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Incident Management: Process Analysis and Improvement

Randolph W. Hall
University of Southern California

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INCIDENT MANAGEMENT:

PROCESS ANALYSIS AND IMPROVEMENT

FINAL REPORT

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Randolph W. Hall
Dept. of Industrial and Systems Engineering
University of Southern California
Los Angeles, CA 90089-0193

TABLE OF CONTENTS

Abstract ii
Executive summary iii
1. Introduction 1
2. Process Analysis 4
3. Incident Dispatching, Clearance and Delay 15
4. INCISIM: Incident Simulator 18
5. Analysis of Cases 22
6. Conclusions and Recommendations 34
7. References 35
8. Appendix: Example CAD Files for 9 Incident Types 37

LIST OF FIGURES

1. Paths for Dispatching Incident Crew with Fixed Beats 16
2. Paths for Reaching an Incident, From Crews on Rolling Beats 16
3. INCISIM Screen Shot 21
4. Media CAD Screen Shot for Major Truck Incident 24
5. SmartTraveler Incident Report for Major Truck Incident 24
6. PEMS Screen Shot for Major Truck Incident 25
7. SmartTraveler Screen Shot for Major Truck Incident 25
8. Speed Profile, Sig Alert Incident on I10 Eastbound, Midday 29
9. Vehicles Between Upstream and Downstream Detectors 29
10. Speed Profile, Peak Period Incident on I5 Southbound 30
11. Vehicles Between Upstream and Downstream Detectors 30
12. Speed Profile, Minor Offpeak Incident on I405 Northbound 31
13. Speed Profile, Sig Alert Incident on 101 Southbound, Peak Period ... 32
14. Speed Profile, Minor Peak Period Incident, I5 Northbound 33

LIST OF TABLES

1. CAD File for Major Truck Incident 23
2. CAD Log, Sig Alert Incident on I10 Eastbound, Midday 29
3. CAD Log, Peak Period Incident on I5 Southbound 30
4. CAD Log, Sig Alert Incident on I10 Eastbound, Midday 31
5. CAD Log, Sig Alert Incident on 101 Southbound, Peak Period 32
6. CAD Log, Minor Peak Period Incident, I5 Northbound 33

ABSTRACT

This is the final report for the project Incident Management: Process Analysis and Improvement. The report summarizes findings from three earlier working papers (1998-31, 2000-14 and 2000-15) completed under this project, and provides additional analysis on specific scenarios.

This study highlights the importance of the following principles:

1) Response units should be adequate in number to handle anticipated demand.
2) Response units should be strategically located to minimize maximum response times.
3) Especially during busy periods, response units should not be dispatched over long distances. It is better to wait for a closer unit to become available than to waste capacity on overly long response distances.
4) Because response units are frequently mobile, and because response units are frequently busy responding to other incidents, it would be very beneficial for dispatchers to have access to location data.

EXECUTIVE SUMMARY

Incidents – such as collisions, stalls, and dropped loads -- are known to be a major source of highway delay. The amount of delay occurring during an incident depends on three primary factors: (1) the nature of the incidents, (2) roadway conditions, and (3) execution of incident clearance. Clearly, incidents that block more lanes and require more equipment to be cleared (e.g., those involving heavy-duty trucks), will create more delay. The amount of delay will also increase when the roadway operates close to capacity and does not have alternatives for diverting traffic (either shoulders or parallel roadways). And delay also depends on how quickly the incident can be cleared and the actions taken during the incident to ensure smooth traffic flow.

The focus of this report falls in the area of incident clearance. For the purposes of this report, clearance time can be divided into four elements, which we call: (1) detection time, (2) verification/dispatch time, (3) response time, and (4) service time.

Special attention has been given to dispatch time and response time, and the contribution of dispatching policies to delay. Dispatch time merits special attention because it is one of the more controllable elements of clearance time. We consider here policies for dispatching mobile emergency crews, such as police officers and freeway-service-patrol trucks. The key characteristic is that the crews move around the network instead of residing at a stationary base (as is the case for fire crews). We also provide some analysis on response from stationary bases.

A fundamental question in dispatching incident crews is whether to send the closest vehicle that is currently available or to wait for another vehicle to become available that is even closer. Waiting for a closer vehicle is advantageous because service time is effectively reduced, adding to capacity and providing stability at higher levels of utilization. By contrast, a system can become unstable if capacity is insufficient to serve the normal occurrence of incidents. For instance, if response distance becomes excessive, incident crews may be unable to serve incidents as quickly as they occur, causing an increasing backlog of calls. The problem would be aggravated if the dispatcher serves calls in a first-come-first-served order – as incident crews would end up driving very long distances (through congested traffic) to reach incidents. By contrast, by forcing incidents to wait for nearby crews, response time does not grow and the incident response system is able to handle incidents more quickly. This creates a stable system for higher incident occurrence rates.

On the other hand, waiting for a vehicle to become available adds uncertainty, which contributes to expected traffic delay. As a consequence, any reasonably robust dispatch strategy must provide for a hybridization of the two objectives, trading-off greater certainty in response time against stability at higher utilization levels.

In the case of individual beats, expected response time is a linear function of both the interchange spacing and the time penalty for changing direction of travel on the highway. On the other hand, with rolling beats (either with fixed spacing or Poisson process locations), increases in interchange spacing and the direction-change penalty do not cause expected response time to increase without bound. Instead, it approaches a limit, for which the responding vehicle always reaches the incident from an upstream location on the same side of the highway. However, rolling beats, in which the closest available vehicle is dispatched to the incident, have the drawback that they become unstable more easily.

This study focused on the process for dispatching incident response units because this is one of the more controllable aspects of incident clearance, and because it is a major contributing factor to the delays incurred in incidents. In the example incidents examined in this study, incident response time appeared to be the dominating factor in determining incident duration. Incidents appeared to be detected very soon after their occurrence – especially for the larger incidents. However, response times sometimes took more than 30 minutes.

The study highlights the importance of the following principles:

1) Response units should be adequate in number to handle anticipated demand.
2) Response units should be strategically located to minimize maximum response times.
3) Especially during busy periods, response units should not be dispatched over long distances. It is better to wait for a closer unit to become available than to waste capacity on overly long response distances.
4) Because response units are frequently mobile, and because response units are frequently busy responding to other incidents, it would be very beneficial for dispatchers to have access to location data.

As a practical matter, it is frequently better to let an incident wait for a nearby unit to become available than to dispatch the closest available unit, which may be far away. By dispatching far away units, system capacity is wasted, making it impossible to respond to incidents as quickly as they occur. It would be highly beneficial for dispatchers to establish rules that upper-bound response distances, based on the nature of incidents, so that response time does not become excessive.

With respect to the latter point, we feel it is very important for dispatchers to have access to GPS based location data, so that they can ensure that the proper units are being dispatched to the scene. Due to their mobility, it is difficult to predict the location of CHP officers and other units at any point of time. Though mobile units are typically assigned to beats, they are frequently drawn outside of their beats to respond to incidents. This creates uncertainty for the dispatcher as to where units are located at any time, and can lead to dispatching a non-optimal unit to the scene. A GPS system can be used to predict response distance or time for a particular unit, to ensure that the best unit is dispatched, and to determine whether it is better to wait for a nearby unit to become available.

1. INTRODUCTION

The amount of delay occurring during an incident depends on: (1) the nature of the incidents, (2) roadway conditions, and (3) execution of incident clearance. Clearly, incidents that block more lanes and require more equipment to be cleared (e.g., those involving heavy duty trucks) create more delay. The delay will also increase when the roadway operates close to capacity and does not have alternatives for diverting traffic (either shoulders or parallel roadways). And delay also depends on how quickly the incident is cleared, and the actions taken during the incident to ensure smooth traffic flow.

This report documents research for the PATH project "Incident Management: Process Analysis and Improvement." The report summarizes the findings of three prior working papers, and provides new results based on simulation and empirical analysis.

The incident clearance process can be divided into four elements: (1) detection, (2) verification & dispatch, (3) response, and (4) clearance/service. Detection time is the time from when the incident occurs until the emergency response agency detects the presence of the incident. Verification/dispatch time is the time from initial detection until an emergency crew (or crews) is dispatched to the incident. Response time is the travel time for the emergency response crew to the scene of the incident. Last, service time is the time required to remove the incident and restore traffic once the emergency crew (or crews) has arrived at the scene. The initial working paper under this project (Hall and Mehta, 1998) examined these processes in depth (excerpts are provided later), as they take place in Southern California.

Within this project, considerable emphasis was placed on response and dispatch time, and the contribution of these to congestion and delay. There already exists a very large literature on incident detection, as well as many empirical studies on incident clearance times (Nam and Mannering, 2000, provide a recent review). Dispatching and response to highway incidents have received much less attention from an operational perspective. Of particular interest is the dispatching process for mobile emergency crews, such as police officers and freeway-service-patrol trucks. The key characteristic is that the crews move around the network instead of residing at a stationary base (as is the case for fire crews).

Dispatching processes and response times for police agencies is a well-studied topic in the field of operations research. Police are typically modeled as a spatial queueing system in which the servers (police cars) are mobile. The response time depends on the density of servers (cars per square mile), their overall utilization (ratio of demand to capacity) and the policy for dispatching officers. As the utilization increases, a greater percentage of cars are busy at any given time. Effectively, this causes the density of cars to decline and the response time to increase.

The most famous research in this area is the hypercube model developed by Larson (1974), along with related research by the author (e.g., Larson 1972; Larson and McKnew, 1982; Larson and Rich, 1987). The hypercube model is a stochastic queueing models that accounts for the assignment of patrol cars to districts (or beats), and rules for dispatching officers within and across districts. More recently, the spatial queueing approach has been extended to systems in which multiple cars must be dispatched (e.g., Green (1984), Green and Kolesar (1984), Green and Kolesar (1989), Ittimakin and Edward (1991)).

The design of emergency response systems has also been studied by a number of authors, including an extensive series of work through RAND in the 1970s (for example, Chaiken and Dormont, 1978; Ignall et al, 1978; Kolesar et al, 1975). One of the notable findings to come out of this work is the "square-root" rule for estimating average response distance to an incident. By this model, the response distance equals a constant multiplied by the square-root of $1/\rho$, where ρ is the density of patrol cars per unit area. Ignall et al (1978) reported that this square-root relationship is even a reasonable approximation when the number of busy patrol cars is a random variable.

With respect to incident dispatching on highways, Nathanail and Zografos (1994, 1995), Zografos and Nathanail (1991) and Zografos et al (1993) have evaluated various aspects of the incident response and clearance process through analytical models, including where to locate response vehicles, which vehicles to dispatch and how to manage the process during clearance. Smith (1997) and Anderson and Fontenot (1992) examined response times and optimal vehicle positioning along linear roadways, but did not consider directional effects and interchanges, as are covered here.

Our work considers dispatching within the context of incidents that induce delays on highways. Travel time models were created to account for specific characteristics of highways: the side of the highway on which the incident occurs and the side of the highway on which the emergency crew is traveling; the location of interchanges at which the emergency crew can reverse direction to reach the opposite side; and the linearity of the network. In addition, we evaluate the second moment of the clearance time distribution because delay can be a quadratic function of the time required to clear an incident.

Within the PATH program, a number of projects have investigated the effects of incidents on congestion, and investigated methods for detecting incidents. In evaluations of the Freeway Service Patrol systems in the Bay Area and Los Angeles, Skabardonis et al (1995, 1998) created and evaluated a large incident dataset. For instance, in their Los Angeles study, they found that 93 incidents occurred per one million vehicle miles of travel, though just 6.5% of these incidents were collisions and just 10% of incidents blocked lanes (average duration of 20 minutes). Al-Deek et al (1988, 1989) modeled the occurrence of incidents in a highway corridor, and estimated benefits associated with diverting traffic to alternate routes. The dynamics of traffic flows during incidents was also studied by Heydecker (1994) within the context of alternative diversion strategies.

With respect to incident detection, PATH researchers have developed algorithms for interpreting conventional highway sensor data, with methods such as artificial-neural-networks (e.g. Abdulhai et al, 1999a, 1999b), cost-benefit analysis (Petty et al, 2000), and occupancy measurements (Lin and Daganzo, 1996). Other types of input data have been investigated as well, including cellular phones (Skabardonis et al, 1998), video imaging (Malik and Russell, 1997; MacCarley, 1999) and probe vehicles (Petty et al, 1997). Our work is the first within PATH to examine the processes of incident management.

The remainder of this report is divided into five sections. Section 2 describes processes used in clearing incidents; Section 3 describes principles for dispatching mobile response units to incidents; Section 4 describes INCISIM (an incident simulator) and Section 5 analyzes individual incidents. The report offers conclusions in Section 6. The modeling contained in Sections 3 and 4 were added to this project's work after problems were encountered in obtaining data through the Caltrans District 7 TMC. Although data analysis is still provided in Section 5, the analysis is less ambitious than originally intended, due to the fact that data were only available very late in the project.

2. INCIDENT PROCESS ANALYSIS

The initial working paper for this project (Hall and Mehta, 1998) documented the process followed by incident management agencies in Southern California.

California Highway Patrol (CHP) The primary law enforcement agency on state highways and the scene commander for incidents.

California Department of Transportation (Caltrans) Caltrans comprises many divisions that are together responsible for the construction, maintenance and operation of the highways, including the following functions:

- Transportation Management Center (TMC): Focal point for monitoring freeway operations through traffic sensors and closed-circuit-television, and for controlling changeable message signs and traffic meters. The TMC also disseminates information through the media, controls dispatch of maintenance equipment and co-locates CHP officers for coordinated incident response.

- Traffic Management Team (TMT): Places portable message signs upstream from major incidents or events to warn drivers.

- Maintenance: Clears debris from the roadway and restores the highway to safe operation after major incidents.

- Hazardous Materials (HazMat): A section within Maintenance that assesses, cleans and disposes hazardous materials that spill on state highways.

LA County MTA Freeway Service Patrol (LACMTA FSP) Private tow trucks contracted through the Metropolitan Transportation Authority that assist motorists when their vehicles break down on highways, at no charge to the motorist.

Local Fire Departments Fighting fires on highways, providing paramedics and ambulance service at accidents and providing environmental and health services in case of hazardous material spills.

Local Police Departments Local police departments respond to and investigate serious crimes that occur on highways (homicides, assaults, etc.), and often provide support in the event of major incidents.

Private Tow Operators Tow operators are responsible for restoring vehicles to operating conditions and removing damaged vehicles from the roadway. Tow operators either specialize in ordinary light-duty vehicles or heavy-duty vehicles, such as trucks or busses.

Cargo Salvage Cargo salvage companies assist trucking companies when they spill their loads on a highway. Their job is to retrieve the cargo, transport it off the highway and salvage what is still usable.

Environmental Environmental agencies such as CalEPA are concerned with the use of correct procedures so as to minimize damage to the environment due to incidents.

Coroner The Coroner determines the manner, mode and cause of an unnatural death or a natural death in which the deceased was not under medical supervision. Their function is to identify the dead, locate the nearest kin, notify them and return the body to them, after investigation, if any.

Information was collected on the individual agencies through a combination of three methods:

Document Review: Incident procedure manuals, dispatching plans, Internet web pages and other documents were obtained and reviewed.

Interviews: A questionnaire was developed to obtain information on incident management procedures and technologies. Interviews were administered in person, usually on a one-on-one basis.

Observation: Ride-alongs were completed with CHP officers, LACMTA FSP trucks, and Caltrans Maintenance to observe how incidents are handled, and to obtain further information through interviews. Additional observations were completed at the Caltrans Distrcit 7 TMC and CHP Southern Division's Communication Center.

2.1 Incident Management Process

The incident management process is customarily divided into four steps, representing incident detection, incident verification, incident response, and incident clearance.

Incident Detection Incident detection initiates the incident management process. It occurs when something unusual is noticed on a roadway, in any of the following ways:

- Detection by a patrolling unit (law enforcement officer, FSP truck, Caltrans, etc.)
- Detection by a passing motorist
  - 911 calls
  - Call boxes
- Call by someone involved in an incident
  - 911 calls
  - call boxes
- TMC observation (unusual traffic pattern or closed circuit television)
- Airborne traffic reports

If an incident is seen in the field by Caltrans, CHP, or FSP staff, then it is considered immediately verified, and appropriate incident response procedures are initiated. Most incidents today are detected by patrolling units or 911 calls.

Incident Verification Incident verification is sometimes needed when the initial report comes from an untrained observer who might exaggerate the severity of an incident or mix up the location of the incident with other details. It is also required when an incident is detected from unusual traffic patterns observed at the TMC. Sometimes, incidents can be verified from closed-circuit-television cameras (CCTV). More likely, someone (such as a CHP officer) must be dispatched to the reported scene to assess the situation. It should be noted that actual incidents might require no other resource than a single CHP officer, so incident verification and incident response are a single step.

Incident Response Incident response represents the deployment of resources to the incident. The process includes generating a response plan, dispatching resources, and response by various organizations. The effectiveness of incident response depends on the speed of communication and decision-making, organizational readiness, placement of resources, and travel time to the scene. For major incidents, incident response can occur in stages, where different resources are dispatched for different phases of the clearance process.

Incident Clearance/Service Once responding units arrive at the scene, they will be responsible for any or all of the following:

- assisting injured parties,
- controlling hazards and extinguishing fires
- clearing vehicles and debris from the scene,
- controlling traffic and preventing rear end type collisions,
- disseminating information to motorists,
- investigating the cause of the incident
- reporting their findings.

CHP/Caltrans (1991) have defined five classes of incidents, representing their severity:

Stage 1: Up to 2 vehicles on shoulder or center divider
Stage 2: 3 or more vehicles on shoulder or center divider
Stage 3, minor: intrusion of incident into one or more lanes, but not all lanes
Stage 3, major: intrusion of incident into one or more lanes and full closure required for two hours or more
Stage 4: Areawide incident affecting multiple jurisdictions

Simple Stage 1 incidents can often be handled by a single CHP officer, FSP tow truck, or Caltrans maintenance truck. Major Stage 3 or Stage 4 incidents, on the other hand, require a coordinated response from multiple agencies, each serving a unique role in incident clearance. This section describes the roles of each agency, based on our observations, document review, and interviews.

2.2 California Highway Patrol (CHP)

California Highway Patrol (CHP) is the primary law-enforcement agency on California state highways, and is therefore constantly responding to incidents. CHP acts as the overall scene commander for incidents on highways. It functions to safely remove people and vehicles as quickly as possible, to control the movement of incident responders in and out of the scene, and to control the incident scene to prevent follow-on incidents. The CHP also serves as the communication hub through use of its Computer Aided Dispatch system, and through its role as the Public Service Answering Point (PSAP) for cellular 911 phone calls.

CHP serves as the overall incident commander on scene, and remains at the incident site until it is completely cleared and traffic is restored. CHP officers have a "clear the road" policy, whereby the officers can override the owner's wishes and clear the highway. CHP also plays a crucial role in clearing the road to create fast access for other agencies, when required. CHP also stages agencies on the highway whenever required and protect them from fast-moving traffic. Finally, CHP is responsible for incident investigation and reporting.

The CHP makes information available to the media and public on incidents through its "Media CAD." Connections are provided to traffic reporting companies, such as Metro Networks and Shadow Traffic. Incident information can also be obtained through the Internet. CHP officers are also involved in running breaks in traffic to stage various agencies on the scene, and to protect them from fast-moving traffic. CHP officers are involved in enforcement of standards to be followed by FSP, their training (including communication), and maintenance of their trucks.

2.3 Caltrans

Caltrans is the State of California's Department of Transportation. Its primary responsibility is construction, maintenance and operation of the state highway system, but it is also engaged in other modal activities such as airport and transit planning and commercial vehicle inspections. Caltrans is organized into 12 districts, each of which is somewhat autonomous. Each district is headed by a district director, and divided into various divisions (planning, operations, maintenance, etc.) headed by division chiefs. Incident management falls within the operations and maintenance divisions, which are sometimes combined into a single division in the smaller districts.

Transportation Management Center (TMC) The TMC falls under highway operations, and is concerned with maximizing the operational efficiency of the highway system through monitoring traffic conditions, executing control actions and disseminating information to the public. This includes traffic sensors, ramp meters, changeable messages signs (CMS) and closed-circuit television (CCTV).

Occupancy and traffic volumes are measured with magnetic loop detectors and other traffic sensors throughout the highway system. The data are color-coded within the "Freeway Status" map to display calculated speed by highway segment (red, < 20 mph; yellow 20-35 mph; green > 35 mph). This map can be viewed within the TMC, and at remote sites via cable television and Internet. The speed information is most useful in assessing the impacts of incidents, but is also somewhat useful in detecting incidents. Closed-circuit-television cameras are placed at strategic locations, though most of the highway system is uncovered.

Caltrans TMCs exchange information with some city TMCs, such as the City of Los Angeles' ATSAC center. For instance, the Smart Corridor system has been used to coordinate the diversion of traffic onto major arterials in the vicinity of the Santa Monica Freeway. The Smart Corridor treats freeways and surface streets as corridors to move people and goods, instead of separate entities. Therefore, in case of an incident or congestion on the freeway, adjacent city streets act to provide a smooth passage for the freeway traffic, thus relieving congestion on the freeway and reducing the effect on other parts of the highway system.

It is the policy of Caltrans and CHP to collocate communication center activities in their TMC. In Los Angeles, the CHP communication center is separate from Caltrans' TMC, but CHP has located a public information officer within the Caltrans TMC. Caltrans and CHP have agreed to joint responsibility for incident detection, incident verification, system incident management, and operational control of the changeable message signs and any highway advisory radio systems. However, Caltrans has primary responsibility for managing freeway corridor systems impacted by incidents and CHP has jurisdiction over freeway incident scene management and scene traffic control.

TMCs may contain the following representatives:

- Caltrans Traffic, Maintenance, and Public Affairs
- CHP Communication Center, Media Information, and Air Operations
- Local agency staff, media, researchers, and transit authority staff
- Freeway Service Patrol Supervisors

Traffic Management Team (TMT) The TMT provides equipment and trained personnel to aid in the management of traffic congestion around major incidents and planned events on state highways and freeways. The team's primary goal is to provide advance warning of unexpected congestion, to prevent rear end collisions as vehicles approach slowed traffic. The TMT co-ordinates with the TMC and CHP on managing traffic upstream of the incident. TMT operates 24 hours a day, 7 days a week.

Maintenance Highway Maintenance is responsible for the preservation, upkeep, and restoration of the roadway structures, including toll bridges, as well as for the condition in which they are constructed. Maintenance duties also include the operation of highway facilities and services to provide satisfactory and safe highway transportation.

Maintenance work requires interagency cooperation with the incident commander, other Caltrans divisions, and County, State and Federal agencies responding to incidents.

Maintenance activities can be broadly classified as follows:

- Preventive Maintenance of the highways and freeways
- Cleanup of Litter and Debris
- Hazardous materials cleanup
- Weather related maintenance/cleanup
- Repair damaged facility due to accidents

Communication for maintenance is handled through a maintenance communication post within the TMC. They are in constant contact with CHP and, therefore, the TMC is notified by CHP of any incident or hazardous conditions on the highways. Maintenance personnel are trained to handle the closure of freeways, with help from CHP and TMC, by placing signs, cones and flares on the freeway for adequate protection from the fast-moving vehicles. They often require CHP to run breaks in traffic for them to be able to clear the road of litter and debris. For planned incidents such as sweeping the freeways, filling operations on the right of way, and maintenance of ramps, they submit a road closure request one week in advance. In these cases, they stage themselves on the highway, with appropriate CMS and signs.

Caltrans and CHP are jointly responsible for clearing spills of unidentified and/or hazardous substances on the State highways. The law enforcement agency is the overall scene manager, with specialized functions resting with the responsible authorities. This forms a specialized part of maintenance operations and involves other responders (to be discussed later). Weather related maintenance/cleanup is required to clear dirt and rocks that slide onto highways, as well as respond to other degrading effects of weather. This includes snow/ice control, storm maintenance and assessment of highway safety due to these weathering effects. And maintenance is involved in clearance of major highway incidents, especially those involving hazardous material spills. Minor incidents are ordinarily cleared by the CHP officer, FSP tow truck or private tow trucks.

Hazardous Materials Division Caltrans has the overall responsibility for maintaining a safe and usable highway system, which also includes keeping the highway system free from hazardous materials. The action is initiated to detect, assess, contain spilled material, removal by the spiller, a qualified contractor or Caltrans, and to ensure it is disposed of properly. Every maintenance employee of Caltrans is trained for awareness concerning hazardous substances. They are given basic training on whom to call, what to do, how to protect themselves and the members of the public from these substances. Supervisors undergo a higher training over and above the awareness training. There are some hazardous materials specialists within Caltrans, who undergo extensive HazMat training every year, and who determine the action plan for dealing with such incidents.

The law enforcement agency or the incident commander co-ordinates communication and other activities at the scene and is not involved in the specialized functions provided by other agencies. Interagency cooperation during hazardous materials incidents is defined in the California Hazardous Materials Incident Contingency Plan (HMICP) prepared by OES (Office of Emergency Services). HMICP is a broad document covering all aspects of a HazMat Incident including agency responsibilities, command structure, operations, logistics, planning, finance and training.

2.4 Freeway Service Patrol

Freeway Service Patrol (FSP) is a joint program provided and financed by the MTA, Caltrans and CHP. It is a special team of tow trucks and service technicians who reduce highway congestion by helping stranded highway motorists during rush hour at no charge. FSP is also involved in collection and analysis of information about incidents on the highways. They contribute to incident management by eliminating traffic congestion due to minor incidents and at the same time, remove the incident away from public view. Their services include providing gas, water, diesel (up to 1 gallon each), inflating or changing tires, towing the vehicle if disabled to a point of safety outside the highway (specific drop-off locations) where assistance is available. They also minimize the risk of accidents by removing the debris from the freeways.

If the disabled vehicle is larger than can be handled by the FSP tow truck, the CHP is informed or services from the nearest tow truck operator are offered to the owner. FSP operators are trained to provide quality services on the highway and to remove the vehicle from the highway either by putting it back in operation or towing it away. There are specified points where the operator can drop off the motorists and their vehicles, from where the vehicle must be towed by a private tow operator.

2.5 Fire Departments:

Fire departments (FD) are responsible for incident management on highways in two ways:

- Fire: Fire on the highway (usually a vehicle), fires on the side of the highway (usually a brush fire), or spill of a flammable material that might cause a fire.
- Emergency: Medical emergencies or fatalities.

Unlike law enforcement, different fire departments serve the same highway. Fire protection services are provided by local departments, operated by cities or the county. Fire stations are spread all over the county and some of them are located especially close to the highway so that they can provide quick response to incidents on the highway.

The fire department dispatch center is connected to the CHP, the sheriff's department, and 911 trunk facility connecting them to the local PD. After CHP identifies a fire, HazMat or rescue operation, they automatically contact the appropriate fire department. From this point, the FD dispatcher works with the police to gather information about the incident and send appropriate resources. The LA county fire dispatch center handles all dispatch operations through its own CAD, which is completely digital. All responses are computer-generated and sent electronically to the fire stations over mobile data terminals. The selection of equipment is based on the proximity and availability from 50 best choices available to the system. Medical calls receive top priority but all calls are handled within seconds of detection. The county fire department sends two engines in the opposite direction on the highway to minimize the response time.

The fire department takes joint command at the scene with CHP for highway fires. Their roles in incident management are different: CHP evacuates the highway or the adjoining area if required (with help from local PD), and the fire department carries out its operation on extinguishing the fire. The entire operation of fire departments is based on Automatic Aid agreements and Mutual Aid agreements between the various adjoining city fire departments. The California Master Mutual Aid Agreement covers a broad state-wide mutual aid agreement for the various fire departments to respond to a major incident requiring resources beyond the means of a single city or county fire Department. (e.g. for the Malibu Brush Fires, teams of fire fighters from Northern California assisted.) Automatic Aid agreements between cities cover areas adjoining the cities and border areas to avoid duplication of resources and at the same time, ensure prompt services. It also makes available scarce resources, such as helicopters, to smaller cities adjoining larger cities.

For Emergency Medical Services (EMS), fire departments are assisted by CHP to function on the highway until the patient is deemed fit to be transported to the nearest hospital. Most of the calls received require the paramedic squad to roll out due to human life threatening situations or just as a precautionary measure. EMS paramedics assess the situation, examine the patient, provide first aid and stabilize his or her health condition before transporting the patient to the nearest hospital to receive full medical treatment.

2.6 Coroner

The duties of the County Department of Coroner are to determine the manner, mode and cause of death in certain cases prescribed in the law. Their function is to identify the dead, locate the nearest kin, notify them and return the body to them, after investigation, if any. Generally, the Coroner's Department is responsible for investigating any death due to unnatural causes, such as homicides, suicides, fatalities due to accidents, and deaths due to use of drugs or alcohol. All deaths that are not certified by medical practitioners are also to be handled by the coroner and investigated, depending on the case. On the freeways, CHP is the law investigator whereas the coroner functions as the death investigator. On the freeways, their primary role is to determine the cause of death.

Until the Investigator arrives at the scene, it is the duty of the law enforcement agency (CHP) to protect the scene. If the case is simple with eyewitnesses, and other evidence, the body can be moved to the shoulder with Coroner's permission to clear the freeways. If the case is complicated, with uncertainty over the cause of death, the CHP will protect the scene until the investigator completes his report. Generally, the coroner's unit arrives on scene in less than one hour. The investigator reports various bodily injuries, and other evidence that can be collected from the scene, including photographs of the scene. He also tries to get some evidence of the closest kin to the deceased. After the investigation is completed, and the evidence collected and tagged, the transportation vehicle transports the body to the department for a detailed physical examination and investigation. The investigator tries to identify and notify the closest relatives of the deceased. After the body is taken away from the scene, the roadways can be opened for traffic.

2.6 Private Tow Operators and Clearance Companies

The role of the Private Tow Operators and clearance companies is mainly in the incident clearance area, although they also play a critical role in other areas of incident management. Tow operators can be called to the scene by the CHP officer or, in some cases, by the driver (e.g., through use of a cellular phone). CHP follows a rotation policy when it calls in a tow operator, unless the driver has requested a particular operator (e.g., AAA). Operators are divided into four classes (A, B, C, D), based on the gross-vehicle-weight-rating of vehicles that they are capable of towing. To participate in rotation towing, operators must pre-enroll according to CHP's Tow Service Agreement, and demonstrate that they are capable of providing required service.

Area Commanders are responsible for defining the geographic area covered by tow districts. When a tow operator is needed for a given class of vehicle in a given district, the dispatcher calls the operator at the top of the rotation tow list. That operator then moves to the bottom of the list, and all other operators move up one step. The exact location of the operator relative to the incident plays no part in the process, other than the requirement that the operator is qualified to serve the tow district as a whole.

The field officer/incident commander has a number of responsibilities in the process, including conveying information about the accident to the communications center, ensuring safety, determining whether the operator's equipment is adequate, monitoring response times and reporting any violations of the Tow Service Agreement.

2.8 Health, Environmental and Safety

Apart from the first responders, other Health, Environment and Safety agencies play important roles in incident management. Their involvement is typically limited to hazardous materials spills, which may endanger the environment, workers or the general public. They are involved from the standpoint of setting standards for incident clearance and occasionally from the standpoint of inspecting to ensure that standards have been satisfied.

Federal

1. **Environmental Protection Agency (EPA):** Identifies and sets standards for hazardous materials and hazardous wastes, which are usually applied and enforced by states. The Comprehensive Environmental Response Compensation and Liability Act

(CERCLA) program of EPA locates, assesses and cleans up potentially hazardous waste sites.

2. **U.S. Department of Labor, Federal Occupational Safety and Health Administration (OSHA)**: Sets and enforces health and safety standards for workers in the work place.

3. **U.S. Coast Guard, Marine Environmental Protection**: The Federal Department of Transportation (DOT) regulates the transportation of hazardous materials and hazardous waste on any or all of land, air, and water. Within the DOT, the U.S. Coast Guard is responsible for the response and investigation of release of oil and hazardous substances that enter U.S. waters. It also has the authority to enforce the federal pollution laws and to arrange for removal of hazardous substances.

State: (California)

1. **The California Occupational Safety and Health Administration (Cal OSHA):** Enforces chemical and other hazardous material exposure standards designed to assure the protection of workers' health and safety.

2. **Department of Fish and Game:** Protect the fish and wildlife from chemical contaminants in all state waterways located forty miles inland.

3. **The California Environmental Protection Agency (Cal EPA):** Provide and enforces the standards on environment protection and provides funds, if necessary, for major incidents threatening environment.

4. **Department of Health Services, Toxic Substances**: Sets statewide standards for hazardous waste facilities and enforces both State and federal EPA standards.

5. **Health and Welfare Agency:** Implements Proposition 65 and provides information related to its implementation including information about the governor's list of carcinogens.

6. **Air Resources Board:** Sets standards for the protection and preservation of air quality. It is responsible for controlling mobile sources of emission and oversees the management of the local air quality management districts.

Local: (Los Angeles County)

1. **L.A. County Agricultural Commission:** Maintains a countywide pesticides sampling program of wells and run-off water and to investigate complaints and incidents involving pesticides and their misapplication, and obtains and analyzes soil samples, if necessary.

2. **Forester and Fire Warden:** Responds to hazardous materials releases and regulates the storage of flammable, explosive and water reactive materials in industrial facilities through its Fire Prevention Program.

3. **Department of Health Services, Toxic Epidemiology Program:** Investigate human illness cases resulting from environmental exposure to hazardous materials.

4. **Department of Public Works, Waste Management**: Provides construction plan check, issues permits and regulates waste discharge to sewers. In addition, it works to regulate industrial waste storage facilities, issues permits and regulates underground storage tanks for hazardous materials or wastes within unincorporated areas or cities without a local regulatory body.

Apart from these, incorporated cities operate programs for health, environment and safety within local agencies such as fire, police, or sheriff departments.

3. INCIDENT DISPATCHING, CLEARANCE AND DELAY

Our observations of incident management agencies in action revealed that the incident management process is greatly influenced by the process for dispatching units to the scene. Important issues in this regard are the definition of beats followed by responding units, and the degree to which the closest available unit is dispatched to the scene, instead of waiting for an even closer unit that is currently busy.

In a second working paper (Hall, 2000), analytical models were created to approximate system performance measures for dispatching officers. The purpose in using these models was to determine relationships between fundamental system parameters – such as the spacing between interchanges and the time to maneuver through an interchange – and system performance. In this regard, we simplified the analysis by only considering incidents that require a response from a single emergency vehicle, and did not consider multiple levels of incident priority. We also assumed that the dispatcher is aware of the locations of responding units through use of automatic vehicle location technology. Nevertheless, the findings provide building blocks that might be used in creating more complex models.

Because the relationship between incident delay and incident duration is approximately quadratic, the paper evaluated the expectation of the duration-squared in addition to the usual measured of expected duration. In addition, results were developed for highways with and without congestion-induced-delays in response time, and results were provided for an equilibrium response time, measured as a function of the rate of incident occurrence. Lastly, the following dispatching scenarios are represented.

Individual Beats Individual beats means that response units serve distinct territories with one unit per territory. Units do not cross territory boundaries. As shown in Figure 1, there are four ways that a vehicle can respond to an incident in this dispatch scenario: (a) incident is ahead and on same side of highway; (b) incident is ahead on opposite side, (c) incident is behind and on same side, or (d) incident is behind and on opposite side. Scenarios (b) and (d) demand that the unit cross over to the opposite side of the highway, which adds to response time. Scenario (d) requires crossing over twice, because the unit first must change direction to move backward, and then must change direction again to reach the specific location of the incidents.

Closest Vehicle/Constant Spacing (Rolling Beats) In this scenario response vehicles maintain constant spacing, though their relative position on opposite sides of the highway is constantly changing due to forward progression (i.e., "rolling" beats are created). Units do not adhere to fixed territories, which greatly reduces the need to switch directions or to serve an incident on the opposite side of the highway. Response time is defined by the minimum of four random variables, representing the response times for the adjacent vehicles on each side of the highway (Figure 2).

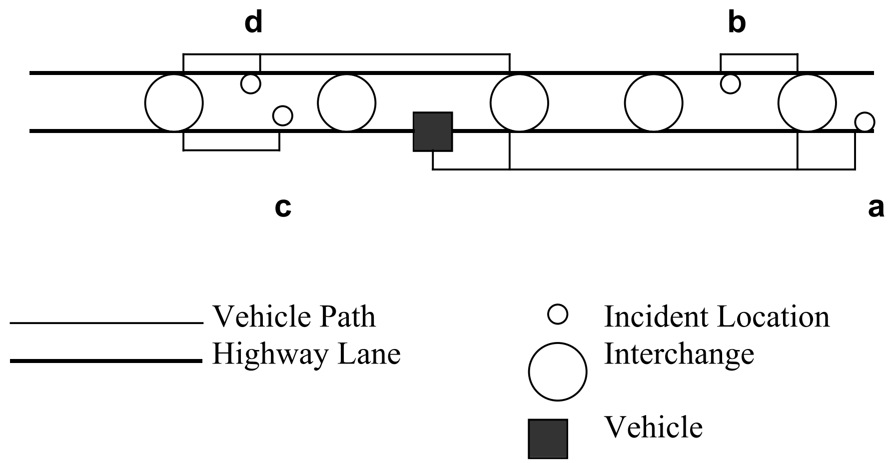

Figure 1. Paths for Dispatching Incident Crew with Fixed Beats

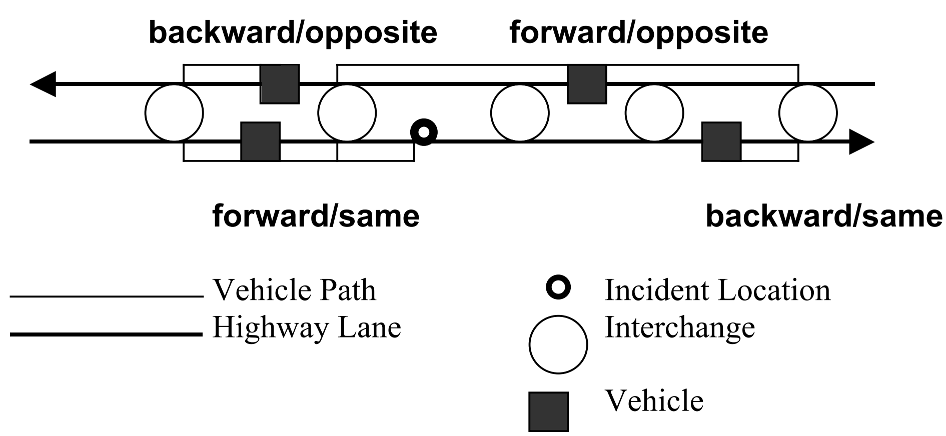

Figure 2. Paths for Reaching an Incident, From Crews on Rolling Beats

As a practical matter, it is virtually impossible to maintain constant spacing, as the random arrival of incidents can disrupt the spacing pattern. This leads to the following pattern.

Poisson Process Locations (Rolling Beats) Randomly spaced response units, following a Poisson process, provide a more stable pattern than constant spacing, while still having the feature of rolling boundaries. As for constant spacing, the response time for Poisson process vehicle locations is defined by the minimum of four random variables. The mean response time is greater, however, because of the variation in the intervals between response units.

In the case of individual beats, expected response time is a linear function of both the interchange spacing and the direction-change penalty. On the other hand, with rolling beats (either with fixed spacing or Poisson process locations), increases in interchange spacing do not cause expected response time to increase without bound. Instead, it approaches a limit, for which the responding vehicle always reaches the incident from an upstream location on the same side of the highway. However, rolling beats, in which the closest available unit is dispatched to the incident, have the drawback that they become unstable more easily.

Fundamentally, any reasonably good dispatch strategy must balance the advantage of immediately dispatching a unit against the advantage of waiting for a closer unit to become available, as well as compare the travel times for units on the same side of the highway to units on the opposite side.

A fundamental question in dispatching incident crews is whether to send the closest unit that is currently available or to wait for another unit to become available that is even closer. The advantage of waiting for a closer unit is that service time is effectively reduced, adding to capacity and providing stability at higher levels of utilization. On the other hand, waiting for a unit to become available adds uncertainty, which contributes to expected traffic delay (because traffic delay depends on the second moment of the clearance time distribution). As a consequence, any reasonably robust dispatch strategy must provide for a hybridization of the two objectives, trading-off greater certainty in response time against stability at higher levels of utilization.   Individual beats provide stability at higher utilization levels, but longer waits at lower utilization levels because the assigned vehicle may be busy.

For these reasons, we recommend placing an upper limit on response distance, contingent on the nature of the incident. The upper limit should vary over time. During periods in which there is very heavy demand and not enough response units, the upper limit should be set to a low value, so that each unit serves a relatively small territory. During periods of lighter demand, the upper limit can be extended. This approach can help keep the response system from going out of control, with too much time consumed in driving to incidents and not enough time spent in serving incidents.

4. INCISIM INCIDENT SIMULATOR

As part of this project a simulation model was also created for more detailed evaluation of incident response strategies. This level of detailed analysis is not possible with analytical models. The program – INCISIM -- is designed to evaluate traffic congestion (vehicle delay), incident response times and incident clearance times (Liu and Hall, 2000).

The key feature of INCISIM is that it models many different types of incident response crews. Incident clearance begins when the crews arrive at the scene of the incident. The response time to the incident depends on where the crews are currently located, whether they are available for dispatch, and the policy for selecting the dispatch crew. Two different types of crews of represented: those that travel in beats (e.g., highway patrol and freeway service patrol), and those that operate from fixed bases (e.g., fire crews).

In order to focus on dispatching policies, INCISIM utilizes a simplified representation of the highway system. Highways are defined by a collection of sections. Users enter data representing the normal amount of traffic, by time of day, for each section, along with section capacity. The interdependence between congestion on nearby sections is only modeled approximately by considering interactions with downstream sections. This allows calculation of net changes in delay in the following way. When a section experiences an incident, its capacity is reduced, possibly causing a reduction in traffic emerging from the section. If this occurs, the outflow rate is compared to the downstream capacity to determine whether downstream delay is reduced.

INCISIM also utilized incident profiles to characterize incidents of different magnitude and different dispatch requirements. For instance, some proportion of incidents will be discovered and served by FSP units alone or CHP units alone. Other require dispatch of multiple response units of different types. These characteristics are controlled through the program's incident files.

4.1 Dispatching Rules For Highway Patrol

INCISIM simulates four policies for dispatching highway patrol units: (1) Priority based without AVL (Automatic Vehicle Location system); (2) Priority based with AVL; (3) Location based without AVL; (4) Location based with AVL. In rules without AVL, response time is based on a pre-determined average value, as entered by the user for each section. With AVL, the value is computed from the actual location of the response unit, and not from a pre-determined average.

Priority Based Without AVL In this dispatching rule, each incident is assigned a priority rank based on a user entered incident code. Based on its priority rank, each new incident is inserted into a queue that stores all the incidents waiting for required response units. The dispatcher keeps track of the availability of highway patrol units based on beat. If the incident waiting queue is not empty, the dispatcher will sequentially fetch every incident and look for available units that can satisfy their dispatching requirements. A highway patrol unit is dispatched if it is free, it can satisfy the incident's dispatching requirement, and it has the smallest mean response time to the incident location among all qualified highway patrol units. Once all required units arrive at the scene, the actual clearance time is simulated. All units dispatched to that incident are freed after the incident is cleared, and the incident is removed from the waiting queue. If an incident has started its dispatching, but does not have all the required units on scene, it is given the highest priority rank and put at the head of the queue.

Priority Based with AVL This dispatch rule is very similar to the first rule, with differences in choosing qualified highway patrol units. In addition to tracking the availability of units, the dispatcher in this rule also tracks the "real-time" location of the available units. Because of this, a highway patrol units dispatched when it is free, it can satisfy the incident's dispatching requirement, and it is the *nearest to the incident site* among all qualified CHP units.

Location Based Without AVL This dispatch rule is similar to the first rule, with differences in managing the incident waiting queue. Instead of using its priority rank, each incident is inserted in a first-come-first-served queue for its section. However, the incidents that are partially through dispatching (i.e., some but not all units have been dispatched) are given special ranks and are prioritized in each dispatch iteration. As in the first rule, a highway patrol unit is dispatched if it is free, it can satisfy the incident's dispatching requirements, and it has the smallest mean response time to the incident site among all qualified CHP units.

If there are insufficient units to respond to all incidents, priority is given to the closest incidents, in the following way. All incident/unit pairings are compared to determine the shortest response time, and make the first assignment. The assigned incident and officer are then removed from the list of pairings, and the process is repeated for the remaining unassigned officers and incidents. The steps are repeated until there are either no more incidents or no more officers.

Location Based with AVL This dispatch rule is a combination of the second and third rules. It keeps track of both the availability of highway patrol units and the "real-time" location of the available units; and it follows the same rule as used in the second rule in dispatching a highway patrol unit. On the other hand, it uses the same method as used in third rule in managing the incident waiting queue.

4.2 Dispatch Rules For FSP Units

Freeway Service Patrol (FSP) vehicles are treated like special emergency units in INCISIM. Like CHP dispatching, FSP units can response to an incident. Unlike CHP dispatching, FSP is only dispatched within its assigned territory and to minor incidents. The territory to which a FSP unit can be dispatched is defined in the Network Description section. The types of incidents that can be served by FSP units are defined in the Incident Profile Description section. Due to the limitation of a FSP's service area, AVL is not modeled in the current version of INCISIM. Therefore, two dispatch rules are used for dispatching FSP, based on two specific dispatch requirements: (1) FSP Only and (2) FSP/CHP Only.

With “FSP Only”, the dispatcher will locate the nearest available FSP unit. If a unit is found, it will be dispatched to the incident. If there is no free unit or there is no FSP service at all in the incident area, the dispatcher will try to find and dispatch the nearest available CHP unit. If neither a FSP unit nor a CHP unit can be found, the incident will be put in the waiting queue.

In the case of “FSP/CHP Only”, the dispatcher will search for both the nearest available FSP unit and the nearest available CHP unit. If both are available, the dispatcher will send out the one that is nearest to the incident area. If either a FSP unit or a CHP unit is found, but not both, that unit will be dispatched to the incident. If neither a FSP unit nor a CHP unit is found, the incident will be put in the waiting queue.

Technically, FSP and CHP frequently discover incidents while traveling their beats, instead of following a pure dispatch. This is accommodated within INCISIM by setting the proportion of incidents reported by FSP and reported by CHP. It is also possible to set up the incident profile such that FSP is never dispatched to incidents, and entirely serves incidents that they discover.

4.3 Dispatch Rules For Other Emergency Units

In INCISIM, other units refer to: (1) Auto tow units, (2) Truck tow units, (3) Fire engines, (4) CalTrans units. Generally, these units only have two dispatch rules, corresponding to two incident categories: (1) Incidents that need verification, (2) Incidents that do not need verification.

For incidents that need verification, units are dispatched only when they are required by the incident and the first highway patrol unit is on scene. For incidents that do not need verification, units are dispatched when the incident has been reported and they are required in the dispatching requirement. The program assumes that these types of response units are always available. The response time to the scene is based on values entered by the user for each highway section.

4.4 Delay Calculation

Delays are computed by modeling a simple queueing process. Let:

A_t = number of vehicles that arrive at section in time period t
C_t = section capacity during time period t
Q_t = number of vehicles in queue at the end of time period t

Then:

$$Q_{t+1} = \max \{0, Q_t + A_t - C_t\}$$

The total delay is computed by summing Q_t across time intervals.

Three different delay values are provided: (1) normal delay, (2) current delay, and (3) downstream delay. Normal delay is the delay in the absence of incidents. Current delay is the delay within the section in the presence of incidents. Downstream delay is the delay in the downstream section, in the absence of incidents (if any).

The difference between normal and current delay during gives the incremental delay during an incident within the incident's section. The difference between current delay and the *maximum* of downstream delay and normal delay approximates the systemwide incremental effect of incidents.

Incidents that overlap within a section (i.e., one occurs before the delay from the prior incident vanishes) are grouped in the output. This means that the incident log shows delay for a pairing of incidents rather than individual incidents, because the effects of each cannot be separated.

INCISIM is programmed to operate under MS Windows. An example screen shot is shown in Figure 3.

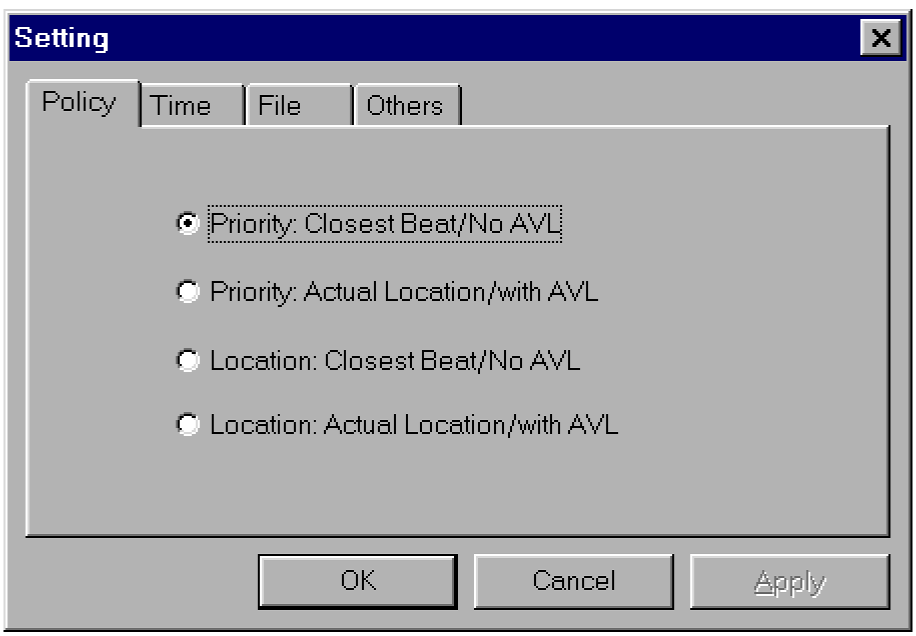

Figure 3. INCISIM Screen Shot

5. ANALYSIS OF SPECIFIC SCENARIOS

A series of incidents was examined to assess the relationship between dispatching processes and highway performance. We had initially intended to examine a large number of incidents. However, we were unable to access data from the Caltrans TMC until late in the project due to firewalls constructed in their system (workstations did not even include disk drives for data download). We were able to obtain data after the PATH Performance Monitoring System (PEMS) went live. Even then, however, a large portion of loop detectors were inoperable at any time, and data transfer sometimes entailed a time-consuming manual transcription of values read from PEMS graphs.

As an indication of the challenges, Table 1, and Figures 4-7 provide a dataset for a major truck –involved incident on the I405 southbound. The incident occurred in the vicinity of Wilshire Boulevard, blocked multiple lanes, caused a fuel spill, and took well more than an hour to clear. As indicated in the Computer-Aided-Dispatch (CAD) log, the problems were magnified because the tow operator became stuck in traffic caused by the incident.

During the course of the incident, the public received conflicting information. While the PEMS indicated that the 405 detectors were generating no data (Figure 6), the SmartTraveler website was simultaneously indicating "green" (no delay) conditions. (In fact, loops were not generating data at this time, preventing performance analysis.) CAD information was also somewhat conflicting as to whether all lanes were closed. Helicopter radio reports were also monitored during the incident, which indicated that some lanes remained open.

In fact, no loop data were available for this incident, so it was impossible to compare incident clearance processes to highway performance.

Tables 2-6 and Figures 10-14 provide data for five incidents in which both performance and CAD data were obtained. These represent a cross-section of incident types. Two of the events were relatively minor. Of these, one occurred during a travel peak and the other did not. Two incidents were very large ("Sig Alert") incidents, one during a travel peak and the other offpeak. The off-peak Sig Alert came after a smaller downstream incident. The incident was also notable because the freeway was shutdown for about 10 minutes to allow for a medic-vac helicopter landing. The last incident was moderate in size, occurring during a travel peak.

In all cases, highway performance mirrored specific events in the CAD log. There was very little timelag between drops in vehicle speeds and the first report of the incident. There was also very little timelag between an "all clear" or "vehicles on right shoulder" event and an increase in vehicle speed.

Other incident characteristics are consistent with traffic flow theory: (1) immediately downstream, speeds usually reached free-flow values soon after the occurrence of an incident; (2) upstream speeds declined after the incident, with the decline moving upstream as time progressed, (3) downstream speeds tended to decrease immediately

Table 1. CAD file for Major Truck Incident

Incident: 1168 Type: Traffic Collision - No Details Location: SB I405 AT WILSHIRE BLVD Zoom Map: 632 4A Info as of: 3/16/2001 10:45:52 AM

ADDITIONAL DETAILS
10:44AM - HOWARD SOMMERS ARE STUCK IN HEAVY TRAFFIC W/HAVE AN EXTENDED ETA
10:21AM - #4,5,6, LANES BLOCKED UD SIG
10:19AM - 1039 H SOMMERS ETA 25-30 DEPENDING ON TRF
10:12AM - 1039 MEDIA RE SIGALERT; CHPTMC
10:10AM - IS THERE AN EST ON HOW MUCH FUEL IS SPILLED?
10:06AM - CONFIRM ALL LNS CLOSED AND TRAFFIC IS BEING DIVERTED? CHPTMC
10:04AM - PLS ISS SIG FOR APPRX 1 HR--ALL LANES
10:03AM - CAL TRANS WILL NEED ENOUGH SAND FOR APPROX 1/4 MILE IN ALL LANES AND NEEDSW STREET SWEEPER
10:02AM - COULD U PLEASE ADVS ETA ON EXPEDITE
10:01AM - TWO FSP TRUCKS 1097 FUEL IS PRETTY --MUCH CONTAINED ON RS--TRUCK IS STILL LEAKING
10:00AM - PER 63M DIESEL IN PARTICALLY--VEHICLES SPINNING OUT JSO OF THIS 1020 PLS ROLL CAL TRANS ON EXPEDITE
9:55AM - 1039 LAFD
9:54AM - PER DUPE BIG RIG IS LEAKING FUEL
9:54AM - RP SAID TRK IS LOSING DIESEL FUEL IN SL LN
9:51AM - PER RP FUEL SPILLING
9:49AM - JACKKNIFE BIG RIG BLKING 3-4 LNS

RESPONDING OFFICERS STATUS
9:57AM - CHP Unit On Scene
9:59AM - CHP Unit On Scene
10:09AM - CHP Unit On Scene
10:23AM - CHP Unit On Scene
10:35AM - CHP Unit On Scene
10:37AM - CHP Unit On Scene

Incident: 1223 Type: Signal Alert - Lane Closure Location: SB I405 AT WILSHIRE BLVD Zoom Map: 632 4A Info as of: 3/16/2001 10:59:13 AM

ADDITIONAL DETAILS
10:30AM - SIGALERT UPDATED - #4,5,6 LNS BLK D
10:09AM - ALL LANES CLOSED FOR 1 HOUR DUE TO A TC LOG 1168
RESPONDING OFFICERS STATUS
10:10AM - CHP Unit On Scene

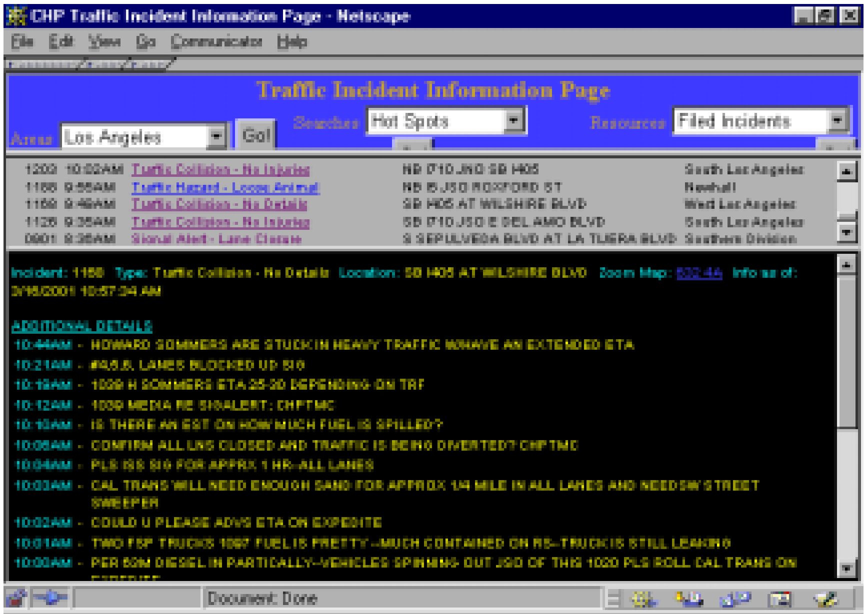

Figure 4. Media CAD Screen Shot for Major Truck Incident

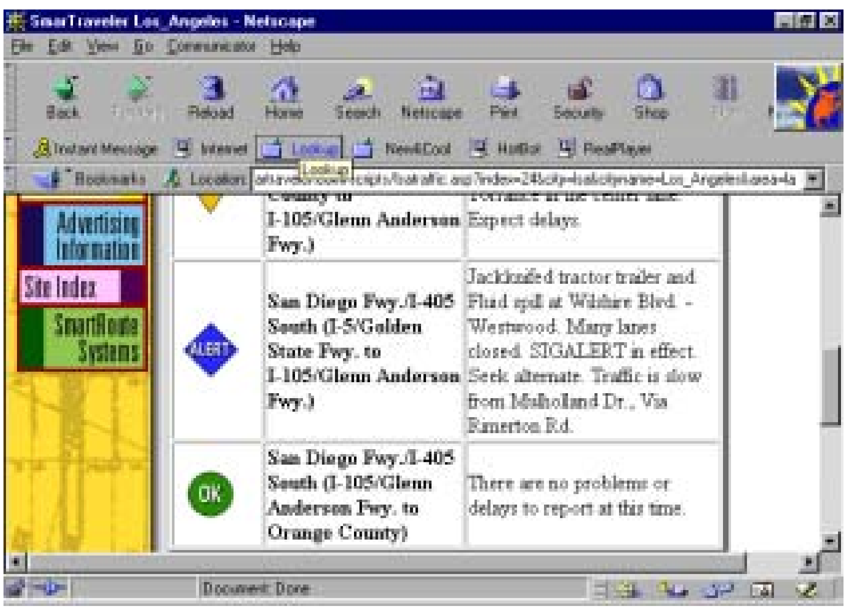

Figure 5. SmartTraveler Incident Report for Major Truck Incident

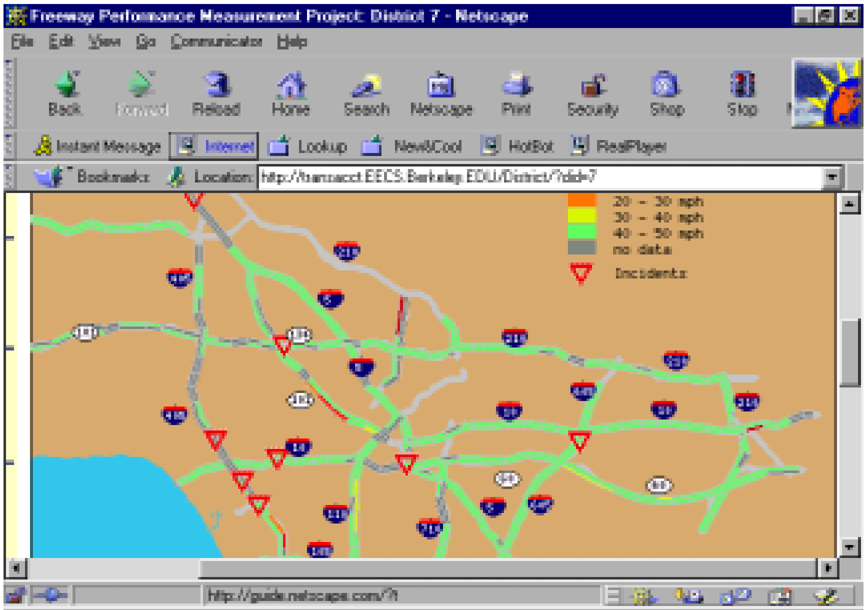

Figure 6. PEMS Screen Short for Major Truck Incident; Showing No Data on I405 Southbound

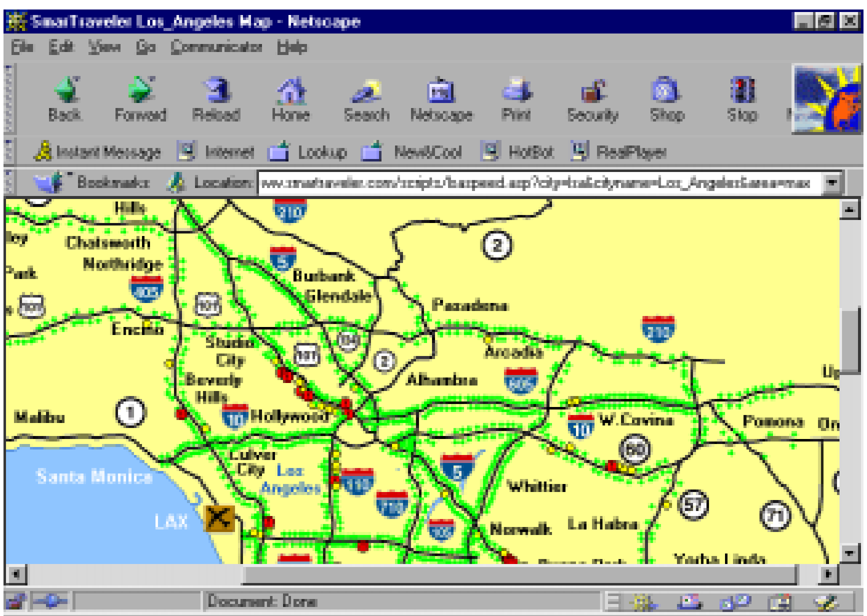

Figure 7. Smart Traveler Screen Shot for Major Incident, Falsely Reporting “green” conditions on I405 Southbound During Major Incident.

after the incident was cleared, and (4) upstream speeds increased after the incident, with the increase moving upstream as time progressed. However, in two incidents traffic speeds remained reduced for several hours after the incident was cleared.

Speed profiles are shown for all five incidents. Each profiles includes speeds at a downstream location (solid black line), immediate upstream from the incident (shaded line), and far upstream from the incident (dashed line). Speeds are also provided for various upstream detectors to show the progression of delays over time. Several events are also marked on each graph, including the time the incident was first reported and the time that the roadway was cleared. The CAD log is also provided for each incident, showing how the response strategy affects highway performance.

For two of the incidents, we have provided graphs for incident queue size as a function of time. The queue size approximates the number of vehicles located between a downstream detector and an upstream detector as a function of time. It is determined by taking the difference in cumulative vehicle volume at the two locations, with the downstream location shifted by the free-flow travel time between the detectors. Graphs were not provided for three incidents, one because it was so minor that appreciable queues never appeared, and the others because the complexity of traffic patterns prevented meaningful analysis.

5.1 Incident Descriptions

I10 Eastbound: The first incident was a major (Sig Alert) injury collision, on Interstate 10 in West Covina. Even though the accident occurred in the off-peak (1:09 p.m.), its effects were substantial. This incident apparently occurred as a follow-on to a prior downstream incident, which began affecting speeds around 12:15 p.m. Immediately preceding the incident, there was a large speed variation between the detector located 1 mile upstream, and the detector located .5 miles upstream. During the course of this incident, the freeway was closed for a short period to permit a helicopter landing on the freeway.

Speeds were greatly reduced (to about 10 mph) for a period of about 1 hour, over a section of highway extending 3 or more miles upstream from the incident. Speeds were reduced to about 20 mph six miles back from the incident. Subsequent to the “roadway clear” sign, it took nearly one hour for freeway speeds to climb to free-flow values in the immediate vicinity of the incident (up to 3 miles upstream). Speed reductions persisted through the afternoon peak 5.9 miles upstream from the incident. Apparently, the queue created by the incident could not be cleared prior to the arrival of afternoon commuters at an upstream bottleneck and, therefore, drivers were delayed throughout the afternoon as a consequence of the off-peak incident. It can also be seen that downstream speeds declined immediately after the incident was cleared, as a consequence of the rapid release of traffic.

The queueing diagram does not account for all delay. The upstream detector was located 5 miles from the incident, short of the end of the queue. About 30 minutes after the incident was cleared, the queue had dissipated at this detector, whereas it persisted throughout the afternoon at an upstream bottleneck. The upstream bottleneck was not analyzed, due to insufficient data representing the recurrent portion of delay. Even not accounting for this upstream delay, queues were significant, reaching a peak of several thousand vehicles, and lasting for at least 1 _ hours. Some of these delays, however, can be attributed to the prior downstream incident, mentioned earlier. Nevertheless, the total delay for this incident would certainly be measured in thousands of vehicle hours.

5 Southbound This incident occurred at the tail end of the morning peak, just north of the point where the I5 freeway merges with the 170 freeway. Speeds were somewhat reduced prior to the incident (presumably normal recurrent congestion), and were increasing toward free-flow values as the peak was nearing its end. As with the I10 incident, speed variations may have been a contributing factor.

Compared to the I10 incident, this collision was relatively minor. The CHP officer was able to clear the involved vehicles to the right shoulder six minutes after the incident was reported. Traffic improved somewhat after the vehicle was cleared, and significantly about 20 minutes later when tow trucks arrived. Because this incident occurred at the end of the peak period, traffic speeds recovered fairly rapidly after the incident was cleared. Speeds reached free-flow values throughout the affected area within one hour of the incident's first report. Nevertheless, vehicle queueing was still significant, with approximately 300 vehicle-hours of delay, as represented by the increase in queue size in Figure 11 between 8:50 and 10:00.

I405NB This incident was both minor and off-peak. As a consequence, speeds were only affected in the immediate vicinity of the collision. Speeds climbed to 55 mph even prior to the arrival of the CHP officer, indicating that drivers had been able to maneuver their vehicles to the shoulder on their own. Speeds returned to free-flow values (> 60 mph) soon after the CHP officer arrived. There were no measured effects upstream or downstream of the incident, and queueing was certainly minimal.

101 Southbound The 101 incident was a Sig Alert, though its duration was substantially shorter than the I10 incident, and the freeway did not need to be closed. The total duration from first report until all vehicles were on the right shoulder was 36 minutes.

Although the incident occurred toward the end of the morning peak, it was located in a highly congested section of the 101 freeway. Speeds were approximately 25 mph prior to the incident, dropped to less than 10 mph during the incident, and returned to approximately 25 mph after the incident. Downstream speeds, however, increased from about 20 mph to 60 mph immediately following the incident, and remained that high for the remainder of the morning.

It is difficult to determine whether this incident, despite its size, had a substantial affect on delay. Its effect may have been to shift congestion from a downstream bottleneck, to a point upstream from the incident. Nevertheless, it is evident that speeds remained at a reduced level immediately upstream from the incident for the remainder of the morning.

Due to the complexity of this situation, combined with the placement of the incident in the vicinity of a freeway merge point, a queueing diagram was not created.

I5 Northbound This incident occurred around the start of the morning peak period, on a highly congested section of the highway, southeast of Downtown Los Angeles. The incident was classified as a "traffic hazard" – possibly a stalled vehicle. Nevertheless, it took some time to clear the incident, in part the consequence of a 17 minute response time for the CHP officer. It took an additional 23 minutes before the roadway was clear.

Speeds during the incident declined to the 10 to 15 mph range, stretching more than 5 miles upstream. They remained reduced for about 45 minutes, and then oscillated in the 20 to 45 mph range (indicating stop-and-go driving). Speeds did not fully recover until the end of the morning peak.

This incident demonstrates that even a minor event can lead to large delays when it occurs at the wrong time (start of a peak period) and wrong place (a congested highway segment). Unfortunately, a relatively long response time aggravated the situation, causing the incident to impact on the order of 15,000 vehicles, with varying amounts of delay.

5.2 Summary

Although the five incidents have widely varying characteristics, they all share the common features that (1) time from incident occurrence until incident detection was very short (apparently no more than a few minutes), (2) time from incident detection until the arrival of clearance units was much larger than the detection time, and (3) roadways were cleared and traffic speeds began recovering soon after the arrival of clearance units.

Incident detection time was defined as the time of the first report of an incident in the CHP CAD (shown as the first event in the following speed profile graphs). Incident occurrence was defined as the time when a detector in the immediate vicinity of an incident exhibited an abnormal speed. The difference was typically not more than a few minutes.

Although the sample of incidents is too small to draw statistical conclusions, they do provide anecdotal evidence that the most important part of incident clearance is ensuring that response units quickly arrive on the scene of the incident. This means following an effective dispatch strategy and ensuring that units are adequate in numbers and adequately placed for response to incidents. Detection time seems to be a relatively small problem, as these times were small.

Appendix 1 provides additional CAD logs for 9 incident types. These provide a rough indication of both the type of information available from the CHP CAD, and the range of incident types encountered on highways.

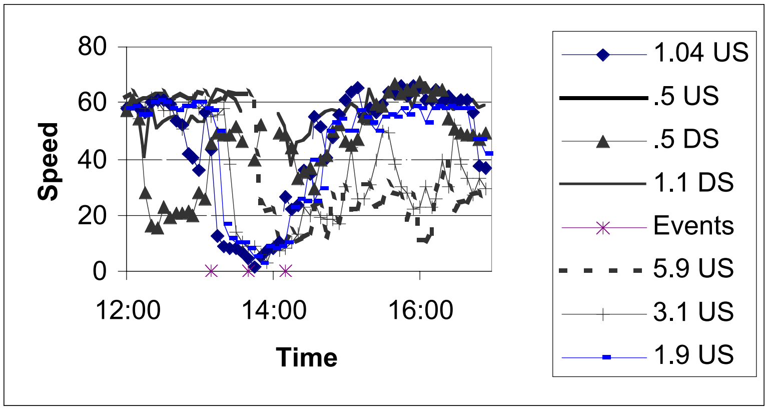

Figure 8. Speed Profile, Sig Alert Incident on I10 Eastbound, Midday

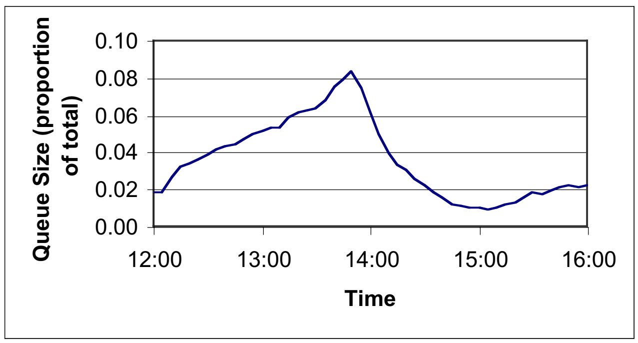

Figure 9. Vehicles Between Upstream and Downstream Detectors

Table 2. CAD Log, Sig Alert Incident on I10 Eastbound, Midday

Incident: 1799 Type: Traffic Collision - Ambulance Responding Location: EB I10 JEO N VINCENT AV Zoom Map: 598 7G Info as of: 3/16/2001 2:41:09 PM

ADDITIONAL DETAILS
2:12PM - 1039 MEDIA
2:12PM - SIG ALERT 1021 ED
2:11PM - PER 22T RDWY CLEAR - 1021 SIGALERT **Event 3**
1:49PM - 1039 RECALL A&A ADVISED MC ON RS
1:47PM - PER 105M * PLS ADVSD A A TOW MC IS NOW ON RS THXS
1:42PM - PER S1 * CLR AIR * RESTRICT TRAFFIC **Event 2**
1:41PM - 1039 WALNUT VLY TO 1021
1:40PM - 1039 A & A FLATBED ETA 10-15
1:36PM - PER M13 * PLS 1021 WALNUT VALLEY TOW AND ROLL A A TOW FOR INVESTIGATION TO WB 10 JEO VINCENT THXS
1:28PM - 1039 WALNUT VLY TOW FOR FLATBED ETA 20
1:26PM - PER 22T * WILL BE STOPPING TRAFFIC BY HAND ON THE EB SIDE, 105M IS ON THE WB SIDE * AIRSHIP SHOULD BE LANDING ON THE EB SIDE IN 10-12 MINS JFI CS
1:24PM - PER 105M * PLS ROLL 1 1185 FLTBED TO WB 10 JEO VINCENT FOR MC IN THE CD THXS
1:24PM - 1039 MEDIA RE SIGALERT; CHPTMC
1:22PM - PER 22T * THE #1 LN WILL BE SHUT DWN FOR APPROX 1 HR DUE TO THIS TC * PLS ISSUE A SIGALERT
1:16PM - WCPD IS 97 REQ POSS ETA
1:10PM - 1039 W COV FD
1:09PM - MC VS WALL **Event 1**

RESPONDING OFFICERS STATUS
1:17PM - CHP Unit On Scene
2:11PM - CHP Unit Enroute

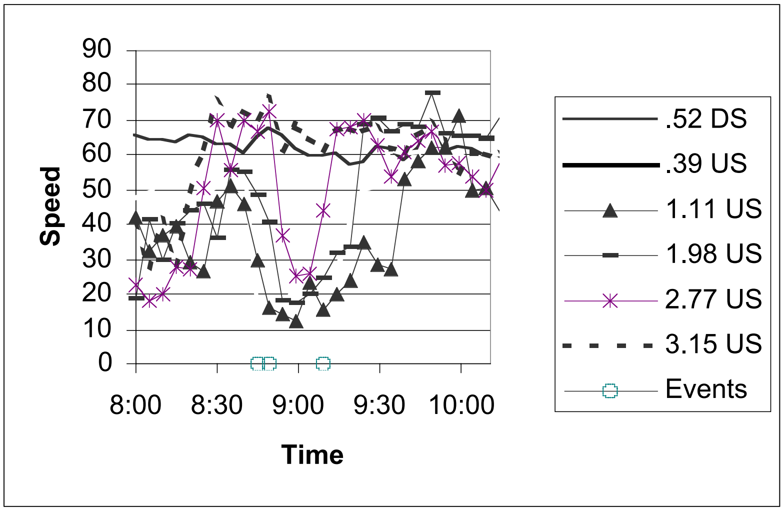

Figure 10. Speed Profile, Peak Period Incident on I5 Southbound

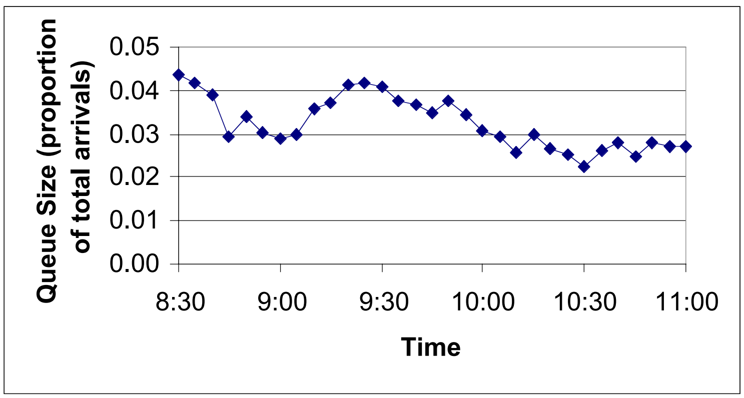

Figure 11. Proportion of Vehicles Queued Between Upstream and Downstream Detectors

Table 3. CAD Log, Peak Period Incident on I5 Southbound

Incident: 1039 Type: Traffic Collision - Ambulance Responding Location: SB I5 AT SR170 Zoom Map: 502 7E
Info as of: 3/19/2001 9:09:35 AM

ADDITIONAL DETAILS

8:59AM	-	1039 MID VALLEY TOWING ADVSD TOW ENRT HAS DOLLIES WILL THIS BE SUFFICIENT	
8:53AM	**-**	**1039 MID VALLEY TOWING ETA 15**	**Event 3 (-15 min)**
8:51AM	**-**	**PER 53 PUSHING VEH TO RS - PLS ROLL 1185**	**Event 2**
8:50AM	-	PER CCTV PANEL TRK AND SUV ON RS; SIL COMPACT MAJOR REAR DAMAGE BLKING LN; ROLL A 1185; CHPTMC	
8:46AM	-	1039 LAFD #98	
8:46AM	-	PER DUPE THERE ARE POSS INJURIES	
8:45AM	-	TRK AND 2 VEHS INVD	
8:45AM	**-**	**3 VEH TC BLKNG #2 LANE**	**Event 1**

RESPONDING OFFICERS STATUS

8:51AM - CHP Unit On Scene

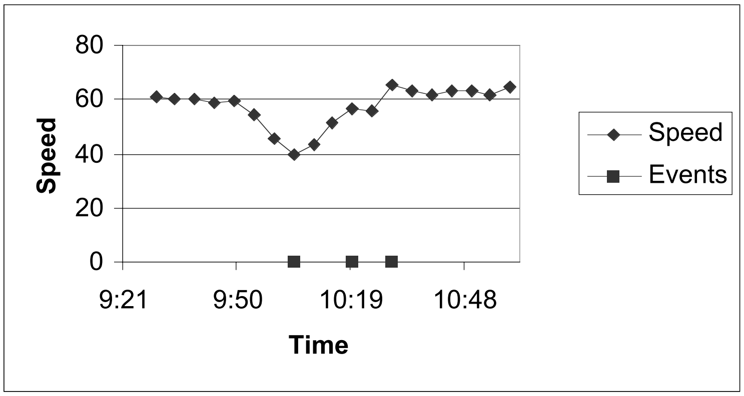

Figure 12. Speed Profile, Minor Offpeak Incident on I405 NB

Table 4. CAD Log, Sig Alert Incident on I10 Eastbound, Midday

Incident: 1208 Type: Traffic Collision - Ambulance Responding Location: NB I405 AT ARTESIA BLVD Zoom Map: 763 1E Info as of: 3/16/2001 10:47:47 AM

ADDITIONAL DETAILS

10:28AM	**-**	**RDWY CLR ** ON RS**	**Event 3**
10:27AM	-	1039 S & W ETA W/IN 20	
10:27AM	-	ROLL 1 1185	
10:03AM	-	IN THE #2 LANE	
10:03AM	**-**	**4 VEHS INV A 1141**	**Event 1**

RESPONDING OFFICERS STATUS

10:20AM	**-**	**CHP Unit On Scene**	**Event 2**

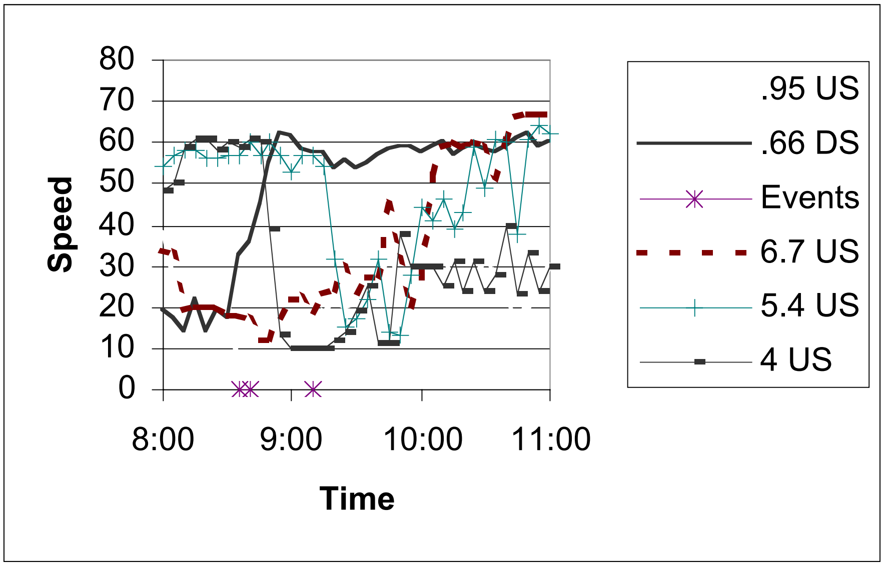

Figure 13. Speed Profile, Sig Alert Incident on 101 Southbound, Peak Period

Table 5. CAD Log, Sig Alert Incident on 101 Southbound, Peak Period

Incident: 0835 Type: Traffic Collision - Ambulance Responding Location: EB US101 AT TUJUNGA AV Zoom Map: 562 4J Info as of: 3/15/2001 9:45:49 AM

ADDITIONAL DETAILS

9:12AM	**-**	**PLS 1021 SIGALERT --ALL ON RS—THKS**	**Event 3**
8:46AM	-	1039 MEDIA RE SIGALERT; CHPTMC	
8:43AM	-	SPEEDY TOW ER WITH FLTBED ON LOG 804	
8:42AM	-	PER 56-N4 ISSUE SIGALERT FOR ABT 30 MINS TUJUNGA OFF CLSD	
8:36AM	**-**	**PLS ROLL LAFD THANX**	**Event 1**

RESPONDING OFFICERS STATUS

8:42AM	**-**	**CHP Unit On Scene**	**Event 2**
8:42AM	-	CHP Unit On Scene	
8:48AM	-	CHP Unit On Scene	
9:18AM	-	CHP Unit Enroute	

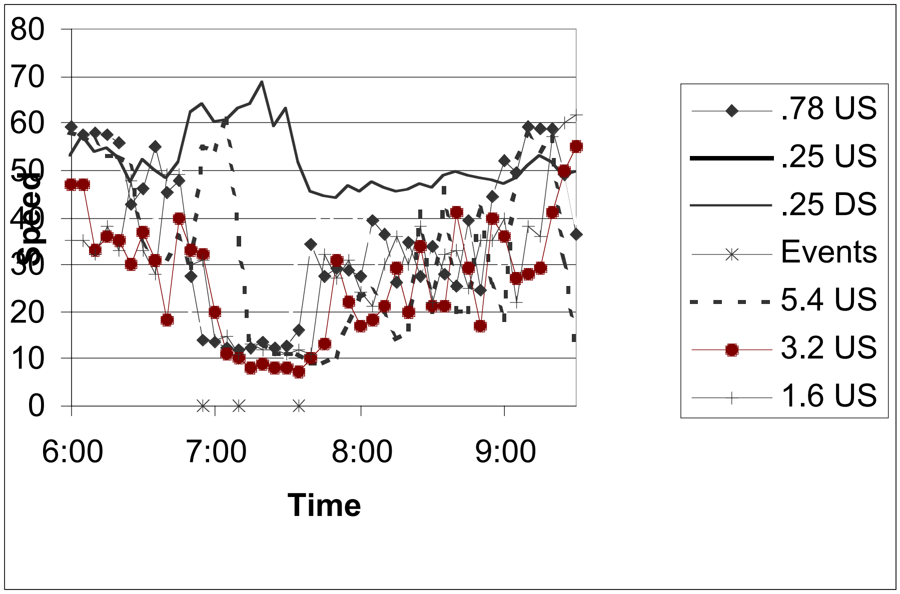

Figure 14. Speed Profile, Minor Peak Period Incident, I5 Northbound

Table 6. CAD Log, Minor Peak Period Incident, I5 Northbound

Incident: 0510 Type: Traffic Hazard Location: NB I5 JNO E WASHINGTON BLVD Zoom Map: 675 4J Info as of: 3/16/2001 8:12:10 AM

ADDITIONAL DETAILS

7:33AM	**-**	**500 ADVISED RDWY CLR**	**Event 3**
7:23AM	-	PER 82-500 CITY TERRACE AND CITY WIDE 1097 - CITY TERRACE TOW W/BE HANDLING - THKS	
7:21AM	-	PLS ADVS IF YOU WANT ME TO 1021 CITY WIDE - CITY TERRACE IS RESP ING FOR A PRVT TOW OF THERE OWN EMPLOYEE THX	
6:58AM	-	1039 CITY WIDE TOW RQ NED ON EXP ETA 20 OR LESS	
6:53AM	-	PLZ ROLL 1 1185 MED ON EXP	
6:53AM	**-**	**WHI TK BLKG #2 LAN**	**Event 1**

RESPONDING OFFICERS STATUS

7:10AM	**-**	**CHP Unit On Scene**	**Event 2**

5. CONCLUSIONS AND RECOMMENDATIONS

This project has examined the processes used to clear incidents on highways, with focus on highways in the Southern California region. The project has documented incident clearance processes, and documented the processes used in clearing specific incidents. It has also developed models and simulations for evaluating alternative dispatch processes.

This study focused on the process for dispatching incident response units because this is one of the more controllable aspects of incident clearance, and because it is a major contributing factor to the delays incurred in incidents. In the example incidents examined in this study, incident response time appeared to be the dominating factor in determining incident duration. Incidents appeared to be detected very soon after their occurrence – especially for the larger incidents. However, response times sometimes took more than 30 minutes.

The study highlights the importance of the following principles:

5) Response units should be adequate in number to handle anticipated demand.
6) Response units should be strategically located to minimize maximum response times.
7) Especially during busy periods, response units should not be dispatched over long distances. It is better to wait for a closer unit to become available than to waste capacity on overly long response distances.
8) Because response units are frequently mobile, and because response units are frequently busy responding to other incidents, it would be very beneficial for dispatchers to have access to location data.

With respect to the latter point, we feel it is very important for dispatchers to have access to GPS based location data, so that they can ensure that the proper units are being dispatched to the scene. Due to their mobility, it is difficult to predict the location of CHP officers and other units at any point of time. Though mobile units are typically assigned to beats, they are frequently drawn outside of their beats to respond to incidents. This creates uncertainty for the dispatcher as to where units are located at any time, and can lead to dispatching a non

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Appendix: Example CAD Files for 9 Incident Types

Incident: 0295 Type: Animal on Road Location: TOPANGA CANYON BLVD AT BROOKSIDE DR Zoom Map: 630 5D Info as of: 3/19/2001 9:42:31 AM

ADDITIONAL DETAILS
5:51AM - 1039 56-S10 FOR A S
5:45AM - DEAD DOG IN SB LANES

RESPONDING OFFICERS STATUS
7:06AM - CHP Unit On Scene

Incident: 1994 Type: Cargo or Hazardous Material Spill Location: SB I710 ON BANDINI BLVD OFR Zoom Map: 675 4F Info as of: 3/15/2001 5:45:21 PM

ADDITIONAL DETAILS
5:11PM - 1039 UNITED PUMPING - ETA OF 30 MIN
5:04PM - PLZ CALL UNITED PUMPING FOR ETA,THX
4:11PM - LACOFD IS 1097
4:10PM - JUST CONFIRM LACOFD NEEDS TO ROLL THEIR HAZMAT TEAM, THX
3:42PM - CAL TRANS IS 1097
3:35PM - DOT CAN YOU ADVS ETA
3:13PM - DOT COPY - PLS ADVS QUANTITY SPILLED
3:07PM - PER 500, DOT NEEDS TO RESP FOR DIESAL SPILL
3:04PM - 1039 CONTINENTAL 20-30 W/HD
3:02PM - HAVE TOW ACCESS FROM OFR ON ATLANTIC
3:02PM - PLZ ROLL 1185 HD, THX
2:58PM - 1039 S5
2:57PM - 1039 S12
2:57PM - 1039 MEDIA
2:57PM - SIGALERT ISSUED ON THE BLU
2:55PM - PLS ISSUE SIGALERT FOR ATLANTIC/BANDINI OFR FOR UNK DURATION
2:47PM - FIRE ALSO 1097
2:29PM - RP SAID BIG RIG TRK LEAKING DIESEL

RESPONDING OFFICERS STATUS
3:10PM - CHP Unit On Scene
3:24PM - CHP Unit On Scene
5:02PM - CHP Unit On Scene

Incident: 0735 Type: Hit and Run - Injuries Location: WB SR118 JWO SHARP AV Zoom Map: 501 3J Info as of: 3/19/2001 9:11:46 AM

ADDITIONAL DETAILS
9:00AM - PER 56-406 THE SV IS 1097
8:07AM - PER 406 THIS TC IS A 20001
7:48AM - 1039 RANDY S TOW - ETA 15
7:44AM - PSL ROLL 1185
7:44AM - PER 406 - PTY TRAPPED IN VEH FIRE TRYING TO EXTRICATE
7:43AM - 1-2 BLKD FIRE 1097 - VEH O/TURNED

RESPONDING OFFICERS STATUS
8:07AM - CHP Unit On Scene
9:00AM - CHP Unit On Scene
9:09AM - CHP Unit On Scene

Incident: 1047 Type: Hit and Run - No Injuries Location: SB I405 JNO SKIRBALL CENTER DR
Zoom Map: 591 1G Info as of: 3/19/2001 9:43:23 AM

ADDITIONAL DETAILS
9:16AM - SUSP FULL SIZE VN L/BUDSVAN LS SB 405 JSO SKIRBALL TC D INTO VEHS FSP WAS IN TOW WITH AND THEN TC D INTO ANOTHER VEH - PLS ROLL CHP
8:47AM - PLS ROLL BT 5 NO CLR UNITS
8:46AM - BLK LATE MODEL SEDAN IN #2

RESPONDING OFFICERS STATUS
9:17AM - CHP Unit On Scene

Incident: 1248 Type: Lane Closure Location: NB 5 AT WAYSIDE Zoom Map: Click Here Info as of: 3/19/2001 9:43:54 AM

ADDITIONAL DETAILS
9:27AM - FRM WAYSIDE HONOR RANCH RD TO NO HASLEY CANYON-#4 LN WILL BE CLOSED TILL 1500 FOR RD CONSTRUCTION

RESPONDING OFFICERS STATUS
9:28AM - CHP Unit On Scene

Incident: 0720 Type: Traffic Advisory Location: NB I5 JSO PICO CANYON RD Zoom Map: 4640 3F Info as of: 3/15/2001 9:48:56 AM

ADDITIONAL DETAILS
8:20AM - LINE 5 SHOULD READ TRAFFIC ADVISORY NOT SIGALERT
8:19AM - COPY THANKS; 1039 MEDIA RE SIGALERT; CHPTMC
8:17AM - PER 78-R1 3,4 LNS CLOSED
8:16AM - PLS ADVISE WHICH LNS ARE CLOSED; THANKS CHPTMC
8:06AM - FWY DOWN TO 2 LNS FOR CONSTRUCTION TFC BACK UP IS 2MILES

RESPONDING OFFICERS STATUS
9:03AM - CHP Unit On Scene

Incident: 0677 Type: Traffic Collision - Ambulance Responding Location: NB I5 JSO PICO CANYON RD Zoom Map: 4640
3F Info as of: 3/15/2001 9:48:19 AM

ADDITIONAL DETAILS
8:10AM - PER 506 JUST 1021 D FIRE AT SCENE
8:08AM - 1021 THEY ADV 1097 NOW
8:08AM - PER LACOFD THEY ARE GOING TO BE EXTREMELY DELAYED DUE TO HEAVY TRAFFIC ARE THEY STILL NEEDED
8:05AM - 1039 AL FURMAN S TOWING ETA 15
7:57AM - 1039 LACO FD
7:57AM - VEH IS IN CD - PTY IS OUT OF VEH
7:56AM - O/TURNED VEH

RESPONDING OFFICERS STATUS
8:05AM - CHP Unit On Scene

Incident: 1494 Type: Traffic Collision - No Injuries Location: NB I110 JSO W FLORENCE AV
Zoom Map: 704 1C Info as of:
3/15/2001 12:38:37 PM

ADDITIONAL DETAILS
11:57AM - POSS A BORDER LINE CALL PLS ROLL SLA
11:56AM - BOTH VEH S ON RS WILL 1023 FOR 1110
11:55AM - TC OCC D NB 110 JNO 105FWY - BLU HOND ACCORD VS BLK TOYT CAM

RESPONDING OFFICERS STATUS
12:28PM - CHP Unit On Scene
12:30PM - CHP Unit On Scene
12:30PM - CHP Unit On Scene

Incident: 2729 Type: Traffic Hazard Location: NB I110 JNO S FLOWER ST Zoom Map: 634 7C Info as of: 3/15/2001 5:50:25 PM

ADDITIONAL DETAILS
5:46PM - VEH NOW ON THE RS
5:26PM - 15-10M ETA 3-5 MINS
5:26PM - PEPE S TOW ENRT ETA APPX 20
5:00PM - PLS ROLL CHP
5:00PM - CITY OF CARSON BUS BLKNG #3 LN * NEG PASSENGERS ON BOARD * BUS DRIVER TRYING TO OBTAIN ASSIST NOW
4:57PM - TX FSP-VEHICLE HAZARD IN LANE

RESPONDING OFFICERS STATUS
5:46PM - CHP Unit On Scene