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The I-880 Field Experiment: Effectiveness Of Incident Detection Using Cellular Phones

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ABSTRACT

This report describes the evaluation of the effectiveness and adequacy of cellular phones for incident detection as an alternative to infrastructure-based surveillance systems. The analysis was conducted as part of the I-880 field experiment using the California Highway Patrol's (CHP) Computer Aided Dispatch (CAD) incident database. Cellular phones have the highest detection rate among the detection sources examined. They detect 38 percent of the freeway incidents (accidents and lane-blocking disablements). The combined cellular phones, freeway service patrol (FSP) and the CHP detect 75 percent of all the incidents. The results from the statistical analysis indicate a significant effect of the incident detection source on the incident duration. Incidents reported by cellular phones show greater incident durations by an average of 14 minutes than similar incidents reported by the CHP or the FSP. This additional delay is due to the incident verification process.

Keywords:

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

EXECUTIVE SUMMARY

Objectives and Methodology

Unpredictable events that occur frequently on freeways include accidents, stalled vehicles, and spilled loads. When incidents occur during peak periods and affect the available freeway capacity, motorist delays usually increase many-fold. Freeway surveillance and incident management systems are key components of the Advanced Traffic Management and Information Systems (ATMIS) aim to detect and respond to incidents reliably and rapidly. One disadvantage of infrastructure-based freeway surveillance systems is that they are capital intensive due to the high costs of installing inductive loop detectors, closed-circuit television (CCTV) and trunkline communication along the entire roadway.

Cellular phones have served as sources of incident detection in the San Francisco Bay Area. Calls can be made from cellular phones by motorists to report incidents on freeways. Information obtained from cellular phones vary in the detail and quality, and also, the incident may be reported after considerable time has elapsed. Therefore, the feasibility of freeway surveillance systems utilizing cellular phones needs to be carefully evaluated. This report presents the findings of the evaluation of the feasibility of using cellular phones for freeway surveillance as an alternative to infrastructure-based surveillance systems.

Incidents reported by cellular phones and other sources on a 9 mile section of the I-880 freeway were obtained from the California Highway Patrol (CHP) computer aided dispatch (CAD) center, along with field observations on incidents by probe vehicle drivers traversing the same freeway section with an average headway of 7 minutes. Supplementary data were gathered from the freeway service patrols (FSP) and tow truck companies' logs. The database includes 264 incidents (accidents and lane-blocking vehicle disablements) and 1429 "other events" (vehicle stalls, and other non-accident events that did not block travel lanes.)

The data were analyzed to assess the quality and adequacy of cellular phone calls for incident management using the following performance measures: a) incident detection rate, b) false alarm rate, c) timeliness of incident detection, and d) available details essential for initiating response actions for incident removal (incident location and type, incident severity, and the number and type of vehicles involved). Analyses also were performed to assess the effects of the timeliness of incident detection on duration, and the effects of incident duration on traffic congestion.

Findings

Cellular phones detect 38 percent of the incidents, and 1 percent of the other events. This is probably because incidents (having blocked travel lanes and impeded traffic flow) are likely to get immediate attention from other road users. On the other hand, other events (breakdowns on the shoulders which occur with greater frequency and do not present a hazard to other motorists) are often not noticed by other motorists. About 7 percent of all reported incidents by cellular phones are false alarms (moving violations and other events that could not be verified by the CHP). The false alarm rate for other events is much higher (32 percent), reflecting cellular-phone callers' difficulties in judging whether vehicles resting on freeway shoulders are disablements or just temporary stoppage. A significant contribution of cellular phones is that they capture additional 35 percent of the incidents not witnessed by the CHP. The detection rate by the combined CHP and cellular phones was 60 percent. Adding FSP to the combined CHP and cellular phones increases the incident detection rate from 60 to 75 percent, i.e., the majority of the freeway incidents were detected by the CHP/FSP (that are typical components of urban freeway management) plus the cellular phone users.

The evaluation results show that relative to other detection sources, cellular phones have the highest detection rate and are the fastest detection source. They are reasonably effective (with above-average ranking) in terms of correct reporting of incident locations, and availability of information about the incident type and the number of vehicles involved. Weaknesses of cellular phones include a very low rate of detecting other events, the highest rate of false alarms, and limited information on the incident severity. Also, cellular phones need verification and cannot tell when the incident is cleared.

The testing of loop data based incident detection algorithms produced very low incident detection rates and high false alarm rates. Reasonable performance of these algorithms was reported when they applied to only a small preselected sample of lane-blocking incidents. These results indicate that existing incident detection algorithms do not perform satisfactorily in real-world operating conditions with high frequency of incidents and other events.

Incidents reported by cellular phones show greater incident durations by 14 minutes on the average than similar incidents reported by the CHP/FSP. This extra delay is due to the incident verification process. When the CHP (or FSP) detects an incident, they usually take actions to respond to it immediately. On the other hand, for the incidents reported by cellular phone, the CHP officer is dispatched to the scene to *verify* the existence of that incident before taking response actions. The verification plus response time is significantly affected by the incident type and detection source. Smaller response time can be expected for accidents than for lane-blocking vehicle disablements, and for incidents reported by cellular phones than call boxes. The clearance time is expected to be the highest for injuries, followed by for non-injury accidents and breakdowns in travel lanes. Further, for each incident type, events that take longer to verify/respond to also take longer to clear.

Recommendations

Incident management requirements for ATMIS systems cannot rely solely on cellular phones. Cellular phone reports may contribute significantly to the incident detection in combination with other sources, and may be utilized in the verification of incidents detected by loop based systems. This would require proper fusion of cellular phone data with information from other sources and utilization of other technologies (video surveillance.)

Under the existing incident management practice, incident detection by cellular phones (as well as by call boxes or public entities) is simply not as time-effective as incident detection by the CHP or the FSP. To make cellular-phone incident detection as effective as the detection by CHP/FSP, in terms of the incident duration, current incident verification and response practices associated with cellular-phone detection need to be revised.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Incidents that occur frequently on freeways include accidents, stalled vehicles, spilled loads and other random events. When incidents occur during peak periods, motorist delays usually increase many-fold. The California Department of Transportation (Caltrans) estimated that over 50 percent of motorist delays on the freeway are incident related (Hicomp 1992). Freeway surveillance and management systems that quickly detect, respond and clear incidents will result in reductions in congestion and motorist delays.

Freeway surveillance systems are a key component of Advanced Traffic Management Systems (ATMS). Inductive loop detectors, closed-circuit television (CCTV), and trunkline communication are essential parts of infrastructure-based surveillance systems. Loop detectors provide the means for detecting incidents, as well as measuring traffic flow conditions with reasonable accuracy. CCTV cameras detect incidents and at the same time identify the nature of incidents so that appropriate actions can be pursued to clear the incidents. One disadvantage of infrastructure-based surveillance systems is that they are capital intensive due to the high costs of installing CCTV, loop detectors, and trunkline communication along the entire roadway.

Cellular phones have served as sources of incident detection in the San Francisco Bay Area. Calls can be made from cellular phones by motorists to report freeway incidents. Monitoring of roadway performance and traffic flow parameters will still be needed and have to be accomplished by some other supplemental data collection methods. Information obtained from cellular phones vary in the detail and quality. Further, the incident may be reported after considerable time has elapsed. Therefore, the feasibility of freeway surveillance systems utilizing cellular phones needs to be carefully evaluated.

1.2 Objectives of the Study

A research study was undertaken as part of the I-880 field experiment (Skabardonis 1996) to assess the effectiveness of cellular phones for incident reporting. The study had the following specific objectives:

- Assess the effectiveness and adequacy of information from cellular phones for incident management purposes relative to other detection sources
- Develop incident duration models to assess the effects of the incident detection source and speed on incident duration

1.3 Use of Cellular Phones in Incident Management

Currently, the number of cellular phone subscribers in the US exceeds 40 million, and it is estimated that about 10 percent of new automobiles would be equipped with cellular phones by the year 2000. Several transportation agencies throughout the country are implementing systems to receive cellular calls reporting incidents on freeways.

In Chicago, the Illinois Department of Transportation established a center to receive *999 incident reporting cellular calls since 1989 (McLean 1991). In 1990, a total of 116,000 calls were received of which 67 percent were first time reports of incidents. Approximately 70 percent of the calls reported accidents and vehicle disablements. Massachusetts' state police have implemented a cellular phone free service for incident reporting (*SP), which is logging about 6000-8000 calls per month (Kennedy 1991). It was reported that the system has reduced response times by 10-15 minutes. A free emergency cellular phone service (*11) was also established as part of the incident management system for the Pennsylvania Turnpike, and it receives about 1,100 calls per month (Pennsylvania Turnpike Commission 1993). Similar services have been instituted in Portland, Oregon (McCourt, 1993), and Denver Colorado (Hattan, 1993).

Problems with the use of cellular phones for incident detection include the accuracy of the reported incident location, and the diversity of calls received by the operators. In some areas, 0.1 milepost markers and ramp identification markers have been installed so callers would have a better reference to report the incident location (Judycki 1992.) Public information programs have been developed for operator training and to educate cellular phone users on incident reporting (Robinson 1989).

An experiment was conducted in Houston to obtain real-time travel information from cellular phone users (Levin 1993). Cellular phones were provided to 200 volunteers to serve as traffic reporters (probes) during their work commute trips. The results indicated that the cellular phone probes provided reliable incident reporting information but no significant change in travel patterns in the corridor was found. An incident detection algorithm based on the probe travel times was developed with promising results (Balke 1996). In another field operational test in Washington DC, a system is being developed to estimate link travel times by matching the locations of cellular callers in the network (Sumner 1994).

In summary, facilities to receive incident report from cellular phone users are being implemented as standard components of the existing and planned incident management systems, because of their low capital and operational costs. However, there is a lack of studies to systematically evaluate the effectiveness of cellular phones as an incident management tool and how they compare with other means of incident detection.

1.4 The Bay Area's CHP/CAD Incident Management System

In 1992, the Golden Gate Division of the California Highway Patrol (CHP) created the Computer Aided Dispatch (CAD) Center in Vallejo to assist the CHP officers in responding to freeway incidents. The CAD Center covers the nine Bay Area counties and

11 CHP area offices and operates 24 hours a day. Figure 1.1 illustrates the sources of calls received via phone lines at the CAD center. Also, CHP officers communicate directly via radio, and Freeway Service Patrol (FSP) trucks through mobile data terminals. Communication operators I handle only calls from non-beat CHP officers. Communication operators II handle calls from CHP beat officers and other sources. The incident calls received at the CAD center are classified by the detection source as follows:

(1) **CHP calls:** There are about 50 freeway segments (beats) patrolled by CHP officers, each averaging about 10 miles in length. Each beat is handled by specific workstations within the CAD center. CHP calls receive immediate attention from the center's operators.

(2) **Call** boxes: There are approximately 2,000 call boxes on the Bay Area's freeways, installed on the right shoulder at about 1/4 mile spacing. Call boxes are wireless cellular phones utilizing solar panels atop 14-foot poles to recharge the batteries. Each call box has a unique identification number which permits the operator to know the location from which the call is made, and a built-in detection system to notify the CHP if the unit has failed (or vandalized). Call boxes are used by motorists to request assistance and report incidents.

The call box program is funded from a $1 annual surcharge on motor vehicle registrations in the six Bay Area counties -- Alameda, Contra Costa, San Mateo, Santa Clara, Solano, and Sonoma -- participating in the Metropolitan Transportation Commission's (MTC) SAFE (Service Authority for Freeways and Expressways) program.

(3) Cellular 911 calls: When motorists use their cellular phone to report freeway incidents, these calls are directly routed to the CAD center. These calls are referred to as MO911 calls and can be identified by the caller's name and phone number, which are automatically registered in the CAD system. Cellular calls not related to freeway incidents are transferred to the appropriate agency.

(4) Public Entities' calls: Personnel from public organizations (e.g., Caltrans maintenance crews, local police departments, fire departments, county medical services, etc.) often report freeway incidents to the CAD center. These calls are usually made via phone lines (hot numbers).

(5) Freeway Service Patrol (FSP) calls: A fleet of 52 FSP trucks are monitoring 218 miles of the Bay Area's most congested freeways, and covering 20 beats (Figure 1.2) mostly during weekday peak periods (6-10 a.m., and 3-7 p.m.) The FSP drivers communicate with the CAD center via two-way radios and onboard Mobile Data Terminals (MDTs). The MDT unit provides for automated routine communications and transmittal of text messages by the operator. The FSP trucks also are equipped with GPS (Global Positioning System) and AVI (Automatic Vehicle Identification) system, which permit the operators to monitor the location and status of each FSP truck and dispatch available units to incidents reported by CHP or other sources.

FIGURE 1.1 SOURCES OF INCIDENT REPORTING--CHP/CAD CENTER

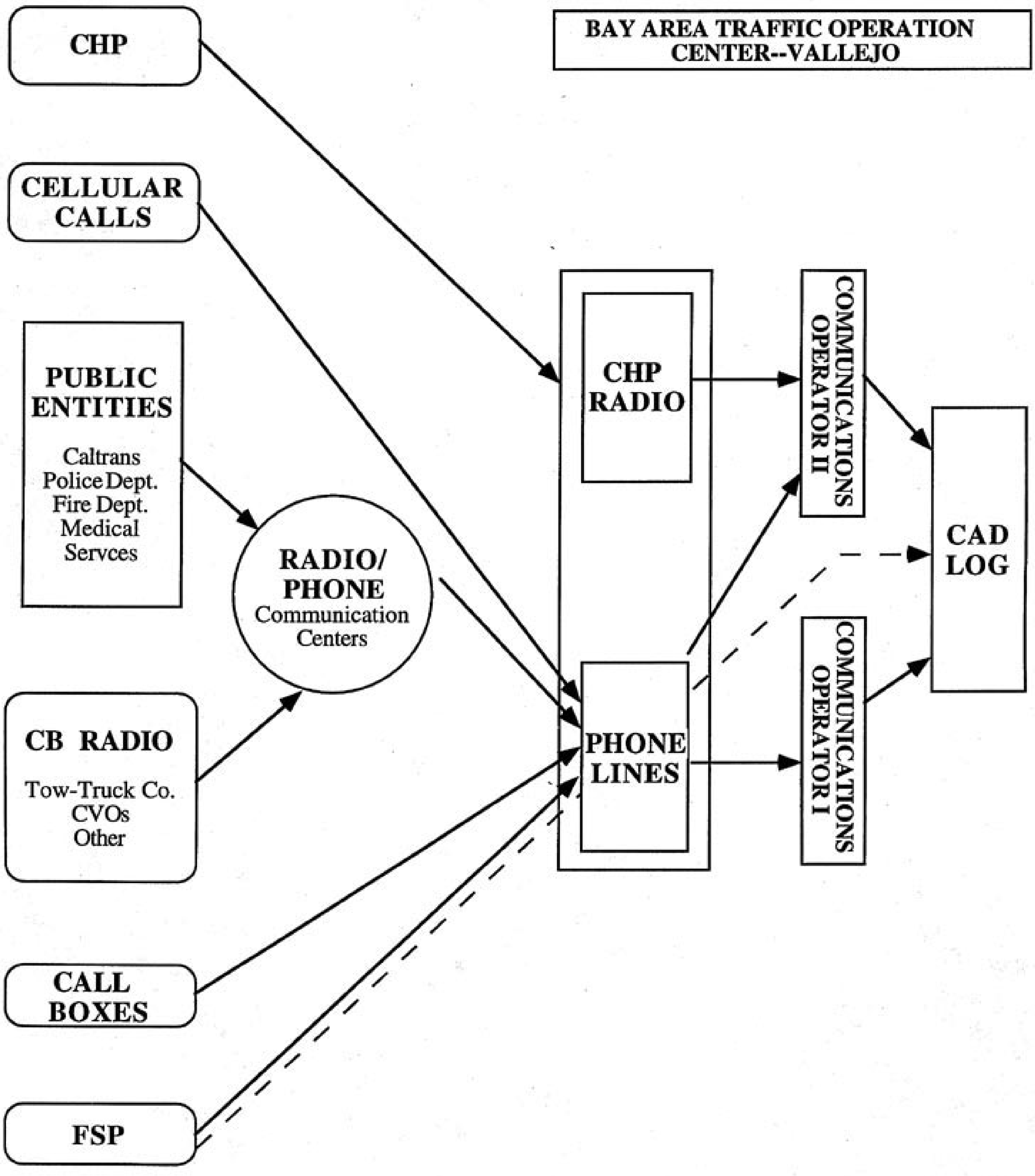
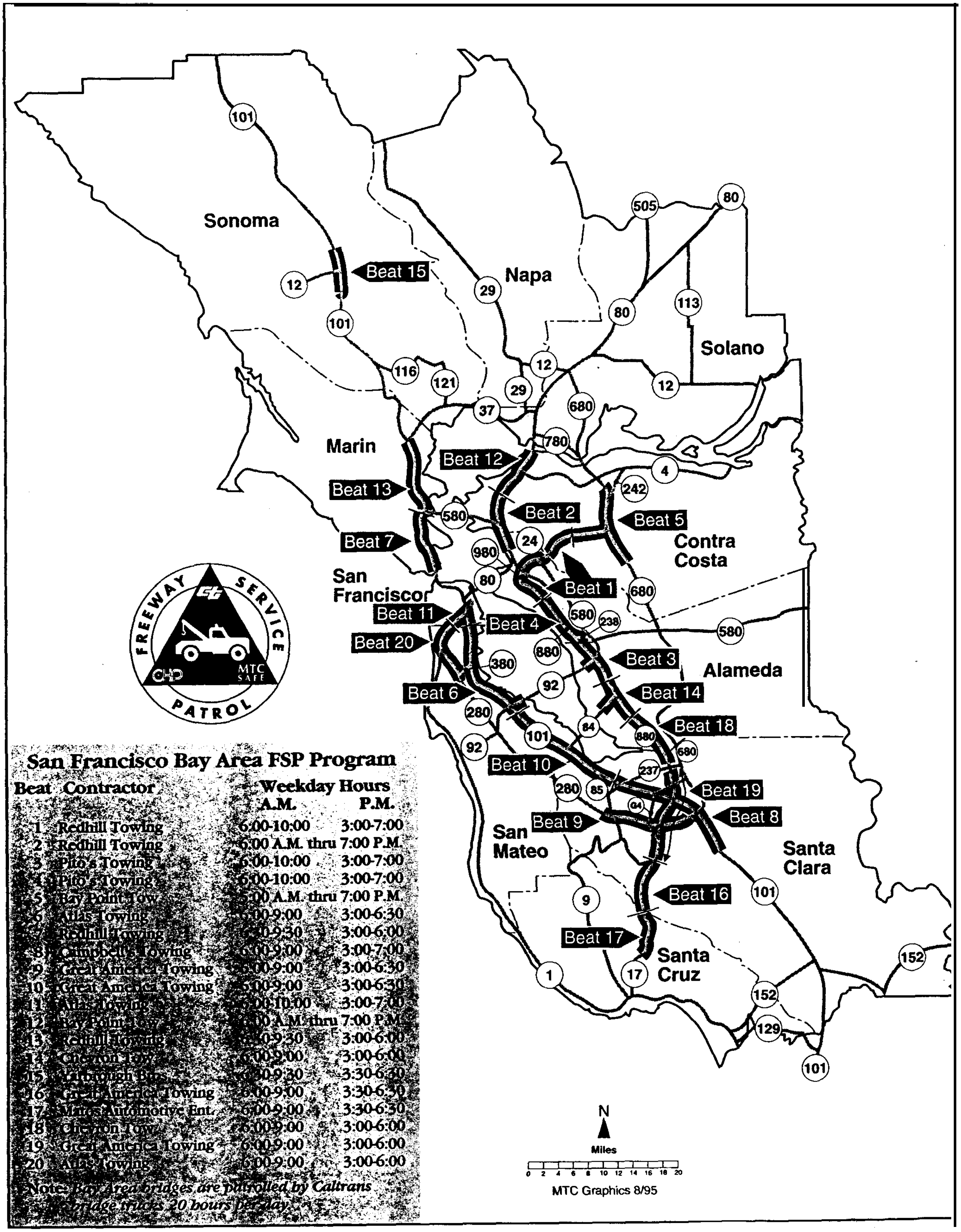


FIGURE 1.2 BAY AREA FREEWAY SERVICE PATROL BEATS
As of September 30, 1995 (Source: MTC SAFE 1995)



San Francisco Bay Area FSP Program

Beat	Contractor	Weekday Hours A.M.	Weekday Hours P.M.
1	Redhill Towing	6:00-10:00	3:00-7:00
2	Redhill Towing	6:00 A.M. thru 7:00 P.M.	
3	Pito's Towing	6:00-10:00	3:00-7:00
4	Pito's Towing	6:00-10:00	3:00-7:00
5	Bay Point Tow	5:00 A.M. thru 7:00 P.M.	
6	Atlas Towing	6:00-9:00	3:00-6:30
7	Redhill Towing	6:30-9:30	3:00-6:00
8	Campbell's Towing	6:00-9:00	3:00-7:00
9	Great America Towing	6:00-9:00	3:00-6:30
10	Great America Towing	6:00-9:00	3:00-6:30
11	Atlas Towing	6:00-10:00	3:00-7:00
12	Bay Point Tow	6:00 A.M. thru 7:00 P.M.	
13	Redhill Towing	6:30-9:30	3:00-6:00
14	Chevron Tow	6:00-9:00	3:00-6:00
15	Yarbrough Bros.	6:30-9:30	3:30-6:30
16	Great America Towing	6:00-9:00	3:30-6:30
17	Matos Automotive Ent.	6:00-9:00	3:30-6:30
18	Chevron Tow	6:00-9:00	3:00-6:00
19	Great America Towing	6:00-9:00	3:00-6:00
20	Atlas Towing	6:00-9:00	3:00-6:00

Note: Bay Area bridges are patrolled by Caltrans bridge trucks 20 hours per day.

(6) Transfer 911 calls: Citizens can report freeway incidents by dialing 911 on regular phones. These non-cellular 911 calls are first routed to the precinct in which the call is made. The precinct then re-routes calls about freeway incidents to the CAD center.

(7) Citizen/private band radios: Citizen band (CB) calls are routed to the CAD center through their corresponding radio communications center, but only those calls from tow trucks are identified as CB calls in the CAD database. Other CB calls (e.g., from tractor trailers, other commercial vehicles or private two-way communications) are also not identified as such in the CAD system.

(8) Unknown origin: Those are calls that their origin is unknown. Most of these calls are cellular calls with no information about the caller. Other calls may include calls from public entities and CB radio calls.

Phone operators who answer calls from the CHP and other sources record the information directly into a computerized database using a standardized format (CAD log.) The entered information includes: the time and source of the call, incident location, incident type, vehicle description, CHP/FSP or tow truck arrival and departure. The contents and format of the CAD logs is discussed in more detail in Chapter 3.

1.5 Other Sources for Incident Management

Caltrans maintains incident management teams on the six Bay Area toll bridges for which Caltrans is responsible. Roving tow trucks and call boxes are the key component of these teams. Caltrans also has five Traffic Management Teams, equipped with seven truck mounted and three trailer mounted CMSs and two mobile highway advisory radios (HAR).

On the San Francisco-Oakland Bay Bridge (SFOBB), electronic surveillance equipment in place on eight miles of the upper deck includes magnetometers, optical detectors, call boxes, 17 CCTV cameras and 11 changeable message signs (CMS). Additional surveillance equipment, CCTV and CMSs have been added to the bridge’s lower deck and approach freeways (a total of 23 miles). However, due to the ongoing seismic retrofit and other construction in the area, the surveillance system is not currently operational.

The Golden Gate Bridge District also maintains a 24-hour incident management program, with four tow trucks operating between Spencer Avenue and the Marina (roving and/or stationary strategies, depending on the time and day). Each tow truck is outfitted with fire fighting equipment. With this program in place, augmented by incident reporting communications with their transit bus drivers, the District has achieved a 2 to 3 minute response time.

The Caltrans Traffic Management Center (TMC) is located at the Caltrans District 4 Headquarters in downtown Oakland. It became operational in the summer of 1996 and it is still under development. The ultimate configuration of the Bay Area TMC will include detection, surveillance and information systems (loop detectors, CCTV, CMSs) on 500 freeway miles. The TMC was located in Vallejo at the time of the study.

1.6 Incident Response/Clearance Procedures

The occurrence of an incident on the freeway initiates a potentially complicated chain of events. This sequence can be summarized in the following way:

1. Incident occurs:
   a) Incident not detected.
   b) Incident detected. Considered detected if a CAD log is created at the CHP/CAD Center

2. Incident detection.
   a) Detection source calls into the CAD center.
   b) Operator acts upon the quality of the information given.
   c) Operator expedites, denies service or dispatches.

3. Incident classification
   a) Classified as incident: accident, breakdown, pedestrian, debris, abandoned vehicle, or roadway hazard.
   b) No action if non-incident (false alarm)
   c) Broadcast to all CHP units if moving incident/violation.

4. Verification
   CHP and FSP calls are considered verified. Also, verified are public entity calls if the entity is at the incident scene, and the calls from call boxes for self-help. The rest of the reported incidents are considered unverified and the CHP (or FSP) are dispatched to verify the incident. If the incident is not found at the reported location it is labeled as "Unable to Locate" (UTL). Any detected incident not reported by CHP is dispatched to CHP units. If a severe incident is reported such as multicar accidents, the dispatcher may request immediate assistance (ambulance, two truck) prior to verification.

5. Response
   Proper response determined
   Response implemented
   Service arrives

8. Incident Clearance
   Once the service has arrived at the incident scene, the clearance procedures may follow an almost infinite number of paths depending on the incident type, the CHP/FSP standards and operating procedures, and the motorists rights under the California Vehicle Code. Some typical situations are described below:

accidents: CHP would request medical assistance if needed, and attempt to move any lane blocking vehicles to the shoulder if possible or call a tow truck. The motorists, however, have the right to refuse medical services even if injury is evident. The FSP unit may be used to clear the traffic lanes while an alternate tow service is enroute. FSP will move vehicles involved in the accident upon CHP direction.

breakdowns: If the vehicle occupies travel lanes, CHP will move to shoulder if possible and call for assistance (FSP or rotational tow trucks). The motorists have the right to refuse the service offered even if it is faster, and request their own service (e.g., AAA). FSP will assist in clearing the travel lanes and attempt to fix the problem. If they cannot have the vehicle moving within 10 minutes they would tow the vehicle to a designated location off the freeway. If the motorist denies the towing, the FSP would call the requested service.

abandoned vehicles: If a vehicle is abandoned on the freeway travel lanes or is a hazard to other motorists, the CHP unit will call for a tow truck to remove the hazard, and remain with the vehicle until its removal from the freeway. The FSP unit would also request a CHP dispatch to initiate a hazardous vehicle impoundment. If a vehicle is abandoned on the shoulder and is not a hazard to other motorists, the CHP (or FSP) will attach a yellow “422” tag which informs the motorist of their right to abandon their vehicle for 4 hours before the vehicle will be towed off the freeway.

CHAPTER 2

RESEARCH METHODOLOGY

Freeway incidents are detected by means of a number of sources--loop detectors, call boxes, electronic surveillance, CCTV, police patrols, CB radios, or cellular phones. Then, personnel are dispatched to the site to identify the nature of the incident and initiate actions to clear the incident. The time elapsed between the incident occurrence and the start of clearance represents idle delays, during which traffic congestion can continue to grow.

To be effective as part of an advanced freeway management system an incident and surveillance component must be capable of:

- Detecting the incident reliably and rapidly.
- Determining the incident’s nature and other essential details accurately and quickly to facilitate the initiation of response actions needed to clear the incident.
- Predicting incident durations and traffic flow conditions
- Providing information about the actual incident startup and traffic flow conditions so that timely information can be given to travellers to adjust their travel as needed.

The evaluation of the feasibility of cellular phones in freeway incident detection consists of the following set of analyses:

- Assessment of the quality and adequacy of cellular-phone information as part of advanced incident management systems in the ATMIS context.
- Assessment of the effects of the timeliness of incident detection on incident duration.
- Assessment of the effects of incident duration on traffic congestion.

2.1 Quality and Adequacy of Incident Information Reported by Cellular Phones

Incidents reported by cellular phones and other sources on a 9-mile section of I-880 freeway were obtained from the Bay Area’s CHP/CAD database. These cellular-phone incident data were evaluated against incident data obtained from field observations and other detection sources using the following measures of effectiveness (MOEs):

- Incident detection rate
- Rate of “false alarms”.
- Timeliness of incident detection
- Available details essential for initiating response actions to clear the incident: incident location, type and severity, and the number and type of vehicles involved.

The adequacy of cellular phones in detecting and reporting freeway incidents was evaluated relative to the other detection methods. Furthermore, the incident detection capabilities of cellular phones plus CHP (both of which are and will be always an integral part of incident reporting) was analyzed in the absence/presence of incident management measures such as the FSP, and infrastructure-based systems using loop detector data for incident detection.

2.2 Incident Duration Models

Incident duration is defined to consist of three major time components -- detection time, verification plus response time, and clearance time. Detection time is the time between the incident occurrence and the incident reporting. Verification plus response time is the time between the incident reporting and the arrival of the response team. Clearance time is the time between the response team's arrival and the completion of the incident clearance.

A number of studies investigated factors affecting the incident duration. Golob et al (1987) reported that the accident type, number of lanes closed, and accident severity were significant explanatory variables of accident duration. Jones et al (1991) used "survival model" to investigate factors affecting accident duration, and reported that accident type, time-of-day, accident severity, special events, driver age, and driver intoxication were significant explanatory variables. Giuliano (1989) investigated factors affecting the magnitude of incident response/clearance time, using the analysis of variance. She reported that the incident type, time-of-day, lane closure, and truck involvement were significant explanatory variables of incident response/clearance time. However, prior studies generally did not examine the effects on incident duration due to the incident detection source (e.g., police and motorist assistance patrol, cellular phones, call boxes, public entities), and detection time (i.e., the time it takes to report the incident after its occurrence).

The CHP/CAD incident data were analyzed to determine relationships between the incident duration, and incident characteristics, detection time and incident reporting source. Such models would be useful for assessing potential changes in the length of incident duration due to different incident detection times brought about by different detection technologies (e.g., cellular phones, FSP, and call boxes). Analyses were also performed to determine how and the extent to which incident detection, response, and clearance times are dependent on the time it takes to complete the preceding activities.

2.3 Relationships among Detection, Response and Clearance Times

Incident verification plus response time typically consists of times involved in verifying the existence of the incident, determining the type of response needed to clear the incident, dispatching the response team, and response team traveling to the site. Clearance time can include a large number of activities such as removals of the vehicles and debris from the roadway, cleanup, attending to the injured, and on-site incident investigations. As it was discussed in Section 1.6, the procedures followed and the time to complete these activities vary widely depending on the incident type, detection source, type of service (FSP or other), as well as freeway geometric and traffic conditions.

The development of statistical models to predict incident verification plus response and clearance times included a range of independent variables deemed likely to influence the time it takes to complete any one of these activities. These variables would include but not limited to, the following: the incident type, location (mainline, shoulder, ramp related), weather, day/night, traffic conditions, vehicle type, number of vehicles involved, and incident severity.

To date, only a handful of prior studies have attempted to systematically investigate factors affecting the incident response and clearance times in the incident management process. Results from these prior studies, however, have limitations. Most of these studies investigated only accidents, primarily because traffic accident records were more readily available. Also, prior studies investigated the effects of explanatory variables in the statistical hypothesis-testing framework (as opposed to stating functional relationships between the dependent and the explanatory variables). Therefore, the applicability of these results for prediction is quite limited.

Previous studies usually combined the response time with the clearance time as the dependent variable in their analysis, even though significant variables may have diametrically opposite effects, on the response time and the clearance time. For example, major injury accidents may induce a very quick response time, but may lengthen the incident clearance time due to the response team having to also attend to the injured; spilled loads, may have little-to-no effect on the response time, but can lengthen the clearance time significantly. Therefore, studies that combined both the response time and clearance time as the dependent variable might yield misleading results.

The analysis of the data would determine relationships among detection time, verification plus response time, and clearance time, in order to assess the potential impacts and benefits of various alternative incident surveillance options, as well as to identifying effective ways to reduce the entire incident duration.

CHAPTER 3

DATA COLLECTION AND PROCESSING

This Chapter describes the development of an incident database to provide input to the analyses described in Chapter 2. The primary data sources were the I-880 incident database consisting of field observations on incidents by probe vehicle drivers, incident reports obtained from the CHP/CAD center, and supplementary data such as freeway service patrols (FSP) records and rotational tow truck companies' logs.

3.1 The I-880 Incident Database

This incident database was specially developed as part of FSP Evaluation Study (Skabardonis 1995). It was derived from field observations utilizing probe vehicles to detect freeway incidents. The data collection took place along a 9.2 mile section of the I-880 freeway in the city of Hayward, Alameda County (Figure 3.1). The study section has 3 to 5 lanes in each direction, and includes an HOV lane between Lewelling and Tennyson Street exits. Loop detectors are installed every one-third mile on the freeway mainline and the ramps, and call boxes are located at approximately 1/4 mile intervals.

Incidents and their characteristics were recorded by roving vehicles traversing the freeway section with an average headway of 7 minutes. These probe vehicles were also instrumented so that travel speeds could also be recorded. In addition, traffic data (flow, occupancy, and speed) from loop detectors were also collected at l-second intervals. The field data were collected for six hours per day during the peak periods (6:30-9:30 am and 3:30-6:30 pm) "before" and "after" the deployment of FSP. The "before" study was conducted for 24 weekdays from February 26, through March 19, 1993, and the "after" study took place from September 15 through October 29, 1993 (a total of 22 weekdays). Most of the data were collected under clear weather conditions. Rainy periods accounted for about 20 percent of the data collection periods.

The probe vehicle drivers reported via a two-way radio every incident and its characteristics witnessed on the freeway as follows:

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

The data were recorded in the field on a incident data collection form and then input in a computerized database for further analysis. The field observations are summarized in Table 3.1. A total of 1594 incidents were observed (excluding ticketing motorists by the CHP officers.) Accidents accounted for about 10 percent of the total incidents, and approximately 4 percent of all the incidents were blocking travel lanes.

FIGURE 3.1 THE I-880 STUDY AREA

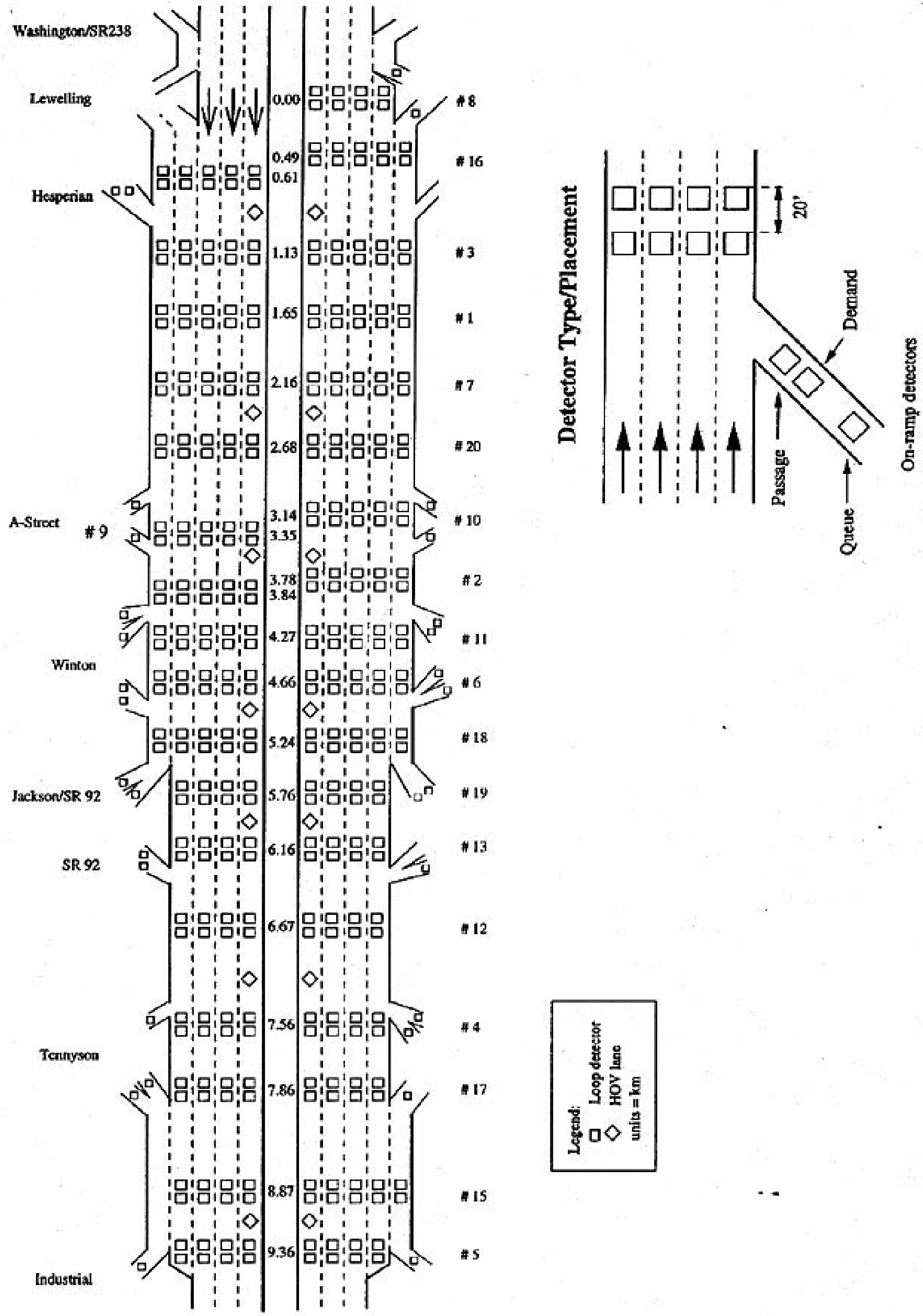


TABLE 3.1 THE I-880 INCIDENT DATABASE (Probe Veh)

INCIDENT TYPE	LOCATION In-Lane	Shoulders	TOTAL	%
Accident	35	132	167	10.5
Breakdown	27	1382	1409	88.4
Debris/Peds	15	3	18	1.1
TOTAL	77	1517	1594	

3.2 The CHP/CAD Database

Calls to report incidents to the CAD center by all detection sources are entered in computerized logs (CAD logs) directly by the telephone operators, using a standardized format. Figure 3.2 shows a hard copy of this log. The CAD logs include the following information foe each incident:

Time of *the call:* time the call was received recorded to the nearest minute

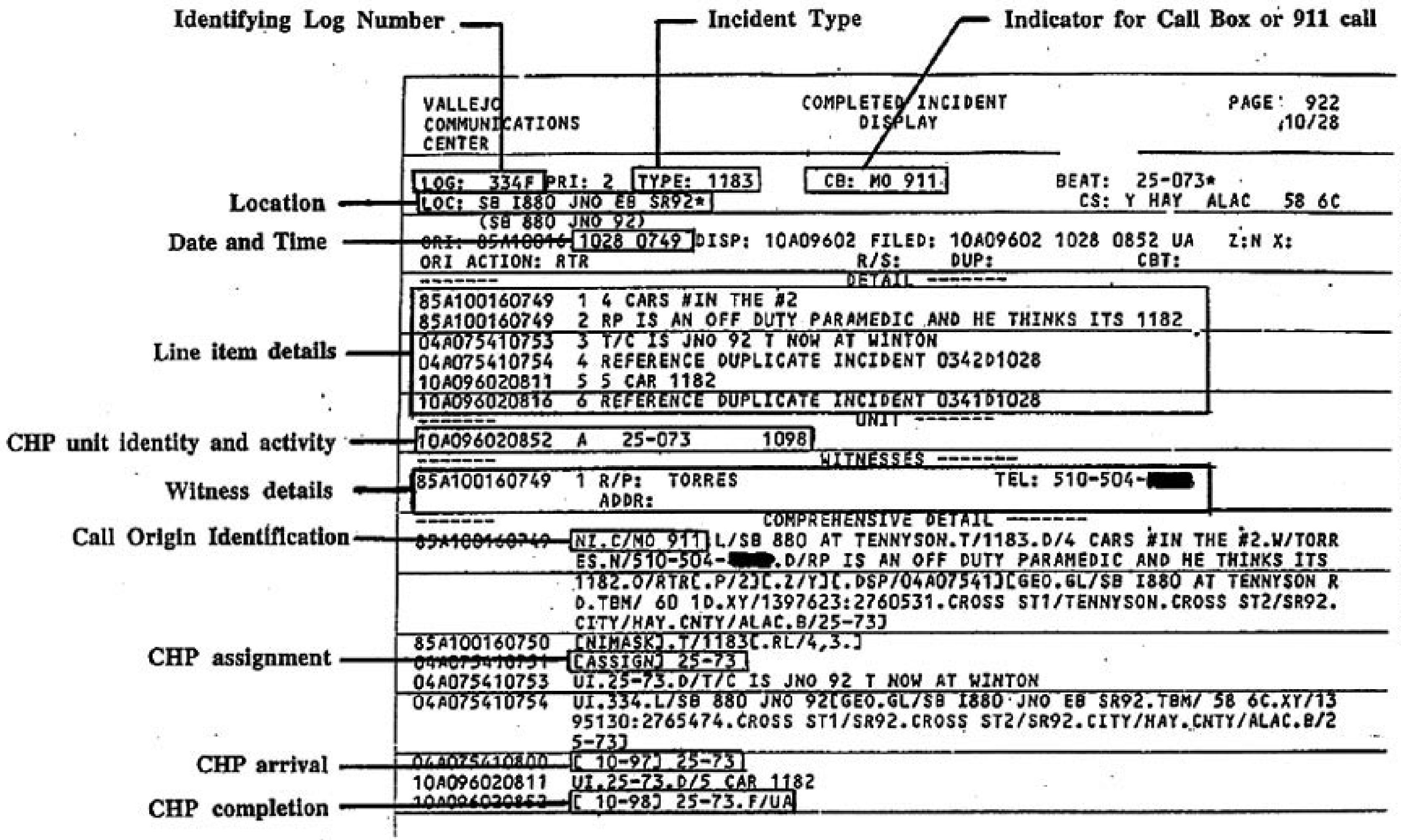
Source of the call: source of the original (first reporting) and duplicate calls

Incident location: the freeway, direction of travel, travel lane or shoulder, and relative distance from the nearest freeway exit (e.g., south of, just south of, at the exit, etc.)

Incident type: incidents are classified into the following categories:

- 11-79: accident with ambulance rolling
- 11-80: major-injury accident
- 11-81: minor-injury accident
- 11-82: property damage only (PDO) accident
- 11-83: accident with no detail
- 11-24: abandoned vehicle
- 11-25: traffic hazard
- 11-26: disabled vehicle (occupied)
- Other

FIGURE 3.2 STANDARDIZED CAD LOG



CHP(FSP) activity: Time and which CHP (or FSP) unit is assigned, arrives and leaves the incident scene

Time help was called: time the telephone operator re-routes a call for assistance to AAA and other tow companies, County medical services, etc.

Vehicle description: license plate number, vehicle type, color, make, etc.

The CAD logs also provide the following information not available from the probe vehicles: moving violations, source of the original and duplicate calls, incidents that the response teams could not verify, time of CHP arrival (more accurate than probe vehicles), accident severity, details of vehicle disablement, and in some cases the time the incident was moved to the shoulder. However, important information was not provided for many of the incidents including the type of vehicles, tow truck/ambulance arrival and departure, time the incident is cleared from the shoulder, and whether the CHP is towing vehicles off the freeway for a report.

For the I-880 study section covered by the probe vehicles during the field data collection periods, there are a total of 218 CAD logs in the “before” and 283 in the “after” study. The higher number of calls in the “after” study was mostly due to the FSP service. Approximately 39 percent of the reported incidents were accidents, 54 percent were breakdowns and 7 percent other (pedestrians, debris on the roadway, other).

A number of CAD records logs were excluded from the analysis because the reported incidents could not be matched with the probe vehicle data. These included a) incidents reported before the beginning of the field data collection periods (i.e., before 6:30 am or 3:30 pm) that were in progress at the start of the probe vehicle runs, b) data for those days that probe data were not available because of equipment malfunctions such as poor radio communications and probe vehicle failures (9/28 PM, 9/29 AM, 10/27 PM, and 10/28), and c) CAD entries related to CHP ticketing violations. The final CAD database used in the analysis consists of 364 incidents (174 in the “before,” and 190 in the “after” study.)

Table 3.2 shows the number and type of incidents by each original (“first call”) reporting source. Most calls about accidents were originated by cellular phones (44 percent) and the CHP (34 percent). The primary sources for reporting vehicle disablements were the CHP (35 percent) followed by call boxes (28 percent) and cellular phones (20 percent.)

Figure 3.3 shows the proportion of reported incidents by source in the “before” and “after” study. In the “before” study CHP accounted for about 44 percent of all the source calls. In the “after” study, the portion of CHP original calls dropped to 24 percent because FSP reported 18 percent of the calls, mostly breakdowns. Cellular phones accounted for about 30 percent of the source calls in each study period. Call boxes accounted for about 16 of the original calls, and public entity originated about 9 percent of the calls in both study periods.

TABLE 3.2 SOURCE OF CALLS IN THE CHP/CAD DATABASE

INCIDENT TYPE	Cellular Phone	CHP	FSP*	Public Entity	Call Box	Total
Accident	61	47	10	16	6	140
Breakdown	39	70	21	13	55	198
Debris/Ped	15	4	4	3	0	26
Total	*115*	*121*	*35*	*32*	*61*	*364*

**FSP Service only in the "after" study*

FIGURE 3.3 DETECTION SOURCES IN CAD

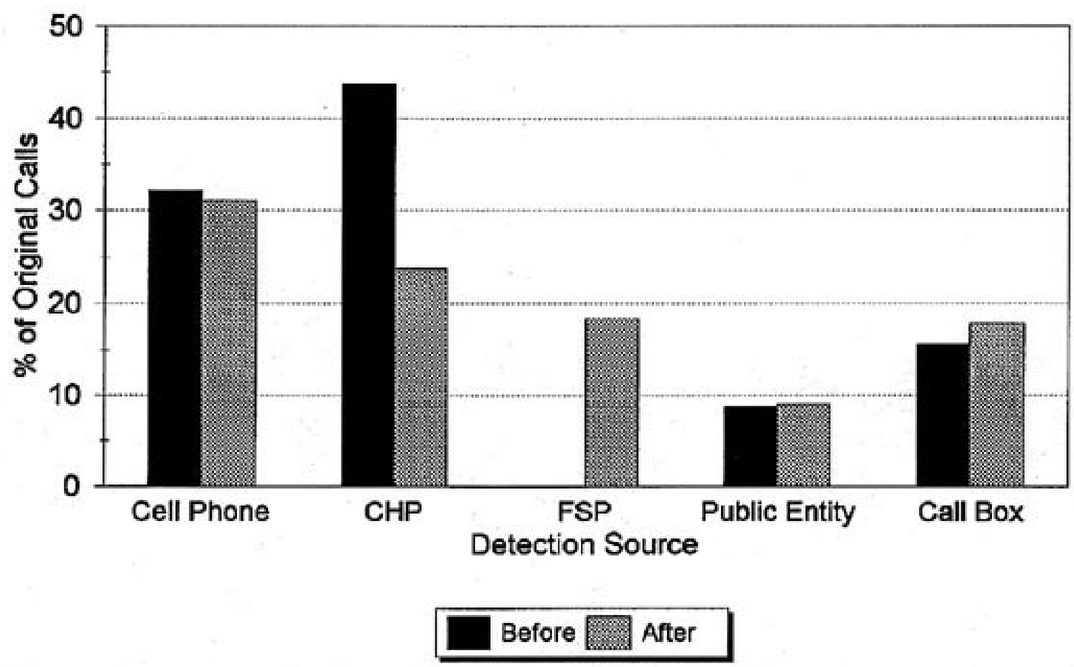


Table 3.3 shows a detailed classification of incidents in the CAD database by incident type and location and source of original call. About 58 percent of all the accidents were occupying travel times, and injuries were 14.3 percent of the total accidents. Fifty-three (23.6 percent) of the reported breakdowns were lane-blocking, of which about 25 percent of them with mechanical or electrical problems. Incomplete information was provided for 29 percent of the reported vehicle disablements, and several of those reports were related to moving violations that could not be verified. Cellular phones is the primary source of calls regarding lane blocking incidents (57 percent), followed by the CHP (19 percent). For shoulder incidents, CHP (41 percent), call boxes (25 percent) and cellular phones (17 percent) were the primary sources of incident reporting.

The processing of the CAD logs was a difficult and time-consuming process because the data could only be made available in hard copy. The incident information in each log had first to be recoded in a coding scheme compatible with the I-880 incident database and then input in a computerized database for further analysis.

3.3 FSP and Tow Truck Companies Logs

The FSP tow truck drivers are required to fill out an assist form each time they respond 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. These logs were obtained from the Caltrans District 4 staff for the duration of the "after" study and were used to supplement and verify the information in the CAD database about FSP assisted incidents.

Data on tow truck activity were also requested from the thirteen rotational tow truck operators in the CHP list who responded to incidents during the I-880 field data collection periods. The tow truck operators were contacted by the CHP to provide the following data:

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

Only three tow companies responded with mostly incomplete data, except the AAA service which submitted to us detailed tow truck logs. The data were used in conjunction with the probe vehicle field observations to determine the times of tow-truck call, arrival and departure. This information is often missing in the CAD logs for those incidents assisted by non-FSP tow trucks.

The tow companies logs were also used to explain the long response times for some incidents observed by probe vehicles. The information in the logs revealed that tow trucks were called as long as two hours after the incident was first observed. This is probably because the drivers "abandoned" their vehicles and called a tow truck for assistance at a later more convenient time.

TABLE 3.3 INCIDENT CLASSIFICATION BY DETECTION SOURCE

INCIDENT TYPE	Cell Phone		CHP		FSP		Public Entity		Call Box		TOTAL
	In-L	Sh	In-L	Sh	In-L	Sh	In-L	Sh	In-L	Sh	
Accident											
Injury	10	2	1	3	1	0	2	0	0	1	20
Non-Injury	37	12	13	30	4	5	11	3	2	3	120
Breakdown											
Flat Tire	0	2	0	4	0	1	0	0	0	11	18
Me&/Electrical	8	7	3	29	0	14	1	5	1	29	97
out of Gas	1	0	0	4	0	3	1	1	0	9	19
Other	10	11	5	25	1	2	3	2	0	5	64
Debris/Peds	11	4	4	0	2	2	2	1	0	0	26
TOTAL	*77*	*38*	*26*	*95*	*8*	*27*	*20*	*12*	*3*	*58*	*364*

3.4 Database for Evaluation of Detection Sources

3.4.1 Definitions

A reported event is an "unexpected" occurrence on the travel lanes, shoulder, or the median of the freeway. Reported events in the CAD database include: accidents, lane blockages/closures, spilled loads, vehicle breakdowns, and other events (e.g., calls to report an individual engaged in "reckless" driving.) Reported events may be incidents, and other events based on the following definitions adopted in this study:

Incidents: These are reported events that result in partial or total blockage of at least one travel lane, which temporarily reduces the freeway capacity. Accidents are considered to be incidents regardless of the severity level and final resting positions of the vehicles involved. Breakdowns, debris, and other non-accident events are defined as incidents if they are partially or totally blocking at least one travel lane.

Other Events: These include reported events that do not result in partial or total blockage of a travel lane. Examples include: stalled or abandoned vehicles and debris on the shoulders.

Reported calls: The number of reported calls includes the source calls plusthe calls for incidents that were originally reported by other sources. For example, a cellular call for an incident already reported by the CHP is a cellular reported call because it was made independently of the CHP call. This number of reported calls is used to determine the detection (and false alarm rates) per detection source. The number of reported calls by detection source is shown in Table 3.4, broken down by incidents (accidents and lane-blocking disablements) and other events as defined above.

3.4.2 Matching Probe and CAD Data

The probe vehicle and CAD data were processed to match incidents in the two data sources and develop the final database for the evaluation. Table 3.5 shows the percent matching per detection source and reported event. Primary matching indicators included the time of incident reporting, location (direction, distance, lane) and information on the number and type of vehicles involved. Secondary indicators included the updates and reported times toward clearance. A total of 138 field observed incidents were matched 71.5 percent of the incidents in the CAD), and 127 other events (or 74.3 percent of the 171 CAD reported events.)

Most of the events that were missed by the probe vehicles were actually false alarms involving pedestrians and moving violations that could not be verified by the CHP or FSP, and debris on the roadway. Also, the probe vehicles could miss some events that lasted less the probe vehicles' headway (an average of 7 minutes.)

TABLE 3.4 REPORTED EVENTS BY DETECTION SOURCE

DETECTION SOURCE	CAD Source Calls			Other Source			Reported Calls		
	Acc	L-Blk	Other	Acc	L-Blk	Other	Acc	L-Blk	Other
CELLULARPHONE	61	30	24	13	4	1	74	34	25
CHP	47	12	62	6	1	0	53	13	62
FSP	10	3	22	6	4	10	16	7	32
PUBLIC ENTITY	16	7	9	10	4	0	26	11	9
CALL BOX	6	1	54	3	2	2	9	3	56
TOTAL	*140*	*53*	*171*	*38*	*15*	*13*	*178*	*68*	*184*

TABLE 3.5 MATCHING CAD and PROBE VEHICLE DATA (%)

DETECTION SOURCE	Incidents	Other-Events	Total
CELLULAR PHONE	71.4	41.7	65.2
CHP	72.9	80.6	76.9
FSP	61.5	72.7	68.6
PUBLIC ENTITY	69.6	44.4	62.5
CALL BOX	85.7	87.0	86.9
ALL EVENTS	71.5	74.3	72.8

In the case of conflicting classifications by CAD and by the probe vehicle for an incident, the CAD classification was adopted. For example, an event reported in CAD as an accident but reported by the probe vehicle as a breakdown (because, the vehicle was seen on the shoulder by the probe vehicle driver) was classified as an accident and the corresponding entry in the probe database is updated.

The final database for the evaluation of the cellular phones and other detection sources is shown in Table 3.6. It includes a total of 264 incidents and 1429 other events. The database consists of the events reported by the probe vehicle drivers plus the events reported in the CAD that were missed by the probe vehicles. As it is shown in Table 3.1 the probes reported 209 incidents (167 accidents and 42 other lane-blocking events) and 1385 other events.

TABLE 3.6 DATABASE FOR EVALUATING DETECTION SOURCES

DATA SOURCE	Incidents	Other-Events	Total
CAD Database	193	171	364
Matched w Probes	138	127	265
Missed by Probes	55	44	99
Probe Vehicles	209	1385	1594
TOTAL DATABASE	*264*	*1429*	*1693*

3.4.3 Computation of Incident Detection, Response and Clearance

Incident duration is defined in this research as consisting of three major time components -- detection time, verification plus response time, and clearance time (Figure 3.4), defined as follows:

A. **Incident Detection Time**

Incident detection time is the time between the incident occurrence and the first reporting of the incident. The time when the incident occurs is not known exactly. The information available is the time at which the incident was reported to the CAD center, as well as the time profiles of several probe vehicles before and after the CAD time. Based on this information, the detection time can be estimated as follows (Figure 3.4):

$$T_D = t_{CAD} - t_o \tag{3-1}$$

where:

t_{CAD} : *time incident was first reported to the CAD by a particular source time*
t_o : *of incident occurrence*

To calculate t_0 it is assumed that the incident occurred at half the headway between the probe vehicle first witnessing the incident and the immediately previous probe vehicle passing the incident location:

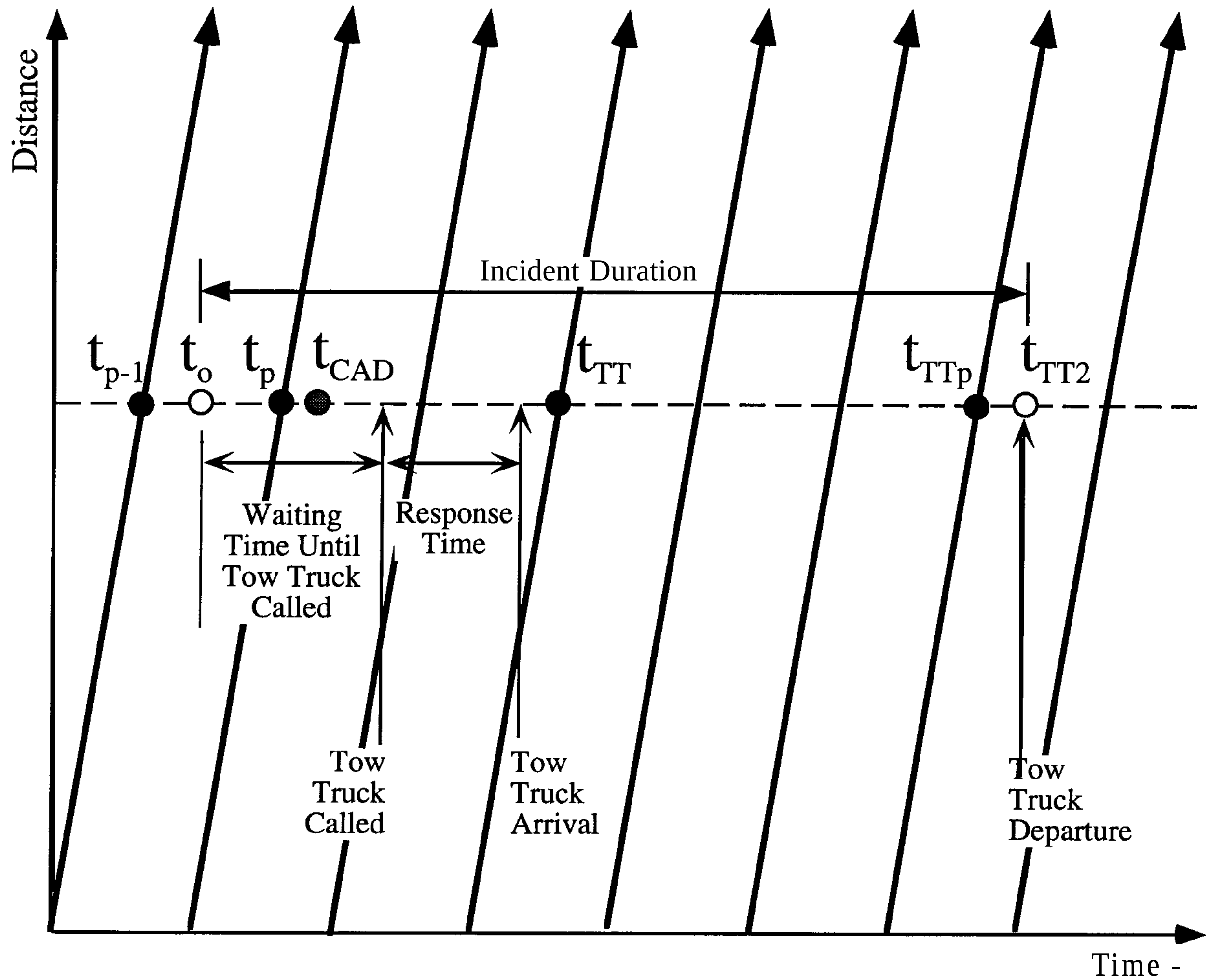
$$t_o = t_{p-1} + (t_p - t_{p-1})/2 \tag{3-2}$$

where.

t_p : *time incident was first observed by the probe vehicle. time the*
t_{p-1} : *previous probe vehicle passed the incident location.*

In a number of cases, the probe vehicle reported the incident after that incident had been reported to the CAD center by a particular source. In such cases:

t_p : t_{cad}
t_{p-1} : *the time a probe vehicle passed the incident location immediately before the CAD time.*



LEGEND

→	Probe Vehicle Trajectories
t_o	Time of Incident Occurrence (unknown)
t_p	Time Detected by Probe Vehicle
t_{CAD}	Time Incident Reported to CAD
t_{TT}	Time Tow Truck Detected by Probe Vehicle
t_{TTp}	Time Tow Truck Last Detected by Probe Vehicle
t_{TT2}	Actual Time of Tow Truck Departure

Figure 3.4 Computation of Incident Detection, Response and Clearance Times

In a small number of cases, the calculations of detection time using the above procedures may be negative. This happens when the detection times are very short (i.e., the reported time was very close to the actual occurrence time). In such cases, a very small detection time (of 0.2 minutes) was assumed.

B. Incident Verification plus Response Time

Verification plus response time is the time between the first incident reporting and the arrival of the response team. This time includes the CHP verification of the existence of the reported incident, determination of response actions needed to clear the incident, dispatch of the response team, and the response team's travel to the site.

C. Incident Clearance Time

Incident clearance time is the time between the response team's arrival and the completion of the incident clearance. Clearance time can include a large number of activities such as removals of the vehicles and debris from the roadway, cleanup, attending to the injured, and on-site incident investigations. However, there is no information available on the various stages of incident clearance that may significantly affect the impact of incident on traffic flow, i.e, the time lane-blocking incidents moved to shoulder, and incident removal.

As it was previously mentioned, there was no information in the CAD on clearance times for incidents assisted by other than FSP tow trucks. Such information was provided by the tow truck companies' logs and the probe vehicle data.

CHAPTER 4

EFFECTIVENESS OF CELLULAR PHONES IN INCIDENT DETECTION

This Chapter assesses the advantages and disadvantages utilizing cellular phones in freeway incident detection, relative to other detection sources.

4.1 Evaluation Approach

The following measures of effectiveness (MOEs) were selected to evaluate the adequacy and effectiveness of cellular phones for incident detection and reporting:

- Detection rate
- False alarm rate
- Timeliness of incident detection
- Accuracy of incident location
- Detail of incident type
- Detail of incident severity
- Detail on the number and type of vehicles involved

The rate of incident detection is a key determinant of the effectiveness of any incident detection source. Incident detection is the first step, and the key activity, of freeway incident management. An ideal detection source is one that is able to detect as many freeway incidents as possible. Incident detection, as well as incident reporting to the proper authority, enable freeway incident management personnel to take actions to clear the roadway and attend to the injured. Once detected and verified by the proper authority, the vehicles involved in many incidents can be quickly removed to the shoulder, which minimizes their impact of freeway congestion. On the other hand, freeway incidents that are not detected by, or reported to, proper authority could result in blockage of travel lanes for a long time, thus escalating freeway congestion upstream of the incident.

The rate of false alarms generally does not contribute to freeway congestion. However, an incident detection source with a high rate of false alarms is likely to decrease the efficiency, and increase expenditures, of the incident management process.

Timeliness of incident reporting is important because it helps to speed up the incident response, and thus shortening the incident duration. Therefore, the freeway can be more quickly restored to its full capacity, and injured motorists can receive medical treatments in a timely manner.

The ability of an incident detection source to provide clear and accurate incident locations, as well as details about the incident type, incident severity, and the number and kinds of vehicles involved, is important for timely incident management. This is because these kinds of information are essential for the traffic control center to mobilize appropriate incident response actions to clear the freeway.

The evaluation addressed the following issues/questions:

(i) The adequacy of cellular phones in detecting and reporting freeway incidents, relative to each of the other incident detection methods.

(ii) The incident detection capabilities of cellular phones plus CHP (both of which are an integral part of freeway operations), in the absence/presence of FSP as well as absence/presence of surveillance system with loop detectors.

The evaluation of advantages and disadvantages of cellular phones in incident detection, relative to other detection sources, is based on the incident database for the 9-mile section of I-880 monitored during the FSP Study as described in Chapter 3.

The total numbers of reported incidents and other events consist of those reported by the probe vehicles and those reported in the CAD database that were not captured by the probe vehicles. The probe vehicles could miss some incidents with very short durations (i.e., shorter than the probe vehicles' headway). Also, probe vehicles would miss moving violations, pedestrians and debris on the roadway reported by mobile sources. A total of 264 incidents and 1,429 other events were reported on the studied I-880 section during the data collection period (Table 3.6).

4.2 Evaluation Results

Results of comparisons of the above mentioned MOEs between cellular phones and other detection sources are presented below.

4.2.1 Detection Rate

Preliminary examination of the data revealed that it was common for some events to be detected by more than one detection source, or by more than one party of the same detection source. For example, the FSP personnel could detect an incident blocking travel lanes, which was also reported by passing motorists using cellular phones, as well as by the driver himself using a call box. Furthermore, it is not uncommon for an event to be reported by several motorists using cellular phones (duplicate calls).

Events reported by sources other than the CHP or the FSP sometimes cannot be verified by CHP officers who are later dispatched to the reported locations. Such events are defined as *"false alarms"*.

Table 4.1 has been constructed from Table 3.4 (total reported events) and shows a classification of the calls in the CAD database by detection source. An incident detection rate for a particular detection source is the percent of total (264) incidents in the database detected by that detection source. The rate of detecting other events is similarly defined. The calculation of detection rates is based on the detection calls shown in Table 4.1 (excluding the false alarms). Note that FSP was not in operation in the "before" study, and the FSP detection rates were calculated using the reported events during the "after" study.

TABLE 4.1 CLASSIFICATION OF CALLS BY DETECTION SOURCE

A. INCIDENTS

DETECTION SOURCE	Source Calls	Other Source	Total Reported	Detection Calls	False Alarms
CELLULAR PHONE	91	17	108	100	8
CHP	59	7	66	66	0
FSP	13	10	23	23	0
PUBLIC ENTITY	23	14	37	35	2
CALL BOX	7	5	12	12	0
TOTAL	*193*	*53*	*246*	*236*	*10*

B. OTHER EVENTS

DETECTION SOURCE	Source Calls	Other Source	Total Reported	Detection Calls	False Alarms
CELLULAR PHONE	24	1	25	17	8
CHP	62	0	62	62	0
FSP	22	10	32	32	0
PUBLIC ENTITY	9	0	9	8	1
CALL BOX	54	2	56	52	4
TOTAL	*171*	*13*	*184*	*171*	*13*

A. Rate of Incident Detection

The analysis results shown in Table 4.2 indicate that cellular phones have the highest incident detection rate (38 percent), followed by the CHP (25 percent), the FSP (17 percent), public entities (13 percent), and call boxes (5 percent).

A further analysis is performed to determine the contribution of cellular phones in detecting incidents in the presence of the CHP. Because the CHP patrol will always be part of freeway operations, it is of interest to determine whether incidents reported by cellular phones are usually the same ones witnessed by the CHP. If so, the contribution of cellular phones in detecting incidents is probably not critical. In this regard, the rate of incident detection by the combined CHP and cellular phones is found to be 60 percent (Figure 4.1). Comparing this combined incident detection rate with that by the CHP alone indicates that cellular phones capture additional 35 percent of freeway incidents not witnessed by the CHP, indeed a significant contribution of cellular phones.

The addition of the FSP to the combined CHP and cellular phones is found to increase the rate of incident detection from 60 to 75 percent. This indicates a significant contribution of the FSP as they detect additional 15 percent of freeway incidents that are not captured by the CHP or cellular-phone motorists.

B. Detection Rate--Other Events

The calculation of the detection rates for other events indicate that all detection sources show low rates of detecting other events (Table 4.2). Among the various detection sources examined, public entities and cellular phones show the lowest detection rate (0.6-1.2 percent), compared with the call boxes (3.6 percent), CHP (4.4 percent) and FSP (4.9 percent).

The contribution of the cellular phones in detecting other events in the presence of CHP was marginal; The detection rate of combined CHP and cellular phones was 5 percent as opposed to 4.4 percent by the CHP alone. However, the addition of FSP to CHP almost doubled the combined detection rate to 8.5 percent.

The above analysis results on detection rates for cellular phones imply that:

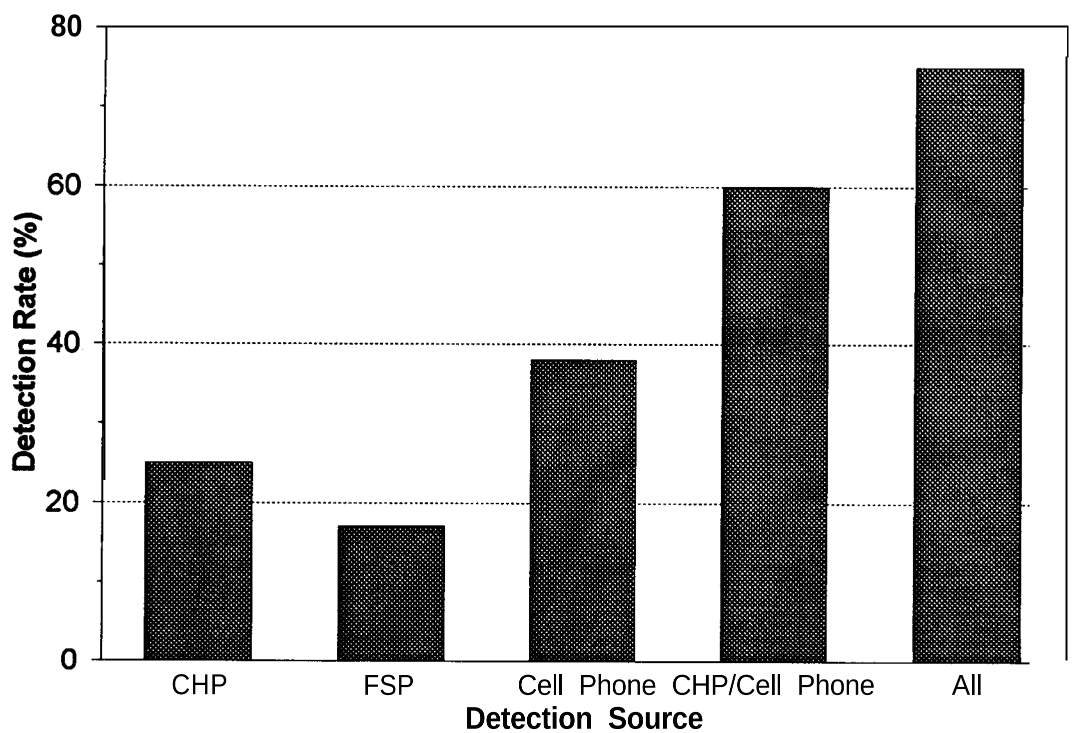
Cellular phones have the highest rate among the different detection sources in detecting freeway incidents (i.e., accidents plus events resulting in lane blockage), but they are the least effective in reporting other events (i.e., vehicles stalled/resting on the shoulder or median).

- Cellular phones capture a significant proportion of freeway incidents not witnessed by the CHP.
- Cellular-phone motorists are about 30 times more likely to detect and report incidents than other events.

TABLE 4.2 DETECTION AND FALSE ALARM RATES (%)

DETECTION SOURCE	DETECTION RATE		FALSE ALARM RATE	
	Incidents	Other Events	Incidents	Other Events
CELLULAR PHONE	37.9	1.2	7.4	32.0
CHP	25.0	4.3	0.0	0.0
FSP	17.1	4.9	0.0	0.0
PUBLIC ENTITY	13.3	0.6	5.4	11.1
CALL BOX	4.5	3.6	0.0	7.1

FIGURE 4.1 INCIDENT DETECTION--COMBINED SOURCES



Drivers themselves have to report other events far more frequently than incidents. This is probably because freeway incidents (having blocked travel lanes and impeded traffic flow) are likely to get immediate attention from other road users and public officials as soon as they occur. On the other hand, other events (which occur with greater frequency such as breakdowns on the shoulders) are often not noticed by other road users.

4.1.2 False Alarm Rate

False alarms are reported events that cannot be verified by the CHP officers dispatched to the scene. Examination of the CAD database reveals that false alarms are usually reported by one party without duplicate calls.

The incident false alarm rate for a detection source is defined as the percent of al the incidents reported by that source that are false alarms. Similarly, the false alarm rate for other events is the percent of total other events reported by a detection source that are false alarms. By design, the number of false alarms for the CHP and the FSP is zero because when the CHP or the FSP detect and report an event, that event is automatically considered verified. For events reported by cellular phones, public entities, and call boxes, the CHP officers are typically dispatched to the scene to verify the existence of the reported events before response actions are mobilized.

The analysis results indicate that 7.4 percent of reported freeway incidents by cellular phones are false alarms (Table 4.2). The percent of incident false alarms for public entities is 5.4 percent, while call boxes show zero false alarms.

Cellular phones are found to have a high false alarm rate in reporting other events (32 percent), compared with public entities (11 percent) and call boxes (7 percent). This reflects cellular-phone callers' difficulties in judging whether vehicles resting on freeway shoulder/median are disablements or just temporary stoppage. Also, several callers report reckless drivers or other moving violations that cannot be located.

4.13 Timeliness of Incident Detection

The evaluation of timeliness of incident detection for a particular detection source involves comparing the average time that source takes to report freeway incidents with the time the probe vehicles take to detect the *same* incidents. The CAD database does not have necessary details to enable direct comparisons of timeliness among various detection sources.

The differences in incident reporting times between the probe vehicle and each detection source are calculated for all incidents detected by both sources. Then, a paired t-test is performed on these differences to determine whether the mean detection time by that detection source is significantly different from that by the probe vehicles.

Table 4.3 shows the mean and standard deviation of the differences in incident detection time between the probe vehicles and each detection source. Results of the paired t-tests for each detection source against the probe vehicles are also shown in Table 4.3, which indicates that:

- On the average, cellular-phone motorists report freeway incidents about 3 minutes sooner than the probe vehicles. This difference is statistically significant at α of 0.05.
- On the average, the CHP officers detect freeway incidents about 2 minutes slower than the probe vehicles. However, this difference is statistically significant at α of 0.20.
- On the average, the FSP personnel detect freeway incidents about 1 minute faster that the probe vehicles. This difference is not statistically significant for any reasonable value of α.
- On the average, public entities and probe vehicles report incidents at the same
- On the average, call box users report incidents about 2 minutes sooner than the probe vehicles. A paired t-test for call box versus probe vehicles are not performed due to the small sample size.

TABLE 4.3 TIMELINESS OF INCIDENT

DETECTION SOURCE	Sample Size	CAD-Probe time (min) Mean	St Dev	p-value*
CELLULAR PHONE	62	-2.7	1.2	0.05
CHP	39	1.9	1.5	0.20
FSP	7	-0.7	1.9	0.70
PUBLIC ENTITY	12	-0.2	1.8	0.90
CALL BOX	6	-2.0	2.6	Small sample

**for paired t-test of the means*

Based on the above results, the various detection sources examined can be ranked according to their relative incident detection speeds, from the fastest to the slowest as follows: cellular phones, call boxes, the FSP, public entities, and the CHP.

It should be noted that the probe vehicle drivers were instructed to report incidents witnessed on their direction of travel. The other detection sources in the CAD did report incidents on the opposite travel direction (e.g., a motorist traveling northbound reporting an accident on the southbound lanes.) This partly explains the differences in the timeliness of incident detection between probe vehicles and the other detection sources.

4.2.4 Accuracy of Reported Incident Location

How well a detection source reports incident locations is evaluated by analyzing a subset of incidents reported by both that detection source and the probe vehicles. Reported incident locations by that detection source are compared with locations reported by the probe vehicles as follows. Reported incident location by the detection source of interest is within the same freeway link as reported by the probe vehicle, the reported location is different from the location reported by the probe vehicle by one link, the reported location is different by more than one link, and the reported location is in the wrong travel direction relative to the probe vehicle. A freeway link is defined as the distance between two successive exit ramps in the same direction of travel.

The analysis results shown in Table 4.4 indicate that all detection sources report the incident location correctly 87 percent of the time. CHP and call boxes report the incident location correctly 100 percent of the time. FSP, public entities and cellular phones report incident location correctly about 75 percent of the time. Regarding other events (shoulder disablements) all detection sources report the event locations correctly (83 to 100 percent), except for cellular phones (55 percent).

4.2.5 Available Information on Incident Type

An analysis is performed to compare the ability of various detection sources to provide information about the incident type. The results indicate that most detection sources have good capabilities in reporting the incident type. The CHP, FSP, and call boxes show 100 percent correct reporting of the incident type. Cellular phones and public entities are found to correctly report the incident type about 94-98 percent.

4.2.6 Available Information on Incident Severity

An analysis is performed to compare the ability of various detection sources to provide information on the incident severity. The results indicate that, for freeway accidents, the CHP and FSP have the highest reporting of the accident severity among the various detection sources examined (95 percent). They are followed by call boxes (78 percent), public entities (72 percent), and cellular phones (51 percent).

TABLE 4.4 ACCURACY OF REPORTED INCIDENT LOCATIONS (%)

DETECTION SOURCE	INCIDENTS Same Link*	INCIDENTS I-Link Apart	INCIDENTS 2-Links Apart	INCIDENTS OTH**	OTHER EVENTS Same Link	OTHER EVENTS I-Link Apart	OTHER EVENTS 2-Links Apart	OTHER EVENTS OTH
CELLULAR PHONE	76	21	0	3	55	45	0	0
CHP	100	0	0	0	100	0	0	0
FSP	75	25	0	0	93	7	0	0
PUBLIC ENTITY	75	25	0	0	83	17	0	0
CALL BOX	100	0	0	0	87	11	0	2
ALL SOURCES	*87*	*12*	*0*	*1*	*90*	*9*	*0*	*1*

** Link: freeway segment between successive exit ramps*
***OTH: wrong direction*

4.2.7 Available Information About Number and Type of Vehicles Involved

An analysis is performed to compare the ability of various detection sources to provide information about the number of vehicles involved (Table 4.5). The results indicate that all detection sources provide this information for all vehicle disablements blocking travel lanes. For accidents, CHP, cellular phones, and call boxes show the highest percent of cases with information about the number of vehicles (89-100 percent), followed by FSP and public entities (71 percent).

An analysis is performed to compare the ability of various detection sources to provide information about the vehicle type. CHP provides this information 100 percent of the time. The results shown in Table 4.5 indicate that the rest of the detection sources are better able to provide this information if the incidents were vehicle disablements blocking travel lanes than if they were accidents. For accidents, call boxes show the highest cases with information on the vehicle type (56 percent), followed by cellular phones (30 percent), the FSP (21 percent), and public entities (11 percent).

For vehicle disablements blocking travel lanes, cellular phones show the highest percent of cases with information on the vehicle type (89 percent), followed by the FSP (71 percent), call boxes (67 percent), and public entities (57 percent).

TABLE 4.5 INFORMATION ON NUMBER & TYPE OF VEHICLES INVOLVED

DETECTION SOURCE	# OF VEHICLES		VEHICLE TYPE	
	Accident	Other	Accident	Other
CELLULAR PHONE	91.2	100.0	29.8	89.3
CHP	100.0	100.0	100.0	100.0
FSP	70.6	100.0	21.4	71.4
PUBLIC ENTITY	71.4	100.0	10.7	57.1
CALL BOX	88.9	100.0	55.6	66.7

4.3 Summary of the Evaluation of Detection Sources

Based on the above analysis results, the various detection sources in the CAD system are ranked by their effectiveness with respect to each MOE, as shown in Table 4.6. Rank "1" designates the lowest effectiveness, while rank "5" designates the highest effectiveness. Table 4.6 indicates that, relative to other detection sources, cellular phones have the highest incident detection rate, and are reasonably effective (with above-average ranking) in terms of the rate of incident detection, timeliness of incident detection, correct reporting of incident locations, and availability of information about the incident type and the number of vehicles involved. On the other hand, weaknesses of cellular phones include a very low rate of detecting other events, the highest rate of false alarms, and limited information on the incident severity.

TABLE 4.6 RANKING OF DETECTION SOURCES

PERFORMANCE MEASURE	Cell Phone	CHP	FSP	Public Entity	Call Box
Detection Rate-- Incidents	5	4	3	2	1
Detection Rate-- Other Events	1	5	5	1	4
False Alarm Rate	1	5	5	3	4
Timeliness of Detection	5	1	4	4	3
Correct Incident Location	2	5	4	3	4
Detail on Incident Type			*About the same*		
Detail on Incident Severity	2	5	5	3	4
Detail on Number of Vehicles	4	5	2	2	3
Detail on Vehicle Type	3	5	2	1	4

4.4 Incident Detection by Loop Detectors

Extensive work has been undertaken on detecting incidents by loop detectors, and a number of incident detection algorithms have been proposed. These incident detection algorithms generally fall into two major categories: threshold based and dynamic flow predictions. Threshold based approaches compare real time data on occupancy and volumes against preset thresholds to determine the occurrence of the incident. Flow prediction based methods compare the predicted (from time-series data) and actual detector data to identify changes due to an incident occurrence. Recent approaches include the application of expert systems, Bayesian analysis, neural networks and catastrophe theory.

The incident database and traffic flow data from the loop detectors (speed, flow, occupancy) was applied to several incident detection algorithms to estimate detection and false alarm rates. The algorithms tested included the threshold based California algorithms #2, 7 and 8 (Payne, 1978), and the Minnesota algorithms based on exponential smoothing of occupancy data (Stefanedes, 1996.)

The selected incident detection algorithms were first applied with their parameter values as reported in the literature. The incident detection rates were negligible. Next, an attempt was made to calibrate the parameters for each algorithm to achieve a high detection rate with an acceptable false alarm rate. Despite the calibration efforts, there was no significant improvement in the results.

Recently, other researchers proposed and applied incident detection algorithms on the same I-880 database and reported promising results. Stefanedes (1996) found that the exponential smoothing of occupancy algorithm produced detection rates of 89 percent and false alarm rates of 0.1 percent. A probabilistic neural network algorithm (Baher 1997) produced detection rates of 98 percent with zero false alarms. However, in these studies the algorithms were developed and tested only to a small sample of incidents in the database (about 50 incidents out of 209 incidents and 1385 other events observed by the probe vehicles.) This sample of incidents was *pre-selected* from the entire database as the ones are most likely to be detected prior to the application of the incident detection algorithm. Furthermore, these studies provide different interpretations of the *same sample of incidents.* According to Baher "the effects of incidents of traffic conditions were not severe, and hence were less detectable." On the other hand, Stefanedes states that "the site includes severe, more easily detectable incidents."

The exploratory analysis of loop detector incident detection algorithms indicate that the existing detector algorithms cannot perform satisfactorily in a real-world operating environment with a high frequency of incidents and other events. It is impossible in a real-world TMC to be able to pre-screen incidents to apply the incident detection algorithm. Instead it is important that the algorithm should be able to detect incidents in the presence of noise in the data. One possible approach is to combine the information from loop detectors and other sources to determine the incident occurrence, such as cellular phone reports, and video surveillance. Such an incident detection framework is currently under development as part of a federally sponsored project (Payne, 1996).

CHAPTER 5

MODELING OF INCIDENTS

This Chapter describes existing techniques for estimating the incident impacts, and presents the development of incident duration models. The proposed models would be used in identifying control strategies to reduce incident duration, and thus the impact of incidents on freeway congestion.

5.1 Incident Impact Models

A number of techniques can be used to estimate the incident impacts--delay, fuel consumption and air pollutant emissions. This section describes existing incident impact models and illustrates through an example the significance of incident characteristics (type, severity, duration) and freeway operating conditions (volume, capacity) on the incident impacts.

5.1.1 The Queuing Diagram

Figure 5.1 shows vehicle cumulative vehicle arrivals and departures at a freeway location as a function of time. At time $t=T_s$, an incident occurs reducing the available freeway capacity from *(c)* to *(c')*. If the traffic volume *(q)* is higher than the remaining capacity *(c')* at the incident location, a queue is formed and increases at a rate *(q-c')* until the incident is cleared at time $t=T_e$. The delay due to the incident is the area between the arrival and departure curves:

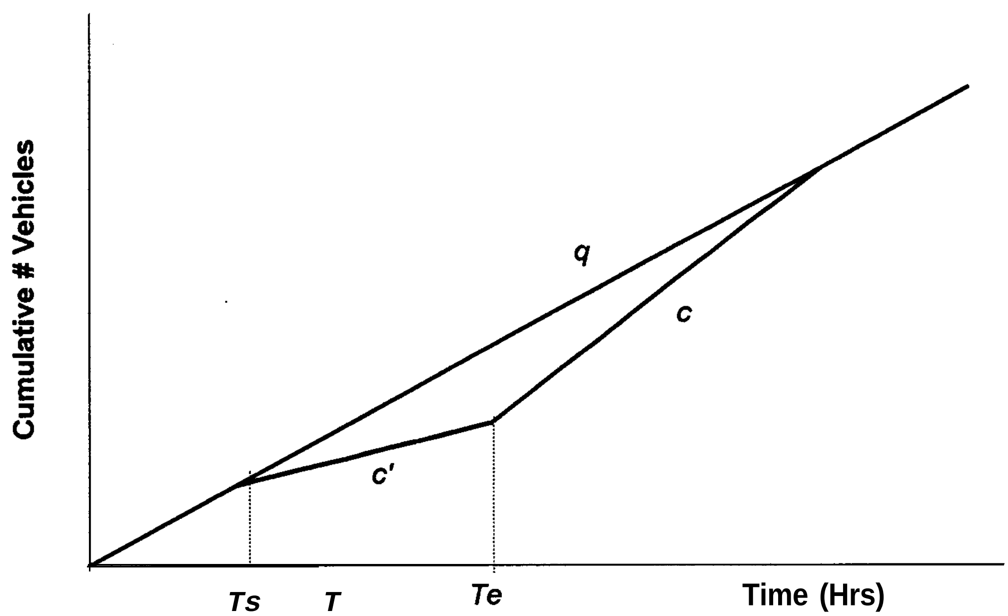
$$D = \frac{(q-c')(1-c'/c)\,T^2}{2\,(1-q/c)} \qquad (5\text{-}1)$$

where:

D: incident delay (veh-hr)
q: traffic volume (veh/h)
c': remaining capacity (veh/h)
c : freeway capacity (veh/h)
T: incident duration (hr)

This queuing diagram originally discussed in the freeway operations context by Moskowitz (1963) has been extensively used to estimate incident delay and the effectiveness of incident management measures (Urbanek and Rodgers 1978, Lindley 1986, Roper 1990.) The critical inputs to this method are traffic demand, remaining roadway capacity due to the incident, and the incident duration.

FIGURE 5.1 QUEUING AT INCIDENT LOCATION

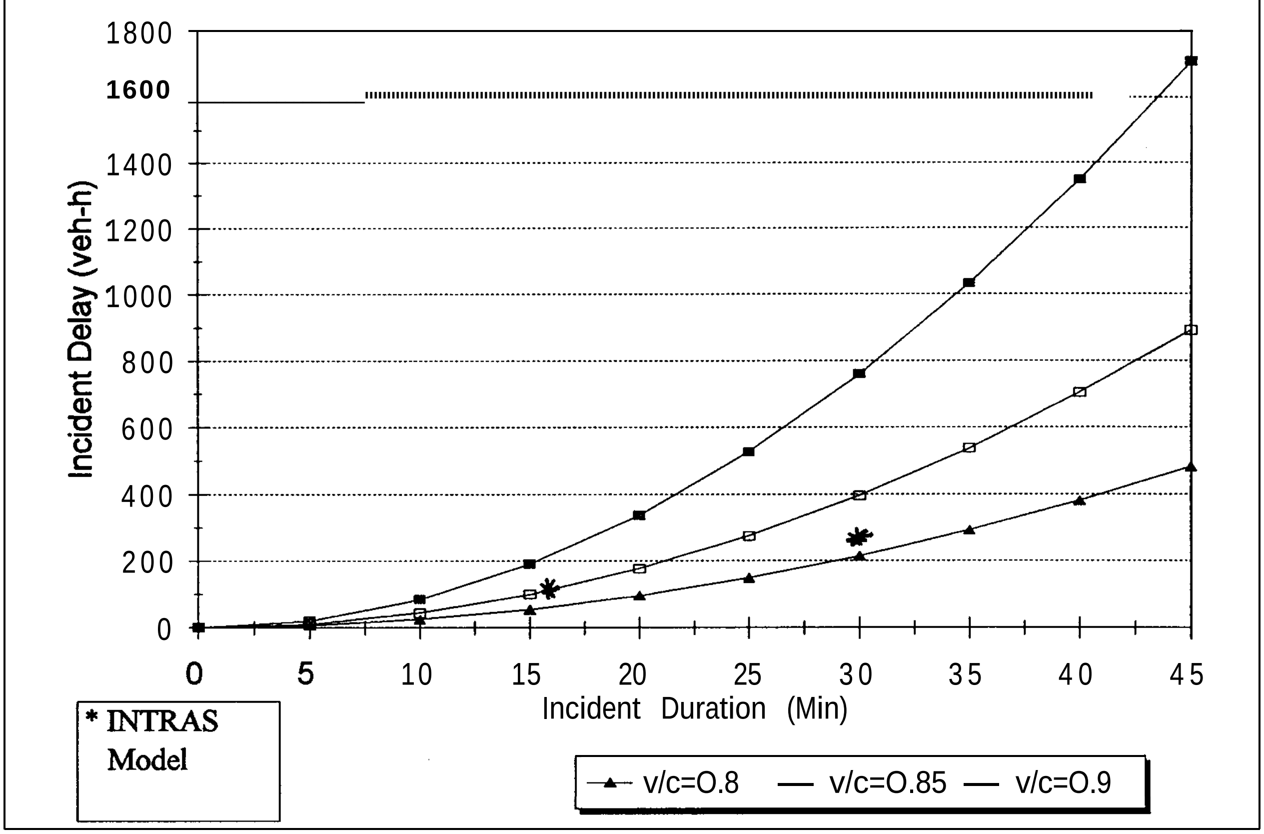


Incidents reduce freeway capacity when they block traffic lanes and cause rubbernecking, i.e., the tendency of drivers to slow down and observe the incident particulars or shy away from the incident location. Limited field data show that the capacity loss is disproportionate to the physical lane blockage; incidents blocking one travel lane reduce capacity by 51 percent on a six lane freeway, and by 42 percent on a eight lane facility (Goolsby 1971). Shoulder accidents involving ambulance/police on the scene would reduce capacity by about 19 percent on a six lane freeway. These findings are based on old data and may not represent today's conditions on freeways with much higher commute traffic and different driver-vehicle characteristics. Therefore, current location specific field data are needed for accurate estimation of incident impacts.

The impacts of incidents are higher as the traffic demand approaches the freeway capacity. The incident delay also depends on changes in traffic demand during the incident because of diversion of traffic to other routes. The diversion rate depends on the availability of alternate routes, timeliness of transmitted information, familiarity with the area, trip characteristics, and drivers' compliance rate. Also, the traffic demand at the incident of interest could be metered from other incidents occurred upstream.

The queuing diagram was applied to calculate the incident delay for a typical four lane freeway section (capacity c=8,000 vph) and one-lane blocking incident (remaining capacity c'=5400 vph) for a range of demand levels (volume/capacity ratio) and incident durations. The results are shown in Figure 5.2. These results indicate that the incident duration is a critical determinant of the delay.

FIGURE 5.2 DELAY vs INCIDENT DURATION



5.1.2 Travel Time Difference Method

This method estimates the incident delay as the difference in travel times to traverse a freeway section under normal and incident conditions:

$$D = QTL\left(\frac{1}{V} - \frac{1}{V_f}\right) \qquad \textbf{(5-2)}$$

where:

D = *incident 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 (mph)*
V_f = *average travel speed under prevailing incident free conditions (mph)*

This method was applied to estimate: the incident impacts in the FSP Evaluation Study (Skabardonis 1995). The freeway section upstream of the incident location is divided into k segments of approximate equal length L_k (Figure 5.3a) The speeds and volumes on each segment are assumed to be constant and equal to the values provided by the loop detectors within the segment. The average incident-free speed is based on the loop detector data throughout the study period. The delay is then calculated for each time slice (typically 1 to 5 minutes long) on each segment upstream of the incident as follows:

$$D_{ki} = L_k \frac{t}{60} Q_{ki} \left(\frac{1}{V_{ki}} - \frac{1}{V_{kif}} \right) \quad 0 < V_{ki} < V_{kif} \qquad (5\text{-}3)$$

The delay values on each freeway segment from the Equation (5-3) are plotted as delay contours as a function of time and distance at loop detector spacings (Figure 5.3b), and the occurrence of incidents are then plotted on the same diagram. Different symbols are used in the plotting of incident occurrence to provide information on incident type. The area of influence of the incident in time and space can be easily seen on those plots. For example, the incident # 117 (accident on the shoulder) is causing significant delays, but both incidents #110 and 116 (right shoulder breakdowns) do not cause any delay on the freeway.

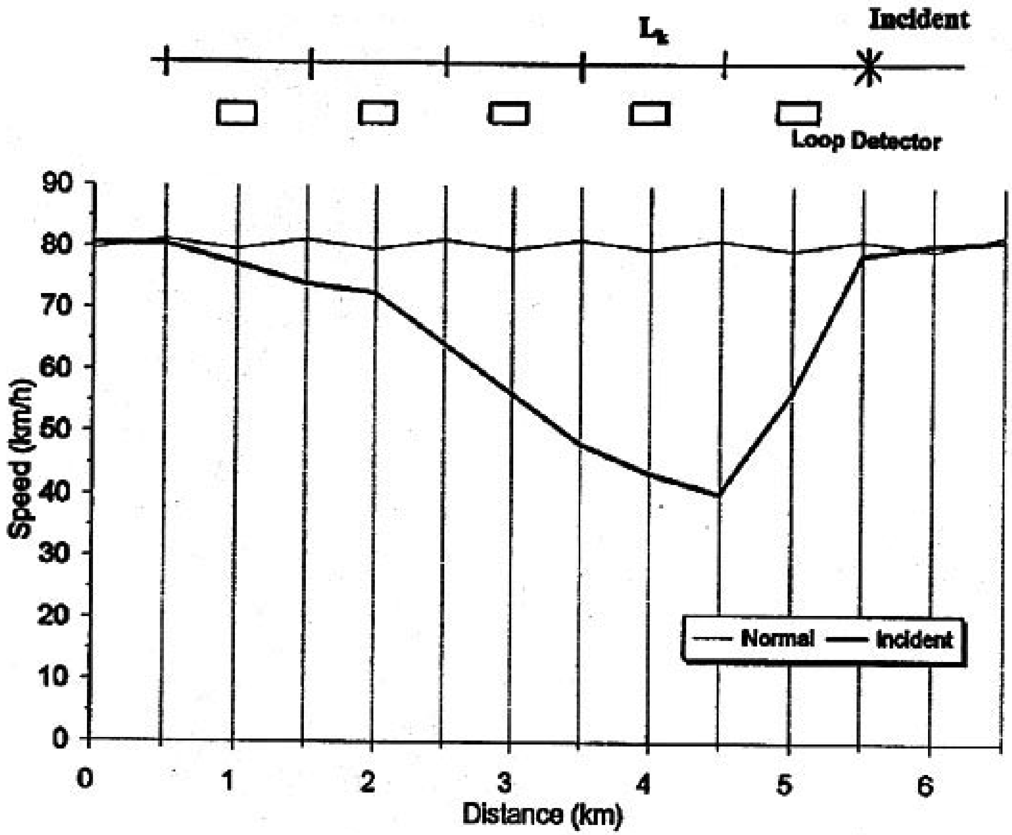
The total incident specific delay is calculated as the sum of delays during the time period [T_s, T_e], L_e, *m* time slices, over the freeway section [L_s, L_e] (*n* freeway segments):

$$D = \sum_{k=1}^{n} \sum_{i=1}^{m} D_{ki} \qquad (5\text{-}4)$$

5.13 Simulation Models

A number of models are available to simulate traffic flow on freeways and predict the incident impacts. The existing models fall into two major categories: macroscopic models use analytical relationships between the average traffic stream characteristics (speed, flow, density) to simulate traffic flow. Examples include the FREQ10 (Leiman & May 1991) and the FREFLO (Payne 1979) models. Microscopic models in contrast, e.g., INTRAS (Wicks 1980), simulate individual vehicles based on car-following, lane changing and queue discharge algorithms.

The INTRAS model was applied to predict the incident delay on the example problem used in the application of the queuing diagram. The following two scenarios were simulated: v/c of 0.85 and incident duration of 15 minutes, and v/c of 0.8 and incident duration of 30 minutes. The predicted delays are shown in Figure 5.2 and are in close agreement with the estimates from the queuing diagram method.



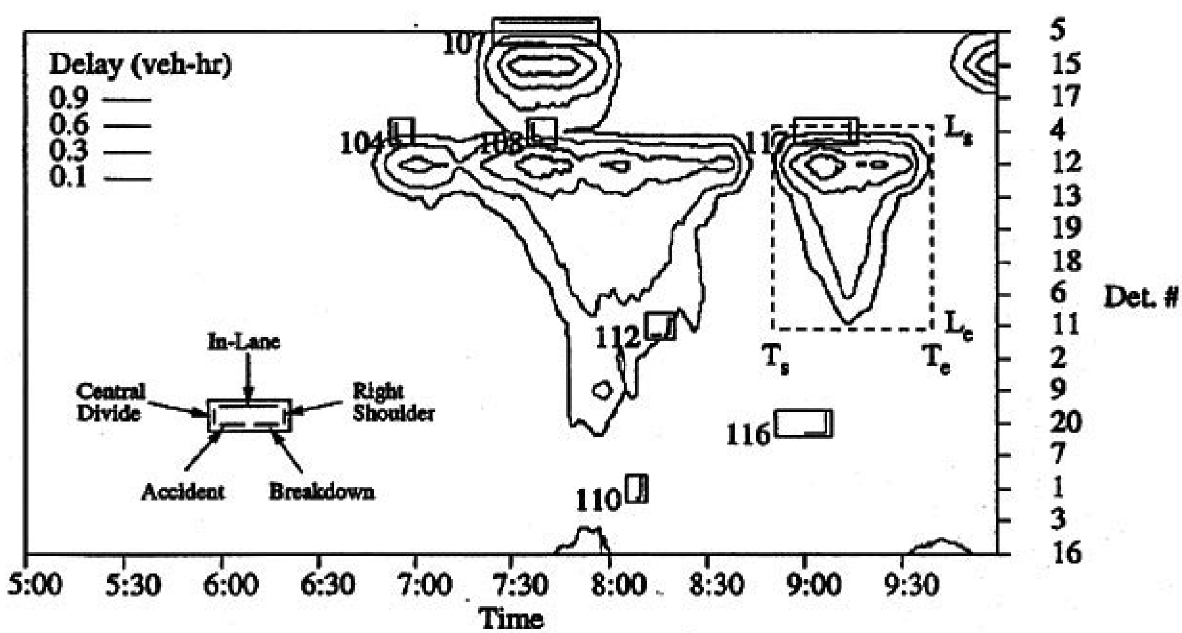


FIGURE 5.3 INCIDENT DELAY ESTIMATION FROM LOOP DETECTORS

5.2 Incident Duration Models

The results from the application of incident impact models indicate that the incident duration is a critical determinant of the delay. Therefore, a goal of freeway incident management is to shorten the duration for which the roadway capacity is being reduced by the incident (i.e., incident duration) as far as possible, and/or move lane-blocking incident to the shoulder(s) as fast as possible.

As it was discussed in Section 2.2, several prior studies attempting to quantify incident duration as a function of influencing factors (e.g., Jones et al 1991; Giuliano 1989; and Golob et al 1987) reported similar sets of variables affecting incident duration. These variables are the incident type and severity, number of vehicles involved, number of lanes blocked, time of day, and special events. Prior studies generally did not examine the effects on incident duration due to the incident detection source (e.g., police and motorist assistance patrol, cellular phones, call boxes, public entities), and detection speed (i.e., the time it takes to report the incident after its occurrence).

The purpose of developing incident duration models is to determine relationships between incident duration and influencing variables. Such models would be useful for assessing potential changes in the length of the incident duration due to different detection times brought about by different technologies (e.g., cellular phones, FSP and call boxes.)

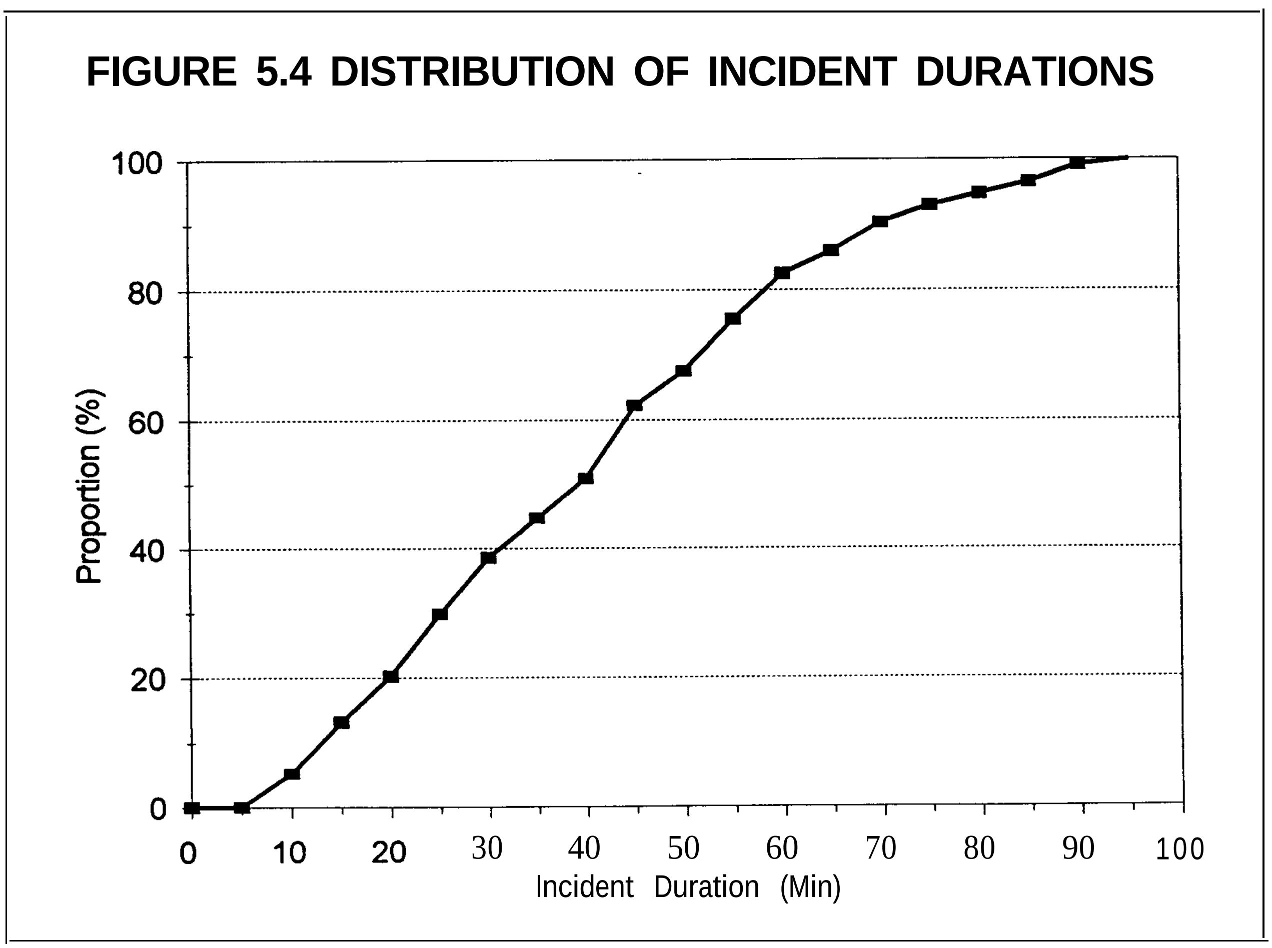
The CAD database was used as the data source for the development of the incident duration models. The database includes all the accidents and events that result in partial or total blocking of at least one travel lane (a total of 194 incidents). Breakdowns, spilled loads and other non-accident events that did not block travel lanes were excluded from the development of incident duration models. A number of observations were excluded because of unknown durations (false alarms, moving violations, or unknown response/clearance times).

Table 5.1 shows the duration statistics in the modeling database per incident type and detection source. The average duration of all incidents is 40 minutes, and on the average, the incident detected by CHP/FSP are shorter by about 16 minutes. Injury accidents have the highest durations followed by non-injury accidents and lane-blocking disablements. The average duration of FSP assisted incidents were 36 minutes and 59 minutes for the non-FSP tow trucks. The FSP trucks proceed immediately to clear the incident while the rest of the assisted incidents have to wait for the arrival of the rotational tow trucks. Also, non-FSP tow trucks are mostly involved in removing accidents.

The distribution of incident durations is shown in Figure 5.4. About 85 percent of all the incidents lasted up to 60 minutes. Most of the lengthy incidents were multicar injury accidents.

TABLE 5.1 INCIDENT DURATIONS* STATISTICS (Minutes)--CAD Database

INCIDENT TYPE	CHP/FSP			Other Sources			All		
	N	Mean	SDev	N	Mean	SDev	N	Mean	SDev
Injury Accident	4	51.4	12.8	10	68.0	21.0	14	63.0	18.0
Non-Injury Accident	42	33.9	19.3	36	46.9	18.4	78	39.9	19.2
Disablement	9	20.6	10.2	13	29.2	13.3	22	25.7	12.9
ALL	55	33.0	19.0	59	46.6	21.0	114	40.0	21.2



5.2.1 Description of the Variables

A. The Dependent Variable

The dependent variable is the incident duration in minutes. Incident duration, the time interval between the moment the incident occurs until the moment the incident is cleared, consists of three contiguous phases: detection, verification and response, and incident clearance. The definition and computation of those time elements have been described in Chapter 3.

B. Candidate Independent Variables Examined

The following candidate independent variables are examined in developing incident duration models (Table 5.2):

Detection Time: Incident detection time (in minutes) is a continuous independent variable in the regression analysis.

Detection Source: The incident reporting sources in the CAD database, include CHP, FSP, cellular phones, call boxes and public entities. The results shown in Table 5.1 and additional preliminary analyses revealed that incident duration characteristics were similar for incidents reported by the CHP and FSP. Duration characteristics for incidents reported by the other detection sources were similar, and were different from those reported by the CHP/FSP.

For the modeling purposes, the incident detection source variable is defined as a dichotomous variable: CHP or FSP; and cellular phones, call boxes, or public entities. It is treated as a dummy (0,l) variable in the regression analysis, with CHP and FSP being coded as 1 while the other sources as zero.

Incident Type: This independent variable consists of three levels: injury accident, non-injury accident, vehicle disablement in travel lanes. It is treated as a set of three dummy (0,l) variables in the regression analysis.

Number of Lanes Closed: This independent variable consists of three levels: none, one lane, and more than one lane. This variable is treated as a set of three dummy (0,l) variables in the regression analysis.

Number of Vehicles Involved: This independent variable consists of three levels: one, two, more than two vehicles. This variable is treated as a set of three dummy (0,l) variables in the regression analysis.

Time of Day (Morning or Afternoon Peak): The CAD database contains freeway incidents during the morning (6:30 - 9:30 am) and afternoon (3:30 -6:30 pm) peak periods only. The morning/afternoon variable is treated as a (0,l) dummy variable in the regression analysis.

Any Large Commercial Vehicle Involved? Incidents involving large commercial vehicles may require different response and clearance actions than those involving only passenger cars, which in turn may affect the incident duration. This variable, with two levels (yes, no), is treated as a dummy (0,l) variable in the regression analysis.

TABLE 5.2 LIST OF INDEPENDENT VARIABLES FOR STATISTICAL ANALYSIS

CANDIDATE INDEPENDENT VARIABLE	DESCRIPTION
Detection Time	Minutes
Detection Source	CHP or FSP Cell Phone, Public Entity, Call Box
Incident Type	Injury Crash Non-Injury Crash Disablement
Number of Lanes Closed	None One Lane More Than One Lane
Number of Vehicles Involved	One Two More Than Two
Is Large Commercial Veh Involved?	Yes No
Time Period	AM Peak PM Peak

5.2.2 Results of the Regression Analysis

The “best” fitted regression model for incident duration was found to be:

$$Y = 41.25 + 0.90X, - 14.40X, -17.02X, +21.76X, \qquad (5\text{-}5)$$

where Y is the incident duration in minutes. The four significant independent variables are as follows:

Explanatory Variable	Estimated Coefficient	Standard Error	p-value
Intercept	41.25	2.91	0.0001
Detection time (Xi)	0.90	0.23	0.0002
Detection source (X,)	- 14.40	3.23	0.0001
Vehicle disablement (X,)	-17.02	4.08	0.0001
Injury accident (X,)	21.76	4.95	0.0001

where:

Detection source variable:

X_2 : *1 CHP or FSP*
0 cellular phone, call box, public entity

Incident type variable:

x, : 1 disablement
0 otherwise

x, : 1 non-injury accident
0 otherwise

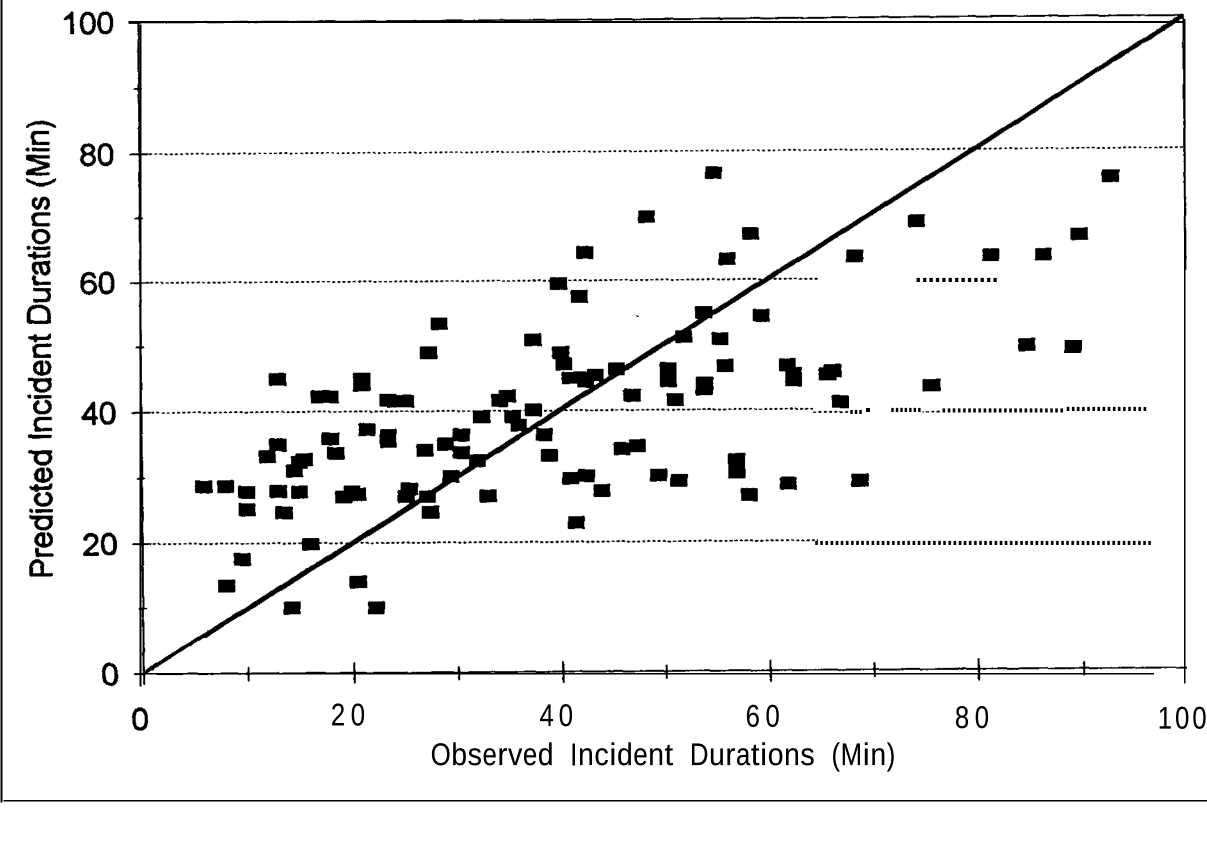
x, : 1 injury accident
0 otherwise

(X, is excluded as required in the regression analysis involving a set of three dummy variables).

The number of lanes closed, number of vehicles involved, large commercial vehicle involvement, and morning vs afternoon peak periods are found to be non-significant independent variables.

The estimated model (Equation 5-5) is based on 114 observations. The R^2 value for the estimated model is 0.40, implying that 40 percent of total variation in incident duration is explained by the estimated regression model. Figure 5.5 shows the observed and predicted incident durations.

FIGURE 5.5 OBSERVED vs PREDICTED DURATIONS



Based on this estimated model, incident duration models for various subsets (made up of the incident type and the detection source) are shown in Table 5.3. The modeling results are plotted in Figure 5.6, in which each line represents a plot of the estimated incident duration as a function of incident detection time for each subset. The Figure indicates that:

- Incident duration models are identical for CHP and FSP reported incidents, which are different from models for incidents reported by cellular phones, public entities and call boxes. Other things being equal, incidents reported by the CHP or the FSP show considerably smaller incident durations than similar incidents reported by the other detection sources. For example, the figure shows that if the CHP detects a non-injury crash about 5 minutes after its occurrence, the total incident duration is expected to last for about 31 minutes. However, if this same non-injury crash is detected by a cellular phone about 5 minutes after its occurrence, the total incident duration is expected to last for 46 minutes.

- For incidents reported by cellular phones, public entities, and call boxes, estimated incident durations for injury crashes are about 1.5 times that for non-injury crashes, and about 2.7 times that for vehicle disablements. For incidents reported by the CHP or the FSP, estimated incident durations for injury crashes are about 1.8 times that for non-injury crashes, and about 5.5 times that for vehicle disablements.

The results of the model estimations presented above suggest that, under the existing incident management process and practice, incident detection by the CHP or the FSP are more time-effective than those involving cellular phones (as well as call boxes and public entities). One reason for this is that when the CHP (or FSP) detects an incident, they usually take actions to respond to it immediately. On the other hand, when a cellular phone caller (call box or public entity) reports an incident to the CAD center, the CHP officer will be dispatched to the scene to *verify* the existence of that incident. After the verification is completed, then the CHP officer (with assistance from the CAD center) begins to take actions to respond to the incident. Therefore, extra delay is incurred in this incident verification process. To make cellular-phone incident detection as effective as the CHP or the FSP detection, in terms of the length of the incident duration, current incident verification and response practices associated with cellular-phone detection need to be revised.

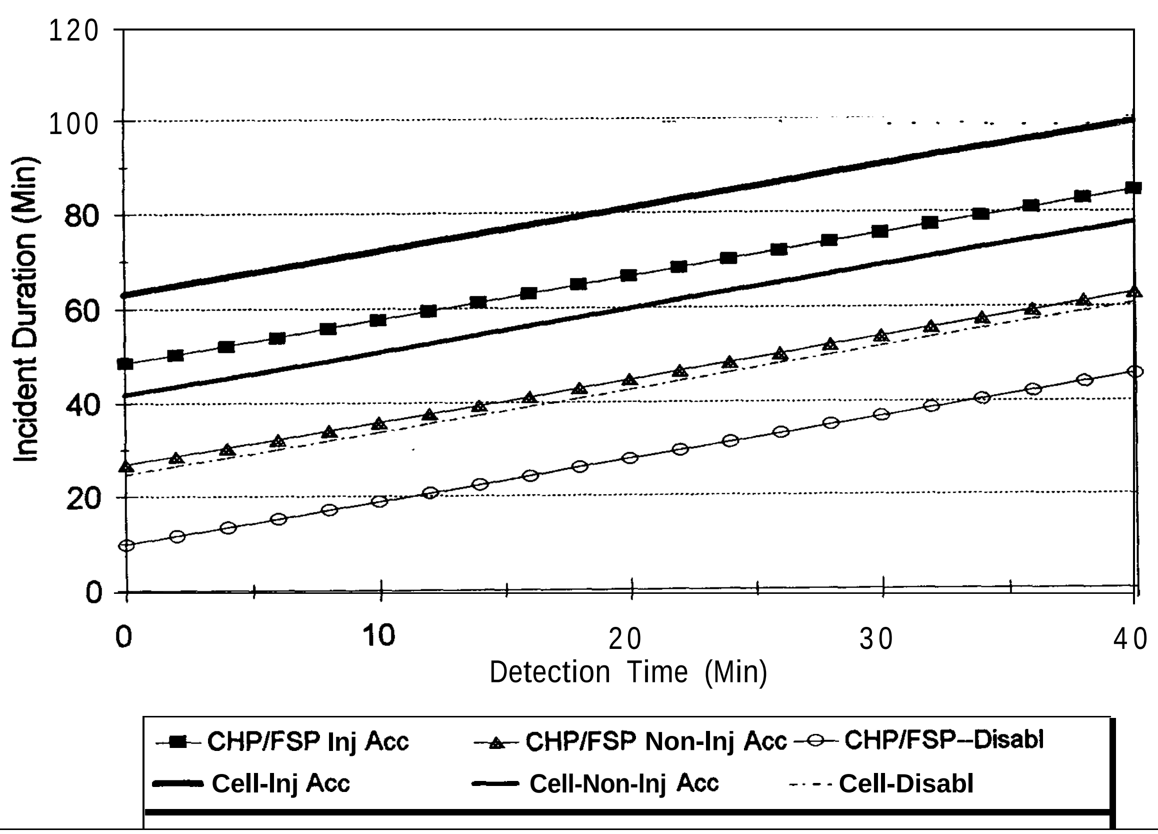
5.3 Relationship Between Detection Times and Incident Durations

The estimated regression model in Equation (5-5) shows that given a particular detection source, incident durations are expected to increase with increasing incident detection times. Further analyses were performed to determine whether the statistical association between incident duration and incident detection time is a cause-effect dependency or simply reflects that incident detection time is one component of incident duration.

TABLE 5.3 ESTIMATED INCIDENT DURATION MODELS

DETECTION SOURCE	INCIDENT TYPE	INCIDENT DURATION (Min)
CHP/FSP	Injury Accident	48.61+0.9* (Detection Time)
CHP/FSP	Non-Injury Accident	26.85+0.9* (Detection Time)
CHP/FSP	Disablement	9.83+0.9* (Detection Time)
Cellular Phone	Injury Accident	63.01+0.9* (Detection Time)
Cellular Phone	Non-Injury Accident	41.75+0.9* (Detection Time)
Cellular Phone	Disablement	24.73+0.9* (Detection Time)

FIGURE 5.6 INCIDENT DURATION MODELS



A regression analysis was performed to determine whether incident verification plus response time is affected by incident detection time. The results indicate that verification plus response time is significantly affected by the incident type (i.e., smaller verification plus response time can be expected for accidents than for vehicle disablements in travel lanes). Incident verification and response time is also affected by whether the incident detection source is the cellular phone or the call boxes/public entity (the former shows smaller verification plus response time than the latter). However, incident detection time is found to be a non-significant independent variable of verification plus response time.

A regression analysis was performed to determine whether incident clearance time is affected by incident detection time. The results indicate that incident clearance time is significantly affected by the incident type, but not by incident detection time or the incident detection source.

A regression analysis was performed to determine whether verification plus response plus clearance time is affected by incident detection time. The results indicate that verification plus response plus clearance time is significantly affected by the incident type and the incident detection source, but not by incident detection time.

Finally, a close examination of the estimated model of Equation (5-5) reveals that the coefficient estimate for detection time is 0.90 with a standard error of 0.23. Therefore, a 95% confidence interval for the coefficient estimate of detection time is [0.44, 1.361, which includes 1.00. The coefficient estimate of 1.00 implies that incident duration is expected to change by the exact same margin as a change in incident detection time.

The findings from the above described analyses collectively suggest that there is probably no cause-effect dependency between incident duration and incident detection time after accounting for the incident type and incident detection source. That is, incident detection time affects the incident duration simply because it is one component of the latter.

5.4 Relationship Between Incident Clearance and Incident Verification plus Response

The analysis of incident clearance time and verification plus response time for those incidents detected by sources other than CHP/FSP indicates the following relationship between the two:

$$Z = 51.29 - 53.52X_3 - 25.93X_4 + 1.43VR \qquad (5\text{-}6)$$

where **Z** is incident clearance time in minutes. The three significant independent variables are as follows:

Explanatory Variable	Estimated Coefficient	Standard Error	p-value
Intercept	51.29	6.32	0.0001
X_3	-53.52	8.09	0.0001
X_4	-25.93	6.38	0.0001
VR	1.43	0.58	0.0162

where.

X_3, X_4, and X_5 are (0, 1) dummy variables representing the three incident types as previously defined (here, X_5 is dropped as required in the regression analysis).

VR is the veriflcation plus response time in minutes.

The R^2 value for the estimated model of Equation (5-6) is 0.40.

This estimated regression model of Equation (5-6) states that incident clearance time is expected to be the highest for injury accidents, followed by for non-injury accidents and vehicle disablements in travel lanes. Further, as verification plus response time for a particular incident type increases, so will incident clearance time. That is, for each incident type, incidents that take longer to verify/respond to also take longer to clear.

CHAPTER 6

CONCLUSIONS

6.1 Summary of the Study Findings

This study performed a systematic evaluation of the effectiveness of cellular phones and other detection sources in the incident management process based on detailed field data on incident characteristics and the CHP/CAD database along a section of I-880 freeway. The results indicate that cellular phones had the highest detection rate (38 percent) for incidents (accidents and lane-blocking vehicle disablements). Relative to the other detection methods, cellular phones are reasonably effective (with above-average ranking) in terms of the timeliness of incident detection, correct reporting of incident locations, and availability of information about the incident type and the number of vehicles involved. On the other hand, weaknesses of cellular phones include a very low rate of detecting "other events" (vehicle stalls and other non-accident events that do not block travel lanes), the highest rate of false alarms, and limited information on the incident severity:

- The detection rate of cellular phones is 38 percent for incidents and about 1 percent for other events. Cellular-phone motorists are about 30 times more likely to detect and report incidents than other events. This is probably because freeway incidents (having blocked travel lanes and impeded traffic flow) are likely to get immediate attention from other road users as soon as they occur. On the other hand, other events (such as vehicle stalls on the shoulders which occur with greater frequency) are often not noticed by other road users.

- About 7 percent of reported freeway incidents by cellular phones are false alarms, usually calls not duplicated by other road users or other detection sources. Cellular phones are found to have a high false alarm rate in reporting other events (32 percent). This reflects cellular-phone callers' difficulties in judging whether vehicles resting on freeway shoulder/median are disablements or just temporary stoppage.

- Comparisons of the average time that a detection source takes to report freeway incidents with the time the probe vehicles take to detect the *same* incidents show that on the average, cellular phones is the fastest detection source followed by call boxes, FSP, public entities, and the CHP.

- Cellular phones reported the incident location correctly 76 percent of the time. They reported the location of other events correctly 55 percent of the time. Cellular phones found to correctly report the incident type and the number of vehicles involved in more than 95 percent of the cases. Information on vehicle type is provided for 89 percent of lane-blocking breakdowns and 29 percent for accidents. Incident severity was reported correctly in 51 percent of the cases.

The incident detection rate by the combined CHP and cellular phones was 60 percent compared to 25 percent by CHP alone. Thus, cellular phones capture additional 35 percent of freeway incidents not witnessed by the CHP, indeed a significant contribution of cellular phones. The addition of the FSP to the combined CHP and cellular phones increased the incident detection rate from 60 to 75 percent, i.e., the majority of the incidents were detected by the CHP/FSP patrols (that are standard components of freeway operations on most urban freeways) plus the cellular phone users.

The exploratory analysis of existing incident detection algorithms to the incident database and the data from loop detectors showed that all algorithms produced very low detection rates and high false alarm rates. Other studies reported high detection rates on the same I-880 test site & they calibrated and applied their algorithms to only a small subset of incidents (about 50 incidents or 18 percent of the total) and ignored other events (shoulder disablements). Therefore, an objective comparison of the loop data based incident detection algorithms and mobile sources cannot be made.

The modeling of incident durations and the statistical analysis to determine relationships between detection, verification plus response and clearance times produced the following results:

- The average duration of all incidents was 40 minutes. The detection source and incident type (disablement, non-injury accident, and injury accident) were significant variables affecting the length of incident duration. Incidents reported by cellular phones (call boxes and public entities) show greater incident durations by about 14 minutes on the average than similar incidents reported by the CHP or the FSP. This extra delay is due to the incident verification process. When the CHP/FSP detects an incident, they usually take actions to respond to it immediately. On the other hand, when other sources report incidents to the CAD, the CHP officer is dispatched to the scene to *verify* the existence of that incident, and after the verification is completed, then the CHP initiates response actions to clear the incident.

- For incidents reported by cellular phones, public entities, and call boxes, estimated incident durations for injury crashes are about 1.5 times that for non-injury crashes, and about 2.7 times that for vehicle disablements. For incidents reported by the CHP or the FSP, estimated incident durations for injury crashes are about 1.8 times that for non-injury crashes, and about 5 times that for vehicle disablements.

- There is probably no cause-effect dependency between incident duration and incident detection time after accounting for the incident type and detection source. Some anecdotal evidence in the literature has suggested that the longer it takes to detect an incident, the more vehicles will be queued upstream of the incident, and the traffic congestion would delay the arrival of the incident response team. However, in the majority of the incidents on the study area, the incident is quickly moved to the shoulder thus significant buildups of the upstream queues do not materialize. Also, the CHP/FSP in most minor incidents, also act as a sole response team as soon as they detect the incidents.

- Verification plus response time is significantly affected by the incident type (i.e., smaller verification plus response time can be expected for accidents than for vehicle disablements in travel lanes). Incident verification and response time is also affected by whether the incident detection source is the cellular phone or the call boxes/public entity (the former shows smaller verification plus response time than the latter). The verification plus response plus clearance time is significantly affected by the incident type and the incident detection source, but not by incident detection time.

- The incident clearance time is not significantly affected by incident detection time or the incident detection source. The clearance time is expected to be the highest for injury accidents, followed by for non-injury accidents and vehicle disablements in travel lanes. Further, as verification plus response time for a particular incident type increases, so will incident clearance time. That is, for each incident type, incidents that take longer to verify/respond to also take longer to clear.

6.2 Discussion

Incident reporting by cellular phones is becoming a standard component of the TMCs throughout the country. However, incident management systems based solely on cellular phones cannot provide the detection requirements of ATMIS systems. Cellular phones can contribute significantly in the incident detection in combination with other sources and provide useful information in the incident management process.

Under the existing incident management process and practice, incident detections by cellular phones (as well as by call boxes or public entities) are simply not as time-effective as incident detections by the CHP or the FSP. To make cellular-phone incident detection as effective as the CHP or the FSP detection, in terms of the length of the incident duration, current incident verification and response practices associated with cellular-phone detection need to be revised.

A significant amount of work remains to be done on incident detection algorithms using data from loop detectors in real-time as transmitted to a TMC. One approach to improve the accuracy and reliability of loop based algorithms is to combine data from other sources including cellular phone reports. Efficient data fusion supplemented by video surveillance (where available) would minimize the rate of false alarms and would provide essential information on the incident nature for quick response/clearance actions.

Considerable amount of time and effort was spent in this project to process the CAD incident data and correlate them with other data sources (field observations, FSP and tow companies' logs.) There is a need to improve the data acquisition and processing including standardization of the incident definitions, reporting of standard vehicle features (e.g., color) and availability of CAD reports in electronic format. This would substantially facilitate the analysis of historical incident data for research and development of operational procedures.

The findings of this study are based on data from one freeway section in the Bay Area, with a limited study period. Additional data and analyses are needed for other freeways in California and other parts of the country (taking also into consideration the increasing usage of cellular phones) to generalize the study findings to other areas.

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