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Freeway Service Patrol Evaluation

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California PATH Research Report
UCB-ITS-PRR-95-5

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FREEWAY SERVICE PATROL EVALUATION

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June 1994

ABSTRACT

Freeway service patrols (FSP) facilitate the quick removal of incidents to reduce congestion delay and other adverse impacts on urban freeways. The benefits of FSP depend on the freeway design characteristics, traffic volumes and incident frequency and patterns. The report presents the findings of a comprehensive evaluation of the FSP program at a San Francisco Bay Area freeway section. More than 276 hours of field data were collected “before” and “after” the implementation of FSP, consisting of incident observations, travel times from instrumented vehicles, and speeds, flows and occupancies from loop detectors. Procedures were then developed to estimate the impact of FSP on incident delay and other performance measures.

Software was developed to process the data into an integrated computerized database. The database provides a complete representation of the freeway operating conditions at the test site. Incident type, time of day, day of the week, presence of shoulders and weather conditions accounted for most of the variability in incident occurrence and duration. The FSP service resulted in a significant increase in the number of assisted incidents, and reductions in their response times and durations. Based on the incident delay and fuel consumption savings, it was found that the FSP service has been cost-effective at the specific site. Other benefits of FSP are also discussed, along with suggestions for accurately assessing the effectiveness of incident management programs.

Keywords:

Freeways, Freeway Service Patrol, Evaluation Techniques, Incident Management, Traffic Delay, Traffic Flow

EXECUTIVE SUMMARY

Objectives and Methodology

Incidents (accidents, vehicle breakdowns, spilled loads or other random events) that reduce the roadway capacity account for a significant portion of the congestion delay on urban freeways, and to the increase of accidents, fuel consumption and air pollutant emissions. Freeway service patrol (FSP) is an incident management program implemented in a number of metropolitan areas to facilitate the quick removal of incidents. FSP tow truck drivers continually patrol freeway segments during commute hours and provide assistance to disabled vehicles. The California FSP program is funded by the legislature as well as federal and local monies, and is jointly administered by the California Department of Transportation (Caltrans), California Highway Patrol (CHP) and local transportation planning agencies. This report presents the findings of a comprehensive evaluation of the FSP program on a specific freeway section in the San Francisco Bay Area.

The study methodology consisted of determining the savings in incident delay and other performance measures "before" and "after" the implementation of FSP based on field data and improved analysis procedures. Data were collected during the peak periods on a 9 mile section of the I-880 freeway in the City of Hayward, Alameda County. The "before" study was conducted for 24 weekdays in the Spring of 1993, and the "after" study took place in the Fall for a total of 22 weekdays. Incident information (type, location, severity, type of assist and duration) was obtained through observations of probe vehicle drivers traveling at an average of 7 minute headways. Speeds, flows and occupancies at 1-sec intervals were collected from loop detectors spaced approximately 1/3 mile apart on the freeway mainline and on all the ramps. Vehicle trajectories and travel times were obtained from the specially instrumented probe vehicles. Supplementary information was collected from the CHP computer aided dispatch system, FSP records, and rotational and membership tow truck companies logs.

Software was developed to process the field data and create a computerized database. The I-880 database consists of 276 hours of field data that are uniquely linked to provide a complete representation of the freeway operating conditions at the test site. This is the largest and most comprehensive database on freeway operations to date and is readily available for other studies. The estimation of the incident specific delay was based on the difference in average travel speeds under normal and incident conditions using data from loop detectors and instrumented vehicles.

Findings

A high number of incidents was observed at the study section. The average frequency was 8 incidents/hour in the peak periods, about 100 incidents per million vehicle miles of travel. The proportion of accidents was 10 percent of all the incidents. Only 4 percent of all the incidents were blocking travel lanes, most of them accidents. In addition, there was a significant number of CHP ticketing incidents, mostly citations for violations of the HOV lane usage in the study section. Time of day, day of the week, presence of shoulders and weather conditions accounted for most of the variability in incident occurrence.

The proportion of tow truck assisted incidents increased from 9 percent “before” to 24 percent “after” the implementation of the FSP service. About 80 percent of the assists were provided by FSP, mostly vehicle breakdowns with mechanical or electrical problems. About 30 percent of those breakdowns had to be towed. The response times of the FSP assisted breakdowns were reduced by 57 percent, and the response times of all assisted incidents were cut by 35 percent in the “after” study. The differences in the average clearance times “before” and “after” were not statistically significant for both accidents and breakdowns. The incident durations “before” and “after” were similar for all the incident categories. Significant reductions in durations were found only for the assisted incidents, because of the faster response times of the FSP service.

The estimation of the FSP benefits was based on the savings in the incident delay and fuel consumption due to the FSP service excluding accidents, incidents of short duration and abandoned vehicles. The estimated benefit/cost ratio of 3.4:1 shows that the program has been cost-effective at the specific test site. In addition, reductions in air pollutant emissions include 77.2 tons of carbon monoxide, 19.1 tons of oxides of nitrogen and 7.6 tons of hydrocarbons. Additional benefits that were not included in the calculation of the benefit/cost ratio include a) time and cost savings to the motorists assisted by FSP, b) improved incident detection and reporting by the FSP drivers, and c) reduction in the number of, and the time spent on incidents by CHP officers. The survey of motorists assisted by the FSP showed overwhelming approval with 93 percent rating the service as excellent. Motorists also wrote complementary comments, left voice mail and sent letters to show their support of the program. Furthermore, FSP vehicles provide a sense of security on the freeway and faster clearance of incidents reduces the chance of secondary accidents.

Recommendations

The estimated benefit/cost ratio applies to sites with traffic and incident characteristics similar to the ones in the study area, and may not be used as a guideline for the effectiveness of the FSP elsewhere. The effectiveness of FSP would be higher on locations with similar incident patterns but higher traffic volumes, mixed lanes and narrow or no shoulders. However, the benefits would be limited on sites with few major incidents as opposed to sections with high frequency of vehicle disablements. Additional evaluation studies should be performed to quantitatively determine the range in the FSP benefits. This study provides a framework for the accurate assessment of the FSP impacts.

There is a need for comprehensive databases such the one developed in this study for other freeway sites under a range of operating conditions. Most of the studies on incident characteristics and impacts were conducted in the 60’s and 70’s, when urban freeways were less congested, and driver behavior and vehicle characteristics were quite different. Further work is also needed to develop improved procedures for estimating incident delays from various data sources.

A number of issues related with the operation of FSP need further investigation including a) the effectiveness of the service on sites with narrow or no shoulders because of potential safety problems, b) advantages of stationary vs. roving service patrols under different incident management systems, and c) utilization of FSP as a mobile data source for incidents and freeway operating conditions. Steps could be also taken through regulation means to reduce the number of incidents on urban freeways. Fines and citations for running out of gas and mandatory inspections for serviceability of the vehicle’s electrical and mechanical systems could reduce the number of breakdowns.

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CHAPTER 1

INTRODUCTION

1.1 Background

Incidents are accidents, vehicle breakdowns, spilled loads or any other random events that reduce the capacity of the road, and cause congestion if the traffic demand exceeds the reduced capacity at the incident location. Major incidents resulting in total freeway closures cause excessive areawide congestion. Even minor incidents can significantly increase traffic delay along heavily traveled urban freeways during peak periods. Furthermore, incidents may cause accidents because of the stop-and-go traffic conditions and the hazards of vehicles and pedestrians stalled in the roadway.

The impacts of incidents on traffic flow depend on the incidents' frequency, location, type, severity and duration, the traffic demand and capacity at the facility, the availability of incident management programs to detect and clear the incidents, and other factors. Several studies have investigated the detrimental impacts of incidents on the quality of traffic flow. The most often cited FHWA study (Lindley 1986) reports that incidents account for 61 percent of all the congestion delay in the US, and it is estimated that by the year 2005, over 70 percent of the total delay in urban areas would be incident related causing excess travel costs of $35 billion. The California Department of Transportation (Caltrans) also estimates that 50 percent of motorist delays on freeways are incident related (Hicomp 1992.)

In response to the growing adverse impacts of incidents on travel conditions, incident management programs have been initiated in several metropolitan areas, with the cities of Chicago and Los Angeles having the most comprehensive programs. The goal of such programs is to restore the freeway to full capacity after the incident occurs and to provide information to motorists until the incident is cleared. Incident management programs require the cooperative and coordinated actions of several operating agencies and include freeway surveillance systems, incident response teams, law enforcement officers, motorist assistance patrols and other means to detect, respond to and clear incidents (Roper, 1990). Any reduction in detection, response, and clearance time reduces the total incident duration which in turn reduces the congestion delay. Also, information to motorists is provided via changeable message signs (CMS), Highway Advisory radio (HAR) and other means to alert drivers, suggest alternate routes or direct traffic in case of total closures.

Traditionally, freeway incidents are detected by means of detection/surveillance devices (e.g., loop detectors, call boxes, electronic surveillance, closed curcuit television (CCTV)), police patrols, citizen band radios (CB), or cellular phones. Loop detectors allow traffic flow parameters to be continually monitored with reasonable accuracy. However, loop detectors detect the effect of incidents, i.e., an increase in occupancy and fall in flows and speeds. The type of incidents and the clearance requirements are not known and have to be verified in the field by other means. CCTV can be used for detecting incidents, but it requires extensive coverage and continuous monitoring of the TV screens in the transportation management center (TMC). CCTV is particularly useful for monitoring critical bottlenecks and once an incident has been detected to verify the incident's characteristics so appropriate actions can be taken. Soon to be generally available systems include video image processing (VIPS), and automatic vehicle identification/location (AVI/AVL) equipped vehicles.

Incident response teams and motorist assistance (or service) patrols are one approach of facilitating the quick removal of incidents through fast response and clearance times. Freeway service patrols (FSPs) consist of teams of tow truck drivers who continually patrol certain freeway segments ("beats") during commute hours, and provide assistance to disabled vehicles and tow them if necessary to designated areas off the freeway. FSPs serve also as a detection and verification mechanism for major incidents by providing information to transportation management centers. FSPs are able to handle a large number of minor incidents (stalls, flat tires, out of gas, and minor accidents) that constitute the largest portion of all freeway incidents.

Freeway service patrols have been operating on tunnels and bridges and other facilities without shoulders where traffic flow obstructions have a large effect on the quality of flow. Starting with the Chicago's "Minutemen program" in 1961 (McDermott 1975, 1991) FSPs operate in several metropolitan areas on isolated freeway segments ranging from 6 to 10 miles to entire freeway systems (Morris 1994.) Most of the freeway service patrols involve tow trucks equipped to handle minor vehicle repairs. Communication with the dispatch/operation center is provided through two-way radio and/or cellular phones. The FSPs in the San Francisco Bay Area and Los Angeles are equipped with AVL systems and mobile data terminals (MDTs).

Funding for the freeway service patrols is provided through State transportation departments, federal funds as part of the Intermodal Surface Transportation Efficiency Act (ISTEA) and other sources. Private businesses have sponsored FSPs in at least nine cities (Dudek 1992) in return for improving their public image and direct advertising of the sponsoring business or agency. Benefits of freeway patrols include reduction in incident duration thus reducing freeway congestion and delay. They also provide benefits to law enforcement agencies by reducing the amount of time officers spend on non-enforcement activities. Previous evaluations have reported benefit/cost ratios of FSP ranging from 2 to 1 (Fambro 1976) to 36 to 1 (Wohlschelager 1992.) The FSP service has been received very favorably by motorists. Responses to surveys, questionnaires and motorist assist forms designed to gauge the public perception, indicate that over 93 percent of the motorists rate the service as excellent and a worthwhile expenditure of public funds.

1.2 The California FSP Program

The California FSP program is geared toward congested segments of urban freeways during the peak periods. The FSP program is jointly administered by Caltrans, the California Highway Patrol (CHP) and local transportation planning agencies (e.g., the Metropolitan Transportation Commission Service Authority for Freeways and Expressways (MTC SAFE) in the San Francisco Bay Area and the Metropolitan Transportation Authority (MTA) in Los Angeles County.) The service is provided by private tow truck companies selected through the competitive bid process, under contract to the local transportation planning agencies. Sources of funding include state funds approved by the legislature that require 25 percent local contributions, federal ISTEA funds, County SAFE $1 per vehicle registration fees (used primarily to fund installation and operation of motorist aid call boxes), Transportation Management Plan (TMP) funds on reconstruction projects, and funds from the Congestion Mitigation and Air Quality Programs (CMAQ). Criteria for funding allocations have been based on population (50%), urban freeway lane miles (25%) and measured vehicle hours of congestion delay (25%). Recently, a recommendation has been made to change the funding formula based on congested directional miles (40%), number of peak period accidents (30%), vehicle hours of congestion delay (15%), and areas of narrow (widths less than 8 feet) shoulders (15%).

FSP vehicle drivers provide in-the-field assistance to disabled vehicles free of charge (e.g., jump start of cars, provide a gallon of gas, refill radiators and change flat tires or other minor repairs). If the FSP driver cannot get the vehicle running in about 10 minutes, then the vehicle is towed to a designated drop location off the freeway. FSP drivers may be also called for assistance in removal of vehicles involved in collisions and removal of debris from the roadway. The FSP service is provided free of charge to the user. FSP drivers do not have peace officer powers. They explain the program to the assisted motorists and request that motorists complete a motorist assist form. All assists and responses are recorded in a daily log.

The Bay Area FSP Program started in August 1992 along the 11.5 miles section of I-680 and SR 24 freeways in Contra Costa County with four tow trucks. Currently FSPs operate on 17 beats along I-80, I-280, I-880, I-980, US101, SR 237, and Highway 17 freeways in Alameda, Contra Costa, Marin, San Francisco, San Mateo, Santa Clara, Santa Cruz and Sonoma counties (Figure 1.1.) Figure 1.2 shows key statistics on the Bay Area FSP program for an approximately 22 month period of operation, based on the daily logs. FSP provides about 7,500 assists per month. Most of the assists involve vehicle breakdowns on the right shoulder and the average waiting time for the FSP service is about eight minutes.

1.3 Objectives of the Study

The California FSP program is rapidly expanding to most urban areas. Currently, it covers about 600 centerline miles of freeways with over 200 trucks in six areas in the State (Morris 1994.) There is a need for a thorough evaluation of the program to assess its effectiveness in reducing freeway congestion delay and other adverse impacts of incidents. Furthermore, there is not recent empirical evidence on incident characteristics and existing methods for estimating incident delay have several shortcomings. The objectives of the study described in this report are:

- Develop a comprehensive database on freeway incidents and operational characteristics
- Develop and apply an improved methodology for estimating incident delay
- Evaluate the effectiveness of the freeway service patrols at a Bay Area location

FIGURE 1.1 BAY AREA FREEWAY SERVICE PATROL BEATS
As of June 30, 1994 (Source: MTC SAFE 1994)

Beat	Contractor	Hours of Operation
1	Pito's Towing	6 am - 10 am / 3 pm - 7 pm (weekdays)
2	Redhill Towing	6 am - 7 pm (weekdays) / 10 - 6 pm (weekends)
3	Hank's Towing	6 am - 10 am / 3 pm - 7 pm (weekdays)
4	Pito's Towing	6 am - 10 am / 3 pm - 7 pm (weekdays)
5	Bay Point Tow	5 am - 7 pm (weekdays) / 10 - 6 pm (weekends)
6	Atlas Towing	6 am - 9 am / 3 pm - 6 pm (weekdays)
7	Redhill Towing	6:30 am - 9:30 am / 3 pm - 6 pm (weekdays)
8	Campbell's Towing	6 am - 9 am / 3 pm - 6 pm (weekdays)
9	Great America Towing	6 am - 9 am / 3 pm - 6 pm (weekdays)
10	Great America Towing	6 am - 9 am / 3 pm - 6 pm (weekdays)
11	Atlas Towing	6 am - 10 am / 3 pm - 7 pm (weekdays)
12	Bay Point Tow	6 am - 7 pm (weekdays) / 10 - 6 pm (weekends)
13	Redhill Towing	6:30 am - 9:30 am / 3 pm - 6 pm (weekdays)
14	Chevron Tow Service	6 am - 9 am / 3 pm - 6 pm (weekdays)
15	Yarbrough Bros. Towing	6:30 am - 9:30 am / 3:30 pm - 6:30 pm (weekdays)
16	Great America Towing	6 am - 9 am / 3:30 pm - 6:30 pm (weekdays)
17	Matos Automotive	6 am - 9 am / 3:30 pm - 6:30 pm (weekdays)

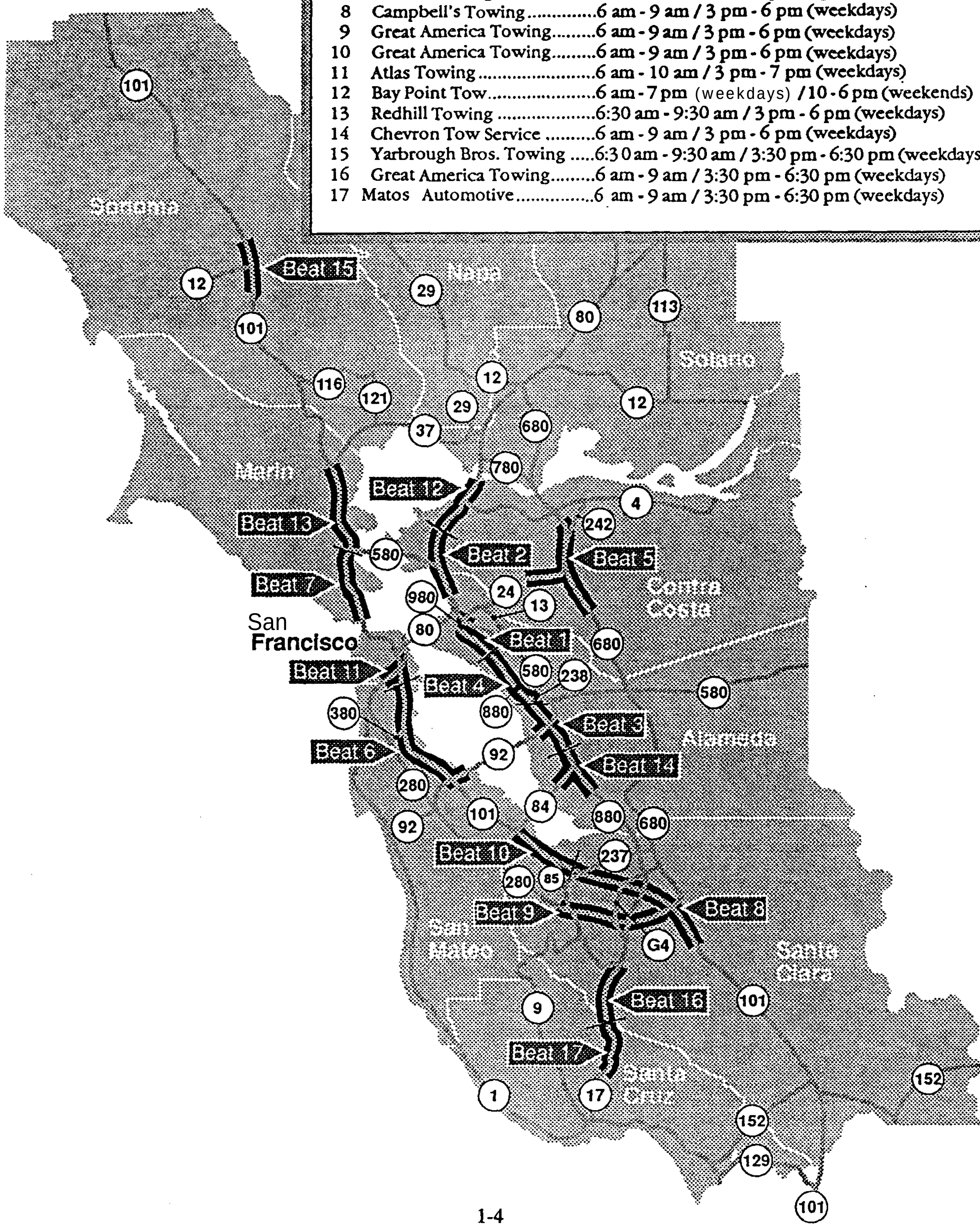
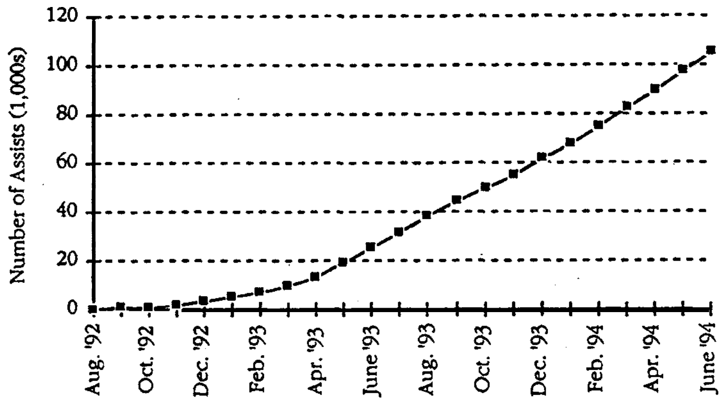


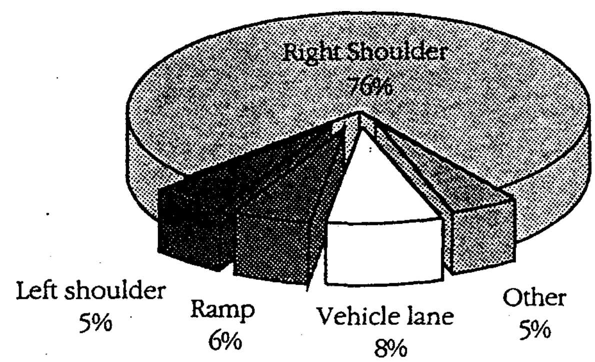
FIGURE 1.2 FREEWAY SERVICE PATROL STATISTICS: August 1992-June 1994 (Source: MTC SAFE 1994)

Cumulative Number of Assists

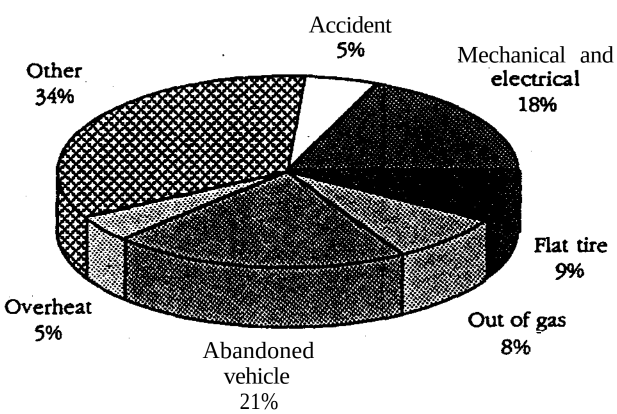


Cumulative Number of Assists Through Date Shown

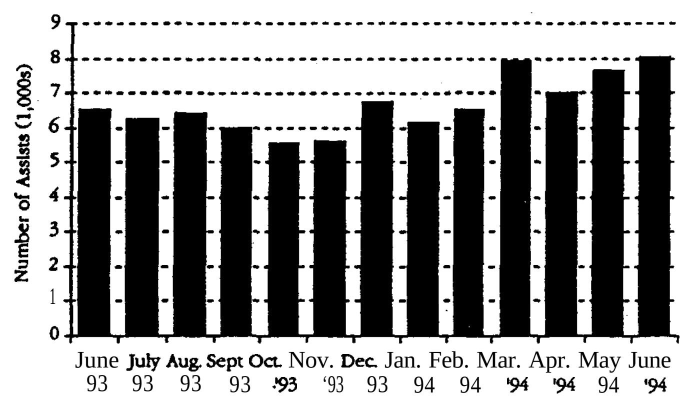
Location of Assists



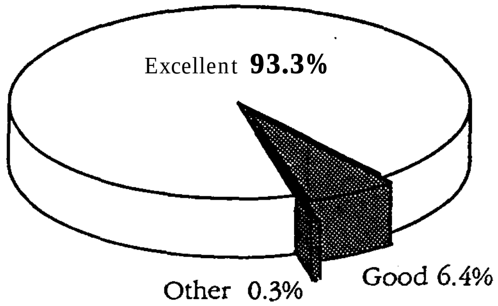
Types of Assists



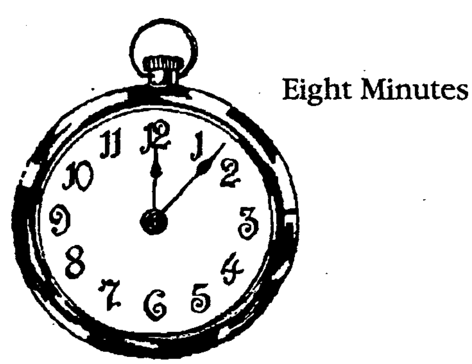
Number of Assists by Month



Service Rating



Average Time Waiting for FSP to Arrive



The research also addressed several issues related with the FSP implementation including the reduction in the time for detection, verification, response and clearance of incidents, and the effects of freeway design and operational parameters to FSP benefits.

The study has been conducted as part of the Partners for Advanced Transit and Highways (PATH) Program at the Institute of Transportation Studies (ITS) at the University of California, Berkeley. The scope of work consisted of the following major tasks: a) select a test site to field measure incidents, and traffic flow characteristics "before" and "after" the implementation of FSP, b) analyze the field data and develop models to estimate delays and other measures of effectiveness (MOEs), and c) determine the benefit/cost ratio of the FSP program at the selected test site.

1.4 Organization of the Report

This is the final report for the study and describes in detail the work performed and presents the project findings. Chapter 2 describes the research approach, including the design of the experiment and the procedures of estimating the selected measures of effectiveness. The study area and the procedures for data collection and processing are described in Chapter 3. Chapter 4 presents the findings from the analysis of the incident data. Chapter 5 presents the evaluation of the FSPs at the selected test site, and Chapter 6 summarizes the study findings along with suggestions for future research.

Detailed documentation on the comprehensive integrated database and software for data processing and analysis developed in this study is given elsewhere (Petty 1994.) The database and software are also available through the Internet network. The development and application of a freeway traffic simulation model on the test site is presented in a separate report (Sanwal and Fawaz 1994.)

Several appendices attached to the body of the report provide additional information on the study and documentation on the findings. Appendix A includes the procedural guide and protocols developed for the field data collection, and Appendix B includes the incident data collection forms developed in the project. Appendix C includes a summary of the probe vehicle runs performed along with a description of the data files created by the in-vehicle data collection system. Appendix D summarizes the data available from the loop detectors and sample outputs from the loop data processing software. The estimation of the costs of the FSP service in the test site as provided by MTC is included in Appendix E.

CHAPTER 2

METHODOLOGY

The effectiveness of the freeway service patrols as an incident management tool depends on several factors including incident frequency and characteristics, freeway operational characteristics and FSP implementation. FSP would be beneficial on freeway segments with high number of vehicle disablements, operating near or at capacity with narrow (or no) shoulders. FSP effectiveness would be limited on a site with a few major accidents and other incidents that require police investigation and specialized equipment to be cleared, and on uncongested freeways with wide shoulders. Also, the benefits of FSP depend on the number of tow trucks involved, hours of operation, and dispatching strategy.

Several approaches have been used to evaluate the effectiveness of freeway service patrols. Most of the approaches to-date use historical incident and flow data from records of traffic operations centers and use analytical techniques or simulation models to determine the impacts of FSPs based on certain assumptions on incident frequency, type and duration, and freeway demand and capacity. The research approach for assessing the possible benefits of FSP adopted in this study placed major emphasis in field data collection to measure all the variables that are likely to affect incident impacts on traffic operations and quantitatively evaluate the effectiveness of FSP through a “before” and “after” study.

The study methodology consists of collecting detailed incident data during “before” and “after” implementation of FSPs on a test site supplemented by detailed information on operational characteristics (volumes, travel times). Models were then developed to calculate the incident delay and other measures of effectiveness based on the field data and to estimate the benefits from the FSP service.

2.1 Design of the Experiment

The design of the experiment for the FSP evaluation in this study consisted of the following steps:

- Selection of the test site(s) for the field experiment
- Selection of the measures of effectiveness
- Development of a test plan for data collection/analysis

2.1.1 Selection of the Test Site

The selection of the test site(s) for the field experiment was based on the following criteria:

- ***Data*** collection ***system:*** availability of closely spaced (less than 1/2 mile apart) loop detectors to continually obtain data on traffic volumes, speeds and occupancies on the freeway and the ramps.

- ***Lack of (or narrow) shoulders:*** higher benefits are expected on sections with no shoulders since accidents or stalled vehicles occupy travel lanes and cause higher delay.
- ***Incident frequency:*** sites with high number of accidents and other incidents are likely to have higher benefits from FSP service.
- ***Recurrent congestion:*** congested beats have a higher incident frequency and incident delay affects a considerably higher number of road users.
- ***Tow truck service:*** there is a lack of specialized tow truck service in the study corridor.
- ***Avoidance of reconstruction activities:*** to differentiate the reduction in capacity and delays due to work zones and incidents, and avoid construction caused incidents.

Ten beats in the Bay Area with existing or proposed FSP service were proposed to the ITS research team by Caltrans, CHP and MTC for evaluating the effectiveness of FSP. Beat #3, a 14.6 kilometers (9.1 miles) section along the I-880 freeway located in the city of Hayward, Alameda County was selected as the test site for the field evaluation (Figure 1.1.) This beat is the only site in Caltrans District 4, and possibly in the State, that is instrumented with closely spaced loop detectors to provide for continuous monitoring of volumes, speeds and occupancies on the freeway mainline and the on-and off-ramps. These detectors were recently installed as part of the Cornerstone project of the Bay Area’s Traffic Operations System (BATOS).

The selected test site exhibits a very high frequency of accidents and other incidents. According to the CHP the section between SR238 and Highway 92 within the study area, is one of the most dangerous stretches in the San Francisco Bay Area’. Figure 2.1 shows historical data on the number of accidents/month in the test site. The accident frequency was considerably higher in 1992, largely because it was an unreasonably high rain year.

The average daily traffic (AADT) throughout the section ranges from 160,000 to 200,000 vpd.[2] The freeway section has been recently widened and a High Occupancy Vehicle (HOV) lane was added. Following the widening of the freeway there is no recurrent congestion on the section except the spillbacks from the on-ramps of SR238 and Highway 92. The typical peak flow rates range from 1400 to 1800 veh/hour/lane along the segments of the site, and the proportion of trucks was about 6 percent. All the reconstruction work was completed prior to the field study, except near the Washington and Whipple street exits. This often created congestion at the vicinity of the Whipple street exit.

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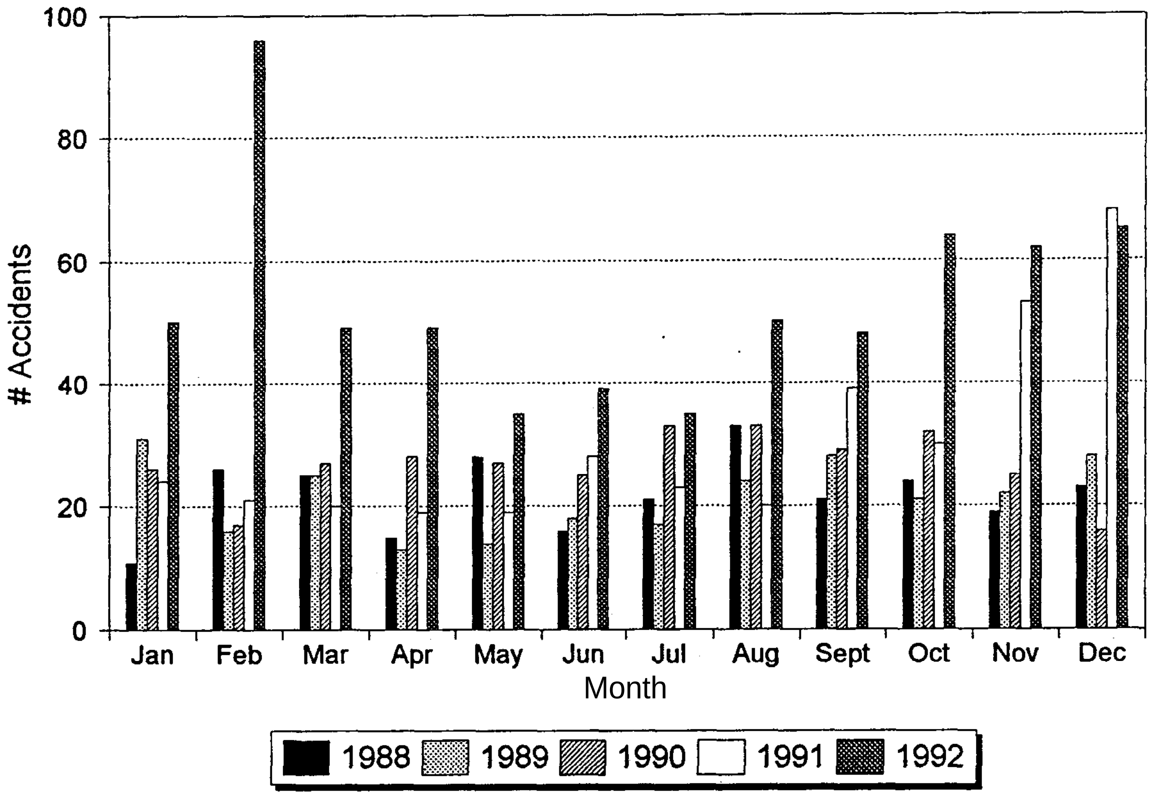
[1] *San Francisco Chronicle*, May 11, 1994

[2] Caltrans,"Route Segment Report”, 1992

FIGURE 2.1 ACCIDENT FREQUENCY--BEAT 3
(Source: Caltrans D4 &TASAS System)



2.1.2 Measures of Effectiveness (MOEs)

Several measures have been proposed and applied to evaluate freeway service patrols in other studies. These include incident delay, average freeway travel speeds, freeway throughput, fuel consumption, air pollutant emissions, incident response and clearance times, number of secondary accidents, and public perception (Finnegan, 1992, Morris, 1994.) The effectiveness of the FSP is determined by translating the benefits in delay and other MOEs into monetary values, and calculating the benefit/cost ratio.

The primary measure of effectiveness selected in this study for the FSP evaluation is savings in delay. Other MOEs include savings in fuel consumption and air pollutant emissions, and benefits to the freeway systems operators (improved incident detection, response and clearance times.)

2.1.3 Test Plan

A detailed test plan was developed for the collection and processing of the field data. The field data on incidents and traffic flow characteristics were collected for a period of about one month "before" and "after" the implementation of FSPs. The duration of the data collection period was selected based on i) sample size requirements on incidents for determining statistically significant differences in response times, durations and delays "before" and "after" the FSP implementation, and ii) budget and time constraints.

The times of the data collection were the am (6:30-9:30) and pm (3:30-6:30) peak periods, to correspond with the times of the day that the FSP is operating on the test site. FSP operates from 6:00-10:00 am and 3:00 to 7:00 pm on weekdays. To minimize seasonal variations in the incident and traffic patterns, the time periods for data collection were selected based on historical data on the accidents and traffic volume patterns in consultation with Caltrans District 4 staff. The process of study design, preparation for fieldwork, and data collection and processing is described in detail in Chapter 3.

2.2 Estimation of Measures of Effectiveness

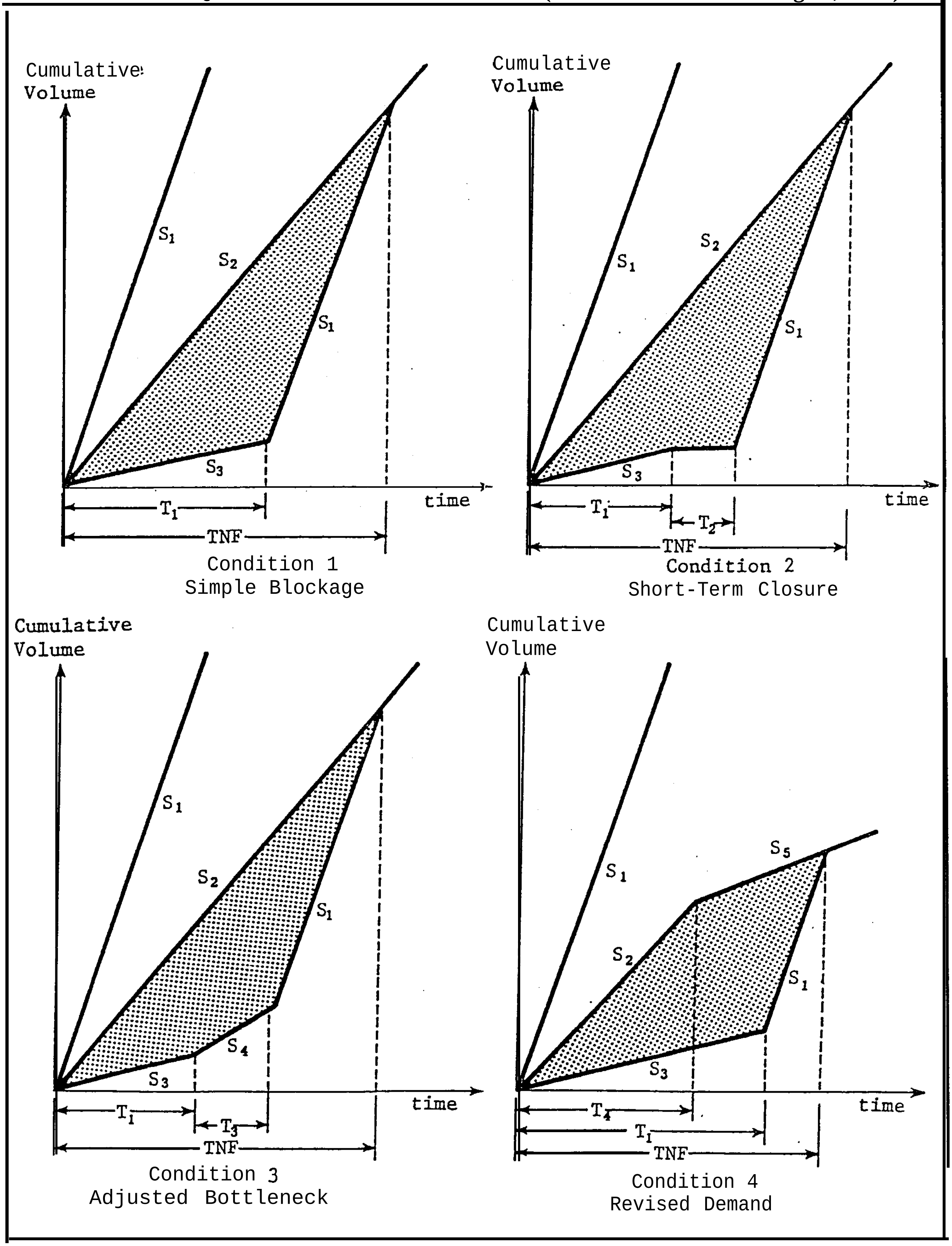
2.2.1 Estimation of Incident Delay

The delay due to freeway incidents can be estimated from a number of methods depending on the level of accuracy and input data requirements. The most commonly used methods include i) input-output (queuing diagram), ii) difference in the average travel speeds (times) for a segment with and without the presence of an incident, and iii) application of traffic simulation models.

A. The Queuing Diagram

The queuing diagram is the most widely used method to estimate delay at a bottleneck location, which is typically the case for incidents obstructing traffic flow, and it has been applied in numerous studies. This diagram originally discussed in the freeway operations context by Moskowitz (Moskowitz 1963), has been extended to consider various situations under incident conditions (Urbanek and Rodgers 1978.) Figure 2.2 illustrates typical queuing diagrams showing vehicle cumulative arrivals and departures at a location as a function of time for different types of incidents and traffic patterns. The shaded area between the arrival and departure curves is the total delay to the traffic stream. The method can be applied manually (FHWA 1983) or using spreadsheets on personal computers (Morales 1986). It has been used by most of the studies to date for determining the impacts of incidents (Lindley 1986 Roper 1990), and the benefits of FSP (Caltrans 1992, Cambridge Systematics 1990, Cuciti 1993). It can be seen from Figure 2.2 that the critical inputs to this method are the demand volume, freeway capacity, remaining capacity during the incident, and the incident duration. The effects of those parameters on the estimated incident delay are briefly discussed below:

FIGURE 2.2 THE QUEUING DIAGRAM METHOD (Source: Urbanek & Rodgers, 1978)



Traffic demand: the demand flow rate (S,) is used to determine the cumulative number of vehicles at the incident location. The closer the demand flow rate is to capacity (S,), the higher the delay during an incident and the longer the recovery time following the incident removal. The delay is also influenced by changes in demand during the duration of an incident. Usually, information about incidents is reported via commercial broadcasting stations, HAR or changeable message signs. As a result a certain portion of traffic diverts to other routes reducing the total demand at the incident location. The amount of the diverted traffic depends on the availability of alternate routes, timeliness of transmitted information, familiarity with the area, trip characteristics, and drivers' compliance rate. In past studies, the diverting traffic (S_2-S_5) was assumed to be from 5 percent of the initial traffic volume up to a maximum of 40 percent for major incidents involving total freeway closures. Furthermore, the change in demand may be constant or variable (i.e., increases with the incident duration.)

Remaining capacity (S,): Incidents reduce freeway capacity when they block traffic lanes and cause rubbernecking, i.e., the tendency of drivers to slow down and observe the incident particulars or shy away from the incident location. The loss of capacity depends on the incident characteristics. For example, shoulder accidents involving ambulance and police on the scene would reduce capacity by about 19 percent on a six lane freeway (three lanes per direction). Stalled vehicles on the shoulder by contrast have minimal effects on capacity.

Remaining capacities for various freeway facilities have been measured in some sites in the 70's (Goolsby 1971) and are still widely used (Lindley 1986). These studies indicate that the capacity reduction is disproportionate to the physical lane blockage. Incidents blocking one lane reduce capacity by 51 percent on a three lane freeway, and by 42 percent on a four lane facility. These reported capacity reductions are based on limited data collected about 25 years ago, and may not be representative of today's conditions on freeways with much higher commute traffic and different vehicle characteristics.

Incident duration: Normally, the average duration per incident type from historical data is used to calculate the incident delay. Any incident management measure such as FSP reduces the incident duration and this in turn affects the delay. The use of the average durations, however, may overestimate the incident delays. This is because the distribution of durations is heavily skewed (Giuliano 1989, Golob 1987) with most incidents having lower durations than the average value, and few incidents with long durations that do not normally benefit from the FSP service (e.g., overturn trucks or spill loads that require major efforts for removal.) Also, incidents do not occupy travel lanes for their entire duration. Most breakdowns and minor accidents move to the shoulder within 10 minutes, and the assumption that a lane blocking incident would occupy travel lane(s) for its entire duration seriously overestimates delays. The significance of those assumptions on incident duration is illustrated in the following table (original data are from the Cambridge Systematics, Incident Management Study 1990):

Effects of Assumptions on Duration on Delay Estimation--One Lane Blocking Incident

I. Average Incident Duration: 75 min	Delay: 2,700 veh-h
II. Average Incident Duration:75 min (vehicle in shoulder for 50 % of time)	Delay: 2,100 veh-h
III. Average Incident Duration:75 min (average duration of FSP affected incidents: 60 min) (vehicle in shoulder for 70 % of time)	Delay: 1,250 veh-h

Several of the assumptions discussed above with the application of the queueing diagram could be relaxed by using field data to determine the arrival and departure curves and observations on incident characteristics and durations. A method was proposed as part of this study to construct arrival and departure curves from loop detector counts, and its application to sample data produced more realistic delay estimates (Al-Deek 1993.)

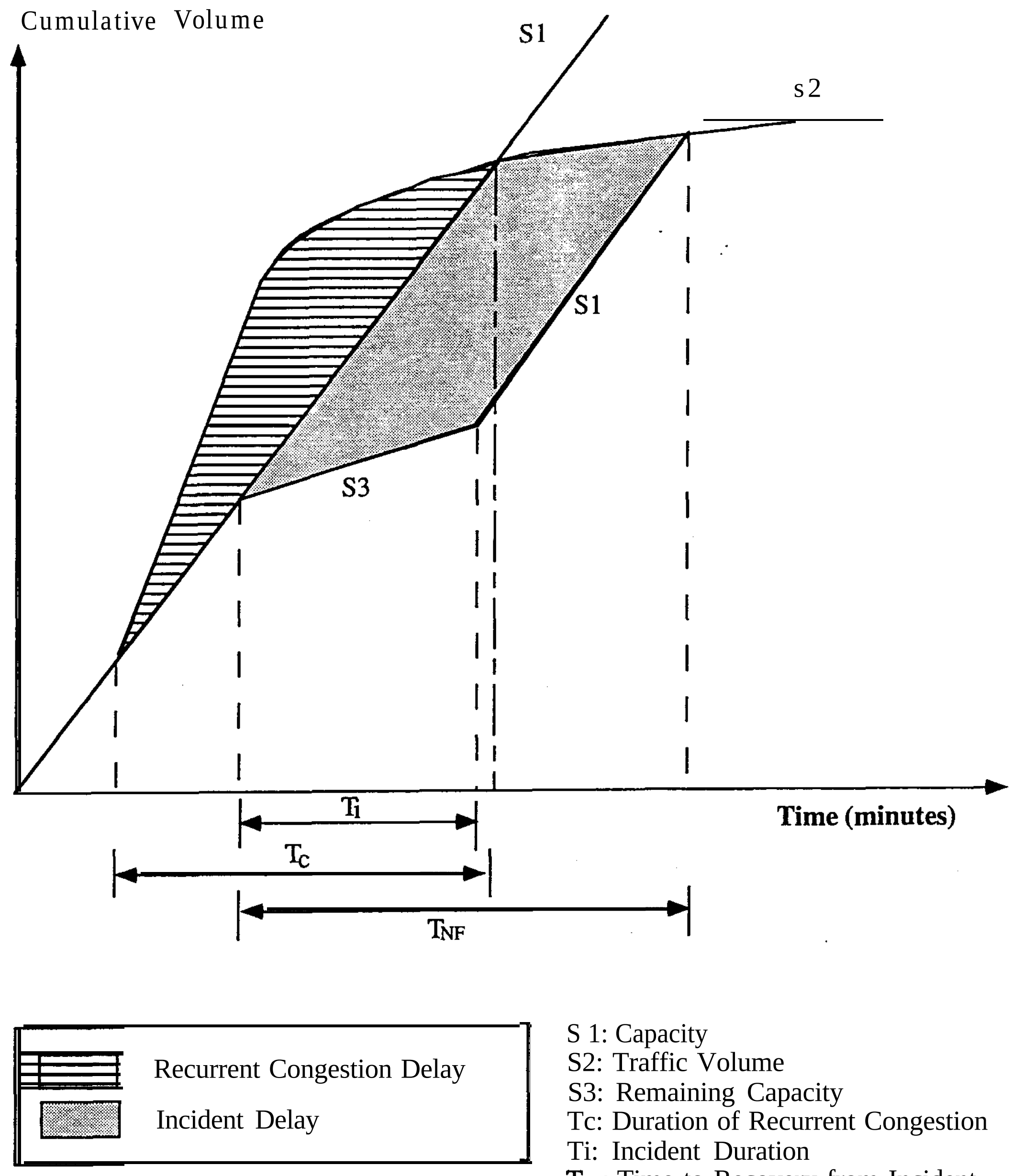
The queueing diagrams shown in Figure 2.2 are applicable for locations without recurring congestion, i.e., the traffic demand does not normally exceed the freeway capacity (S, < S,). The method also can be applied for typical peak period freeway bottlenecks as illustrated in Figure 2.3. In those segments, incidents with the same severity and duration cause higher delays than in sections with spare capacity, and the total delay strongly depends on the time period T_c that demand exceeds capacity. Note that incident management measures such as FSP affect only the incident delay component of the total congestion delay.

A major limitation of this method which is often overlooked is that it estimates delays at a specific point. Several incidents, however, may occur simultaneously along a freeway section and the traffic conditions at the incident of interest could be influenced by upstream incidents. Proposals for addressing this issue include the determination of the “effective” capacity along a freeway section (Hall 1993), or the use of shock-wave analysis to determine the incident specific area of influence (Al-Deek 1993.)

B. Travel times Difference Method

This method estimates the delay on a freeway segment as the difference in travel times under normal and incident conditions. This approach is currently used by all Caltrans districts, with the exception of District 7 who use loop detectors, to estimate the recurrent congestion delay on urban freeways (Epps and May 1994). A number of floating car runs are performed during the peak periods on normal weekdays, and in-vehicle instrumentation records the time and distance traveled. The data are processed to produce the average speed-distance (time) profiles along the freeway segment. Figure 2.4 shows speed-distance (time) plots provided by District 4 from floating car runs on the northbound direction of the I-880 test site in the pm peak. The recurring congestion delay then is calculated as follows:

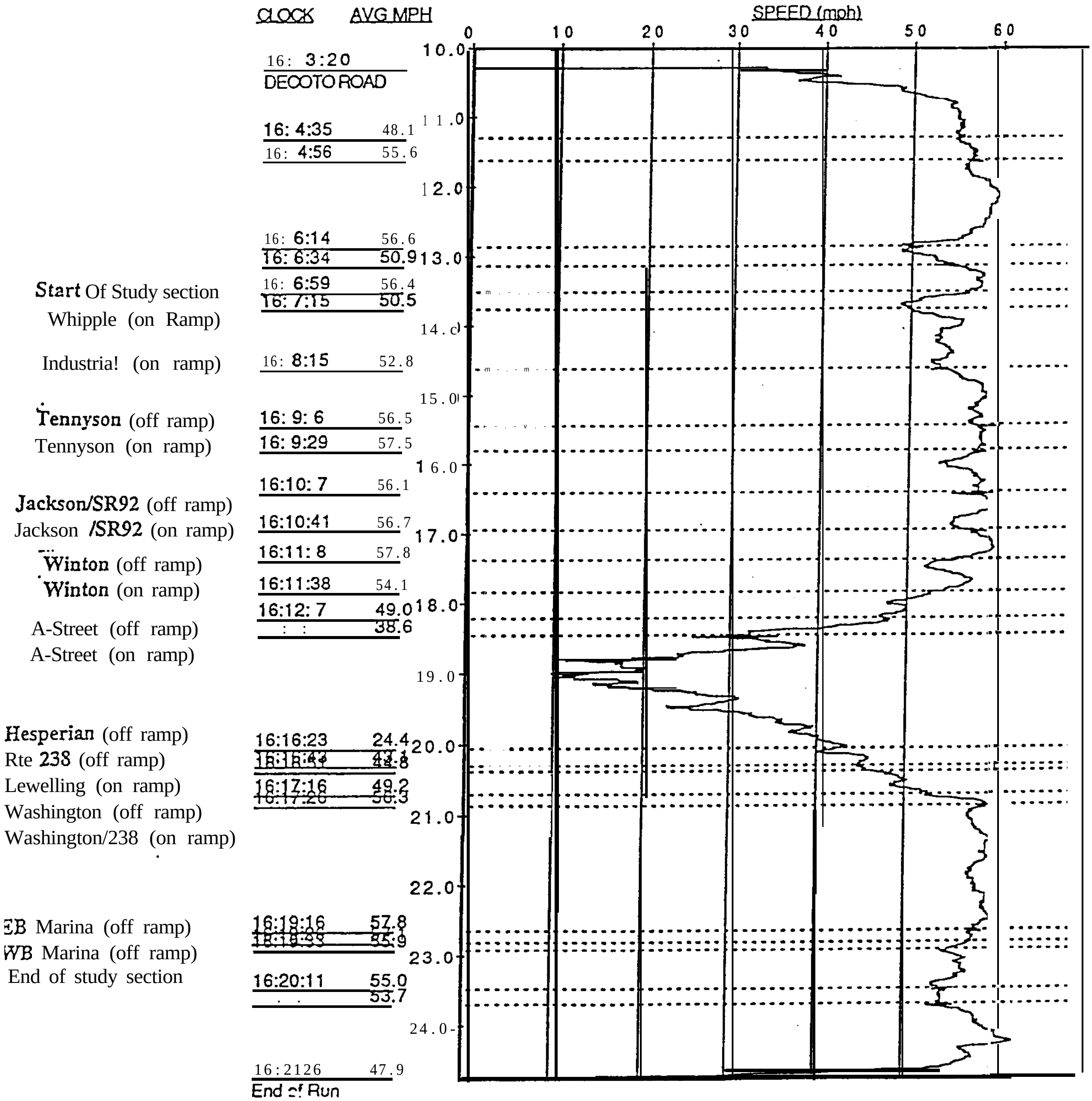
FIGURE 2.3 QUEUING DIAGRAM FOR RECURRING CONGESTION



S 1: Capacity
S2: Traffic Volume
S3: Remaining Capacity
Tc: Duration of Recurrent Congestion
Ti: Incident Duration
T_{NF}: Time to Recovery from Incident Congestion.

FIGURE 2.4 TACH VEHICLE RUNS--I-880
(Source: Caltrans D4)

Location: ALA-880-1 0.3/24.9 Date: 02-1 O-l 993 Period: PM
Driver: MEHRAN LAJEVARDI Run: 1 Direction:: NB



$$D = QTL\left(\frac{1}{V} - \frac{1}{V_{cr}}\right) \tag{2-1}$$

where:

D: recurrent congestion delay (veh-h)
Q: traffic volume (veh/h)
T: time period under congested conditions (hr.)
L: length of the freeway segment (miles)
V: average travel speed from floating car runs (mph)
V_{cr}:threshold speed below which a segment is defined as congested

Currently, Caltrans use 35 mph as the threshold speed, and define congested times as the periods with average speeds below 35 mph for at least 15 minutes (Hicomp 1992).

This approach was used as the basis for the proposed methodology to estimate incident delay based on field data from loop detectors (illustrated in Figure 2.5):

The freeway section upstream of the incident is divided into k segments of approximate equal length L_k. The speeds and volumes on each segment are assumed to be constant and equal to the values provided by the loop detectors within each segment.

The average incident free speed and the average travel speed are calculated from the loop detector data. The delay is then calculated for each time slice (l-5 min) and each segment upstream that is influenced by the incident:

$$D_{ki} = L_k \frac{\Delta T}{60} Q_{ki}\left(\frac{1}{V_{ki}} - \frac{1}{V_{kif}}\right) \quad for\ 0 < V_{ki} < V_{kif} \tag{2-2}$$

$$D_{ki} = Q_{ki}\left(\frac{\Delta T}{60}\right)^2 \quad for\ V_{ki} = 0 \tag{2-3}$$

where:

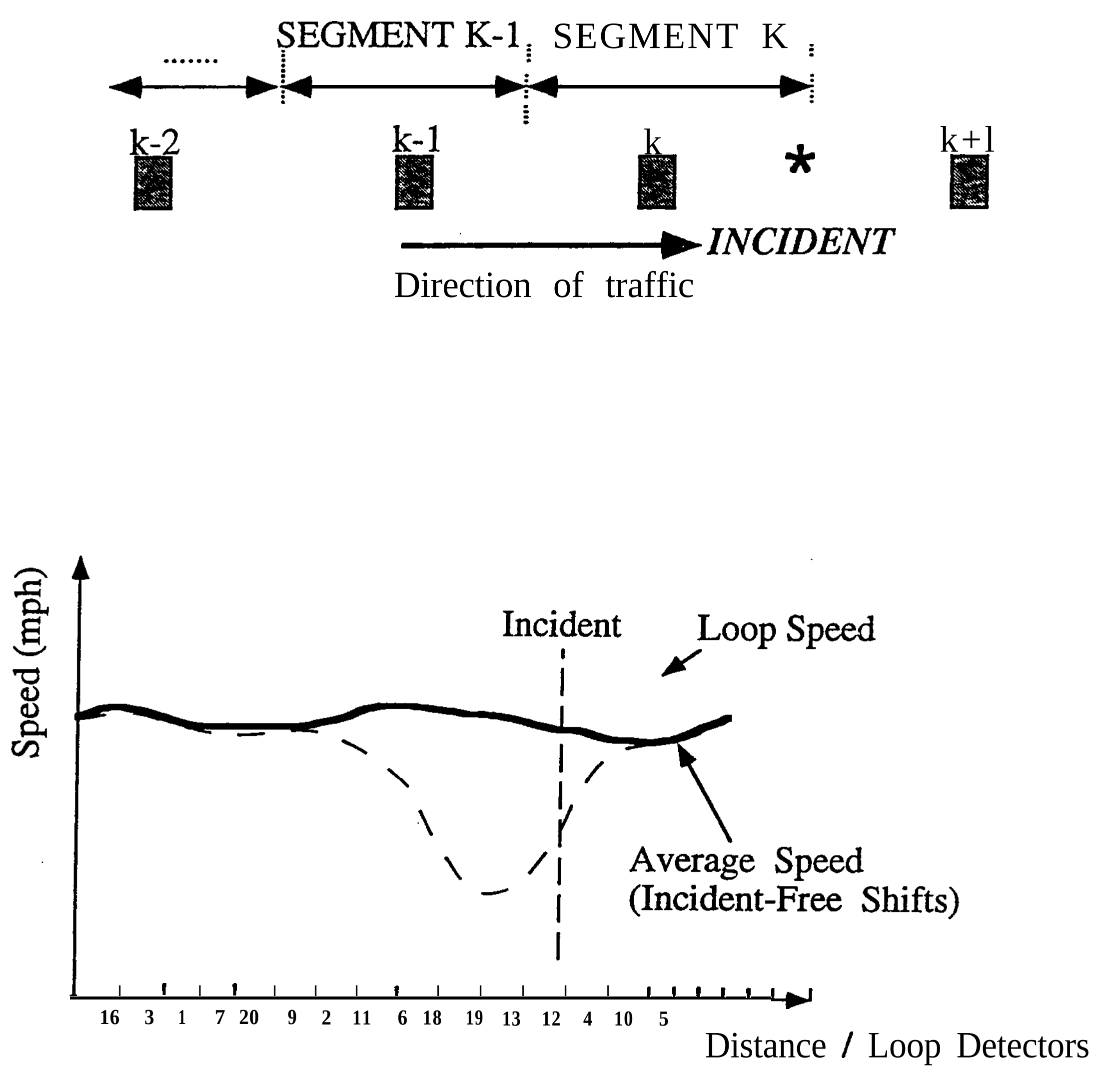
D_{ki} : incident delay on segment k during time-slice i (veh-hr)
Q_{ki} : traffic volume on segment k during time slice i (veh/h)
T : length of the time slice (min)
L_k: length of the freeway segment (miles)
V_{ki}:average travel speed on segment k during time-slice i (mph)
V_{kif}:average travel speed under prevailing incident free traffic conditions (mph)

The total incident delay then is:

$$D = \sum_{k=1}^{n} \sum_{i=1}^{m} D_{ki} \tag{2-4}$$

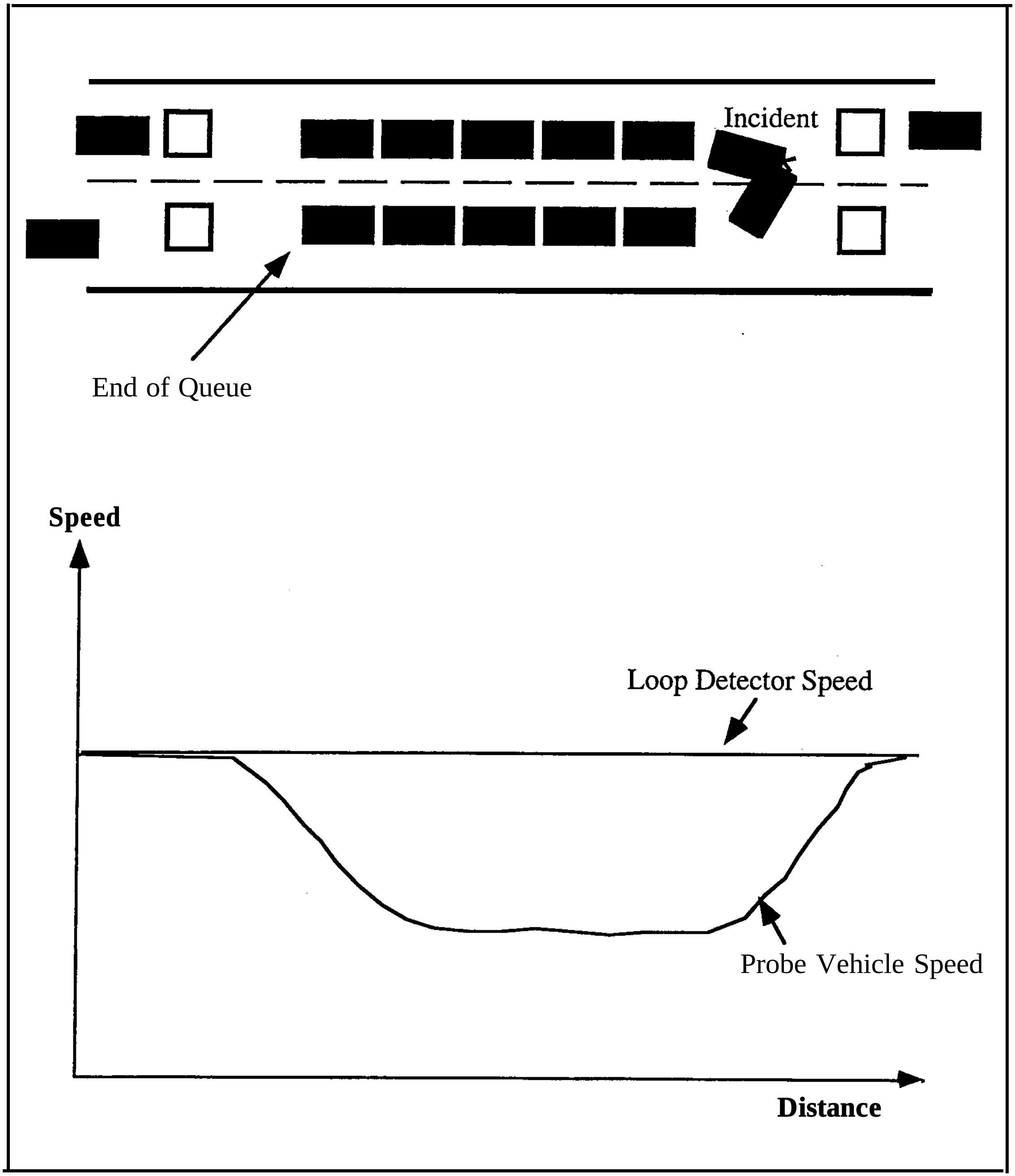
where ***n*** is the number of the freeway segments upstream affected by the incident (i.e., the end of the queue because of the incident,) and *m* is the number of congested time slices (i.e., the incident duration plus the time it takes for the queue to clear.) These n and m values represent the spatial and temporal effects of the incident and are determined from the loop detector data on occupancies, flows and speeds. This method therefore estimates incident specific delays based on the difference of travel times which is the delay perceived by the motorists. The application of the method in this study is described in detail in Chapter 5 (Evaluation.)

FIGURE 2.5 PROPOSED DELAY ESTIMATION METHOD



The estimation of incident delays according to this methodology based on average speeds from loop detectors ignores the delays accrued due to incidents that cause queues that do not extend to the upstream detector station but create slowdowns for vehicles traveling through the section. Figure 2.6 below illustrates the underestimation of delay in such situations. The speed profile from the loop data does not indicate any delay because the incident queue does not extend to the upstream loop. Such delays can be captured from floating car runs.

FIGURE 2.6 LOOP vs. PROBE VEHICLE SPEEDS



C. Simulation Modeling

A number of simulation models have been developed over the last twenty years to analyze traffic operations on freeways. These models fall into two major categories. Macroscopic models consider the average traffic stream characteristics (flow, speed, density) and incorporate analytical procedures to simulate traffic flow. Examples include the FREQ10 model (Leiman & May 1991) and the FREFLO model (Payne 1979). Microscopic models in contrast consider the characteristics of each individual vehicle, and its interactions with other vehicles in the traffic stream. The INTRAS model (Wicks 1980) simulates the movements and interactions of individual vehicles based on car-following, lane changing and queue discharge algorithms.

Both the INTRAS and macroscopic models were tested to estimate incident delay as part of this study. Work concentrated on macroscopic dynamic models because of less data and computational requirements and their applicability for freeway control (e.g., ramp metering.) The model provided by Papageorgiou (Papageorgiou 1990) was selected for further application. The highway is divided into homogeneous sections each having at most one on-ramp and off-ramp. Traffic flow is modelled as a compressible fluid (Lighthill & Whitham 1955) based on the conservation equation and an equilibrium speed-density relationship.

The original model was extended to simulate the freeway incident conditions. This was done by specifying the number of lanes available to traffic as a function of time, and introducing a new model parameter f_{lb} for the incident induced lane blocking. The model was implemented in a computer program written in C programming language, and was applied to simulate traffic flow on the selected I-880 test site under normal and incident conditions. The model results on average speeds and densities were quite consistent with the field measurements. This indicates that this model could be a useful tool for assessing the effectiveness of FSP and other incident management strategies. The development and application of the model is described elsewhere (Sanwal and Fawaz 1994.)

2.2.2 Estimation of Fuel Consumption and Emissions

The amount of fuel consumption on each freeway segment affected by an incident was calculated based on a method derived by Lindley (Lindley 1988) for freeway segments:

$$F_{LT} = L\frac{\Delta T}{60}Q_{LT}\,(0.00657/1000 + 0.20319/1000V_{LT}) \qquad (2\text{-}5)$$

where:

F_{LT}: fuel consumption on freeway section of length L during time period T (gal)

The amount of carbon monoxide CO, hydrocarbons HC and oxides of nitrogen NO, air pollutant emissions from motor vehicles is calculated as follows:

$$E_{LTn} = L\frac{T}{60}Q_{LT}e_{VLTn} \tag{2-6}$$

where:
n: air pollutant (1:HC, 2:CO, 3:NO_x)
E_n: amount of emissions on the section L during time T for pollutant n (grams)
e_{VLTn} emission factor for average speed V_{LT} for pollutant n (grams/mile)

The emission factors used were based on the EMFAC7 factors developed by the California Air Resources Board (ARB) for California conditions.

The calculation of fuel and emissions consider the average speeds of vehicles and not explicitly the time spent in each driving mode (cruising, acceleration, deceleration and idling.) The amount of fuel consumption and emissions would be higher than the values estimated based on the above shown relationships especially for congested freeway segments with significant portion of the time spent under stop-and-go traffic conditions.

CHAPTER 3

DATA COLLECTION AND PROCESSING

3.1 Overview

This Chapter describes the field data collection and processing for the FSP evaluation based on the design of the experiment described in Chapter 2. The data consists of three major categories: incidents, probe vehicle runs, and data from loop detectors, that are uniquely linked to obtain a complete representation of the operational characteristics in the study area. Figure 3.1 provides an overview of the data collection and processing process.

The "before" study was conducted for 24 weekdays from February 26, 1993 through March 19, 1993. Following the implementation of FSP at the site, the "after" study took place from September 15 through October 29, 1993 (a total of 25 weekdays). However, three days of "after" data were lost because of malfunctions in the data collection equipment. Data were collected for six hours per day during the peak periods (6:30-9:30 am and 3:30-6:30 pm.) The majority of the data were collected under clear weather conditions. Rainy periods accounted for 30 percent of the data collection periods (shifts) in the "before" study, and for 9 percent of the shifts in the "after" study. The effects of weather and other environmental factors on incident characteristics are discussed in Chapter 4.

3.1.1 Test Site Characteristics

The selected test site is a section of the I-880 freeway, extending from the Marina Blvd. exit to Whipple Street exit for a total length of 9.2 miles (Figure 3.2). Table 3.1 provides information on the pertinent site characteristics. The geometry of the section varies from 3 to 5 lanes, and the segments between Lewelling Street and Tennyson Street exits include an HOV lane. There are no right shoulders on two segments (Marina to Washington Street exits, and Industrial Parkway to Whipple Street exits); also several sections lack left shoulders. Call boxes have been installed at approximately 1/4 mile intervals. Ramp metering signals were installed but they were not operational during the study.

Loop detectors were installed both on the freeway mainline and on all the on- and off-ramps on the section extending from the SR238 to Industrial Parkway exits (total length of 5.8 miles.) Figure 3.3 shows the typical loop detector type and placement. There are 322 mainline loops placed as pairs at approximately 1/3 mile intervals, 57 on-ramp loops (18 passage, 19 queue and 20 demand loops), and 14 off-ramp loops. These loops are connected to 19 detector stations equipped with Type 170 controllers (see Figure 3.2 for the connections of the sensors to each station.) Also, the 170s at the boundaries of the instrumented section (stations #5,16) are equipped with the INRAD (Inductive Radio) system (Winter 1993). INRAD communicates with suitably instrumented vehicles by transmitting information (time, event) to the probe vehicles' on board computer as they pass over the sensors. Two southbound and one northbound INRAD loops were operational during the field study.

FIGURE 3.1 DATA COLLECTION AND PROCESSING

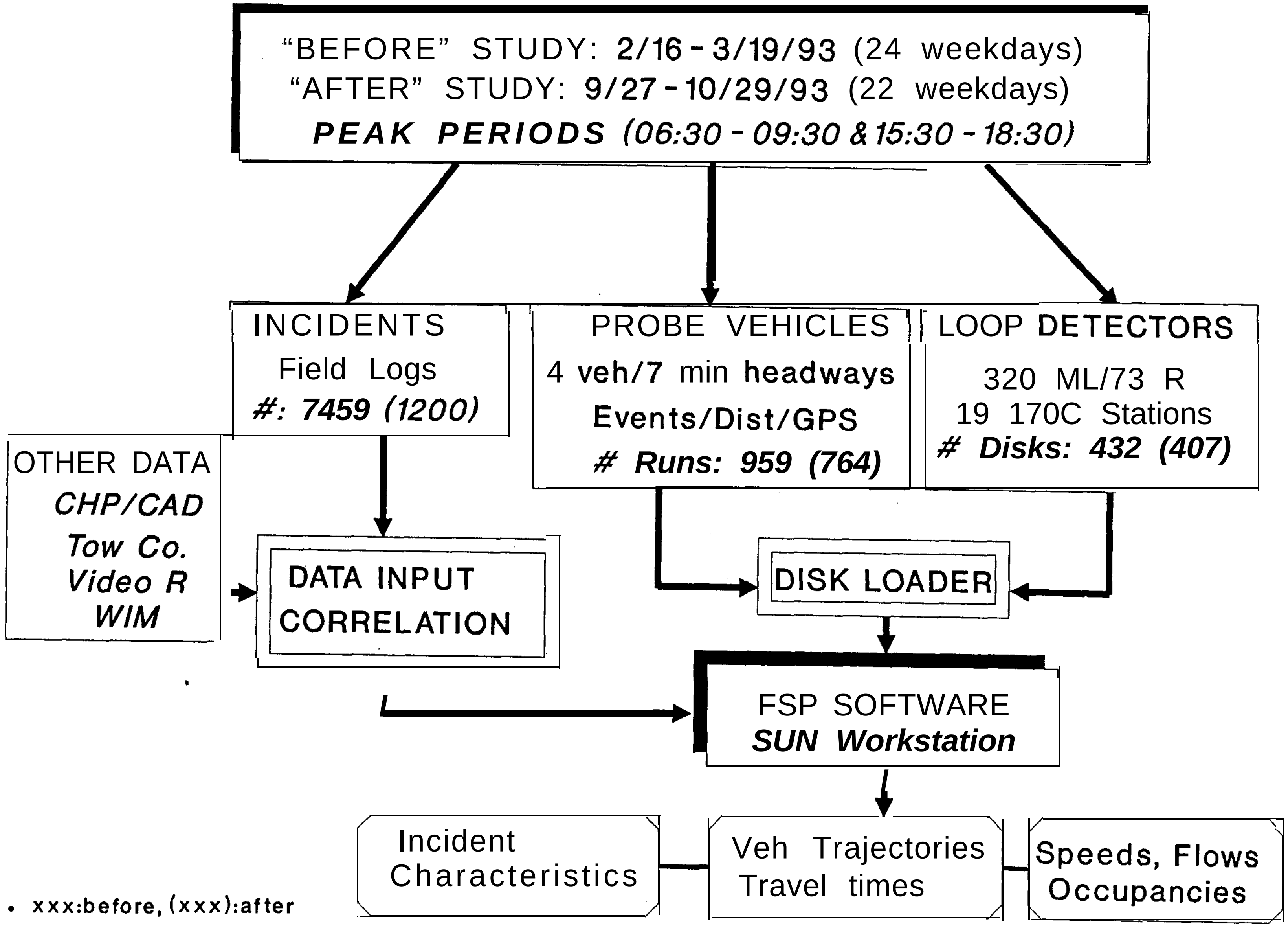


FIGURE 3.2 THE STUDY AREA

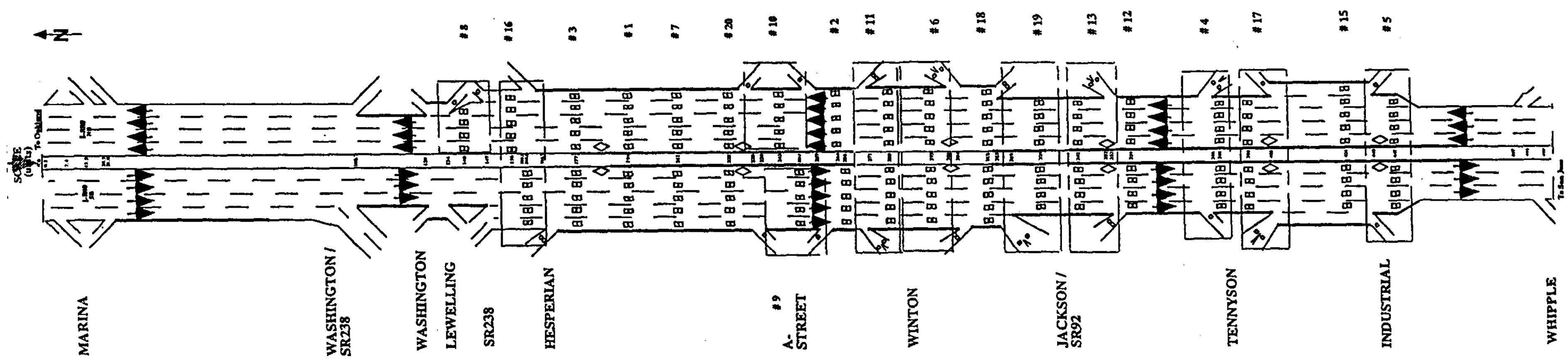
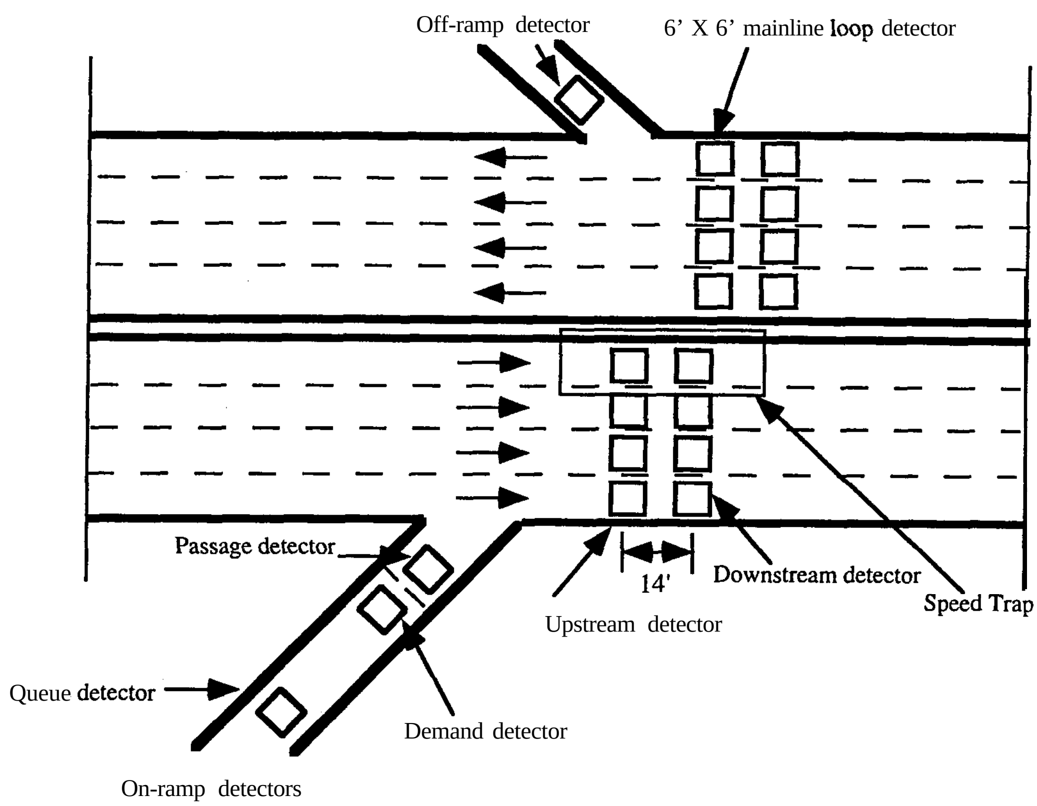


TABLE 3.1 TEST SITE CHARACTERISTICS

SEGM #	DIST (mi)	Southbound FROM	TO	DIST(ft)	Northbound FROM	TO	DIST(ft)	# LANES	RTSH	TSH	HOV	DETECTOR STATION#
1	1.75				Marina Off	Marina Loop Off	750	3	N	N		N/A
		Marina On	Wash/SR 238 Off	8520	Wash/SR 238 On	Marina Off	8470	4	Y	N		N/A
2	0.78	Wash/SR 238 Off	Wash/SR 238 On	2230	Washington Off	Wash/SR 238 On	2230	3	Y	N		N/A
		Washington On	Lewelling Off	600	Lewelling On	Washington Off	600	3	Y	N		N/A
		Lewelling Off	SR 238 On	1300	SR238 Off	Lewelling On	1300	3	Y	N	Y	NB #8
3	2.35	SR 238 On	Hesperian On	1970	Hesperian Off	SR238 Off	1250	5	N	N	Y	16
		Hesperian On	A Street Off	7130	A Street On	Hesperian Off	7550	5	Y	Y	Y	3,1,7,20
		A Street Off	A Street On	1900	A Street Off	A Street On	2200	5	Y	Y	Y	9
		A Street On	Winton Off	1400	Winton On	A Street Off	1400	5	Y	Y	Y	2
4	0.91	Winton Off	Winton On	3300	Winton Off	Winton On	3000	5	Y	N	Y	11,6
		Winton On	SR92 Off	1500	SR92 On	Winton Off	1400	5	Y	N	Y	18
5	2.29	SR92 Off	SR92 On	3400	SR92 Off	SR92 On	3700	4	Y	Y	Y	19,13
		SR92 On	Tennyson Off	3300	Tennyson On	SR92 Off	3400	4	Y	Y	Y	12
		Tennyson Off	Tennyson On	2000	Tennyson Off	Tennyson On	2000	4	Y	Y	Y	4,17
		Tennyson On	Industrial Off	3400	Industrial On	Tennyson Off	3400	4	Y	Y	Y	15
6	1.08	Industrial Off	Whipple Off	5700	Whipple On	Industrial On	5100	3	N	N		5
Total	9.16											

FIGURE 3.3 LOOP DETECTOR CONFIGURATION



3.1.2 Preparation for the Field Study--Pilot Study

The preparation for the field study involved a) development and testing of data collection forms, b) hiring and training the probe vehicle drivers, c) installation and testing of the instrumentation in the probe vehicles, and d) installation and calibration of the data acquisition system from the loop detectors.

The drivers, all UC Berkeley students, were selected by the ITS research team and hired by Caltrans District 04. The drivers were first trained in safe driving procedures by the CHP and Caltrans staff. Several test runs were then conducted to familiarize them with the study area, incident reporting, and the instrumentation in the probe vehicles. Appendix A includes the drivers’ and supervisor data collection guides developed for the field study.

The installation and fine-tuning of the detectors was performed by the Caltrans District 4 staff, with assistance from the Caltrans Transportation Laboratory. The loops in the study area were not previously connected to the detector stations, and a number of 170 controller cabinets even lacked power supply. Following the installation of the 170’s and connection of the loops, the calibration of the detectors was carried out. Sample detector data were downloaded daily and checked for accuracy and consistency. The loops had to be repeatedly tuned in several locations until there were working correctly. The process of making the detector stations operational, connecting and calibrating the loops took about ten weeks of effort in the Fall and Winter of 1992.

During the time of detector installation and calibration, probe vehicle runs were performed and incident data were collected by student drivers. Any problems found with the instrumentation in the probe vehicles were corrected, and refinements were made to the data collection and reporting procedures. A total of five weeks of incident data and probe vehicle data were collected during the period of late October to early November of 1992. These data could not be used directly in the FSP evaluation because of the lack of traffic volume information from the loop detectors but provided valuable information on the incident frequency and characteristics in the study area, and were used in the analysis and testing of the software developed for the analysis of the field data.

3.2 Incident Data

The primary source of information on incidents was the observations of the probe vehicle drivers. They reported via a two-way radio to the supervisor every incident and its characteristics they witnessed on the freeway as they traveled along the test area. The supervisor recorded the data on a specially developed incident data collection form (Form 1, Appendix B), and he dispatched to the incident scene to verify the information reported and record additional data related to the incident. However, the unusual high number of incidents made it impossible for the supervisor to dispatch to the incident location and also required that the supervisor have an assistant to record the incidents on the data form. An alternative way was used to verify information on a reported incident. The drivers provided updates on each incident observed (e.g., tow truck arrival) as they were traveling through the section. The following information on each incident was recorded:

Type (e.g., accident, stall, breakdown)
Severity (number of lanes affected)
Description of the vehicles involved (type, color)
Location (direction, lane, upstream/downstream to the nearest exit)
Time first witnessed
Update (times of CHP arrival, tow truck arrival, clearance)
Weather conditions

Additional data on incidents in the study area were collected by field observations, from the CHP (CAD system and officers ' records), rotational tow truck companies, and from the FSP vehicles' logs (in the "after" study.)

CHP/CAD system: The purpose of the CAD (computer aided dispatch) system is to facilitate the dispatching of CHP officers in responding more efficiently to emergency situations. The CAD database includes records of all calls directed to CHP and information for each incident situation a CHP officer has been involved:

Call source/time (CHP calls, Cellular 911 calls, other 911 calls, Call boxes, FSP calls)
Incident type and severity (e.g., accident, stall, breakdown, number of lanes affected)
Description of the vehicles involved (License plate **#**, color, type)
- Relative location (direction, lane, upstream/downstream to the nearest exit)
Reporting and clearance times (CHP, FSP if any, tow truck call, arrival and departure)

The information from the CAD system was obtained from the CHP communications center in Vallejo. Unfortunately, the data could only be obtained in hard copy. Therefore, the study team had to manually search the CAD printouts to identify the incidents during the time periods of the field study, translate the CHP codes into the ones used in the data collection form, and input the data in the computer for subsequent processing.

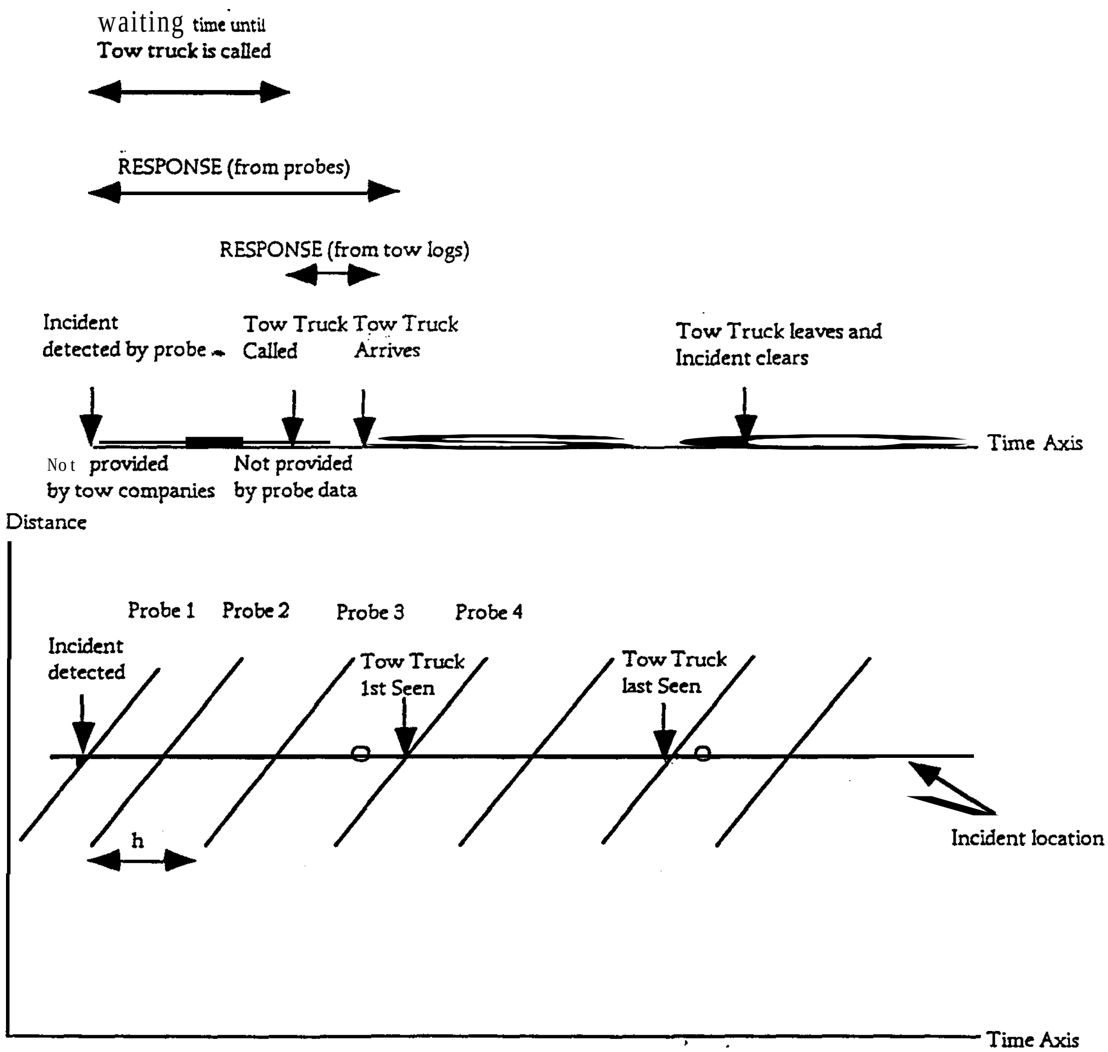
CHP Records: A significant number of the observed incidents involved citations by the CHP officers, especially for violations of the HOV lane in the study area. However, information on CHP ticketing is not maintained by the CAD system, it is only available in the CHP officers logs. These logs are kept by the officer's name, not by the violations times and locations, which makes the retrieval of information difficult and time consuming. The data retrieved from the CHP logs was only used to verify the accuracy of data on incidents observed either as ticketing or incidents involving a CHP officer without any additional information.

Tow Truck companies: The CHP maintains a list of thirteen rotational tow truck operators in the study area. These tow companies were providing service to stranded motorists during the before study and when requested during the after study. The study team prepared a log (Log 2 Appendix B) for the tow truck operators requesting information on:

Tow truck call/dispatch, arrival and departure
Vehicle description, towing location (if any)
Incident location, type (accident, other)

Rotational tow truck operators were contacted by the CHP and asked to fill out the logs during the days of the field experiment and send it back to the research team. Follow-up contacts were made to verify the information. Only three tow companies responded, and the information provided was incomplete, except the AAA service which submitted detailed logs for both the "before" and the "after" study.

The tow truck companies data were not critical in this study since this data was used to supplement, but not to replace the field observations. Tow companies do not provide the time that the incident occur but the time when they were called, i.e., the response times from such logs do not include the time lapsed until the tow companies were called. The field data based response times include the time from the incident occurrence until the tow truck arrived as observed by the probe vehicle drivers. This is illustrated below. The primary measures for FSP evaluation are i) how long a driver has to wait until for an assist and ii) what is the total incident duration. Those time periods can only be provided by the field observations.



Tow company data can be used to explain the long response times observed for some incidents. The data revealed that tow trucks were called as long as two hours after the incident was first observed. This is probably due that the drivers "abandoned" their vehicles and called a tow truck for assistance at a later more convenient time.

FSP Data: The FSP tow truck drivers are required to fill out an assist form each time they provide assistance to an incident. The FSP logs include information on type and location of the incident, type of assistance provided, and time of arrival and departure of the FSP vehicles (Log 3, Appendix B). These logs were obtained from the Caltrans staff for the "after" study. The FSP vehicles are also equipped with an AVL (automatic vehicle location) system and an on-board computer that logs in all the FSP trucks activity for processing by the Management Reporting System (MRS). The MRS computer tape with the FSP data was obtained by Caltrans and the information was processed. However, the MRS system was not operational for the first two weeks of the “after” study, and the incident information (description of vehicle type and involvement) in the tape was not sufficient to correlate the recorded incidents with the field logs and other data sources. Therefore, the information on the FSP driver logs were used in the data processing.

The information on incidents was coded into spreadsheet using a coding scheme (Appendix B). The incident data base was also exported to the Sun workstation for use by the software for correlation with the other data sources and estimating incident delays.

Sometimes it was not possible to accurately identify the type of incident. For example, an incident involving a CHP officer in the right shoulder could be ticketing, assisting a breakdown, or clearance activity from an earlier incident, especially if the incident is witnessed only once. Based on the field experience, and the information from the CHP/CAD system and other sources, the observed incidents were classified into the following major categories for subsequent analysis:

Accidents
Breakdowns
Ticketing
Debris/Pedestrian

A subsequent correlation with the CHP CAD data showed a 100 percent match of incident types between the two sources for the correlated incidents.

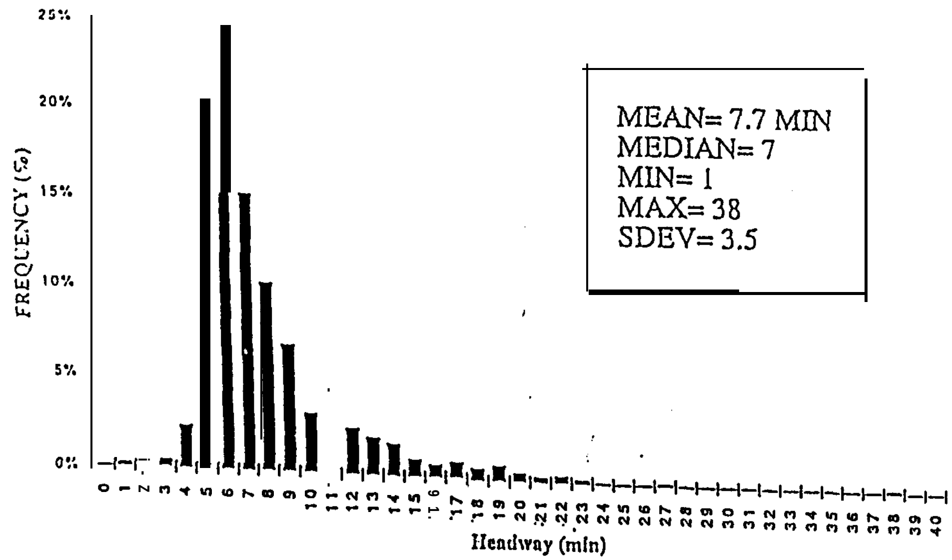
3.3 Probe Vehicles

Probe vehicle runs were performed on the test site using four specially instrumented vehicles provided by Caltrans. A fifth instrumented vehicle served as a back-up car and was used by the supervisor to dispatch to incident scenes. The test run consists of a loop from the Marina to the Whipple exit and back to Marina. The vehicles were dispatched by the field study supervisor via the two-way radio. Each driver reported to the supervisor via the radio every time he/she passed the Marina Exit. The supervisor recorded the arrival and departure times on a Headway Log (Form 1, Appendix C), and instructed the drivers whether to wait or continue. Figure 3.4 shows the distributions and statistics of the arrival and departure headways in the “before” and “after” study. The average headway was 7 minutes. About 80 percent of the probe vehicle headways were within 7 minutes. Longer headways were due to car breakdowns on some days during the data collection and congested time periods.

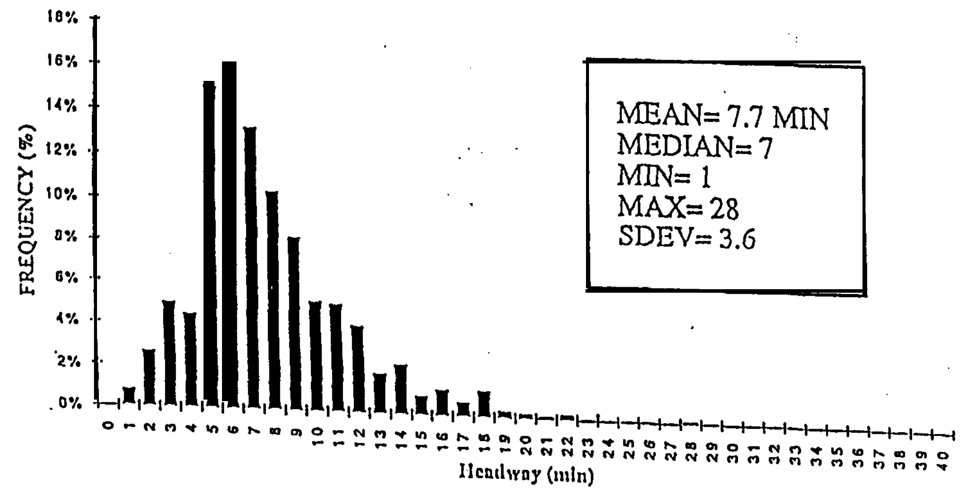
The in-vehicle instrumentation consisted of a transmission speedometer transducer to collect distance data, a rate of turn indicator, a magnetic compass to collect direction data, a Global Positioning System (GPS) and a Citizen Band (CB) radio to communicate with the supervisor. Also, watches synchronized with the CHP/CAD clock were provided to allow for time synchronization of all car runs.

FIGURE 3.4 PROBE VEHICLES HEADWAY DISTRIBUTIONS

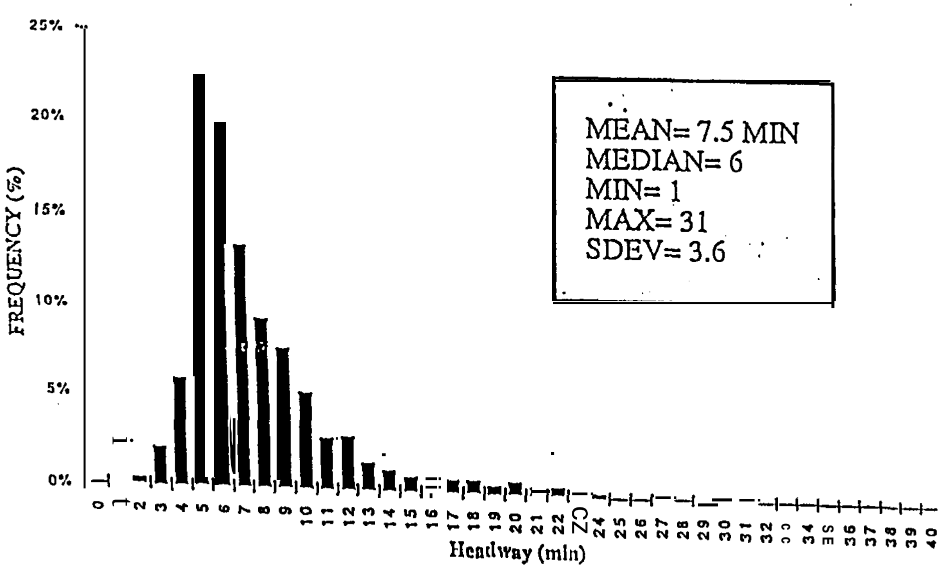
DEPARTURE (BEFORE)



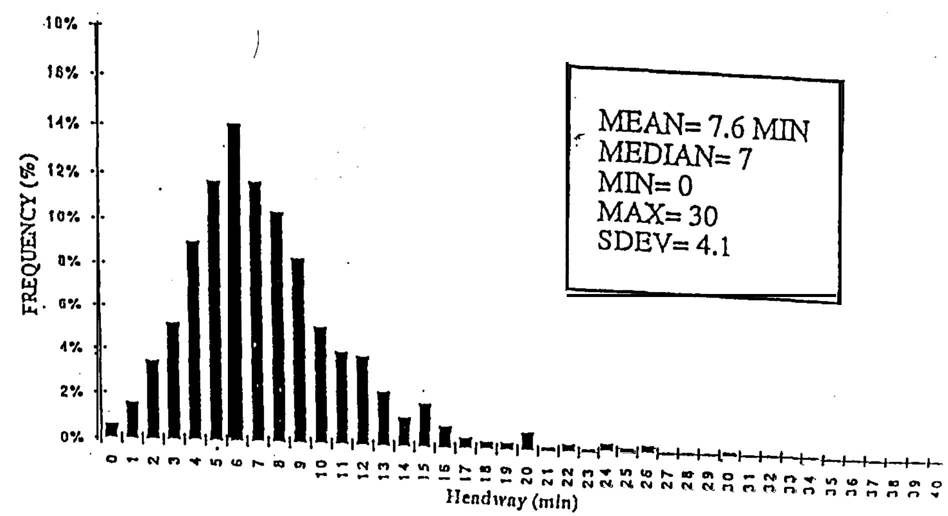
ARRIVAL (BEFORE)



DEPARTURE (AFTER)



ARRIVAL (AFTER)



The instrumentation was calibrated to correctly translate odometer readings into distance (miles.) This was accomplished by driving the vehicles over exact known distances on a test track. The in-vehicle data collection system stores the data each second on 256K RAM cards in compressed binary format. A RAM card reader then provides tab delimited ASCII DOS files with the following fields (Appendix C includes detailed information on files/data fields):

Incremental distance (from the time the equipment was turned on)
Magnetic direction
Rate of turn
GPS information (latitude, longitude, number of satellites)
Keyboard event (single ASCII character indicating an incident, start of the run or a certain location such as gore point). Also, as was previously mentioned, each time a vehicle traveled over an INRAD loop a mark was stamped in the keyboard event file along the time. This permits synchronization with the loop data and recording of the travel time to traverse the entire length of the study section.

Each vehicle is equipped with a laptop computer to automatically store data from the instrumentation. The drivers initiate the data collection system via the laptop's keyboard by entering the start time, name and vehicle ID number. The drivers enter a keystroke each time the vehicle passes an incident, as they pass the Marina, Washington, Industrial and Whipple Rd exits, and a specific code indicating the completion of a test run ("qwe"). At the end of the three hour shift, the data stored in the laptop's RAM are downloaded into 3.5" floppy diskettes. Each floppy disk was labeled with date, shift, and car number.

The data in diskettes were then transferred to the workstation for processing. Specially written software checked the data and produced plots of the traveled routes. The software identifies malfunctions of the data acquisition system (no data recordings), drivers not following the predetermined routes, and checks the distance traveled and travel times against the exact length of the route and the free flow travel times (e.g., 19.5 miles at 20-30 minutes.) The processing of the probe vehicle data provides several plots and statistics including:

Travel times
Distance traveled and position
Exact incident location and time it was witnessed by the driver
Number of runs completed

Sample outputs from the data processing software are shown in Figures 3.5 and 3.6. Figure 3.5 shows a time-distance plot of a probe vehicle with the locations of the observed incidents shown on the vehicle's trajectory. Figure 3.6 shows the travel times of the probe vehicles per direction of the freeway test section vs. the start time of the run for a particular data collection period (am peak of 3/10/93.) Note, that probe vehicles experience significant delay in the northbound direction from 7:30 until 9:00 am.

FIGURE 3.5 PROBE VEHICLE TRAJECTORY

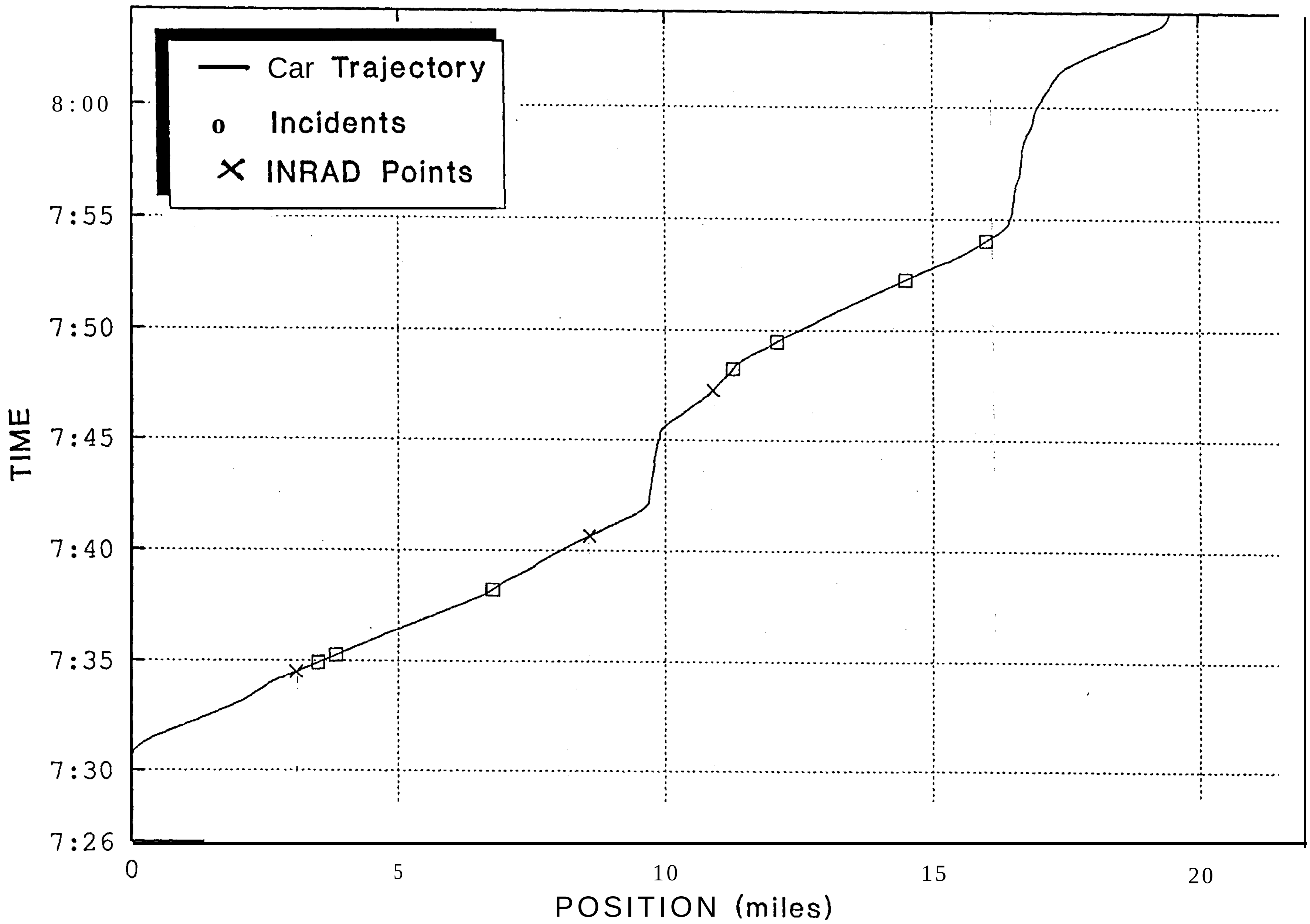
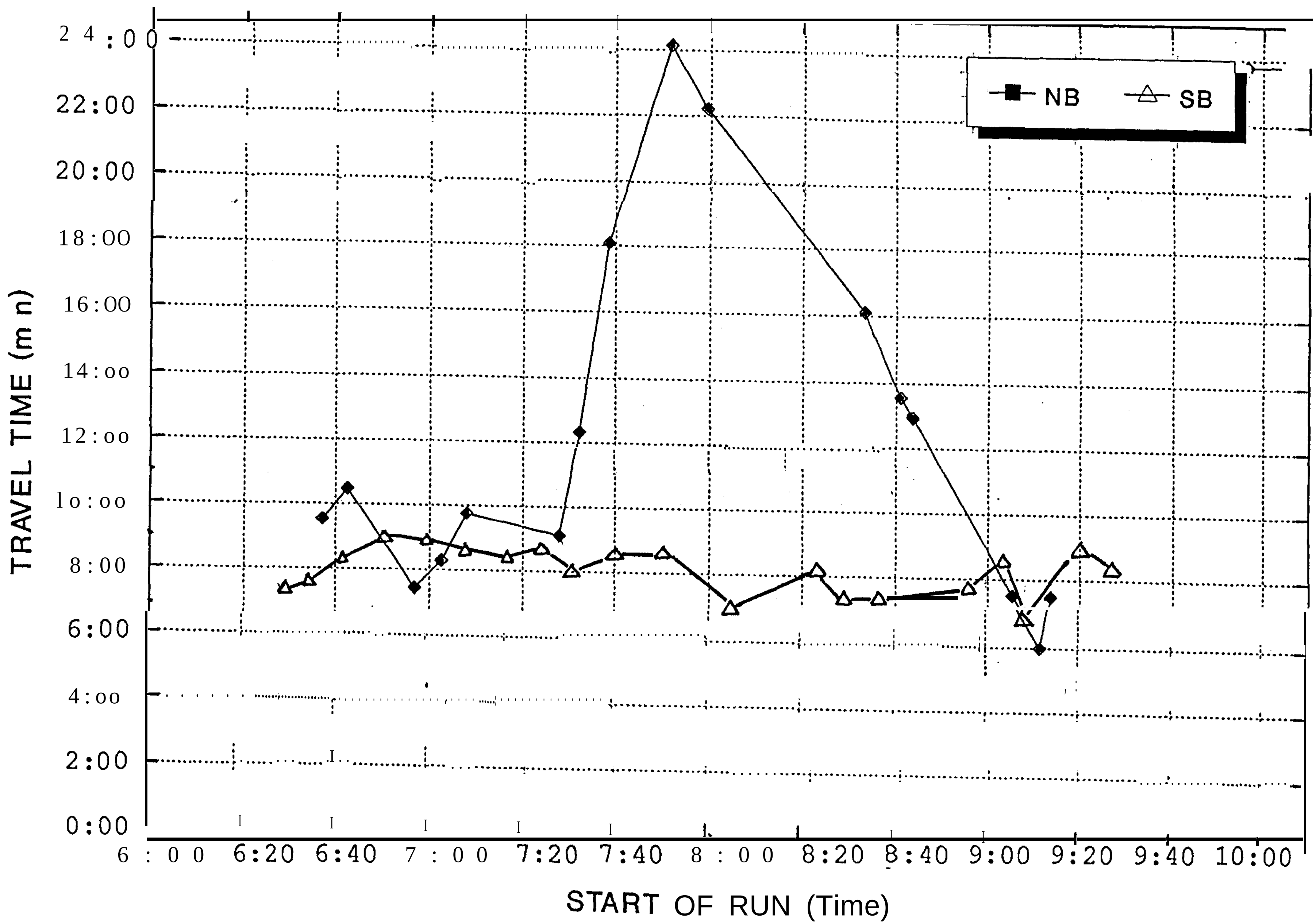


FIGURE 3.6 PROBE VEHICLES TRAVEL TIMES (3/10/93, AM PEAK)



The number of test runs depends on the prevailing traffic conditions, with fewer runs completed under congested conditions. In the "before" study, six runs per each three hour shift were achieved on the average, which translates into 1152 expected runs. A total of 959 test runs were made, with 881 runs containing good data. Data losses were due to test car breakdowns, defective diskettes, and malfunction of the in-vehicle equipment. There were 764 runs in the "after" study because of frequent car and data collection equipment breakdowns.

3.4 Loop Detectors

The data acquisition system developed and installed by Caltrans District 04 staff in the Type 170 controllers records speeds, flows, occupancies and loop on and off times on 256K RAM cards in compressed binary format. A RAM card reader then reads the data and outputs a tab delimited ASCII DOS file with the volume, speed, and occupancy data for each lane on the freeway and the ramp every 1 second. Data were recorded from 5:00 am to 10:00 am and from 2:00 to 8:00 pm each weekday.

The detector stations are not connected to a transportation management center (TMC) via dedicated or telephone lines. Therefore, the data were stored on PC/DOS based notebook microcomputers installed inside the controller cabinets and downloaded to 3.5" high density diskettes, and the diskettes had to be replaced at the end of each day. The data in the diskettes were transferred to a Sun Workstation for processing. The data transfer was performed using a disk loader and software to automatically load and copy the files in each diskette into the appropriate data directories in the workstation's hard disk. A total of 432 high density diskettes were collected during the 24 days of the "before" field study out of the possible 456 disks (19 detector stations sampled over 24 days). The remaining diskettes were lost during data downloading or use of defective disks (5 percent lost data.) A total of 402 diskettes are available from the 22 days data collection period in the "after" study.

The loop data were processed through a suite of specially written computer programs that a) check the information recorded against suitably assigned thresholds for speeds, flows and occupancies for every single loop, b) check the measurements across the lanes at a single location to verify that the data show reasonable distribution of traffic across lanes, and c) identify changes in data between upstream and downstream loops at a single location. The software provides both preliminary data summaries and error reports with time and detectors ID information. Table 3.2 shows the operational loops in the study area per detector type based on the results of the data processing software. Sample outputs of the error reports produced by the software are included in Appendix D, along with a summary of loop data availability at each detector station. The software produces summaries and plots of loop data at any level of aggregation (Figure 3.7 is a sample plot of minute counts for a particular loop.) Figure 3.8 shows three dimensional plots of volume, speed and occupancy along the test site.

TABLE 3.2 OPERATIONAL LOOP DETECTORS

Loop Type	(#)	Operational (%) Before	Operational (%) After
Mainline	322	96	98
On Ramp Passage	18	89	83
On Ramp Demand	20	80	75
On Ramp Queue	19	100	79
Off Ramp	14	86	86

FIGURE 3.7 SAMPLE COUNTS FROM LOOP DETECTORS

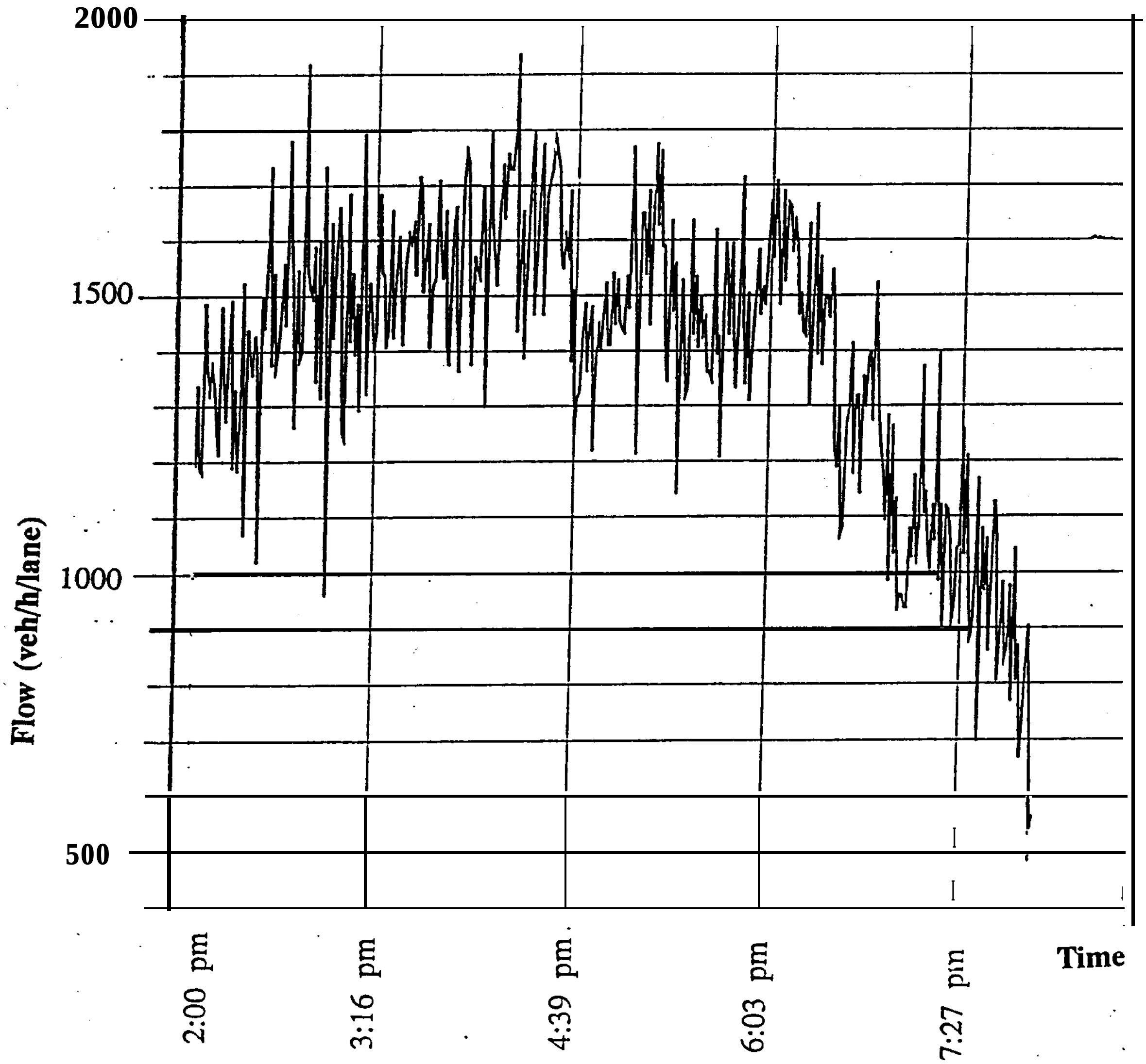
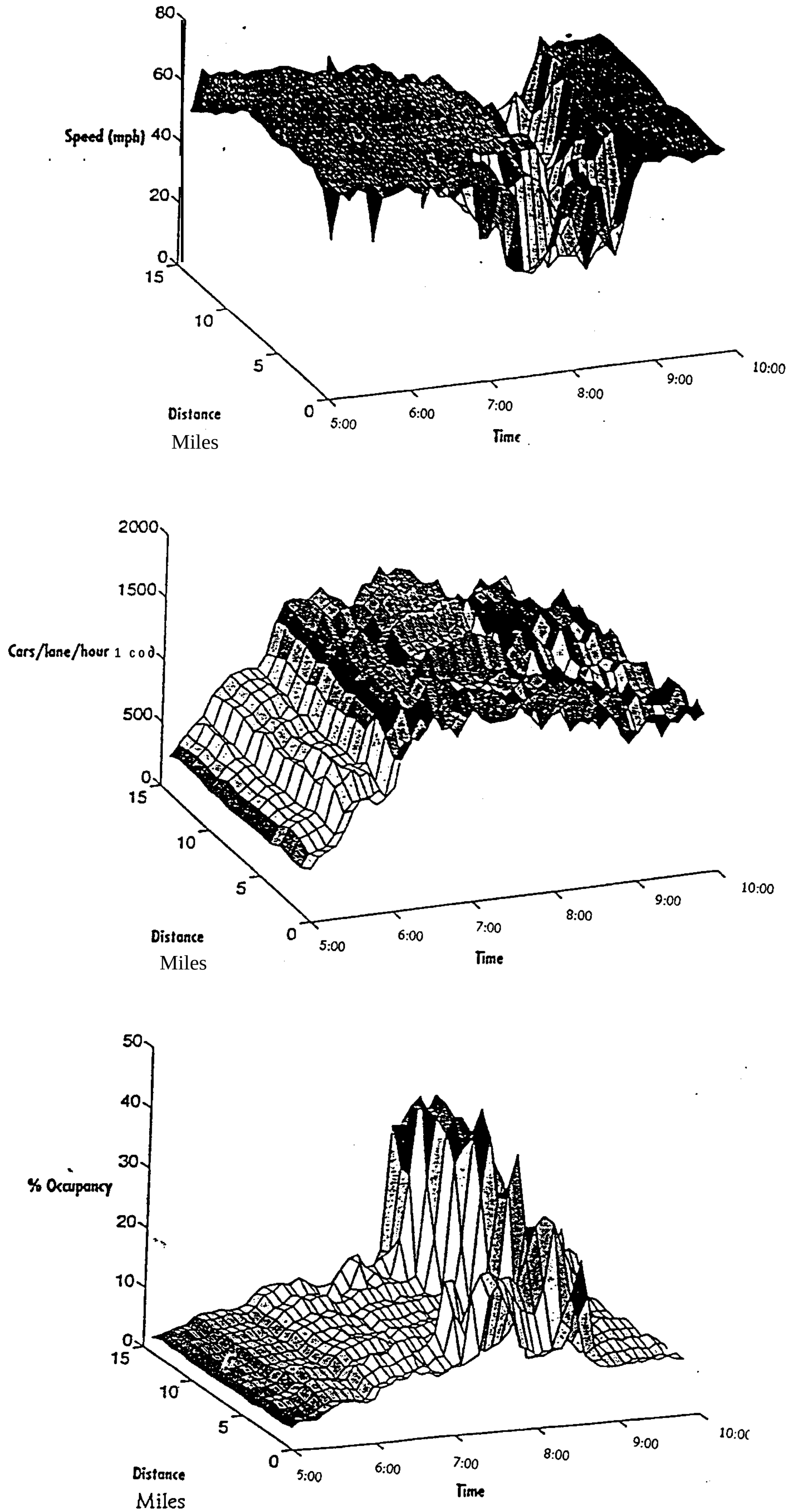


FIGURE 3.8 SPEED / VOLUME / OCCUPANCY PLOTS (3/10/93, AM PEAK)

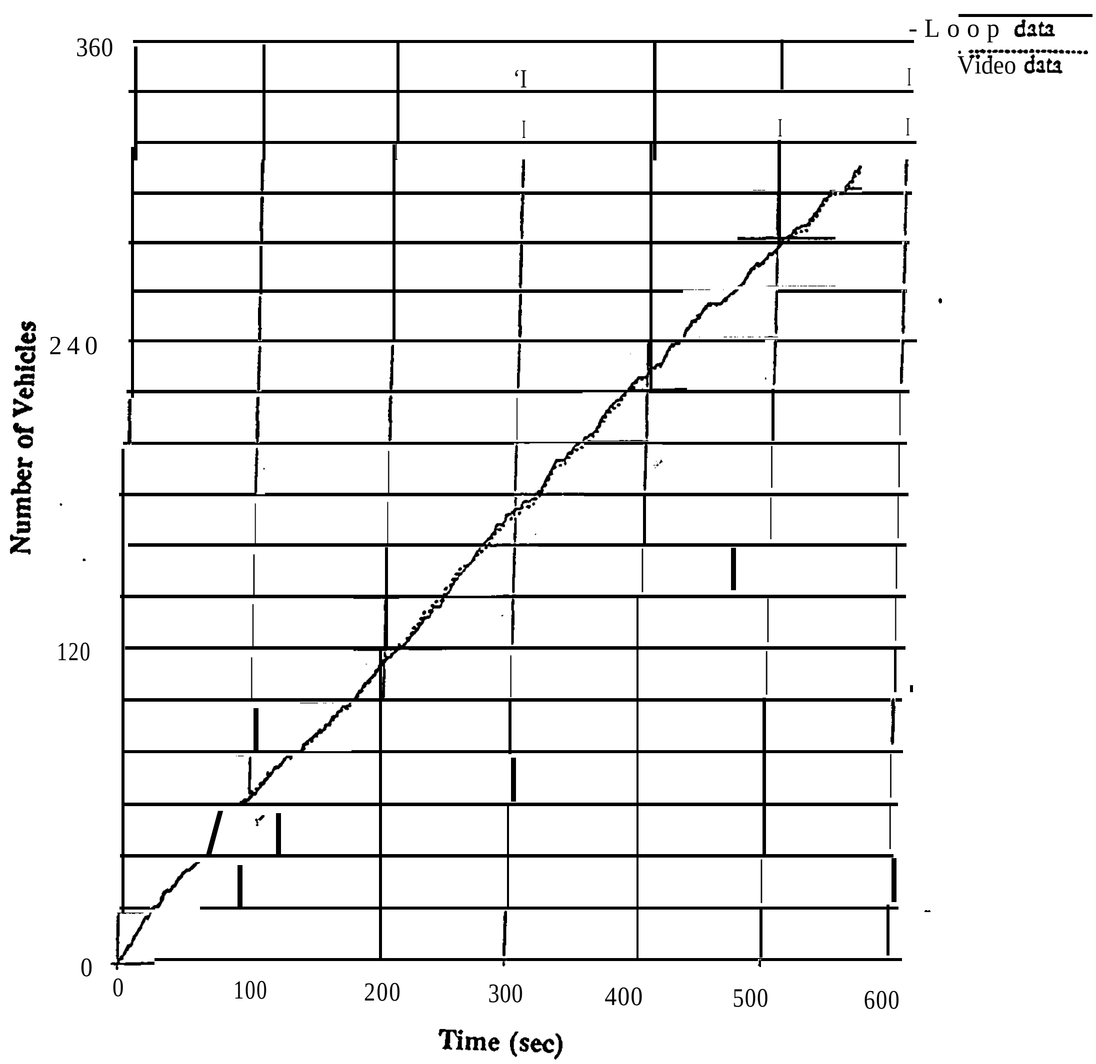


The main problem with the loop data was missing information from specific loops for the entire length or portion of a shift ("data dropouts"). The software computes the missing data by interpolating the values from the adjacent loops. Other problems were overcounting (sensing vehicles into adjacent lanes), undercounting (missing vehicles near the centerline attempting to change lanes), and bad traps (one of the loop pairs is not working resulting into wrong volume and speed values). Several routines were written to correct the data for those problems.

The following supplementary data on traffic characteristics were also collected:

Video recordings: Sample video recordings were taken from the overpass located at the Tennyson Exit for 15 minute periods. Data were extracted from the video tapes and compared with the loop data from detector station #4. (Figure 3.9). Differences of about 1 percent were found between the total volumes from the loops and the flows measured from the video at the selected times and locations. Comparisons of traffic counts for each lane showed a maximum difference of 4 percent.

FIGURE 3.9 LOOP .vs VIDEO RECORDING COUNTS



Weigh-in-motion data: The selected test site includes a weigh-in-motion station instrumented to classify and/or weigh vehicles moving at the prevailing highway speeds. Data were collected by Caltrans for six weeks during the "before" study. The data include counts per lane classified into fifteen vehicle classes. A portion of the data was analyzed to determine the proportion of trucks during the data collection period. The average daily truck traffic in the study area was about 5,500 trucks per day of which about 35 percent were within the data collection shifts. The percent of the peak hour truck traffic was about 7 percent on the average.

3.5 The Integrated FSP Database

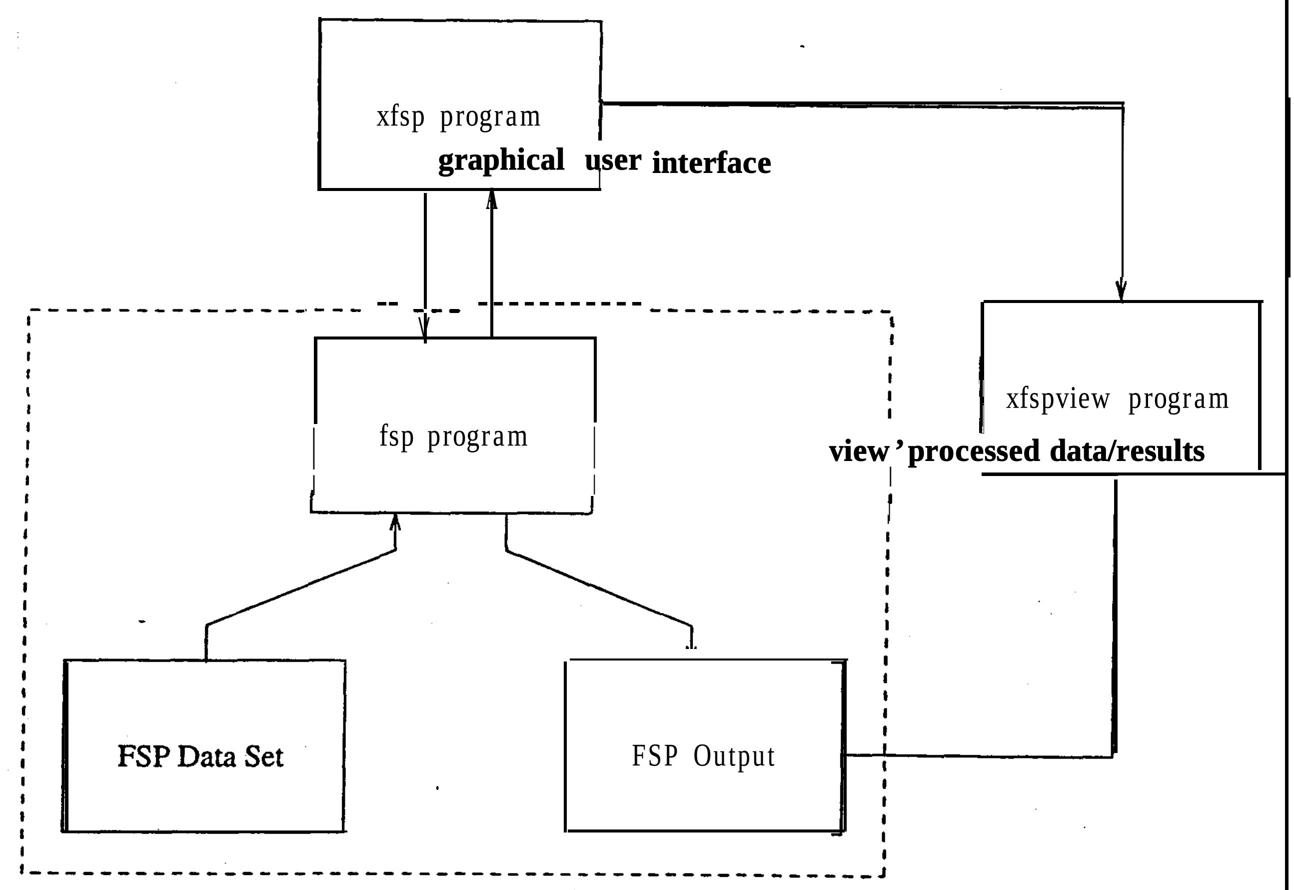
The collection and processing of the field data in. this study has resulted perhaps in the largest and most comprehensive database on freeway operations to-date. A total of 276 hours of field data were recorded and have been integrated in a fully computerized integrated database. This allows to correlate incidents with the probe vehicle runs, by matching the observed times and locations with the event codes in the files generated the probe vehicle runs, and superimpose the incident location on the vehicle's trajectory to query on the incident impacts on the vehicle's travel time (Figure 3.5). The probe vehicles runs are synchronized with the loop data through the INRAD system, which allows to verify the loop data and assess the incident's impacts on traffic operations. Figure 3.8 shows a significant reduction in speed and increase in occupancy indicating the presence of congestion as measured from the loop data. The travel times of probes in the northbound direction (shown in Figure 3.6) show the same patterns for the same time period.

The database and the FSP software for data processing and analysis have been thoroughly documented (Petty 1994), and are available to other researchers on-line through the Internet. Figure 3.3 shows an overview of the software and Table 3.3 shows a summary of the program outputs.

TABLE 3.3 FSP SOFTWARE OUTPUTS

Loop Data	Probe Veh Data	Performance Measures
. Speed/Vol/Density Plots	Vehicle Trajectories Speed vs. Time (Distance) Plots	Incident Duration/Response Time Statistics/Distributions
Data Summaries per user input time period	Travel Time vs. Run Start Time	Incident Delays Delay Contours
Error Reports Dropout times	Latitute vs. Longitute Plots GPS Data Plots	Fuel/Emission Estimates
	Correlation Car and Incident Data	
	Driver Evaluations	

FIGURE 3.10 OVERVIEW OF THE FSP SOFTWARE



CHAPTER 4

INCIDENT CEIARACTERISTICS

This Chapter presents the findings from the analysis of incidents observed by the drivers in the probe vehicles, and the incident data obtained from the CHP/CAD system and the FSP logs.

4.1 Incident Frequency

A total of 1453 incidents were observed in the “before” study and 1210 in the “after” study in Beat 3. These include 243 “before” and 239 “after” incidents that were observed on segment 1 (from Marina to Washington Exits.) This segment, however, had FSP service in operation during the “before” study, and therefore those incidents were excluded for further analysis in evaluating the effects of FSP in the study area. The remaining 1210 and 971 incidents in each study period were grouped into the following categories:

Accidents: single or multi-vehicle accidents

Breakdowns: stalls due to mechanical or electrical problems, flat tire, and out of gas. This category also includes abandoned vehicles and all other stops (e.g., check maps, etc.)

Debris/pedestrians: debris, other fixed objects or pedestrians observed on the roadway.

CHP/Ticketing: incidents involving the presence of CHP other than accidents and breakdowns.

Table 4.1 shows the classification of incidents based on their type and place of occurrence for the “before” and the “after” study. Most of the incidents were stalls on the right shoulder. The incident frequency and patterns were similar for both study periods; The number of incidents per shift was higher by about 12 percent in the "before" study, but the difference in the average breakdowns and accidents per shift “before” and “after” were not statistically significant. The estimated incident rate on the study section was 109.8 “before” and 92.4 “after” incidents per million vehicle miles of travel.

There was a high proportion of CHP/ticketing related incidents. Those incidents account for 27.3 percent of the total incidents in the “before” and for 24 percent in the “after” study. These incidents were mostly citations for violations of the HOV lane usage in the study area. Note that the CHP office is located close to the study corridor and the freeway section is quite heavily patrolled because of the known high frequency of accidents and other incidents. Although there may be some effects of those incidents on traffic flow, it is unlikely that these incidents would be affected by the FSP service, or any other traffic management measure, and therefore were not considered in the FSP evaluation.

TABLE 4.1 INCIDENT CLASSIFICATION

A. 'BEFORE' STUDY

Incident Type	Location			Total	%*
	C.Divide	In-Lane	Right Side		
Accident	23	18	53	92	10.5
Breakdown	32	15	728	775	88.1
Debris/Pedestrian	1	11	1	13	1.5
CHP/Ticketing	57	1	272	330	
TOTAL	113	43	1054	1210	
TOTAL (excl. CHP/Ticketing)	56	42	782	880	100

* excluding CHP/Ticketing

B. 'AFTER' STUDY

Incident Type	Location			Total	%*
	C.Divide	In-Lane	Right Side		
Accident	6	19	50	75	10.2
Breakdown	28	9	619	656	89.1
Debris/Pedestrian	0	4	1	5	.7
CHP/Ticketing	52	0	183	235	
TOTAL	86	32	853	971	
TOTAL (excl. CHP/Ticketing)	34	32	670	736	100

Table 4.2 shows the incident frequency per segment, excluding CHP/ticketing incidents. Segments 3 and 6 had the highest incident frequency. The average frequency of 1.24 (1.13) incidents per directional freeway mile per data collection shift translates into about 2.41 (2.65) hours between incidents occurring within a mile section of freeway in the "before" and "after" study. Figure 4.1 shows the incidents/shift per day throughout the data collection periods. The variation in the observed incidents was due to time of day, day of the week, types of vehicles involved and weather conditions.

The frequency of incidents by the time of the day is shown in Figure 4.2. More incidents were observed in the pm than the am peak in both study periods, especially breakdowns on the right shoulder and CHP/ticketing incidents. This is because of the higher volumes in the pm peak period. Also, most of the traffic in the am peak consists of commuters on travel to work who are less likely to be involved in ticketing incidents. More incidents were observed on Mondays and Fridays than on the rest of the weekdays.

Most of the incidents involved passenger cars. Trucks were involved in about 6 percent of the accidents, and 16 percent of the breakdowns (Figure 4.3.) Less than 2 percent of the CHP/Ticketing incidents involved trucks.

Weather conditions had a significant impact on accident occurrence, but not on vehicle breakdowns. Figure 4.4 illustrates the effects of weather on the incident's frequency for the "after" study. The average accident frequency for rainy days doubled (3.5 accidents/shift during rainy shifts as opposed to 1.5 accidents/shift under clear weather.) The number of breakdowns, either in-lane or the shoulders, increased slightly during the rainy periods.

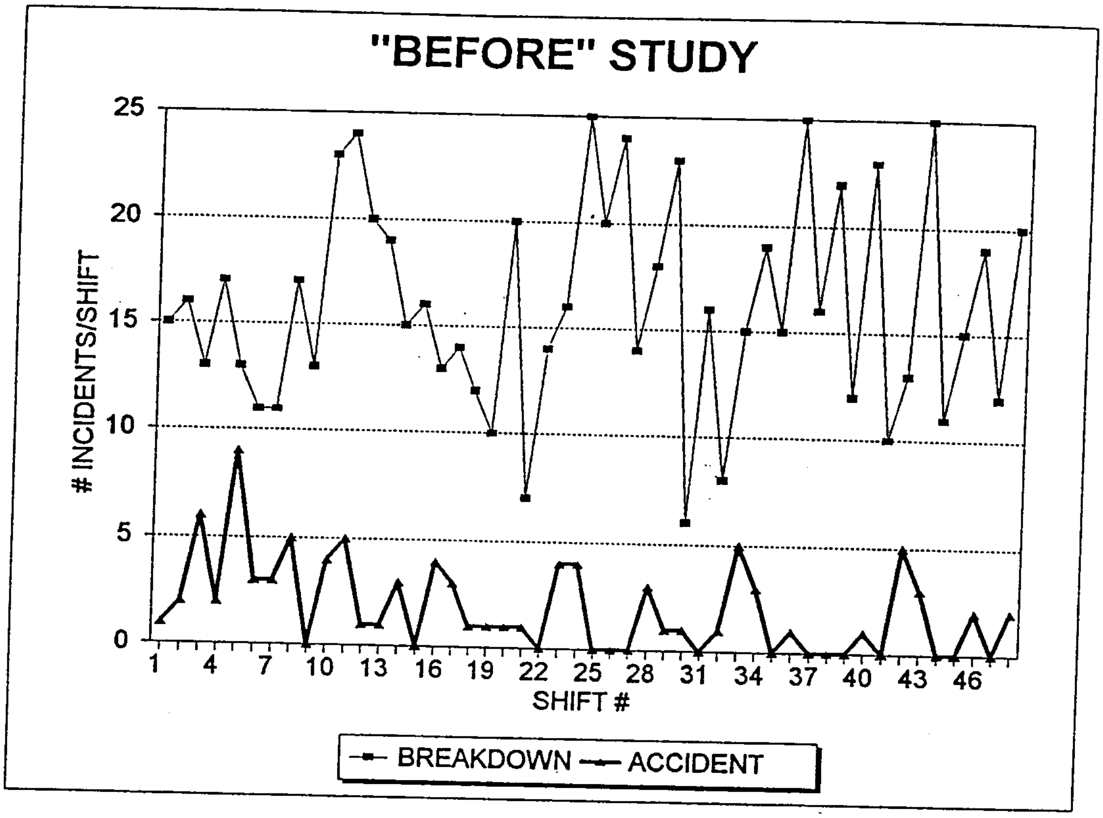
The number of in-lane incidents depends on the presence of shoulders, incident type, type of vehicles involved and the data collection methodology. In this study, in-lane incidents are those that are first witnessed on the freeway mainline. The proportion of the in-lane incidents was 4.7% and 4.3% in the "before" and "after" study periods respectively, excluding CHP/ticketing incidents (Table 4.1). This translates into .0051 and .0042 lane-blocking incidents/hour/lane-mile. Higher rates have been reported in other studies (Giuliano, 1989). However, it is plausible being that more incidents do first occur on the mainline and are moved to the shoulder before observed by the probe vehicle drivers, and higher frequency of in-lane incidents would have been observed if other means (e.g., CCTV) had been used for data collection.

Figure 4.5 shows the incident trees constructed for the "before" and "after" study summarizing the overall incident patterns in the study area (excluding CHP/Ticketing and debris/pedestrian incidents). Also, shown are values reported by FHWA (Lindley, 1986) based on studies conducted in the 70's. The proportion of in-lane incidents (about 4 percent of the total), and the proportion of accidents (about 10 percent of the total incidents) are very close to the previously reported data. The I-880 section, however, has a much higher proportion of in-lane accidents, particularly in the "after" study (67.9 percent of accidents in travel lanes as opposed to 21.3 percent reported in the literature.) Also, the I-880 data show a much higher proportion of accidents occupying two or more travel lanes.

TABLE 4.2 INCIDENT FREQUENCY BY SEGMENT (excl. CHP/Ticketing)

SEGM #	LENGTH (miles)	'Before" SB	NB	TOTAL	"After" SB	NB	TOTAL	#Incidents/mile/day BEFORE	AFTER	#Inc/mile/shift/dir BEFORE	AFTER
2	0.78	27	28	55	32	6	38	2.93	2.21	0.73	0.55
3	2.35	114	159	273	134	127	261	4.84	5.05	1.21	1.26
4	0.91	49	56	105	49	34	83	4.81	4.15	1.20	1.04
5	2.29	193	136	329	151	100	251	5.98	4.98	1.50	1.24
6	1.08	44	74	118	41	62	103	4.55	4.34	1.14	1.08
Total	7.41	427	453	880	407	329	736	4.95	4.51	1.24	1.13

FIGURE 4.1 VARIATION OF OBSERVED INCIDENTS



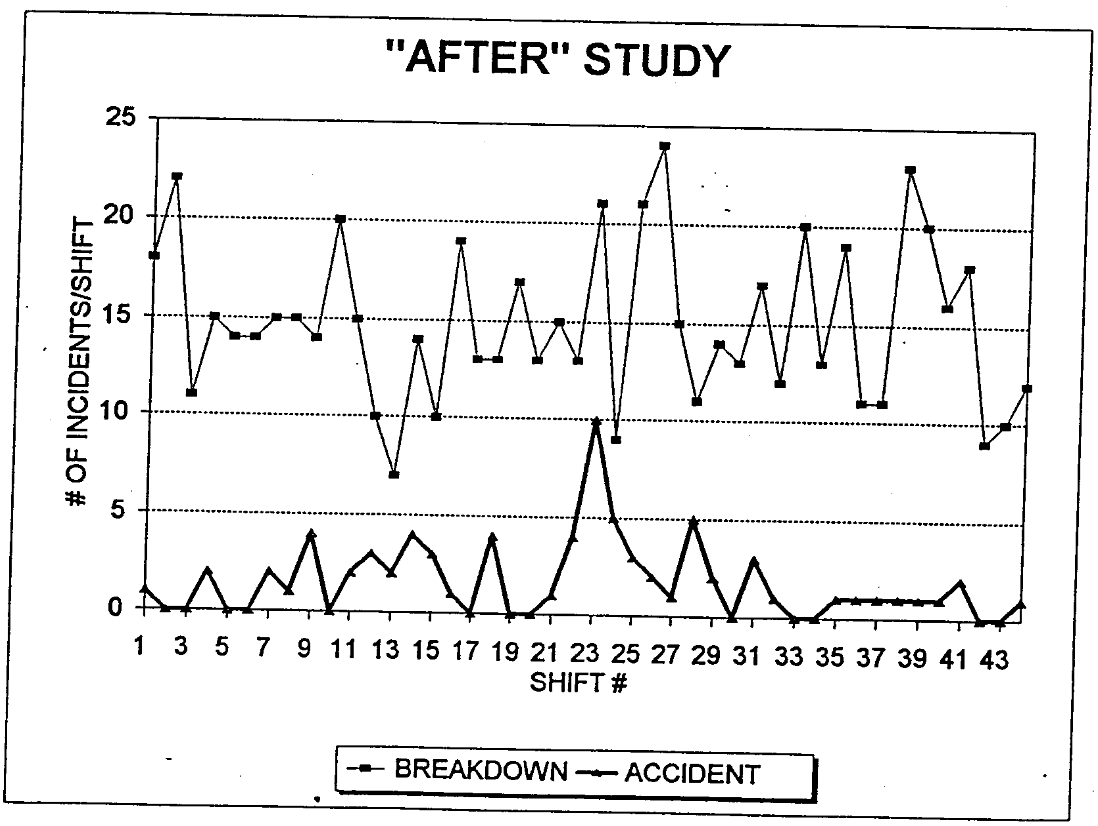
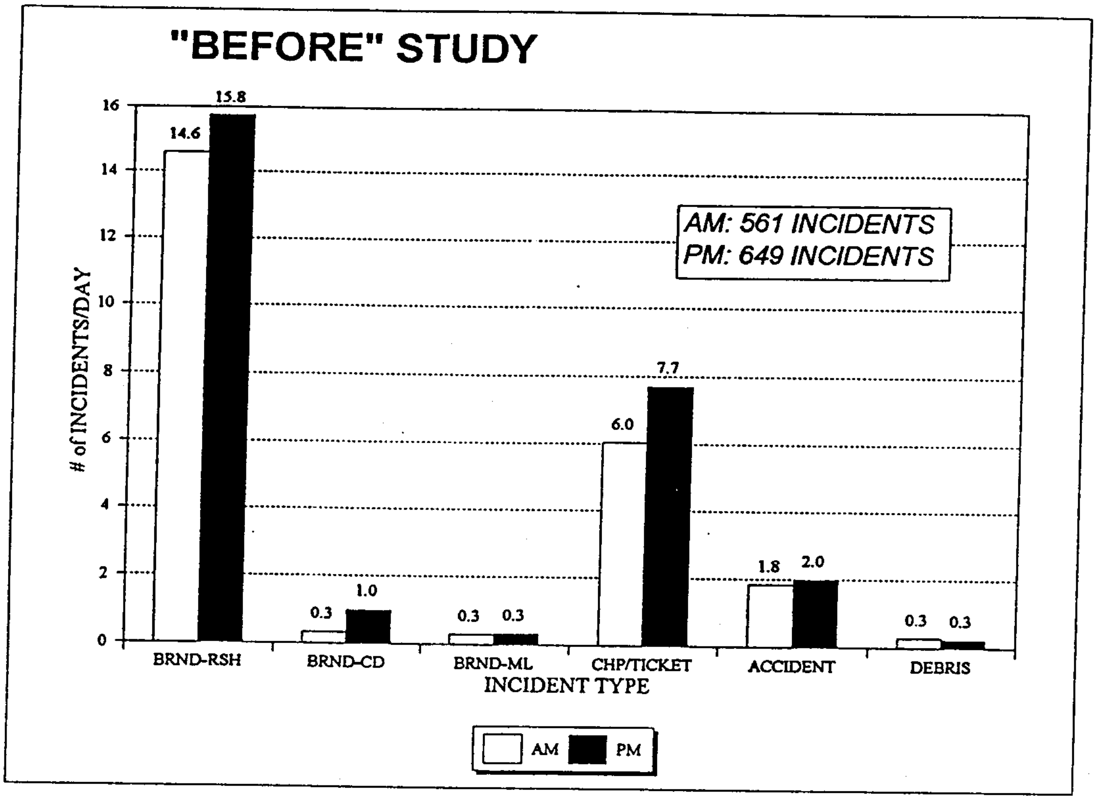


FIGURE 4.2 INCIDENT FREQUENCY BY TIME OF DAY



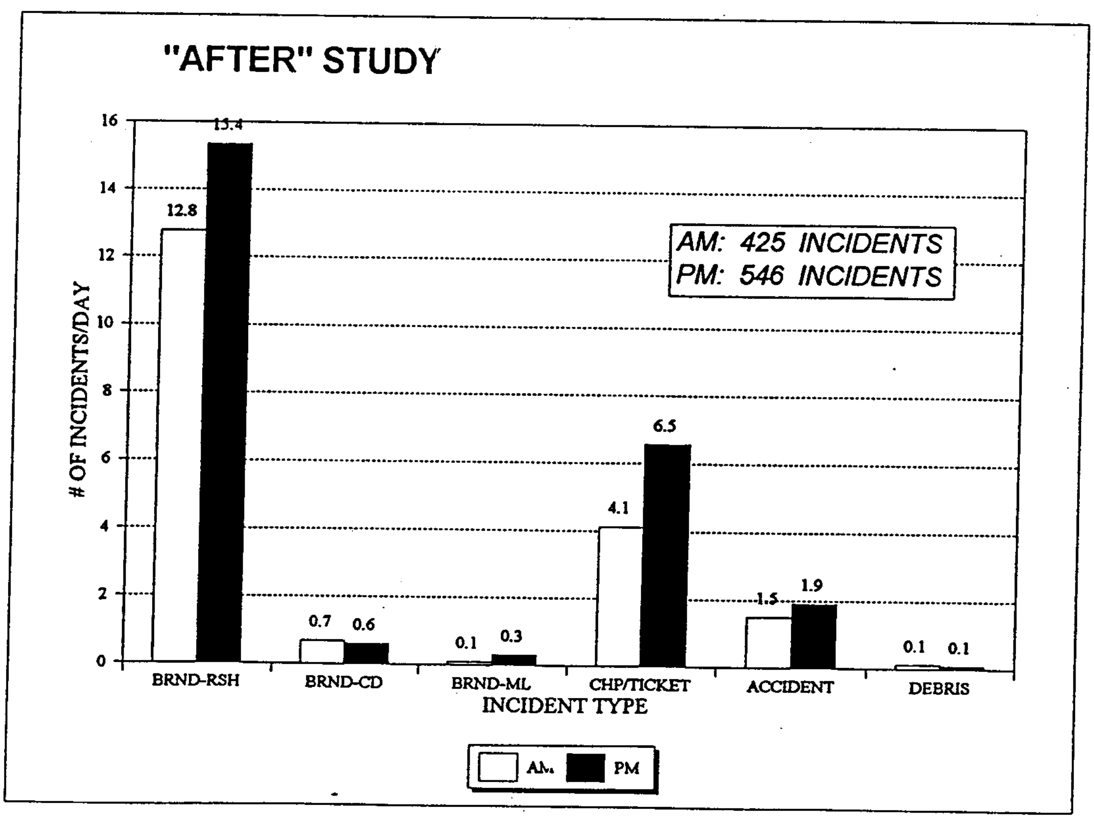


FIGURE 4.3 TRUCK RELATED INCIDENTS

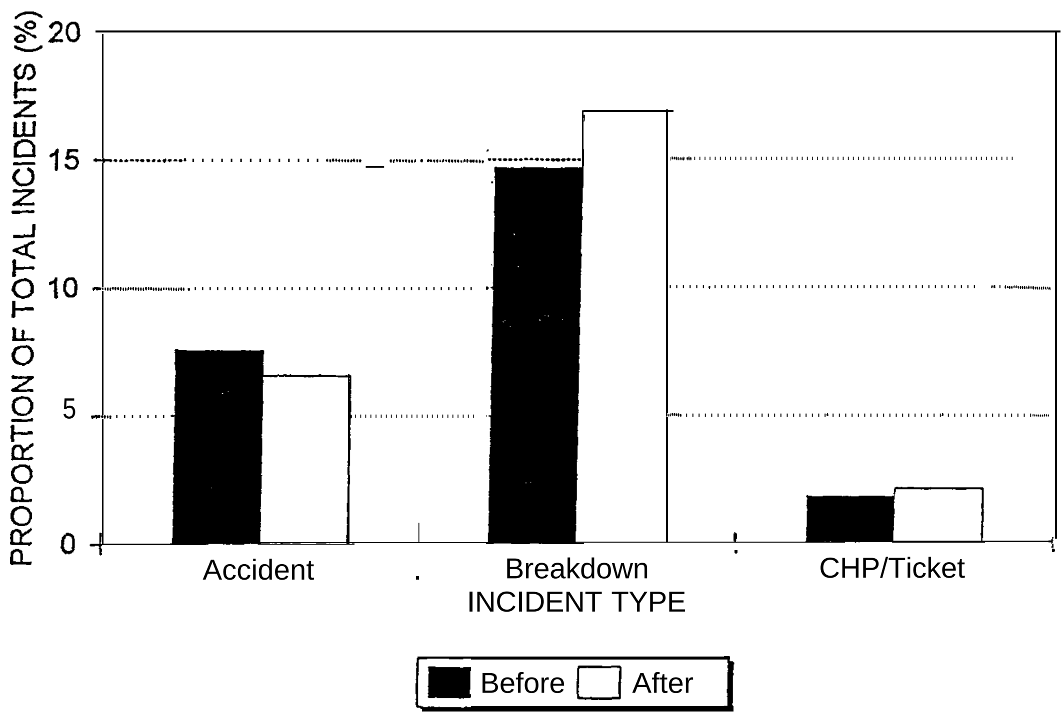


FIGURE 4.4 EFFECT OF WEATHER ON INCIDENTS ("After" Study)

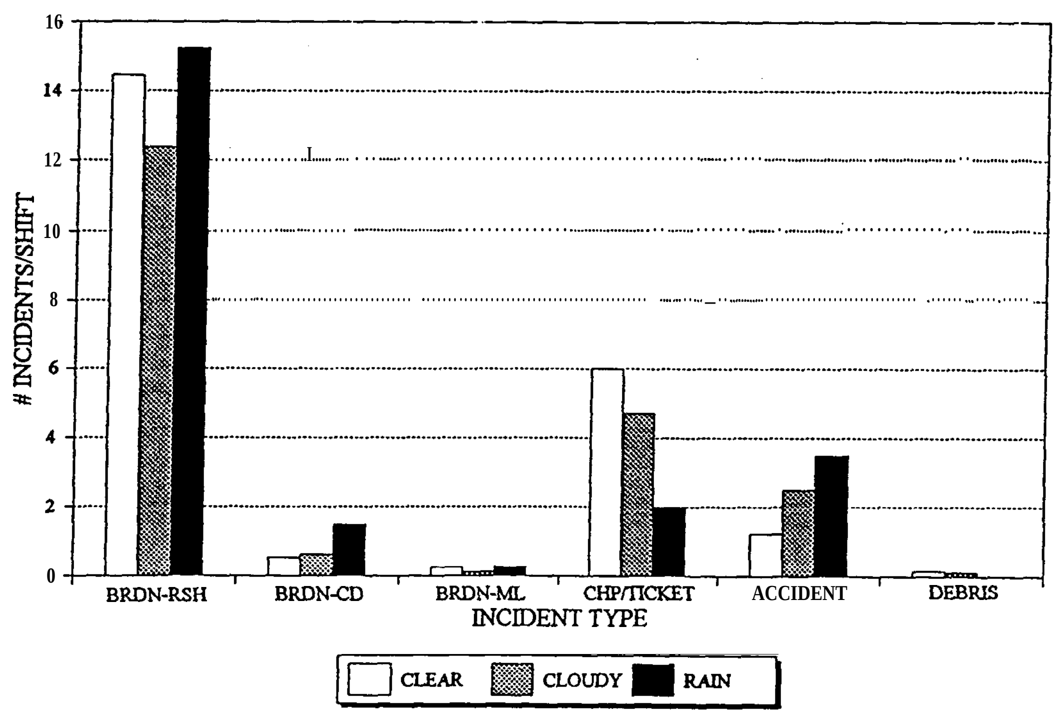
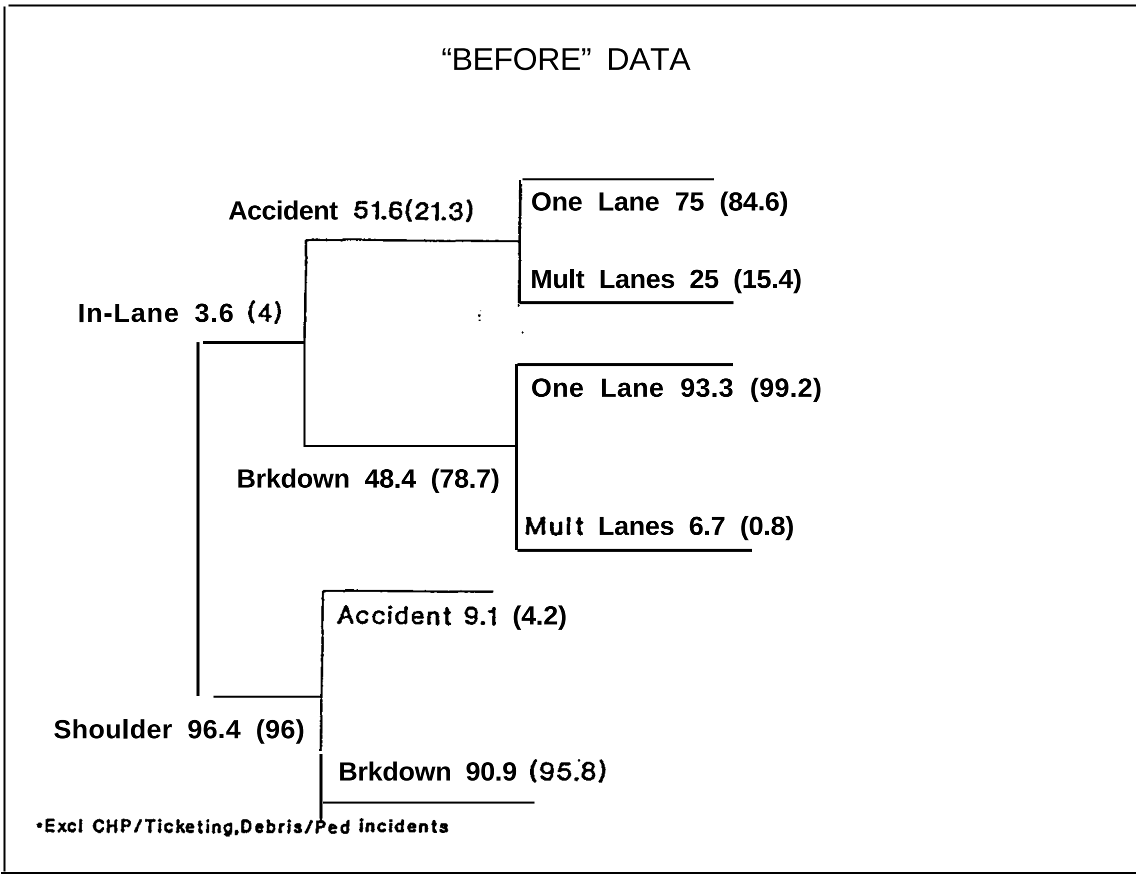
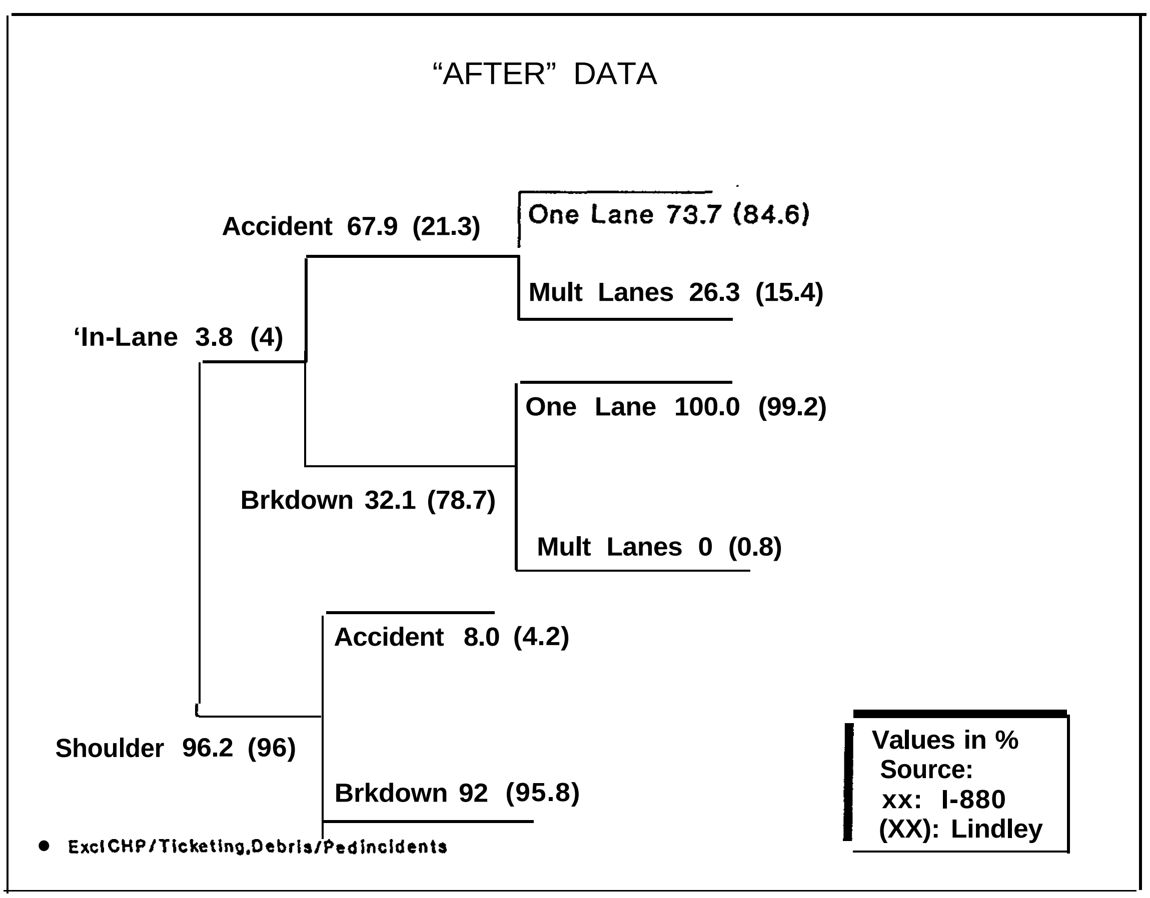


FIGURE 4.5 INCIDENT TREES--I-880 TEST SITE





A fairly large number of observed incidents (about 30 percent of the total) started or cleared outside the data collection periods (Table 4.3). Incidents first observed at the start of the data collection and not cleared by the end of the 3 hour shift were vehicle breakdowns and mostly involved abandoned vehicles; it was noticed that a number of drivers abandoned their vehicles in case of breakdowns and returned later (after work) with assistance. The percentage of abandoned vehicles was reduced in the "after" study by about 40 percent, largely because of the FSP service.

TABLE 4.3 START/END TIMES OF OBSERVED INCIDENTS

INCIDENT TYPE	STARTED BEFORE SHIFT	ENDED AFTER SHIFT	START/END OUTSIDE SHIFT	WITHIN SHIFT	Total
Accidents	9 (10)	8 (8)	0 (0)	75 (57)	92 (75)
Breakdowns	80 (72)	116 (81)	57 (32)	522 (471)	775 (656)
Debris/Ped	1 (0)	1 (2)	0 (0)	11 (3)	13 (5)
Total	90 (82)	125 (91)	57 (32)	608 (531)	880 (736)

XX: Before, (XX): After

Most of the accidents observed were non-injury accidents, and most of the accidents were first observed in the shoulder (Table 4.4) for both the "before" and the "after" study. The proportion of single car accidents was small; there was a high proportion of accidents involving more than two vehicles in the "before" study (57.6 percent of the total accidents.) More in-lane accidents were observed in the "after" study (25.4 percent of all accidents as opposed to 17.4 percent in the "before" period.) The average accident frequency of 3.8 accidents/day during the peak periods is considerably higher than the accident frequency observed elsewhere in the State (e.g, 3.1 accidents/24 h day on I-10, Giuliano 1989.)

TABLE 4.4 ACCIDENT SEVERITY CHARACTERISTICS

A. 'BEFORE' STUDY

INJURIES*			VEHICLES INVOLVED			LANES CLOSED		
N	# accidents	(%)	N	# accidents	(%)	N	# accidents	%
0	82	(89)	1	8	(8.7)	0	76	(82.6)
1+	10	(11)	2	31	(33.7)	1	12	(13.0)
			3	31	(33.7)	2	4	(4.4)
			4	18	(19.6)			
			5+	4	(4.3)			

B. 'AFTER' STUDY

INJURIES*			VEHICLES INVOLVED			LANES CLOSED		
N	# accidents	(%)	N	# accidents	(%)	N	# accidents	%
0	68	(91)	1	4	(5.3)	0	56	(74.6)
1+	7	(9)	2	42	(56.0)	1	14	(18.7)
			3	19	(25.3)	2	5	(6.7)
			4	6	(8.0)			
			5+	4	(5.4)			

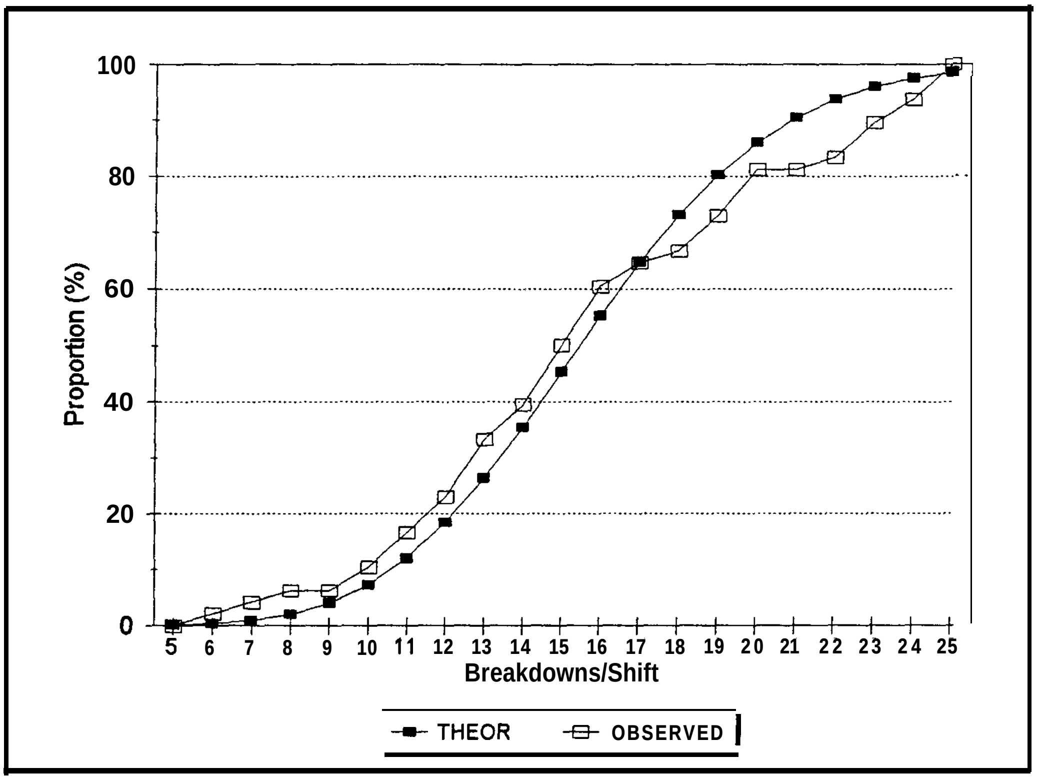
* Assuming if ambulance arrives it is an injury accident.

The observed distributions of incident occurrence per incident type were tested against theoretical distributions. The Poisson distribution provided an adequate fit for the breakdown incidents on both study periods (Figure 4.6) suggesting that the number of breakdowns at any time period is random and independent of the number of breakdowns in any other time interval. The form of the Poisson distribution is:

$$P(n) = (\exp(-m)m^n)/n! \qquad (4\text{-}1)$$

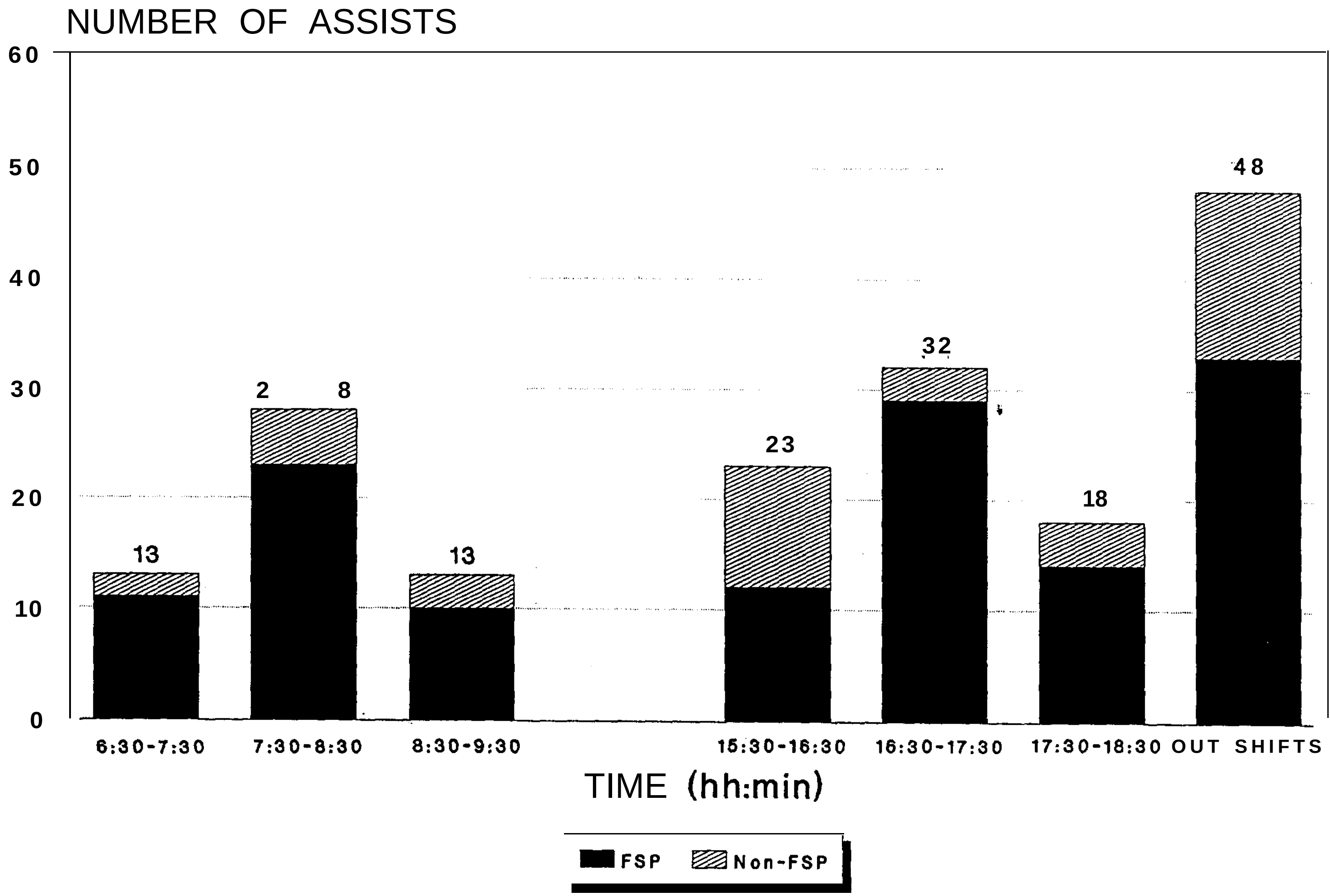
where ***P(n)*** is the probability of having *n* incidents/shift, and ***m*** is the Poisson parameter.

FIGURE 4.6 DISTRIBUTION OF INCIDENT FREQUENCY--Breakdowns



The number of assisted incidents increased substantially in the "after" study, largely because the FSP tow trucks provided assistance free of charge to all the stranded motorists encountered during the patrol of the beat. In the "before" study, tow trucks were called by the motorists or the CHP when assistance was needed. A total of 79 assists were observed "before" and 175 assists "after," an increase of about 120 percent. Figure 4.7 shows the number of assisted incidents in the "after" study. About 80 percent of all the assists were provided by FSP tow trucks and the rest by rotational tow truck companies. Most of the non-FSP assists involved accidents.

FIGURE 4.7 ASSISTED INCIDENTS
("After" Study)



4.2 Incident Response and Clearance Times

Incident response and clearance times were calculated for the tow truck assisted incidents in the "before" and "after" study. Table 4.5 shows the calculated values per incident type and location. These times have also been calculated separately for the FSP and the non-FSP tow trucks in the "after" study (Table **4.6),** and for the CHP officers (Table 4.7). The cumulative distributions of response times for vehicle breakdowns are shown in Figure 4.8.

The response time was calculated as the difference between the time the incident was first witnessed and the tow truck arrival time; clearance time then was the difference between the tow truck arrival time and the time it leaves the incident scene. For those accidents or breakdowns involving CHP officers, the response time was calculated as the difference between the time the incident was first witnessed and the arrival time of the first CHP unit; the clearance time was the difference between the arrival time of the first CHP unit and the time the last CHP unit left the incident scene. The response and clearance times could not be calculated for i) assisted incidents witnessed only once, ii) cases where the tow truck did not clear the incident, iii) the tow truck was the "incident" itself (e.g., a single tow truck was observed on the shoulder), and iv) there was no record of tow truck's departure time.

The average response time of all the assisted incidents was reduced by 36 percent in the "after" study. This reduction was due to i) the faster response times to breakdowns on the right shoulder because of the FSP service (a 57 percent reduction in response time was measured for those incidents), and ii) the larger sample of assisted incidents because of the FSP service. The sample of the FSP assisted incidents represent 63 percent of the total assisted incidents in the "after" study, and is twice as large the sample of incidents assisted "before". The response times of the non-FSP assisted breakdowns remained the same (33 minutes "before" vs. 30.8 minutes "after"). Eighty percent of the assisted breakdowns in the "after" study had response times less than 20 minutes as opposed to only 40 percent "before" (Figure 4.8.)

The assisted accidents had similar average response times "before" and "after" (20.8 vs. 20.1 minutes), despite that fact that the FSP assisted accidents had about 50 percent shorter average response time (Table 4.6). This reduction, however, is not reflected in all the assisted accidents in the database because of the small sample size, and the large response time for five major accidents in the "after" study (those accidents mostly involving more than one tow truck and their average response time was 44 minutes.)

The average clearance times were very similar in the "before" and "after" study (about 9 minutes for all assisted incidents.) The differences per incident type and location were small and not statistically significant given the small sample size in each incident category. The breakdown clearance times were short, about 4 to 7 minutes on the average indicating that most of those incidents were minor stalls on the shoulder. As was expected, accidents and in-lane incidents had considerably longer and highly variable clearance times.

TABLE 4.5 RESPONSE AND CLEARANCE TIMES FOR TOW TRUCK-ASSISTED INCIDENTS
(Excluding Incidents Witnessed Once)

A. "BEFORE"

INCIDENT TYPE/ LOCATION	N	RESPONSE			CLEARANCE		
		Mean	S.Dev	S.err	Mean	S.Dev	S.err
Accidents	17	20.8	22.9	5.6	20.0	13.1	3.2
Breakdowns	33	33.0	26.9	4.7	4.3	7.0	1.2
Debris/Pedestrian	0	-					
In-Lane	5	34.8	22.1	9.9	18.4	21.0	9.4
Right Shoulder	36	28.2	27.4	4.6	8.0	9.5	1.6
Central Divide	9	28.6	24.4	8.1	11.3	14.3	4.8
All	50	28.9	26.1	3.7	9.6	12.0	1.7

B. "AFTER"

INCIDENT TYPE/ LOCATION	N	RESPONSE			CLEARANCE		
		Mean	S.Dev	S.err	Mean	S.Dev	S.err
Accidents	19	20.1	20.5	4.7	15.9	19.3	4.4
Breakdowns	77"	18.0	18.9	2.1	6.2	6.7	.8
Debris/Pedestrian	0	-			-		
In-Lane	8	29.5	23.0	8.1	19.3	23.7	8.4
Right Shoulder	73	16.7	19.3	2.3	7.0	9.1	1.1
Central Divide	15	20.5	14.4	3.7	7.5	5.6	1.4
All	96	18.4	19.1	1.9	8.1	11.0	1.1

* 2 incidents were excluded because tow truck departure time was not known

TABLE 4.6 RESPONSE AND CLEARANCE TIMES PER TYPE OF ASSIST--"AFTER STUDY"
(Excluding Incidents Witnessed Once)

A. FSP Tow Trucks

INCIDENT TYPE / LOCATION	N	RESPONSE			CLEARANCE		
		Mean	S.Dev	S.err	Mean	S.Dev	S.err
Accidents	14	11.5	13.2	3.5	17.1	19.2	5.1
Breakdowns	60	14.3	15.0	1.9	6.8	6.5	.8
Debris/Pedestrian	0	-					
In-Lane	4	14.3	11.9	6.0	22.8	27.3	13.7
Right Shoulder	57	12.3	14.5	1.9	7.9	9.5	1.3
Central Divide	13	20.2	15.2	4.2	7.9	5.6	1.5
All	74	13.8	14.6	1.7	8.7	10.8	1.3

B. Non-FSP Tow Trucks

INCIDENT TYPE / LOCATION	N	RESPONSE			CLEARANCE		
		Mean	S.Dev	S.err	Mean	S.Dev	S.err
Accidents	5	44.0	19.0	8.5	12.6	21.3	9.5
Breakdowns	17	30.8	25.3	6.1	4.4	6.9	1.7
Debris/Pedestrian	0	-					
In-Lane	4	44.8	21.8	10.9	15.8	23.2	11.6
Right Shoulder	16	32.4	25.9	6.5	4.0	7.0	1.8
Central Divide	2	23.0	11.3	8.0	5.0	7.1	5.0
All	22	33.8	24.3	5.2	6.2	11.6	2.5

TABLE 4.7 CHP RESPONSE AND CLEARANCE TIMES (Min)

INCIDENT TYPE	BEFORE			AFTER		
	N	Response	Clearance	N	Response	Clearance
Accident	45	5(8)	18(17)	33	6(9)	20(17)
Breakdown	30	5(8)	17(24)	24	4(11)	12(16)
ALL	75	5(10)	18(20)	57	5(10)	17(17)

Notes:

xx: Mean (XT): S Deviation

RESPONSE TIME=time CHP arrives-time incident first observed

CLEARANCE TIME=time incident cleared-time CHP arrival

Excludes CHP/Ticketing and Debris/Pedestrian incidents

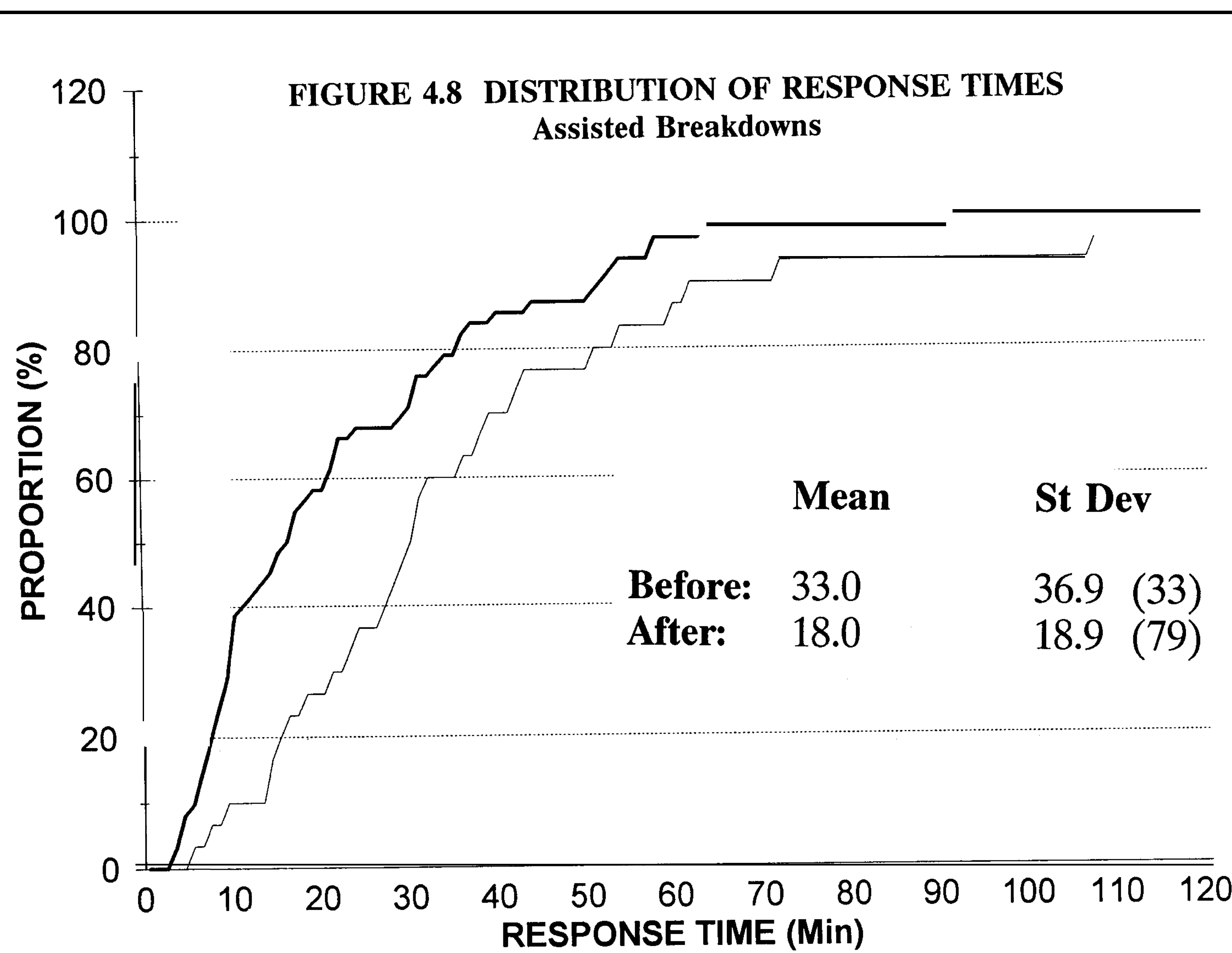


FIGURE 4.8 DISTRIBUTION OF RESPONSE TIMES
Assisted Breakdowns

4.3 Incident Durations

The total incident duration was calculated as the difference between the first and the last time the incident was witnessed by the probe vehicles' drivers. Table 4.8 shows the incident durations for each incident type and location. Figures 4.9 and 4.10 show the incident durations separately for assisted and non-assisted incidents (excluding the incidents observed only once.) Figures 4.9 and 4.10 illustrate the average incident duration patterns for breakdowns and accidents. Plots of the frequency and cumulative distributions of incident durations are shown in Figures 4.11 through 4.14.

The average duration times for different incident types were generally within one standard error of the estimate of the mean value for the "before" and "after" study periods, except for the in-lane incidents which had a small sample size and the results are biased because of a few lengthy incidents (Table 4.8.) The frequency distributions of the incident durations shown in Figures 4.11 and 4.12 and the cumulative distributions of durations (Figure 4.13) show that there is no significant change in the distribution of the durations for all the incidents "before" and "after".

Statistical analysis were performed to i) determine if the incident durations belong to different distributions "before" and "after", and ii) fit a theoretical distribution to the observed data.

The durations of all the incidents and separately for the breakdowns in the "before" and "after" study periods were found to have the same distribution based on the Kolmorogov-Smirnof (K-S) statistical test. The results of the K-S Test shown below indicate that the hypothesis that the two samples come from the same distribution cannot be rejected.

K-S test for the distribution of durations 'Before' and 'After' --Breakdowns

Max difference	.033	Conclusion
n	247	
alpha = 10%	.078	don't reject
alpha = 5%	.086	don't reject
alpha = 1%	.104	don't reject

Statistical distributions were tested to observed incident durations in a number of studies, and the lognormal distribution has been found as an adequate model for incident durations (Golob 1987, Giuliano 1989, Jones 1991.). This distribution also theoretically appears to provide a good model for durations since incident duration consists of detection, response, and clearance times; each of those time components is dependent on the time it takes to complete the preceding activities (Golob 1987). However, most of these studies were concerned with accident durations. The lognormal and several other distributions were tested in the observed data and all of them failed to provide an adequate fit for the incident durations. The same results were found elsewhere (Giuliano 1989) for vehicle breakdowns, which is the majority of the incidents on the I-880.

Figure 4.11 explains why the incident durations are the same “before” and “after” despite the significant reductions in response times. Most of the assisted incidents by FSP were of short duration, i.e., the sample of the short length assisted incidents was considerably higher in the “after” study. This is also shown in Figure 4.13 where the fractions of assisted incidents are considerably higher for short incidents “after”, which indicates that FSP mostly assists minor incidents. The reduction in duration of those short incidents could not change significantly the overall pattern of durations because their duration “after” is the same as the durations of non-assisted incidents (Figure 4.9).

4.3.1 Breakdowns

The majority of the observed breakdown incidents were witnessed only once (64.8 percent of the total incidents for both the “before” and the “after” study--Figure 4.9). Those incidents have zero duration according to the definition used for calculating duration from the field logs. The “true” duration of such incidents does not exceed 7 to 8 minutes. This indicates that most of the breakdowns observed were minor involving short stops. Note also that most of those incidents were not assisted.

The incident durations for all the breakdowns excluding incidents observed only once were very similar (average values of 25.3 minutes in the “before” and 23.6 minutes in the “after” study.) Significant reductions in durations were found for the incidents assisted by tow trucks. Durations decreased by about 35 percent on the average because of the faster response times of the FSP service. This is also shown in the distribution of durations of assisted incidents (Figure 4.14). As expected, no improvement in durations was observed for non-assisted incidents, and for those incidents assisted by non-FSP vehicles.

4.3.2 Accidents

The analysis of the results shows that no difference in the incident durations was found “before” and “after” (Figure 4.10). The difference in the average durations are small for all the categories and well within the standard error of estimate of the mean durations (Tables 4.8 through 4.10).

Again, the highest reduction in average duration is for incidents assisted by the FSP vehicles (41.2 minutes “before” vs. 28.6 minutes “after”.) However, as was mentioned in Section 4.3, the small sample size of observed accidents and the high durations of a few major accidents reduces the level of improvement for all incidents.

TABLE 4.8 OBSERVED INCIDENT DURATIONS

A. All Incidents

INCIDENT TYPE/ LOCATION	"BEFORE"				"AFTER"			
	N	Mean	S.Dev	S.err	N	Mean	S.Dev	S.err
Accidents	75	16.4	20.4	2.3	57	19.3	22.3	2.9
Breakdowns	522	8.9	20.2	.9	471	8.3	17.2	.8
Debris/Pedestrian	11	5.91	8.2	2.5	3	10.7	18.5	10.7
In-Lane	33	15.7	21.7	3.8	25	19.6	24.3	4.9
Right Shoulder	530	9.2	20.1	.9	476	8.5	17.5	.8
Central Divide	45	12.0	19.4	2.9	30	17.8	18.3	3.3
All	608	9.8	20.2	.8	531	9.5	18.1	.8

B. Excluding Incidents Observed Once

INCIDENT TYPE/ LOCATION	"BEFORE"				"AFTER"			
	N	Mean	S.Dev	S.err	N	Mean	S.Dev	S.err
Accidents	45	27.3	19.8	2.9	38	28.9	21.5	3.5
Breakdowns	184	25.3	27.4	2.0	166	23.6	21.9	1.7
Debris/Pedestrian	6	10.8	8.4	3.4	1	32.0	-	-
In-Lane	21	24.7	22.8	5.0	16	30.6	24.3	6.1
Right Shoulder	195	25.0	26.7	1.9	169	23.8	22.2	1.7
Central Divide	19	28.4	20.6	4.7	20	26.9	16.0	3.6
All	235	25.6	25.8	1.7	205	24.7	21.9	1.5

TABLE 4.9 INCIDENT DURATIONS--ASSISTED INCIDENTS (Excluding Incidents, Observed Once) :

INCIDENT TYPE/	"BEFORE"				"AFTER"			
LOCATION	N	Mean	S.Dev	S.err	N	Mean	S.Dev	S.err
Accidents	17	41.2	21.2	5.1	19	36.0	20.3	4.7
Breakdowns	33	37.6	25.7	4.5	79	24.6	18.7	2.1
Debris/Pedestrian	0	-	-	-	0	-	-	-
In-Lane	5	53.2	23.3	10.4	8	48.8	20.7	7.3
Right Shoulder	36	36.4	24.7	4.1	74	23.8	18.7	2.2
Central Divide	9	40.6	21.3	7.1	16	29.5	15.5	3.9
All	50	38.8	24.1	3.4	98	26.8	19.5	2.0

TABLE 4.10 INCIDENT DURATIONS--NON-ASSISTED INCIDENTS (Excluding Incidents Observed Once)

INCIDENT TYPE/	"BEFORE"				"AFTER"			
LOCATION	N	Mean	S.Dev	S.err	N	Mean	S.Dev	S.err
Accidents	28	18.8	13.4	2.5	19	21.8	20.9	4.8
Breakdowns	151	22.6	27.0	2.2	87	22.8	24.6	2.6
Debris/Pedestrian	6	10.8	8.4	3.4	1	32.0	-	-
In-Lane	16	15.8	13.8	3.5	8	12.4	8.8	3.1
Right Shoulder	159	22.5	26.5	2.1	95	23.8	24.8	2.5
Central Divide	10	17.5	13.0	4.1	4	16.8	15.4	7.7
All	185	21.6	25.1	1.9	107	22.7	23.8	2.3

FIGURE 4.9 INCIDENT DURATION PATTERNS-Breakdowns

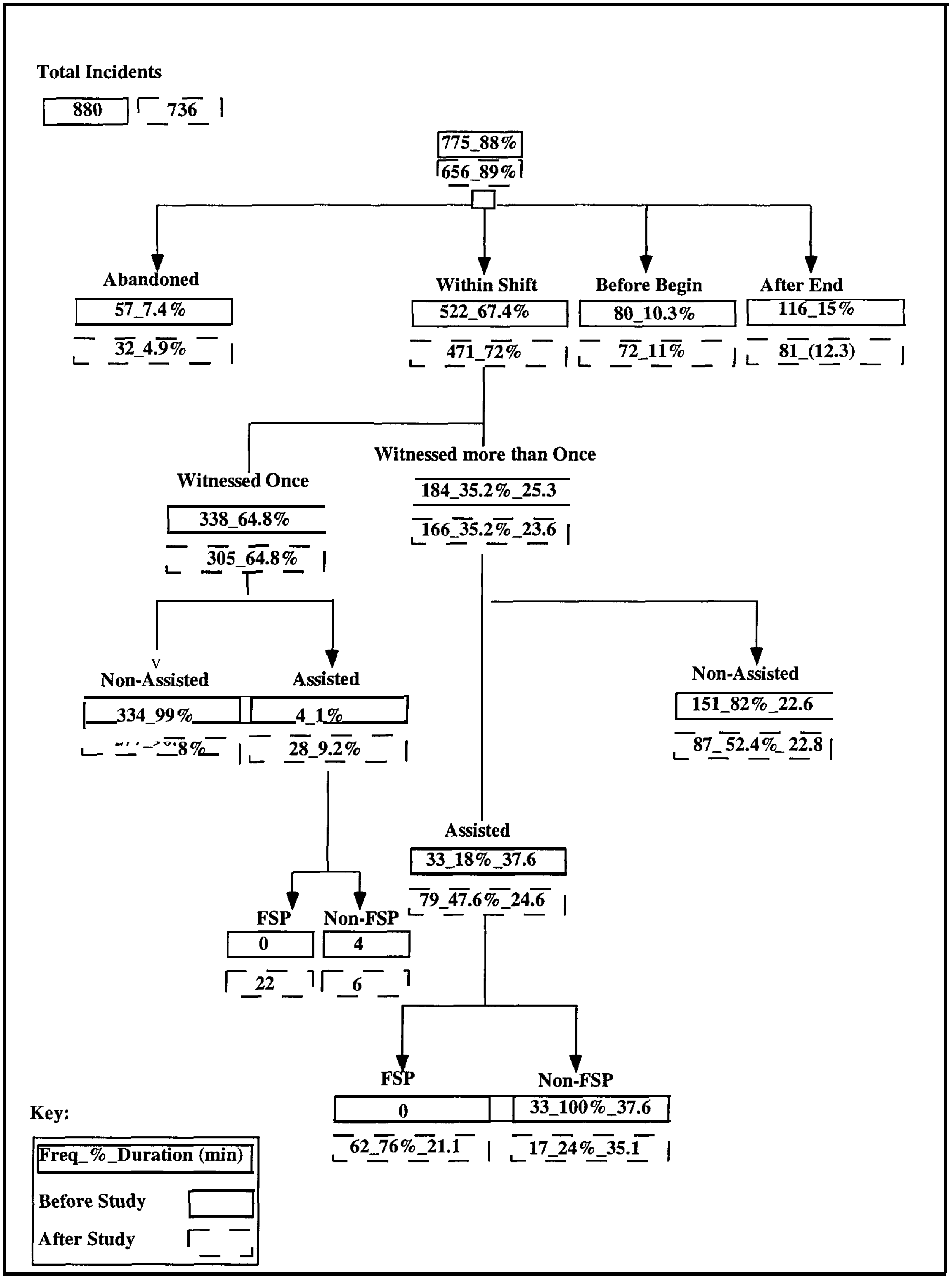


FIGURE 4.10 INCIDENT DURATION PATTERNS-Accidents

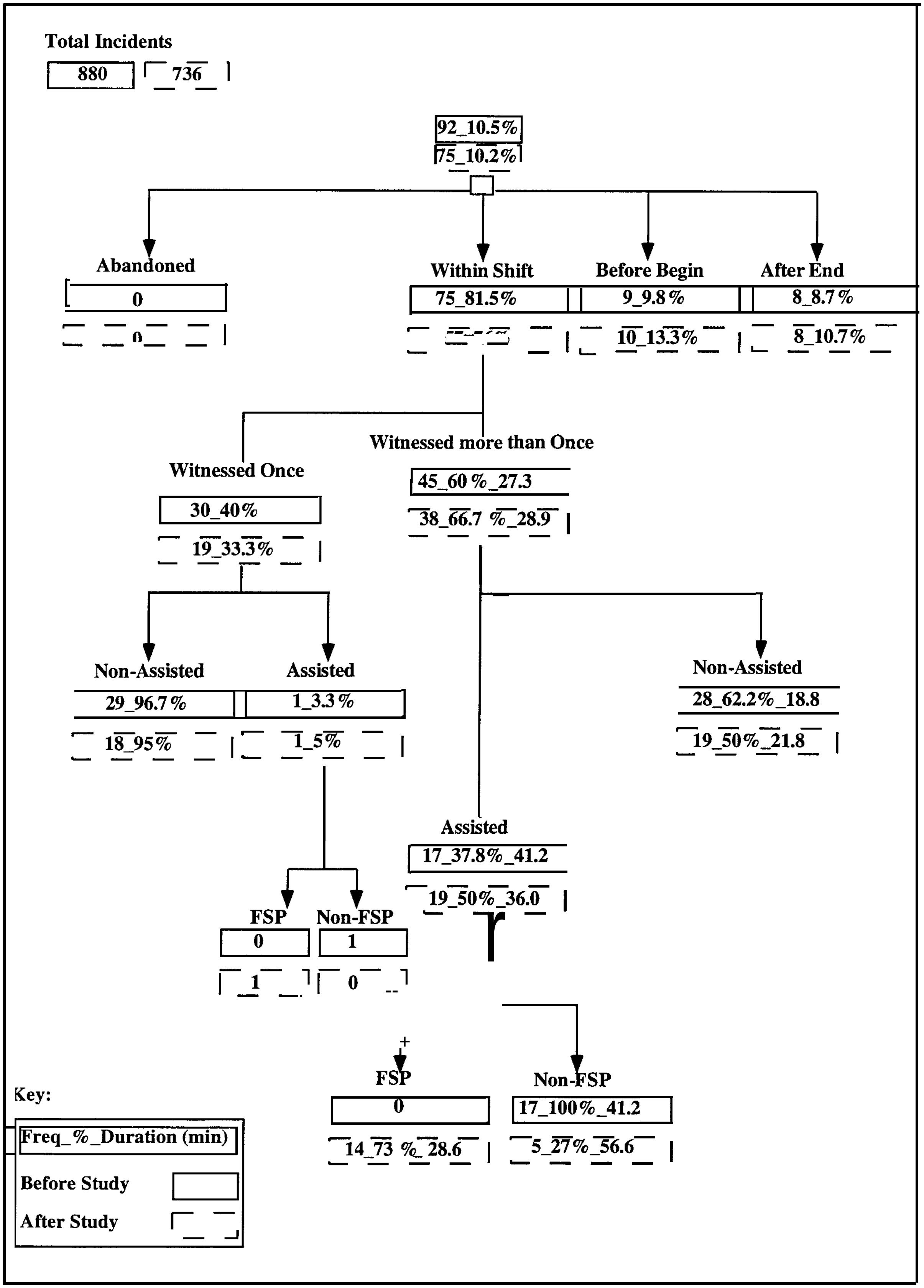
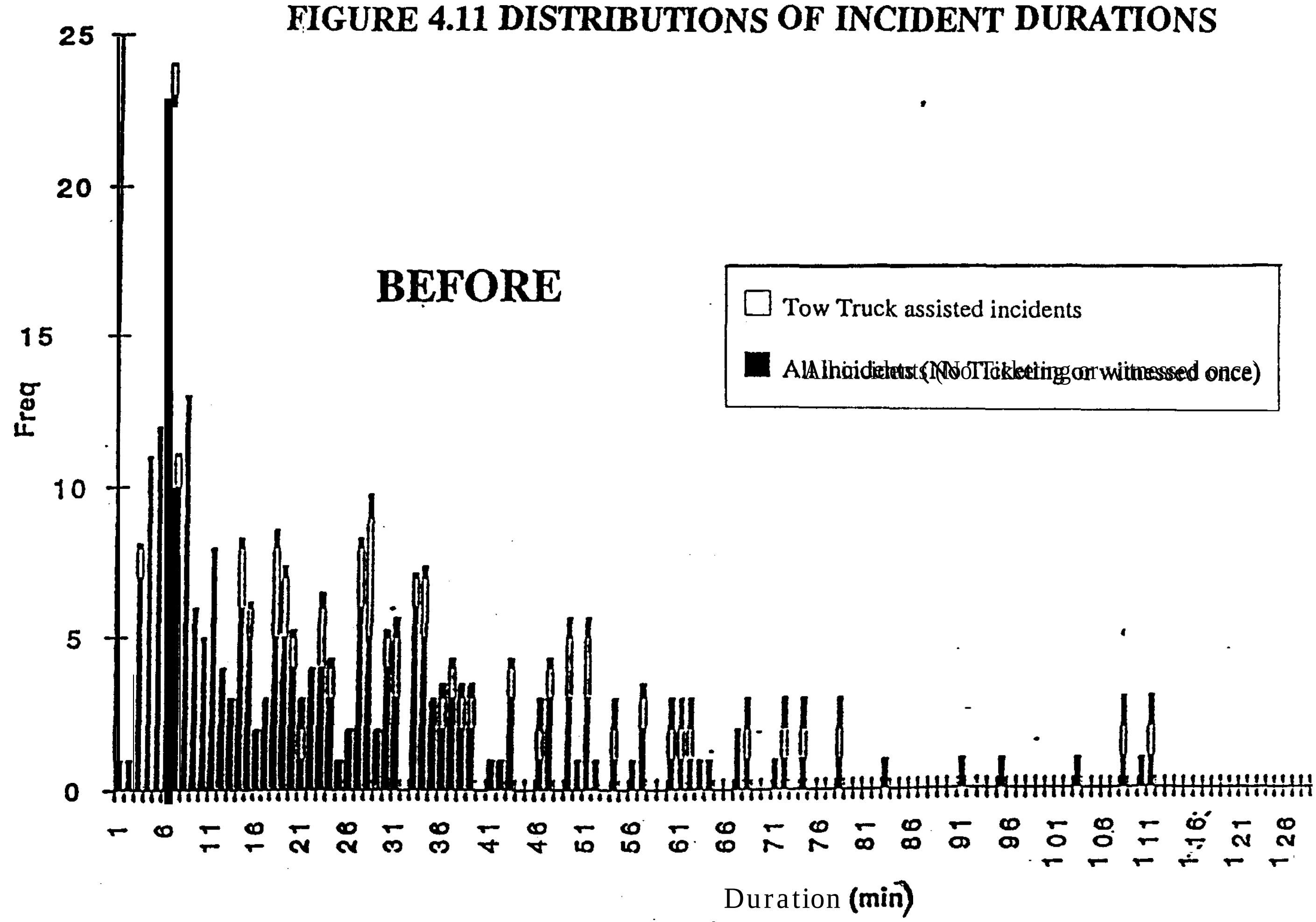


FIGURE 4.11 DISTRIBUTIONS OF INCIDENT DURATIONS



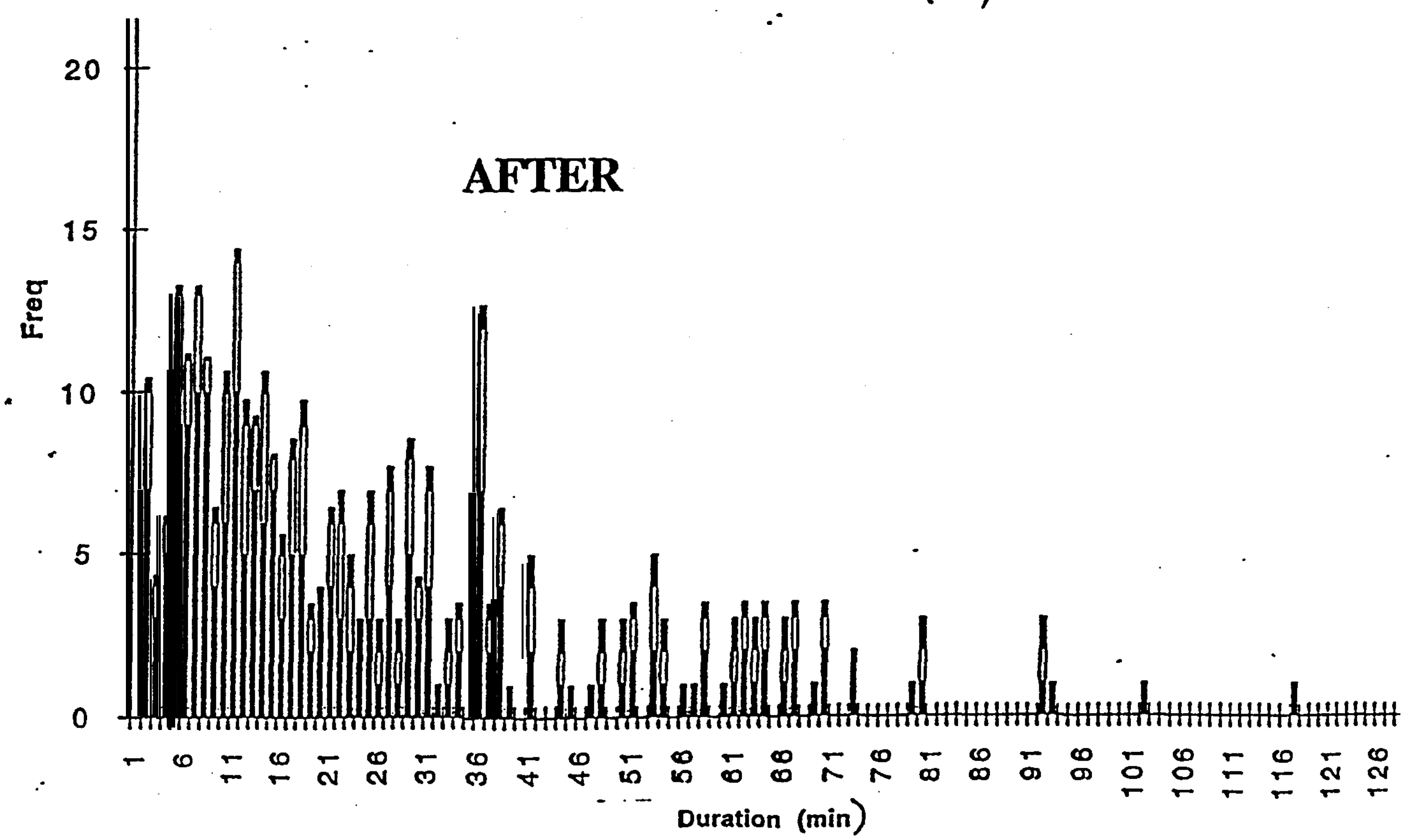
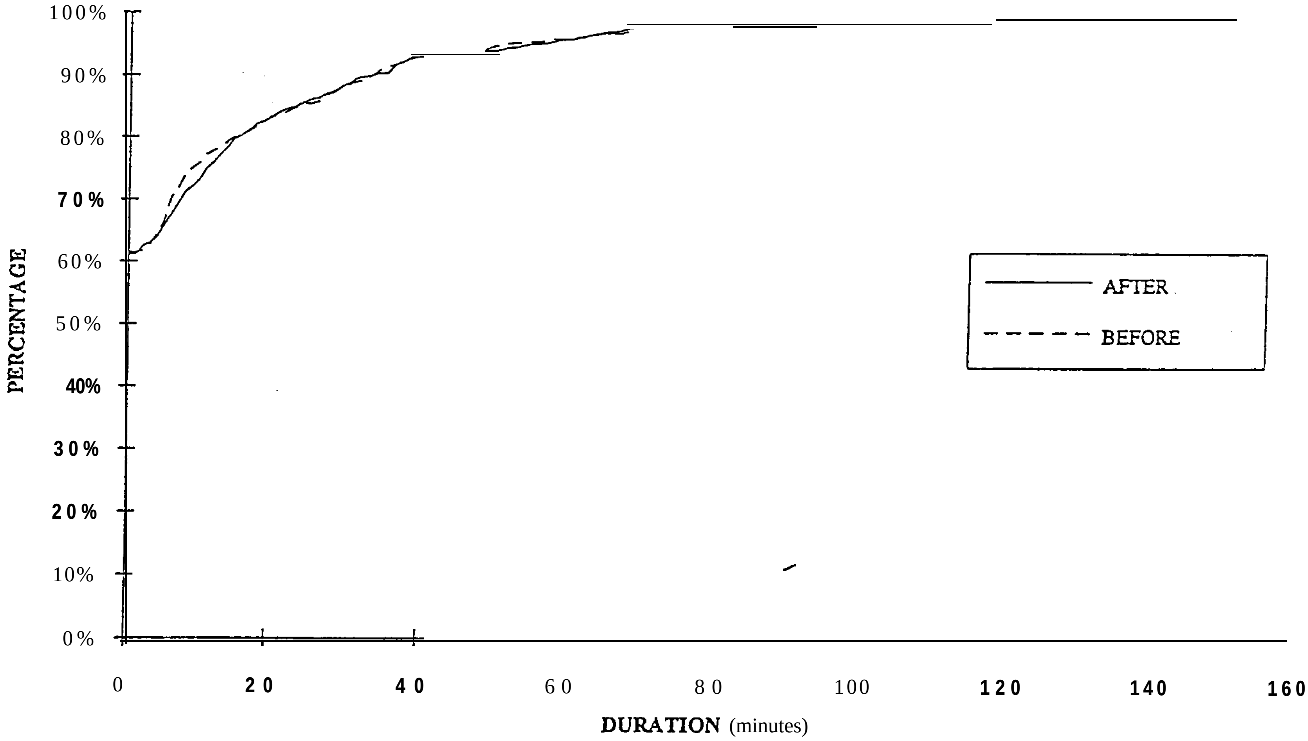
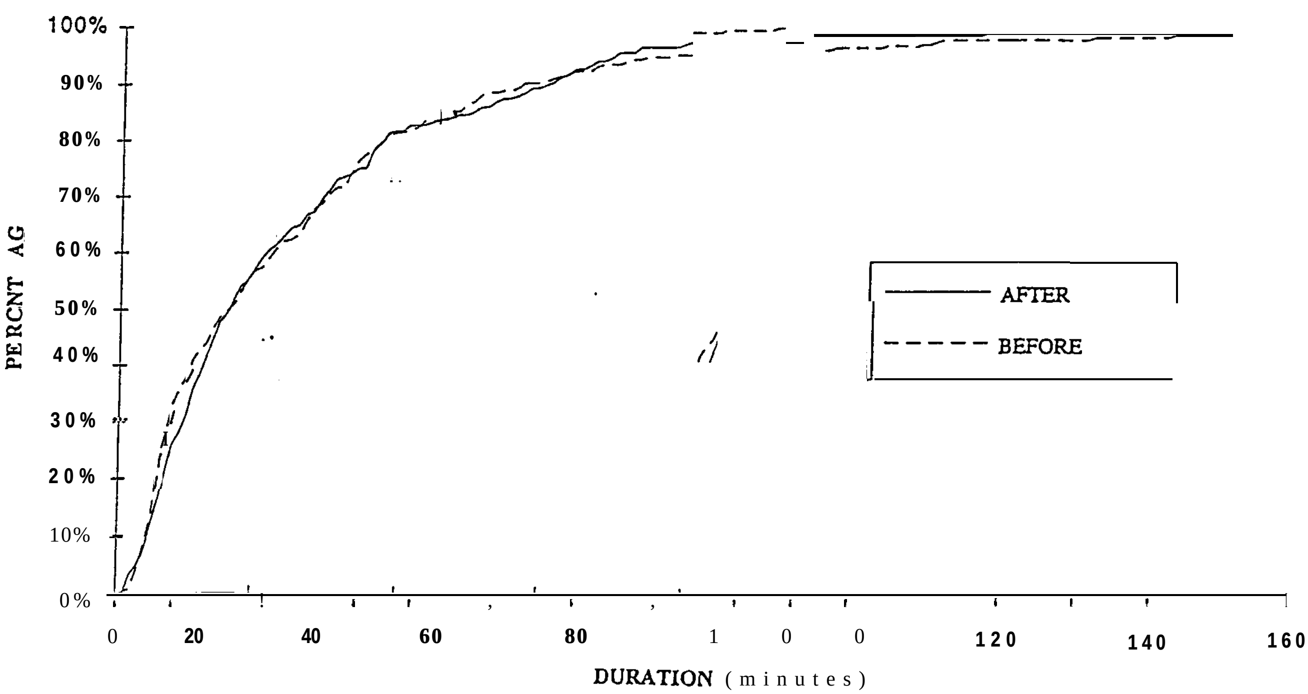


FIGURE 4.12 CUMULATIVE DISTRIBUTIONS OF INCIDENT DURATIONS

A. All Incidents



B. Excluding Incidents Observed Once



Excluding CHP/Ticketing

FIGURE 4.13 CUMULATIVE DISTRIBUTIONS OF DURATIONS--Assisted Incidents

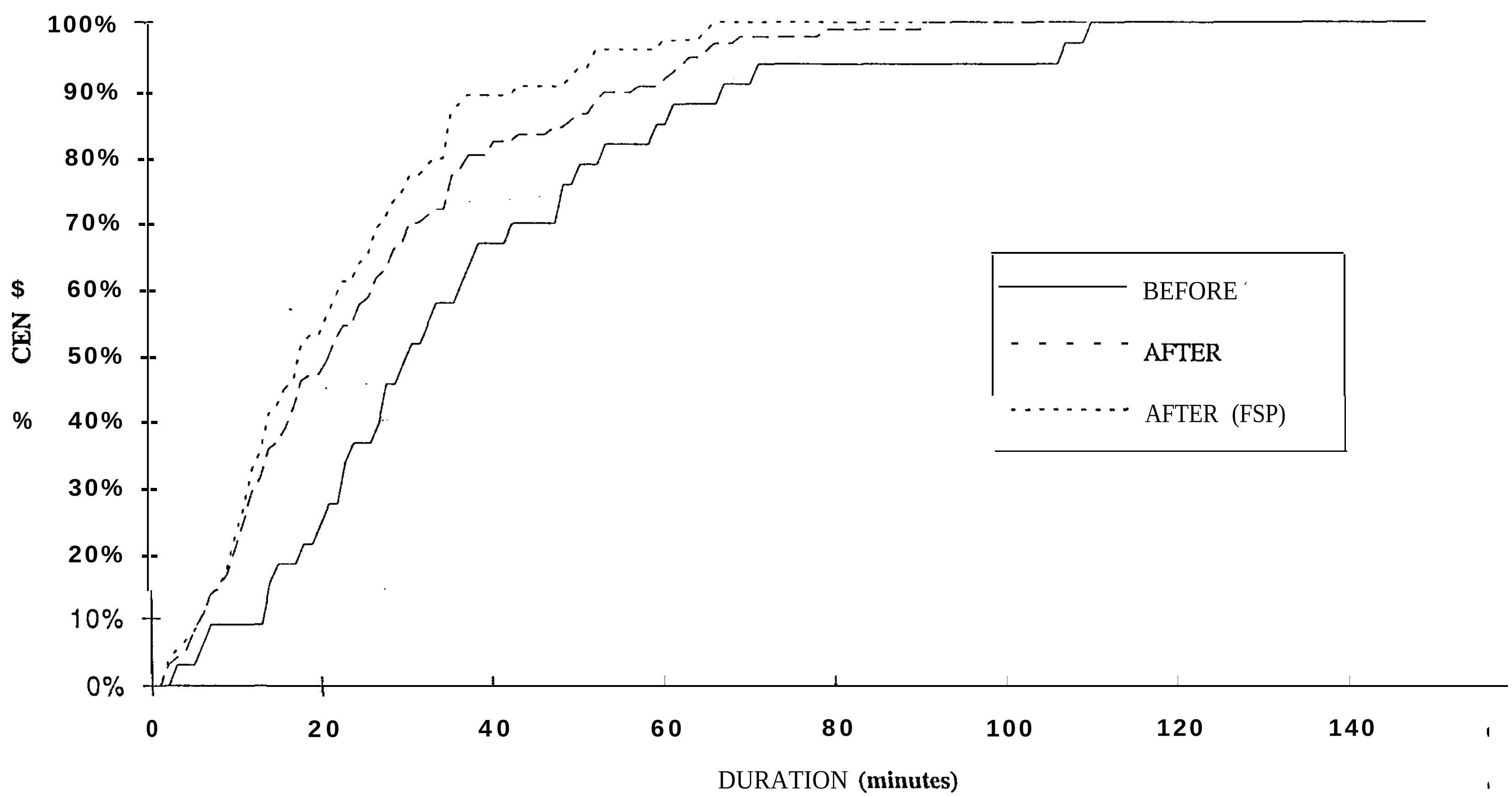
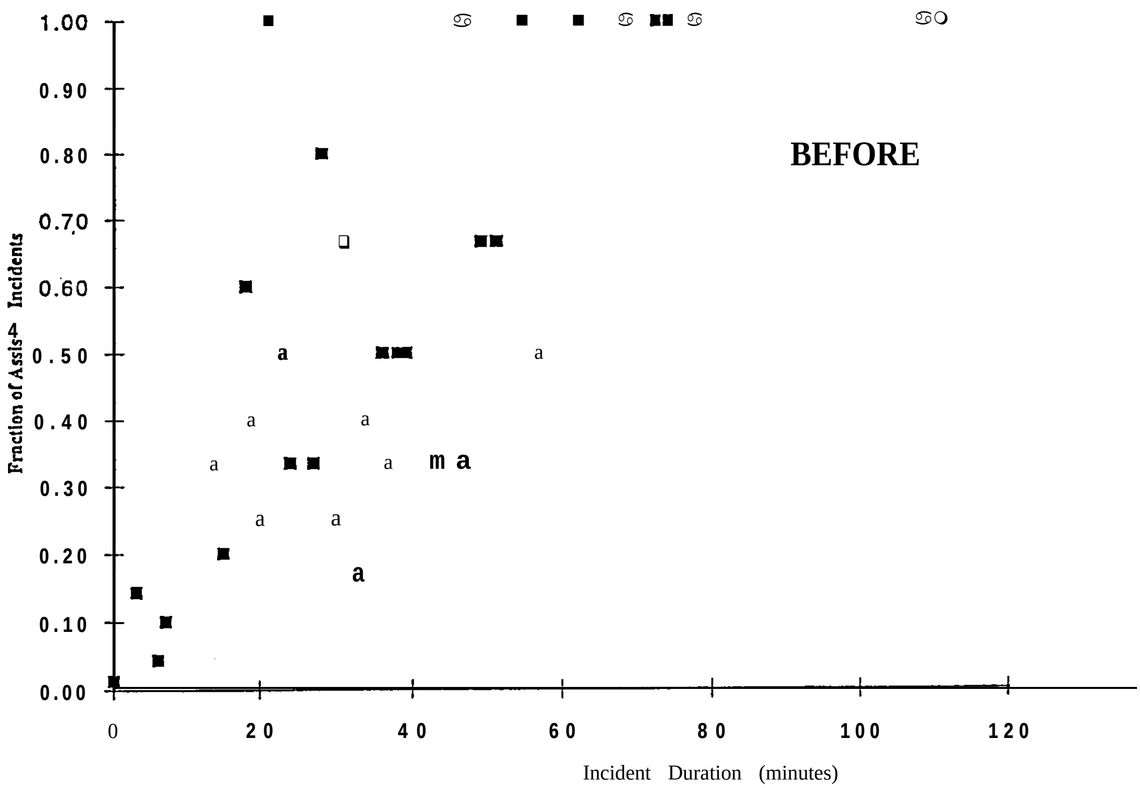
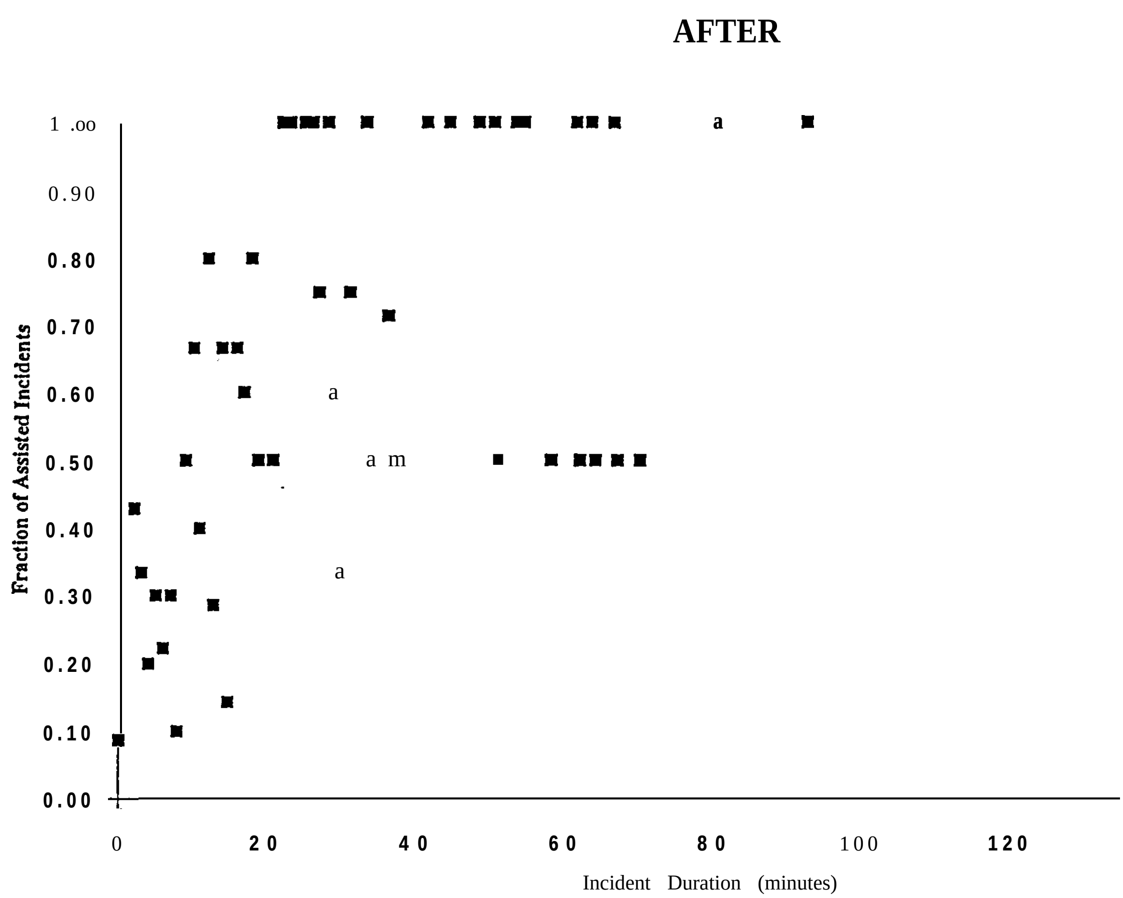


FIGURE 4.14 DISTRIBUTIONS OF FRACTIONS OF ASSISTED INCIDENTS

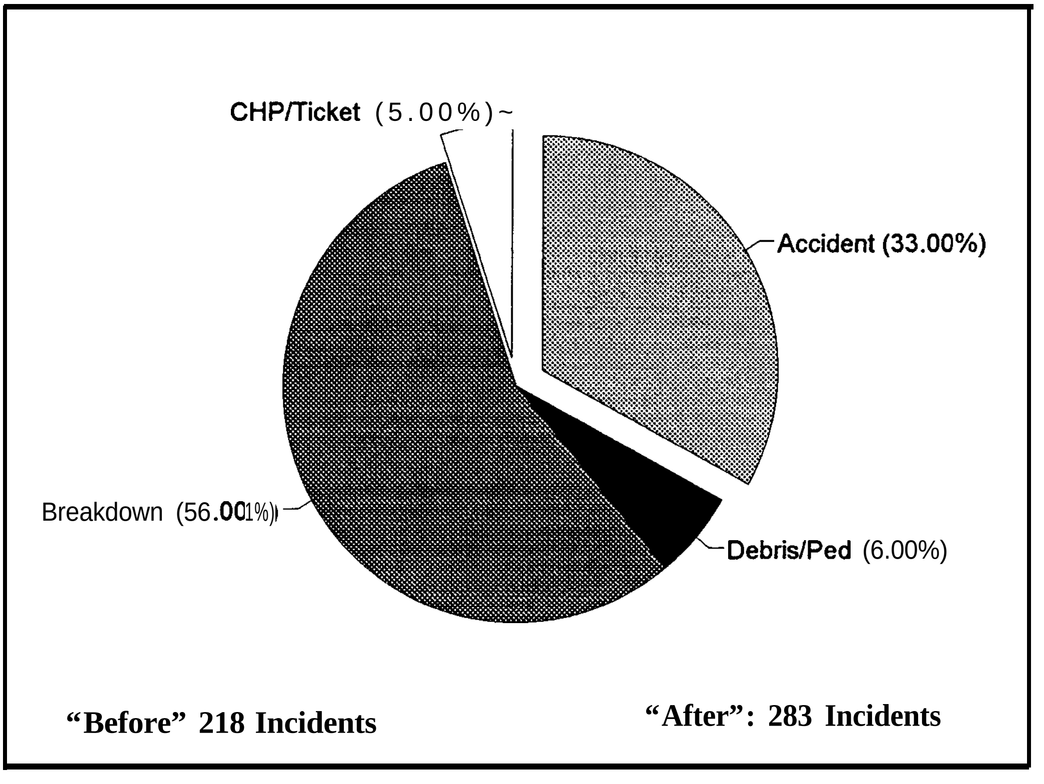




4.4 Analysis of CHP CAD Data

Figure 4.15 shows the proportion of each incident type in the CHP/CAD database. The types of reported incidents were very similar in both study periods, except the number of injury accidents which was higher in the "after" study (Table 4.11.) Those incidents were reported to CAD by various sources including CHP calls, cellular 911 calls, other public calls, and FSP drivers' calls. There was a 30 percent increase in the number of reported incidents in the CHP/CAD database between the two study periods, from a total of 218 incidents in the "before" to 283 cases in the "after" study. The increase in the number of reported incidents in the "after" study is almost entirely due to the calls made by the FSP vehicles (a total of 52 calls.)

FIGURE 4.15 THE CHP/CAD INCIDENT DATABASE



There are a number of differences in the CHP activity "before" and "after" because of the FSP service (Table 4.12). These differences mostly are in the CHP involvement to breakdown incidents including a) reduction in the number of breakdowns attended by the CHP, b) reduction in the average time per breakdown spent by CHP and c) reduction in the portion of the CHP time spent for breakdown incidents. The reduction in time for breakdowns did not reduce the total time spent by CHP in the "after" study, because of the different characteristics of accidents requiring CHP involvement (more injury accidents occupying travel lanes as shown in Table 4.11.)

TABLE 4.11 ACCIDENT SEVERITY (CAD Database)

ACCIDENT TYPE	"Before"		"After"	
	N	%	N	%
Abulance/Severe Injury	4	5.5	3	3.3
Minor injury	5	6.8	11	12.2
Property Damage	52	71.2	65	72.2
No Detail	12	16.4	11	12.2
Total	73		90	

TABLE 4.12 CHP ACTIVITY BREAKDOWN (CAD Database)

INCIDENT TYPE	# (%)* CHP Incidents B	# (%)* CHP Incidents A	Time/Incident (min) B	Time/Incident (min) A	% Time Spent B	% Time Spent A
Accident	72 (98.6%)	79 (87.8 %)	27	29.1	61.2	74.1
Breakdown	93 (77.1 %)	77 (49.1 %)	13.3	10.5	38.8	25.9

Notes:
B/A : "Before"/"After" FSP
Excl. CHP/Ticketing
**% of total incidents in the CAD database*

4.5 Analysis of FSP Logs

A total of 473 separate incidents were recorded by FSP vehicle drivers during the "after" study (Table 4.13). Of those incidents, 356 (75 percent) occurred during the data collection shifts. Table 4.14 shows the types of FSP vehicle activity. Most of the FSP assists were vehicle breakdowns. The FSP trucks did not provide assistance to about 22 percent of the incidents logged, because of motorist refusal, unable to locate incident, other assistance en route and told to disregard by CHP. The proportion of disabled vehicles that had to be towed by FSP was 34 percent of the total breakdowns, excluding abandoned vehicles, with most of them having mechanical/electrical problems. Only 3 percent of the breakdowns were moved to the shoulder without been cleared by the FSP. The FSP logs did not provide sufficient information on the assistance provided to accidents, except that about 19 percent of accidents were moved to the shoulder.

TABLE 4.13 FSP ASSISTS (FSP Logs)

TIME OF DAY	Separate Incidents	Both FSP Trucks	Helped Twice	Total
AM Peak	208	7	3	218
Within Study Shift	158	5	1	164
PM Peak	265	2	1	268
Within Study Shift	198	1	1	200
Total FSP Shifts	473	9	4	486
Total Study Shifts	356	6	2	364

FSP Shifts: 6-10 am & 3- 7 pm

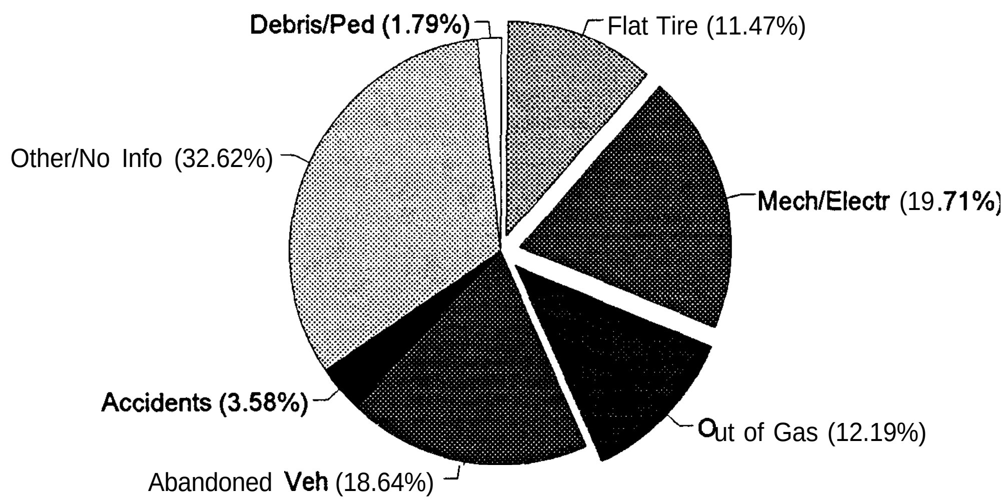
Study Shifts: 6:30-9:30 am & 3:30-6:30 pm

Figure 4.16 shows the types of incidents that were assisted by the FSP vehicles. Most of the assisted breakdowns had mechanical or electrical problems. Vehicles with flat tire and out of gas accounted for about 24 percent of the assisted incidents, and 18 percent of the incidents involved abandoned vehicles. The proportion of assisted accidents shown here accounts only for the accidents that the type of assist was recorded (i.e., moved to shoulder.) The rest of the accidents with no information provided were included in the "other/no information category." This was done in accordance with the classification used by Caltrans and MTC in the calculation of the overall FSP statistics for all the Bay Area beats.

TABLE 4.14 TYPES OF FSP ACTIVITY DURING STUDY SHIFTS (FSP Logs)

INCIDENT N P E	FSP ACTIVITY								Total
	Field Assist	Tow	Declined Help	Moved Shoulder	Motorist Drove off	Other TT en Route	Told to Disregard	Unable to Locate	
I. BREAKDOWN									
Flat Tire	28	4	2	0	0	0	0	0	34
Mech/Electrical	31	21	3	3	1	1	1	1	62
Out of Gas	34	0	0	0	0	0	0	0	34
Abandoned Veh	52								52
No Information	15	33	27	2	16	5	2	14	114
Total	160	58	32	5	17	6	3	15	296
II. ACCIDENT									
Activity				10			1	2	13
No Information									41
Total	0	0	0	10	0	0	1	2	54
IH. DEBRIS/PED									
Debris	2			2				1	5
Pedestrian									1
Total	2	0	0	2	0	0	0	1	6
Totals	162	58	32	17	17	6	4	18	356

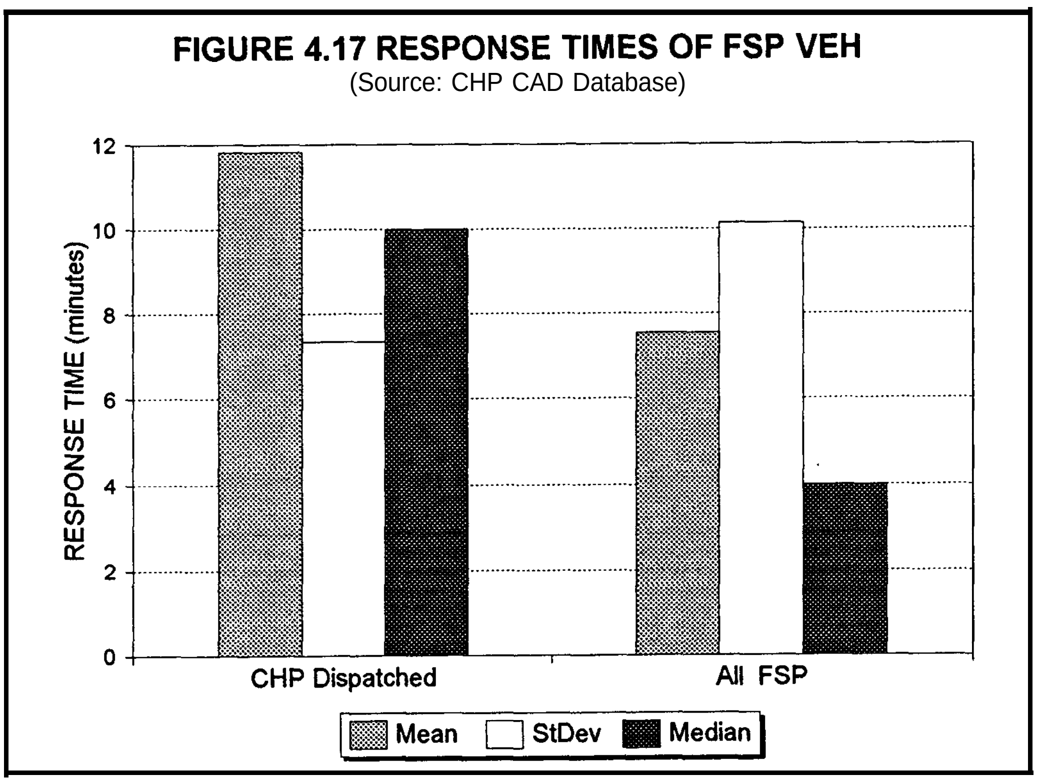
FIGURE 4.16 TYPES OF FSP ASSISTS
(Source: **FSP Logs)**



The average clearance time for the field assisted incidents was about 12 minutes, and the average time for incidents that had to be towed off the freeway was 28.6 minutes (Table 4.15). These estimates also include the time that the tow truck becomes available for service. Figure 4.17 shows the response times of the FSP trucks based on the CHP/CAD database. The average response time of all the FSP trucks was 7.5 minutes with median value of 4 minutes. The average response time of FSP assigned by the CHP Dispatch was 12 minutes. These findings are close to the results reported for the entire Bay Area FSP program (Figure 1.2.)

TABLE 4.15 FSP CLEARANCE TIMES (Minutes) (FSP Logs)

INCIDENT TYPE	Field Assist			Moved to Shoulder			Tow	
	N	Mean	(StD)	N	Mean	(StD)	N	Mean (StD)
Breakdown	113	11.9	(6.7)	5	14.6	(10.5)	58	28.6(13.6)
Accident	N/A	N/A		10	19.0	(13.1)	N/A	N/A



CHAPTER 5

EVALUATION OF FREEWAY SERVICE PATROLS

5.1 Program Benefits

The benefits of the FSP service include travel time and fuel savings to the motorists because of the reduction in the incident delay and fuel consumption, reductions in the air pollutant emissions, and other benefits to the assisted motorists, CHP and the freeway operators.

5.1.1 Delay Benefits

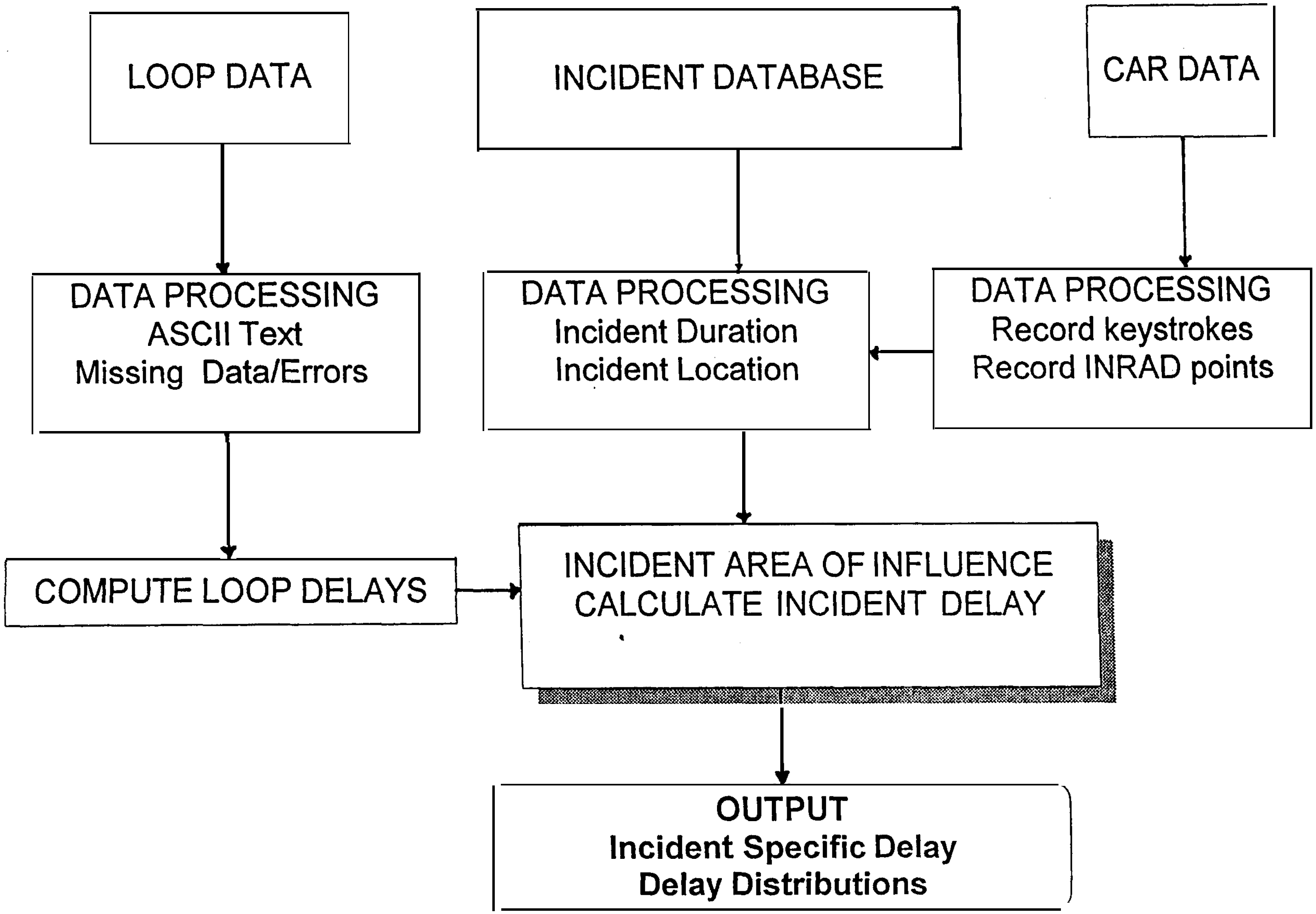
The delays caused by incidents were calculated according to the travel times incident method described in Chapter 2. The methodology consists of estimating the delay on the study section from loop data on flows and speeds, mapping the congestion and incidents on the same diagram, associating pockets of congestion with incidents where the association is apparent, and calculating the average congestion delay per incident. This process is implemented in the FSP software through the following steps (Figure 5.1):

(1) **Loop data processing:** The raw loop detector data are processed to determine "error-free" flow rates, speeds and occupancies. As it was discussed in Section 3.4, the software checks and adjusts the raw loop data for accuracy and consistency, and computes any missing data by interpolating the data values from the adjacent loop detectors.

(2) Incident location/duration: The database with incident characteristics is correlated with the data from the probe vehicle runs to determine the exact location and duration of each incident (Figure 5.2). The location of an incident was reported by the probe vehicle drivers as the perceived location upstream or downstream to the nearest exit, which is only an approximate location. Also, the incident durations are calculated from the time that the incident was first and last witnessed by the probe vehicle driver. However, an incident is already in progress at the time it was first witnessed and it could have cleared any time between the time it was last observed and the passage of the next probe vehicle. The software determines the exact incident location by matching the keystrokes in the event(key.dat) file of the probe vehicles with the reported locations from the incident data forms. Figure 5.3 shows a sample output used to determine the exact incident location. The "true" incident start and end times are found from the observed times and the headways between probe vehicles at the incident location.

(3) Loop delay estimation: The delay at each loop is calculated from the equations (2-2) and (2-3) based on the speed and volumes provided by the loop detectors. The average "incident-free" speed for each loop is based on the field measurements

FIGURE 5.1 PROCESS FOR INCIDENT DELAY ESTIMATION



throughout the study period. The software then produces delay contours (Figure 5.4) as a function of time and distance at loop detector spacings (approximately 1/3 of a mile.) The occurrence of incidents are then plotted on the same time-distance diagram of loop delays based on incident location/time determined in Step 2 to relate the loop delays with incidents. Different symbols are used in plotting the incidents to provide information on incident type (Figure 5.4).

(4) **Incident specific delay estimation:** The area of influence of the incident in time and space is determined from the association of the loop delay and incidents, as shown in Figure 5.5. The total incident specific delay then is the difference in travel times of vehicles during the time period [T,, T’,] in the segment [T,, T'_e] traveling at the actual and incident free speed based on the equations (2-2) through (2-4).

FIGURE 5.2 DETERMINATION OF THE EXACT INCIDENT DURATION/LOCATION

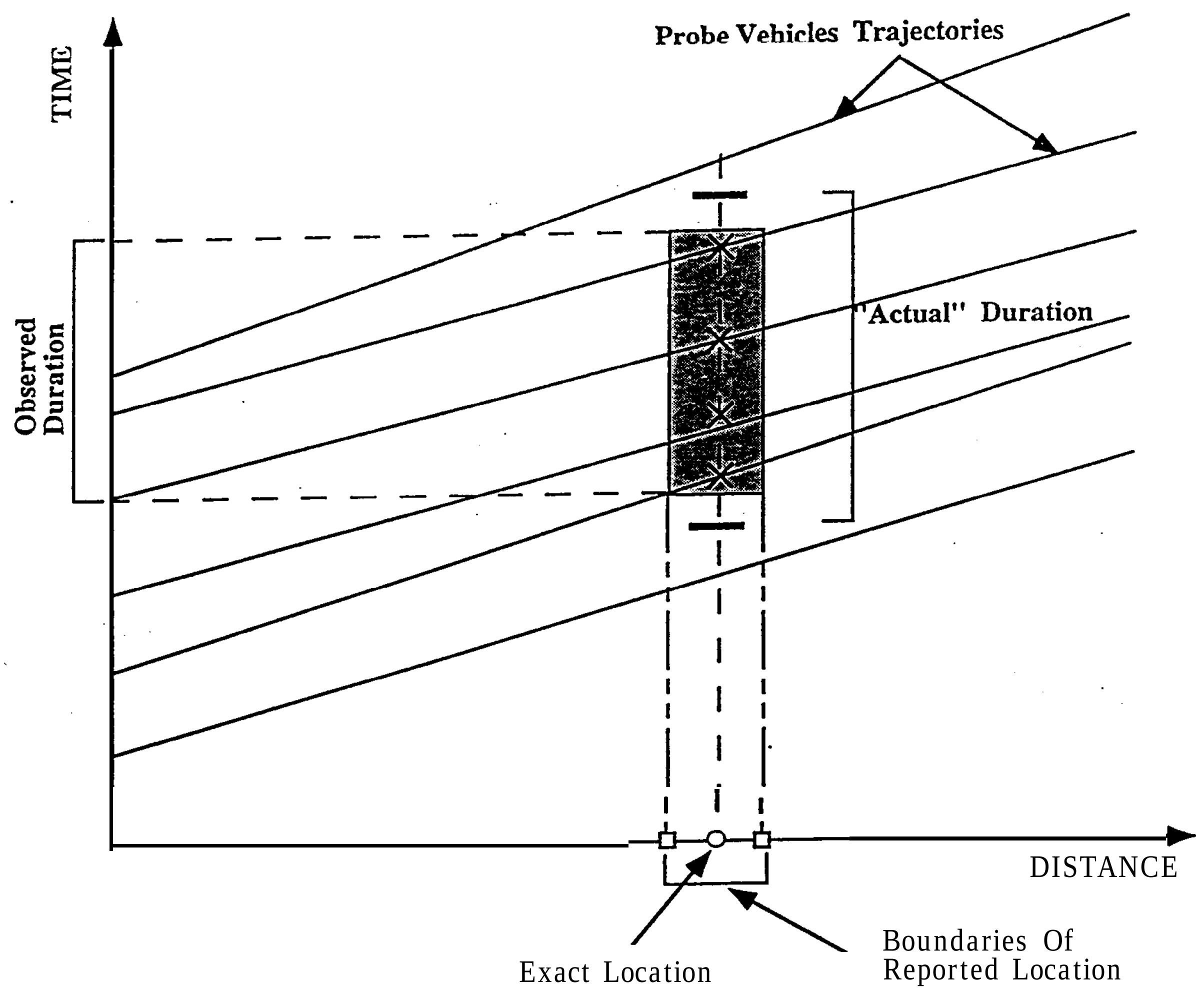


FIGURE 53 EXAMPLE OF MATCHING REPORTED INCIDENT LOCATIONS AND PROBE VEH DATA

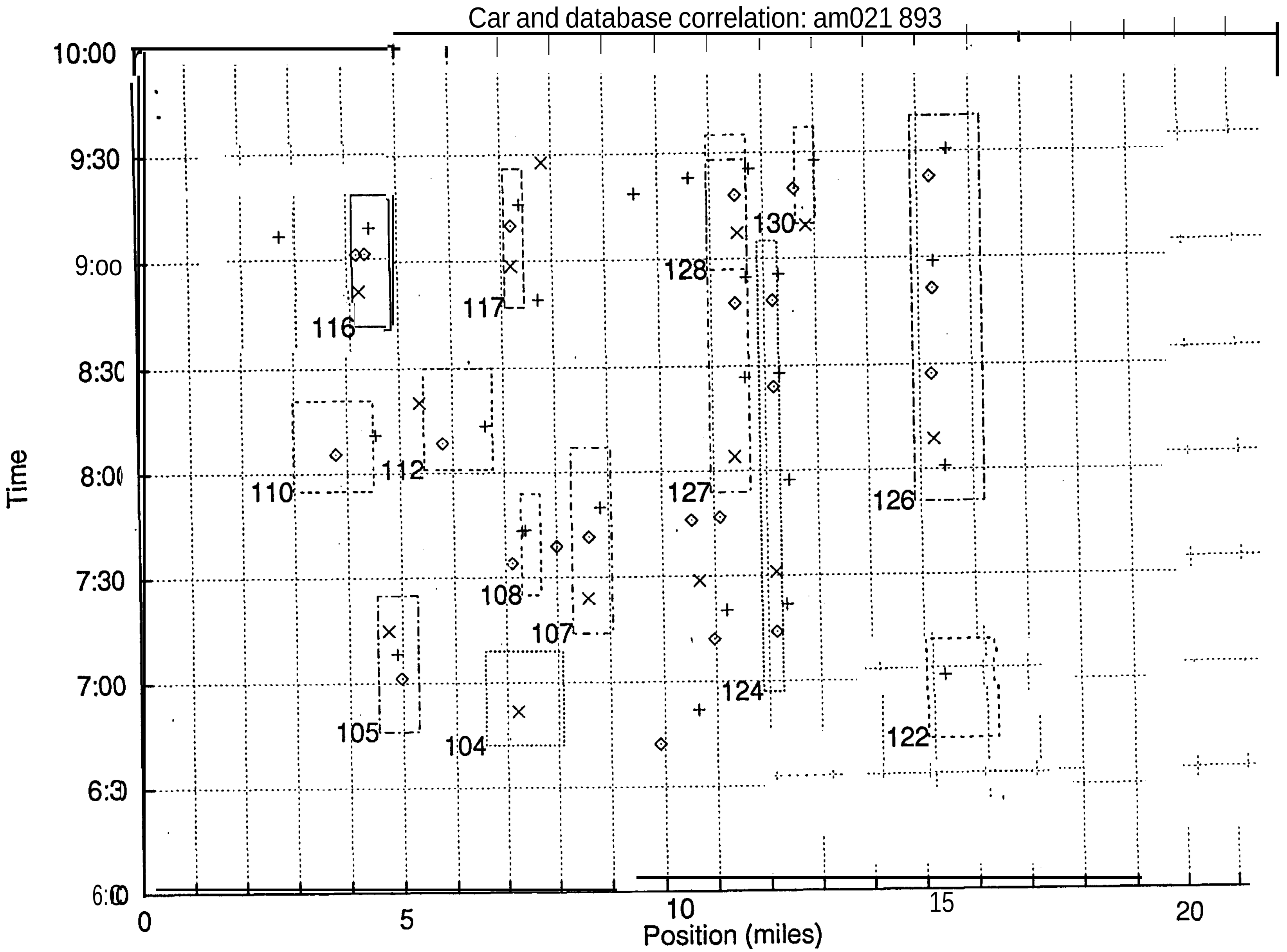


FIGURE 5.4 TRAFFIC DELAYS AND INCIDENTS

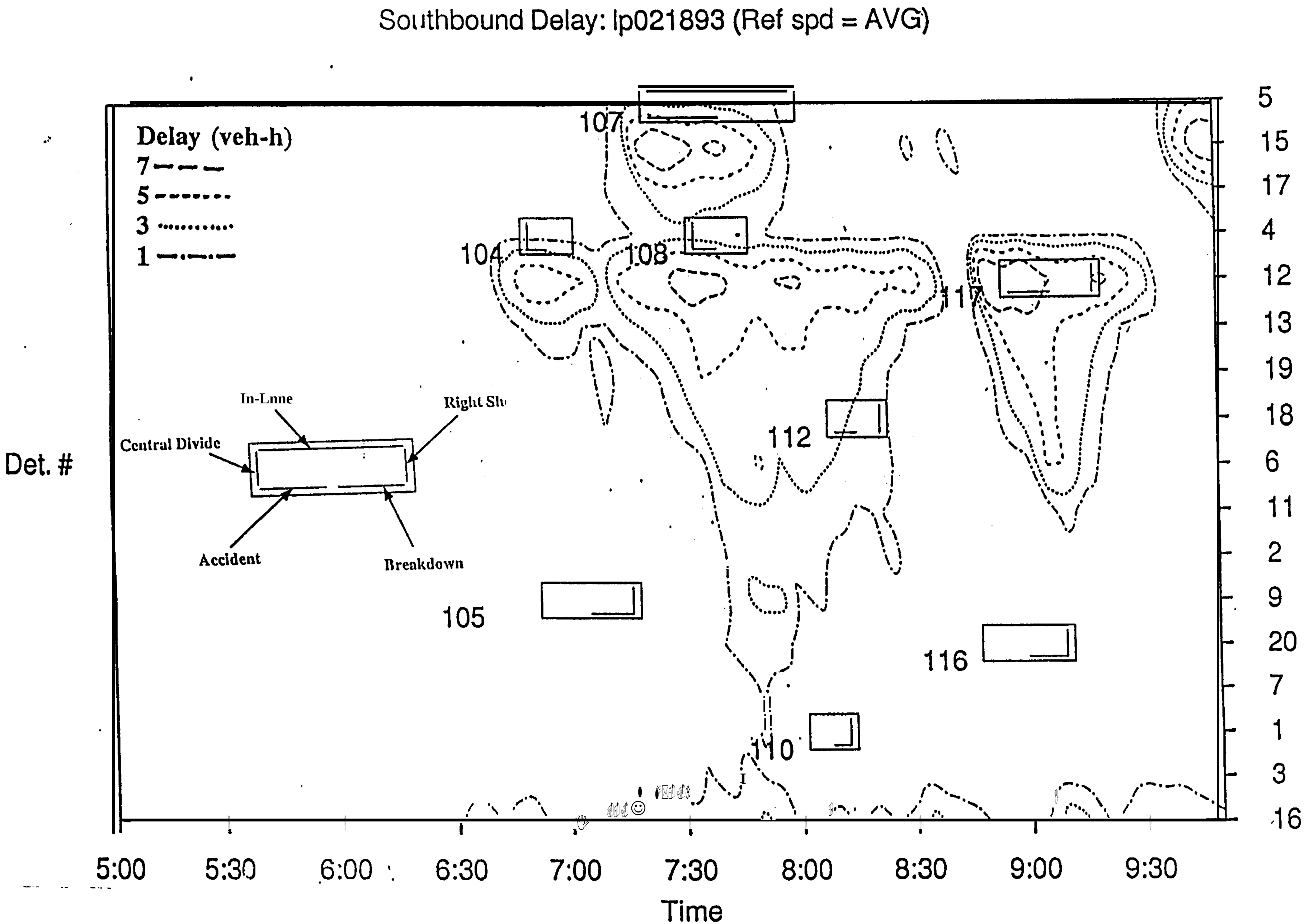
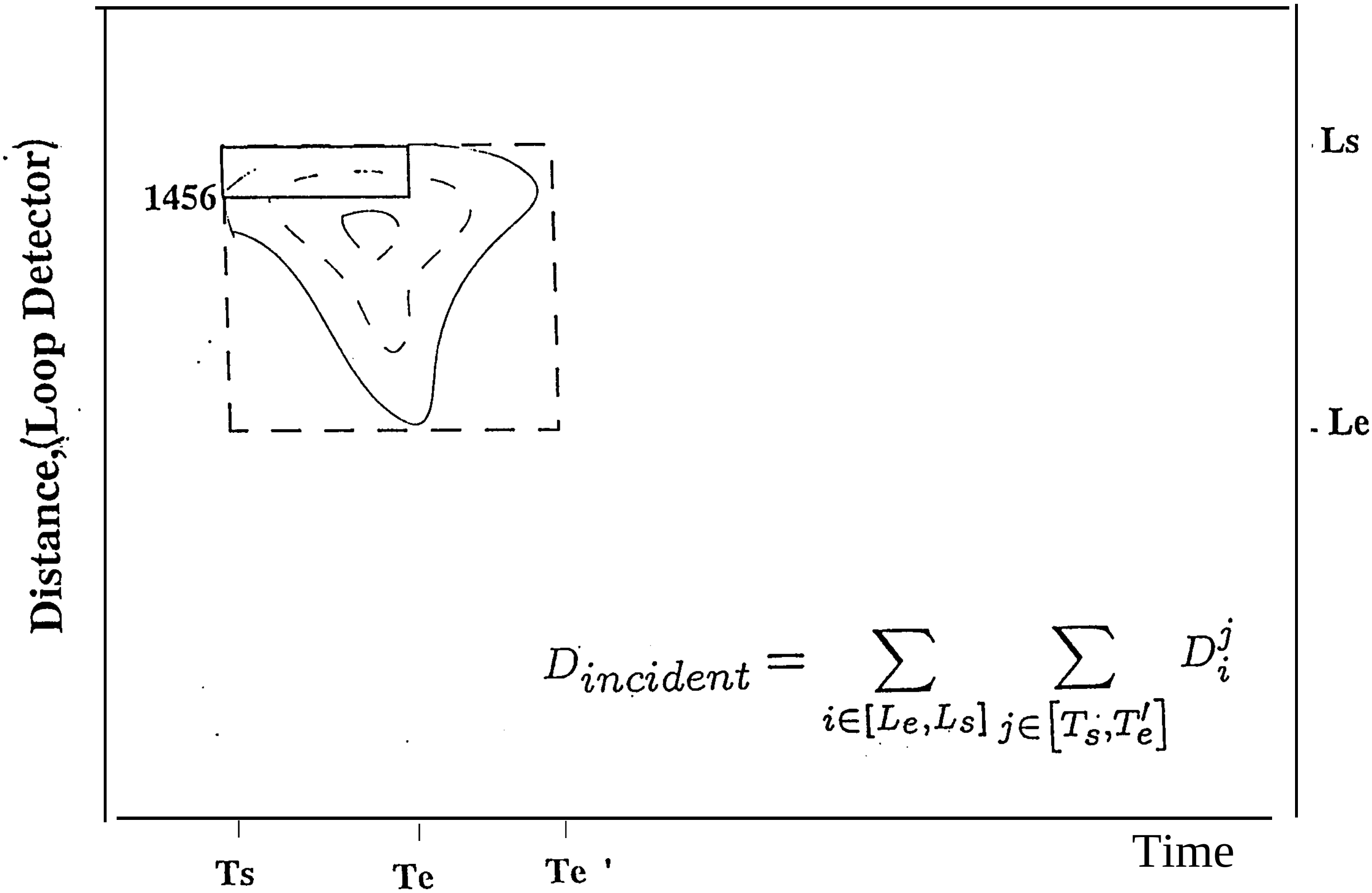


FIGURE 5.5 ESTIMATION OF INCIDENT SPECIFIC DELAY



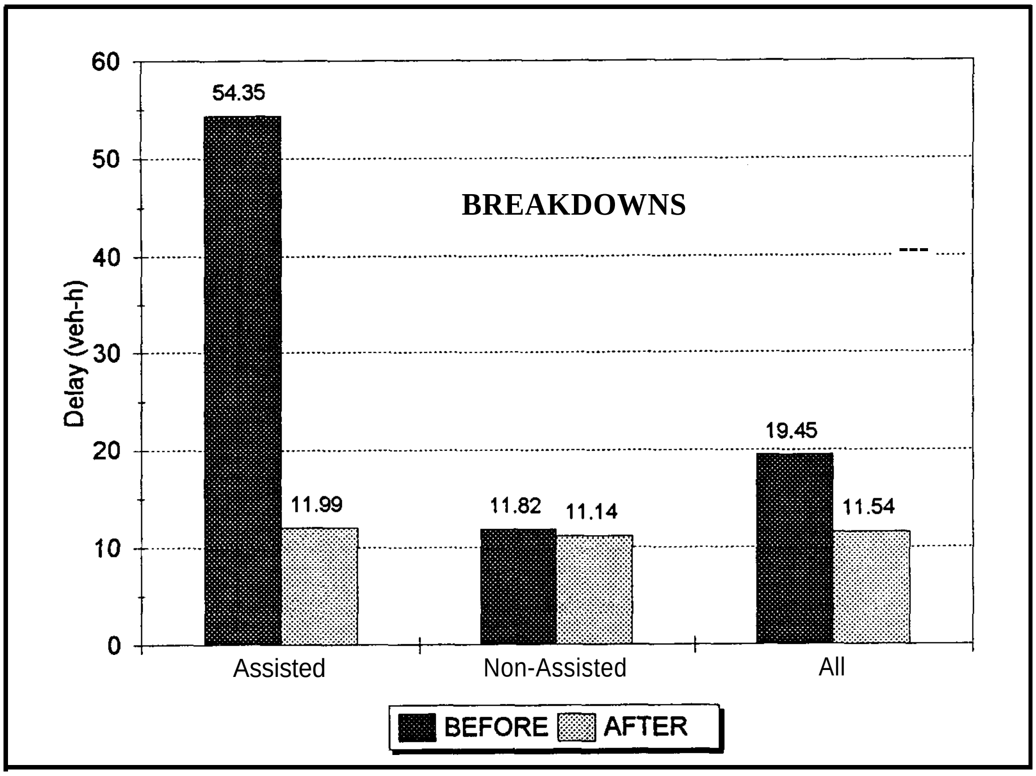
The delay was calculated for those incidents observed within the data collection shift, and with observed start and end times, i.e., incidents observed once were excluded. Incident delays were calculated for a total of 229 incidents "before" and 204 incidents "after". Figure 5.6 shows the estimated delay for accidents and breakdowns, separately for the assisted and non-assisted incidents.

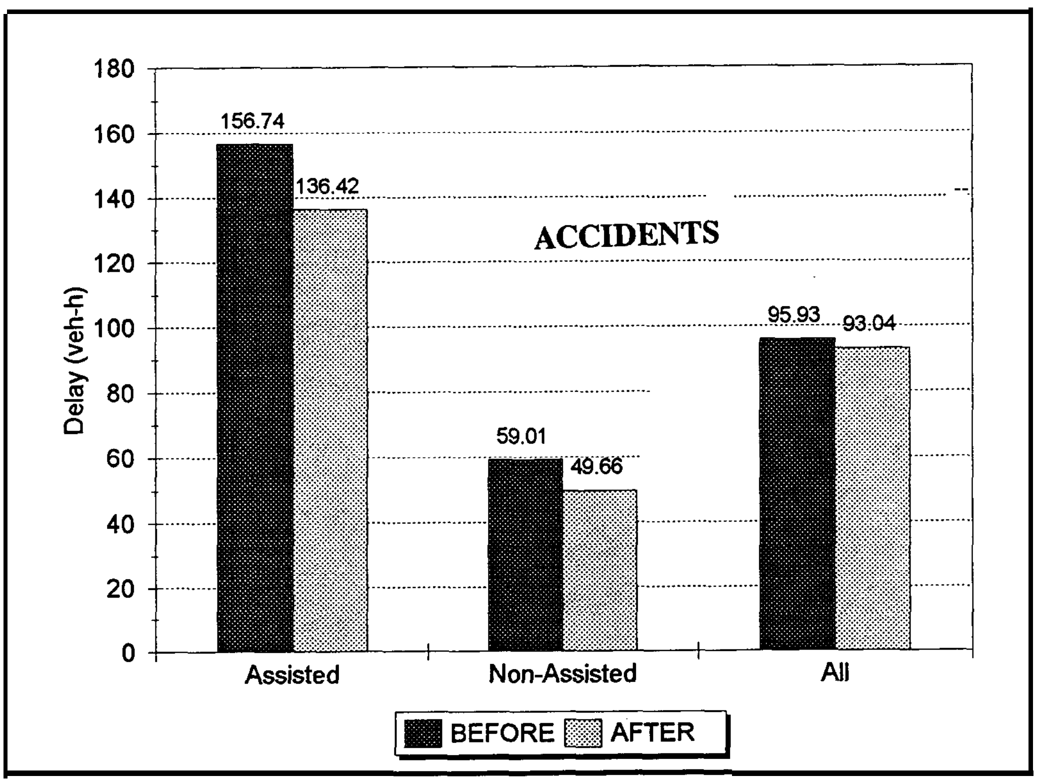
The delay savings per assisted breakdown were 42.36 veh-h. As was expected, there was no difference in delay for non-assisted breakdowns "before" and "after". The savings for assisted accidents were 20.32 veh-h/incident, and 9.35 veh-h for the non-assisted ones.

5.1.2 Fuel Consumption and Emissions

The reduction of congestion delay due to faster response time to incidents results in higher average speeds and smoother traffic flows which reduce the amount of excess fuel consumption and air pollutant emissions. The amount of fuel consumption and emissions were calculated for the assisted breakdowns "before" and after" and the estimated savings include 31 gallons of fuel, and 3.51 Kg of HC, 35.84 Kg of CO and 8.85 Kg of NO, per incident.

FIGURE 5.6 ESTIMATED DELAY PER INCIDENT





5.13 Other Benefits

Benefits to motorists assisted by FSP: Drivers and passengers of the vehicles assisted by FSP receive time savings because of faster response time, and direct cost benefits because of the free service. The average time savings were 16.5 minutes for the FSP assisted breakdowns and 12.6 minutes for accidents based on the field observation (Figures 4.9 and 4.10). The cost of a tow truck attending a disabled vehicle can range from $5 for refueling to over $60 in case of towing off the freeway.

After each assist involving a motorist, FSP drivers give a motorist a survey to fill out rating the service. From August 1992 to June 1994, over 12,000 motorists have returned this survey. In response to the question "Overall, how would you rate the Freeway Service Patrol service?" approximately 93 percent of the motorists rated the service as excellent. Six percent rated the service as good, and less than one percent rated it as fair, poor or other. These outstanding ratings show that the public receiving assistance from the FSP appreciate the service. Many motorists took the time to write complimentary comments on the service on the survey. Others expressed their appreciation by writing letters or calling into the FSP voice mail system.

Benefits to CHP: As was discussed in Section 4.4, the FSP service resulted in a fewer number of incidents attended by CHP, and reduction in the time spent assisting motorists with vehicle breakdowns. The total time spent by CHP officers was about the same "before" and "after" because CHP attended a higher number of accidents in the "after" study.

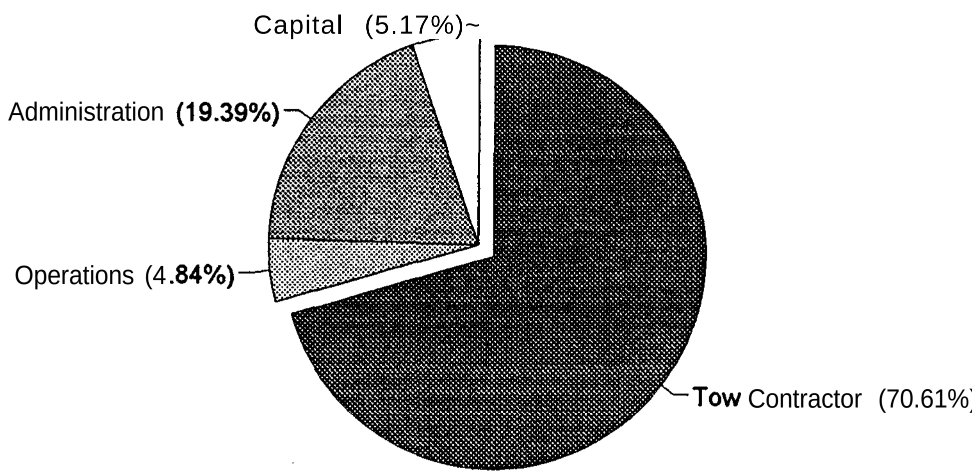
Benefits to the freeway operators: FSP service provides faster recovery of the freeway to normal conditions, and improved incident detection capabilities. The FSP roving trucks are able to locate the presence of incidents and report to the TOC and CHP. An increase of about 30 percent in the reported incidents was found in the "after" study on the study section. In addition, the in-vehicle equipment and software could provide information on the average speeds and other freeway operational characteristics, which correlated with other data sources (loop detectors) would improve the surveillance and information capabilities in a transportation management center.

Improved safety: FSP vehicles provide a sense of security on the freeway, and the faster clearance of incidents may contribute to avoiding secondary accidents. The determination of the safety improvements, however, requires data on accident rates and traffic volumes on the FSP beats over long time periods.

5.2 FSP Costs

The costs of the FSP operation at the test site were calculated by the MTC SAFE staff (shown in Appendix E of the report.) The total cost includes the capital, operating and administrative costs for providing the service, taking into account the hours of operation and the number of the tow trucks involved. Figure 5.7 shows the cost breakdown based on the information provided by MTC. Most of the costs were to private tow contractors. The estimated cost per truck/hour was $72.36 and the total annual costs for the FSP service in Beat 3 is $295,526. There were 257 service days at a total of 4,084 truck hours.

FIGURE 5.7 FSP SERVICE COST BREAKDOWN
Source **MTC/SAFE**



53 Cost/Effectiveness

A measure of the FSP program cost-effectiveness was estimated by calculating the benefit/cost ratio based on the annual delay and fuel benefits to the motorists, and the total savings in air pollutant emissions (in tons). The annual savings in MOEs were first calculated as follows:

$$S_d - s_{di} K F \tag{5-1}$$

where:

S_d: annual MOE savings
s_{di}: MOE savings per incident
K: number of delay causing incidents/day affected by FSP
F: # of days in a year that FSP is operating (257 weekdays, the same as the service days used in the FSP cost calculations by MTC)

The number of incidents affected by FSP was taken from the FSP logs for vehicle breakdowns during the study data collection shifts (Table 4.14). A total of 160 incidents were assisted in the field, 58 were towed and 5 were moved to the shoulder. Thus, there were 171 FSP assisted breakdowns excluding the abandoned vehicles category (52 incidents.) Also, another 17 incidents were "cleared" by FSP tow trucks (motorist drove-off category.) Therefore, a total of 188 incidents were considered for the evaluation of FSP.

A portion of those 188 incidents were of short duration, i.e., their duration would be less than 7 minutes, that do not normally cause delay. Based on the findings from the field study shown in Figure 4.9 28 out of the 107 observed FSP assists in the "after" study were involved incidents witnessed only once, i.e., 26 percent of all assisted incidents. Because, no delays were calculated for those incidents, the number of FSP assisted incidents (188) was reduced by the same factor (73.8 percent) of observed FSP assists to account for short non delay causing assisted incidents.

FSP operates for eight hours a day on the test site and the field observations and FSP logs (Table 4.14) cover only six hours. A total of 473 incidents were logged by FSP drivers of which 356 were within the study shift (Table 4.13). Therefore, the 188 incidents in the study shift were adjusted to account for the hours of FSP operation.

The final number of incidents/day for the calculation of benefits is:

$$K = \frac{\textit{(Total FSP Assisted Incidents)}}{\textit{(FSP assists in shift) (days in after study)}} (\textit{Assisted Breakdowns}) \qquad (5\text{-}2)$$

$$K = \frac{473}{356*22}(0.738 * 188) = 8.38 \textit{ incl day}$$

The annual savings in the MOEs are summarized below:

MEASURE	SAVINGS/ INCIDENT	ANNUAL SAVINGS	
DELAY (veh-h)	42.36	91229.04	veh-h
FUEL (gal)	30.99	66741.92	gal
HC (kg)	3.51	7.56	tons
CO (kg)	35.84	77.19	tons
NOx (kg)	8.85	19.06	tons

The value of time for estimating the delay savings was taken as $10/hr based on i) a value of $8/h per car, ii) average vehicle-occupancy of 1.15 persons/vehicle in peak periods, and iii) 8 percent trucks with $25/h per truck (the average wage rate excluding fringe benefits). The value of fuel was taken as $1.15/gallon (excluding state and local taxes.)

The annual benefits ($) then from the delay and fuel savings are:

$$\boldsymbol{B} = (91229.04\ \boldsymbol{veh\text{-}h})\ (\$10/h) + (66741.92\ gal)\ (\$1.15/gal) = 989{,}044(\$/yr) \tag{5-3}$$

The benefit/cost (B/C) ratio is:

$$B/C\ \frac{989{,}043}{295{,}526} = 3.35 \tag{5-4}$$

This B/C ratio shows that the FSP program in Beat 3 is cost-effective.

5.4 Discussion

The calculated B/C ratio did not consider the time and cost benefits to the motorists assisted by the FSP vehicles, and CHP time savings, and safety benefits. More important, however, the delay benefits were influenced by the following factors:

Delay causing incidents: The number of incidents considered in the evaluation were based on only on breakdowns that were assisted by the FSP vehicles excluding abandoned vehicles, incidents of short duration and accidents. Only 39 percent of all the incidents in the FSP logs during the study shifts were considered as “delay causing” for calculating the FSP benefits.

The number of delay causing incidents depends on the incident and beat characteristics. For example, beats with higher volumes and narrow shoulders may have a higher proportion of delay causing incidents. If it is assumed that all the FSP assisted incidents in the FSP logs cause delay (Caltrans, 1992) then the B/C ratio on the test site would be 9:1.

The analysis showed that were delay and other MOE savings for assisted accidents (20.32 veh-h/incident.) However, the sample size of observed accidents was too small to determine that the FSP service produced significant delay savings. Also, no change was found in accident durations for most of the accident categories. Finally, the FSP logs did not provide sufficient information on the assistance provided to accidents (Table 4.14), except for only 10 accidents that were moved to the shoulder. No information was provided on the type of assistance for the rest of the accidents, and those incidents are normally grouped in the “other/no detail” category by Caltrans and MTC. Better reporting and a larger database periods is needed to determine quantitatively the delay savings for accidents due to FSP service.

FSP costs: The cost of providing the FSP service may affect significantly the benefit/cost ratio. For example, the contract cost of $45/truck-h was reported as the cost of FSP service in Los Angeles (Caltrans 1992) which is lower that the estimated cost for the Bay Area probably due to economies of scale in proving the service and less expensive communications equipment. It is likely that the FSP costs/truck-h would drop with the increase in the areas of coverage.

Delay Estimation: The methodology used for estimating incident delays based on average speeds from loop detectors ignores the delays accrued due to incidents that cause queues that do not extend to the upstream detector but cause vehicles to slowdowns traveling through the section as was discussed in Section 2.2.1 Such delays could only be determined by probe vehicle speed profiles.

The estimated benefit/cost ratio applies only for Beat 3 and cannot be used as a guideline for the effectiveness of the FSP in other locations in the Bay Area or elsewhere in the State. Other beats with higher volumes, narrow or no shoulders and mixed lanes could have higher delay savings per incident but on the other hand may have fewer incidents.

CHAPTER 6

CONCLUSIONS

6.1 Summary of the Study Findings

The objectives of this study were to investigate the incident characteristics. develop a methodology for estimating incident delays and determine the effectiveness of the freeway service patrols on a Bay Area freeway section. More than 276 hours of field data were collected during the peak periods "before" and "after" the implementation of the FSP on a 9 mile section of the I-880 freeway in the city of Hayward, Alameda County (Beat 3). The field data consisted of incidents observed by probe vehicle drivers at 7 minute headways; speeds, flows and occupancies from closely spaced loop detectors on the freeway mainline and the ramps; and travel times from the specially instrumented probe vehicles. Additional information was collected from the CHP CAD system, FSP records and rotational tow truck companies logs.

Software was developed to process the field data and create a computerized database. The I-880 database is the most comprehensive integrated computerized database on incidents and freeway operational characteristics to date. Improved procedures for estimating incident delay and other performance measures were developed and incorporated into the data processing and analysis software.

The findings from the analysis of the field data and the application of the evaluation methodology are summarized below:

The incident frequency and patterns were similar for both study periods. The average incident frequency was 47 incidents/day during the peak periods, and the estimated incident rate was about 100 incidents per million vehicle miles of travel. Trucks were involved in about 6 percent of the accidents, and 16 percent of the breakdowns. Approximately 25 percent of the incidents were CHP/ticketing incidents, mostly citations for violations of the HOV lane usage in the study section. Those incidents were excluded from further analysis because they are not affected by FSP or other incident management measures. The following are the major findings from the analysis of the remaining incidents:

- There were about 0.4 incidents per directional freeway mile per hour on the study section. Most of the incidents were vehicle breakdowns on the shoulders. Only 4 percent of all the incidents were blocking travel lanes, most of them accidents. Time-of-day, day-of-the week, presence of shoulders, traffic volumes and weather conditions accounted for most of the variability in the incident occurrence. The Poisson distribution provided an adequate fit for the observed frequency distribution of breakdowns per data collection shift.

- Approximately 10 percent of all the observed incidents were accidents. The average accident frequency of 3.8 accidents/day during the peak periods is considerably higher than rates reported on other freeway sites in the State. Most of them were non injury accidents. There was a high variation in the accident characteristics in the two study periods. A high proportion of accidents involved more than two vehicles in the "before" study, and more in-lane accidents were observed in the "after" study. The accident frequency increased significantly on rainy days.

- The number of tow truck assisted incidents increased by 120 percent in the "after" study, because FSP drivers provided assistance free of charge to all the stranded motorists they encountered during the patrol of the beat. In the "before" study, tow trucks had to be called by the motorists or the CHP when assistance was needed. About 80 percent of the assists were provided by FSP, and most of the non-FSP assists involved accidents. FSP assisted 3.3 incidents per truck during each three hour data collection shift. Eighty-three percent of the assists were breakdowns mostly with mechanical or electrical problems. Vehicles with flat tire and out of gas accounted for about 22 percent of the assisted incidents, and 17 percent of the incidents involved abandoned vehicles. About 30 percent of the assisted breakdowns had to be towed off the freeway. The proportion of the FSP assisted accidents was significantly higher than in other Bay Area FSP beats.

- The average response time for all assisted incidents was 29 minutes in the "before" and was reduced by 38 percent to 18 minutes in the "after" study, because of the FSP service to breakdowns. The average response time of FSP assisted breakdowns was 13.8 minutes, a 57 percent reduction than the "before" study. Eighty percent of those incidents had response times under 20 minutes in the "after" study as opposed to only 40 percent in the "before" study. The difference in the average response time for accidents was insignificant. Those accidents assisted by FSP had about 50 percent shorter response times, but these reductions were not reflected in all the assisted accidents because of their small sample size, and the large response time of a few accidents in the "after" study. The average clearance times for accidents and lane blocking incidents were about 20 minutes; breakdowns and shoulder incidents in contrast took only about 5 minutes to clear. The differences in the clearance times "before" and "after" were not statistically significant for all the incident categories.

- More than 60 percent of all the incidents were witnessed only once, i.e., they lasted less than the average 7 minute headway of probe vehicles. The majority of those incidents were minor stalls and not assisted by tow trucks. The average duration of the rest of the incidents was about 25 minutes, and 85 percent of the durations were 50 minutes or less. The FSP service did not have a significant impact on the total incident durations. The difference in the average durations "before" and "after" were within the standard error of estimate of the mean durations for both accidents and breakdowns. Significant reductions in average durations by about 35 percent were found only for the assisted incidents, because of the faster response times of the FSP tow trucks.

The assessment of the effectiveness of FSP considered only the savings in performance measures for breakdowns. The estimation of the incident specific delay, fuel consumption and emissions was based on the difference in average travel speeds under normal and incident conditions using the data from loop detectors. The estimation procedure first determines the exact incident locations and times by matching the data from the incident field logs and the probe vehicles, and the spatial and temporal area of influence of an incident based on the delays along the section calculated from the loop detector data. The findings from the evaluation are:

- The estimated average delay savings were 42.36 (veh-h) per assisted breakdown, and 20.32 (veh-h) per assisted accident. A total of 31 gallons of fuel was saved per each assisted breakdown. The annual savings were calculated based only on the delay and fuel savings from the FSP assisted breakdowns excluding incidents of short duration and abandoned vehicles (about 36 percent of the total FSP assisted incidents.) Assisted accidents were also excluded because it was not possible to determine that the savings were significant because of their small sample size and the high variability in accident characteristics “before” and “after.” The calculated benefit/cost ratio of 3.4:1 shows that the FSP program in Beat 3 has been cost/effective. In addition, air quality savings include a total of 7.6 tons of hydrocarbons, 77.2 tons of carbon monoxide and 19.1 tons of oxides of nitrogen pollutant emissions.

- The FSP service provided additional benefits that were not included in the calculation of the benefit/cost ratio. The assisted motorists received time savings because of the faster response time, and direct cost benefits because of the free service provided by FSP (estimated at $70/assist). The survey of motorists assisted by the FSP showed overwhelming approval with 93 percent rating the service as excellent. Motorists also wrote complimentary comments, left voice mail and sent letters to show their support of the program. The number of detected and reported incidents in the CAD database increased by 30 percent in the “after” study almost exclusively due to the calls made by the FSP vehicles. Also, the FSP service resulted in fewer incidents attended, and reduction in the time spent to vehicle breakdowns by CHP officers. Furthermore, the presence of FSP provides a sense of security on the freeway and the quicker removal of incidents could reduce secondary accidents.

6.2 Recommendations

The estimated benefit/cost ratio applies to sites with traffic and incident characteristics similar to the ones in the study area, and may not be used as a guideline for the effectiveness of the FSP elsewhere. The effectiveness of FSP would be higher on locations with similar incident patterns but higher traffic volumes, mixed lanes and narrow or no shoulders. However, the benefits would be limited on sites with few major incidents as opposed to sections with high frequency of vehicle disablements. Additional evaluation studies should be performed to quantitatively determine the range in the FSP benefits. This study provides a framework for the accurate assessment of the effectiveness of FSP.

Field data on incident characteristics and their impacts on traffic flow so far have been limited, and most studies were conducted in the 60’s and 70’s, when urban freeways were less congested, and driver-vehicle characteristics were quite different. For example, the original source of the most often quoted incident rate of 200 incidents/million veh-miles (Urbanek 1978, Lindley 1986) has been derived from limited data conducted in 1958 on five interstate segments in Upstate New York with a average daily traffic of 10,000 vpd (Billion, 1959, Kuprijanow 1969). Recent studies (Golob 1987, Jones 1991) focused on accidents using police reports and patrol logs as data sources. Giuliano's study on incident characteristics on I-10 freeway was also based on information from the TASAS system and CHP logs (Giuliano 1989). There is a need for additional comprehensive data collection and analysis efforts on other sites to determine incident patterns and their impacts on freeway traffic flow for a range of operating conditions. Such databases similar to the one developed in this study could be used to formulate improved guidelines for deployment and evaluation of incident management programs, as well as develop and calibrate improved incident detection algorithms and simulation models.

Existing approaches for estimating incident specific delay rely on several simplifying assumptions and have limited application for multiple incidents. The methodology developed in this study results in improved delay estimates but requires extensive data, and may underestimate the delay for those incidents causing queues that do not extend to the upstream detector station. Work is in progress to develop improved delay estimation procedures based on probe vehicles and other data sources and test them through simulation and field data.

The effectiveness of FSP service on freeway segments with narrow or no shoulders should be further investigated because of potential safety problems. On several Bay Area beats with narrow shoulders FSP vehicles have been instructed to tow vehicles to a safe location before they assist in the field. This would increase the FSP response times particularly on high incident locations and may require additional trucks to provide the same level of service on those beats. Further work is needed to determine the advantages of roving vs. stationary service patrols. Roving patrols provide a better coverage and faster response times but respond to every situation, such as minor stalls, which may not be effective from the freeway congestion standpoint. Stationary patrols, however, require electronic surveillance systems and CCTV for reliable incident detection and verification.

Efforts should be undertaken to maximize the utilization of FSP as a mobile data source for incidents and freeway operating conditions in the context of the advanced traffic management and information systems (ATMIS). FSP vehicles could serve as incident detection and verification mechanisms. The in-vehicle equipment and software could provide information on the average speeds and other freeway operational characteristics, which fused with other data sources (e.g., loop detectors, other probe vehicles) would improve the surveillance and information capabilities in a transportation management center.

Steps could be also taken through regulation means to reduce the number of incidents on urban freeways, especially breakdowns. About 12 percent of the FSP assists involved vehicles out of gas, which may not be the best use of the service on urban freeways with interchanges spaced about one mile apart. Also, FSP had to tow vehicles with flat tires traveling without a spare. Institutional measures may include fines and citations for running out of gas and traveling without a spare tire, and mandatory inspections for serviceability of the vehicle's electrical and mechanical systems.

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APPENDIX A

DATA COLLECTION PROCEDURAL GUIDE

FSP PROJECT

FALL, 1993

DRIVERS' BOOKLET

BACKGROUND

The Freeway Service Patrol (FSP) is a special team of tow truck drivers who continuously patrol certain sections of congested freeways during commute hours. The FSP tow truck drivers look for disabled vehicles and offer motorists help by changing a flat tire, "jump starting" a dead battery, refilling a radiator or providing a gallon of fuel. If the vehicle can not be restarted the FSPs tow it off the freeway to the nearest CHP-identified drop location.

The objective of FSP program is to relieve freeway incident congestion through quick detection, verification, and removal of accidents and disabled vehicles during peak commuting hours. The program is jointly administered by Caltrans, CHP, and the Bay Area Metropolitan Transportation Commission (MTC).

The objective of the field study is to evaluate FSP effectiveness in reducing incident congestion in the freeway system, and to find its cost/benefit ratio.

DRIVING PROCEDURES (DRIVERS)

1) Meet Supervisor at MTC parking lot (see project site map)
2) Get key and radio from supervisor, supervisor will inform student drivers of any special conditions
3) Enter personal user ID #, car number, date (m/d/y), and military time on laptop (see computer procedure).
4) Conduct Radio and Time check with supervisor
5) Proceed to field start-up location (Denny's Parking Lot at MARINA)
6) Contact supervisor on radio transmitter upon arrival at start-up location
7) Driver enter field test area upon prompt of supervisor. When you enter the on-ramp, hit the **start** key. Every time you enter the MARINA on-ramp hit the start key.

8 a) Hit the **SB BOUND** key at the start and at the end of the SB run (See map)

8 b) Hit the **NB BOUND** key at the start and at the end of the NB run (See map)

8 c) Hit the **GORE** keys every time you pass a gore point (See map)

9) Do not drive in HOV lane nor extreme right-hand lane
10) Contact supervisor when passing the gore of the ~~Marina Blvd.~~ off-ramp (end of cycle)
11) Follow supervisors instructions to stop at waiting location, if instructed to do so
12) **1st personal witnessing of incident**

    Procedure to Follow:

    i. when passing an incident location, hit the INCIDENT key then hit return kev

    ii. communicate with supervisor on radio to report the incident

13) **When reporting incident to supervisor** (see incident log)

    Indicate the following:

    i. time of incident

    ii. direction of travel NB/SB

    iii. location, relative to last and/or next freeway exit

    iv. vehicle type and color

    v. incident type (accident, breakdown, CHP , object on road)

    vi. detail description (which lane, vehicle type, severity, etc.)

    vii the lead driver will report incidents present at start of shift.

14) **Repeat witness of an incident**

    Hit the **INCIDENT** key when you're perpendicular to the incident.

    Report the incident to the supervisor

Indicate that you are updating an incident. **<u>Include:</u>**

i. location of incident

ii. color and vehicle type

iii. status update to include <u>brief</u> description (i.e.... no change, tow truck, CHP, ambulance, fixing flat, etc..)

iv. time of status update

15) Stop driving at 9:30 a.m. & 6:30 p.m., use next exit to loop around (if necessary), follow computer instructions, and proceed to gas station

16) Fill gas tank (write plate number on the receipts) and return vehicle to MTC parking lot

17) Fill out vehicle log book, Return Radio and keys to supervisor

SUPERVISOR PROCEDURE

PRE TACH RUNS

1) Supervisor arrives 30 minutes prior to scheduled shift.
2) Make sure to have enough incident log sheets, headway logs, and field attendance sheets before start of shift.
3) **Car Keys :** retrieve from office (beginning of shift).
4) **Laptop Computers :**
   (Morning)- collect from MTC office.
   (Afternoon)- retrieve from vehicle trunks.
5) **Hand-held radio transmitter**
   collect from chargers in office.
6) Supervisor will call the TOC to synchronize digital watches in the car with the CHP CAD at the beginning of every shift.
7) Connect laptops, put an empty preformatted diskettes, and synchronize times in laptops.
8) Check condition of car (exterior), gas, and tires.
   if necessary contact service station (minor repairs).
9) Ascertain driver status by 5:50 a.m. OR 2:50 p.m.
10) At 6:00 a.m. OR 3:00 p.m. use reserve drivers if necessary and/or release their services.
11) Radio and time check with all drivers.
12) Inform drivers of special conditions.
    if gas is necessary send first arrival with vehicle to fill tank.
13) Proceed to supervisor field location after all vehicles leave MTC parking lot.
14) At the start-up location, remind students to input the following information in the program in the same order:
    - Student ID: P10
    - Car number: 7944
    - Date: 02/16/93
    - Time: 16:55

DURING TACH RUN

1) Radio checks with drivers.
2) Monitor driver arrivals to field start-up location.
3) Leave for supervisor field location after last driver out.
4) Dispatch drivers at 5 minute intervals from start-up location.
5) Record driver announced arrival time at off-ramp of Marina St. in the headway log as well as their departures.
6) Instruct drivers when to stop at waiting location, this is to maintain minimum headway.

7) When drivers signal that there is an incident:
Supervisor will:
- Fill out supervisor incident log.
- If possible, proceed to incident location.
*If it is a life or death situation supervisor will use cellular phone to call CHP TOC in Vallejo.

8) If incident involves a project driver then supervisor will contact TOC and Caltrans District IV. Supervisor will provide information for vehicle location and situation.

POST TACH RUNS

1) Collect keys and transmitters from drivers.
2) Save data on diskettes and remove from lap tops.
3) (Morning)- Put laptops and transmitters in trunk.
4) (Evening) - Put laptops and transmitters in office.
5) Put parking permits in Supervisor's vehicle.
6) Put keys, and diskettes in office.
7) Remind drivers to fill the log book, and to write car number on gas receipts.
8) At end of each week, collect white sheets from log books and send to Caltrans.

INSTRUCTIONS FOR OPERATING THE FSP DATA COLLECTION SYSTEM

1 Turn on the car

2 Connect the cable with the **9-pin** connector to the mating connector on the back of the laptop computer **(COM1).**

3 Plug the laptop's cigarette lighter adapter (DC adapter) into the mating connector on the back of the laptop (DC IN).

4 Switch on the laptop.

5 At the **C:\>** prompt, type 'cd fsp' and press ENTER

6 At the **C:\FSP\>** prompt, type 'VSC' and press ENTER

7 While holding down the ALT key, press the SPACE bar.

8 Turn on the power switch (Orange Toggle) on the dashboard.

9 At the 'Enter New Time:' prompt enter the time of day (military time)
Use the following format: -press space bar then enter the next even minute. HH:MM:OO
Wait until the time passes through 00 seconds and press enter.
Note: **The** time is **recorded when ENTER is pressed.**

10 The computer will print a message indicating how much disk space is available and how many more hours of data collection can be accomplished (A maximum of 4.1 hours for an empty J: d If this amount of time is less than the expected run time, you must firs: delete old data files from the J: drive before you can proceed. To delete old files:

Press 'B' and then the 'ESC' key (escape)
At the ZT J:\> prompt type 'del ● .dat' and press Enter.
Turn off the power switch (Orange Toggle) on the dashboard.
Turn on the power switch (Orange Toggle) on the dashboard.

11 If it was **necessary** to delete old files repeat step 9, otherwise continue to step 12.

12 Press **'B'** to begin data collection.

13 Type in your name (ie. **4-FSP-10),** terminating with ENTER.

14 Type in your 4digit vehicle number, terminating with ENTER.

15 Type in the date (ie. **02/16/93),** terminating with ENTER.

16 Wait until the time passes through 00 seconds, then press the space bar and enter the time
Use the following format: HH:MM:OO.
NOTE: The time was recorded when the space bar was pressed.

The curser should be at the beginning of the next tine, if it is not press ENTER.

17 Drive the data collection route.

18 At the end of the run, proceed to a safe location to do the end of run log-out procedure.
Wait until the time passes through 00 seconds, then press the space bar and enter the time
Use the following format: HH:MM:OO.
The curser should be at the beginning of the next line, if it is not press ENTER.

19 Press the 'ESC' key to end the data collection.

20 The run data has now been stored on the J: drive.

21 While holding down the ALT key, press the SPACE bar.

22 The screen will display the **C:\FSP\>** prompt.

23 Type 'CD..' and press ENTER.
The screen should now display the **C:\>** prompt.

24 While holding down the ALT key, press the SPACE bar.

25 The screen should now display the **ZT J:\>** prompt.
Type 'Copy ● .dat C:
The screen should immediately scroll to or prompt **'NAV1.dat'.**
This indicates that it is copying the run's data to C:\ drive.

26 Drive back to MTC parking lot while the data is being copied.

27 When you get to MTC parking lot leave the car running for the supervisor to complete data col
NOTE: Do not turn anything off as it is possible for all the data to be lost!

PROJECT SITE ACCESS MAP

Public Transit Access

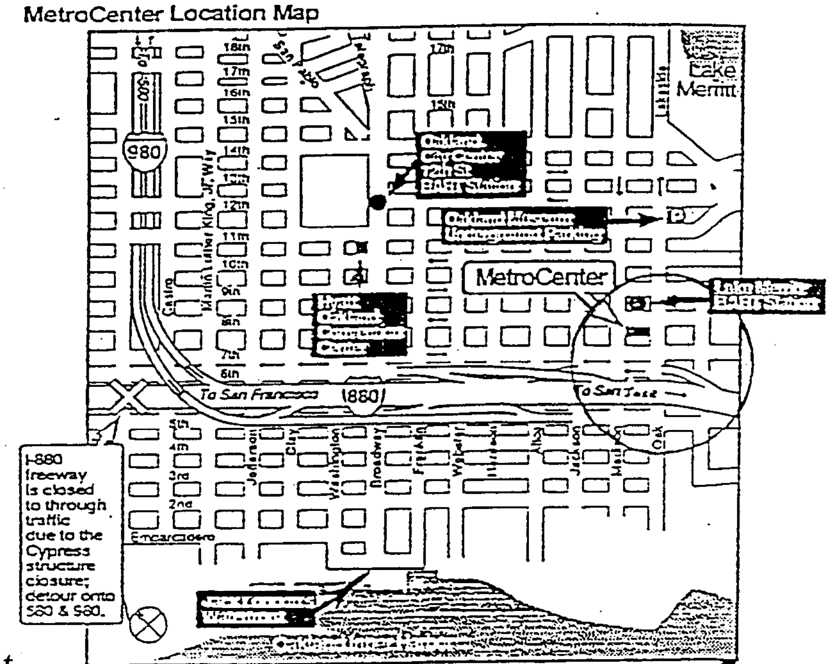
BART: *Lake Merritt Station*
AC Transit: *Lines 11, 59, 59A, 62, 35X, 36X or 40X*

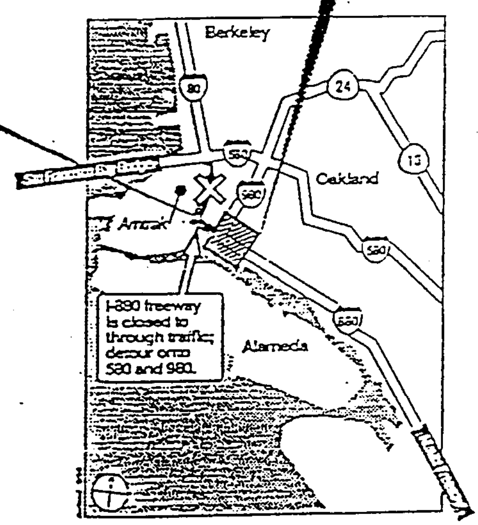
Auto Access

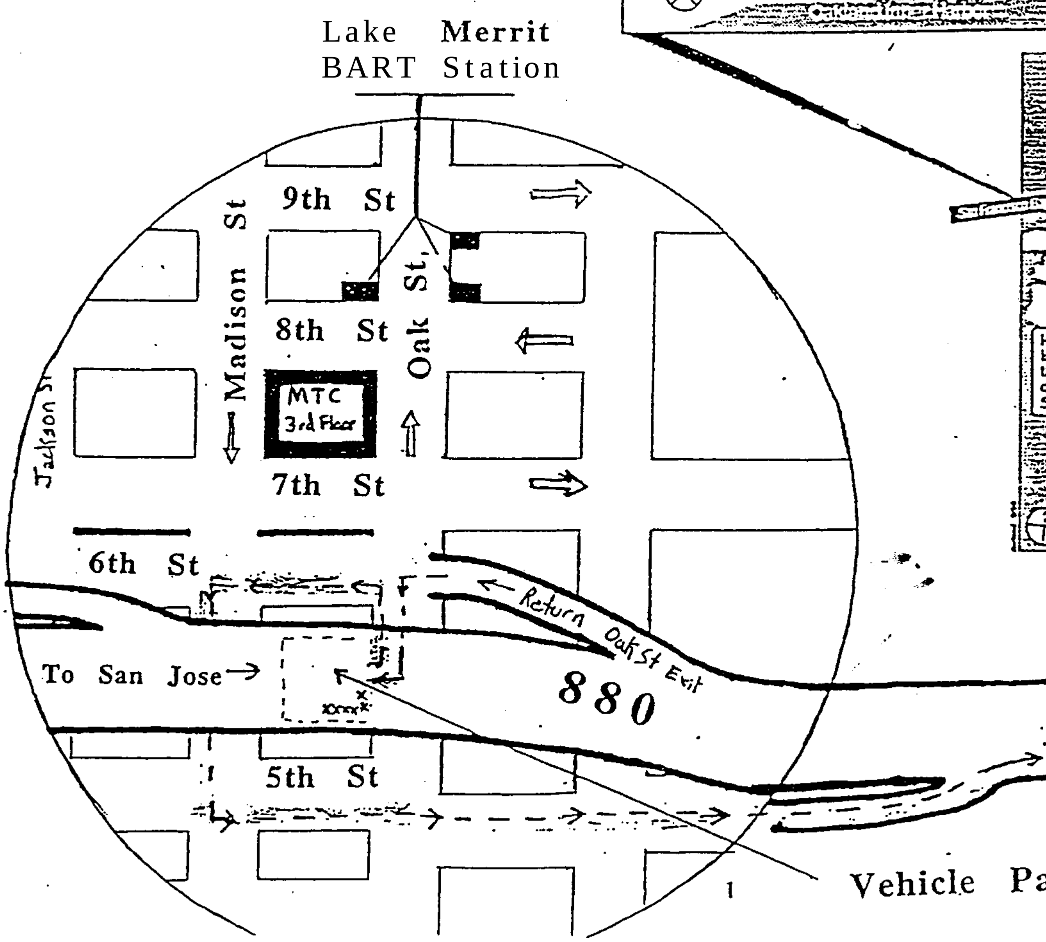
- *Travelling south on Route 980, take the Jackson St. Exit and go straight on 5th, left on Oak and left on 8th.*
- *Travelling north on the Nimitz (Rte. 880—formerly Rte.17), take the Oak St. Exit.*

Parking:
Oakland Museum — 11th & Oak (Underground parking, entrance on Oak between 11th & 12th)
Metered parking available on streets in the MetroCenter vicinity —
Parking lot behind the MetroCenter is for BART patrons only.

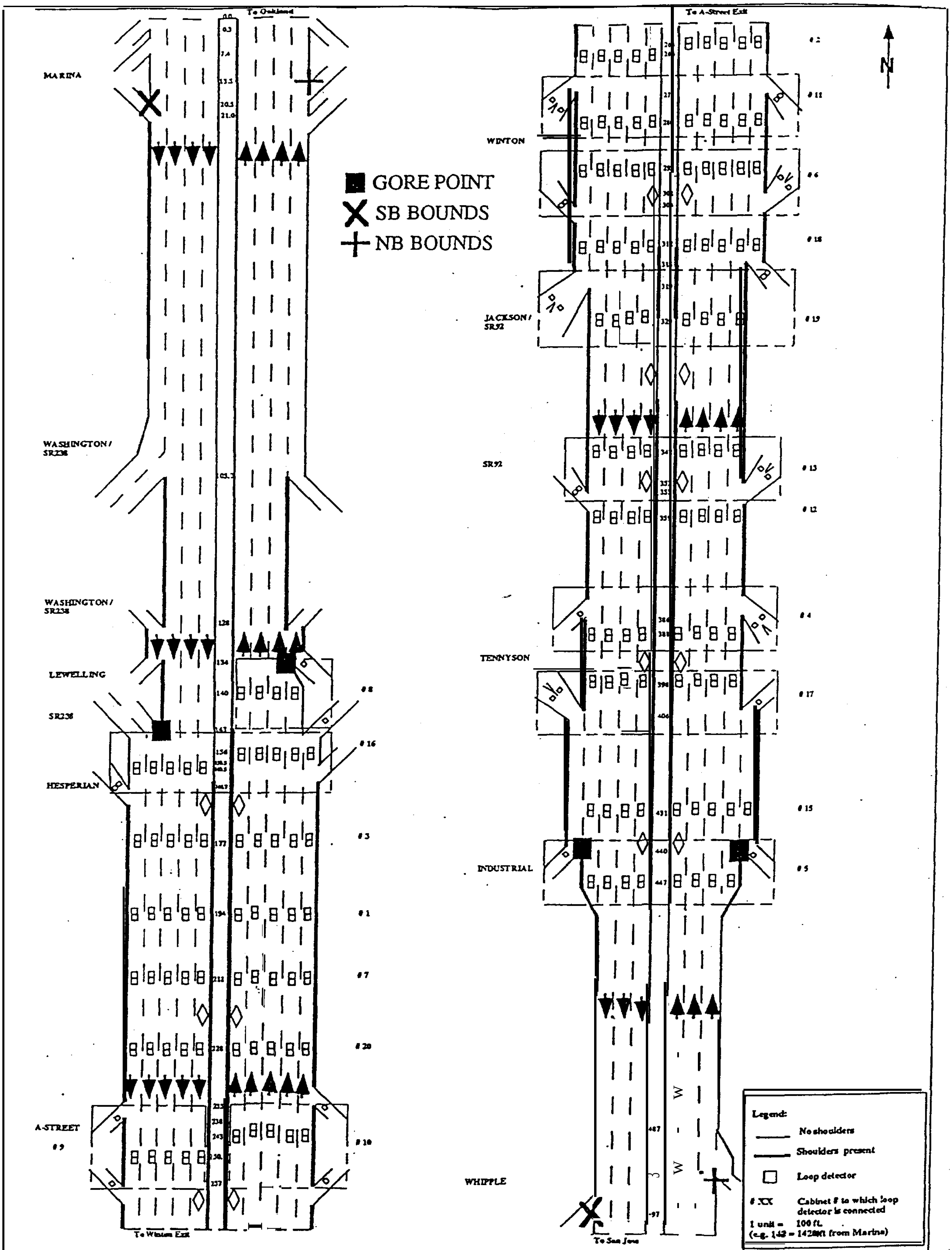
MetroCenter Location Map



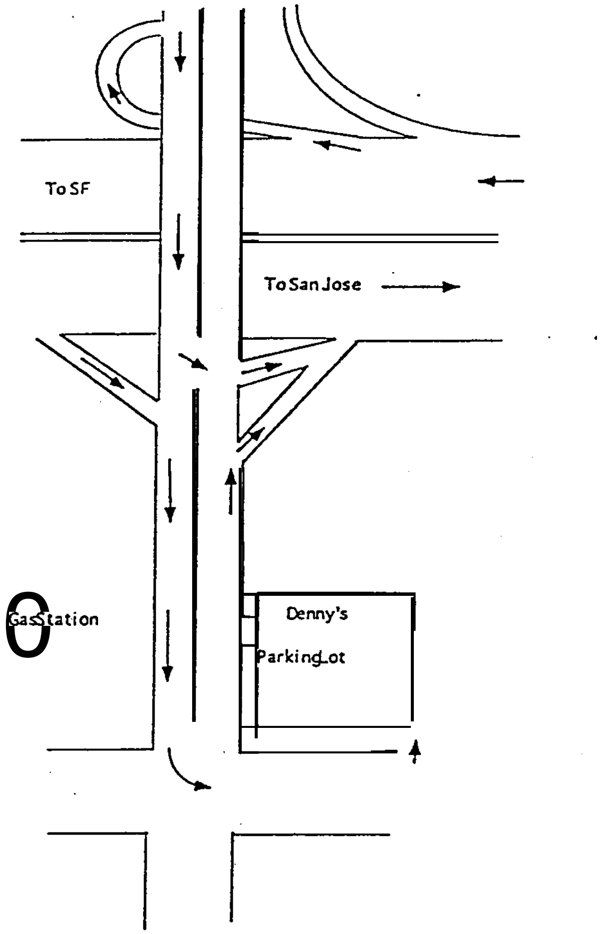




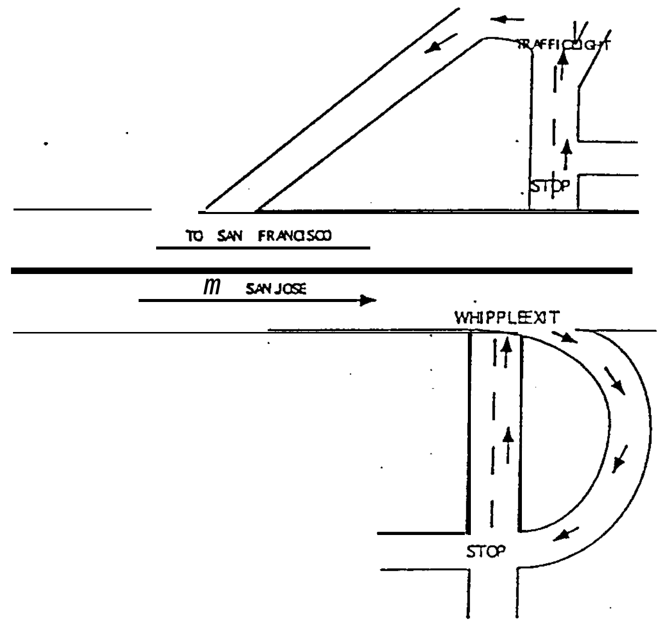
TEST ROUTE



GORE POINT
SB BOUNDS
NB BOUNDS
MARINA
WASHINGTON/ SR238
WASHINGTON/ SR238
LEWELLING
SR238
HESPERIAN
A-STREET
WINTON
JACKSON/ SR92
SR92
TENNYSON
INDUSTRIAL
WHIPPLE
To Oakland
To Winton Exit
To A-Street Exit
To San Jose
N
Legend:
No shoulders
Shoulders present
Loop detector
XX Cabinet # to which loop detector is connected
1 unit = 100 ft.
(e.g. 142 = 14200ft from Marina)



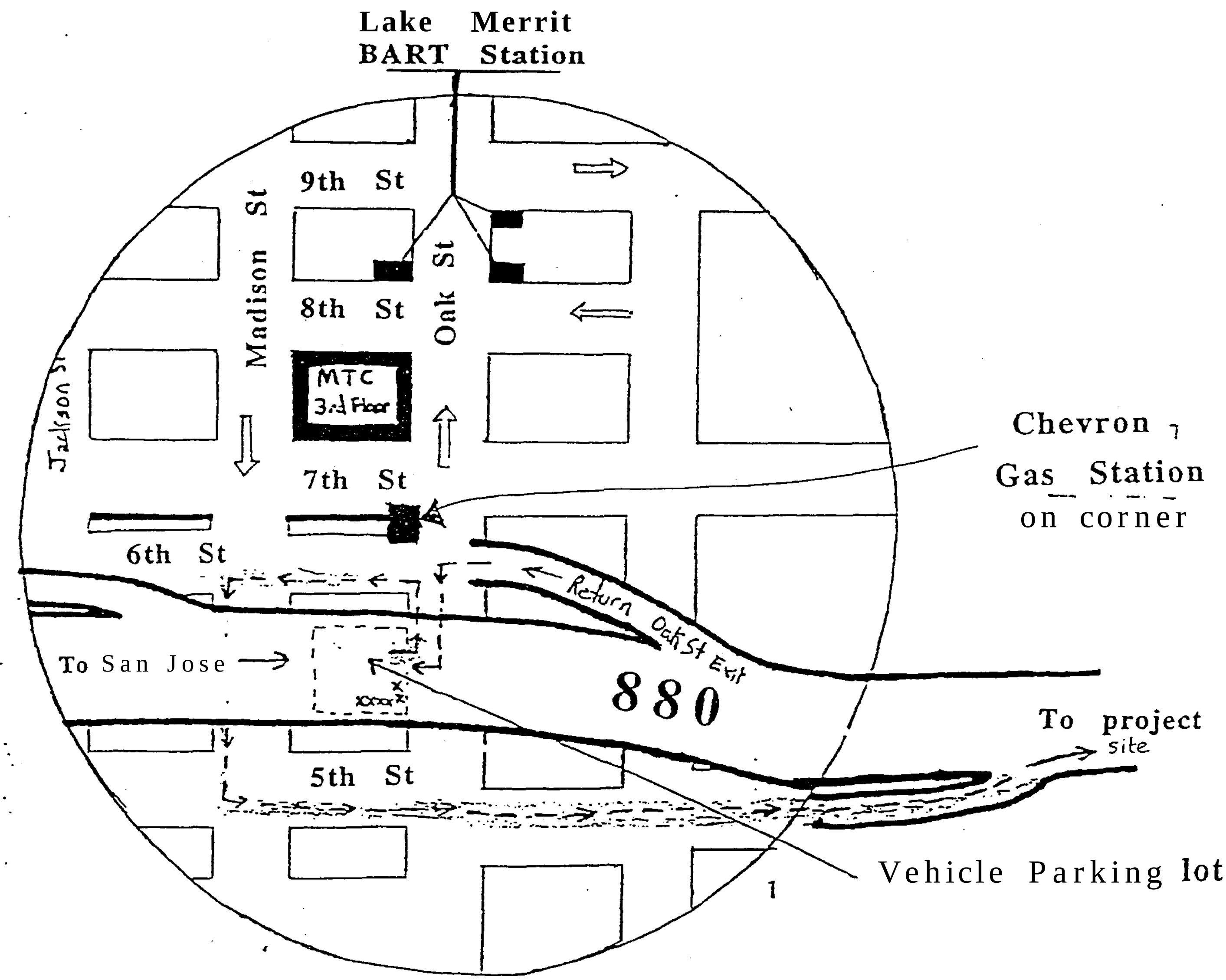
MARINA BLVD. EXIT



WHIPPLE ST. EXIT

START-UP LOCATION

GAS STATION MAP and FILL UP PROCEDURE



VEHICLE LOG BOOK PROCEDURE

VIEW FOLLOWING FORM:

State of *California* - Department of Transportation
Mileage Vehicle Log

OCT 21 '92 03:11PM CALTRANS DISTRICT 4 OPERATIONS P.2

STATE OF CALIFORNIA—DEPARTMENT OF TRANSPORTATION

Mileage Vehicle **Log**

MONTH YEAR	ITEM	C NO.	ACCOUNTING USE ONLY: TC	GSL	SHEET NO	E	BEGINNING ODOMETER READING
10 92	00101						5351.0

	DATE	SOURCE DIST	SOURCE UNIT	CHARGE DIST	EXPEND AUTH	SUBJOB	SPECIAL DESIGNATION	FA	MGMT SYSTEM ACTIVITIES	ENDING ODOMETER
1	26	04	392	04	936208		6FSP			368.0
2										.0
3										.0
4										.0
5										.0
6										.0
7										.0
8										.0

USE RESPECTIVE LINES BELOW TO COINCIDE WITH DATA SHOWN ABOVE

	DATE	START TIME	ITINERARY	END TIME	AFTER HRS CALL OUT	STORAGE	OPERATOR'S NAME
1	26	0600	MTC, Oakland	1930		MTC Oakland	Student's name
2							
3							
4							
5							
6							
7							
8							

FILL THE LOG BOOK OUT AT THE END OF YOUR SHIFT!!!!

1 Check month and year
2 . (Check item number is '00101'
3 Check that 'source dist' and 'charge dist' both read '04'
4 Check that 'source unit' reads '392'
5 Check that 'expend auth' reads '936208'
6 Check that 'special designation'. reads '6FSP'
7 Check that 'itinerary' and 'storage' read 'MTC Oakland'

8 In 'C NO.' bdx put in the 4-digit number on the car's gas tank
9 In the 'E' box put in the license plate number of the vehicle
10 Enter the date in the date column as shown
11 Enter your name in the 'Operators Name' box as shown
12 Enter the end-of-shift odometer mileage reading as shown

HELPFUL INFORMATION FOR

RADIO OPERATIONS

A15

Ra' operation procedure

1) Select S -TOPS -C channel by pressing "menu 6" and selecting "F".

2) When calling others, place the radio close to your mouth, press the button on the left side, allow 1 second pause, then begin your conversation/ transmission.

3) When calling others, use their call number followed by your call number. Example: 4FSP-10. . . . ..4FSP-11 (4FSP-11 is calling 4FSP-10).

4)Always repeat your call number at the end of your transmission. This will tell others that you have completed your conversation and you are clearing the channel. Example: 4FSP-10 Clear,

5) Knowing the 10 codes will help you communicate quickly and effectively. Use 10 codes when possible.

6) Remember once on the air, you can be heard by many. Minimize conversation time and avoid using any obscene language.

LIST OF 10-CODES

10-1 Poor Reception
10-2 Good Recep tion
10-4 Message received
10-5 Relay Message
10-7 Out of service
10-8 In Service
10-9 Repeat
10-10 End of Duty
10-20 What is your location
10-22 Cancel Message
10-23 Stand by
10-33 Emergency Traffic
10-39 Message delivered
10-44 Traffic check
10-45 Negative traffic
10-97 Arrived at scene
10-98 Assignment completed

In case of emergency

1) Notify your field supervisor, using your hand-held radio to communicate that you have an emergency. Example: 4FSP2 emergency traffic.....4FSP10.

2) Your field supervisor has a cellular phone. You can call him at (510) 5040153, using a public phone if necessary.

3) You can contact the following people, if your field supervisor can not help:

Traffic Operation Center (707) 648-4061

Barry Loo	(510)286-4550 office	(415)719-0493 Pager
Ron Ho	(510)286-4511 office	(415)719-0494 Page;
Cyrus Mashhoodi	(510)286-4513 office	(415)719-0495 Pager

APPENDIX B

INCIDENT DATA COLLECTION FORMS

INCIDENT DATA CODING SCHEME

FIELD INCIDENT LOG

Date: ______________

DIR: NB/SB
LANE: LT 1 2 3 4 5 RT

LANES AFFECTED 1 2 3 4 5

<1/4 1/4 1/2 3/4 1 Before/After

BLACK
BLUE
BROWN
GOLD
GREEN
GREY
ORANGE
RED
WHITE
YELLOW

Marina
Washington/238 inter.
Lewelling/Hesperian
A-Street
Winton
Jackson/San Mateo Br.
Tennyson
Industrial
Whipple

Breakdown — Flat tire / Gas / Mechanical / Can't Tell
CHP present
Accident — car(s) ____
Can't Tell

4x4 Van Pick-up Stn Wgn Other

☐ Witnessed Incident
☐ FSP Involved
☐ At Start of shift incident

	CHP 1 2 3	TT 1 2 3	AMB
ARRIVAL TIME			
TIME LEFT			

Description

TIME MAIN IS CLEARED	
TIME SHOULDER IS CLEARED	
TIME CAR IS TICKETED FOR TOWING	

DIR: NB/SB
LANE: LT 1 2 3 4 5 RT

LANES AFFECTED 1 2 3 4 5

<1/4 1/4 1/2 3/4 1 Before/After

BLACK
BLUE
BROWN
GOLD
GREEN
GREY
ORANGE
RED
WHITE
YELLOW

Marina
Washington/238 inter.
Lewelling/Hesperian
A-Street
Winton
Jackson/San Mateo Br.
Tennyson
Industrial
Whipple

Breakdown — Flat tire / Gas / Mechanical / Can't Tell
CHP present
Accident — car(s) ____
Can't Tell

4x4 Van Pick-up Stn Wgn Other

☐ Witnessed Incident
☐ FSP Involved
☐ At start of shift incident

	CHP 1 2 3	TT 1 2 3	AMB
ARRIVAL TIME			
TIME LEFT			

Description

TIME MAIN IS CLEARED	
TIME SHOULDER IS CLEARED	
TIME CAR IS TICKETED FOR TOWING	

DIR: NB/SB
LANE: LT 1 2 3 4 5 RT

LANES AFFECTED 1 2 3 4 5

<1/4 1/4 1/2 3/4 1 Before/After

BLACK
BLUE
BROWN
GOLD
GREEN
GREY
ORANGE
RED
WHITE
YELLOW

Marina
Washington/238 inter.
Lewelling/Hesperian
A-Street
Winton
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Tennyson
Industrial
Whipple

Breakdown — Flat tire / Gas / Mechanical / Can't Tell
CHP present
Accident — car(s) ____
Can't Tell .

4x4 Van Pick-up Stn Wgn Other

☐ Witnessed Incident
☐ FSP Involved
☐ At start of shift incident

	CHP 1 2 3	TT 1 2 3	AMB
ARRIVAL TIME			
TIME LEFT			

Description

TIME MAIN IS CLEARED	
TIME SHOULDER IS CLEARED	
TIME CAR IS TICKETED FOR TOWING	

DATE ____________________

INCIDENT LOG FOR TOW TRUCK OPERATORS

TIME CALLED	TIME DISPATCH	TIME ARRIVE SCENE	TIME LEAVE SCENE	LOCATION OF SCENCE PLEASE CHECK X WHERE IT APPLIES						VEHICLE DISCRIPTION		ACCIDENT YES or NO	IF ACCIDENT, THEN PLEASE MENTION	VEHICLE REMOVED TO STORAGE YES or NO
				DIRECT. NB	SB	NEAREST EXIT	DISTANCE TO EXIT	NORTH OF EXIT	SOUTH OF EXIT	VEHICLE TYPE	VEHICLE COLOR		NO. OF VEHICLES	
AM														
PM														

Freeway Service Patrol Daily Field Record

Date: ____________________ **10-8 time:** ____________________

Driver: ____________________ **10-10 time:** ____________________

ID Number: ____________________ **Beat:** ________ **Contractor:** ____________________

Start Time	End Time	Activity	Form #	License plate	Location of incident	Comments (include drop location)	Auth. #

INCIDENT DATA CODING SCHEME

COLUMN		
A	TYPE:	DATA TYPE: F = FIELD DATA, C = CHP DATA, T = TOW TRUCK DATA
B	INCIDENT:	INCIDENT NUMBER
C	DATE.	DATE OF INCIDENT OCCURANCE
D	SHIFT	SHIFT DURING INCIDENT. AM SHIFT = 0, PM SHIFT = 1
E	TIME.	TIME LISTED IN MILITARY TIME, ie. 14:OO = 2:00 p.m. :-THIS IS THE FIRST WITNESSED TIME OF INCIDENT
F	DIRECTION:	DIRECTION LISTED AS 0 = NB, 1 = SB
G	BEGINNING:	INCIDENT PRESENT AT BEGINNING OF SHIFT. NO = 0, YES = 1
H	END:	INCIDENT PRESENT AT END OF SHIFT. NO = 0, YES = 1
I	LINK IDENTITY	LINK IDENTITY ACCORDING TO BETWEEN EXITS 1 = MARINA - WASHINGTON/238 INTERSECTION 2 = WASHINGTON/238 INTERSECTION --- LEWELLING/HISPERIAN 3 = LEWELLING/HISPERIAN -A-STREET 4 = A-STREET - WINTON 5 = WINTON - JACKSON/92/SAN MATE0 BRIDGE 6 = JACKSON/ 92 /SAN MATE0 BRIDGE - TENNYSON 7 = TENNYSON - INDUSTRIAL 8 = INDUSTRIAL - WHIPPLE :--IF INCIDENT IS LISTED AT EXIT, LINK IS UPSTREAM LINK
J	LOCATION:	LOCATION LISTED ACCORDING TO FOLLOWING LIST 1 = MARINA 2 = WASHINGTON/238 INTERSECTION 3 = LEWELLING/HISPERIAN 4 = A-STREET 5 = WINTON 6 = JACKSON/ 92 /SAN MATE0 BRIDGE 7 = TENNYSON 8 = INDUSTRIAL 9 = WHIPPLE
K	RELATIVE:	RELATIVE LOCATION. 0 = AT EXIT, 1 = BEFORE, 2 = AFTER
`L	EXIT DISTANCE:	DISTANCE OF INCIDENT FROM SPECIFIC EXIT 1 = RIGHT AT OVER/UNDER-PASS 2 = <1/4 MILE 3 = 1/4 MILE 4 = 1/2 MILE 5 = 3/4 MILE 6 = 1 MILE 7 = >1 MILE

INCIDENT DATA CODING SCHEME (cont'd)

COLUMN

M - O LANE AFFECTED:

M Primary lane LANE(S) INVOLVED	N 2ND LANES: MORE THAN 1 LANE	O 3RD LANES: MORE THAN 2 LANES
1 = LANE 1	0 = PRIMARY ONLY	0 = 1 ST & 2ND LANE ONLY
2 = LANE 2	1 = LANE 1	1 = LANE 1
3 = LANE 3	2 = LANE 2	2 = LANE 2
4 = LANE 4	3 = LANE 3	3 = LANE 3
5 = LANE 5	4 = LANE 4	4 = LANE 4
	5 = LANE 5	5 = LANE 5
7 = RIGHT SHOULDER	6 = LANE 6	6 = LANE 6
8 = CENTER DIVIDE	7 = RIGHT SHOULDER	7 = RIGHT SHOULDER
	8 = CENTER DIVIDE	8 = CENTER DIVIDE

P INCIDENT: TYPE OF INCIDENT - vehicle = 0 Debrie/Pedestrian = 1
Sweeping/Clearing Debrie = 2

Q - S INCIDENT TYPE:
NATURE OF INCIDENT

Q TYPE I **breakdown**	R TYPE II **accident**	S TYPE III **CHP**
0 = NOT THIS TYPE	0 = NOT THIS TYPE	0 = NOT THIS TYPE
1 = FLAT TIRE	1 = single car incident	3 = CHP IS INCIDENT
2 = GAS	2 = multiple car incident	4 = TICKETING
3= MECHANICAL		
5 = CAN'T TELL/USING CALL BOX		

T B/E
BEGIN/END
0 = incident started & ended during the shift
1= otherwise

U NO. VEHICLES: LISTED ACCORDING TO NUMBER OF VEHICLES INVOLVED
ie.. 1 , 2 , 3 , etc

INCIDENT DATA CODING SCHEME (cont'd)

COLUMN

V - X VEHICLE TYPE: VEHICLE TYPE LISTED ACCORDING TO FOLLOWING LIST

V 1 ST VEHICLE
0 = NO VEHICLE INVOLVED
1 = STANDARD CAR

W 2ND VEHICLE
2 = PICKUP TRUCK
3 = VAN

X 3RD VEHICLE
4 = STATION WAGON
5 = MOTORCYCLE
6 = VEHICLE WITH TRAILER
7 = DUMP TRUCK/COMMERCIAL TRUCK
8 = 18-WHEELER TRACTOR TRAILER
9 = CALTRANS CONSTRUCTION VEHICLE
10 = OTHER
11 = TOW TRUCK
12 = 4 X 4 VEHICLE

Y - AA COLOR OF VEHICLES

Y 1 ST VEHICLE COLOR OF VEHICLE
0 = NOT A VEHICLE

Z 2ND VEHICLE
1 = BLACK
2 = BLUE

AA 3RD VEHICLE
3 = BROWN
4 = GOLD
5 = GREEN
6 = GREY
7 = ORANGE
8 = RED
9 = WHITE
10 = YELLOW
11 = BEIGE
12 = BLACK AND WHITE (CHP)

AB TICKETED FOR TOW VEHICLE TICKETED FOR TOW TO STORAGE BY CHP
0 = NO, NOT WITNESSED
1 =YES

AC CHP ARRIVAL OF CHP AT SCENE
0 = CHP DOES NOT ARRIVE DURING SHIFT AT INCIDENT
1 = CHP PRESENT AT BEGINING OF WITNESS
2 = CHP ARRIVES DURING SHIFT AT SCENE

AD ENTRIES IN LOG NUMBER OF TIMES INCIDENT IS ENTERRED IN TIME LOG
ie.. 1 -- 29 ?

INCIDENT DATA CODING SCHEME (cont'd)

COLUMN

AE - BH	TIME ENTRY AND UPDATES IN LOG		
	AE TIME 1	**AO** TIME 11	**AY** TIME 21
	AF TIME2	**AP** TIME 12	**AZ** TIME22
	AG TIME 3	**AQ** TIME 13	**BA** TIME23
	AH TIME 4	**AR** TIME 14	**BB** TIME 24
	AI TIME5	**AS** TIME 15	**BC** TIME 25
	AJ TIME6	**AT** TIME 16	**BD** TIME 26
	AK TIME 7	**AU** TIME 17	BE TIME27
	AL TIME 8	**AV** TIME 18	
	AM TIME 9	**AW** TIME 19	
	AN TIME 10	**AX** TIME20	

BF NO TOW: NT= 1: Tow Truck left without assisting; 2: Clearance time not known; 0: otherwise

BG TIME MAIN IS CLEAR * IF NOT AVAILABLE

BH FSP ARRIVAL: 0: No FSP 1: FSP present at first witness
2: FSP present during incident 3: FSP is incident
4: FSP present but another Tow Truck did the towing

BI	CHP ARRIVAL TIME	* IF NOT APPLICABLE
BJ	TOW TRUCK ARRIVAL TIME (if FSP and non-FSP Tow Truck arrives, it's non-FSP Tow Truck arrival time)	* IF NOT APPLICABLE
BK	AMBULANCE ARRIVAL TIME	* IF NOT APPLICABLE
BL	FIRE DEPARTMENT ARRIVAL TIME	* IF NOT APPLICABLE
BM	CHP DEPARTURE TIME	* IF NOT APPLICABLE
BN	TOW TRUCK DEPARTURE TIME	* IF NOT APPLICABLE
BO	AMBULANCE DEPARTURE TIME	* IF NOT APPLICABLE
BP	FIRE DEPARTMENT DEPARTURE TIME	. IF NOT APPLICABLE
BQ	COMMENTS	0 = NONE, 1 = COMMENT WRITTEN IN FIELD LOG
BR	OFFICIAL	0 = NO OFFICIAL VEHICLES AT INCIDENT 1, 2, 3....# = NUMBER ARRIVING AT INCIDENT
Bs	NON-OFFICIAL	0 = NO NON-OFFICIAL VEHICLES AT INCIDENT 1, 2, 3....# = NUMBER ARRIVING AT INCIDENT
BT	Tow Truck Response Time	* IF NOT APPLICABLE
BU	Tow Truck Clearance Time	* IF NOT APPLICABLE
BV-CW	Headways	* IF NOT APPLICABLE
CX	Duration	
CY	Weather	

0: Clear
1: Partly Cloudy
2: Cloudy
3: Light Rainy
4: Rainy

APPENDIX C

SUMMARY OF PROBE VEHICLE TEST RUNS

HEADWAY TABLE

DATE ____________

this table is to help maintain minimum headway

SUPERVISOR ____________

time	vehicle	time	vehicle	time	vehicle	time	vehicle	time	vehicle
6:20		7:00		7:40		8:20		9:00	
6:21		7:01		7:41		8:21		9:01	
6:22		7:02		7:42		8:22		9:02	
6:23		7:03		7:43		8:23		9:03	
6:24		7:04		7:44		8:24		9:04	
6:25		7:05		7:45		8:25		9:05	
6:26		7:06		7:46		8:26		9:06	
6:27		7:07		7:47		8:27		9:07	
6:28		7:08		7:48		8:28		9:08	
6:29		7:09		7:49		8:29		9:09	
6:30		7:10		7:50		8:30		9:10	
6:31		7:11		7:51		8:31		9:11	
6:32		7:12		7:52		8:32		9:12	
6:33		7:13		7:53		8:33		9:13	
6:34		7:14		7:54		8:34		9:14	
6:35		7:15		7:55		8:35		9:15	
6:36		7:16		7:56		8:36		9:16	
6:37		7:17		7:57		8:37		9:17	
6:38		7:18		7:58		8:38		9:18	
6:39		7:19		7:59		8:39		9:19	
6:40		7:20		8:00		8:40		9:20	
6:41		7:21		8:01		8:41		9:21	
6:42		7:22		8:02		8:42		9:22	
6:43		7:23		8:03		8:43		9:23	
6:44		7:24		8:04		8:44		9:24	
6:45		7:25		8:05		8:45		9:25	
6:46		7:26		8:06		8:46		9:26	
6:47		7:27		8:07		8:47		9:27	
6:48		7:28		8:08		8:48		9:28	
6:49		7:29		8:09		8:49		9:29	
6:50		7:30		8:10		8:50		9:30	
6:51		7:31		8:11		8:51		9:31	
6:52		7:32		8:12		8:52		9:32	
6:53		7:33		8:13		8:53		9:33	
6:54		7:34		8:14		8:54		9:34	
6:55		7:35		8:15		8:55		9:35	
6:56		7:36		8:16		8:56		9:36	
6:57		7:37		8:17		8:57		9:37	
6:58		7:38		8:18		8:58		9:38	
6:59		7:39		8:19		8:59		9:39	
								9:40	

HEADWAY TABLE

DATE ____________

this table is to help maintain minimum headway

SUPERVISOR ____________

time	vehicle	time	vehicle	time	vehicle	time	vehicle	time	vehicle
3:20		4:00		4:40		5:20		6:00	
3:21		4:01		4:41		5:21		6:01	
3:22		4:02		4:42		5:22		6:02	
3:23		4:03		4:43		5:23		6:03	
3:24		4:04		4:44		5:24		6:04	
3:25		4:05		4:45		5:25		6:05	
3:26		4:06		4:46		5:26		6:06	
3:27		4:07		4:47		5:27		6:07	
3:28		4:08		4:48		5:28		6:08	
3:29		4:09		4:49		5:29		6:09	
3:30		4:10		4:50		5:30		6:10	
3:31		4:11		4:51		5:31		6:11	
3:32		4:12		4:52		5:32		6:12	
3:33		4:13		4:53		5:33		6:13	
3:34		4:14		4:54		5:34		6:14	
3:35		4:15		4:55		5:35		6:15	
3:36		4:16		4:56		5:36		6:16	
3:37		4:17		4:57		5:37		6:17	
3:38		4:18		4:58		5:38		6:18	
3:39		4:19		4:59		5:39		6:19	
3:40		4:20		5:00		5:40		6:20	
3:41		4:21		5:01		5:41		6:21	
3:42		4:22		5:02		5:42		6:22	
3:43		4:23		5:03		5:43		6:23	
3:44		4:24		5:04		5:44		6:24	
3:45		4:25		5:05		5:45		6:25	
3:46		4:26		5:06		5:46		6:26	
3:47		4:27		5:07		5:47		6:27	
3:48		4:28		5:08		5:48		6:28	
3:49		4:29		5:09		5:49		6:29	
3:50		4:30		5:10		5:50		6:30	
3:51		4:31		5:11		5:51		6:31	
3:52		4:32		5:12		5:52		6:32	
3:53		4:33		5:13		5:53		6:33	
3:54		4:34		5:14		5:54		6:34	
3:55		4:35		5:15		5:55		6:35	
3:56		4:36		5:16		5:56		6:36	
3:57		4:37		5:17		5:57		6:37	
3:58		4:38		5:18		5:58		6:38	
3:59		4:39		5:19		5:59		6:39	
								6:40	

Files and Contents from Probe Vehicles

We get a total of four files from each *car* for each run. They are: key.dat, fsp.dat, nav.dat, and gsp.dat. Below is a short sample of each type of file and a description of what it.is:

1) key.dat

SAMPLE:

```
 6:54:15   3- 8-93
 0: 0: 2.618         1  14
 0: 0: 5.493         1  7311
 0: 0:21.549         1  03/07/93
 0: 0:44.645        76   06:55:00
 0: 0:56.244        76  qwe
 0:18:16.297     65278  d
 0:21:27.264     81942  k
 0:26:42.116    106153  d
 0:32:53.528    112000  d
 0:36:32.899    132595  1
 0:39:13.795    147085  1
 0:40:29.114    153335  d
 0:41:30.855    158933  k
 0:42:13.116    162578  k
 0:44: 3.463    168739  qwe
```

This is a file that saves the keys that the drivers type in. They type a sequence of keys each time they start a loop. Each time they pass an incident and each time they *pass* a *gore* point they type in a single key. The file starts off with a date and time stamp on the first line. This is put there by the computer when it is turned on. The next four lines are just start up information that the user types in. The first main column is the time since the start of the file, the second is the odometer reading of the car, and the third is the text that the driver has typed in. There is one line in this file for every line the driver types in.

In this file, a quick explanation of a few of the lines follows:

```
 0: 0: 2.618         1  14         <- Driver ID number
 0: 0: 5.493         1  7311       <- Car ID number
 0: 0:21.549         1  03/07/93 <-  Date
 0: 0:44.645        76   06:55:00 <- Time
 0: 0:56.244        76  qwe        <- Sequence to indicate start of loop
 0:18:16.297     65278  d          <- Key to indicate gore point
 0:21:27.264   . 81942  k'         <- Key to indicate an incident
```

2) fsp.dat

SAMPLE:

```
 6:54:15   3- 8-93
 0:19:19.557     70913  CS4NE
 0:19:19.582     70915  CS4NE
 0:19:19.608     70918  CS4NE
 0:25:37.642    103309  CS2SE
 0:25:37.663    103310  CS2SE
 0:25:37.685    103311  CS2SE
```

This file is saved automatically by the INRAD equipment in the car each time that it drives over an INRAD beacon. The first line is the date Stamp (that shows up in all the files). All of the other lines are times when the car picked up an INRAD beacon. The first column is the time since the start of the file, the second column is the odometer reading of the car, and the third column is a string to indicate which INRAD signal was picked up. There are a total of three different INRAD points.

3) nav.dat

SAMPLE:

```
 6:54:15     3- 8-93
      0, 2565, 2640, 2356
      1, 2565, 2640, 2356
      1, 2563, 2641, 2354
      1, 2515, 2639, 2355
      1, 2575, 2639, 2355
      1, 2575, 2639, 2355
```

The nav.dat file is a binary file when it is stored on disk. We convert this to it's ascii equivalent which is what is shown above. Once again, the first line is the date stamp. The rest of the rows are stored for each second.- The first column is the odometer reading, the second and third column is the digital compass reading, and the fourth column is the angular rate sensor. We get our position plots from the digital compass.

4) gps.dat

SAMPLE:

```
 6:54:15   3- 8-93
$GPGGA,025602,3747.75,N,12216.00,W,0,3,000,041,M,-028,M*6E
$GPGGA,025602,3747.75,N,12216.00,W,0,3,000,041,M,-028,M*6E
$GPGGA,025602,3747.75,N,12216.00,W,0,3,000,041,M,-028,M*6E
$GPGGA,025602,3747.75,N,12216.00,W,0,3,000,041,M,-028,M*6E
$GPGGA,025602,3747.75,N,12216.00,W,0,3,000,041,M,-028,M*6E
```

The gps.dat file is the data from the GPS equipment in the car. It is stored one line per second, just like the nav.dat file. The first line is the date stamp. The following lines are a bunch of stuff that the GPS equipment stores that we don't really use. Only the third and fifth columns are of use to us. They contain the latitude and longitude of the car which we use to plot the trajectory.

APPENDIX D

DATA FROM LOOP DETECTORS

CABINETS WIRING TABLE

AFTER STUDY PERIOD

D2

TRAP	CABINET NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	19	20
1	N1-1	N1-1	N1-1	N1-1	N1-1	S1-1	N1-1	N1-1	S1-1	N1-1	N1-1	N1-1	S1-1	N1-1	N1-1	N1-1	N1-1	N1-1	N1-1
	N1-2	N1-2	N1-2	N1-2	N1-2	S1-2	N1-2	N1-2	S1-2	N1-2	N1-2	N1-2	S1-2	N1-2	N1-2	N1-2	N1-2	N1-2	N1-2
2	N2-1(s)	N2-1	N2-1	N2-1	N2-1	S2-1	N2-1	N2-1	S2-1	N2-1	N2-1	N2-1	S2-1	N2-1	N2-1	N2-1	N2-1	N2-1	N2-1
	N2-2(s)	N2-2	N2-2	N2-2	N2-2	S2-2	N2-2	N2-2	S2-2	N2-2	N2-2	N2-2	S2-2	N2-2	N2-2	N2-2	N2-2	N2-2	N2-2
3	N3-1	N3-1	N3-1	N3-1	N3-1	S3-1	N3-1	N3-1	S3-1	N3-1	N3-1	N3-1	S3-1	N3-1	N3-1	N3-1	N3-1	N3-1	N3-1
	N3-2	N3-2	N3-2	N3-2	N3-2	S3-2	N3-2	N3-2	S3-2	N3-2	N3-2	N3-2	S3-2	N3-2	N3-2	N3-2	N3-2	N3-2	N3-2
4	N4-1	N4-1	N4-1	N4-1	N4-1	S4-1	N4-1	N4-1(r)	S4-1	N4-1	N4-1	N4-1	S4-1	N4-1	N4-1	N4-1	N4-1	N4-1	N4-1
	N4-2	N4-2	N4-2	N4-2	N4-2	S4-2	N4-2	N4-2(r)	S4-2	N4-2	N4-2	N4-2	S4-2	N4-2	N4-2	N4-2	N4-2	N4-2	N4-2
5	N5-1	N5-1	N5-1	P-1	P-1	S5-1	N5-1	F-1	S5-1	N5-1	N5-1	N5-1		N5-1	N5-1		N5-1		N5-1
	N5-2	N5-2	N5-2	P-2		S5-2	N5-2		S5-2	N5-2	N5-2	N5-2		N5-2	N5-2		N5-2		N5-2
6						N1-1		P-1			S1-1		N1-1		F-1	F-1		S1-1	
						N1-2					S1-2		N1-2					S1-2	
7	S1-1	S1-1	S1-1	S1-1	S1-1	N2-1	S1-1				S2-1	S1-1	N2-1	S1-1	S1-1	S1-1	S1-1	S2-1	S1-1
	S1-2	S1-2	S1-2	S1-2	S1-2	N2-2	S1-2				S2-2	S1-2	N2-2	S1-2	S1-2	S1-2	S1-2	S2-2	S1-2
8	S2-1	S2-1	S2-1	S2-1	S2-1	N3-1	S2-1				S3-1	S2-1	N3-1	S2-1	S2-1	S2-1	S2-1	S3-1	S2-1
	S2-2	S2-2	S2-2	S2-2	S2-2	N3-2	S2-2				S3-2	S2-2	N3-2	S2-2	S2-2	S2-2	S2-2	S3-2	S2-2
9	S3-1	S3-1	S3-1	S3-1	S3-1	N4-1	S3-1				S4-1	S3-1	N4-1	S3-1	S3-1	S3-1	S3-1	S4-1	S3-1
	S3-2	S3-2	S3-2	S3-2	S3-2	N4-2	S3-2				S4-2	S3-2	N4-2	S3-2	S3-2	S3-2	S3-2	S4-2	S3-2
10	S4-1	S4-1	S4-1	S4-1	S4-1	N5-1	S4-1				S5-1	S4-1		S4-1	S4-1	S4-1	S4-1		S4-1
	S4-2	S4-2	S4-2	S4-2	S4-2	N5-2	S4-2				S5-2	S4-2		S4-2	S4-2	S4-2	S4-2		S4-2
11	S5-1	S5-1	S5-1			Q-1	S5-1		Q-1	Q-1	Q-1		Q-1		S5-1	P-1	S5-1	Q-1	S5-1
	S5-2	S5-2	S5-2			Q-2	S5-2				Q-2		Q-2		S5-2	P-2	S5-2	Q-2	S5-2
12				F-1	F-1	P-1			P-1	P-1	P-1		P-1		P-1			P-1	
						P-2					P-2		P-2		P-2			P-2	
13				D-1	D-1	D-1		D-1	D-1*	D-1	D-1		D-1		D-1	D-1		D-1	
				D-2		D-2			D-2*	D-2	D-2		D-2		D-2	D-2		D-2	
14				Q-1	Q-1	F-1		Q-1	F-1	F-1	F-1		F-1		Q-1	Q-1		F-1	
				Q-2	Q-2	F-2					F-2		F-2		Q-2	Q-2		F-2	

AFTER

note that the off-ramp detector is not connected in cabinet 16

shaded boxes indicate malfunctioning detectors found in the after study

* D-l connected to become a passage detector and D-2 conntected to become a demand detector

(s): speeds are consistenly low

(r): loops on shoulder

CABINETS WIRING TABLE

BEFORE STUDY PERIOD

TRAP	CABINET NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	19	20
1	N1-1	N1-1	N1-1	N1-1	N1-1	S1-1	N1-1	N1-1	S1-1	N1-1	N1-1	N1-1	S1-1	N1-1	N1-1	N1-1	N1-1	N1-1	N1-1
	N1-2	N1-2	N1-2	N1-2	N1-2	S1-2	N1-2	N1-2	S1-2	N1-2	N1-2	N1-2	S1-2	N1-2	N1-2	N1-2	N1-2	N1-2	N1-2
2	N2-1(s)	N2-1	N2-1	N2-1	N2-1	S2-1	N2-1	N2-1	S2-1	N2-1	N2-1	N2-1	S2-1	N2-1	N2-1	N2-1	N2-1	N2-1	N2-1
	N2-2(s)	N2-2	N2-2	N2-2	N2-2	S2-2	N2-2	N2-2	S2-2	N2-2	N2-2	N2-2	S2-2	N2-2	N2-2	N2-2	N2-2	N2-2	N2-2
3	N3-1	N3-1	N3-1	N3-1	N3-1	S3-1	N3-1	N3-1	S3-1	N3-1	N3-1	N3-1	S3-1	N3-1	N3-1	N3-1	N3-1	N3-1	N3-1
	N3-2	N3-2	N3-2	N3-2	N3-2	S3-2	N3-2	N3-2	S3-2	N3-2	N3-2	N3-2	S3-2	N3-2	N3-2	N3-2	N3-2	N3-2	N3-2
4	N4-1	N4-1	N4-1	N4-1	N4-1	S4-1	N4-1	N4-1(r)	S4-1	N4-1	N4-1	N4-1	S4-1	N4-1	N4-1	N4-1	N4-1	N4-1	N4-1
	N4-2	N4-2	N4-2	N4-2	N4-2	S4-2	N4-2	N4-2(r)	S4-2	N4-2	N4-2	N4-2	S4-2	N4-2	N4-2	N4-2	N4-2	N4-2	N4-2
5	N5-1	N5-1	N5-1	P-1	P-1	S5-1	N5-1	F-1	S5-1(k)	N5-1	N5-1	N5-1		N5-1	N5-1		N5-1		N5-1
	N5-2	N5-2	N5-2	P-2		S5-2	N5-2		S5-2(k)	N5-2	N5-2	N5-2		N5-2	N5-2		N5-2		N5-2
6						N1-1		P-1			S1-1		N1-1		F-1	F-1		S1-1	
						N1-2					S1-2		N1-2					S1-2	
7	S1-1	S1-1	S1-1	S1-1	S1-1	N2-1	S1-1				S2-1	S1-1	N2-1	S1-1	S1-1	S1-1	S1-1	S2-1	S1-1
	S1-2	S1-2	S1-2	S1-2	S1-2	N2-2	S1-2				S2-2	S1-2	N2-2	S1-2	S1-2	S1-2	S1-2	S2-2	S1-2
8	S2-1	S2-1	S2-1	S2-1	S2-1	N3-1	S2-1				S3-1	S2-1	N3-1	S2-1	S2-1	S2-1	S2-1	S3-1	S2-1
	S2-2	S2-2	S2-2	S2-2	S2-2	N3-2	S2-2				S3-2	S2-2	N3-2	S2-2	S2-2	S2-2	S2-2	S3-2	S2-2
9	S3-1	S3-1	S3-1	S3-1	S3-1	N4-1	S3-1				S4-1	S3-1	N4-1	S3-1	S3-1	S3-1	S3-1	S4-1	S3-1
	S3-2	S3-2	S3-2	S3-2	S3-2	N4-2	S3-2				S4-2	S3-2	N4-2	S3-2	S3-2	S3-2	S3-2	S4-2	S3-2
10	S4-1	S4-1	S4-1	S4- 1	S4-1	N5-1	S4-1				S5-1(k)	S4-1		S4-1	S4-1	S4-1	S4-1		S4-1
	S4-2	S4-2	S4-2	S4-2	S4-2	N5-2	S4-2				S5-2(k)	S4-2		S4-2	S4-2	S4-2	S4-2		S4-2
11	S5-1	S5-1	S5-1			Q-l	S5-1		Q-l	Q-l	Q-l		Q-1		S5-1	P-1	S5-1	Q-1	S5-1
	S5-2	S5-2	S5-2			Q-2	S5-2				Q-2		Q-2		S5-2	P-2	S5-2	Q-2	S5-2
12				F-1	F-1	P-1			P-1	P-1	P-1		P-1		P-1			P-1	
						P-2					P-2		P-2		P-2			P-2	
13				D-1	D-1	D-1		D-1	D-1	D- 1	D-1		D-1		D-1	D-1		D-1	
				D-2		D-2			D-2	D-2	D-2		D-2		D-2	D-2		D-2	
14				Q-1	Q-1	F-1		Q-1	F-1	F-1	F-1		F-1		Q-1	Q-1		F-1	
				Q-2	Q-2	F-2					F-2		F-2		Q-2	Q-1		F-2	

BEFORE STUDY

KEY:

(r): loops on the shoulder

(k): not working until 3/2/93 PM

(s): speed readings are consistently low

note that the off-ramp detector is not connected in cabinet 16

LOOP DATA AVAILABILITY

BEFORE STUDY

Cabinet No.	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	19	2n
2/16/93	14:00-19:50	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	NO DATA	x	x
2/17/93	x	x	x	x	x	x	x	x	x	x	x	x	x	x.	NO DATA	x	NO DATA	x	x
2/18/93	6:50-9:50 14:00-19:50	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	5:10-9:50	x	x
2/19/93	NO DATA	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2/22/93	5: IO-950 14:00-15:10	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2/23/93	x	x	NO DATA	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2/24/93	NO DATA	x	x	x	x	x	x	x	16:40-16:50	x	x	NO DATA	x	x	NO DATA	x	x	x	x
2/25/93	NO DATA	x	x	x	x	x	x	x	x	x	x	NO DATA	x	x	NO DATA	x	NO DATA	18:50-19:50	x
2/26/93	NO DATA	x	x	x	x	x	x	x	14:00-19:50	x	x	NO DATA	x	x	NO DATA	x	NO DATA	x	x
3/1/93	NO DATA	x	x	x	x	x	x	x	x	x	x	NO DATA	x	x	5: 10-9:50	x	x	x	x
3/2/93	5:10-9:50	x	x	x	x	x	5:10-9:50 14:00-14:20	x	x	x	x	x	x	x	6:30-9:50	x	5:10-9:50	x	x
3/3/93	x	x	x	x	x	x	x	x	x	x	x	NO DATA	x	x	17:10-17:40	6:50-9:50 14:00-19:50	x	x	x
3/4/93	x	x	x	x	x	x	x	x	x	x	x	5: IO-950	x	x	x	5:10-9:50	x	17:00-19:50	x
3/5/93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
3/8/93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	6:30-9:50 14:00-19:50	x
3/9/93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	6:30-9:50 14:00-19:50	x	x	x	x
3/10/93	6:30-9:50	x	x	x	x	x	x	x	x	x	x	8: IO-950	x	x	5:10-9:50	x	x	x	x
3/11/93	x	x	x	x	x	x	x	x	x	x	x	8:10-9:50 14:00-19:50	x	x	x	x	x	x	x
3/12/93	x	x	x	x	x	x	x	x	x	x	x	NO DATA	x	x	6:30-9:50 14:50-19:50	x	x	x	x
3/15/93	x	x	x	x	x	x	x	x	8:20-9:50 14:00-19:50	x	x	5:10-7:50	x	x	x	x	x	x	x
3/16/93	x	x	x	x	x	NO DATA	x	x	NO DATA	x	x	x	x	x	6:20-9:50 14:00-19:50	x	x	x	x
3/17/93	x	x	x	x	x	x	x	x	x	x	x	NO DATA	NO DATA	x	x	x	x	x	x
3/18/93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
3/19/93	9: IO-930 14:00-19:50	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

LOOP DATA AVAILABILITY

AFTER STUDY

Cabinet No.	1	2	3	4	5	6	7	8	9	10	11	12	13	1.5	16	17	18	19	20
9/27/93	x	x	x	x	x	x	x	x	x	x	x	9:03-10:00	x	x	x	x	5:01-5:07	x	x
9/28/93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
9/29/93	x	x	x	x	x	x	x	x	x	x	x	5:01-10:00	x	x	x	x	x	x	x
9/30/93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
10/1/93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
10/4/93	x	x	x	x	x	x	x	x	x	x	x	5:01-10:00 14:58-19:59	x	x	x	x	x	x	x
10/5/93	x	x	x	x	x	x	x	x	x	x	x	9:04-10:00	5:20-10:00	x	5:01-10:00 14:00-19:59	x	x	x	x
10/6/93	x	x	x	x	x	5:01-5:07	x	x	x	x	x	no data	x	x	7:03-10:00	x	x	x	x
10/7/93	x	x	x	x	x	x	x	x	7:09-10:00	7:09-10:00	x	5:01-10:00	x	x	5:01-10:00	x	x	x	x
10/8/93	x	x	x	x	x	x	x	x	x	5:01-10:00	x	x	no data	x	x	x	x	x	x
10/11/93	x	x	x	x	x	x	x	x	x	5:01-10:00	x	x	x	x	5:01-10:00	x	x	x	x
10/12/93	x	x	x	x	x	x	x	x	x	5:01-10:00	x	9:03-10:00	x	x	7:04-10:00	x	x	x	x
10/13/93	x	x	x	x	x	x	x	x	x	5:01-10:00	x	5:01-10:00	x	x	5:01-10:00	x	x	x	x
10/14/93	x	x	19:09-19:59	x	x	8:06-10:00	x	x	x	5:01-10:00	x	x	5:01-5:07	x	x	7:11-10:00	x	x	x
10/15/93	x	5:01-5:06	no data	7:20-10:00	x	x	x	x	x	5:01-10:00	x	x	x	x	7:07-10:00	no dam	x	x	x
10/18/93	x	x	x	x	x	x	x	x	x	x	x	no data	x	x	x	x	x	x	x
10/19/93	x	x	x	x	x	x	no data	x	x	no data	no data	x	x	no data	x	X	x	x	x
10/20/93	x	x	x	x	x	x	x	x	x	6:41-10:00	no data	x	x	no data	7:07-10:00	x	x	x	x
10/21/93	x	x	x	x	x	x	x	x	18:21-19:59	no data	no data	x	x	x	5:01-10:00	x	x	x	5:31-10:00
10/22/93	x	x	x	x	x	x	x	x	15:01-19:59	no data	no data	5:01-5:07	x	x	x	x	x	x	14:27-19:59
10/25/93	x	x	x	x	x	x	14:04-19:59	x	9:51-10:00	no data	15:45-19:59	no data	x	x	x	x	x	x	x
10/26/93	x	x	no data	x	x	x	x	x	x	x	x	5:01-10:00	x	x	x	x	x	x	x
10/27/93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	7:19-10:00	x	x	x
10/28/93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	no data	x	x	5:01-5:07
10/29/93	5:01-9:34	x	x	x	x	x	x	x	x	x	x	9:03-10:00	x	x	x	5:01-10:00	x	x	x

SAMPLE DATA FILE PROM LOOP DETECTOR

summary Text Report for Loop Data:
File name: /home/clair0/PATH/FSP/Loopdata/1p031093/cab5.stxt
P P S period: 360.0 seconds

TINE: 5:oo:oo to lo:oo:oo

5:06:00 INDUSTRIAL_NB

	1	2	3	4	5	6	7
PPS	0.00	35.10	73.20	30.08	0.00		57.16
occ	0.00	1.86	5.49	2.40	0.00		3.50
ON	0.00	190.95	270.09	262.7'3	0.00		220.47
PPS	0.00	33.09	70.19	29.08			56.16
o c c	0.00	1.84	5.54	2.28			3.50
ON	0.00	200.51	284.29	267.24			224.40
SPD	0.00	68.70	61.85	61.00			64.62

	8	9	10	11	12	13	14
PPS	54.15	. 9.03	0.00		15.04	12.03	7.02
occ	3.51	0.56	0.00		1.21	3.11	0.24
ON	233.02	124.07	0.00		288.89	930.56	121.43
PPS	0.00	9.03	12.03				9.03
occ	Cl.00	0.90	0.69				0.30
ON	0.00	231.48	206.94				120.37
SPD	0.00	62.34	0.00				

5:12:00 INDUSTRIAL_NB

	1	2	3	4	5	6	7
PPS	2.00	50.00	73.00	44.00	0.00		71.00
occ	0.09	2.82	5.84	4.66	0.00		4.30
ON	166.67	203.33	288.13	397.73	0.00		221.83
PPS	2.00	49.00	73.00	48.00			71.00
occ	0.10	2.79	5.88	4.81			4.39
ON	183.33	204.76	290.18	370.49			222.54
SPD	65.45	66.99	60.86	57.14			64.83

	8	9	10	11	12	13	14
PPS	65.00	10.00	0.00		6.00	17.00	6.00
occ	5.57	0.70	0.00		0.41	3.73	0.20
ON	305.38	253.33	0.00		283.33	'790.20	119.44
PPS	0.00	10.00	19.00				11.00
occ	0.00	0.70	0.99				0.36
ON	0.00	253.33	187.72				118.18
SPD	0.00	57.62	0.00				

5:18:00 INDUSTRIAL-NB

	1	2	3	4	5	6	7
PPS	1.00	57.00	83.00	41.00	0.00		95.00
occ	0.01	3.33	6.21	3.64	0.00		5.96
ON	50.00	210.23	269.48	319.51	0.00		225.96
PPS	1.00	58.00	82.00	47.00			95.00
occ	0:04	3.36	6.38	3.69			6.02
ON	150.00	208.62	280.28	282.27			228.07
PD	54.55	66.24	60.39	59.37			63.35

	8	9	10	11	12	13	14
PS	95.00	11.00	0.00		17.00	24.00	8.00
ICC	7.89	0.65	0.00		1.50	5.89	0.26
IN	301.05	212.12	0.00		316.67	084.03	118.75
'PS	0.00	11.00	30.00				15.00
)CC	0.00	0.63	1.62				0.50
)N	0.00	207.58	195.00				120.00
SPD	0.00	59.21	0.00				

5:24:00 INDUSTRIAL_NB

	1	2	3	4	5	6	7
PPS	1.00	64.00	86.00	46.00	0.00		149.00
occ	0.04	3.60	6.00	3.73	0.00		9.25
ON	150.00	202.34	250.97	291.61	0.00		223.49
PPS	1.00	68.00	83.00	48.00			146.00
occ	0.05	3.67	6.04	3.79			9.19
ON	166.67	194.12	262.05	284.38			226.60
SPD	68.18	66.20	60.99	58.26			63.91

	8	9	10	11	12	13	14
PPS	102.00	21.00	0.00		22.00	23.00	8.00
occ	9.71	1.45	0.00		2.25	6.62	0.26
ON	342.65	240.41	0.00		368.18	1036.23	118.75
PPS	0.00	19.00	51.00				19.00
occ	0.00	1.46	2.11				0.62
ON	0.00	219.02	191.18				117.54
SPD	0.00	59.38	0.00				

5:30:00 INDUSTRIAL-NB

	1	2	3	4	5	6	7
PPS	2.00	90.00	92.00	56.00	0.00		141.00
occ	0.08	5.03	7.52	5.39	0.00		. 8.96
ON	141.67	201.11	294.30	346.43	0.00		227.54
PPS	2.00	91.00	93.00	61.00			140.00
occ	0.09	5.08	7.50	5.45			8.79
ON	166.67	200.92	290.14	321.86			226.07
SPD	62.94	65.97	60.43	57.56			64.50

	8	9	10	11	12	13	14
PPS	110.00	13.00	0.00		31.00	26.00	15.00
occ	10.19	1.62	0.00		3.14	a.37	0.50
ON	333.40	448.72	0.00		364.52	1158.97	120.00
PPS	0.00	14.00	50.00				21.00
occ	0.00	1.56	2.69				0.69
ON	0.00	400.00	193.67				119.05
SPD	0.00	55.40	0.00				

5:36:00 INDUSTRIAL_NB

	1	2	3	4	5	6	7

SAMPLE ERROR REPORT FOR LOOP DETECTORS

Error Report for loop data:
Summary of error conditions:

Timeperiod: 360 seconds
PPS period: 360.0 seconds
Max percent change in detectors: PPS = 101 occ = 10%

PPS: High threshold = 10 num = 4
Low threshold = 1 num = 4
Num zeros before error = 5
cross lane max percent = 10

occ: High threshold = 60 num = 4
Low threshold = 5 num . 8
Num zeros before error = 5
cross lane max percent = 15

On Time: High threshold = 300 num = 4 Critical = 2000
Cross lane max percent = 15

Speed: High threshold = 65 num = 5
Low threshold = 20 num = 5
Cross lane max percent = 20

Error Report for loop file: /home/clair0/PATH/FSP/Loopdata/lp031093/cab5

From	Till	Duration	Trap	Problem
5:06:00	5:12:00	0:06:00	1 - Down	PPS passed range threshold.
5:06:00	5:12:00	0:06:00	1 - Down	OCC passed range threshold.
5:06:00	5:12:00	0:06:00	1	Cross lanes SPEED: N1, N2
5:06:00	5:12:00	0:06:00	1 - Down	Cross lanes ON: N1, N2
5:12:00	5:18:00	0:06:00	3 - Down	Cross lanes ON: N3, N4
5:12:00	5:18:00	0:06:00	9 - Down	Cross lanes ON: S3, S4
5:18:00	5:24:00	0:06:00	1 - Down	OCC passed range threshold.
5:18:00	5:24:00	0:06:00	4 - Down	PPS passed range threshold.
5:18:00	5:24:00	0:06:00	1 - Down	Cross lanes ON: N1, N2
5:12:00	5:24:00	0:12:00	3 - up	Cross lanes ON: N3, N4
5:12:00	5:24:00	0:12:00	7 - up	cross lanes occ: S1, S2
5:06:00	5:30:00	0:24:00	2 - up	Cross lanes PPS: NZ, N3
5:06:00	5:30:00	0:24:00	2 - Down	Cross lanes PPS: N2, N3
5:12:00	5:36:00	0:24:00	8 - up	On time passed threshold.
5:30:00	5:36:00	0:06:00	3 - up	Cross lanes ON: N3, N4
5:30:00	5:42:00	0:12:00	1 - Down	OCC passed range threshold.
5:06:00	5:42:00	0:36:00	2	SPEED passed high threshold.
5:36:00	5:42:00	0:06:00	4 - Down	PPS passed range threshold.
5:36:00	5:42:00	0:06:00	1	Cross lanes SPEED: N1, N2
5:06:00	5:42:00	0:36:00	2 - up	Cross lanes OCC: N2, N3
5:06:00	5:42:00	0:36:00	2 - Down	Cross lanes OCC: N2, N3
5:12:00	5:42:00	0:30:00	7 - up	Cross lanes ON: S1, S2
5:24:00	5:42:00	0:18:00	9 - Down	cross lanes ON: S3, S4
5:36:00	5:54:00	0:18:00	1 - Down	PPS passed range threshold.
5:30:00	5:54:00	0:24:00	1 - Down	Cross lanes ON: N1, N2
5:36:00	5:54:00	0:18:00	7 - up	cross lanes occ: S1, S2
5:12:00	5:54:00	0:42:00	8 - up	Cross lanes ON: S2, S3
5:48:00	6:00:00	0:12:00	1 - Down	OCC passed range threshold.
5:06:00	6:00:00	0:54:00	1 - up	Cross lanes ON: N1, N2
5:48:00	6:00:00	0:12:00	2 - up	Cross lanes PPS: N2, N3
5:42:00	6:00:00	0:18:00	2 - Down	Cross lanes PPS: N2, N3
6:00:00	6:06:00	0:06:00	2 - Up	Cross lanes OCC: N2, N3
6:00:00	6:06:00	0:06:00	8 - up	Cross lanes ON: S2, S3
6:06:00	6:12:00	0:06:00	1 - Down	PPS passed range threshold.
6:06:00	6:12:00	0:06:00	1 - Down	OCC passed range tbroshold.
:06:00	6:12:00	1:06:00	10 - Down	OCC passed low threshold.
:06:00	6:12:00	0:06:00	1 - Down	Cross lanes ON: N1, N2
:06:00	6:12:00	0:06:00	7 - up	cross lanes occ: S1, S2
:06:00	6:18:00	0:12:00	1 - up	Cross lanes ON: N1, N2
:06:00	6:24:00	0:18:00	2 - up	Cross lanes PPS: N2, N3
:06:00	6:24:00	0:18:00	2 - Down	Cross lanes PPS: N2, N3
:24:00	6:30:00	0:06:00	1 - Down	OCC passed range threshold.
:24:00	6:30:00	0:06:00	1 - up	Cross lanes occ: S1, S2
:48:00	6:36:00	0:48:00	12 - up	On time passed threshold.
:30:00	6:36:00	0:06:00	8 - up	Cross lanes ON: s2, S3
:36:00	6:42:00	0:06:00	1 - Down	OCC passed range threshold.
:36:00	6:42:00	0:06:00	3	Cross lanes SPEED: N3, N4
:48:00	6:48:00	l:oo:oo	9 - Down	Cross lanes ON: S3, S4
:06:00	6:54:00	1:48:00	2 - up	Cross lanes ON: N2, N3
:06:00	6:54:00	1:48:00	3 - up	Cross lanes DCC: N3, N4
:06:00	6:54:00	1:48:00	3 - Down	Cross lanes OCC: N3, N4
:12:00	7:00:00	0:48:00	14 - up	PPS passed high threshold.
:54:00	7:06:00	0:12:00	1 - Down	PPS passed range threshold.
:54:00	7:06:00	0:12:00	3 - up	Cross lanes ON: N3, N4
:00:00	7:06:00	0:06:00	9 - Down	Cross lanes ON: S3, S4
:54:00	7:12:00	0:18:00	1 - Down	OCC passed range threshold.
:48:00	7:12:00	0:24:00	8 - up	Cross lanes ON: S2, S3
:42:00	7:18:00	0:36:00	12 - up	On time passed threshold.
:30:00	7:18:00	0:48:00	1 - Down	Cross lanes ON: N1, N2
:06:00	7:24:00	2:18:00	3 - Down	Cross lanes PPS: N3, N4
:06:00	7:24:00	0:18:00	3 - up	Cross lanes OCC: N3, N4
:06:00	7:24:00	0:18:00	3 - Down	Crosslanes OCC: N3, N4
5:24:00	7:24:00	2:00:oo	1 - up	Cross.lanes PPS: S1, S2
7:12:00	7:24:00	0:12:00	9 - Down	Cross lanes ON: S3, S4
6:30:00	7:30:00	l:oo:oo	2 - up	Cross lanes PPS: N2, N3
5:06:00	7:30:00	2:24:00	3 - Up	Cross lanes PPS: N3, N4
7:24:00	7:30:00	0:06:00	8 - up	Cross lanes ON: S2, S3
7:30:00	7:36:00	0:06:00	3 - up	Cross lanes OCC: N3, N4
7:30:00	7:36:00	0:06:00	3 - Down	Cross lanes OCC: N3, N4
7:30:00	7:36:00	0:06:00	9 - Down	Cross lanes ON: S3, S4
7:30:00	7:42:00	0:12:00	1	Cross lanes SPEED: N1, N2
6:30:00	7:42:00	1:12:00	2 - Down	Cross lanes PPS: N2, N3
7:30:00	7:42:00	0:12:00	3 - Down	Cross lanes PPS: N3, N4
7:30:00	7:42:00	0:12:00	3 - up	Cross lanes ON: N3, N4
7:36:00	7:42:00	0:06:00	1 - up	Cross lanes PPS: S1, S2
7:36:00	7:42:00	0:06:00	8 - up	Cross lanes ON: S2, S3
7:06:00	7:48:00	0:42:00	8 - up	On time passed threshold,
7:36:00	7:48:00	0:12:00	2	Cross lanes SPEED: N2, N3
7:30:00	7:48:00	0:18:00	2 - up	Cross lanes OCC: N2, N3
7:30:00	7:48:00	0:18:00	2 - Down	Cross lanes OCC: N2, N3
7:42:00	7:48:00	0:06:00	7 - up	Cross lanes OCC: S1, S2
5:54:00	7:48:00	1:54:00	7 - up	Cross lanes ON: S1, S2
7:30:00	7:54:00	0:24:00	2 - up	On time passed threshold.
7:30:00	7:54:00	0:24:00	2 - Down	On time passed threshold.
7:48:00	7:54:00	0:06:00	2 - up	Cross lanes PPS: N2, N3
7:48:00	7:54:00	0:06:00	2 - Down	Cross lanes PPS: N2, N3
7:48:00	7:54:00	0:06:00	3	Cross lanes SPEED: N3, N4
7:48:00	7:54:00	0:06:00	3 - Up	Crosslanes ON: N3, N4
7:30:00	7:54:00	0:24:00	3 - Down	Cross lanes ON: N3, N4
7:54:00	8:00:00	0:06:00	2 - Down	Cross lanes OCC: N2, N3
7:54:00	8:00:00	0:06:00	3 - up	Cross lanes PPS: N3, N4
7:48:00	8:00:00	0:12:00	3 - Down	Cross lanes PPS: N3, N4
7:24:00	8:06:00	0:42:00	12 - Up	On time passed threshold.
6:24:00	8:06:00	1:42:00	1 - up	Cross lanes ON: N1, N2
7:24:00	8:06:00	0:42:00	1 - Down	Cross lanes ON: N1, N2
8:00:00	8:06:00	0:06:00	7 - Up	cross lanes occ: S1, S2
7:24:00	8:12:00	0:48:00	3 - up	On time passed threshold.
8:06:00	8:12:00	0:06:00	2 - Do""	Cross lanes OCC: N2, N3
8:06:00	8:12:00	0:06:00	3 - up	Cross lanes PPS: N3, N4

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8:06:00	8:12:00	0:06:00	3 - Down	Cross lanes PPS: N3, N4
7:24:00	8:18:00	0:54:00	3 - Down	On time passed threshold.
7:42:00	8:18:00	0:36:00	9 - Down	Cross lanes ON: S3, S4
7:54:00	8:24:00	0:30:00	7 - up	Cross lanes ON: S1, S2
8:24:00	8:30:00	0:06:00	1 - Down	PPS passed range threshold.
8:18:00	8:30:00	0:12:00	1 - Down	OCC passed range threshold.
7:oo:oo	8:30:00	1:30:00	2 - up	Cross lanes ON: N2, N3
5:06:00	8:30:00	3:24:00	2 - Down	Cross lanes ON: N2, N3
8:18:00	8:30:00	0:12:00	3 - up	Cross lanes PPS: N3, N4
8:24:00	8:30:00	0:06:00	3 - Down	Cross lanes PPS: N3, N4
8:24:00	8:30:00	0:06:00	7 - up	cross lanes occ: S1, S2
8:30:00	8:42:00	0:12:00	1	Cross lanes SPEED: N1, N2
8:36:00	8:42:00	0:06:00	2 - up	Cross lanes OCC: N2, N3
8:36:00	8:42:00	0:06:00	3 - up	Cross lanes OCC: N3, N4
8:36:00	8:42:00	0:06:00	3 - up	Cross lanes ON: N3, N4
8:42:00	8:48:00	0:06:00	3 - Down	On time passed CRITICAL.
8:36:00	8:48:00	0:12:00	3 - Down	PPS passed range threshold.
8:36:00	8:48:00	0:12:00	3 - Down	OCC passed range threshold.
8:30:00	8:48:00	0:18:00	2 - Down	Cross lanes OCC: N2, N3
8:36:00	8:48:00	0:12:00	3 - Down	Cross lanes PPS: N3, N4
8:36:00	8:48:00	0:12:00	3 - Down	Cross lanes OCC: N3, N4
8:36:00	8:48:00	0:12:00	3 - Down	Cross lanes ON: N3, N4
8:30:00	8:48:00	0:18:00	7 - up	Cross lanes ON: S1, S2
8:24:00	8:54:00	0:30:00	3 - Down	On time passed threshold.
7:24:00	8:54:00	1:30:00	4 - Down	On time passed threshold,
8:48:00	8:54:00	0:06:00	7 - up	Cross lanes OCC: S1, S2
6:18:00	9:oo:oo	2:42:00	1 - up	PPS passed high threshold.
6:18:00	9:oo:oo	2:42:00	1 - Down	PPS passed high threshold.
8:24:00	9:oo:oo	0:36:00	9 - Down	Cross lanes ON: S3, S4
7:30:00	9:06:00	1:36:00	14 - up	PPS passed high threshold.
8:18:00	9:06:00	0:48:00	1 - up	Cross lanes ON: N1, N2
8:00:00	9:06:00	1:06:00	2 - up	Cross lanes PPS: Ni, N3
8:00:00	9:06:00	1:06:00	2 - Down	Cross lanes PPS: N2, N3
8:54:00	9:06:00	0:12:00	8 - up	Cross lanes ON: S2, S3
8:54:00	9:12:00	0:18:00	1 - Down	PPS passed range threshold.
8:42:00	9:12:00	0:30:00	1 - Down	OCC passed range threshold.
7:18:00	9:12:00	1:54:00	4 - up	On time passed threshold.
8:18:00	9:12:00	0:54:00	1 - Down	Cross lanes ON: N1, N2
9:12:00	9:18:00	0:06:00	1 - Up	Cross lanes ON: NI, N2
9:oo:oo	9:18:00	0:18:00	2 - up	Cross lanes OCC: N2, N3
9:oo:oo	9:18:00	0:18:00	2 - Down	Cross lanes OCC: N2, N3
9:18:00	9:24:00	0:06:00	1 - Down	PPS passed range threshold.
9:18:00	9:24:00	0:06:00	1 - Down	OCC passed range threshold.
9:18:00	9:24:00	0:06:00	9 - Down	PPS passed range threshold.
9:18:00	9:24:00	0:06:00	2 - Up	Cross lanes PPS: N ? , N3
9:12:00	9:24:00	0:12:00	2 - Down	Cross lanes PPS: N2, N3
9:12:00	9:24:00	0:12:00	8 - up	Cross lanes ON: S2, S3
9:oo:oo	9:30:00	0:30:00	3 - up	Cross lanes OCC: N3, N4
9:oo:oo	9: 30:oo	0:30:00	3 - Down	Cross lanes WC: N3, N4
9:24:00	9:36:00	0:12:00	1 - up	Cross lanes ON: N1, N2
9:24:00	9:36:00	0:12:00	1 - Down	Cross lanes ON: NI, N2
9:24:00	9:36:00	0:12:00	2 - up	Cross lanes OCC: N2, N3
9:24:00	9:36:00	0:12:00	2 - Down	Cross lanes OCC: N2, N3
9:30:00	9:36:00	0:06:00	3	Cross lanes SPEED: N3, N4
9:24:00	9:36:00	0:12:00	3 - up	Cross lanes ON: N3, N4
9:30:00	9:36:00	0:06:00	7 - up	Cross lanes OCC: S1, S2
9:36:00	9:42:00	0:06:00	2 - up	Cross lanes PPS: N2, N3
9:24:00	9:48:00	0:24:00	4 - up	On time passed threshold.
9:36:00	9:48:00	0:12:00	2 - Down	Cross lanes PPS: N2, N3
9:42:00	9:48:00	0:06:00	7 - Up	cross lanes occ: S1, S2
7:48:00	9:54:00	2:06:00	7 - Up	cross lanes PPS: S1, S2
9:06:00	9:54:00	0:48:00	3 - Down	Cross lanes ON: S3, S4
5:06:00	9:59:59	4:53:59	1 - up	OCC passed low threshold.
9:36:00	9:59:59	0:23:59	1 - Down	PPS passed high threshold.

5:06:00	9:59:59	4:53:59	1 - Down	OCC passed low threshold.
9:30:00	9:59:59	0:29:59	1 - Down	PPS passed range threshold.
9:30:00	9:59:59	0:29:59	1 - Down	occ passed range threshold.
5:06:00	9:59:59	4:53:59	2 - up	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	2 - Down	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	3 - up	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	3 - Down	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	4 - up	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	4 - Down	PPS passed hioh threshold.
5:06:00	9:59:59	4:53:59	5 - up	PPS was zero too often.
5:06:00	9:59:59	4:53:59	5 - up	OCC was zero too often.
5:06:00	9:59:59	4:53:59	5 - up	PPS passed low threshold.
5:06:00	9:59:59	4:53:59	5 - up	OCC passed low threshold.
5:06:00	9:59:59	4:53:59	7 - up	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	7 - Down	PPS passed high threshold.
9:30:00	9:59:59	0:29:59	8 - up	On time passed threshold.
5:06:00	9:59:59	4:53:59	8 - up	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	8 - Down	PPS was zero too often.
5:06:00	9:59:59	4:53:59	8 - Down	OCC was zero too often.
5:06:00	9:59:59	4:53:59	8 - Down	PPS passed low threshold.
5:06:00	9:59:59	4:53:59	8 - Down	OCC passed low threshold.
5:06:00	9:59:59	4:53:59	8	SPEED passed low threshold.
5:06:00	9:59:59	4:53:59	8 - Down	PPS passed range threshold.
5:06:00	9:59:59	4:53:59	8 - Down	OCC passed range threshold.
5:12:00	9:59:59	4:47:59	9 - up	PPS passed high threshold.
5106100	9:59:59	4:53:59	9 - Up	OCC passed low threshold.
5:12:00	9:59:59	4:47:59	9 - Down	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	9 - Down	OCC passed low threshold.
5:06:00	9:59:59	4:53:59	10 - up	PPS was zero too often.
5:06:00	9:59:59	4:53:59	10 - up	occ was zero too often.
5:06:00	9:59:59	4:53:59	10 - up	PPS passed low threshold.
5:06:00	9:59:59	4:53:59	10 - up	occ passed low threshold.
5:06:00	9:59:59	4:53:59	10 - Down	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	10	SPEED passed low threshold.
5:06:00	9:59:59	4:53:59	10 - Down	PPS passed range threshold.
5:06:00	9:59:59	4:53:59	10 - Down	OCC passed range threshold.
9:18:00	9:59:59	0:41:59	12 - up	On time passed threrhold.
5:18:00	9:59:59	4:41:59	12 - up	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	13 - up	On time passed threshold.
5:06:00	9:59:59	4:53:59	13 - up	PPS passed high threshold.
9:12:00	9:59:59	0:47:59	14 - up	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	14 - up	OCC passed low threshold.
5:12:00	9:59:59	4:47:59	14 - Down	PPS passed high threshold.
5:06:00	9:59:59	4:53:59	14 - Down	OCC passed low threshold.
5:06:00	9:59:59	4:53:59	1 - up	Cross lanes PPS: N1, N2
5:06:00	9:59:59	4:53:59	1 - Down	Cross lanes PPS: N1, N2
5:06:00	9:59:59	4:53:59	I - up	Cross lanes occ: N1, N2
5:06:00	9:59:59	4:53:59	1 - Down	Cross lanes OCC: N1, N2
9:48:00	9:59:59	0:11:59	1 - up	Cross lanes ON: N1, N2
9:42:00	9:59:59	0:17:59	1 - Down	Cross lanes ON: N1, N2
9:42:00	9:59:59	0:17:59	2 - up	Cross lanes OCC: N2, N3
9:42:00	9:59:59	0:17:59	2 - Down	Cross lanes OCC: N2, N3
8:36:00	9:59:59	1:23:59	2 - up	Cross lanes ON: N2, N3
8:36:00	9:59:59	1:23:59	2 - Down	Cross lanes ON: N2, N3
8:54:00	9:59:59	1:05:59	3 - up	Cross lanes PPS: N3, N4
8:54:00	9:59:59	1:05:59	3 - Down	Cross lanes PPS: N3, N4
9:36:00	9:59:59	0:23:59	3 - up	Cross lanes OCC: N3, N4
9:36:00	9:59:59	0:23:59	3 - Down	Cross lanes OCC: N3, N4
5:06:00	9:59:59	4:53:59	7	Cross lanes SPEED: S1, S2
5:06:00	9:59:59	4:53:59	7 - Down	Cross lanes PPS: S1, S2
9:54:00	9:59:59	0:05:59	7 - Up	Cross lanes occ: S1, S2
5:06:00	9:59:59	4:53:59	7 - Down	cross lanes occ: S1, S2
8:54:00	9:59:59	1:05:59	7 - up	Cross lanes ON: SI, S2
5:06:00	9:59:59	4:53:59	7 - Down	cross lanes ON: S1, S2

APPENDIX E

COSTS OF THE FSP PROGRAM (Source: MTC)

MTC
METROPOLITAN TRANSPORTATION COMMISSION

MEMORANDUM

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SAFE
SERVICE AUTHORITY FOR FREEWAYS AND EXPRESSWAYS

MM

From: Michelle Morris, Jason Munkres JM
To: Alex Skabardonis, ITS; Randy Ronning, Don Howe, Joe Palen, Caltrans
Date: May 23, 1994
Re: Freeway Service Patrol (FSP) Beat 3 Evaluation

We prepared the attached cost summary to use for the benefit-cost analysis for the Freeway Service Patrol (FSP). This cost summary will be used in conjunction with the results from the FSP evaluation conducted by PATH at U.C. Berkeley to calculate a benefit-cost ratio.

Researchers at PATH made observations over the course of several weeks on Beat 3 in 1993. During that time, beats 1 through 10 were in operation during the morning and evening commute hours. In addition, beat 5 operated in the mid-day. The costs included in this evaluation are only those costs associated with the beats that were in operation at the time during which the observations on beat 3 were made. No costs associated with implementing or operating beats 1 l-17 were included.

RESULTS

Four main cost categories were calculated for the FSP as shown on pages 2 and 3 of the attached cost summary: 1. contractor costs (non-capital costs), 2. operational costs (non-capital costs), 3. administrative costs (non-capital costs) and 4. capital costs. The information- is provided in detail so that the assumptions behind the costs can be clearly understood.

The scenario shown below was used to calculate a cost per truck-hour. Two tow trucks operate each hour on Beat 3.

Scenario	Cost per ‘Service Hour
Non-capital costs plus capital costs spread over 7 years:	$72.36

PROCEDURE

Although all beats were not operating for the entire year during the study period, the cost summary was based on the assumption that beats l-10 were operating for one full calendar year. To calculate the cost of beat 3 for one year, the costs for beats l-l 0 were calculated for the period from May 3 to December 1, 1993, then prorated for a whole year of service. Beat 3 accounted for 7.43% of the total number of truck-hours during the observation period, with two trucks operating from 6-10 a.m. and 3-7 p.m. on weekdays. The costs for Beat 3 were assumed to be proportional to its share of the total FSP truck-hours for beats l-10. From the yearly cost, the daily and hourly costs were calculated based on the number of days and hours of service per year.

cc: Haitham Al-Deek, University of Central Florida
Hisham Noeimi, Dan Rydzewski, ITS
Diane Perrine, LAMTA
Liz Mahoney, OCTA
Barry Loo, Caltrans, District 4

Freeway Service Patrol Beat 3 Cost Evaluation

Detailed Costs

These are the Freeway Service Patrol costs for Beat 3 for one year with Beats l-l 0 in operation and Beat 5 operating all day.

Non-capital Costs for Beats 1-10

1) Operational Cost - Tow Contractor Costs for all beats

Yearly Truck Hours	Avg Contract Cost per Truck-Hour	Total
54,985	$51.09	$2,809,302.20

bOpe ational Cost - not incluing tow contractors

Business reply mail	$6,800.00
Graphics/Printing (e.g. public information brochure)	$24,000.00
Fleet Call (radio air time)	$24,564.00
Yearly Maintenance for Communications Equipment	$127,586.09
Scantron Maintenance	$1 ,000.00
Pac Bell/GTE	$8,500.00
	$192,450.09

31 Administrative Costs

MTC Staff (salary, benefits, overhead)	$256,804.65
Public Awareness	$1,394.30
Travel & Training	$2,592.38
Truck/Driver Tr./Merchandise	$7,477.10
Audit	$51123.50
Insurance	$11,283.39
Caltrans personnel (salary, benefits): 2.3 Caltrans PYs @ $70,000	$161 ,000.00
CHP personnel (salary, benefits*): 1 Sgt. 4 Officers, 3 Comm Operators	$325,745.73
	$771,421.04

* time billed to the FSP program

Freeway ⧫ጠ□❖⌘♍ጠ Patrol Beat 3 Cost Evaluation

Cost Summary

These are the Freeway Service Patrol costs for Beat 3 for one year with Beats I-IO in operation and Beat 5 operating all day. Detailed costs are on pages 2 and 3.

Total Costs for Beats I-IO

	Cost per year gver 7 years
1) Operational Cost - Tow Contractor Costs •	$2,809,302.20
2) Operational Cost - not including tow contractors	$192,450.09
3) Administrative Costs	$771,421.04
4) Capital Costs	$205.650.49
TOTAL YEARLY COSTS - Beats I-10	$3,978,823.81

Total Costs for Beat 3

Yearlv		Cost per year over 7 years
7.4275% of FSP Service* •	Per Year:	$295,526.35
257 Service days	Per Service Day:	$1,149.91
4,084 Truck-Hours	Per Truck-Hour:	$72.36
	Per Beat-Hour:	$144.72
	(2 trucks per beat on Beat 3)	

- Costs of tow trucks included in tow contractor costs
- * Percent of total FSP service based on the number of truck hours per year