns; 2) shared turns during time of day CLAS operations; and 3) shared turns during incident management CLAS operations. Table 35 provides lane use violation data on an incident by incident basis. Lane use violation rates are based on the number of lane use violations for the frontage road approach.

During double turn operations, a violation is defined as a through movement in a "must turn" lane. During shared turn operations, a violation is defined as a right or left turn from the middle lane. It was expected that violations during mainlane incidents would be lower with the shared turn configuration than the double turn configuration due to the increase in through demand as vehicles divert to the frontage road and seek lanes with the shortest queues. Lane use violations during incidents when double turns are in effect may be higher than non-incident conditions as some portion of the diverting drivers may be unfamiliar with the turn only lane assignments on the frontage road.

In general, lane use violations increased with increasing intersection approach volumes and were much higher during double turn operations than shared turn operations. Lane use violations during mainlane incident conditions averaged 0.588 violations per cycle (or approximately one violation every two cycles) at intersections with double turn lane assignments, while the corresponding lane use violations during mainlane incident conditions averaged 0.195 violations per cycle (or approximately one violation every five cycles) at intersections with shared turn lane assignments.

Table 35. Summary of Lane Use Violations During Incident Conditions

Mode	Item	Double Turns	Shared Turns - Time of Day	Shared Turns - Incident Management
Mangum	# Cycles	161	181	80
	# Vehicles	3687	4564	2937
	# Violations	111	21	15
	Violations/cycle	0.689	0.116	0.188
	Violations/vehicle	0.030	0.005	0.005
West 34th	# Cycles	185	135	51
	# Vehicles	5737	5908	2146
	# Violations	113	31	10
	Violations/cycle	0.611	0.230	0.196
	Violations/vehicle	0.020	0.005	0.005
Antoine	# Cycles	300	NA	60
	# Vehicles	8859	NA	2012
	# Violations	154	NA	24
	Violations/cycle	0.513	NA	0.400
	Violations/vehicle	0.017	NA	0.012

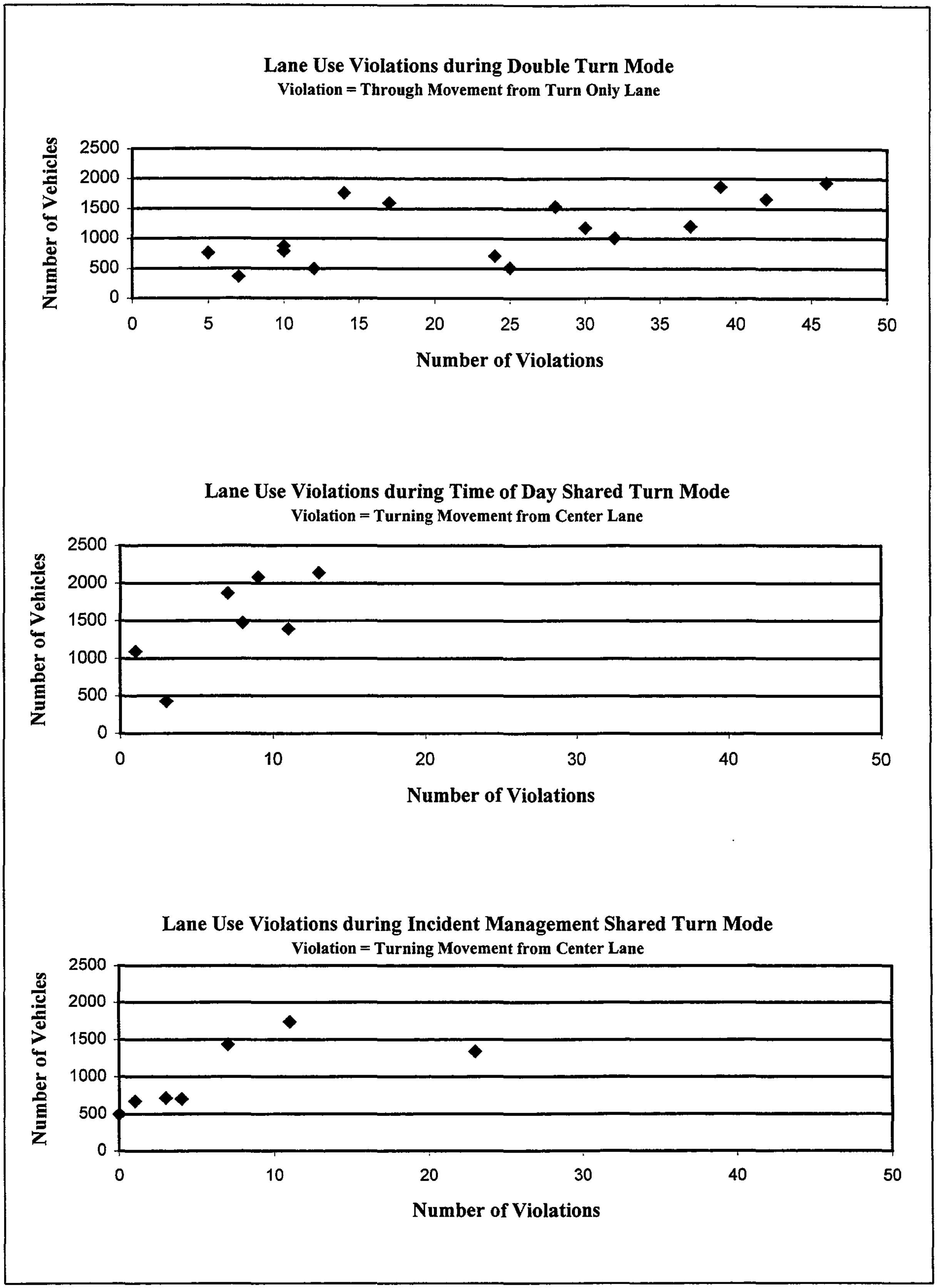


Figure 7. Lane Use Violations during Incidents by CLAS Display Mode

FINDINGS AND CONCLUSIONS

SUMMARY OF FINDINGS

Computer modeling of seven incidents in the US 290 Corridor using FREQ 11 and Syncrho revealed the following:

- The implementation of CLAS produced benefits with respect to total freeway/frontage road network delay and delay per vehicle in six of the seven incidents analyzed. Freeway mainlane delay was reduced in all seven incident analyses, while frontage road delay was also reduced in three of the seven incidents.

- During the one AM peak period incident analyzed, the implementation of CLAS resulted in a 35.4 vehicle-hour, or 8.2 percent, increase in total freeway/frontage road network delay.

- During the three mid-day period incidents analyzed, the implementation of CLAS resulted in reductions in total freeway/frontage road network delay of 82.8 to 317.7 vehicle-hours, or 12.7 to 26.2 percent.

- During the three PM peak period incidents analyzed, the implementation of CLAS resulted in reductions in total freeway/frontage road network delay of 4.7 to 108.7 vehicle-hours, or 0.4 to 11.1 percent.

- Delay per vehicle calculations were used to determine the effect of CLAS on the LOS of operations on the westbound frontage road, eastbound frontage road, and cross street arterials within the study network (Dacoma, West 34th, Antoine, 43rd, and Bingle). The implementation of CLAS improved the LOS on the westbound frontage road during all three mid-day period incidents and one PM peak period incident. The LOS remained unchanged for the westbound frontage road during the remaining four incidents, even though frontage road approaches were experiencing increased demand due to mainlane traffic diversion.

- The implementation of CLAS did not affect the LOS on the eastbound frontage road in six of the seven incidents but resulted in a decrease of LOS during one of the PM peak period incidents.

- The implementation of CLAS did not affect the LOS on the Dacoma and 43rd cross streets in any of the seven incidents. The implementation of CLAS produced mixed results for the LOS on the other cross streets, having no effect during some incidents and decreasing LOS in other incidents.

- The implementation of CLAS resulted in increases in westbound frontage road throughput in all seven incidents. Increases in throughput ranged from 1.1 to 32.1

percent, with an average increase in throughput of 10.2 percent. Westbound frontage road throughput increases due to CLAS by time of day averaged 2.0, 18.8, and 4.3 percent for incidents occurring during the AM peak period, mid-day period, and PM peak period, respectively.

- The implementation of CLAS resulted in decreases in eastbound frontage road throughput in all seven incidents. Decreases in throughput ranged from 0.4 to 2.0 percent, with an average decrease in throughput of 1.2 percent.

- The implementation of CLAS produced mixed results in throughput on the Dacoma, Mangum, West 34th, Antoine, 43rd, and Bingle cross streets. Decreases in throughput were seen in more than half of the seven incidents on Mangum, West 34th, and Antoine, while increases in throughput were seen in more than half of the seven incidents at Dacoma, 43rd, and Bingle.

- Saturation flow rate studies were conducted for the westbound frontage road approaches at Mangum, West 34th, and Antoine during incident conditions with double turn configurations and shared turn configurations. The change of lane assignments from double turn to shared turn configuration resulted in increases in total approach saturation flow rates of 4.2 percent at Mangum, 5.5 percent at West 34th, and 5.1 percent at Antoine.

- Lane use violations during incident conditions were 2.5 times higher at intersections with double turn configurations than intersections with shared turn configurations. Lane use violations averaged 0.588 violations per cycle at intersections operating in double turn mode and 0.195 violations per cycle at intersections operating in shared turn mode. Lane use violations were also significantly higher at intersections with double turn configurations than intersections with CLAS time of day shared turn configurations.

CONCLUSIONS

This study has found that CLAS is an effective incident management tool when deployed in concert with a freeway management system (FMS) which provides visual and/or electronic surveillance of the freeway corridor. Specific conclusions drawn from the findings of this study include:

1. Care should be exercised in implementing CLAS for peak period incidents in the non-peak direction of flow. The single AM period incident (one lane blockage) analyzed in this study indicates that CLAS delay savings in the non-peak direction of flow were more than offset by increased delay in the peak flow direction. For this reason, only rare incidents in the non-peak direction of flow (e.g., those blocking two or more lanes where significant queuing forms) may justify the use of CLAS.

2. Implementation of CLAS may be most beneficial during non-peak hours (mid-day period) because of more available capacity and a more balanced traffic demand.

Therefore, it is easier to accommodate an unbalanced signal timing plan with emphasis on the CLAS approaches.

3. CLAS was found to be beneficial in the PM peak period but resulted in lower benefits as compared to mid-day operations/benefits. When the peak flow direction is the same as the CLAS approaches, the available capacity on the frontage road may not be adequate to accommodate all freeway to frontage road diversion.

4. During incident conditions, saturation flow rate studies indicate that the use of CLAS increases frontage road capacity.

5. During incident conditions, frontage road through demand increases due to mainlane traffic diversion. Lane use violation rates seem to indicate that the use of CLAS will more adequately reflect driver expectation.

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