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16. Abstract

A variety of techniques, ranging from simple motorist call systems to sophisticated surveillance systems, are used to detect incidents. Each technique has its own set of advantages and limitations. One of the purposes of this report is to assess the various techniques and strategies for detecting incidents. The report provides information on the cost and effectiveness of individual strategies for detecting incidents. Whenever possible, quantitative cost and effectiveness data from existing systems are presented.

In addition, a method for assessing alternative strategies for detecting incidents is provided. The method uses incremental benefit-to-cost analysis for selecting between different incident detection strategies. The systems can be used to select the most cost-effective incident detection strategy of expanding an existing incident management system. The method can also be adopted to provide an assessment of how much coverage to provide using a single incident detection strategy.

An illustration of the method is also provided. The method is used to determine the optimum number of motorist assistance patrols in a limit area in Houston. Data indicates that motorist assistance patrols provide a substantial benefit to any incident management system. However, it is difficult to assess objectively how many patrols should be provided to maximize a given level of investment. Existing procedures show only how to determine the benefits of providing a given level of motorist assistance patrols. In order to determine the optimum number of patrols, transportation agencies need to be able to assess the effects of increasing or decreasing the number of patrols.

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ASSESSMENT OF ALTERNATIVE STRATEGIES FOR DETECTING INCIDENTS

by

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Gerald L. Ullman

Research Report 1232-12
Research Study 2-18-90/4-1232

Sponsored by

Texas Department of Transportation
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

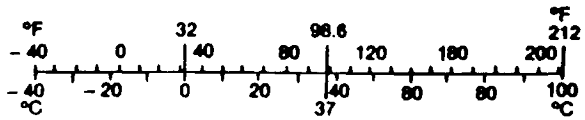
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

SUMMARY

Congestion continues to be one of the major issues facing many of the metropolitan areas in Texas. Incidents account for over half of the delays experienced on freeways in Texas. To combat congestion caused by incidents, many transportation agencies are developing freeway incident management systems that permit them to detect, respond to, and clear incidents quickly and efficiently.

Rapid detection and verification of incidents is one of the most critical components of a freeway incident management system. The speed at which this process is performed can dramatically affect the amount of the congestion and delay caused by an incident. The faster that an incident can be detected, the less of an impact it will have on freeway traffic.

There are a number of strategies or techniques that can be used to detect incidents including motorist assistance patrols, electronic surveillance systems, closed circuit television systems, stationary observers, law enforcement patrols, aerial surveillance, motorist aid call boxes and telephones, CB radio monitoring systems, cellular telephone call numbers, and automatic vehicle identification systems. Each of these have its own advantages and limitations. Since most incident management systems in operation today have evolved over time, they often use more than one technique for detecting incidents.

By far, the most widespread technique for detecting incidents are motorist assistance patrols. Motorist assistance patrols have proven to be a versatile and flexible means of detecting and clearing incidents. Incidents are detected primarily through visual inspection. The primary benefit of a motorist assistance patrol is that the clearing process can begin immediately once the vehicle arrives on the scene. Studies have shown the benefit-to-cost ratio of motorist assistance patrols to range between 7 and 36.

Existing procedure do not permit the incremental benefits of expanding an system to be quantified. Incremental B/C analysis shows amount of improvement that can be achieved in a system for each additional dollar of investment. Even though an analysis of overall B/C ratios at a given level of improvement may indicate that an improvement is feasible, an analysis of the incremental B/C ratios may indicate that a lower level of improvement is all that is economically warranted. An alternative may have a lower overall B/C ratio and yet it may still be the best alternative because it offers the greatest benefits for the total expenditures.

An example of how the method can be used to assess alternative strategies for detecting incidents is included in the report. A key question that arises when deciding to implement motorist assistance patrols (or to enhance an existing patrol system) is how many patrols should be implemented to maximize the benefits achieved. In this report, procedures for estimating how many motorist assistance patrols should be implemented in a given incident management system are discussed. Incremental benefit-cost analysis was used to determine the benefits in reduced delay achieved for a particular level of investment. This type of analysis can be a useful tool in evaluating incident detection strategies, but must be tempered with sound engineering judgement.

IMPLEMENTATION STATEMENT

This report provides an assessment of the various techniques available for detecting incidents on freeways. Whenever possible, cost and effectiveness data from actual systems in operations has been provided. Furthermore, the report also contains information on the techniques that can be used for evaluating alternative strategies for detecting incidents. The information in this report is intended to assist TxDOT personnel in developing and improving freeway incident management systems in Texas.

DISCLAIMER

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. The title of the study was "Urban Highway Operations Research and Implementation Program." The contents of this report do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. The report is not intended for construction, bidding, or permit purposes. The report was prepared by Mr. Kevin Neil Balke (Texas P.E. Registration #66529) and Mr. Gerald Lee Ullman (Texas P.E. Registration #66879).

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1. INTRODUCTION

Congestion continues to be one of the major issues facing many of the metropolitan areas in Texas. Although Texas has only one major metropolitan area that ranks in the top ten most congested cities nationwide (1), congestion and its impacts place a severe economic strain on many communities. For example, both Houston and Dallas lose over $1 billion annually (in terms of delay and excess fuel consumption) due to congestion. Over half of this amount is due to congestion caused by incidents (1). Therefore, the timely detection and clearance of incidents on major freeway facilities, especially during peak periods, is one of the top priorities for many Districts in Texas.

Background

There are two types of congestion on freeways: recurrent congestion and nonrecurrent congestion. Although both are a result of when traffic wishing to use the freeway (demand) exceeds the traffic-carrying capabilities of the freeway (capacity), they have different causes and solutions. Typically, recurrent congestion occurs during high volume periods (such as during the morning and afternoon peak periods). It is caused when the demand exceeds the physical capacity (as determined by the geometry) of the freeway. In most cases, recurrent congestion occurs daily and is predictable in terms of its effect, location, and duration.

Nonrecurrent congestion, on the other hand, is caused by incidents that temporarily, and often unexpectedly, reduce the capacity of a freeway. Most incidents (such as accidents, stalled vehicles, weather, spilled loads, etc.) occur randomly and are unpredictable, both in terms of the time and location at which they occur. Other incidents (such as maintenance activities, construction, and special events) are predictable or planned activities. Regardless of whether they are planned or occur randomly, incidents and the congestion they cause are often unexpected by many motorists, and can create safety hazards and excessive delays for uninformed motorists.

In order to mitigate the impacts of incidents on traffic flow, many highway and transportation agencies are implementing freeway incident management systems. Freeway incident management refers to a coordinated and preplanned approach to restoring normal operations to a freeway when an incident occurs (2). The approach involves a systematic process for 1) detecting and verifying that an incident has occurred, 2) identifying the magnitude and severity of the incident (i.e., the number of vehicles involved, the number of lanes blocked, the type and location of the incident, etc.), and 3) determining and dispatching the appropriate type of response (i.e., service patrol, police, fire, ambulance, etc.) to aid the motorists involved and to minimize the impacts of the incident. Freeway incident management also includes systems for providing motorists with information that will permit them to divert around or away from the incident site, change their times of travel, switch to alternate modes of transportation, and increase their awareness of impending congestion.

There are a number of factors that effect the amount of congestion that occurs as a result of an incident. Only some of these factors can be influenced by a freeway incident management system. The one factor that a highway or transportation agency can influence is incident duration. The duration of an incident is affected by the time required to detect, respond to, and clear the incident. Often, the time required to detect and verify an incident (particularly a minor incident) constitutes the majority of the total duration of an incident. Therefore, to reduce the impacts of incidents, one of the most critical elements of an incident management program is the detection of incidents.

Purpose and Scope of Report

A variety of techniques, ranging from simple motorist call systems to sophisticated surveillance systems, are used to detect incidents. Each technique has its own set of advantages and limitations. The purpose of this report is to assess the various techniques and strategies for detecting incidents. The report includes information on the cost and effectiveness of individual strategies for detecting incidents. Whenever possible, quantitative cost and effectiveness data from existing systems are presented.

In addition to providing cost and effectiveness information on the various techniques for detecting incidents, a procedure for analyzing alternative strategies for detecting incidents is provided. The procedure uses standard incremental benefit-to-cost techniques for analyzing the benefits and costs of alternative incident detection strategies. Using the procedure, traffic engineers and policy-makers can select the most cost effective strategies for detecting incidents in their system. A description of a method of assessing multiple incident detection strategy is provided in Chapter 3.

Chapter 4 of the report illustrates how the procedure can be used to determine the optimum number of motorist assistance patrols for a given service area. Data indicate that motorist assistance patrols provide a substantial benefit to any incident management system. Motorist assistance patrols are a cost effective means of detecting and clearing minor incidents. However, it is difficult to assess objectively how many patrols should be provided to maximize a given level of investment. Existing procedures, such as those developed by Urbanek (3), show how to determine the benefits of providing a given level of motorist assistance patrols; however, to determine the optimum number of patrols, transportation agencies need to be able to assess the effects of increasing or decreasing the number of patrols.

The information contained in this report was obtained through a review of existing literature and through interviews with representatives from various incident management systems throughout the nation. No additional field data were collected as part of this report.

2. STRATEGIES FOR DETECTING INCIDENTS

The major goal of all freeway incident management systems is to reduce the impacts of both major and minor incidents on the traffic stream. One of the critical components for achieving this goal is the quick and accurate detection and verification that an incident has occurred on a freeway. A variety of strategies and techniques exist for detecting incidents. Each strategy has its own advantages and limitations.

In this chapter, the importance of incident management will be discussed. Following this discussion, a review of the advantages and limitations of the various strategies for detecting incidents will be presented. Because most systems in operation today use more than one strategy to detect incidents, it is difficult to isolate the cost and effectiveness of an individual strategy to detect incidents in some systems; however, wherever possible, quantitative information on the cost and effectiveness of each strategy has been provided.

Importance of Incident Management

An incident is any non-recurring event which causes a reduction in the capacity or an abnormal increase in the demand on a roadway (4). These events may be either planned or unplanned. Unplanned incidents are random or unpredicted occurrences such as traffic accidents, disabled or stalled vehicles, spilled cargos, etc. Planned activities, such as roadway maintenance activities, construction, or special events, can be considered as incidents since they occur irregularly and are often unexpected by motorists.

Incidents can have a devastating effect on traffic flow and safety. One study in Houston, Texas has shown that, depending upon the type, location, and number of lanes blocked, the capacity of a three-lane freeway is reduced by 26 to 79 percent as a result of an incident (5). Such reductions in capacity can have a dramatic impact on the delay experienced by motorists. In 1984, incidents accounted for over 60% of the total vehicular delay (1.25 billion vehicle-hours) and over 826 million gallons of wasted fuel nationwide (6). In terms of user costs, this is equivalent to over $5.5 billion. An incident blocking one inbound lane for only 18 minutes on the Gulf Freeway during the morning peak would result, theoretically, in over 800 vehicle-hours of delay (2). In another study, the California Department of Transportation (Caltrans) determined that for every minute a lane was blocked during off-peak periods, four to five minutes was added to the total time required to restore the freeway to free-flow conditions (7).

In addition to excessive delays, incidents on freeways also pose a serious safety concern. Because incidents cause unexpected congestion and slowdowns, incident caused congestion can also lead to secondary accidents. On one freeway in Minneapolis, Minnesota, approximately 13 percent of all the accidents occurring in the peak periods were attributed to the congestion caused by previous incidents (8). Furthermore, incidents often place motorists, police officers, and response personnel in hazardous situations because they are out of their vehicles and exposed to oncoming traffic. It has been estimated that between 20 to 30 percent of all freeway pedestrian fatalities involve individuals whose vehicles have become disabled (9).

To reduce the effects of incidents on congestion and safety, many state and local agencies are implementing programs to detect and manage incidents on freeways. These programs, which are often part of an overall freeway management system, involve a spectrum of activities to detect, respond to, and clear incidents from the freeways as quickly as possible. An incident management program provides a coordinated, preplanned approach for using human and technological resources to restore the full capacity of the freeway after an incident has occurred, and to provide motorists with information until the incident is cleared.

As shown in Figure 2-1, there are five main tasks that must be accomplished in clearing an incident. Even without a formal incident management program, these five tasks must still be accomplished. The primary benefit of an incident management program is that these tasks occur more efficiently and require less time; thereby, reducing the total impact of the incident on traffic (10). With incident management programs, transportation agencies attempt to reduce the impacts of incidents by accomplishing one or more of the following:

- reduce the time to detect and verify incidents,
- reduce the time to respond and clear incidents,
- increase the capacity past the incident by effective on-site management procedures, and
- reduce the demand for the facility by diverting entering traffic upstream of the incident.

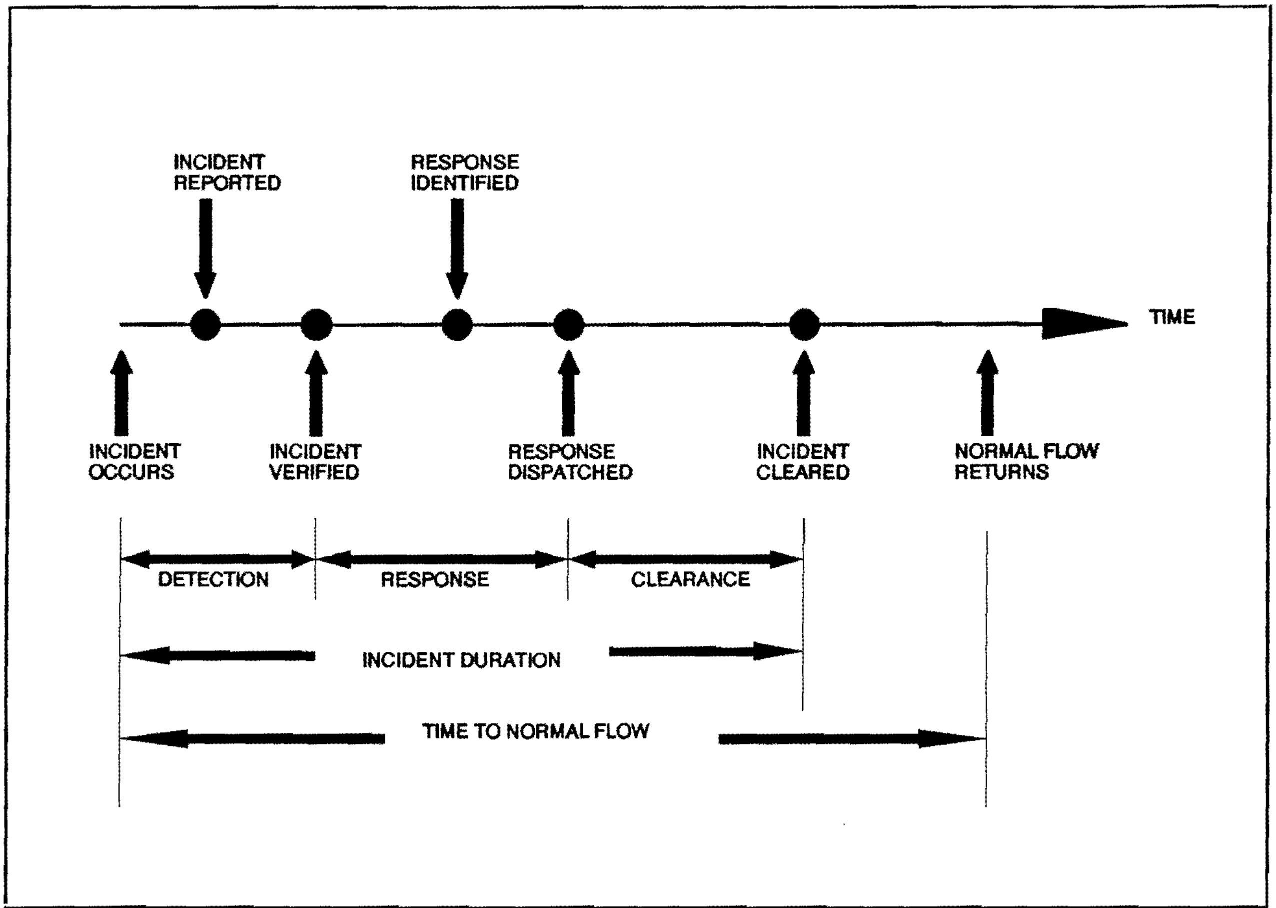

Figure 2-1. Tasks Required to Detect, Respond to, and Clear Incidents.

Techniques for Detecting Incidents

Rapid detection and verification is one of the critical components to minimizing the impacts of incidents. Incident detection and verification is the process of determining that an incident has occurred and communicating this information to the appropriate agencies. This process includes determining whether or not a report is truly an incident or a false alarm. As illustrated in Figure 2-2, the speed at which the detection and verification process can be accomplished impacts the amount of congestion that will occur as a result of an incident. Generally, the faster an incident can be detected and verified, the less of an impact the incident has on the freeway. Therefore, the fast, accurate detection of incidents can often result in the least amount of traffic disruption and can produce considerable time savings (10).

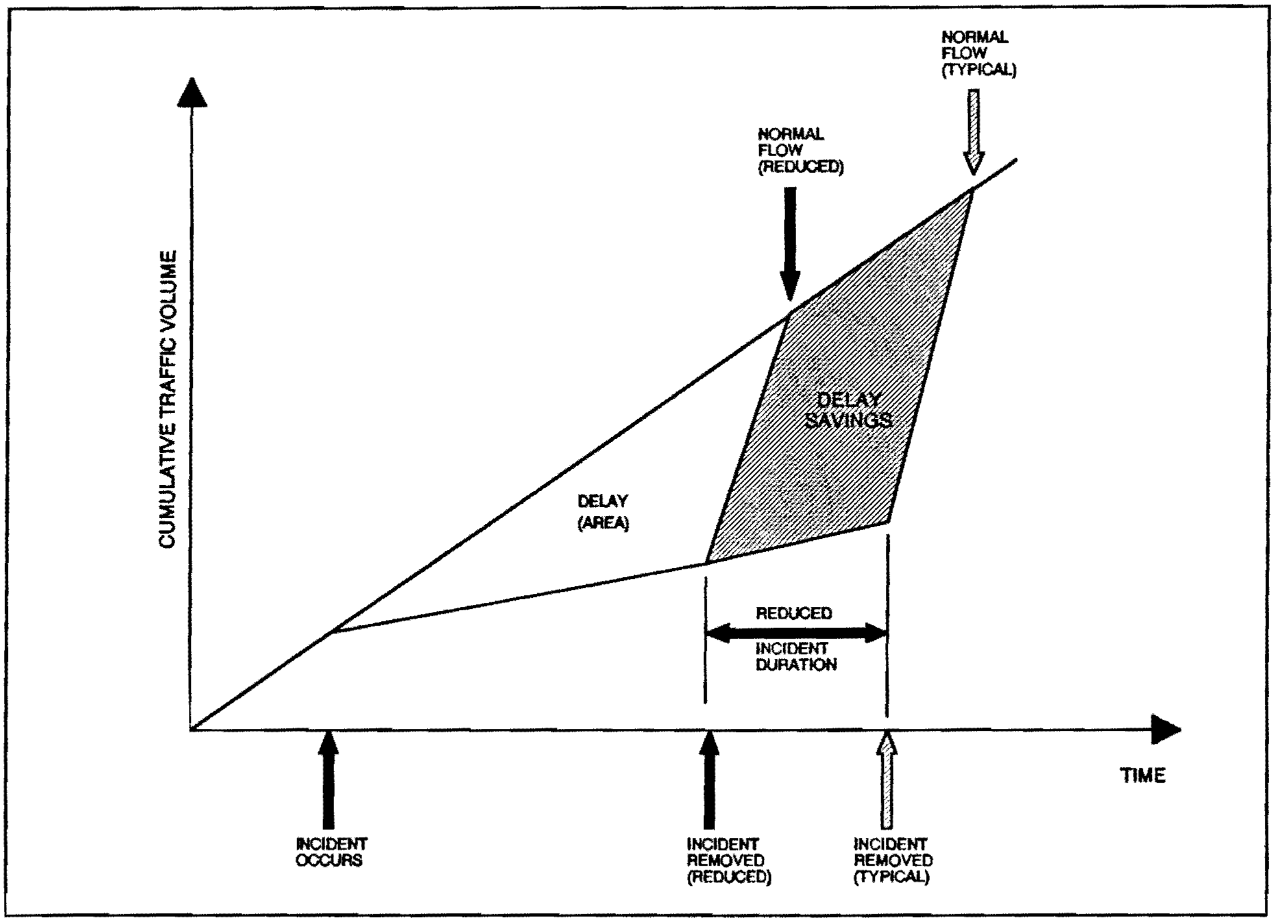

Figure 2-2. Illustration of Savings Caused by Reducing Incident Duration.

A variety of techniques exists for detecting and verifying incidents . Each has its own advantages and limitations. The more commonly used techniques for detecting incidents are discussed below.

Motorist Assistance Patrols

Motorist assistance patrols (or sometimes referred to as Service Patrols or Courtesy Patrols) are perhaps the most commonly used method of detecting and servicing incidents. Motorist assistance patrols consist of specially equipped vehicles (i.e., pickup trucks, vans, or tow trucks) for locating and removing incidents from a travel lane as quickly as possible and for providing motorists with assistance, if needed. Patrols may either circulate through the freeway network or be placed on stand-by at critical locations (such as bridges or tunnels). The types of services provided by motorist assistance patrols range from basic motorist assistance (e.g., providing gasoline, water, air, jumper cables, etc.) to sophisticated emergency and incident management (e.g., removing spilled loads, righting overturned vehicles, etc.). Appendix A shows examples of some of the motorist assistance patrols in operations nationwide.

With most motorist assistance patrols, incident detection is accomplished primarily by visual inspection. In most systems, patrols are assigned to specific routes or freeways and circulate through the area looking for incidents. The time required to detect an incident is directly related to the number and frequency of patrol vehicles. For example, the Motorists Assistance Program in Houston, Texas operates nine vans on seven different freeway facilities. The patrol routes are designed such that a single patrol vehicle will pass any given point on a freeway once per hour. Since patrols monitor both sides of the freeway at once, the effective headway between patrol vehicles is 30 minutes (11). With these approximate 30 minute headways, the average detection time for incidents on the freeway is estimated to be 13.90 minutes (12).

Incident detection may also be accomplished by monitoring CB radio traffic or other sources of traffic information. Motorist assistance patrols can also be used to verify incidents, assess the response needed, and verify possible false incidents sensed by electronic loop detectors.

Even though motorist assistance patrols tend to be labor intensive, they are still one of the most effective means of detecting and clearing incidents on freeways. For example, the Minuteman program, operated by the Illinois Department of Transportation (IDOT) in the Chicago area, produces approximately $17 in delay savings benefits for every $1 invested in the program (13). The Motorists Assistance Program (MAP) in Houston, Texas produces a benefit/cost ratio ranging from 7 to 36, depending upon the method used to estimate time saving benefits (12). The costs associated with each of these programs are summarized in Tables 2-1.

The primary benefit of using motorist assistance patrols as an incident detection technique is that the time required to begin clearing the incident is greatly reduced. Since motorist assistance patrols are equipped to handle most minor incidents, the response and clearance task can begin immediately once the service patrol arrives on the scene. At major incidents, motorist assistance patrols can assist in the clearance functions by performing one or more of the following tasks:

TABLE 2-1. ANNUAL OPERATING COST OF TWO SERVICE PATROLS

	Chicago	Houston
Personnel	$2,400,000[1]	$527,203[2]
Vehicle Replacement	$240,000/yr[3]	N/A
Operations Fuel & Oil Maintenance	 $4,900/veh $6,067/veh	 $4,752/veh $5,658/veh

[1] 54 drivers, 9 supervisors, 12 support
[2] 19 deputies and one clerk
[3] Purchase 8 chassis/yr @ $30,000.
Sources: (12, 14)

- direct traffic at the incident scene,
- help plan and implement emergency alternative or detour routing,
- provide emergency medical assistance until additional help arrives
- coordinate communications among various response agencies,
- provide traffic reports or other information to highway or enforcement personnel, local media, or the public, and
- provide emergency transportation to motorists and response to medical personnel.

The typical functions and duties performed by motorist assistance patrols are listed in Appendix B.

Electronic Surveillance

Another technique for detecting incidents in major metropolitan areas is through electronic surveillance systems. With electronic surveillance, sensors are place alongside the roadway or embedded in the travel lanes to detect the presence of vehicles. Although many types of sensors (such as magnetometers, sonic, and wide-area detection systems) can be used to detect incidents, by far, the most common type of sensor used in incident detection systems is the induction loop. Induction loops are typically embedded in the pavement at 1/4 to 1/2 mile spacings and are used to measure traffic flow parameters (such as speed, volume, and occupancy levels) in the travel lanes. Information from each loop is fed into a computer monitoring system which uses an incident detection algorithm to evaluate the incoming traffic information. When conditions on the freeway exceed a predetermined threshold, an alarm is triggered, thereby, alerting the operator of the presence of a potential incident. At this point, the operator must then use some other type of surveillance technique, usually a service patrol or a closed circuit television camera system, to verify the occurrence of the incident and to determine the appropriate type of response needed to clear the incident.

Even though electronic surveillance systems are currently operating or being installed in many large metropolitan areas, the effectiveness of these systems for solely detecting incidents is limited. For example, in Chicago, Illinois, over 600 mainline detector stations have been installed on more the 250 roadway miles of freeway, and yet, most incidents are detected by means other than the electronic surveillance system (15). The electronic surveillance system is used primarily as a tool to help identify congestion locations and incident situations not covered by the other portions of the overall incident management program. The "alarm" produced by the incident detection algorithm merely serves to alert the operator to monitor one or more of the detector locations in the vicinity of the potential incident. Another disadvantage to installing electronic surveillance systems solely for incident detection purposes is the high cost to install, operate, and maintain the system.

Closed Circuit Television

Closed Circuit Television (CCTV) is an effective means of verifying that an incident has indeed occurred on the freeway lanes. It allows a quick assessment of the severity of the incident, and can be used to determine quickly the type of equipment that is needed to clear an incident. However, the use of CCTV as the sole means of incident detection is not recommended because of the tedious nature of watching video images. Using CCTV for detecting incidents is also labor intensive. For these reasons, most CCTV systems are used only to verify or confirm incidents.

The primary quantifiable benefit to installing and operating a CCTV system is the time savings that can be generated in responding to incidents. With the SCANDI system in Detroit (16), the average duration of a lane-blocking incident was reduced by 3 minutes after the CCTV system became operational. Most of the time savings was directly attributed to a shortening of the detection time by 2.5 to 4 minutes per incident. The estimated benefits of installing the CCTV system in Detroit averages approximated $79,000 per year.

On the down side, CCTV systems typically require a large capital investment on behalf of the transportation agency. The costs associated with installing and operating a ten camera CCTV system in Detroit are summarized in Table 2-2. There are many variables that effect the overall cost of the systems. The camera itself is only a minor part of the cost. The cost to purchase and install a single video camera on a utility pole ranges from $20,000 to $25,000 per camera. As with electronic surveillance systems, the most costly component of a CCTV system is the communications system needed to transmit video images back to the control center. In the past, most systems were developed using coaxial communications cabling. However, coaxial cable systems require the video image to be regenerated every mile or so in order to maintain the strength of the video signal (17).

Most systems being installed today, however, use fiber optic cables to transmit video images. With fiber optics, video images can be sent directly to the control center without having to be regenerated along the way. Each camera requires a transmitter and a receiver ($1,500 per unit) to transmit the video image to the control center. The cost to install fiber optic cable underground can be as high as $10 per foot. Fiber cables can also be strung overhead on existing utility poles in the freeway corridor or down a parallel arterial street. This can significantly reduce the costs for using fiber optics. Other means of transmitting video images, such as satellite transmissions, short-haul microwave, etc., are currently being explored (17).

Stationary Observers

In some instances, stationary observers can be positioned at locations where incidents frequently occur. Observers can be located in office or apartment buildings overlooking the freeway. From these vantage points, observers can scan significant lengths of roadway and report incidents to the appropriate response agencies as they occur.

Because stationary observer systems are extremely labor intensive, their application as a long-term incident detection system is limited. In most cases, stationary observers

TABLE 2-2. COSTS OF CCTV SYSTEM IN DETROIT.

Item	Cost
Capital Costs	
• Cameras (10 cameras)	$250,000
• Control Center	
- Monitors (12 monitors)	$18,000
- Electronics	$5,000
TOTAL	**$273,000**
Annual Operating (1)	**$17,700**
Annual Maintenance (2)	**$5,500**
Total Annual Costs (3)	
• System Cost	**$50,500**
• Per Camera	**$5,000**

(1)Seven half time employees ($8.70/hr) who spend 28% of time monitoring system.
(2)3.3% of time for five employees at $16.00 per hour (salary plus fringe).
(3)Based on 10 year service life for cameras.
Source: (16)

are used as a temporary means of detecting incidents until more sophisticated systems can be implemented. One application of this type of system would be for incidents during reconstruction. Furthermore, because the observer is stationary, the amount of area that can be covered using a fixed observer type of system is also limited. The construction of an observation tower or the identification of other vantage points may be required to increase coverage area (4).

Perhaps the most feasible application of a fixed observer type of surveillance system is in construction areas. Observers can be placed at key bottleneck locations during critical travel periods to ensure that incidents are detected and cleared rapidly. Other locations where fixed observers may be feasible include tunnels, bridges, causeways, etc.

Law Enforcement Patrols

One technique for reducing the time to detect incidents is to increase the frequency of law enforcement or highway department patrols circulating in the traffic network during critical travel periods (18). More patrols can be added to the system by either purchasing additional vehicles or by reducing the non-freeway duties of existing patrol units. Adding new patrol vehicles will require an additional capital investment to purchase and equip new vehicles, whereas reducing the non-freeway duties of patrol units may require law enforcement and transportation agencies to reorder their priorities for service. Personnel from non-freeway duties (such as traffic and parking enforcement) can be used to increase patrol frequencies in some areas during high incident periods. The circulation patterns of other patrol units in the area may need to be adjusted in order to ensure that adequate coverage of essential duties and services are maintained.

The primary advantage to using enforcement patrol vehicles as an incident detection technique is that these vehicles perform both the detection and verification functions simultaneously. With most other methods of detecting incidents, police or service patrol vehicles must be dispatched to the site in order to verify that an incident has occurred and to determine what type of response needs to be dispatched to clear the incident. Since most patrol vehicles are either law enforcement or highway department personnel, the time delay associated with dispatching a unit to verify the incident is eliminated.

The main disadvantage to using patrol vehicles as an incident detection technique is that additional vehicles and personnel may be required in order to maintain established patrol frequencies during congested conditions. Because patrols are stopping to service incidents, the headway between patrol units can become non-uniform. This may result in sporadic reports and delays in detecting incidents (4).

Aerial Surveillance

Although seldom used by transportation agencies, aerial surveillance is often used by police and commercial traffic reporting services to obtain a general overview of traffic flow on a particular facility or corridor. Using light planes or helicopters, a birds-eye view of the traffic conditions in a wide geographic area can be achieved. From the air, locations and potential causes of bottlenecks can be identified (19). Most often, congestion and incident information is then broadcast to motorists via private radio or television stations as a pubic service or marketing tool.

The costs to the transportation agency associated with using aerial surveillance for detecting incidents varies depending upon whether or not the agency plans to own and operate their own aircraft. The most expensive option is for the public agency to purchase its own aircraft and to assume the associated maintenance and operating costs. However, in order to make aerial surveillance cost effective, a wide geographic area must be covered by a single aircraft. As a result, considerable delays may occur in reporting incidents until the aircraft has passed over the incident location. Often, the use of aerial surveillance is limited to peak hours only because of the high operating costs associated with aircraft. For these reasons, aerial surveillance is not generally considered to be a feasible technique for detecting incidents by many transportation agencies.

However, aerial surveillance is used by many private sector companies as a source of congestion and incident information. Many private sector companies, such as radio or television stations, and traffic reporting services, own and operate their own aircraft for publicity and advertising reasons. Incident and congestion information is then sold to other agencies as a service or broadcast directly to motorists as a marketing tool. In order for this type of arrangement to work as an incident detection technique, the transportation agency must establish a direct communication link with the private sector company operating the aerial surveillance system.

Motorist Aid Call Boxes and Telephones

One of the earliest systems for detecting incidents on freeways was Motorist Call systems. Motorists involved in or witnessing an incident use a device placed alongside of the freeway to report incidents or request assistance. Typically, these devices are spaced every 1/4 to 1/3 mile on both sides of the freeway.

There are two types of motorists aid call systems: motorist aid call boxes and motorist aid telephones. Motorist aid call boxes consist of a box with push-buttons or toggles that signal the operating agency via a telephone line that an incident has occurred. Inside the box, several push-buttons corresponding to the type of service needed to respond to the incident (i.e., police, ambulance, wrecker, etc.) are provided. The motorists presses a button and waits for the appropriate response to appear.

Message sent indicators inside the box signal to motorists that the appropriate response agency has been notified.

Motorists aid telephone systems are a variation of the call box concept. Because telephone systems involve two-way communication (as opposed to the call box system which uses one-way communication), details of the incident and specific requests for assistance can be provided by the monitoring agency. Considerable time saving can be generated in the response times because the operator has more information about the incident from which to determine the type of response needed to clear the incident.

Unfortunately, motorists aid call boxes and telephones are not a very effective means of detection incidents. Studies have shown that considerable delay may result between when an incident occurs and the time that the monitoring agency receives notification of the incident. In order to use a call box or telephone system, the motorists must first decide to use the system, locate the nearest call device, walk to that device, and make the appropriate request for assistance.

Texas was one of the early users of motorist aid call boxes. A motorist aid call box system was installed alone 11 miles of I-45 in the late 1960s. Unfortunately, the system proved to be not very effective at detecting incidents and was not well received by the motoring public. The system experienced a large number of false or gone-on-arrival calls and long response times to calls. In addition, motorists were charged for services rendered in response to calls. Often, these charges were more than many motorists were willing to pay. For these reasons, the call box system was removed from the freeway (20).

Futhermore, motorists aid call boxes and telephones also tend to be a maintenance liability of many agencies. One system reports that only a third of their telephones are operational at any given time (16). Call box and telephones devices are also susceptible to vandalism in many areas.

Table 2-3 shows the capital, operating, and maintenance costs of one motorist aid call system on I-94 in Detroit. The system consists of 69 telephone type call boxes located along 13.5 miles of the Ford Freeway (I-94) in Detroit. The devices were spaced a third of a mile along both sides of the freeway. An average, the system received 11.7 calls per day. Most of these calls (60%) were requests for assistance. Only 7% of the calls were to report the occurrence of an accident (16). The average costs per call is

TABLE 2-3. COSTS OF MOTORIST AID TELEPHONE SYSTEM IN DETROIT.

Item	Total Costs	Cost per Device	Cost per Mile
Capital Costs[1]			
• Call Box Telephones	$151,700	$2,199	$11,237
• Installation	$19,800	$290	$1,480
• Connection	$178,865	$2,592	$13,249
• Communication	$596,000	$8,638	$44,156
TOTAL	**$946,645**	**$13,719**	**$70,122**
Annual Operating and Maintenance[2]			
• Labor	$21,600	$313	$1,600
• Parts	$5,000	$72	$370
• Power	$3,000	$44	$222
TOTAL	**$29,600**	**$429**	**$2,192**
Total Annual Costs [3]	**$124,265**	**$1,800**	**$9,205**

[1]Does not include cost of coaxial communications cable.
[2]Does not include cost for volunteers or stat police to monitor phones
[3]Assumes ten-year service life on Capital Costs
Source: (16)

equal to $43 when considering total costs and $7 per call when considering only operating costs (21).

Recently, the Michigan Department of Transportation has removed the telephone system from I-94, citing extensive deterioration of the systems electronics, as well as the deterioration of the telephone housings themselves as reasons for removing the system. The telephone system will be replaced with a "Good Samaritan" cellular 911 system for reporting emergencies on I-94 (22).

Similarly, the Minnesota Department of Transportation has decided to discontinue the installation of a call box system in the Minneapolis/St. Paul area. Ninety push-button type call boxes along a 22 mile segment of I-35W, north of the Minneapolis CBD were activated in August 1989. Based on a 1991 evaluation study of this system, it was determined that the call boxes were not a cost-effective means of managing congestion and detecting incidents on this section of I-35W. For this reason, MinDOT has decided not to install any additional call boxes in the Twin Cities Metropolitan Area, and continue operating their existing system as a motorist aid system only (23).

Citizens' Band (CB) Radio Monitoring

Although CB radios were a popular fad during the middle to late 1970s, their popularity as an in-vehicle communication device for private automobiles has declined in recent years. The decline in popularity has lessened the feasibility of CB radios systems as an incident detection and reporting technique. Despite the decline, many still believe that there are ample vehicles equipped with radios to provide ample surveillance (10). Many long-haul trucks still use CB radios to communicate with each other. Conceivably, truck traffic can used to provide incident detection capabilities in rural or less populated urban areas where incident detection times are traditionally lengthy. By incorporating transit bus drivers and commercial delivery vehicle operators into the system, radio coverage in urban areas can be greatly improved.

A CB monitoring system can be implemented by establishing a radio frequency (or channel) dedicated for reporting incidents. Drivers equipped with CB radios in their vehicle report observed incidents on the channel. A central center monitors the transmission and forwards incident information to the appropriate agencies who dispatch the required type of assistance. A transportation agency's existing dispatching operators or volunteers from local CB clubs or other service agencies can be used to staff the monitoring center.

The key to a successful CB monitoring system is having motorists and commercial fleet operators who know that the system exists and who are willing to use the system to report incidents. Roadside signs may be required to remind drivers of the dedicated frequency channel and to increase citizen awareness of the system itself. To ensure that the system is used to its full potential, CB radio operators in the region should be educated as to the current procedures for reporting incidents, including the type of situations to report as well as the type, location, and direction of the incident.

Cellular Telephones

In recent years, the use of cellular telephones in vehicles has increased dramatically. The reason for the phenomenal growth is the convenience and flexibility offered by this technology. As cellular networks continue to grow, the number of vehicles equipped with cellular telephones is expected to continue to grow as well. In fact, it has been estimated that by the year 2000 one in every ten vehicle will possess a cellular telephone (24).

Because of the increasing number of motorists with cellular telephones, many transportation agencies are implementing systems that permit motorists to use their cellular telephones to report incidents and congestion. For example, motorists in the Chicago area can dial *999 to report incidents or request assistance. The Illinois Department of Transportation (IDOT) operates a dispatching center which receives the calls from motorists reporting incidents on their cellular telephones and notifies the appropriate response or service agency. All calls to the IDOT center using *999 are free-of-charge (25).

The program in Chicago has been extremely successful. The cellular telephone system is now the primary means of detecting incidents in the Chicago area (24). During 1990, 115,845 cellular telephone calls were received by the *999 Dispatch Center. Approximately 67% of these calls were first time reports of incidents. Only 21% of the calls that were received by the Center were "duplicate" calls (i.e., incidents that had already been reported by other sources). IDOT has found that over 97% of the calls to the Center were "good samaritan" calls where motorists are reporting incidents involving other vehicles.

The *999 program in Chicago has also produced several unexpected benefits. While originally the system was intended to receive information about the freeways and expressways in the Chicago area, many of the calls received by the Center were to report incidents and traffic hazards (e.g. malfunctioning traffic signals, debris in the roadway, spilled loads, etc.) on the arterial street system. Since these calls are relayed to the appropriate municipal or county enforcement agency, the cellular telephone system provides incident detection and surveillance on the arterial street system. Motorists are also using the cellular telephone system to report other traffic safety (e.g."driving under the influence") and criminal activities (e.g."fight in progress", "crime in progress", etc.).

Since most cellular telephone systems are privately owned, another benefit of the cellular telephone systems is that the costs to install, operate, and maintain the system are relatively low, from the public agencies standpoint. With the Chicago system, IDOT established a contract with the two Chicago area cellular telephone providers to provide free calls for cellular phone users to report observed traffic problems. Most of the costs associated with cellular telephone systems are operating costs where personnel must be present to receive and process callers from motorists in the traffic stream.

Automatic Vehicle Identification (AVI) Systems

With recent advances in computer, electronic, and communication systems, new types of technologies are becoming available that will improve mobility in the United States. These technologies make it possible to locate and track vehicles as they travel through the roadway network. Conceptually, these systems can also be used to obtain real-time information about the incidents and travel conditions directly from vehicles traveling in the traffic stream. Specially equipped vehicles traveling in the network serve as probes (or moving sensors) that can provide information on travel conditions and report incidents throughout the network.

Automatic Vehicle Identification (AVI) systems are one such technology that is currently available that can potentially be used to detect incidents on a roadway. Originally designed for automatic electronic toll collection, vehicles in an AVI system are equipped with transponders which have been encoded with a unique identification number. Through a system of antennae and readers installed over or adjacent to the travel lanes, vehicles equipped with transponders can be individually identified as they pass specific points on a roadway. By monitoring the time it takes for each vehicle to travel between reader locations, a real-time estimate of the link travel time can be obtained. By comparing the current estimate with historical information, the travel time information can then be used to identify areas of unusual congestion and incidents.

A system which uses AVI concepts and technologies is currently under development in Houston, Texas (26). This system, called the Real-Time Traffic Information System, uses a vehicle probe concept to obtain travel time and incident information directly from motorists traveling in several of the major commuting corridors. The system is designed to be implemented in two separate phases. In Phase I, which is a prototype of the ultimate system design, travel time and incident information are obtained from commuters equipped with cellular telephones. In Phase II, the cellular

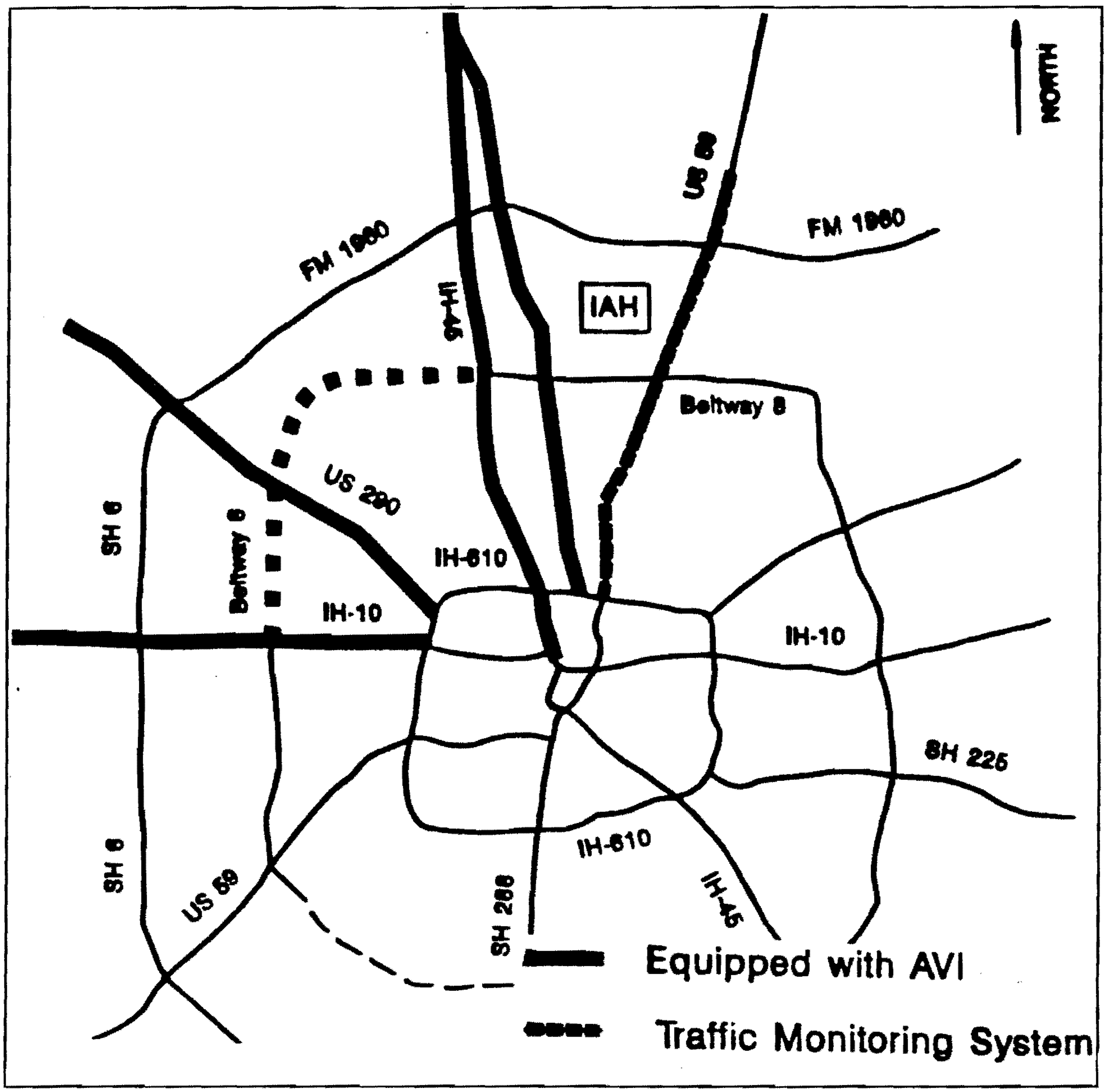

Figure 2-3. Proposed Coverage Area of AVI System in Houston, Texas.

telephone system will be replaced by a AVI system. As shown in Figure 2-3, the AVI system will be used to provide surveillance coverage on the main lanes and the HOV lanes of three major freeways (I-45 North Freeway, US-290 Hempstead Highway, and I-10 Gulf Freeway) and two toll roads (the Hardy Toll Road and the Sam Houston Toll Road) will be covered by the AVI system. The AVI system is expected to be operational by the beginning of 1993. Preliminary data collection and conceptual design testing is currently underway.

3. METHOD FOR SELECTING ALTERNATIVE INCIDENT DETECTION STRATEGIES

In general terms, all urban areas have some incident detection capabilities. Even in the absence of any formal detection system, incidents (at least the very major ones) are eventually detected through normal police patrols or by motorists calling the police department on telephones. In most urban areas, fortunately, detection capabilities exceed these basic levels. Many television and radio stations maintain their own "eye-in-the-sky" traffic surveillance; private traffic information services use stationary observers and moving probes to keep informed of traffic conditions; and the transportation agencies themselves, through the years, may have enacted one or more strategies to help detect and respond to incidents.

The previous chapter outlined several strategies available for incident detection. Most of these strategies have been utilized (with varying degrees of success) for many years. Many freeway management systems often use more than one of the strategies for detecting incidents. Often, multiple incident detection strategies are implemented by design so that the strengths of one detection strategy can offset the weaknesses of another strategy. Other times, multiple strategies evolve as a result temporary measures during periods of funding limitations. Regardless of why multiple incident detection strategies are used in a system, procedures are needed to evaluate the expected effect of multiple detection strategies on incident detection and response times.

The research by Urbanek et al in the 1970s still serves as the primary basis for incident detection and management trade-off analysis (3). The ability to assess the operation of an incident management system, consisting of more than one component for incident detection or response, was of particular importance in the final documentation of that research.

The output of the procedure in an operational measure of system effectiveness in terms of motorist delay. The procedure is theoretically sound, although it is somewhat cumbersome to use. However, it does not provide guidance as to how the operational measures should be used to make system design decisions in terms of which strategies to employ, and more importantly, how many units of each individual strategy should be implemented. Different strategies have varying capital, operations, and maintenance costs. Furthermore, economies of scale sometimes come into play, altering the unit cost values for these strategies as a function of the number of units implemented in the overall system. Obviously, a method of objectively assessing these benefit-cost trade-offs is required, so that the transportation agency can obtain the greatest benefit for the public from each dollar invested in the system.

The purpose of this chapter is to present a method that can be used to evaluate different incident detection alternatives and to select the right types and mix of incident detection strategies for an existing system. The method uses standard procedures for assess the economic impacts of modify or improving a freeway management system. The procedure can be used to assess the benefits achieved in the overall incident detection and management systems for each additional dollar expended to expand or improve the system.

Choice of Assessment Measures

A standard economic assessment of a proposed transportation improvement compares the expected benefits of the improvement to the costs of its implementation (27). In many instances, an improvement may generate a number of different types of benefits. In the case of freeway incident management systems, they are enacted to improve overall traffic flow (measured in terms of higher average traffic volumes, reduced travel times, and higher average speeds), reduce incident delays, and reduce the number of secondary accidents (14). They may also improve the public's image of the transportation agency. Obviously, some of these can be easily quantified, whereas others cannot.

There are two major types of measures for evaluating transportation improvements:

- Assessments of cost-effectiveness, and
- Comparisons of benefits and costs.

Traditionally, cost-effectiveness comparisons are used when the benefits being accrued are not reducible to monetary terms (27). With freeway management systems, for example, the improved public image of the transportation agency cannot easily be reduced to a dollar value. Even so, some quantifiable measure, may exist from which a unit cost-effective measure could be defined (i.e., the number of incidents detected per $1,000 invested). In order to judge an investment's worth, however, some target level of effectiveness must first be defined by the agency.

Benefit-cost comparisons, on the other hand, are possible when the benefits of an improvement can be assigned a monetary value (27). This value is compared to the costs of the improvement. If the benefit's value exceeds the costs, the improvement is economically justifiable. In the case of freeway incident management systems, reductions in travel times, fuel consumption, and secondary accidents can all be considered to involve a monetary benefit to the motoring public. Unfortunately, little data are available regarding the reduction in secondary accidents from most systems, and so it is difficult to consider these benefits in any assessment of freeway incident management benefits. In contrast, computational procedures for estimating delays due to incidents (and thus reductions in delay due to reduced incident duration) are well established (3). Thus, evaluations of freeway incident management systems generally focus on the delay-reducing benefits they provide.

Types of Benefit-Costs Comparisons

Once estimates of the benefits of a proposed improvement are obtained, the next step is to compare those benefits to the costs of implementing that improvement. Different techniques can be used to conduct these comparisons. Each technique leads to slightly different interpretations of the impact of the proposed improvements. The different techniques for comparing alternative improvements include the following:

- An analysis of the excess benefits of the improvement,
- An analysis of the overall benefit-to-cost (B/C) ratio of the improvement, or
- An analysis of the incremental B/C ratio of the improvement.

Computing the excess benefits of an improvement provides an indication of the absolute dollar value of the improvement being returned to the public. For example, an improvement that is estimated to generate $1,000,000 in benefits for a $200,000 investment is said to return $800,000 in excess benefits to the public. In comparison, the overall B/C ratio is a measure of the relative worth of an improvement, indicating the number of times the cost of the improvement is recovered through the benefits generated. The overall level of improvement (and associated costs) is what is considered in the analysis. Using the previous example, the $200,000 cost of the improvement is recovered 5 times in the $1,000,000 in benefits that are expected. The third option, the incremental B/C ratio, can be used when an improvement consists of a number of separate components (or unit levels of a given component). The application of the overall B/C ratio is expanded to consider the benefits achieved by each added component (or unit) of the improvement. These incremental benefits are compared against the incremental costs for the added component.

Of these three analysis approaches, the excess benefits are probably most easily understood by the general public. In addition, the magnitude of these estimates can be the most convincing argument in support of a proposed improvement, particularly when working with transportation investments that return benefits in the millions of dollars. On the other hand, overall and incremental B/C ratios provide a more direct means of comparing different improvement options which have different magnitudes of costs and benefits. As a result, they are more useful to public agency officials as part of their decision-making process.

Of course, a distinction between an overall and incremental B/C ratio exists only when the proposed improvement consists of separate components or units that can be implemented separately. Also, when the costs and benefits are constant for each added component of an improvement, the overall and incremental B/C ratios will be identical. In most situations, however, this will not be the case. For example, the cost per unit of improvement may decrease as the number of units increases. Likewise, the benefit per unit of improvement may change depending on the number of units implemented. As an illustration, Figure 3-1 displays a hypothetical graph of cumulative costs and benefits for a proposed improvement which can be implemented incrementally. The linear cost shown in Figure 3-1 is indicative of a constant cost per unit of improvement. Meanwhile, the curvilinear benefits function shown is indicative of the situation where additional benefits become less dramatic as the overall level of the improvement to the system increases.

In terms of an overall B/C ratio, a given number of units of improvement can be justified as long as the total benefits exceed the total costs. In the figure shown, the shaded area indicates where total costs exceed the total benefits, and thus where the overall number of units of improvement would not be justified. Meanwhile, everything to the left of that shaded area represents improvement levels which are justified on the basis of an overall B/C analysis of the benefits provided at that level of improvement.

An analysis of the incremental B/C ratios presents a slightly different perspective, however. In this case, the cost to add one additional unit of improvement (ΔC) is compared to the benefits achieved by adding that one unit (ΔB). As can be seen in Figure 3-1, the incremental benefits exceed the incremental costs to the left of the hatched area, whereas adding units of improvement at levels within the hatched or

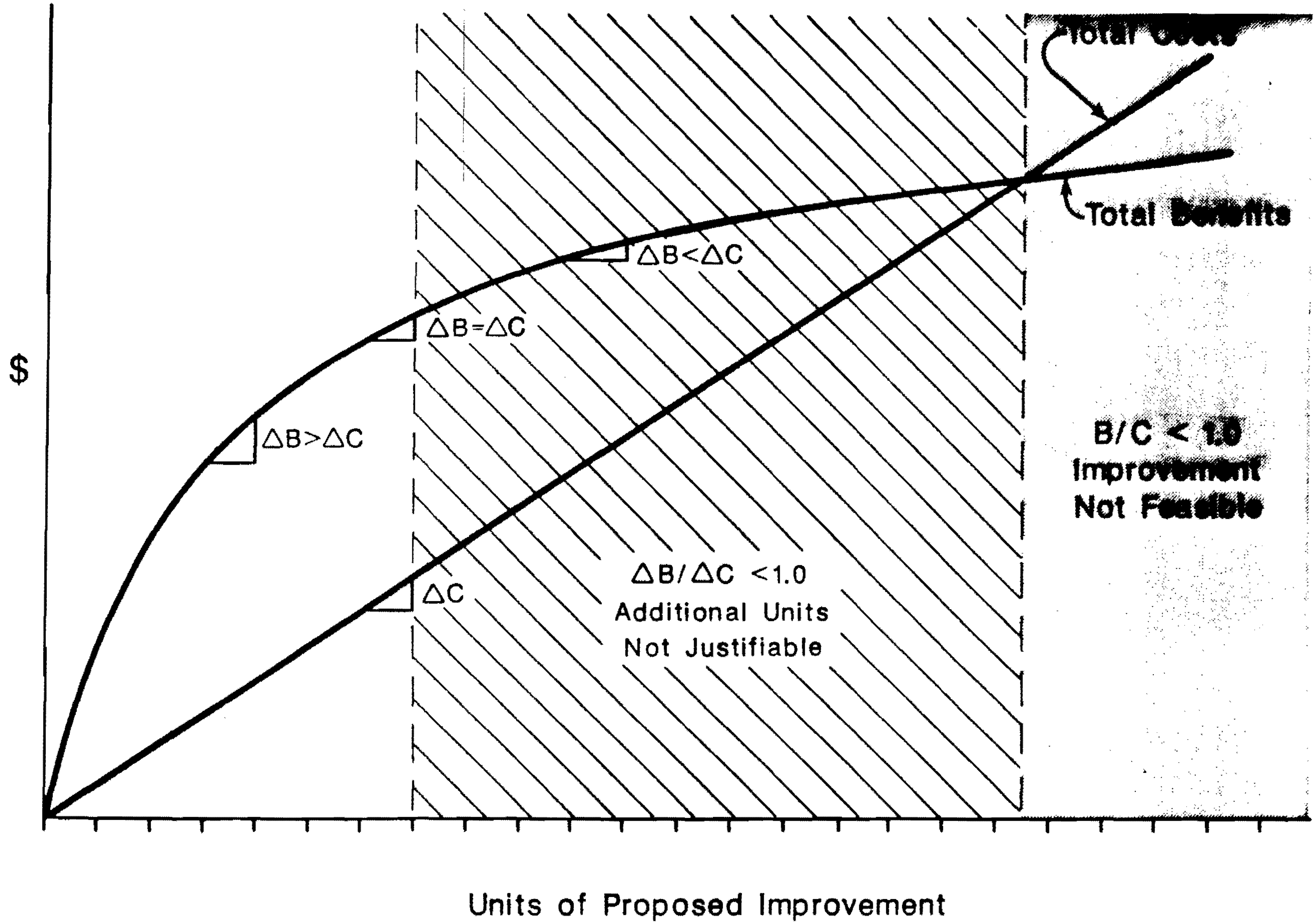

Figure 3-1. Comparison of Overall and Incremental Benefit-to-Cost Ratios

shaded area generates additional benefits which do not exceed the additional costs. Note that the break-even level is much less than it was for the overall B/C analysis. Therefore, although the analysis of the overall B/C ratio at a given level of improvement may indicate that the improvement is feasible, an incremental analysis may indicate that a lesser level of improvement is all that is economically warranted. In simpler terms, an incremental B/C analysis ensures that each dollar spent returns a satisfactory benefit.

Incremental Benefit-to-Cost Analysis

An incremental B/C analysis can be important tool for assessing different incident detection strategies. By using an incremental B/C analysis, engineering and traffic managers can determine the most cost-effective and productive means of improving the operations of an existing incident management system. An incremental B/C analysis can be used to determine whether or not additional expenditures to improve or expand a system is justified.

Listed below are the step required for conducting an incremental B/C analysis of alternative incident detection strategies. Although the discusses uses "alternatives" to describe different incident detection strategies, "alternatives" can also be used to describe different combination of incident detection strategies.

Step 1. Estimate Impact of Alternative on Detection and Response Time

The first step in the procedure is to estimate how implementing the desired alternative incident detection strategy (which may be an increase in the frequency or number of units of an existing strategy) will affect the overall detection and clearance times of the entire incident management system. Because the manor in which an incident is detected may affect the response and clearance times, the impact of the alternative incident detection strategy on response and clearance time must also be considered.

There are two ways to estimate that the impacts of installing or implementing an alternative strategy for detecting incidents. The first is to use historical data from systems which are using the same type of detecting strategy that is being considered in the alternative. Much of the information that is available for existing incident management systems nationwide was presented in Chapter 2. Other information can be obtained by directly contacting the other freeway management systems which have operational experience with the alternative incident detection strategy. Appendix C provides a list of the type of incident detection and response strategies used in various incident management programs throughout the United States.

However, the type of information (and in the level of detail) that is needed to conduct perform a detailed analysis of alternative incident detection strategies is often not available. Many systems that are in operation today do not keep detailed records that permit the impacts of individual detection strategies to be isolated from the rest of the system. Furthermore, the performance of alternative incident detection strategies may vary between systems because of the way they are used and function in different systems. Therefore, it is extremely important to make sure that data for a comparable system is being used to evaluate alternative incident detection strategies.

In the absence of historical or comparative information, the procedure developed by Urbanek et al (28) can be used to estimate the expected system-wide detection time and this total expected incident delay by implementing proposed alternatives. The procedure was designed specifically to account for the use of several different incident detection strategies on a freeway system. The procedure assumes that "base" condition is some type of patrol (either a police or service patrol), and that all other incident detection strategies can be modelled as equivalent service or police patrols, regardless of whether in fact the proposed alternative is in fact a patrol-type of strategy. The procedure also assumes that the headway between consecutive patrols are randomly distributed over time.

Three basic parameters must be known or estimated in order to use the procedure. The first is the average headway or patrol frequency of the "base" patrol. In most cases, this may be a police patrol or a service patrol and can be estimated either through direct observation or derived from patrol logs. The second parameter that is needed is the probability that an incident will be detected first by a base patrol unit. Like patrol frequency, this too can be estimated from dispatching logs. The final parameter that is needed in the procedure is reporting delay that occurs when a mode other than the base patrol detects the incident first. Unfortunately, no rigorous methods are available for estimating the reporting delay. These parameters are then used to evaluate how implementing the proposed alternative incident detection strategy changes the detection time of the base condition.

Step 2. Estimate Delay for "Average" Incident

Once the average system-wide detection and response time have been estimated, the total amount of delay caused by an "average" incident must be determined. As illustrated in Figure 3-2, the total amount of delay of an average incident can be estimated using a simple graphical procedure. The amount of delay caused by an "average" incident is represented by the shaded area in the figure. In order to use this procedure, estimates of two traffic parameters must be known. The first is the duration of the "average" incident. Whenever possible, average number of incidents and incident duration should be known for all of the facilities covered by the incident management system. If the system is being expanded to facilities that are not currently included in the incident management system, estimates of the number and duration of incidents occurring in the system can be obtained from historical police records or by applying the operation records of the existing system.

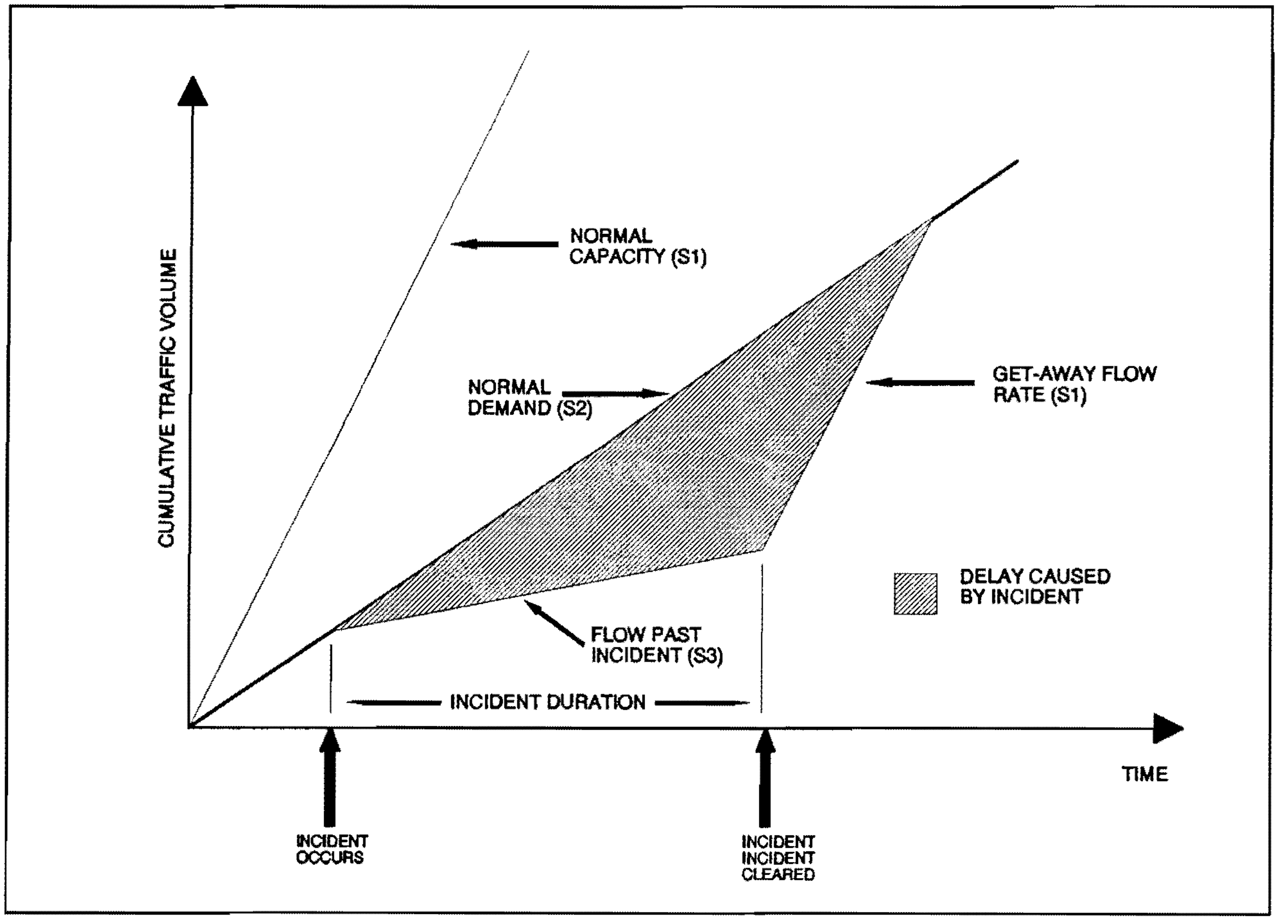

Figure 3-2. Calculation of Delay Caused by Typical Incident (28).

The other traffic parameter that must be known is the average amount of traffic that uses the facilities in the system to be evaluated. At least three flow rates must be known in order to estimate the amount of delay caused by an "average" incident:

- the capacity flow rate for a typical freeway (S_1);
- the normal flow rate for a typical freeway (S_2); and
- the flow rate during the incident (S_3).

Using the above information, the total vehicle-hours of delay caused by an "average" incident in the system can be computed using the following equation:

$$DELAY = T_1^2 \times \frac{(S_1 - S_3)(S_2 - S_3)}{2(S_1 - S_3)} \qquad \textbf{(1)}$$

where,

T_1 = the duration of the incident (as estimated in Step 1),
S_1 = the get-away flow rate (can be assumed to be equal to the capacity of the freeway),
S_2 = the demand flow rate;
S_3 = the flow rate past the incident.

This equation can be used to compute the average delay of all incident occurring in both the peak and off-peak periods. Similarly, this equation can be used to quantify the impacts of both lane-blocking and incidents that have been moved to the shoulder. Whenever possible, a flow rate representative of the system being evaluated should be used to assess the effectiveness of the proposed incident detection strategy. However, if site specific flow rate are unavailable for a system, the typical flow rates in Table 3-1 can be used to estimate delay.

It should also be noted that the equation is only valid for the most simple of incident scenarios when there has been no reduction in demand due to traffic diversion or on-site capacity enhancement strategies. Other equations are should be used if there is are changes in either demand flow rate or the flow rate past the incident. (see Urbanek et al (28)) Also, recent data from short-term freeway lane closures, for example, suggests that a phenomenon known as "natural diversion" occurs when significant queuing occurs on the freeway. Even at locations where normal traffic volumes were three to four times the estimated get-away flow rate past a lane closure of several hours duration, queues stabilized at about 2 miles in length and delays on the freeway averaged about 20 minutes (29).

TABLE 3-1. TYPICAL FLOW RATES FOR DELAY ESTIMATION (28).

NUMBER OF LANES IN EACH DIRECTION	CAPACITY FLOW RATE = GET-AWAY FLOW RATE (VPH)	IN-LANE INCIDENTS - ONE LANE BLOCKED (VPH)	SHOULDER ACCIDENTS (VPH)
	S_1	S_{3a}	S_{3b}
2	3,700	1,300	3,000
3	5,550	2,700	4,600
4	7,400	4,300	6,300

Step 3. Compute System-wide Delay

Once the delay caused by an "average" incident has been computed, total system-wide delay can be computed. This can be accomplished by multiplying the estimated delay for an "average" incident by the total number of incidents expected to detected and responded to by the system. Again, this should included the shoulder and lane-blocking incidents that occur in both the peak and off-peak periods.

Step 4. Compute Travel Time Savings Benefits

The travel time savings benefits generated by implementing the proposed alternative can be estimated by multiplying a standard unit cost of travel time to the motoring public times the total hours of delay savings estimated for the alternative. The unit cost of travel time reflects how much it costs for a vehicle to travel the freeway. Ideally, the unit cost of travel time should be representative of local travel costs. For example, a unit cost of $12.70 per vehicle-hour of delay has been used to reflect travel conditions in Houston (12). For other purposes, a value of $10.00 per vehicle-hour of delay can be used to provide a conservative estimate of travel time savings achieved by implementing the alternative detection strategy (1).

Step 5. Estimate Implementation Costs

In addition to computing the travel time savings benefits that can be achieved by implementing each of the proposed detection strategies, the cost to implement each proposed alternative must also be computed. Actual costs (including construction, maintenance, and operations costs) should be used to determine implementation costs for each alternative incident detection strategy. Cost information has been provided in Chapter 2 on a number of alternative incident detection strategies; however, this cost information should be used with caution because system design and operation procedures affect implementation costs of individual strategies.

Step 6. Compute Incremental B/C

The final step in the procedure is to compute the incremental benefit-to-cost ratio for the each of the proposed alternatives. After computing the travel time savings and implementation costs of each alternative, all of the alternatives should be ordered beginning with the lowest cost alternative (usually the base condition). The incremental B/C ratio of implement each alternative is computed by the following formula:

$$INCREMENTAL\ B/C = \frac{(BENEFITS_{N+1} - BENEFITS_{N})}{(COSTS_{N+1} - COSTS_{N})} \qquad \textbf{(2)}$$

where,

$BENEFITS_N$ = the travel time savings generated by the lowest cost alternative,
$BENEFITS_{N+1}$ = the travel time savings generated by the next lowest cost alternative,
$COSTS_N$ = the total implementation cost of the lowest cost alternative,
$COSTS_{N+1}$ = the total implementation cost of the next lowest cost alternative, and
N = the number of alternative to be evaluated.

This same equation is used to compute the incremental B/C ratios for next two lowest cost alternatives. The equation is used until the incremental costs of all of the alternatives being considered have been computed.

Data Requirements

The data requirements to conduct the actual incremental B/C analysis is limited. Most of the data required is needed to estimate the impacts of the incidents under the different detection strategies. Regardless of the type of procedure used to estimate the impacts of incidents (i.e., historical data or Urbanek et al procedure), the data requirements for estimating the impacts of incidents are the same. First, one needs to estimate the total number of incidents that will be detected by the system being evaluated. Estimates of the number of lane-blocking and shoulder incidents occurring in both the peak and off-peak periods should be made in order to quantify the impacts of incidents on the freeway included in the system. This data can be obtained from existing police or incident records.

Also, one needs to estimate the performance of the incident management system under the different detection strategies being considered. Specific performance measure that must be known or estimated include the following:

- the proportion of incidents detected by each incident detection strategy used in the system, and
- the average detection time for each detection strategy employed in the system.

Another data requirement needed to quantify the benefits of the system is the traffic demand and capacity on the facilities covered by the incident management system. For overall planning and design purposes, an "average" or typical value which is representative of all the freeways covered by the system may be developed. The data required to estimate the impacts of a typical or "average" incident in the system included the following:

- the capacity of the "average" freeway included in the system,
- the flow rate past an "average" incident occurring in the system, and
- the demand for an "average" freeway covered by the incident management system.

In addition to information about the expected incident frequencies and traffic parameters, cost information for each alternative incident detection strategy must be provided. This cost information can be provided on a per unit basis or can represent the total expenditure for installing an alternative (e.g. the cost to equip three mile of freeway with motorist call boxes). Care should be taken to ensure that the units of evaluation (total costs versus unit costs) are consistent when comparing multiple strategies. Also, any changes in the unit costs as a fraction of the number of units employed should be included.

Summary

Whereas the decision to implement new or expanded incident detection capabilities of a freeway incident management system may be a very easy one to make, the decision as to how it should be expanded (i.e., what strategies to use and how many should be installed) is not. Granted, funding limitations and the presence of existing incident detection strategies may be what defines the type and area covered by new detection strategies. Nevertheless, an understanding of the benefits and costs associated with different incident detection strategies is essential in order to assess whether to seek additional funding for improving incident detection or to refocus resources on other management activities.

One approach that can be used to assess and evaluate the cost-effectiveness of using multiple incident detection strategies in a system is the incremental B/C analysis. The method is relatively easy to use and familiar to most traffic engineers and policy makers. By using an incremental B/C analysis, it allows policy-makers to see the amount of benefit that can be achieved for each additional dollar invested in that alternative over another alternative. Therefore, by using an incremental B/C analysis, the most cost effective system can be designed which maximizes the benefits achieved by a system using multiple detection strategies.

The next chapter illustrates how an incremental B/C analysis (as just described) might be used to address the problem of determining adequate coverage of one type of incident detection strategy: Motorist Assistance Patrols. The example uses real data from operating system in Houston, Texas and illustrates how an incremental B/C analysis can be used to select the most cost-effective number of service patrol vehicles to use for a given area of coverage.

4. CASE STUDY -- SELECTING MOTORIST ASSISTANCE PATROL FREQUENCY

Experiences nationwide repeatedly confirm that the initiation of roving motorist assistance patrols (MAPs) provides transportation agencies with one of the most cost-effective means of detecting and clearing incidents from freeways (30). Even given other incident detection strategies that may already be in place (such as electronic surveillance, CCTV, motorist-aid call boxes), the combined detection, response, clearance, and traffic control capabilities provided by each MAP vehicle can result in significant benefits to the motoring public. However, it is difficult to determine exactly how many MAP vehicles are economically feasible and justifiable to provide for adequate detection and clearance on a group of freeways.

The purpose of this chapter is to provide some insight into the trade-off analysis of MAP frequency and road user benefits in Texas. To do this, the MAP system recently established in Houston, Texas is used as a case study. Extensive data regarding incident frequencies, detection and service times, and estimated delay benefits have been documented throughout the two-year existence of MAP in Houston (12, 31). Using these data as a base, the estimated impacts of adding vehicles to the system are investigated. The focus of the chapter, however, is not solely upon the performance of the MAP system in Houston. Rather, the intent of this chapter is to illustrate a simplified approach for evaluating possible changes to a given MAP system. Extrapolating the data from Houston to other Texas cities, it is hoped that the chapter provides some guidance for those cities considering the initiation or enhancement of their patrols.

Description of Case Study Scenario - MAP System, Houston, TX

Established in July 1989, the Motorist Assistance Patrol (MAP) is a combined public/private venture by the Texas Department of Transportation, Harris County Metropolitan Transit Authority, Harris County Sheriff's Department, and the Houston Automobile Dealers Association. The system now includes 121 median miles of freeway which is patrolled 16 hours per weekday (6:00 am to 10:00 pm) using 9 specially-equipped service vans. During the first year of operation, however, the system consisted of 6 vans operating over 96 median miles of freeway. The vans are driven by Harris County Sheriff deputies, who stop to render aid to any stalled vehicle, accident, etc., they encounter. The vans are also dispatched to locations on and off the designated patrol areas when calls concerning incidents come into the interim communications and control

(ICC) center. Given the current size of the patrol area and number of vans in the program, it is estimated that the vans operate on about 1 hour headways over the patrol area. However, the deputies driving the vans look for incidents on both sides of the freeway, such that the effective patrol headway is about 30 minutes.

The Houston MAP program has been very successful. Through a two-year period ending in June 1991, MAP vans had responded to over 24,000 incidents (approximately 1,000 per month (12). According to MAP records, this corresponds to an average productivity level of 3.0 incidents per 100 miles patrolled, or about eight incidents per van per day. Records also indicate that MAP serves as the primary incident detection component on the freeways covered in the system (accounting for 86 percent of all incidents detected). Currently, the cost of the MAP system is nearly $86/incident. The specified patrol frequency has resulted in slightly less than a 15-minute average detection time overall. It was estimated that the program had reduced total incident durations as shown in Table 4-1. Lane-blocking incidents tend to be more severe and require more extensive preparations to remove them. Thus, the duration of lane-blocking incidents tends to be longer than for incidents which have been moved to the shoulder.

TABLE 4-1. EFFECT OF MAP UPON TOTAL INCIDENT DURATION

Type of Incident	Total Duration without MAP	Total Duration with MAP	Reduction due to MAP
Lane-Blocking	68 min	42 min	26 min
Shoulder	30 min	20 min	10 min

TTI has monitored and periodically evaluated the costs and productivity of the MAP program since its inception (12, 31). One of the main tasks of this evaluation has been to estimate the benefit-to-cost ratio for the program. Actual cost data and information concerning incident frequencies and severities have been combined with assumptions regarding the effect of incidents upon freeway delay. Using a standard unit cost of travel time to the motoring public, the travel time savings benefits generated have been estimated and compared to the costs of the program. Based upon these estimated delay savings benefits for the first year of operation, the B/C ratio was computed to be near 26 to 1 (31). Subsequent sensitivity analyses of the delay assumptions resulted in

B/C ratio estimates between 7 and 36 to 1 (12). Regardless of the delay assumptions used, it is apparent that the MAP program has been a major success. In fact, plans are now underway to expand the program to other freeways in Houston as funding becomes available.

Given the large benefits provided by MAP, it is obvious that it would be desirable to further increase the system by adding patrols and increasing the service area. Once the entire metropolitan area was being serviced, though, it would be possible to add even more patrols to the existing service area, reducing headways between those patrols and reducing incident detection time. Even small reductions in detection time could pay big dividends in reduced delay costs. However, the degree to which detection times should be decreased cannot be determined without a complete analysis of the benefits to be expected. The application of an incremental B/C analysis, as described earlier in the chapter, is utilized in the next section as a means of justifying the level to which patrol frequencies could be enhanced.

Applying the Incremental B/C Analysis to the Houston MAP Program

The incremental B/C ratio analysis described in the previous chapter is the more appropriate perspective from which to evaluate MAP frequency for an urban area. In fact, the general shapes of the costs and benefits functions shown in Figure 3-1 would be expected for a MAP analysis. As more and more patrols are added to a MAP program (without expanding the coverage area), patrol frequency will increase and headways between patrol vehicles will decrease. This will reduce incident detection time and thus total incident durations. This reduced incident duration, in turn, would reduce incident delays and directly benefit the travelling public in travel time savings. However, the reduction in detection time per additional patrol will become less and less as the total number of patrols in the system increases (again assuming the patrol area does not increase), and so the benefits in terms of reduced delays would appear to taper off as shown in Figure 3-1. Meanwhile, the costs of adding another patrol to the program would be expected to remain fairly constant. Eventually, the cost of adding one more patrol would be expected to exceed the reduced delay benefits achieved by that addition.

If required, the Urbanek procedure (3) could be used to estimate the impact of increased MAP frequency (and thus reduced detection time) upon delay. Fortunately, however, the documentation of the Houston MAP program to date provides a simpler and more direct basis from which to estimate these benefits. Data on average incident detection, response, and clearance times are available (since the MAP program also reduces incident response and clearance times, relative to a no-MAP condition). In addition, data regarding incident frequencies and locations by time-of-day are also available. Using these data as a frame of reference, proposed changes in patrol frequency over a given patrol area can be quickly assessed with a reasonable degree of confidence. The analysis presented herein is based on the first year configuration of the system (i.e., 96 median miles with 6 patrol vans). Although the system has been expanded both in number of vans and in patrol area, only a limited amount of published data were available for the larger patrol area. Given that this evaluation is for illustrative purposes only (of the use of an incremental B/C analysis), it was felt that an evaluation of the original patrol area would suffice.

Assumptions

To begin, several assumptions must be made concerning the incident database and its relationship to delays. First, it is assumed that adding patrols to the existing patrol area would affect incident detection times only, and that the combined incident response/clearance time would remain constant regardless of patrol frequency over that area. The existing database indicates that lane blocking incidents require, on the average, 27 minutes to clear whereas shoulder incidents require an average of only 5 minutes.

Next, it is assumed that the relative distribution of incidents on the shoulder and in travel lanes would remain constant as patrol frequency over the area is increased, as would the distribution of incidents across peak and off-peak periods. Furthermore, it is also assumed that the number of incidents being detected (approximately 1,000 per month) over the original 96 miles of patrol area would not change if additional patrols were added to that area. This assumption is probably conservative, in that additional patrols may encounter more vehicle stalls on the shoulders that are now being detected and assisted by private towing services. However, no reliable data are available as to how many more incidents might be detected, and so a no-increase scenario was adopted for this analysis.

It is assumed that the MAP program would continue as the prime incident detection component in the system, and that average detection times would be approximately one-half of the effective patrol frequency (remembering that the effective patrol frequency is, in turn, one-half of the actual headway between MAP vehicles so as to account for patrols also monitoring conditions in the opposite direction of travel). Measurements during the first year of MAP operations suggest that this is a reasonable assumption (31). Therefore, an increase in the number of patrols would decrease the average detection time as indicated in Figure 4-1. This reduction in detection time converts into a reduction in overall incident duration as patrol frequency is increased. Therefore, estimates of the total durations of lane-blocking and shoulder incidents at various patrol levels are also shown in Figure 4-1 (based on the previous assumptions that lane-blocking incidents require an average of 27 minutes of response and clearance, whereas shoulder incidents require an average of 5 minutes).

The assumptions of typical delays resulting from lane-blocking and shoulder incidents under peak and off-peak conditions as described in the first year report (31) were used to hypothesize a function between estimated delay and incident duration. Separate functions were defined for lane-blocking and shoulder incidents, and for peak and off peak periods. These graphs are displayed in Figures 4-3 and 4-3. From these functions, it was then possible to estimate expected delays for lane-blocking and shoulder incidents of various incident durations (because incident detection times differ at various patrol frequencies).

Finally, it was assumed that the relative frequency of incidents between the travel lanes and the shoulders would remain constant (27 percent and 73 percent, respectively), as would the distribution between peak and off peak periods (67 and 33 percent, respectively). The monthly incident frequencies expected to be addressed through the MAP program over the original patrol area are shown in Table 4-2.

TABLE 4-2. EXPECTED MONTHLY INCIDENTS ADDRESSED BY MAP

Incident Location	Time of Day	
	Peak	Off Peak
Shoulder	489	241
Lane-blocking	181	89

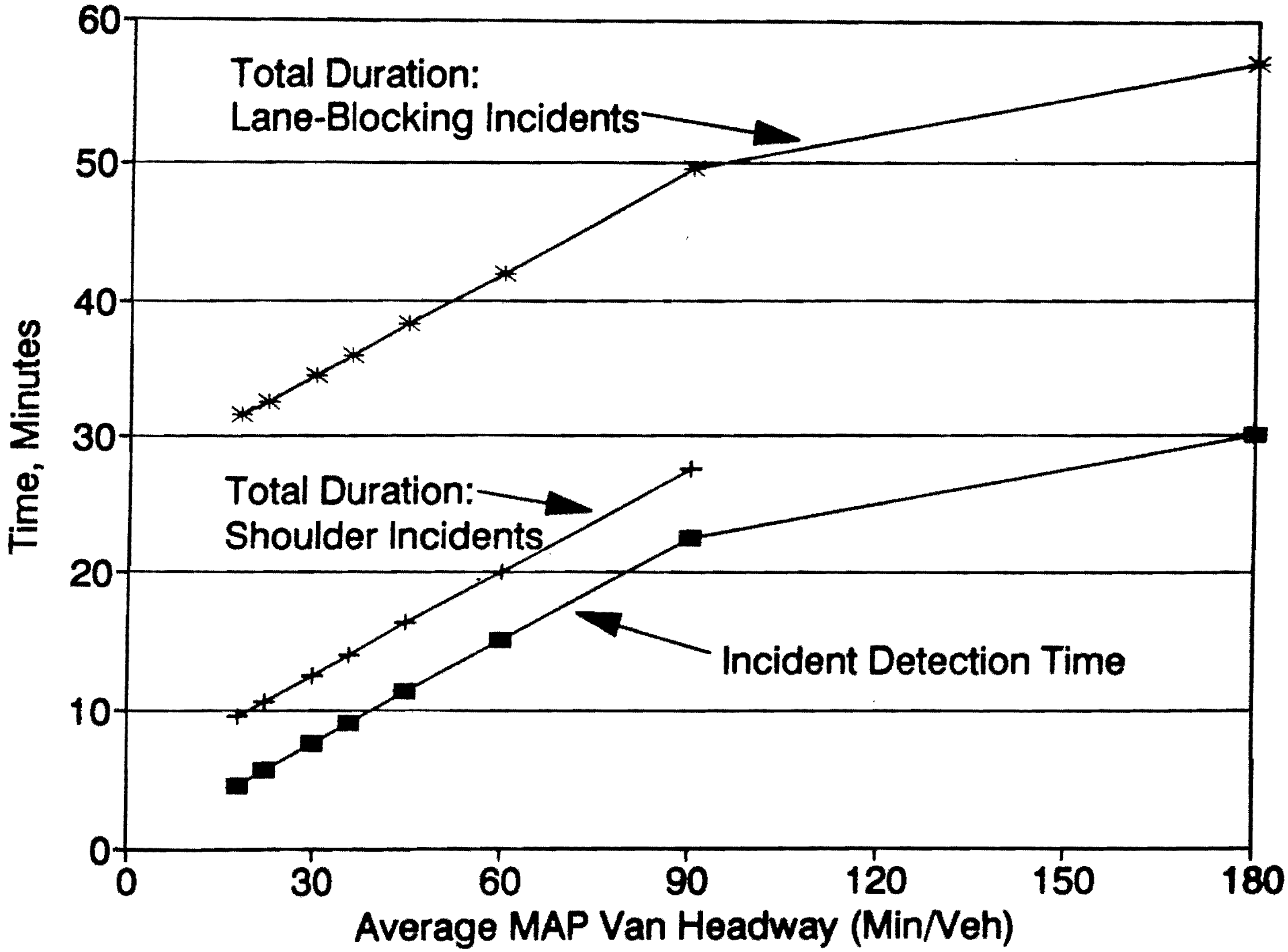

Figure 4-1. Relationship Between MAP Frequency and Incident Detection/Duration

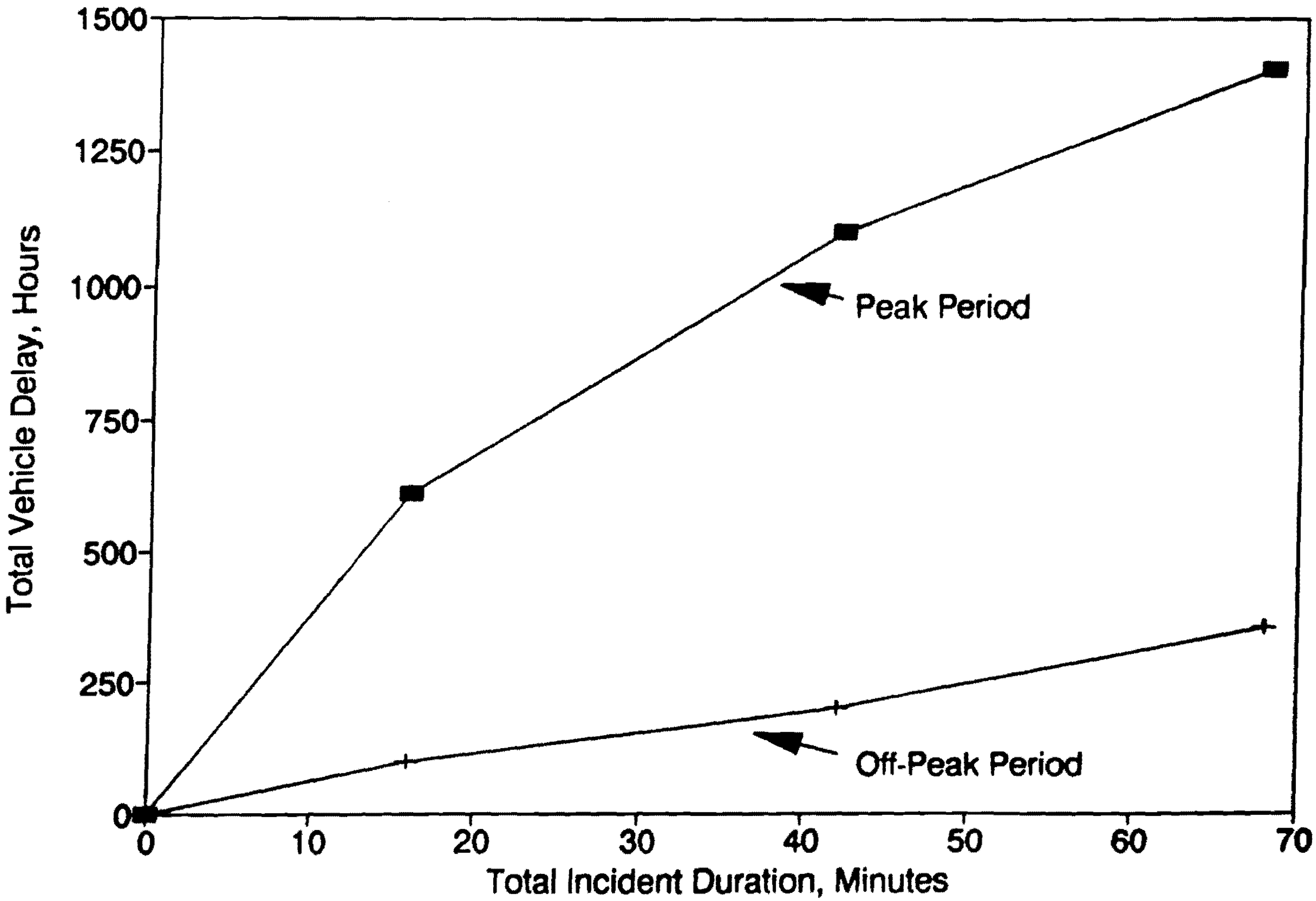

Figure 4-2. Relationship Between Incident Duration and Delay, Lane-Blocking Incidents

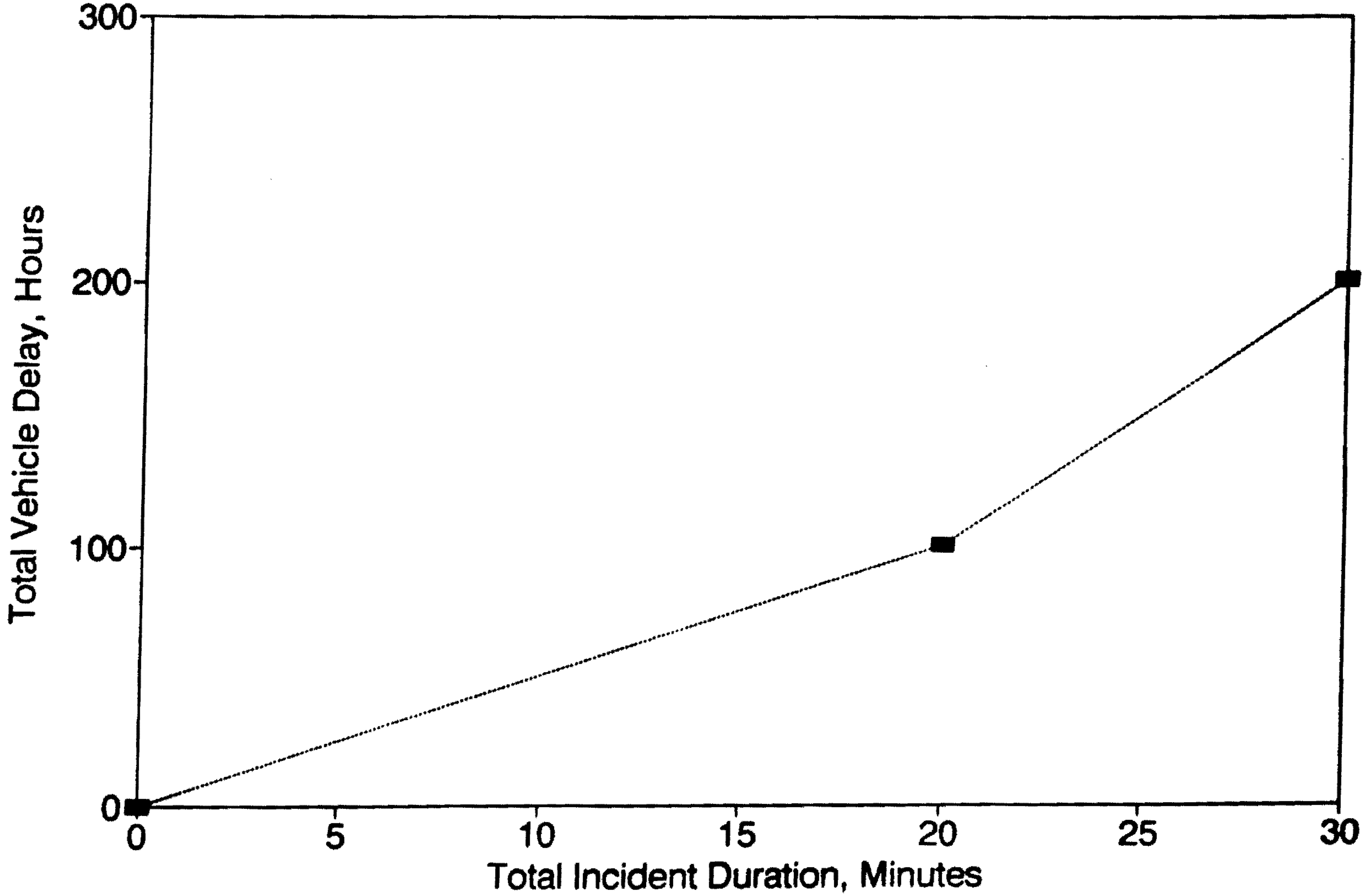

Figure 4-3. Relationship Between Incident Duration and Delay, Shoulder Incidents

Computational Procedures and Results of Analysis

To compute the benefits due to increased MAP frequencies in a given patrol area, the total monthly incident-induced delay at each level of patrol frequency must first be estimated. A total of nine different patrol frequency levels were selected for analysis (corresponding to 0, 2, 4, 6, 8, 10, 12, 16 and 20 vehicles in the original patrol routes). Figure 4-1 was used to estimate average incident durations for lane-blocking and shoulder incidents at these patrol levels. The average delay per lane-blocking or shoulder incident under peak and off-peak periods was then estimated using Figures 4-2 and 4-3. These estimates of average delay per incident were then multiplied by the expected number of such incidents per month (see Table 4-2), and then summed over all four types of incidents to compute the total monthly incident delay at each level of patrol frequency. These computations are summarized in Table 4-3.

To evaluate the benefits, the difference in expected monthly incident delays as the number of patrols was increased to the next level was first computed. Next, this difference in delay was divided by the number of vans that were added to the patrol area to reach the new level (i.e., two vans are added to the six-van level to reach an eight-van level), yielding an estimate of the delay reduction expected per added MAP van. This estimate was then converted to an economic benefit by multiplying the delay reduction by a standard unit value of travel time (previous MAP analyses have utilized a value of $12.70 per vehicle-hour, which was applied in this analysis). To estimate costs, meanwhile, MAP operations records were used to determine that each MAP van costs approximately $9,900 per month (including labor, supplies, maintenance, and vehicle amortization). This value was assumed to remain relatively constant as the number of patrols is increased. To complete the incremental B/C analysis, the average monthly benefits per added van were divided by the costs of implementing an additional van. These sets of computations are summarized in Table 4-4.

The incremental B/C ratios of this analysis are plotted against the total number of MAP vans in the designated patrol area, as shown in Figure 4-4. Based on the assumptions present in this analysis, all levels of patrol frequency evaluated resulted in positive incremental benefit-cost ratios. Nonetheless, the ratios fell greatly after peaking at a six-van system (i.e., 15-minute average incident detection time, or 30-minute average patrol frequency).

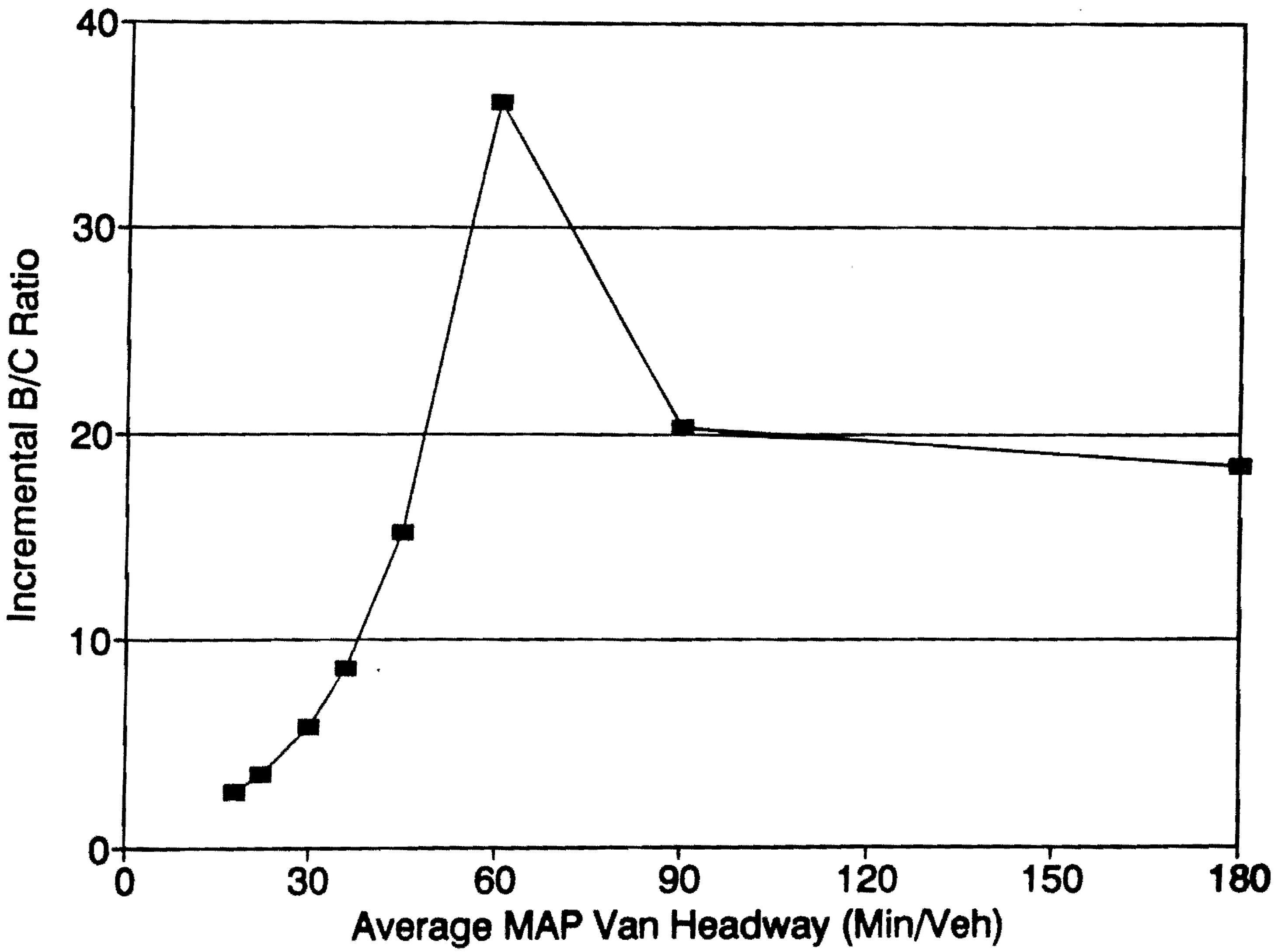

Figure 4-4. Relationship Between MAP Frequency and Incremental B/C Ratio

TABLE 4-3. DELAY COMPUTATIONS

# of Patrols	Average Detection Time	Monthly Delay Peak		Monthly Delay Off Peak		Total Monthly Incident Delay
		Lane-blocking	Shoulder	Lane-Blocking	Shoulder	
0	N/A	253,400	97,800	31,150	0	382,350
2	30.0	230,413	97,800	25,454	0	353,667
4	22.5	214,847	85,575	21,627	0	322,049
6	15.0	199,100	48,900	17,800	0	265,800
8	11.3	185,525	40,098	16,465	0	242,088
10	9.0	178,647	34,230	15,753	0	228,630
12	7.5	173,760	30,807	15,219	0	219,786
16	5.6	168,330	25,917	14,685	0	208,932
20	4.5	163,262	23,472	14,240	0	200,974

It should be noted, however, these findings are extremely sensitive to the assumptions made regarding incident detection frequency per patrol and incident delay functions under peak and off-peak conditions. For example, if the delay function was assumed to be a slightly different shape, such as shown in Figure 4-5, the resulting incremental B/C ratios would plot as shown in Figure 4-6. In the latter case, a 30-minute average patrol headway would still be computed as providing the best return on the investment, but positive incremental B/C ratios would still be significant as the headway was reduced to 20 minutes.

Concluding Remarks

The results of the incremental B/C analysis of the Houston MAP program suggest that implementing additional vans to the existing patrol area to further reduce incident detection times would provide significant benefits to the motoring public. Indirectly, however, the fact that the existing patrol headways were computed to provide the highest B/C ratio indicates that the wisest investment would first be to expand the coverage area

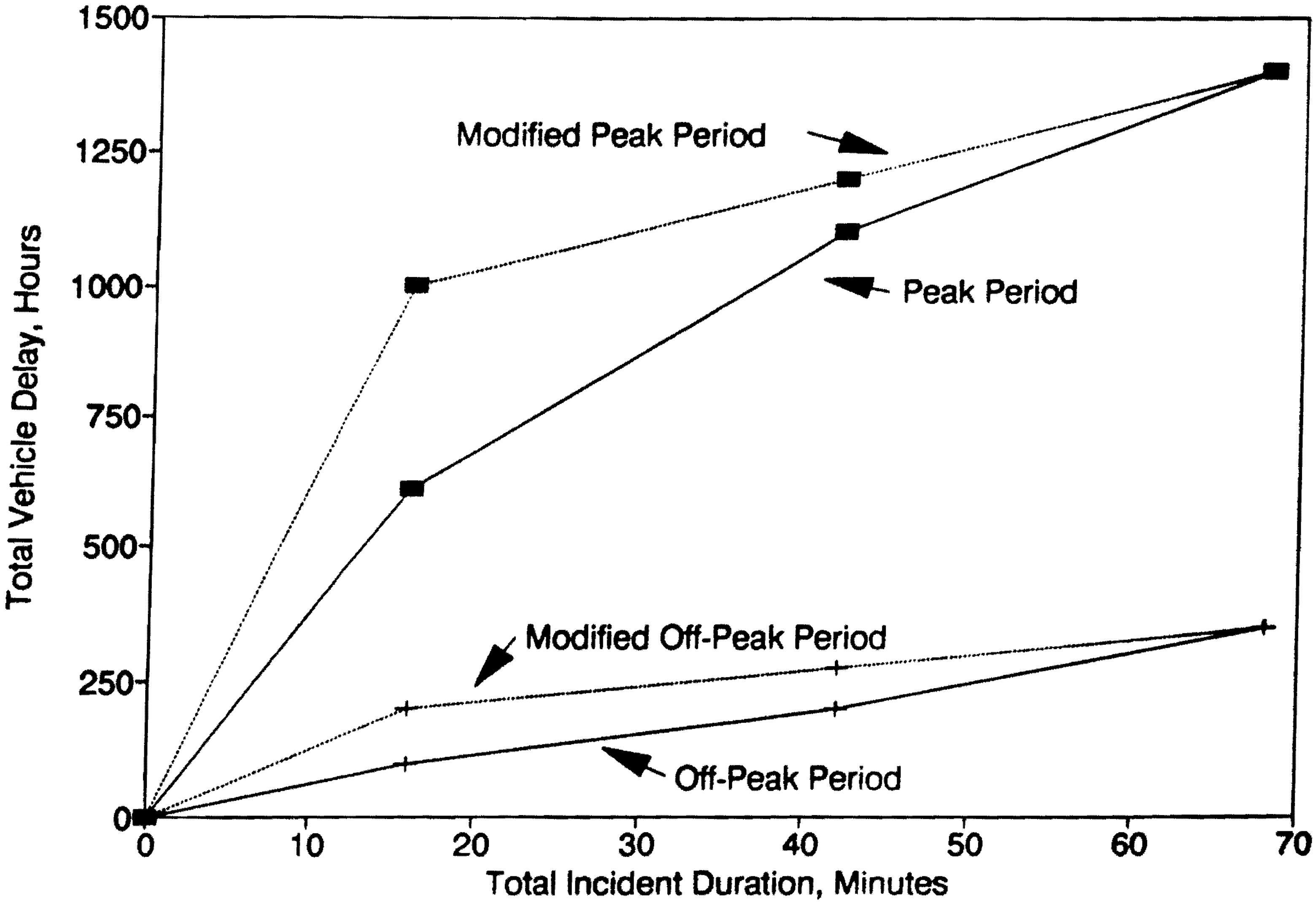

Figure 4-5. Modified Incident Duration – Delay Relationship

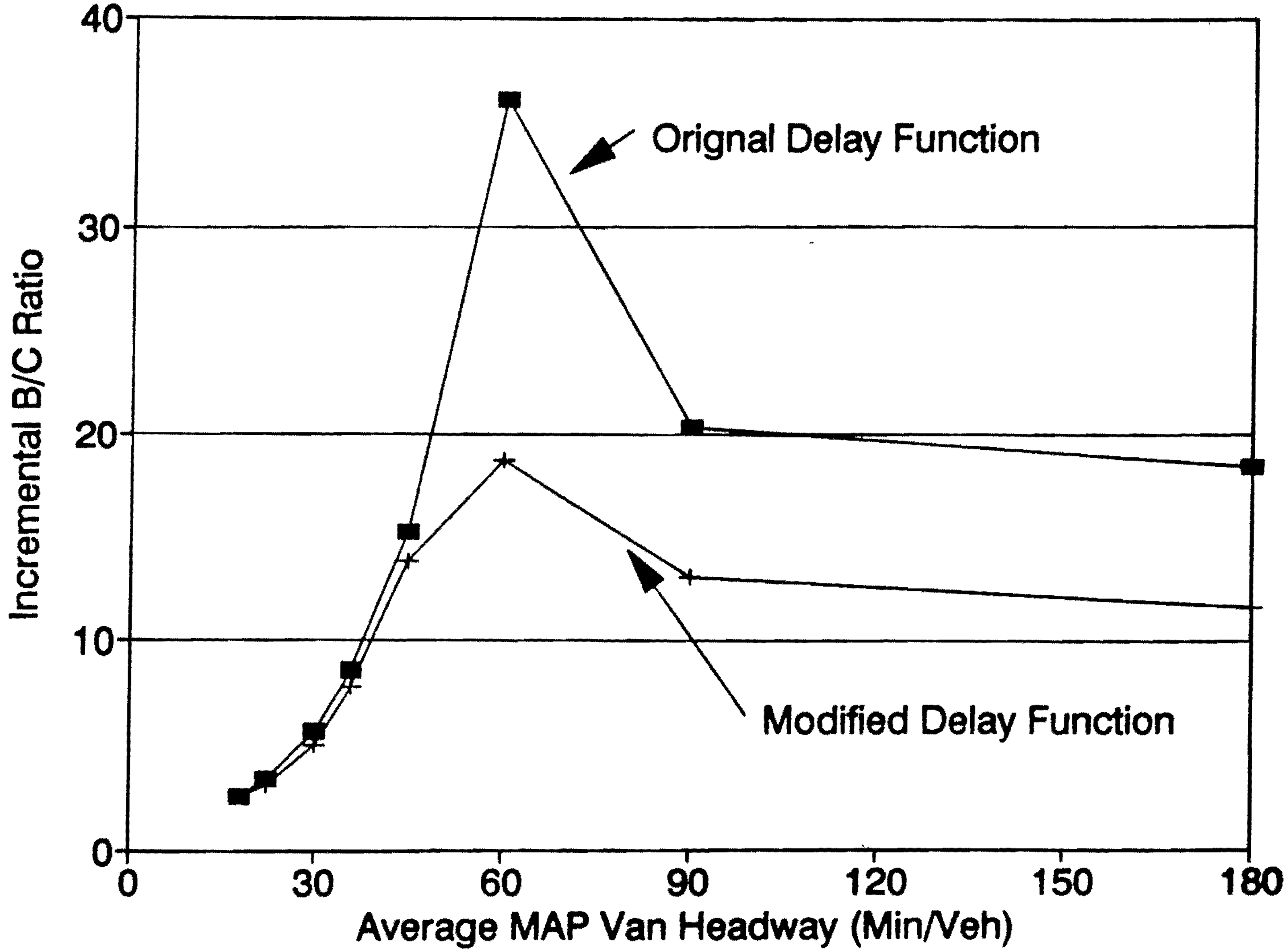

Figure 4-6. Effect of Modified Delay Relationship Upon Incremental B/C Ratio

TABLE 4-4. INCREMENTAL B/C COMPUTATIONS

# of Patrols	Total Monthly Delay	Δ Delay From Previous Row	Δ Delay Per Added Patrol	Benefits Per Added Patrol	Incre-mental B/C Ratio
0	382,350	N/A	N/A	N/A	0.0
2	353,667	-28,683	-14,341	$172,092	17.4
4	322,049	-31,618	-15,809	$200,774	20.3
6	265,800	-56,249	-28,125	$357,188	36.1
8	242,088	-23,712	-11,856	$150,571	15.2
10	228,630	-13,458	-6,729	$85,458	8.6
12	219,786	-8,844	-4,422	$56,159	5.7
16	208,932	-10,854	-2,714	$34,468	3.5
20	200,974	-7,958	-1,990	$25,273	2.6

to all of the area freeways. Once total coverage is achieved, it would then be reasonable to add more vans to the system (to the extent that funds allow).

As a final note, the fact that all B/C ratios exceed 1.0 does not automatically qualify all levels of patrol frequencies studied for possible implementation. Certainly, a B/C ratio that exceeds one is required for an expenditure to be justified. However, there generally exists a number of projects awaiting funds for transportation officials to consider which all meet the basic B/C ratio requirement. As the availability of funds is almost always the limiting factor in public agency operations, the decision as to whether a given project (or enhancement to an existing project or program) should be funded depends on the B/C ratios of the other options. Any projects having a higher ratio than the MAP enhancement would be more justifiable from an economic standpoint.

5. SUMMARY

Incidents continue to be a major source of congestion on many of the freeways in Texas. To combat the problems of incidents and the congestion they cause, many state and local transportation agencies are banding together and developing incident management systems to mitigate the impacts of incidents on freeways. These systems permit transportation agencies to provide a coordinated and preplanned approach to restoring normal operations to a freeway when incidents occur. Incident management is a system approach for detecting and verifying when and where an incident occurs, identifying the magnitude and severity of the incident, and dispatching the appropriate response needed to clear the incidents as quickly and safely as possible. The net result of this process is the quick detection and clearance of incidents on the freeway system.

One of the most critical components of an incident management system (and perhaps the most easiest for the transportation agencies to control) is the detection and verification of incidents. In general, the faster an incident can be detected and verified, the sooner the process of removing the incident can begin. Therefore, the rapid and accurate detection and verification of incidents provides a solid foundation of the entire incident management process.

There are many different strategies (or techniques) for detecting and verifying incident. Each strategy has its own set of advantages and limitations. The more commonly used techniques for detecting and verifying incidents on freeways include the following:

- Motorist Assistance Patrols
- Electronic Surveillance
- Closed Circuit Television
- Stationary Observers
- Law Enforcement Patrols
- Aerial Surveillance
- Motorist Aid Call Boxes and Telephones
- Citizens' Band (CB) Radio Monitoring
- Cellular Telephones
- Automatic Vehicle Identification (AVI) Systems

Most of the freeway incident management systems that are in operation today have evolved over time. Often, these systems use more than one of the above listed techniques for detecting and verifying incidents. Some techniques are also often used to perform functions other than solely incident detection (i.e., electronic surveillance systems are often used to operate freeway ramp metering systems). As a result, it is extremely difficult to isolate the effectiveness of individual techniques on detecting incidents. However, this information is critical when it comes to evaluating options for expanding and improving existing freeway incident management systems. Without specific information on the effectiveness of isolated incident detection strategies, it is difficult to determine how to expand or improve an existing system in a cost effective manner.

Of all the strategies available for detecting and verifying incidents, the motorist assistance patrol (also referred to as a service patrol or courtesy patrol) is perhaps the most widely used. Motorist assistance patrols provide transportation agencies with a flexible means of detecting and servicing incidents. Using specially equipped vehicles (such as pickups, vans, or tow trucks), motorist assistance patrols rove a designated route on the freeway searching for incidents. The time required to detect an incident is directly related to the number and frequency of patrol vehicles. Although other means can be used to inform patrols of incident locations (i.e., electronic surveillance, cellular telephones, CB radio, etc.), the primary means of incident detection for motorist assistance patrols is visual inspection.

The primary benefit of using motorist assistance patrols as an incident detection technique is the reduction in total incident duration that can be achieved. Because most incidents are minor in nature and can be handled by most motorist assistance patrols, the time required to clear an incident is greatly reduced. Essentially, the clearance function of an incident can begin immediately once the patrol arrives on the scene of the incident. At major incidents, motorist assistance patrols can assist in clearing the incident by conducting many specialized tasks such as directing traffic at the incident scene, planning and implementing emergency alternative or detour routes, providing emergency medical assistance until additional help arrives, and coordinating communications among various response agencies.

A key question that arises when deciding to implement motorist assistance patrols (or to ehance an existing patrol system) is how many patrols should be implemented to maximize the benefits achieved. Chapter 4 was devoted to a discussion of an assessment procedure for estimating how many motorist assistance patrols should be implemented in a given incident management system. The application of an incremental benefit-cost analysis was described, along with the rationale for its use in determining the benefits in reduced delay achieved for the money spent on each additional patrol vehicle added to the system. The incremental analysis was demonstrated using available data from the MAP system in Houston. As was described, the analysis can be a useful tool, but must be tempered with sound engineering judgement as the results are sensitive to the assumptions (such as the impact of incidents upon motorist delay) included in the analysis.

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APPENDIX A. EXAMPLES OF MOTORIST ASSISTANCE PATROLS

LOCATION	AGENCY	PATROL TYPE	NAME	EQUIPMENT	COVERAGE	HOURS OF OPERATION	NUMBER OF ASSISTS	COSTS	OPERATION
Howard Frankland Bridge (I-275) Tampa, FL	Florida DOT	Bridge Service	None	2 Wreckers	3 Miles	6-10 am 3-7 pm	8/day	$157,000/ yr. $75/hr.	Contract
Buckman Bridge (I-295) Jacksonville, FL	Florida DOT	Bridge Service	None	2 medium duty pick ups		5 am - 9 pm/ weekday 10 am- 7 pm/ weekends	7.5/day	$214,000/yr. $42/hr.	Maintenance Division
Hampton Roads Bridge Tunnel/ James River Bridge (I-64) Southeastern VA	Virginia DOT	Bridge/ Tunnel Service	None	Dual Purpose tow trucks with hydraulic wheel lifts (no manual hookup of bars or clamps)	10 miles	356 days/year	Hampton Roads 6000/year; James River 3000/year	$100,000/yr.	Virginia DOT
Columbus, OH	Columbus Police Department	Service	None	Specially equipped police cruisers	88 Miles	N/A	N/A	N/A	Columbus Police Department
Richmond, VA	State Police	Service	None	Refurbished backup police cruisers staffed by motorist aid officers (not sworn police officers)	N/A	Weekdays	N/A	N/A	Virginia State Police
Seattle WA	Local Radio Stations KOMO, KIRO	Service	None	3 service patrol vans (KOMO) 1 van (KIRO)	N/A	5:35-8:35 am 3:30-6:30 pm weekdays	N/A	N/A	Private
Houston, TX	Harris County Sheriff's Office/ Houston Automobile Dealers Association	Service	MAP	9 Vans		16 hr./day weekdays	3.65/hr 8/day 12,000/year	$85.67/ incident	Harris County Deputy Sheriff's/ TxDOT/Metro

Source (4).

APPENDIX A. EXAMPLES OF MOTORIST ASSISTANCE PATROLS (CONTINUED).

LOCATION	AGENCY	PATROL TYPE	NAME	EQUIPMENT	COVERAGE	HOURS OF OPERATION	NUMBER OF ASSISTS	COSTS	OPERATION
Chicago, IL	Illinois DOT	Service	Minutemen	35 emergency patrol vehicles 9 light duty 4x4s 3 heavy duty tow rigs, 1 crash crane, 1 extricator truck	100 Miles	24 hrs/day 365 days/year	100,000/year	$33-$35/assist	Contract
Los Angeles, CA	California DOT	Service	Orange Angels	6 trucks	I-5 between Lake Forest Dr. and Grand Ave. S.R. 55 between MacArthur Blvd. & Seventeenth St.	6am - 7pm/ weekdays		$61/hr.	Contractor (2 contracts)
Twin Cities, MN	Minnesota DOT	Courtesy	Highway Helpers	5 heavy duty pick ups	N/A	N/A	4400/year	N/A	Minnesota DOT
Various Northeast Cities	Private Sponsor	Courtesy	Samaritan	One 3/4 ton van	8-25 miles/day	6:30-9:30 am 3:00-6:00 pm weekdays	1500-9000 assists/yr.	$100,000/yr.	Samaritan, Inc.

Source (4).

APPENDIX B: TYPICAL FUNCTIONS AND DUTIES OF MOTORIST ASSISTANCE PATROLS

- Continuously patrol a designated area seeking disabled vehicles, stranded motorists, debris in the roadway, spilled loads, accidents, obstructions to traffic, and other potential hazards or abnormal occurrences, and notify appropriate highway and enforcement personnel of the location and nature of situation.

- Assist motorists by towing and/or pushing disabled vehicles off of the roadway; provide gasoline or water, change tires, provide jump starts with booster cables, perform minor repairs when and if possible.

- Notify enforcement authorities of abandoned vehicles along the roadway -- note location, make, color, body type, license number, and whether or not the vehicle is impeding traffic. If not impeding traffic, tag the vehicle for removal under local regulations. If it is impeding traffic, notify enforcement personnel that: (1) they will remove the vehicle if so authorized, or (2) immediate assistance is required if they are not authorized.

- Assist at freeway accident scenes by providing emergency first aid, notifying enforcement agencies, removing damaged vehicles from the roadway, supplementing or providing traffic control at the scene, assisting in extricating injured motorists, providing and/or coordinating communications at the scene, providing motorist information, traffic reports.

- Remove debris from the roadway -- accident or otherwise, or call for assistance for more complex cleanups.

- Assist in setting up, maintaining, and removing emergency detour routes required because of an incident.

- Assist in the management of traffic in construction and maintenance zones by performing normal service patrol activities and by providing protection to highway workers.

- Report on property damage to the highway system.

- Provide traffic reports to highway agencies, news agencies, and other traffic sources for distribution to motorists.

- Provide travel information and motorist aid to lost or stranded motorists.

- Provide emergency transportation to stranded motorists.

- Remove pedestrians from freeways, bridges, and tunnels, and provide emergency transportation where needed.

- Assist at major accident scenes and other disasters, providing personnel, equipment, and traffic control support.

- Observe work zone traffic controls set up by other agencies and contractors and report on any problems encountered, unauthorized lane closures, or unauthorized work.

- Provide any other assistance as requested by State and/or local enforcement agencies (Highway Patrol, State Police, City Police, Sheriff's Department, etc.)

- Maintain an established service patrol log, completing an entry for each incident encountered and/or handed.

Source: (4).

APPENDIX C: INCIDENT MANAGEMENT PROGRAMS IN THE UNITED STATES

SYSTEM TYPE AND LOCATION	DETECTION & VERIFICATION							RESPONSE				MOTORIST INFO				GENERAL COMMENTS
	[illegible]	[illegible]	[illegible]	CCTV	[illegible]*	[illegible]	OTHERS	[illegible]	[illegible]	[illegible]	OTHERS	[illegible]	HAR	[illegible]	VMS	
EXISTING AREAWIDE SYSTEMS																
Anaheim, CA	X			X		X		X			X	P	P	P	X	Integrated Freeway/Arterial System
Baltimore, MD	X	X					X	X	X	X	X	X	X	X	X	Init. phase of statewide CHART program
Chicago, IL	X	X	X		X		X	X		X	X		X	X	X	Illinois DOT operating since 1960
Detroit, MI	X		X	X	X	X			X						X	Major expansion underway
Fairfax Co., VA	X				X		X	X	X			P		X		Nonfreeway - County Police
Fort Worth, TX	X	X	P	P				X	X		X	P	P	X	X	20-year project over 260 mi of freeways
Houston, TX	P	X	X	X		P	P	X	X		X	P		P	C	20-year project over 555 mi of freeways
Los Angeles, CA	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	System expansion/upgrade underway
MD suburbs of D.C.	X	X			X		X	X	X	X	X	X	X	X	X	Init. phase of statewide CHART program
Minneapolis/St.Paul	X	X	X	X	X	X	X	X	X		X		X	X	X	Major system expansion underway
Northern Virginia	X	X	X	X	X	X	X	X	X			X		X	X	Major system expansion underway
Phoenix, AZ	P		P	P	P			X	X			P	P	P	P	20-year plan - 200+ mi of fwy
Richmond, VA	P	X						X	X			X		X	P	Init. phase of long term program
San Antonio, TX	P	X	P	P				X	X						P	10 year plan developed
San Diego, CA	X		X	X		X		X	X				P	X	X	Major expansion underway
Seattle, WA	X		X	X				X	X	X	X	P	X	X	X	Major expansion underway - FAME program
TRANSCOM - NY/NJ	X						P	X			X	X	P	X		Regional info/response coordination
NEW AREAWIDE SYSTEMS																
Atlanta, GA																Init. scoping phase-lead ARC (Atl MPO)
Austin, TX																Initial scoping phase-lead SDH&PT
Cincinnati, OH	P		P	P	P			P					P	P	P	Feasibility study complete-PE init phase
Columbus, OH	X	X	P	X			X	X		X	X			X	P	10-yr plan.
Connecticut Fwys.		X											X		X	Feasibility study complete-I-95,91,& 84
Dallas, TX	P	X	P	P				X							P	10-yr plan under development-lead SDH&PT
El Paso, TX	P		P	P				X							P	10-yr plan under development-lead SDH&PT
Fresno,CA	P							P							P	Init scoping phase - Caltrans Dist 6
Jacksonville, FL								X								Fwy Management Team
Kansas City, MO																Init scoping phase - MO Hwy & Trans Dept
Massachusetts Fwys.	P				X							P				All I fwys, tied to HazMat evac planning
Miami, FL	P	P	P					X	P			P		P	P	Feasibility study complete
Michigan Fwys.					X			P				P				Incl all I fwys-plan under development
Milwaukee,WI	P	P	P	P	P			P	P			P		P	P	Area study compl.-Impl. plan in develop
Montgomery Co, Md	X			P	P		P	X			X	X		X		County Trf Engr Dept
Orange, CA	X	X	X	X		X		X					X	X	X	Long term plan in development
Orlando, FL	P	P	P	P	P		P	X	X		P	P		P	P	Incl. TravTek IVHS Demo Proj.
Portland, OR	P		P	P	P	P		P				P		P	P	6-yr plan developed
Sacramento, CA	X		P			P		X					X	X	X	Initial scoping phase - Caltrans Dist 3
San Bernardino,CA	P							X					X		X	Initial scoping phase - Caltrans Dist 8
San Francisco, CA	P	X	P	P	P	P		X	X					P	P	20-yr plan developed for 500 mile system
Spokane, WA																Initial scoping phase - Wash SDOT
St. Louis, MO																Init scoping phase - MO Hwy & Trans Dept
Tacoma, WA																Initial scoping phase - Wash SDOT
Tampa/St.Pete Fl																2 Fwy Management Teams
Tidewater Area, VA	P	X	P	P	P			X	X			X	X	X	X	Tie w/ exist br/tunnel systems & new
Westchester Co. NY	P	X		P	P		P	P	X			X	P	P	P	Joint County/State effort

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X = In-Place P = Planned or Proposed
* Citizen reports via cellular, CB, other

APPENDIX C: INCIDENT MANAGEMENT PROGRAMS IN THE UNITED STATES

SYSTEM TYPE AND LOCATION	DETECTION & VERIFICATION							RESPONSE				MOTORIST INFO				GENERAL COMMENTS
	[illegible]	[illegible]	[illegible]	CCTV	*CITIZEN CALL	CALL BOXES	OTHER	TEAMS	[illegible]	[illegible]	OTHER	ALT ROUTES	HAR	MEDIA	[illegible]	
CORRIDOR SYSTEMS																
Dallas, TX, I-75	P	P		P			P	P					P	P	P	Const oriented-will become perm
Dayton, OH I-75												X		X		
Delaware Interstate						X										Call boxes
El Paso, TX/I-10			P	P				X	X	X	X	X			X	Construction oriented-will be permt
Florida rural I						X										Call boxes
NW Indiana I-80	P		P	P				P						P	P	Borman Expy-Impl. plan under development
Ft. Lauderdale/I-95								X								Const oriented. Fwy Management Team
Los Angeles/I-10	X	X	X	X	X	X	P	X	P	X	P	X	X	X	X	"Smart" Corridor Demonstration Project
Maryland(West)/US40					X			X	X	X	X	X	X		X	Init phase of CHART
Maryland/US-50	X	X			X		X	X	X	X	X	X	X	X	X	"Reach-the-Beach" Program
Michigan/I-75					X			X				X				Mich DOT/St Police Dist 6 - nonurban I
NJ Turnpike	X	X	X	P				X	X	X	X	X		X	X	Expansion/upgrade of system underway
NY/Long Island Expy	X	X	X	P	X			X	X	X	X	X		X	X	INFORM-30 mile x 5 mile corridor
NY State Thruway	X	X		P	X			X	X	X		P	X	X	X	559 miles of Toll Road-plan under devel
Pittsburgh I-376	P	P	P	P			P	P							P	Study completed by PaDOT
Penn Turnpike						P										Call boxes planned, tunnel systems
Rhode Island/I-95						X		X				X			X	Public/private Team
BRIDGES, TUNNELS, AND SPOT LOCATIONS																
Baltimore Tunnels	X		X	X			X		X	X		X	X	X	X	Md Transportation Authority
Boston, MA I-93/90	P	P	P	P	P		P	P	P	P	P	P	P	P	P	
Buckman Br, I-295 Jacksonville, FL		X						X	X	X						Florida DOT
Duluth, Mn I-35 and tunnels	X		X			X				X	X				X	Operated by State Police
Eisenhower Tunnel I-70, Colorado	X		X	X						X		X			X	Colorado Dept. of Hwys.
East St.Louis, IDOT		X			X	X				X			X	X		Miss River brs & adj. rwys.
Eliz. River Tunnels Norfolk/Ports., VA	P	X	P	P	X	X	X			X				X	P	
Escambia Bay Brs(2) Florida I-10/US98	X					X		X	X						X	
Hampton Rd.Br/I-64 and Tunnel, VA	X	X	X	X	X		X	X		X	X		X	X	X	
Howard Franklin Br. Tampa, FL	X	X	X	X		X		X	X			X		X	X	
James River Br/SR17 Newport News, VA	X	X		X	X	X				X	X		X			4 mi. of 4-lane divided with no shoulders, ADT=23,000
Lehigh Tunnel, Penn. Turnpike	X	X					X			X					X	
Lincoln & Holland Tunnels, GW Bridge	X	X	X	X			X		X	X	X	X	X	X	X	Port Authority of NY&NJ
Mobile,AL I-10/US98	X			X												
Oakland Bay Br (SF)	X	X	X	X		X	X	X		X	X			X	X	
Sunshine Skyway, FL	X			X		X		X	X			X		X	X	
Tappan Zee Br. NY	X	X		P	X			X		X		X		X	X	3 mi. long across Hudson River
Triborough Bridge & Tunnel Auth., NY	X		P	X		X				X				X	X	7 Bridges, 2 Tunnels

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	[illegible]	[illegible]	[illegible]	CCTV	*CITIZEN CALL	CALL BOXES	OTHERS	TOWING	[illegible]	[illegible]	OTHERS	ALT ROUTES	HAR	MEDIA	VMS	
SERVICE PATROLS																
Albany, NY		X														Corporate sponsored vans operated by Samaritania, Inc.
Boston, MA		X														" " "
Bridgeport, CT		X														" " "
Hartford, CT		X														" " "
New Haven, CT		X														" " "
Stamford, CT		X														" " "
Philadelphia, PA																
Providence, RI		X														" " "
Westchester Co., NY		X														" " "
CALL BOXES																
Imperial Co. CA						P										100 boxes in cooperation w/ San Diego
Kern Co. CA						P										534 CB system under const.
Los Angeles Co. CA						X										3,500 active,4,200 plan: 55,000 calls/mo
Orange County, CA						X										1,100 CB: 15,000 calls/mo
Riverside Co., CA						X										Under const. - 600 planned
Sacramento Co. CA						P										Approx. 1,600 planned
San Bernadino Co.CA						X										1,200 active, 200-300 add'l planned
San Diego Co., CA						X										1,170 CB - 16,000 calls/mo.
SF Bay Area, CA						P										2,100 CB system under const.
Santa Barbara Co,CA						P										310 CB system under const.
Ventura Co., CA						X										464 CB system
Connecticut, I-91						X										
DE/I-95, 295 & 495						X										
Florida Turnpike						X										360 push button boxes, 1-mile spacing
Florida Rural Interstates						X										434 push button boxes in operation @ 1 mile spacing, 900 boxes proposed
Louisiana, I-10						X										
MA/I-93, 95, & 91						X										1-mile spacing, push button
New York/I-87						X										64 call boxes @ 2-mile spacing
Rhode Island I-95						X										

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