Generation and Assessment of Incident Management Strategies

Volume I:
Management, Surveillance, Control, and Evaluation of Freeway Incidents – A Review of Existing Literature

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16. ABSTRACT

This four-volume technical report describes a study of freeway incidents and incident management strategies in the Seattle area. The study statistically analyzed the frequency and duration of freeway incidents on sections of I-5 and SR 520 in Seattle. In addition, a traffic simulation model was operationalized to assess the traffic related impacts of incidents. The findings show that Seattle-area incident management currently responds well to inclement weather and special events (e.g., major sporting games) but has problems with severe accidents. The ongoing operationalization of accident investigation sites and incident equipment storage sites can be expected to improve severe accident management, but response personnel training and the addition of more dedicated tow truck service are also needed. Finally, the study shows that, from a traffic impact perspective, the section of I-5 in downtown Seattle is in need of the most incident management attention.

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GENERATION AND ASSESSMENT OF INCIDENT MANAGEMENT STRATEGIES

VOLUME I: MANAGEMENT, SURVEILLANCE, CONTROL, AND EVALUATION OF FREEWAY INCIDENTS: A REVIEW OF EXISTING LITERATURE

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SUMMARY

With traffic congestion on the rise in virtually all U.S. metropolitan areas, efforts to seek new and innovative methods to mitigate the many adverse impacts of congestion have become a top priority among transportation agencies. Incidents (accidents, vehicle breakdowns, etc.), which are known to result in significant reductions in roadway capacity and, consequently, in additional delay, are obvious focal points for congestion mitigation.

As this literature review indicates, the impacts of incidents generally involve a multi-dimensional strategy consisting of both management and surveillance/ control options. While incident mitigation strategies have been shown to be cost effective in the cities in which they have been implemented, U.S. metropolitan areas still show a surprising range in the intensity of (or level of commitment to) their incident mitigation strategies that can not be explained solely by the range of traffic volumes. This observed variation in intensity suggests the need for additional research to develop evaluation methodologies that can be used to predict, with reasonable accuracy, the potential effectiveness of alternative incident mitigation strategies. Only with further methodological development, substantiated with actual observed data, can incident mitigation strategy intensity and incident mitigation needs properly be matched.

As a final point, the reader should recognize that this report does not cover all of the available literature in the general area of incident management. Several highly detailed and specialized sources have been omitted to provide for a clearer presentation of concepts.

INTRODUCTION

The subject of highway incident mitigation includes a host of options and technologies for dealing with incidents, ranging from accident prevention and education to preplanned hazardous materials cleanup. Most of these mitigation measures for dealing with incidents, which include vehicle accidents, breakdowns, and so on, date back to the early 1960s. Detroit, for instance, provides an example of the early use of these surveillance and control systems, courtesy patrols, ramp metering, and highway advisory radio (Derose (1963)). Since the early systems, many technologies have been refined to include new incident detection algorithms, highway corridor simulation models, and improvements in video (closed circuit television, CCTV) technologies. This review concentrates on incident mitigation and its historical evolution.

Literature on incident mitigation and incident mitigation evaluation can be broadly classified into three categories, (1) incident management options, (2) surveillance and control, and (3) formal traffic research studies. Although some of the more comprehensive works transcend the boundaries of a single category, these three categories provide a useful basis for comparison. The major works within each category of literature are presented in Table 1 and described in detail below.

INCIDENT MANAGEMENT OPTIONS

Relatively few reviews deal specifically with incident management options (Ahmed (1986)). Perhaps the most useful is a highly detailed and comprehensive six volume review and evaluation of low cost incident management options, (Urbanek and Owen (1977), Urbanek and Rogers (1978), and Urbanek and Colpitts (1978)). The emphasis in these works was on low cost options, and therefore they did not treat surveillance and control systems. Urbanek and his co-authors classified

TABLE 1. LITERATURE CLASSIFICATION

1. INCIDENT MANAGEMENT

   Ahmed (1986)
   Urbanek and Owen (1977)
   Urbanek and Rogers (1978)
   Urbanek and Colpitts (1978)
   Dudek (1987)
   Everall (1972)
   Goolsby and McCasland (1969)
   Roper (1987)

2. SURVEILLANCE AND CONTROL

   Desrose (1964)
   Derose (1963)
   Everall (1972)
   Taragin (1976)
   Caravell (1976)

3. TRAFFIC RESEARCH STUDIES

   Goolsby (1971)
   Lari (1982)
   Klucens and Paesani (1988)
   Kraugh (1983)
   McCasland (1975)
   Tignor (1976)
   Lindley and Tignor (1979)
   Ben-Akiva and de Palma (1986)
   Mannering and Hamed (1988)
   Mannering, et al. (1988)

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incident management into surveillance, administrative, organizational, and preplanning alternatives. For each of these, they identified management options and a methodology for estimating the cost of implementing any one of the options. Their demonstration project in Tampa, Florida, showed how low-cost incident management could improve traffic operations on a heavily traveled bridge. They found that emergency vehicle access and stationary tow truck surveillance/response reduced response times by one half. While most of their analysis is still sound, their estimated cost of delay was lower than current studies (for example, Chiu and McFarland (1984) found that the value of commuters' time was about twice that

used by Urbanek and his co-authors), and they did not directly treat departure delay or route diversion as part of the feasibility studies.

Many works dealing with specific management options have emphasized incident detection algorithm development and testing and therefore, fall outside the scope of this paper. However, significant work has been undertaken to assess the effectiveness of a number of incident management options such as call boxes, accident investigation sites, incident response teams, and tow trucks.

Call boxes and accident investigation sites (off-road sites to which commuters drive after an accident to exchange information and complete appropriate accident report forms) share many of the same evaluation criteria. Dudek (1987) cited proximity to high incident occurrence locations, the traffic volumes near the site, and actual frequency of use during the peak hour as critical elements in accident investigation site benefit evaluation. These same elements were cited as benefit measures for call boxes by Everall (1972) in his survey of incident management technology and by Goolsby and McCasland (1969). Of particular interest to these writers were the cost of site preparation and hardware. This is where the evaluation of accident investigation site and call box options diverge. Goolsby and McCasland found that accident investigation site preparation may vary from a simple shoulder widening project to significant right-of-way acquisition and improvements, such as kiosks and telephones, depending on the expected usage. In contrast, call box installation requires no additional land, and installation costs, though high, are not as dependent on local conditions (Everall (1972)).

Incident response teams (multidisciplinary groups specializing in large scale incident management ranging from multiple car, lane blocking accidents to hazardous materials clean up) have been used with considerable success. A recent evaluation of the Los Angeles area freeway management system indicated that a 10:1 cost/benefit ratio may be realized by using freeway incident response teams (Roper (1987)). Although the cost of motorist time was not explicitly addressed,

delay for each minute of lane blocking was found to be 4 to 5 minutes for off-peak periods and 50 minutes for peak periods. Delay savings were approximated as $550,000, and costs recovered from owners of disabled/blocking vehicles were estimated at $30,000. The total cost of the response team project was $85,000 per year.

Tow truck courtesy patrols have been used successfully for rapid removal of disabled vehicles, particularly on point facilities such as bridges (Urbanek and Rogers (1978)). Urbanek and Rogers used incident response time, capacity reduction, and assumed queuing with a constant demand in their evaluation of the potential benefits of tow trucks, the trucks proved quite favorable. As an example of the observed effectiveness of such a system, in 1985 the Illinois Department of Transportation's 35 tow trucks were involved in over 100,000 assists (Roper (1987)). Currently Los Angeles has 35 tow trucks devoted to incident clearing, and it has met with similar success.

SURVEILLANCE AND CONTROL

Early surveillance and control systems are described in Derose (1964) and Estep (1972). As early as 1963, the John C. Lodge Freeway system, in Detroit, included a surveillance and control system, courtesy patrols, ramp metering, highway advisory radio, variable message signs, a traffic surveillance center, and closed circuit television monitoring (Derose (1963)). At the time of his writing, Derose described an induction loop based incident detection algorithm that was under development and he expressed high hopes for this new technology for prevention of multiple car freeway pileups that occurred in bad weather. He envisioned the system to include variable message signs to warn motorists of stopped traffic ahead. Despite much initial promise, both the incident detection algorithms used for determining the presence of an incident and the system hardware components have experienced reliability problems (especially damaged

loops) and are insufficient for surveillance without some type of verification. In other work, Estep (1972) described the basic surveillance system for 42 miles of freeway near Los Angeles in 1972, which at that time included induction loop surveillance and incident detection, a rapid vehicle removal policy and a traffic control center.

Closed circuit television (CCTV) became increasingly popular in the 1970s. In a review of urban freeway surveillance and control, Everall (1972) found that most large freeway systems either had surveillance projects already implemented or had plans to implement at least limited video/CCTV surveillance. Taragin (1976) describes expanded video surveillance on the John C. Lodge Freeway in Detroit, and the Dallas Freeway Corridor System boasted extensive video surveillance capability in 1976 (Carvel (1976)).

The success of such pioneering systems has lead to a proliferation of Surveillance and control systems to the extent that such systems are now in place in Toronto, Seattle, Los Angeles, Houston, Cincinnati, Detroit, Washington D.C., and New York to name a few.

TRAFFIC RESEARCH STUDIES

The impact of accidents and disabled vehicles on traffic operations has long been a motivating force behind incident management. As an example of the impact of such incidents, a study of incidents on the Gulf Freeway near Houston showed that 80 percent of all incidents created a reduction in capacity of at least a third, regardless of whether a lane was blocked. On a three-lane freeway, the capacity was reduced by half (Goolsby (1971)). Also, Goolsby's work found that an incident blocking one lane of a six-lane freeway (three lanes each direction) caused a 50 percent reduction in directional capacity. These data were collected on roadways with dry pavement and in daylight conditions by state patrol officers using a video

monitoring log for a period of two years. Similar results were found by Lari (1982) in a study of the I35-W freeway in Minneapolis.

The most common statistics used in those traffic research studies relating to accidents and incidents are their frequency and location. Klucens and Paesani (1988) summarized five years of frequency, location, and duration of incidents on the Detroit freeway network. During the period of the study, 1546 incidents occurred. Their study indicated that vehicle breakdowns accounted for 54 percent of the incidents, 33 percent were accidents and 13 percent were either spills or some other unusual event such as animal avoidance. The duration of incidents averaged 20.82 minutes for all types; with accident induced incidents having an average duration of 33.72 minutes. The study also found significant improvements in state patrol response time following the installation of video monitoring and traffic flow graphics equipment in the police dispatch office.

In addition to reducing capacity, the effect of stopped vehicles on freeway shoulders has been found to be a very important parameter in highway safety. A study by Kraugh (1983) found that 5 percent of all fatal accidents in California involve stopped vehicles. At night, 55 percent of fatal accidents were found to involve stopped vehicles. The most common misperception of drivers is that a stationary vehicle is thought to be moving on the right of way even though it is often 10 feet from the travelled pavement. This perception leads drivers to believe that they are overtaking these cars, and their incorrect estimate of relative speeds results in an accident.

Lari (1982), McCasland (1975), and Goolsby (1971) have classified accidents by lane, severity, number of lanes blocked, and by number of emergency vehicles required to clear the incident. Video observation has also proven a valuable tool in such classifications (Tignor (1976)).

Lindley and Tignor (1979) analyzed "get away" flow rates from incidents and bottlenecks and estimated capacity reduction for a two-lane facility with one lane

blocked during the peak hour to be 66 percent, where capacity reduction was taken to be the difference between the highest ADT for a link and the get-away flow rate.

From a more methodological perspective, there have been a number of recently developed traffic analysis techniques that appear to be exceedingly well-suited to the incident analysis and mitigation problem. These studies focus on commuters' ability to change routes and departure times in response to incident occurrence (Ben-Akiva and de Palma (1986), Mannering and Hamed (1988), Mannering, et al. (1988)). Although the findings of these studies have not yet been applied to incident analysis the potential for future application is most promising.

OVERVIEW OF ALTERNATIVE INCIDENT MITIGATION STRATEGIES

Given the general overview of existing literature as presented above, attention can now be focused on specific incident mitigation strategies. In so doing, the intent is to provide the reader with a fairly detailed description of alternative options, as well as an assessment of the options' advantages and disadvantages. Both the option description and the options' advantage/disadvantage assessment is based on a compilation of findings in the literature. Such an approach is an efficient means of conveying the essence of the many diverse incident management options that have been historically used.

To be consistent with the previous discussion of existing literature, two categories of incident mitigation strategies are identified: (1) incident management (including administrative, organizational, and preplanning options) and (2)surveillance/control. Table 2 lists the options that make up each of these two categories.

INCIDENT MANAGEMENT

Administrative Options

Fast Vehicle Removal. Vehicles on shoulders have been shown to significantly decrease the capacity of the freeway. A policy for removal of these vehicles within a given short time by the department of transportation or by private wreckers to a holding area is quite beneficial. The owner is generally responsible for the costs associated with the removal of his or her vehicle from the freeway right-of-way.

- ADVANTAGES
  - Cost is low.
  - Increases capacity.
  - Motivates car owners to have their vehicles moved quickly.
- DISADVANTAGES
  - May require passage of an ordinance or legislation.

TABLE 2. INCIDENT MITIGATION STRATEGIES

INCIDENT MANAGEMENT

Administrative Options

- Fast Vehicle Removal
- Dedicated Freeway Patrol
- Emergency Lights
- Accident Investigation Sites
- Equipment Storage Sites
- Removal Crane
- Patrol Car Push Bumpers

Organizational Options

- Interagency Relationships
- Traffic Management Teams
- Incident Phone Lines
- Variable Message Signs
- Media Ties
- Transit Radio
- Incident response teams

Preplanning for Incidents

- Alternative routes
- Emergency Vehicle Access

SURVEILLANCE/CONTROL

- Increase Police Patrols
- Peak Hour Motorcycle Patrols
- Tow Truck Service Patrol
- Aircraft Patrol
- Citizen Band Radio Monitoring
- Cellular Phone systems
- Call Boxes
- Highway Advisory Radio (HAR)
- Volunteer Watch
- Loop Detection
- Video and Closed Circuit Television

Dedicated Freeway Patrols. This option is to assign existing police patrol units exclusively to sections of the freeway with high incident rates, except when the police must respond to assist other officers. Many urban areas already have this

policy. A decrease in response time and quick site management or vehicle removal are the results of this option.

- ADVANTAGES
  - Decreases response time.
  - Incident severity can be quickly assessed.
  - Minor incidents, such as stalled vehicles, can be rapidly removed.
- DISADVANTAGES
  - May conflict with other operating agency budgetary priorities unless funding is found for this particular activity.
  - Additional personnel may be required.

Emergency Light Screens. The presence of an emergency vehicle or of the police slows down traffic flow because of gaper's block or guilty consciences. Emergency lights draw attention. If they are indiscriminately used, their impact may be as large as the incident itself. To minimize the impacts of emergency lights, agency guidelines may be established to indicate where necessary reports should be completed off the freeway right-of-way. Portable screens have been used to hide incident sites from other motorists.

- ADVANTAGES
  - Decreases the number of secondary accidents by warning motorists of potential hazards.
  - Screens increase traffic flow by reducing gaper's block.
- DISADVANTAGES
  - Passing motorists slow down to look at emergency lights and even screens, if they are used, resulting in gaper's block.
  - The screens are flimsy, light-weight, and can be blown away.

Accident Investigation Sites. Accident investigation sites are used for off-road accident investigation. They provide motorists and patrolmen a place to fill

out reports related to accidents. They may include a kiosk for housing accident report forms and a telephone, but a turnout from the freeway mainline is cheapest and is still effective for preventing additional accidents during an accident investigation and as a place to push a disabled vehicle until the vehicle can be removed.

- ADVANTAGES
  - Reduces delay from gaper's block.
  - Reduces secondary accidents.
  - Might provide forms for reporting.
  - Could include a telephone for reporting an accident.
- DISADVANTAGES
  - Finding a good location may be difficult.
  - Site preparation and signing may be costly.
  - Publicity may be costly.
  - Driver education is required.

Equipment Storage Sites. Equipment for handling major incidents must be readily available for use by the responding agency. Small items, such as flares, are typically carried by any emergency vehicle and patrol cars. Larger items, such as portable barriers, highway cones, sufficient absorbent materials for spills, and cleanup tools can be stored near high incident prone areas and made available for use by several agencies. The smaller items, such as sand and flares, may also be stocked.

- ADVANTAGES
  - Provides quick access to emergency equipment.
  - Management and cleanup time are reduced.
  - In some instances, this could be implemented with existing surplus space

- DISADVANTAGES
  - Requires a storage facility near the freeway.
  - Participating agencies must share costs.
  - The storage sites must be stocked regularly.

Removal Crane. A crane suitable for removing very large and/or heavy items (rolled over semi-trucks for instance) and available only for traffic management purposes can be acquired by an agency to facilitate quick restoration of freeway capacity when smaller tow trucks are too small for the job. One cost effective way of implementing this option is to contract with a private construction company for priority use of one of its cranes and allow it to be used at a construction site until it is needed at an incident.

- ADVANTAGES
  - Provides faster removal of oversize vehicles or spills from the freeway.
  - Removes uncertainty regarding where a crane will be acquired when it is needed.
- DISADVANTAGES
  - If the crane is purchased by the operating agency, initial investment costs will be high.
  - The equipment may often be idle.
  - Requires funds for maintenance.
  - Requires training of operators.
  - Requires an "on-call" crew 24 hours a day.

Patrol Car Push Bumpers. Equipping patrol cars with a push bumper (typically, metal bars, covered with a hard plastic coating to prevent scratching, attached to the car's frame near the bumper and extending in front of the bumper) allows patrol cars to move disabled vehicles off the traveled way without need for a

tow truck. The disabled vehicle can be removed from the shoulder when traffic allows.

- ADVANTAGES
  - All patrol vehicles are able to clear minor incidents.
- DISADVANTAGES
  - Liability relating to vehicle damage.

Organizational Options

Interagency Relationships. The definition of interagency relationships, spheres of influence, and operational priorities with respect to incident management has the potential to speed response times and clarify when a specific agency is needed at an incident site. Personnel, equipment, and expertise can be catalogued, and a policy for incident response and site management can be published for each department. Further, a pamphlet with contact persons for different needs in the different agencies can be published for use by dispatch personnel.

An intrastate effort of this kind is described below under traffic management teams. Transcom, an interstate effort between New York and New Jersey agencies (both public and private), provides a clearing house for traffic and congestion information on a timely basis. Transcom's goal is to keep member agencies apprised of any system deficiencies, planned incidents, or potential network improvements that are to be implemented by a member agency.

- ADVANTAGES
  - Agency responsibilities are clearly delineated in the event of an incident.
  - Response can be more efficient when agencies know who to call for special expertise or equipment.
- DISADVANTAGES
  - Meetings with other agencies requires staff time.

Traffic Management Teams (TMT). A traffic management team consists of officials from all incident response agencies. The purpose of such a team is to provide incident management planning.

Random accidents, breakdowns, or spills often require response by one or more jurisdictions and agencies. The traffic management team concept, as defined in Florida and Texas, provides a framework for interagency cooperation and advance planning. Members meet once a month and have the authority to commit their agencies to particular policies and expenditures. Unlike an incident response team, the traffic management team's purpose is to provide the necessary resources that will result in effective incident response and mitigation. Examples of traffic response team products include alternative route maps, funding for tow truck patrol, plans for getting "firefighting" water to inaccessible freeway segments, development of a standard, "Accident Vehicles Must be Removed from Traffic Lanes" sign, management of traffic during special events and construction, and implementation of nearly any other incident management technique that crosses "normal" jurisdictional boundaries (Ewell (1988), Price (1980), Trietsch (1988)).

- ADVANTAGES
  - TMTs provide a forum for interagency cooperation.
  - TMTs can develop personal relations between agency leaders, improving their communication.
  - Agencies can learn about the specific potential abilities and limitations of the agencies they work with.
- DISADVANTAGES
  - If TMT is implemented on too small a scale, senior staff may spend too much time going to each monthly meeting.
  - The TMT quickly becomes ineffective if participants are unable to make commitments for their agency.

Incident Phone Lines. As mentioned above, an incident phone line can be installed so the public may call one number in the event of an incident. A 911 type of number for emergencies can be used. The number can be posted along the freeway.

- ADVANTAGES
  - Motorists are less confused about whom they should call to report accidents or incidents.
- DISADVANTAGES
  - May take up too much emergency resources.
  - An initial publicity effort is required.

Variable Message Signs. After an incident is detected, changeable message signs mounted on trucks or permanent fixtures may be used to close lanes, divert traffic, and warn drivers of slow traffic ahead.

- ADVANTAGES
  - The same sign may be used for many different messages.
  - Drivers can take an alternative route if the sign is placed near an exit.
  - Secondary accidents may be reduced with sufficient advance warning.
- DISADVANTAGES
  - Motorists must become accustomed to different messages on the same sign.
  - Bulbs and other components need to be regularly serviced.
  - The message must be updated regularly.

Media Ties. A good relationship with the local media can shift most of the information dissemination functions to the private sector. Allowing radio and television stations frequent access to the city's traffic surveillance and control center not only provides the media with a service but reduces the need for publicly financed information systems, decreasing the need for or delaying the time when a highway advisory radio system is needed.

- ADVANTAGES
  - Frequent traffic reports may allow motorists to delay their departures or use alternative routes, easing congestion.
  - Good media relations improves the agencies' public image.
- DISADVANTAGES
  - Personnel must be available for media inquiries.
  - Many commercial radio and television stations do not provide traffic information except during the peak hours, even though drivers often come to expect such information.

Transit Radio. Where the transit property has equipped its buses with radios, these can be included in the traffic information gathering effort. Traffic quality and incidents can be reported from the bus to transit, police, or DOT dispatchers.

- ADVANTAGES
  - Incidents can be reported quickly, given the number of buses and their geographic spread.
  - Traffic conditions for both freeways and arterials can be reported.
- DISADVANTAGES
  - Additional personnel may be required to handle the transit calls.
  - Transit drivers may be distracted while driving.

- The transit drivers may want to be paid for reporting traffic conditions.
- The transit authority may want to be paid for providing this service.

Incident Response Teams. Incident response teams are interdisciplinary teams trained in handling large or more severe incidents on the freeway. In some areas they are staffed by volunteers. Their job is to respond quickly, set up an incident management command post, determine the severity of the incident, call in appropriate help from experts, and to contact persons who control special equipment that may be required. They typically coordinate all responding agencies.

- ADVANTAGES
  - Teams are prepared to handle unusual incidents.
  - Individuals know each other and their roles.
  - They reduce the time needed to clear major incidents.
- DISADVANTAGES
  - Agency coordination can be difficult.

Preplanning For Incidents

Alternative Routes. A freeway corridor can be analyzed for alternative routes in case of a lane blocking incident. These routes can be recommended to motorists through media contacts or through other information systems. In some instances route diversion is necessary; detour signs for a preplanned alternative route can be quickly posted by a road crew.

- ADVANTAGES
  - Route diversion occurs quickly.
  - Alternative route recommendations are made quickly.
  - May be part of a civil defense or disaster response program.
  - Provides coordinated alternative route planning for participating agencies.

- DISADVANTAGES
  - Requires sizable initial investment of staff time.
  - Some communities do not wish to have any traffic diverted to their streets, regardless of the circumstances.

Emergency Vehicle Access. This option calls for identification of freeway links that do not have adequate access for emergency vehicles. Movable barriers and U-turns at key locations can reduce response time by fire trucks, aide cars, and the police.

- ADVANTAGES
  - Emergency vehicles can approach the incident from both directions.
  - Reduces response time.
- DISADVANTAGES
  - Unauthorized motorists are tempted to use the U-turns.

SURVEILLANCE/CONTROL

Surveillance and control strategies can be integrated with incident specific strategies to achieve a faster and more efficient response effort. Some of these surveillance control options are described here.

Increased Police Patrols

Increasing police patrols during peak periods, when incidents are most likely to produce high delays, requires additional patrol cars and officers. When officers are taken from another shift, the impacts of fewer officers during that shift and zone-of-responsibility must be examined. The benefit is in the number of response units that are available to respond to an incident and the increased likelihood that a patrol car will be near the incident when it is called in. The increased patrol intensity may require dispatch office upgrading and/or more dispatchers may need to be hired. Additional costs will be encountered for police salaries, benefits, new

vehicles, additional officers, maintenance for new or more frequently used vehicles, and special equipment for incident management such as push bumpers, cones, flares, and gasoline for stalled vehicles.

- ADVANTAGES
  - It does not require investment in a locally untested strategy.
  - Costs can be accurately estimated from agency data.
  - It has a high user acceptance.
- DISADVANTAGES
  - New funding may be required.

Peak Hour Motorcycle Patrols

The cost of the purchase and maintenance of the cycles and the training of a motorcycle patrol officer may be lower than that of increasing the traditional patrol unit, and motorcycles are more flexible in terms of their ability to arrive at an incident site in heavily congested conditions. Although they lack the instant incident clearing capability of a patrol car with push bumpers and although officer safety may be a concern, as previously mentioned, they are able to get to incident sites much quicker in the event of severe lane blocking. Officers can then set up site management to improve traffic flow and safety, set flares, and assist the citizens involved in the incident while other vehicles are finding a way through traffic to help clear an incident.

- ADVANTAGES
  - Increases police mobility during peak hour congestion.
  - Response times are faster.
  - Quickens the assessment of the severity and need for other emergency agencies to respond.

- DISADVANTAGES
  - Motorcycles are not able to move a disabled vehicle.
  - Motorcycles do not offer the same amount of protection to the officer in the event of secondary accidents or inclement weather.

Tow Truck Service Patrols

Tow trucks (private or publicly owned) can be specially equipped for freeway incident management and assigned to patrol a freeway segment or to observe from a stationary vantage point and respond to sighted or to reported incidents (Barnett, et al. (1980)). Contracts may be made with private companies for this service, or an operating agency may choose to provide the service itself.

- ADVANTAGES
  - Tow trucks can respond to and clear nearly all incidents.
  - Tow trucks can carry gasoline for cars, barriers, flares, and cleanup equipment for small jobs.
  - If a contract is given to a private firm, investment can be limited to the hours of patrol operation.
- DISADVANTAGES
  - When the operating agency opts to provide tow truck service patrols on its own, start-up costs are high.
  - Vehicle maintenance and operation costs require funding.

Aircraft Patrol

In many areas aircraft are used to patrol the freeway system. These are usually media sponsored operators providing traffic reports for a radio or television station. Both helicopters and small airplanes have been used.

- ADVANTAGES
  - If the aircraft is supplied by the private sector and the operating agency has a good relationship with the station, then this is a cheap surveillance option.
  - There is potential for monitoring major shifts in route choices.
  - There is potential for photographic analysis of traffic distribution during congested periods and during an incident.
  - Aircraft patrols can quickly verify potential incidents.
- DISADVANTAGES
  - Use is limited to peak hours.
  - Media operated helicopters have been known to impede incident management efforts by hovering too close to the accident (Barnett (1987)).

Citizens Band Radio Monitoring

A radio frequency dedicated to incident reporting can be established, publicized, and monitored. This low cost option may be especially effective in rural areas with low budgets. The effectiveness of citizens band monitoring depends on how it is marketed and how well operating agencies staff the listening post. A new twist in this option was introduced with cellular phones. A traffic report phone number may be established, and drivers may call directly to the dispatch office in the event of an incident.

- ADVANTAGES
  - Could be monitored by existing dispatch staff.
  - Equipment is easy to use and has low operating and maintenance costs.
- DISADVANTAGES
  - Users are limited to owners of CB radios.
  - Increases workload for dispatch personnel.

Call Boxes and Motorist Assistance Phones

A call box is a box with a switch or toggle that signals the operating agency (via phone line) that an incident has occurred. A motorist only needs to flip the toggle to call for help. Motorist aid phones (MAP) include a handset much like a home phone. They are connected directly to the operating agency's dispatch office (or equivalent) and no dialing is required. Because of their expense, call boxes and motorist assistance phones (MAP) have typically been located at high accident locations or along point facilities with limited or no shoulders. They provide a 24-hour detection service. Incidents occurring outside the normal peak hours, when other surveillance options may not be cost effective, can be reported by the motorists involved in an incident. In the case of point facilities, such as bridges, they provide a safety function as well (particularly where there are short sight distances, as over a crest vertical curve) by preventing secondary accidents. They are popular with citizens, who appreciate a nearby way to call the state patrol or DOT instead of having to flag down assistance, especially with the risk associated with accepting help from a stranger.

- ADVANTAGES
  - Incident reporting can be done 24 hours a day.
  - Citizen acceptance is high.
  - Reports directly to response agency dispatch office.
  - Allows motorists to report incidents quickly.
- DISADVANTAGES
  - Accrues monthly telephone usage fees.
  - Creates a potential for vandalism.

Highway Advisory Radio (HAR)

Highway advisory radio is a radio frequency that provides traffic information and potential alternative routes during congested periods. It can be operated 24 hours a day or only when conditions warrant. It can also be combined with other

information such as the weather report. The newest highway advisory radio systems are now able to transmit the latest traffic information (continually updated) and store it on a car radio. When a motorist wants the latest report, he or she presses a button. This eliminates the need to listen to repetitive traffic reports.

- ADVANTAGES
  - Instant traffic reports are available.
  - It helps motorists to decide on alternative routes when they need the information, not when the radio station happens to broadcast it.
- DISADVANTAGES
  - Recorded messages become repetitious if not updated frequently.
  - Motorists quickly stop using HAR if it doesn't provide timely, accurate information.

Volunteer Watch

In some jurisdictions volunteers have been used to observe the freeways during peak hours from vantage points near high incident rate locations.

- ADVANTAGES
  - Provides the citizens with a specific action for reducing congestion in their community.
  - Provides visual verification of incidents where other surveillance systems may not have a good viewpoint.
  - Provides initial assessment of the severity of the incident.
- DISADVANTAGES
  - Volunteers may not be available.
  - Training must be provided for reliable reporting.
  - Since volunteers are unlikely to be required to follow a strict work schedule, incident detection can be "spotty."

Loop Detection

Induction loops have been installed for volume counts and for incident detection. An incident detection system based on induction loops requires major capital and maintenance investments. A system includes loops imbedded into the freeway at regular intervals, a communications link from the loop amplifiers to a central observation station, an observation station, a computer, incident detection software, and staff time to calibrate (or develop) the detection algorithm. As noted above, some method for verifying that an incident has occurred is needed. Most systems are based on "presence loop" type detection technology. A major advantage of this option is that it may be incorporated as part of a comprehensive surveillance and control project that includes ramp metering and video monitoring, as well as a potentially continuous gathering of traffic data (volumes, occupancy). These systems may also provide 24-hour-a-day incident detection service.

- ADVANTAGES
  - Provides 24-hour-a-day surveillance.
  - Can collect traffic data for other uses.
  - Loop information can be represented on a network map.
- DISADVANTAGES
  - Incident detection algorithms often produce false calls.
  - Loops are frequently damaged during resurfacing.

Video and Closed Circuit Television

Closed circuit television (CCTV) has become increasingly popular for incident impact mitigation. It allows visual surveillance of any section or sections of the freeway. It is sometimes used to verify incident detection algorithms and to assess the severity of an incident, allowing the surveying agency to send the right type of assistance to motorists before response units actually arrive at the scene. CCTV is also used to check ramp queues where ramp metering is used. Freeway operations may be recorded on a video cassette for later analysis, or visual image

processing may be performed using a process called the wide area detection system (WADS) now being developed in Minnesota. CCTV is particularly useful for traffic flow analysis and for vehicle classification studies.

- ADVANTAGES
  - Incidents can be visually verified.
  - Allows initial assessment of incident severity.
  - Provides a visual record of freeway operations that may be carefully examined at a later time.
  - Volume, speed, and vehicle classification data can be gathered simultaneously.
- DISADVANTAGES
  - Cable and equipment are not always reliable.
  - Provides opportunity for vandalism.
  - May be obstructed by vertical curves.
  - Video monitoring is a tedious task; some incidents may be missed or go unnoticed.

Table 3 presents the costs of the alternative incident management options. This table provides an important perspective from which to view the various management alternatives.

TABLE 3. INCIDENT MITIGATION OPTIONS RELATIVE COSTS*

INCIDENT MANAGEMENT

Administrative Options	Capital	Maintenance	Operations
Fast Vehicle Removal	L	L	L
Dedicated Freeway Patrol	M	L	M
Emergency Lights/Screens	L	L	L
Accident Investigation Sites	M	L	L
Equipment Storage Site	L	L	L
Removal Crane	VH	H	M
Patrol Car Push Bumpers	L	L	L

Organizational Options	Capital	Maintenance	Operations
Interagency Relationships	L	L	L
Incident Phone Lines	M	L	M
Variable Message Signs	M	M	M
Media Ties	L	L	L
Transit Radio	L	L	L
Incident response teams	M	M	M

Preplanning for Incidents	Capital	Maintenance	Operations
Alternate routes	M-H	L	L
Emergency Vehicle Access	M	L	L

SURVEILLANCE/CONTROL

	Capital	Maintenance	Operations
Police Patrol	M	M	M
Motorcycle Patrol	L-M	L-M	M
Tow Truck Patrol	M-H	M-H	M
Aircraft Patrol	VH	H	H
CB Radio	L	L	L
Cellular Phones	L	L	L
Call Boxes	M	L	M
Highway Advisory Radio	M	M	M
Volunteer Watch	L	L	M
Loop Detection	VH	H	M
Video and CCTV	VH	M-H	M-H

*(L -- Low, M -- Medium, H -- High, VH -- Very High)

INCIDENT MANAGEMENT AND SURVEILLANCE/CONTROL EVALUATION METHODOLOGIES

Aside from looking at the details of specific options, it is also interesting to review the methodologies used to assess such options. Throughout the incident management literature, there is a diversity of evaluation methodologies ranging in sophistication from simplistic estimates to estimates based on complex simulation models. A common measure of the potential or realized effectiveness of an incident management option or strategy is a cost-benefit analysis. However, as will be discussed below, the measurement of costs and benefits is not a trivial task.

Vehicular delay frequently plays a significant roll in the cost-benefit analyses. Historically, delay has been measured using both analytical and simulation techniques. The analytical techniques focus on the loss of capacity caused by an incident and are generally limited to freeway sections (Goolsby (1971), Lari, et al. (1982), Tignor (1976)). In contrast, simulation methods provide a variety of estimates relating to delay, vehicle miles traveled, and so on, for roadway segments by assuming a fixed traffic demand/origin-destination matrix or, in some cases, they may allow for variable traffic demand and changes in delay resulting from route diversion (Mannering, et al. (1988)).

The cost of delay has been estimated by several writers. Logit models comparing the costs people are willing to pay for changing modes have been the most popular. Thomas (1970) estimated the value of commuters' time as approximately one third of their wage rate by using a logit model that estimated a user route choice model in which the choices were a toll road and a free expressway. The value of time for commuters is assumed to be $8.83 per hour in Barnett's (1987) assessment of incident impacts in the Los Angeles area. Another study by Chui and McFarland (1984) used regression methods to develop a speed choice model. They assumed that commuters would minimize both operating and accident costs. Their

findings showed that commuter travel time is valued much higher than had previously been estimated: $8-$10.40 per hour per person for delay, depending on the driver's socio-economic characteristics.

Capital and maintenance costs must also be accounted for, and a discount rate of 6 percent has been recommended (Urbanek and Rogers (1978)). Identification of the capital costs varies from project to project depending on site specific characteristics. Other costs depend on the cost of salaries and benefits for maintenance and operation of the strategy (Gerstan (1984)). An important hidden cost is the commitment of staff to operate the strategies (Ahmed (1986)). Highway advisory radio has had problems in some areas because of repetitive prerecorded messages that were infrequently changed. A commitment of staff to keep programs updated is essential.

Incident simulation has proven to be an important tool for estimating costs and benefits. Simulation has traditionally been done with one of several simulation packages such as INTRAS (Wicks, et al.(1980)) or FREQ (Roden, et al. (1980)). The simulation packages fall into two general categories: macroscopic models and microscopic models. Both provide information on delay, speeds, gasoline consumption, and emissions. The agency may then use these measures in different ways for different audiences.

The most popular and comprehensive simulation approach is network simulation. Network simulation ties together both the freeway corridor and the surrounding arterial systems. The most difficult simulation location is at the interface of an arterial system and a highway with ramp control and signal controls (Yauch (1988)). Network simulation offers the advantages of evaluating the impacts on the system level and adjusting the demand for the facilities if one facility (e.g., the freeway) is over capacity.

OVERVIEW OF SOME EXISTING INCIDENT MITIGATION SYSTEMS

A review of incident mitigation systems shows that most urban areas have at least a few of the options mentioned earlier and that the larger urban areas, Los Angeles and Chicago for instance, are using many of the options. However, specific options are not always appropriate for all facilities, and some of the above options would be redundant if they were implemented together, such as dedicated freeway patrol and increasing police patrols. Smaller cities may also have many of the options, but they may be implemented on a much smaller scale. For example, both Chicago and Seattle have tow trucks, but Seattle uses only four, whereas in Chicago 35 vehicles patrol the freeways. The level of implementation intensity generally depends on the daily travel on the freeways and on the breadth of the network being managed. The Chicago, Houston, Detroit, and Los Angeles systems have higher traffic volumes and cover larger areas than other systems and may be ranked in the first tier of implementation intensity. Other well reported systems may have many of the same elements but not the same numbers. Seattle, Toronto, Minneapolis, and Cincinnati are examples of these systems and are members of the second tier. The eight systems that make up the first and second tiers of implementation intensity are briefly discussed below. Tables 4A and 4B summarize the system elements that have been found in the literature for each city. In reviewing these tables, note that some options have not been reported in the literature.

CHICAGO

The Chicago Area Freeway Traffic Management Program has been cited as the best system currently existing in the United States (circa 1987) by the Institute of Transportation Engineers. It covers six counties and a traffic network that handles 300,000 vehicles daily. It has an extensive loop detection system, a traffic control center, 35 variable message signs, highway advisory radio with an automatic update based on the link volumes, 35 emergency traffic patrol tow trucks, a crash crane for

TABLE 4-A. EXISTING INCIDENT MITIGATION SYSTEMS: INCIDENT MANAGEMENT*

Administrative Options	Chicago	Houston	Detroit	Los Angeles
Vehicle Removal	X	X	X	X
Dedicated Patrol	X	X	X	X
Emergency Lights/Screens	X	O	O	X
Accident Investigation Sites	O	O	O	O
Equipment Storage Site	O	O	O	O
Removal Crane	X	X	O	O
Patrol Car Push Bumpers	X	X	X	X

Organizational Options	Chicago	Houston	Detroit	Los Angeles
Interagency Agreements	X	X	X	X
Traffic Management Teams	X	X	O	X
Incident Phone Number	O	O	O	O
Variable Message Signs	X	X	X	X
Media Ties	X	X	X	X
Transit Radio	O	O	X	X
Incident Response Teams	X	X	O	X

Preplanning for Incidents	Chicago	Houston	Detroit	Los Angeles
Alternate routes	X	X	X	X
Emergency Vehicle Access	X	X	X	X

SURVEILLANCE/CONTROL*

	Chicago	Houston	Detroit	Los Angeles
Police Patrol	X	X	X	X
Motorcycle Patrol	O	O	O	O
Tow Truck Patrol	X	X	X	X
Aircraft	X	X	X	X
CB Monitoring	X	X	X	X
Cellular Phone	X	X	X	X
Call Boxes	O	X	X	X
Highway Advisory Radio	X	X	X	X
Volunteer Watch	O	O	O	O
Loop Detection	X	X	X	X
Video and CCTV	X	X	X	X

*(X -- In Use, O -- Not in Use)

TABLE 4-B. EXISTING INCIDENT MITIGATION SYSTEMS: INCIDENT MANAGEMENT*

Administrative Options	Seattle	Toronto	Minneapolis	Cincinnati
Vehicle Removal	O	X	X	O
Dedicated Patrol	X	X	X	X
Emergency Lights/Screens	X	O	O	O
Accident Investigation Sites	O	O	O	O
Emergency Storage Site	O	O	O	O
Removal Crane	O	O	O	O
Patrol Car Push Bumpers	X	X	X	X

Organizational Options	Seattle	Toronto	Minneapolis	Cincinnati
Interagency Agreements	O	O	O	O
Incident Phone Number	X	O	O	O
Variable Message Signs	X	X	X	X
Media Ties	X	X	X	X
Transit Radio	X	O	O	O
Incident response teams	O	O	O	O

Preplanning for Incidents	Seattle	Toronto	Minneapolis	Cincinnati
Alternate routes	X	O	O	O
Emergency Vehicle Access	X	X	X	X

SURVEILLANCE CONTROL*

	Seattle	Toronto	Minneapolis	Cincinnati
Police Patrol	X	X	X	X
Motorcycle Patrol	X	O	O	O
Tow Truck Patrol	X	O	X	X
Aircraft	X	O	X	X
CB Monitoring	X	O	X	X
Cellular Phone	X	O	X	O
Call Boxes	X	O	X	O
Highway Advisory Radio	X	X	X	X
Volunteer Watch	O	O	O	O
Loop Detection	X	X	X	X
Video and CCTV	X	X	X	X

*(X -- In Use, O -- Not in Use)

oversized vehicles and truck removal, and a direct media link through its computer. The system has been estimated to reduce congestion by 60 percent and accidents by 18 percent (Chicago Area Freeway Traffic Management Program (1987), Illinois State Department of Transportation (1979)).

HOUSTON

In addition to its extensive surveillance and control system (electronic loop detection and associated devices), the Texas Department of Highways and Public Transportation operates tow trucks, accident investigation sites, incident response teams, highway advisory radio, and call boxes. Surveillance by video monitors, aerial patrols by commercial radio stations, privately sponsored motorist aide vehicles, and citizens band radio monitoring provide quick detection and verification of incidents on the U.S. 59 freeway corridor. The corridor management teams have developed a comprehensive route diversion plan. Variable message signs at key off ramps provide motorists the opportunity to leave the freeway before entering severely congested traffic. Intergovernmental cooperation between Houston and its suburbs has smoothed the operation and implementation of these facilities and management options (Derr (1987), Dudek (1978)).

DETROIT

Detroit was one of the first cities to install a loop detection system and incident detection algorithms. It also has tow truck service patrols, highway advisory radio, variable message signs, a fast vehicle removal policy, patrol cars with push bumpers, a dedicated freeway patrol, motorist aid phones, emergency vehicle access at critical points along the freeway, and alternative route planning for incidents (Klucens (1988), Taragin (1976)).

LOS ANGELES

Los Angeles has one of the larger incident detection and mitigation systems. The Los Angeles area freeway management system includes tow trucks, electronic (induction loop) and video based traffic surveillance systems (CCTV), and both

fixed and mobile variable message signs. Incident response teams bring together the municipalities, state agencies, fire, ambulance, and police groups to prepare for large traffic incidents. This close interagency cooperation facilitates incident management and brings together resources that may not otherwise be available at the incident scene without considerable delay. They have worked closely with local media and with municipal governments (Committee on Freeway Operations (1987), Estep (1972), Roper (1987)).

SEATTLE

The Seattle system includes over 900 loop detectors, 27 video cameras, close media ties through the Traffic Management Center, motorist aid phones (MAP) along the Evergreen Point Bridge, four tow trucks for both the Lake Washington bridges, a county 911 emergency phone system, airplane, helicopter and cellular radio reporting through the local radio stations, and a disabled vehicle assistance patrol sponsored by a local business and a local radio station. Highway advisory radio (HAR), route diversion plans, fixed and mobile variable message signs, and motorist information efforts all played important roles in maintaining the level of service during the major renovations of Interstate 5 in 1984 and 1985. The Washington State Department of Transportation is currently expanding its video capabilities on sections of Interstate 5 and 90, and State Routes 405 and 520 in or near Seattle (Kurtzweg, (1987), Washington State Department of Transportation (1987)).

TORONTO

The Queen Elizabeth Expressway freeway management system includes closed circuit television, incident detection software, induction loops, and a central traffic control computer for both detection and ramp metering. Overhead variable message signs have been installed and, together with the route diversion plan, provide commuters with significant time savings (Case and Williams (1978)).

MINNEAPOLIS

The I-694 freeway in Minneapolis is a good example of a small network surveillance and control system. The basic components, electronic loop induction detection, amplifiers, coaxial cable, and a traffic management center, are in place. Ramp metering controls freeway access, and variable message signs warn commuters of congested or stopped traffic. The traffic management center's computer is connected with the state highway patrol dispatching office (complete with a graphic representation of the freeway volumes) and with several local commercial radio and television stations. Good communications between the DOT and the state patrol have been credited with a 20 percent improvement in response times (Lari, et al. (1982), Lari, et al. (1985)).

CINCINNATI

The construction of a new sports stadium in Cincinnati, Ohio, was the initial motivator for the construction of a limited traffic surveillance and control center on Interstate 75 and portions of Interstate 71. It was initially conceived to ameliorate congestion before and after activities in the stadium. Operationally, the most significant benefits were during commuter peak hours. Closed circuit television has been recently added for verification and severity estimates of incidents on those facilities. Highway advisory radio and lamp matrix variable message signs have been installed to facilitate commuter and stadium attender route diversion (Dunn and McDermott (1983), Young (1987)).

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