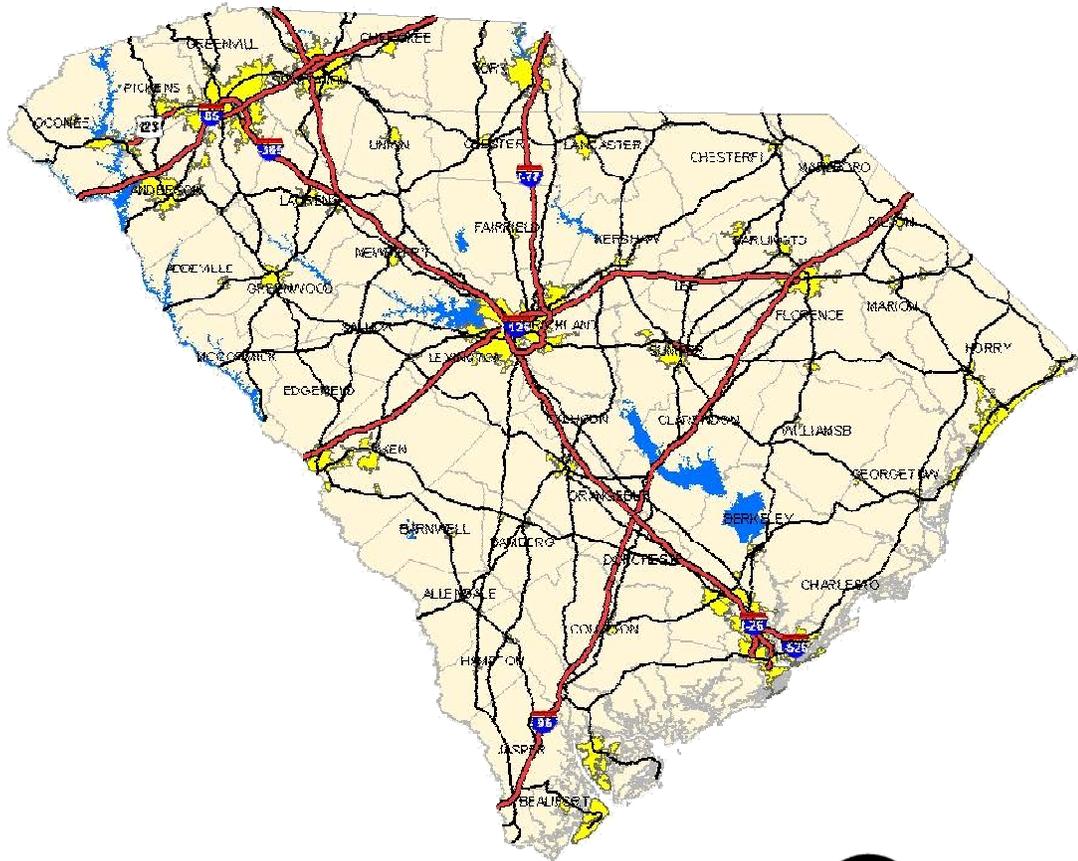


Benefit Cost Analysis of Accelerated Incident Clearance
Final Report
April 2007



Prepared for
South Carolina Department of Transportation



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16. Abstract <p>This study examined the current state of the incident management industry in the US by reviewing the available published literature, and by launching a nation-wide survey of multiple incident management agencies. The study also evaluated the specific impact of traffic incident on both motorists and the environment on South Carolina freeways by using traffic simulation and benefit-cost analysis. Survey responses revealed that technologies such as traffic cameras, dispatched personnel, and freeway service patrols were the most successful in detecting and verifying incidents. Responses also emphasized the importance of effective institutional coordination, and communication to both the public and decision makers for a successful incident management program. Through traffic simulation analysis, researchers examined the effectiveness of traffic sensors, traffic cameras, freeway service patrols, a multiple-strategy approach, a Steer-it Clear-it law, and route diversion. Results of the benefit-cost analysis indicated that using traffic sensors, traffic cameras, freeway service patrols, and a combination of these strategies with an incident report hot line, produced \$7, \$12, \$11, and \$8 of benefit for each dollar invested, respectively. The Steer-it Clear-it scenario produced approximately \$22 for each dollar invested if all drivers were aware of and obeyed the law. The route diversion strategy, evaluated for severe crashes, produced approximately \$55 for every dollar invested with a 100-percent compliance rate.</p>					
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List of Acronyms

AAA – American Automobile Association
ATMS – Advanced Traffic Management System
CAD – Computer Aided Dispatching
CCTV – Closed Circuit Television
CHART – Coordinated Highways Action Response Team
CO – Carbon Monoxide
GIS – Geographical Information Systems
HC - Hydrocarbons
HDDV – Heavy Duty Diesel Vehicle
HDGV – Heavy Duty Gasoline Vehicle
HOV - High Occupancy Vehicle
IDAS – Intelligent transportation systems Deployment Analysis Software
ILD – Inductive Loop Detector
ITS – Intelligent Transportation System
LDGV – Light Duty Gasoline Vehicle
MAP – Motorist Assistance Patrol
MMDI – Metropolitan Model Development Initiative
NO_x – Nitrous Oxide
PARAMICS - PARAllel MICRo-Simulation Software
PM – Particulate Matter
S2P – Shape to PARAMICS
SCDOT – South Carolina Department of Transportation
SCDNR – South Carolina Department of Natural Resources
TMC – Traffic Management Center
TRANPLAN – Transportation Planning Software
VMS – Variable Message Sign
VOC – Volatile Organic Compounds

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Benefit Cost Analysis of Accelerated Incident Clearance

Executive Summary

Overview

Highway incidents bring unexpected harm to both the traveling public and the community. Consequences from these incidents include traffic congestion, increased fuel consumption, and more air-polluting emissions. Moreover, a single incident can cause traffic delays that can result in equally devastating secondary incidents. By nature, incidents are unpredictable, caused by occurrences such as traffic crashes, adverse weather conditions, spills from trucks (possibly hazardous materials), and short-term unscheduled construction work. Therefore, minimizing the disruption these unusual events cause to the transportation system poses a formidable challenge to agencies responsible for assisting victims and returning traffic to normal flow.

Incident management addresses this type of non-recurrent congestion by shortening the duration of incidents to reduce their negative impacts on both highway travelers and the environment. Minimizing the time needed to return a highway to normal flow can greatly reduce delays and the occurrence of secondary incidents.

The research sought to meet the following objectives:

- review state department of transportation survey responses and published literature to identify current state-of-the-practice for accelerated incident clearance;
- identify strategies for incident management to be evaluated in this project;
- estimate the operational impacts of each identified strategy;
- develop benefit-cost estimates for each identified strategy;
- present implementation guidelines, and
- develop a technical report regarding the benefits for the public and state decision makers as revealed through the investigation into the state of the practice in other states and through the primary research work conducted at Clemson for South Carolina sites.

To reach these objectives, this study examined the current state of the incident management industry in the US by reviewing the available published literature, and by launching a nation-wide survey of multiple incident management agencies. The study also evaluated the specific impact of traffic incident management on both motorists and the environment on South Carolina freeways by using traffic simulation and benefit-cost analysis.

Analysis of Survey

An analysis of survey responses revealed that technologies such as traffic cameras, dispatched personnel, and freeway service patrols were the most successful in detecting and verifying incidents. Survey results also found that an efficient and comprehensive incident management program should have dump trucks, sweepers, air-cushioned recovery system, cranes and heavy-duty tow trucks available for clearing incidents. The respondents also emphasized the importance of institutional coordination, and effective communication methods to the public and to decision makers for a successful incident management program.

Impact Analysis

The researchers examined the effectiveness of using traffic sensors, traffic cameras, freeway service patrols, and a multiple-strategy approach. The measures of effectiveness for this simulation analysis included delay, fuel consumption, and emissions. All of the scenarios showed significant reductions in motorist delay, vehicle fuel consumption, and emissions.

Two special cases examined i) severe crashes that required route diversion and ii) minor incidents under the “Steer-it, Clear-it” law, which requires that drivers involved in such minor incidents move their vehicles from travel lanes. Although “Steer-it, Clear-it” provided smaller benefits per incident than other analyzed scenarios, the impact of this law was found to provide significant annual benefits if the SCDOT advertises it and drivers comply, because minor incidents occur much more frequently. Route diversion produced the greatest benefits per incident, because the incidents requiring this strategy are usually the most severe. However, route diversion also requires significant resources, such as dynamic message signs and personnel in the field on alternate routes for directing diverted traffic.

Benefit Cost Analysis

Benefit-cost analysis justified investment in incident management. Analysis results indicated that freeway service patrols produced \$11 of benefit for every dollar invested. Using traffic cameras to detect and verify incidents produced \$12 of benefit for each dollar invested. Using traffic sensors to detect incidents and traffic cameras to verify incidents produced \$7 for every dollar invested. While the multiple strategies scenario, representing a combination of above strategies and telephone calls by motorists reporting incidents, produced high benefits compared to the previous strategies, it only produced \$8 for each dollar invested due to required investment in several systems.

The benefit-cost analysis showed high returns for the “Steer-it Clear-it” and the route diversion scenarios. The “Steer-it Clear-it” scenario produced approximately \$22 for each dollar invested if all citizens were aware of and obeyed the law. While 100-percent compliance is unrealistic, these results justify investment in an aggressive statewide advertisement to increase motorist compliance. The route diversions evaluated produced approximately \$55 for every dollar invested. While route diversion options are not available at all possible crash locations, these results justify future investments in route diversion planning.

Products from This Study

The final report summarized the entire project with a section outlining an implementation strategy. In addition to the final report, this study also produced a brochure and a voice-embedded presentation, describing the benefits of an effective incident management program. These products are provided separately.

1.0 Introduction

Highway incidents bring unexpected harm to both the traveling public and the community. A single incident can cause appalling traffic delays and may even result in the occurrence of equally devastating secondary incidents. Minimizing this disruption poses a formidable challenge to those agencies responsible for assisting crash victims and returning traffic to normal flow. Incidents by nature are unpredictable, including occurrences such as traffic crashes, adverse weather conditions, spills from trucks (possibly hazardous materials), and short-term unscheduled construction work. These unusual events reduce the normal capacity of a highway segment, which in turn generates traffic congestion when the reduced capacity drops below a level that can accommodate the travel demand. Incident management addresses this type of short-term congestion, which can result in smoother traffic flow on South Carolina's highways. Minimizing the time it takes to return a highway to normal flow can greatly reduce delays and reduce the occurrence of secondary incidents.

Effective incident management program requires periodic evaluation of existing systems, so that any existing deficiencies can be identified and corrected. It is also important to evaluate new alternatives, in terms of their benefits and costs, to consider their potential to mitigate any existing deficiencies. Among the types of data that have proven useful in evaluating incident management programs include: time required to detect the incident, time required to reach the incident site, time required to clear the incident, delay caused by the incident, incident management program costs, and costs recovered from at-fault drivers (1).

Since the early 1970s, transportation departments across the United States have recognized the need for a multi-disciplinary team approach for incident management. Figure 1 shows an example of the interactions between the multiple agencies and resources in an incident management program (2). Incident management programs must focus on institutional issues due to the multi-jurisdictional and multi-agency nature of this process. Police officers at the scene often need to coordinate with fire and medical first responders, while state department of transportation personnel attempt to keep traffic flowing at the perimeter of the scene. These multitasking events, which subsequently occur after an incident, makes it clear that centralized traffic operations center is needed for simultaneously managing these post-accident activities. These systems must be easy-to-use, and take advantage of emerging communication and computing infrastructure and sensor information dissemination technologies. More importantly, they must provide a standard incident management architecture to support real-time data sharing and multi-agency incident response through a multi-agency network. Once institutional issues have been adequately addressed, incident management personnel must be given efficient strategies and associated tools to deal with issues related to actual incident management. Both the Federal Highway Administration and individual states recognize the need to develop such systems to assist transportation departments, law enforcement agencies, emergency management services and other related agencies to manage incidents efficiently and effectively.

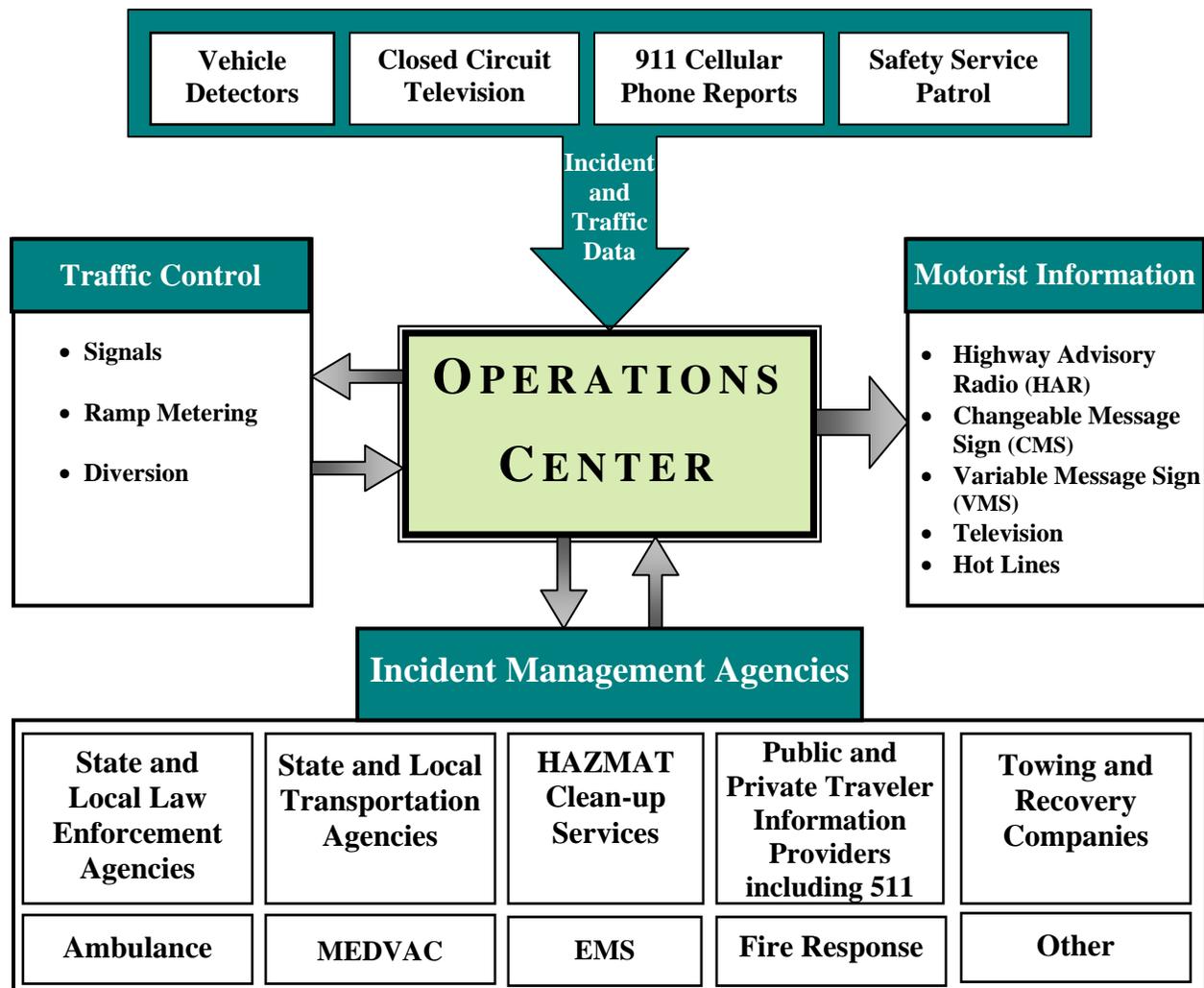


Figure 1: Elements of a traffic system for the incident management process

2.0 Literature Review

Incidents along major roadways throughout the United States cost an estimated \$75 billion in lost productivity in 2005 (3). New technologies in sensor control, communication, processing, and dissemination strategies have capability to create an incident management plan to facilitate accelerated incident detection, verification, and subsequent response, clearance, and recovery. This review of literature examines the documented current practice of incident management and clearance and provides a foundation for the development and analysis of the survey and simulation study. The literature review is organized in the following subsections:

- Common Components of Incident Management Programs
- Multi-Agency Coordination
- Incident Management Technology
- Remaining Questions.

2.1 Common Components of Incident Management Programs

Incident management throughout the U.S. follows a four-step procedure including detection, verification, response, and recovery (2,4). There are many strategies and associated

tools available for each step, and many depend on the type, location, and timing of the incident. The first step, incident detection, is particularly important because the efficiency of the proceeding steps depends on it. A 1998 study found that improving incident detection times indirectly impacted the timeliness of the incident response process (5). For example, if a crash is detected after two minutes, instead of four, the incident response personnel travel through a shorter queue to reach the incident location. The recovery time will also decrease due to the shorter queue.

Incident detection methods include freeway service patrols, traffic sensors (such as radar, loop and video image processors), manual video surveillance, call boxes, and cellular telephone reporting. While many agencies employ freeway service patrols to aid in incident detection, they are more valuable for their use in quick incident response and clearance. Traffic sensors can be used as part of an automated incident detection system, but due to high false alarm rates, are not widely used (6).

Systems in New York (7) and Toronto (8) both used traffic cameras and loop detectors to detect incidents and changeable message signs for response. These systems both reduced average clearance times from approximately 90 minutes to approximately 30 minutes, demonstrating the value of such systems in different settings. Good practice also suggests that providing and promoting dedicated toll-free cellular phone numbers to report incidents, such as 511 or *HP, might improve cell phone based incident reporting timeliness and effectiveness (6).

Call boxes are another incident detection tool used by many agencies (9). The Georgia DOT studied the effectiveness of these devices along 39 miles of I-185, a low volume, rural freeway with call boxes every half mile on both sides. The study examined a six month period and approximated the benefit of the system at \$330,000 or a benefit to cost ratio of 2.76:1 (10), indicating that call boxes are beneficial for rural freeways.

Although some incident management agencies consider call box communication genuine enough to dispatch response workers, incident detection with cell phones and detectors is not always reliable enough to dispatch response personnel (5). To maintain costs, the verification step ensures the presence, type, and location of an incident prior to any response (11).

After an incident is identified and verified, the next step in incident management is response. Response time is linked to the response vehicle locations, dispatching characteristics, and, identification and verification time. Many agencies throughout the US rely on freeway service patrols. Table 1 displays the various locations where freeways service patrols operate and the different names used. Many of these operating agencies have studied the effectiveness of their programs. Studies indicate benefit to cost ratios between 2:1 to 58:1. This wide range indicates the effectiveness is location and operation type specific.

Table 1: Freeway Service Patrol Operators in the US

Location		Name
State	City	
California	Fresno, Hayward, Oakland, Orange County, Riverside County, Sacramento, San Diego, San Francisco	Freeway Service Patrol
	Los Angeles	Metro Freeway Service Patrol
Colorado	Denver	Denver Courtesy Patrol, Mile High Courtesy Patrol
	Greeley	State Patrol Courtesy Patrol
Connecticut	Southern	Samaritan

Georgia	Atlanta	(Highway Emergency Response Operators) (HEROs)
Florida	Florida	Road Ranger Program
	Ft. Lauderdale, Miami	I-95 Service Patrol
	Tampa	I-4 Service Patrol
Illinois	Chicago	Emergency Traffic Patrol
	Indianapolis	Samaritan
Indiana	Northwestern	Hoosier Helper freeway service patrol
Maryland	Maryland	Coordinated Highway Action Response Team (CHART)
Massachusetts	Boston, Springfield, Worcester	Motorist Assistance Patrol Samaritan
Michigan	Detroit	Freeway Courtesy Patrol
Minnesota	Minneapolis	Highway Helper Program
Missouri	Kansas City, St. Louis	Motorist Assistance Patrol
New Jersey	New Jersey	Courtesy Patrol
New York	Albany, Westchester	Samaritan
	New York City	Highway Emergency Local Patrol
North Carolina	Charlotte, Greensboro, Haywood County, Raleigh	Incident Management Assistance Patrol
	Winston-Salem	Motorist Assistance Patrol
Ohio	Cincinnati	Samaritan
Pennsylvania	Pittsburg	Penn-Lincoln Parkway Patrol
	Philadelphia	Incident Management Team
Rhode Island	Providence	Samaritan
South Carolina	Columbia, Greenville, Charleston, Florence, York	SCDOT Incident Response
Tennessee	Chattanooga, Knoxville, Memphis, Nashville	HELP
Texas	Austin, Dallas, El Paso, Fort Worth, San Antonio	Courtesy Patrol
	Houston	Motorist Assistance Program (MAP)
Utah	Salt Lake City	Incident Management Team
Virginia	Norfolk	Safety Service Patrol
	Richmond, Virginia Beach	Motorist Assistance Program
Washington	Seattle, Tacoma	Service Patrol
Washington D.C. & MD	Washington D.C. & MD	CHART
Washington D.C. & VA	Washington D.C. & VA	Motorist Assistance Program, Safety Service Patrol, Samaritan

Incident detection, verification, and response are sometimes very integrated in an incident management program. It is difficult to separate the impacts of individual components of an incident management program and several studies do not. The TranStar System in Houston, Texas, integrates changeable message signs, a traffic management center, ramp meters, traffic cameras, high occupancy vehicle lanes, freeway service patrols, and regional traffic signal

times. Additional causes of increased incident clearance can include heavy-duty towing and spill and cargo cleanup. Historically, many commercial vehicle owners show concern with cargo removal to ensure that salvageable material is handled with care (16). Authority removal and tow laws allow transportation authorities to remove spills and vehicles before the owner has examined the material, without threat of repercussion.

Many state departments of transportation (DOT) are interested in quick clearance of traffic incidents, where either drivers or incident responders remove minor crashes from travel lanes to minimize delays. The I-95 Corridor Coalition defined quick clearance as, “the practice of rapidly and safely removing temporary obstructions from the roadway” (15). In this definition, obstructions include the vehicles involved in an incident and any spilled material from vehicles. Legislation enacted quick clearance practices by protecting incident responders and enforcing driver involvement in incident clearance. State agencies nationwide have some form of quick clearance legislation, but the little is known about the effectiveness of these laws.

Many states that have recently passed quick clearance legislation seem pleased with the effects. For example, the Highway Patrol in North Carolina recently reported a large decline in secondary incidents because of the reduced delays from their Quick Removal Law (15). Others find that the effectiveness of these laws is constrained by public knowledge and understanding of them, which requires effective communication (18). More findings on the effectiveness of such legislation can encourage other states to implement such legislation.

Interagency coordination, incident management awareness, and technological advancements are three significant factors to the efficiency of incident response. Presently, incident response components from different agencies are dispatched independently, and on-scene coordination is sporadic in the US (19). Incident response priorities vary by responding agency—some focus on minimizing traffic delays, while some put their efforts into scene security. It is often the case that communication technology advances have outpaced coordination efforts among responding agencies.

Incident clearance is a multi-agency process that might involve fire and rescue, service patrols, law enforcement, and towing/recovery services. These agencies all share a single objective under the incident command structure: safely and quickly restoring flow (6). Reducing clearance times has the greatest potential effect (benefit) on improving overall incident clearance times. The I-95 Corridor Coalition recommends developing an open roads policy with incident clearance performance measures, aimed at improving incident clearance time. An open roads policy sets tough performance goals to clear incidents quickly and might include incentives for tow companies for clearing the incident quickly (20).

2.2 Multi-Agency Coordination

Multi-agency coordination has become vital in creating an environment where quick detection and verification, and timely clearance of incidents occur. Multi-agency coordination might include state, city or county departments of transportation (DOTs), state highway patrols (SHPs), intelligent transportation systems (ITS) management, and emergency medical services (EMS). Multi-agency operations can be supported by traffic management centers serving as centralized control and management hubs and information clearinghouses (16).

The I-95 Corridor Coalition offers several recommendations for coordinating interagency efforts to respond to a traffic incident. The recommendations include the use of traffic and emergency management centers in coordination with other agencies besides transportation and emergency management services, from multiple jurisdictions. Agencies should develop protocol for incident management with adjacent jurisdictions for smooth management of incidents along jurisdictional borders. The report also recommends increased cooperation between public and

private partnerships, developing agreements with medical responders and developing creative towing contracts with private stakeholders (20).

While law enforcement agencies such as state highway patrols are more closely coordinated with transportation agencies than fire and rescue, maintaining communication between all of these agencies and the local traffic management center is essential. Recurring traffic congestion during peak hours can prolong response times by hindering the arrival of the necessary respondents, but it is not necessary to have law enforcement assets dispatched to every incident because closed circuit television (CCTV) can be used to verify an incident and then dispatch the appropriate resources as needed. For agencies that must respond, motorcycle units can be effective at reaching incidents during these peak hours (6). Response time can also be expedited by accurately locating the incident through the use of investigative technologies such as total stations, satellite photographs, and lasers (21).

One of the components of incident clearance and management that is usually provided by state departments of transportation has been freeway service patrols. These visible patrols typically offer such services as basic motorist assistance, debris removal, vehicle clearance, first aid, basic field repairs, and traffic control assistance. Motorists have responded favorably to service patrols, particularly regarding the timeliness of assistance and the feelings of safety and security derived from assistance from uniformed personnel and the availability of free services (6).

Freeway service patrol vehicles equipped with basic hazardous material (hazmat) response equipment can more effectively identify hazmat incidents. This ability allows service patrol officers to manage minor hazmat spills better and coordinate with other responding agencies such as fire, police, and rescue. Developing standards for fluid and uncommon debris removal might streamline this process further (20).

Because the freeway service patrols usually perform the function of 'first verification', the Georgia Department of Transportation trained a crew of law enforcement and transportation agencies in Atlanta to identify the presence and nature of traffic incidents accurately. This training saved Atlanta highway travelers hundreds of delay hours and damages that might have resulted from environmental spills (6). Research also suggests that providing incentives for hazmat contractors based on timeliness and efficiency of response and cleanup leads to minimized costs while maintaining peak performance (20).

Using common technology (e.g., radio systems, telephone) and terminology facilitates efficient and lucid communications among the different personnel responding from each agency. Formalizing incident command procedures ensures good use of time and resources by removing redundancy and assigning direct responsibility. Conducted regularly, post-incident briefings can evaluate and improve current operating procedures (6). Major incident response teams should be trained to work together in order to accomplish common agency goals using multi agency resources.

2.3 Incident Management Technology

A plethora of technology exists to combat congestion from traffic incidents. Recent advances in technology have improved incident management and clearance (22). Intelligent Transportation Systems (ITS) components including traffic cameras, variable message signs, computer-aided dispatch, automated incident sensors, dynamic lane designation, and automated vehicle locators have revolutionized traffic flow management and have created more efficient incident management programs. Wireless enhanced 911 is a highly recommended technology (20) which provides dispatchers with additional facts such as location of wireless callers (18).

Once an incident occurs, traffic can be re-routed to reduce congestion and delay through the implementation of ramp metering, variable message sign alerts, local arterial signal control, Highway Advisory Radio (HAR) alerts and lane closure systems. Current incident management operations predominately focus on freeways and very few agencies employ arterial signal control for traffic management during incidents, even though it is an effective way to manage traffic in the presence of incidents (6). Route diversion strategies and implementation plans should include coordinated arterial signal control during incidents. Further, collocating traffic management centers with law enforcement dispatch centers is recommended practice (20).

Sharing timely information to motorists is also a vital ITS component aimed at reducing congestion, delay, and even reducing secondary incidents. The primary traveler information devices are variable message signs, highway advisory radio, and lane control signals; however, these devices cannot always provide motorists sufficient information to change travel routes effectively (6). Changeable message signs provide additional incident information to motorists, such as estimated travel times, to improve the value of the information and motorist compliance.

Reviewing current incident clearance methods and technologies leaves several thoughts unaddressed. Although other studies have examined incident detection, verification, response and clearance technologies, each study examined different combinations of technologies, under different traffic conditions, using different analysis methods. Therefore, it is difficult to transfer these results to other states, particularly South Carolina. The application of clearance strategies might benefit from estimates of effectiveness in South Carolina's traffic environment.

3.0 Objectives

Marketing the benefits of incident management to the public and decision makers is an important component in the widespread deployment of accelerated incident clearance strategies. The Transportation Systems Group at Clemson University has conducted research on the benefits and costs of accelerated incident clearance strategies in South Carolina by examining these corridors using traffic simulation and benefit-cost analysis. The research sought to meet the following objectives:

- review state department of transportation survey responses and published literature to identify current state-of-the-practice for accelerated incident clearance;
- identify strategies for incident management to be evaluated in this project;
- estimate the operational impacts of each identified strategy;
- develop benefit-cost estimates for each identified strategy;
- present implementation guidelines, and
- develop a technical report regarding the benefits for the public and state decision makers as revealed through the investigation into the state of the practice in other states and through the primary research work conducted at Clemson for South Carolina sites.

4.0 Methodology

The research team adopted four different tools to attain the research objectives. First, a detailed literature review was conducted to synthesize information on state-of-the-art practices in incident management. Second, a nationwide survey with four different agencies in each state was distributed and results from these agencies were compiled and analyzed. Third, different simulation models were created to identify the impacts of various incident management strategies. Fourth, benefit-cost analysis was conducted to estimate the comparative benefits of

different incident management strategies. Section 2 summarized the literature review and this section presents the methodology adopted in developing, conducting, and analyzing the survey results; the methodology used to develop the simulation and analyze the results; and the methods adopted for the benefit-cost analysis.

4.1 Survey

The research team developed and distributed a web-based and paper survey for incident management agencies across the United States and its associated territories. The survey posed questions to identify the extent of use and usefulness of certain technologies, communication methods, and strategies. To uniquely target state departments of transportation (DOTs), officials involved specifically with intelligent transportation systems (ITS) in each DOT, emergency medical services (EMS), and state highway patrol (SHP), separate surveys were prepared for each of these agencies. While several survey questions were common in all surveys, the unique questions sought to capture the most in-depth view of each agency. The survey aimed to find state of the practice in incident management in the US and use this information to steer the selection of incident management tools and strategies for evaluation in South Carolina. Surveys separately polled state DOTs, ITS divisions, EMS agencies and SHPs, and is available online at www.clemson.edu/transportation.

4.2 Simulation

The research team coordinated with the steering committee to select five study sites throughout the state. All sites were along major freeways in urban areas. Figure 3 shows the locations of all five sites with dark circles.

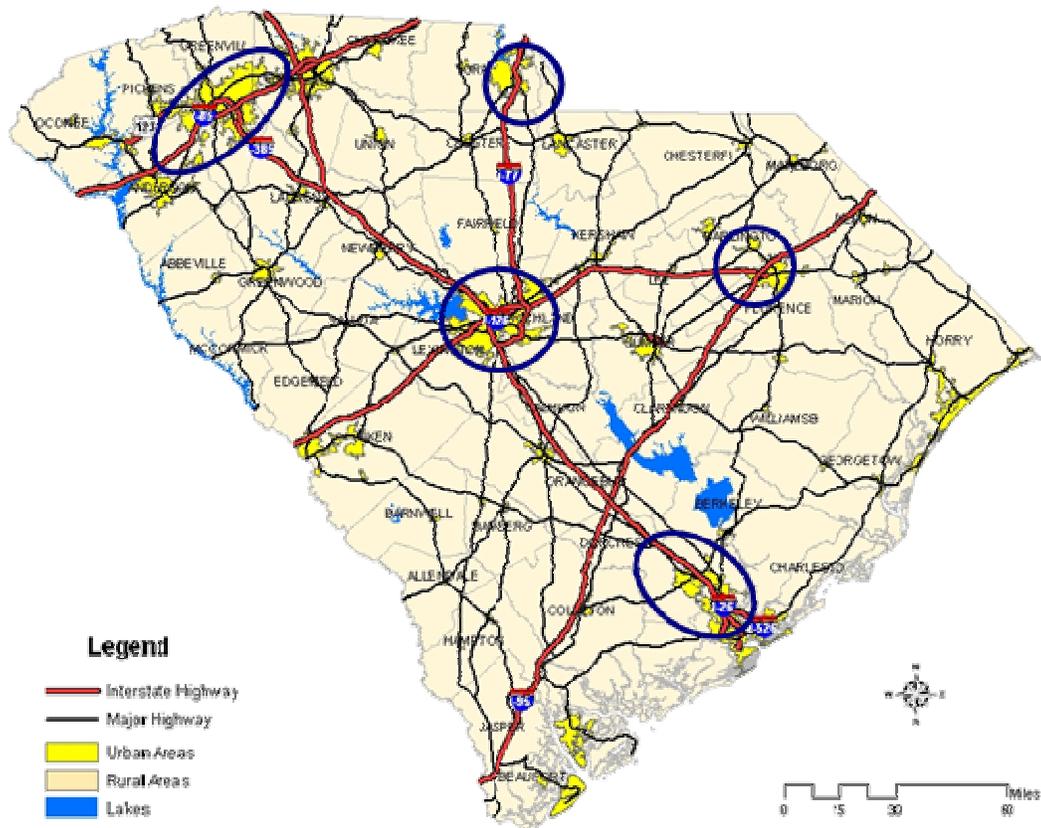


Figure 3: Simulation Study Sites

- Upper left - is located in Greenville County along I-85 and included approximately eleven miles of freeway and eight interchanges
- Top-center - is located in York County along I-77 and included approximately five miles of freeway and three interchanges.
- Center - is located in Richland County site along I-20, just north of the city of Columbia, and included approximately twelve miles of freeway and ten interchanges.
- Upper right - is located in Florence County along I-95 and included approximately seven miles of freeway and three interchanges.
- Lower right - is in Charleston and Berkeley Counties and included approximately eleven miles of freeway and seven interchanges.

Overall, this study included approximately 46 miles of freeway and 31 interchanges. While these sections only represent approximately six percent of the South Carolina's 830 interstate miles, they include a section in almost every major urban area in the state, providing a solid basis for estimating impact of freeway incident management.

4.2.1 Model Building Process

After the research team and the steering committee finalized the study sites, the research team began building traffic simulation models of each site. The microscopic simulation software PARAMICS was chosen for several reasons. PARAMICS's ability to model freeways and traffic incidents accurately is a requirement for this project and its ability to record various MOEs including delay and fuel use for each vehicle individually provided flexibility for detailed data collection if required. PARAMICS also has an extensive Application Programming Interface (API) that allows the simulation of various incident management strategies and unique situations that arise in incident management. The availability of generating a three dimensional animation clip is useful for marketing results towards decision makers and practitioners.

The South Carolina Department of Natural Resources (SCDNR) online database provided Geographical Information Systems (GIS) data of all corridors in South Carolina. From these data, the desired freeway and arterial segments were selected and exported. These segments were saved into a Shape file format, a format commonly used in GIS that ensures proper spatial allocation of the geographic features.

To expedite model building, the research team then used the Shape to PARAMICS (S2P) tool developed by the California Department of Transportation (23). The S2P tool converted the shape file directly into a PARAMICS road network, reading locations and such attributes as numbers of lanes and speed limits of the links. In this manner, all roadway segments were projected to the right length and shape in PARAMICS. Scaled aerial photographs from the SCDNR and other online sources were overlaid in the PARAMICS road network, and aided researchers in modeling the detailed geometric layout of the facilities, particularly at interchange ramps. Planning sheets of the freeway sections at each site, provided by the SCDOT, was used to verify the number of lanes observed on the aerial photos, and provided information about the grades along the freeway. Remaining information, including signage and turn restrictions, was collected during site visits.

Each study site was visited two or more occasions during the model building process. During site visits, researchers observed road characteristics, such as number of lanes, sign posting, and presence of incident detection devices that could not be found from other sources.

Traffic count data was requested from the SCDOT and planning models were requested from planning organizations at each study site in order to accurately reflect the traffic volumes.

The planning models were available in different software formats, mostly (75 percent) in TRANPLAN format and one TransCAD format. Software capability and availability steered the research team to convert all available planning models into TransCAD format.

Since each of the planning models included a much larger region than needed for this study, the models were edited to combine like-zones (zones that would use the same entrance and exit points in the selected freeway network). Where options existed between entrances, such as choosing one interchange when traveling north and another when traveling south, these zones were kept separate and aggregated manually. The end product of this process produced an origin-destination matrix with the same number and location of zones as contained in the simulation model.

PARAMICS required volumes in the form of an origin-destination matrix, which shows how many vehicles travel between each entrance and exit to the road network. This allows familiar drivers to choose alternate routes if congestion causes unwanted delay. Microsoft Excel was used to ensure that volume constraints were met. In some cases, volume data between different sources conflicted, mostly due to varying collection years. In these cases, volumes collected during site visits were considered the most reliable, followed by the most recent DOT volume count and lastly, planning model volume estimations.

Since some matrices contained over 800 cells and more than 100 constraints, a program was developed using the software Matlab to expedite the timely development of origin-destination volumes. The Matlab program satisfied all collected volumes within five percent, ensuring each link had the appropriate volume on it. While Microsoft Excel was used to verify that the origin-destination matrix from Matlab satisfied the volume constraints and fine-tune the demands where necessary, the program developed in Matlab provided an invaluable time-saving tool during the development of the origin-destination matrices.

Other aspects of the traffic simulations models included traffic signals, speed limits, driver behavior, and truck percentages. Traffic signal timing and phasing information was provided by the SCDOT, local jurisdictions, or was collected during site visits. Information about speed limits and truck percentages were obtained during site visits. The driver behaviors were adjusted to match observed travel times. Additionally, queue lengths were also collected during site visits. Characteristics of each study site are shown in Table 2.

Table 2: Study Site Characteristics

Sites by County	Freeway Miles	Interchanges	Origins and Destinations
Greenville	11	8	25
Charleston	11	7	19
Richland	12	10	29
Florence	7	3	13
York	5	3	11

4.2.2 Simulating Traffic Incident Scenarios

Incident scenarios were simulated in PARAMICS. Crash history of each study site was examined for the year 2002 through 2004 to determine high incident locations. In the larger sites (Greenville, Charleston, and Richland) incidents were simulated at the two locations with the highest number of crashes. In the smaller sites (Florence and York) incidents were simulated at

the locations where the highest number of crashes occurred in 2004. Table 3 displays the number and location of crashes that determined the selection of site for simulating crashes. Through literature review, survey responses and coordination with the steering committee, a number of incident management tools and strategies were selected for evaluation. Table 4 shows these selected tools and strategies, and their mapping to various incident management functions. The mappings shown in Table 4 were determined for their anticipated impacts to the mapped incident management functions. See Appendix A for details on networks that were modeled and simulation outputs related to these strategies.

Table 3: 2002-2004 Crash History of Study Sites

Site by County	Total Crashes Analyzed	Most Crashes		Second-to-most Crashes	
		Location	Number	Location	Number
Greenville	1367	Laurens Rd	189	I-385	148
Charleston	1140	Ashley Phosphate Rd	403	Aviation Ave	246
Richland	1367	Monticello Rd	278	Broad River Rd	238
Florence	427	US-52	137	N/A	N/A
York	181	SC-98	86	N/A	N/A

Table 4: Incident Clearance Strategies

Strategy or Tool	Detection	Verification	Response	Clearance	Traffic Management
Traffic Sensors	X				
Traffic Cameras	X	X			
Freeway Service Patrols	X	X	X	X	
Steer-it Clear-it Law				X	
Route Diversion					X
Multiple Strategy	X	X	X	X	

Figure 4 shows the process of simulating traffic and incidents, and the interaction with the various program modules developed to create the incident clearance scenarios. The framework developed for this research was comprised of four components: traffic simulation, incident generation, emissions and fuel consumption estimation, and incident clearance scenario. The traffic simulation model was developed in PARAMICS Modeler, and the other components connect to traffic simulation through the interface provided by PARAMICS Programmer. Upon incorporating the functionality and information of each module, the characteristics of each incident scenario was modeled in the traffic simulation software. The impact generation module utilized emission information from the software MOBILE6 to calculate the rates for different

vehicle types. The types of emissions evaluated will be discussed in more detail in section 4.3 of this report.

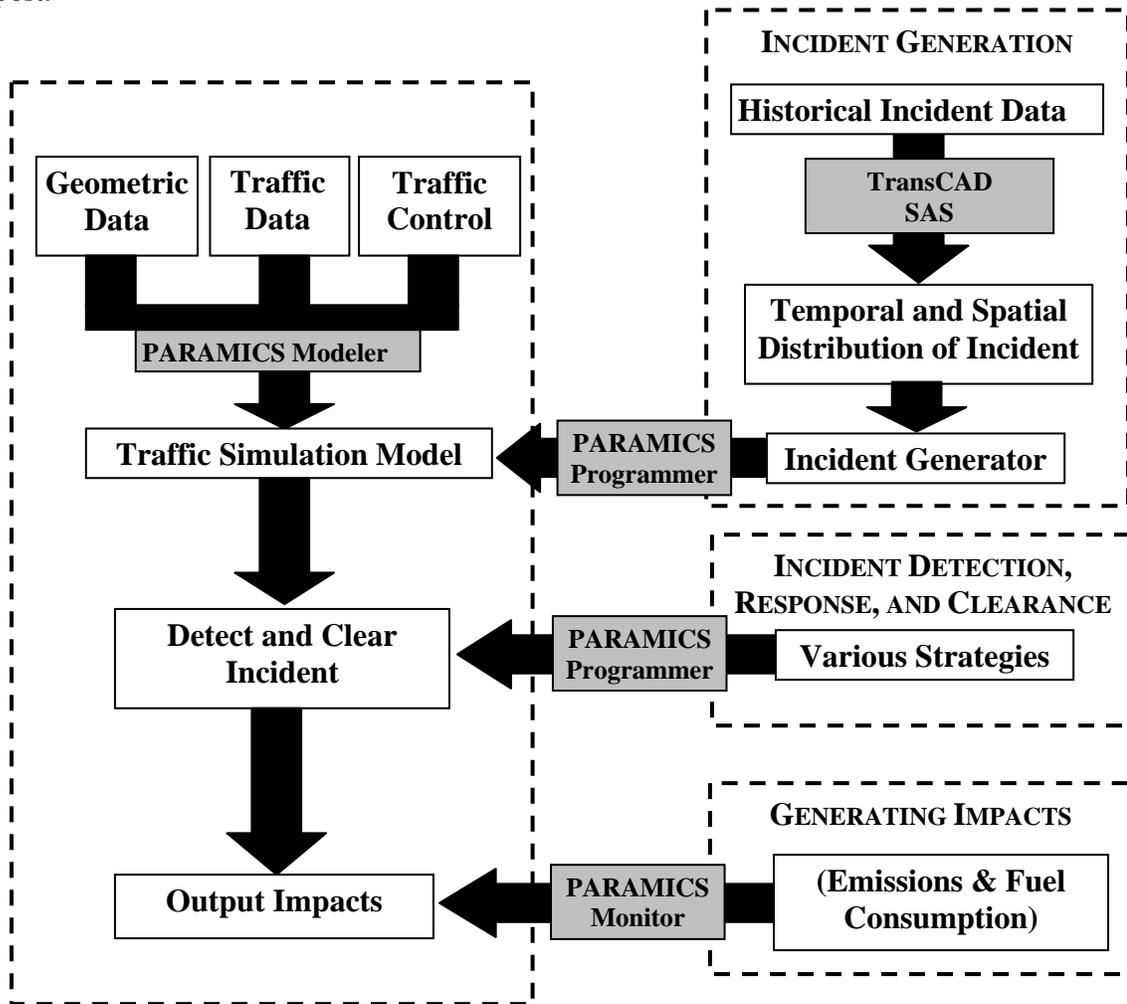


Figure 4: Procedure of simulating traffic incidents

4.2.2.1 Simulating the Impacts of Detecting Incidents with Traffic Sensors

An algorithm was developed to generate incidents in the selected sites (see Figure 5, which shows the process for simulating traffic sensor incident detection using PARAMICS). The algorithm interfaced with the PARAMICS API. To simulate a realistic spatial variation of incidents, each incident scene allowed the incident location to vary approximately one quarter of a mile within the high crash interchange.

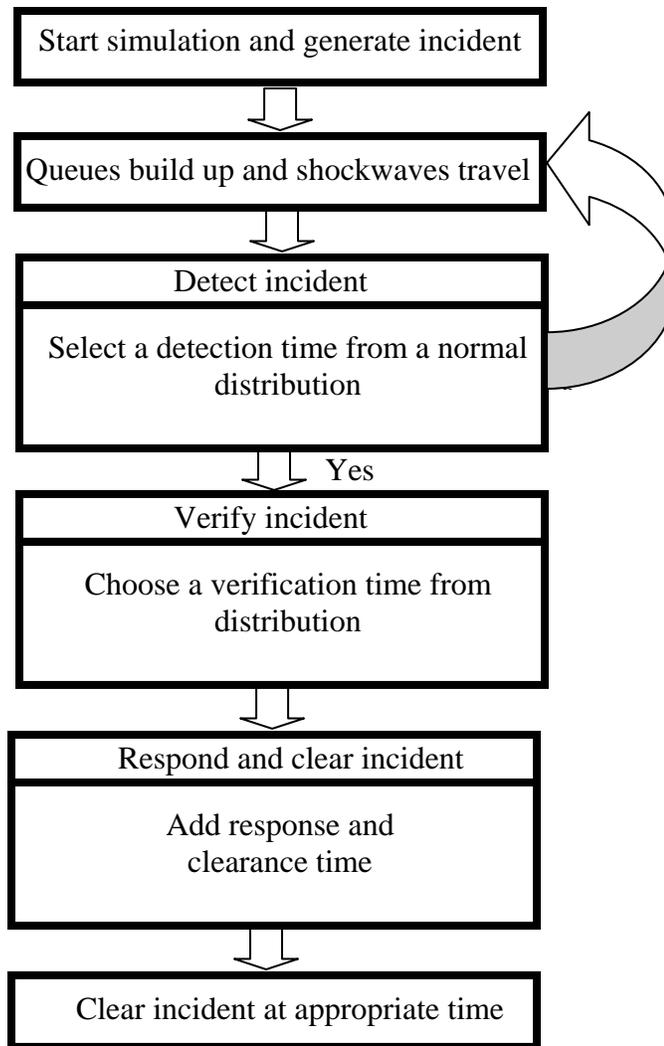


Figure 5: Simulation Process for Incident Detection with Traffic Sensors

The algorithm determined the clearance time by first choosing a detection time. Based on the information from the Columbia Traffic Management Center, detection times ranged from one to five minutes, algorithm chose a detection time from a normal distribution with a mean of three minutes and a standard deviation of one minute. Next, the algorithm chose a verification time assuming traffic cameras were used. Based on the information from the Greenville Traffic Management Center, verification times ranged from thirty to ninety seconds. The algorithm chose a time from a normal distribution with a mean of one minute and a standard deviation of fifteen seconds. An incident arrival time of 9 to 10 minutes, which is the time between notification of incident to the response units and their arrival at the incident scene, was used based on (15).

The research team only modeled incidents blocking two and three lanes for detection by traffic sensors. Incident clearance times were determined from the ranges shown in Table 5. These values were added to the incident detection, verification, and response times to determine the total time required in clearing the incident.

Table 5: Incident Clearance Time by Severity

	Minor	Moderate	Major
Blocks 1 Lane	8-15 minutes	-	-
Blocks 2 Lanes	-	30-50 minutes	-
Blocks 3 Lanes	-	-	120-150 minutes

The simulated incident detection with traffic sensors and verification with traffic cameras were compared to base scenarios that represented no such use of technologies. The research team used a combined detection and verification time of 20 minutes (24, 25, 26, 27) to represent the base scenario.

4.2.2.2 Simulating the Impacts of Detecting Incidents Using Traffic Cameras

For incidents detected by traffic cameras, another API was built following a similar process as incident detection with traffic sensors, as shown in Figure 6. The traffic camera detection times were selected from a normal distribution with a mean detection time of 3 minutes and a standard deviation of 1 minute. The 95 percent confidence interval of this distribution agrees with the observed 1-5 minutes detection time range suggested by the experts in Columbia Traffic Management Center. The verification time was selected from a normal distribution as presented in section 4.2.2.1 Simulating the Impacts of Detecting Incidents with Traffic Sensors. Arrival time of the first responder at the incident scene was used as 9 to 10 minutes (15) and the incident clearance times were determined from Table 5.

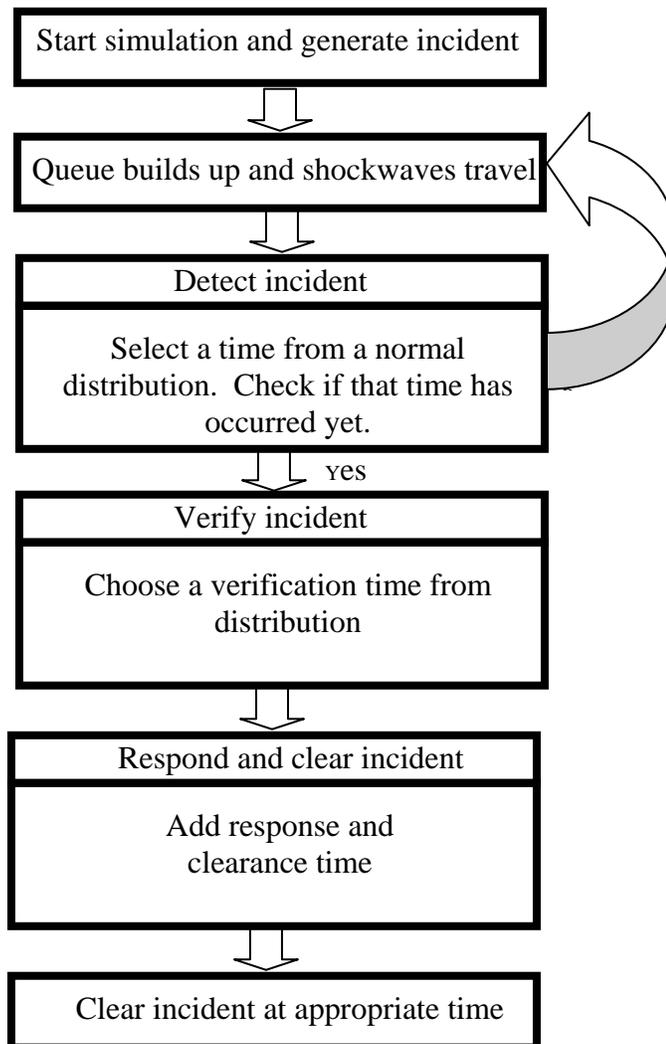


Figure 6: Simulation Process for Incident Detection and Verification with Traffic Camera

4.2.2.3 Simulating the Impacts of Freeway Service Patrols

The traffic simulator released freeway service patrols into the network as predetermined route vehicles that follow the main freeway links. Figure 7 shows the simulation process adopted in this study for freeway service patrols. The freeway service patrols turned around when they reached the end of the network. A random time variance ranging from one to three minutes was added to each freeway service patrol vehicle when it turned around to account for randomness in the traffic conditions and traffic control devices at the interchanges.

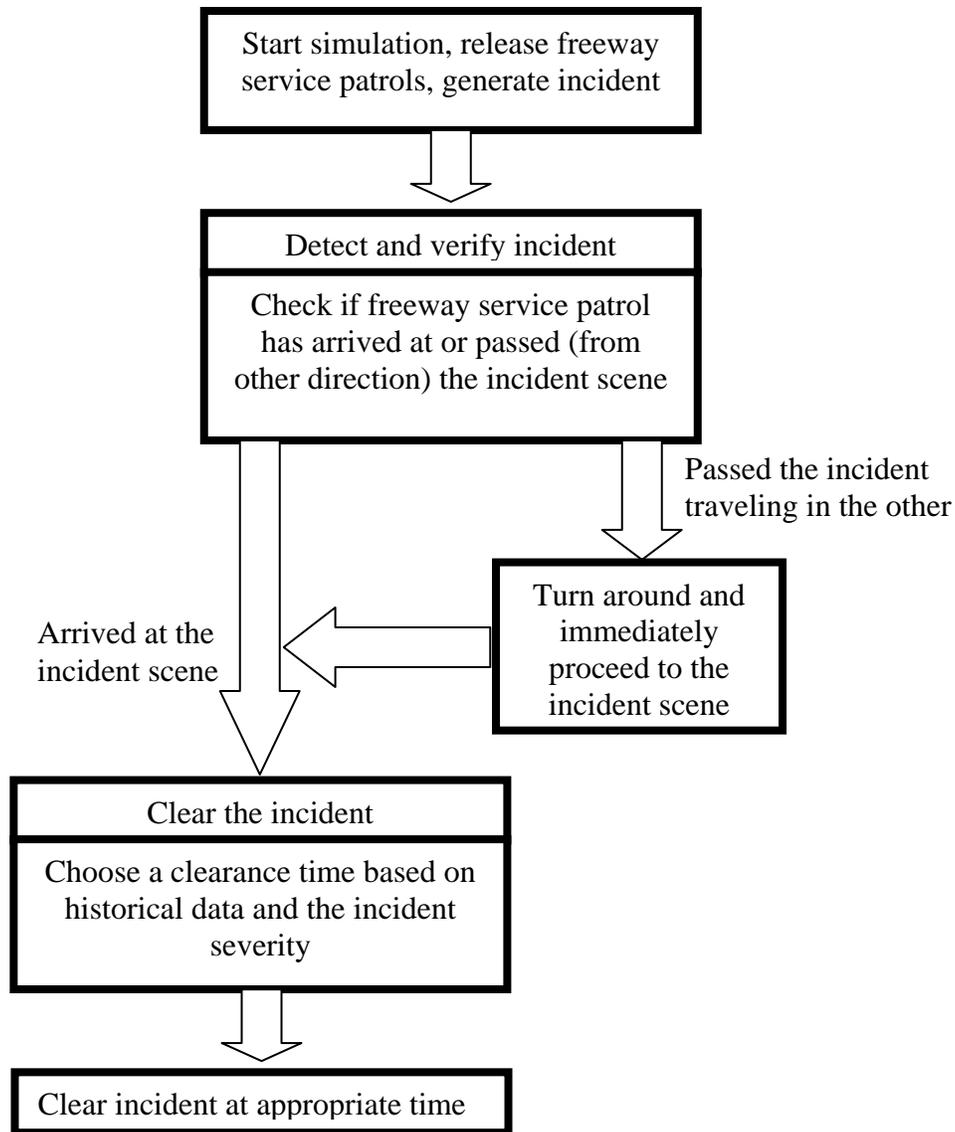


Figure 7: Simulation Process for Freeway Service Patrols

The arrival time of the first freeway service patrol at the incident site depended on the random location of the freeway service patrol vehicle at the time of the incident, the random location of the incident, and the traffic conditions. While the freeway service patrol headway and incident severity was controlled, the randomness of the other factors, such as location of incidents, and assignment of each freeway service patrol (in terms of time of entering the network) were randomly generated. The research team first evaluated the effectiveness of the existing program by simulating the appropriate headways in each network and then evaluated shortened headways to determine if increasing the frequency of these vehicles beyond current conditions, would still provide benefits to travelers.

To compare these results against a situation without freeway service patrols, the researchers relied on the same methods as described in Section 4.2.2.1 to simulate a scenario without freeway service patrols or other incident management infrastructure. The base scenario was simulated when incidents were detected and verified in 20 minutes, a responder arrived on the incident scene after an additional 9 to 10 minutes, and clearance required a time in the ranges displayed in Table 5.

When freeway service patrols encountered dense congestion, they used freeway shoulders or emergency lanes, but at a reduced speed. A research team member working at the South Carolina Highway Patrol suggested that incident respondents would travel at approximately 35 miles per hour along shoulders or emergency lanes.

The arrival time of the first freeway service patrol at the incident site depended on the random location of the freeway service patrol vehicle, the random location of the incident, and the traffic conditions. While the freeway service patrol headway and incident severity was controlled, the randomness of the other factors, such as location of incidents, and assignment of each freeway service patrol (in terms of location in the network) were randomly generated. The research team first evaluated the effectiveness of the existing freeway service patrol program in South Carolina by simulating the existing headways, or time between consecutive service vehicles. The research team then evaluated shortened headways to determine if increasing the frequency of these vehicles beyond current conditions, would still provide benefits to travelers. The existing and reduced headway evaluated in this study are shown in Table 6.

Table 6: Freeway Service Patrol Headways Evaluated

Sites by County	Current Freeway Service Patrol Headways (minutes)	Reduced Headways Simulated (minutes)
Greenville	30	10
Charleston	45	15
Richland	60	15
Florence	30	10
York	15	5

While comparing these results against a situation without freeway service patrols, researchers relied on the same methods as used to evaluate incident detection using traffic sensors. Without freeway service patrols or other incident management infrastructure, the incident was detected and verified in 20 minutes, a responder arrived on the incident scene after an additional 9 to 10 minutes, and the incident was cleared depending on severity.

4.2.2.4 Simulating the Impacts of Multiple Strategy Incident Management

Since several incident management strategies are commonly used at once instead of in isolation, this research also evaluated the impact of a comprehensive incident management program including traffic sensors, traffic cameras, freeway service patrols, and incident reporting hotlines such as 911 and *HP. The freeway service patrols were notified as soon as incidents were detected and they immediately proceeded to the incident scene, turning around if necessary. Because incident clearance did not begin until the first freeway service patrol unit arrived, the headway of these response units played a large role in the incident duration.

Each technology in this scenario operated in the same manner as previously discussed, using the same time distributions and response unit behavior. The 911 and *HP detection time used a normal distribution with an average incident detection time of 2.1 minutes based on call center data for urban areas (28), and an assumed standard deviation of one minute. The interaction of the detection, verification, and response tools is displayed in Figure 8.

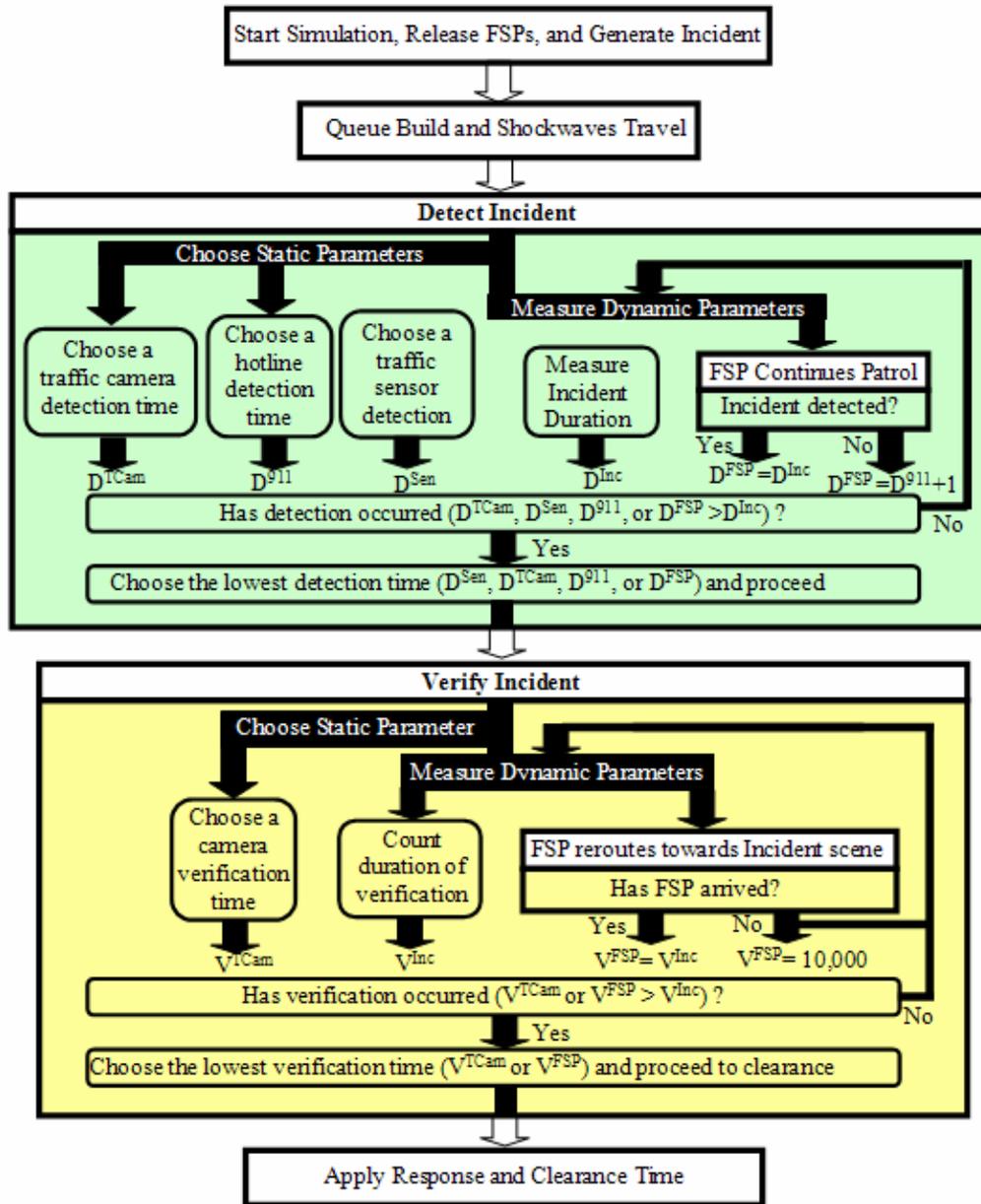


Figure 8: Process for Comprehensive ITS System Incident Management

4.2.2.5 Simulating the Impacts of Steer-it/Clear-it Legislation

From literature, the research team determined that the “Steer it, clear it law” would most likely only impact minor incidents in which drivers were able to clear their own vehicles without tow assistance (20). Since service patrols and police arrive in approximately 9.5 minutes, incidents that reflect after-law situations assign the incident duration using a normal distribution with a 95 percent confidence interval between 2 and 10.5 minutes. The normal distribution used a mean of 6 minutes and a standard deviation of just over two minutes.

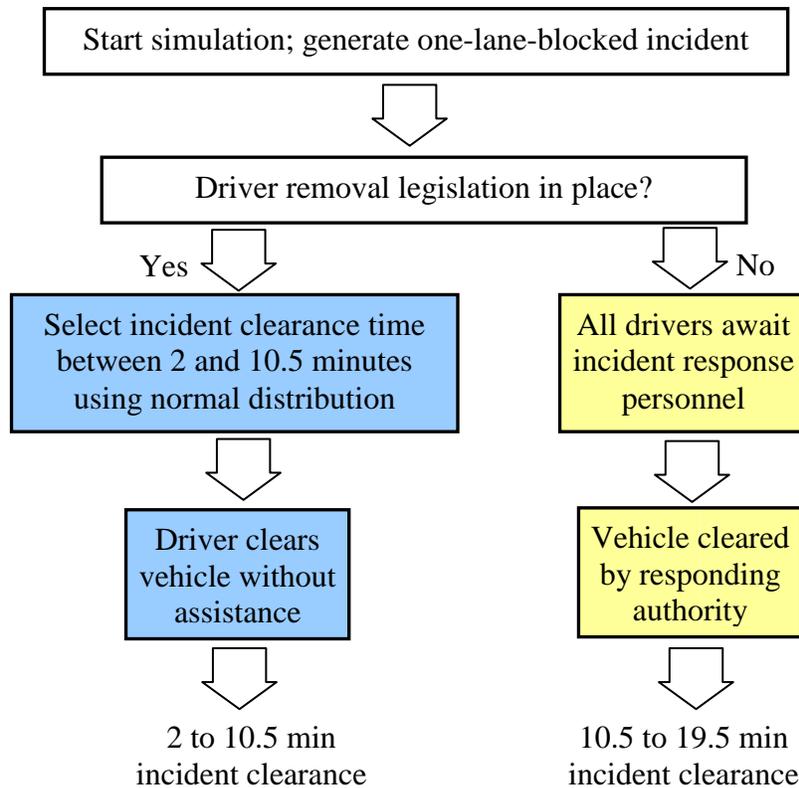


Figure 9: Procedure for Steer-it Clear-it Simulation

To compare these delay impacts to similar crashes, the researchers examined the average clearance time of minor incidents (one lane, property damage only) in South Carolina based on data from the Greenville TMC. Based on this data, and the average police and service patrol arrival rate mentioned above, the incident duration was derived by selecting the incident duration from a normal distribution with a 95 percent confidence interval between 10.5 and 19.5 minutes.

4.2.2.6 Simulating the Impact of Route Diversion

Incident management authorities in South Carolina only consider route diversion for the most severe and long lasting incidents, and since longer incidents cause longer queues, the research team chose two larger simulation networks in Charleston and Greenville to simulate route diversion. Both of these networks could evaluate the impact of a 3-hour 3-lane incident without spilling queues out of the network. If queues spilled out of the network, the delay of those vehicles would not be recorded.

Researchers chose to simulate a route diversion at I-385, the second most frequent crash location in the Greenville site, because its location provided more room for queues to build than at Laurens Road, the location has most frequent crash. Figure 10 shows the multiple locations of the simulated crashes along the primary route with solid squared blocks and the location of the diversion route marked with text and white dots along the route.

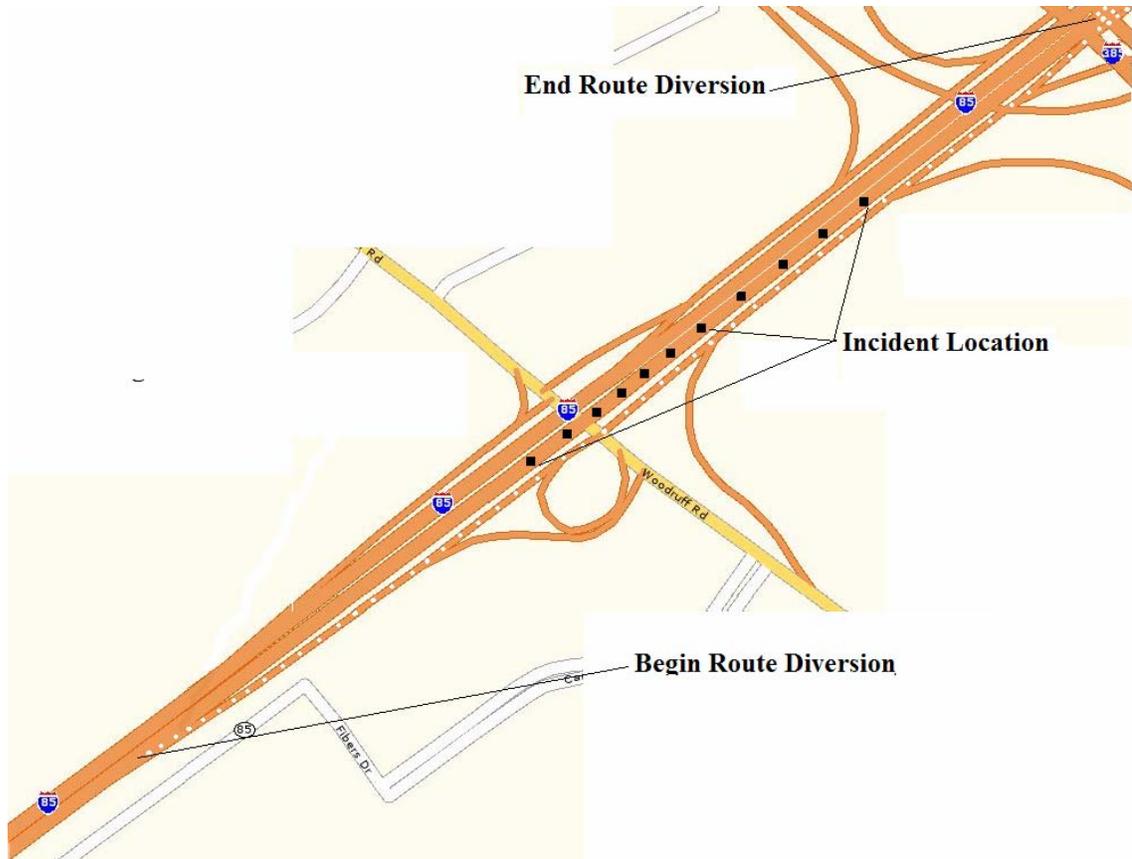


Figure 10: Greenville Route Diversion

Researchers chose to simulate a route diversion along I-26 in Charleston at the interchange with Ashley Phosphate Rd, which has the most crashes in the network. The South Carolina SHP helped researchers identify the most feasible alternate route, the number of officers, barriers, vehicles, and amount of time required to implement a route diversion at that interchange. Figure 11 shows the route diversion for Charleston with squares representing multiple incident locations along the primary route, and dots along the diversion route.



Figure 11: Charleston Route Diversion

To isolate the impacts route diversion, researchers used 20 minutes as the incident detection and verification time, as used in the base scenario. As recommended by the South Carolina State Highway Patrol, a route diversion operation began 15 minutes after the incident was detected and verified, allowing time for officers and incident managers to activate VMS notifying traffic to slow down, erect barricades, and deploy officers at key locations, such as at traffic signals.

4.3 Benefit-Cost Analysis Methodology

The simulation runs provided four categories of results including vehicle-miles traveled (VMTs), vehicle-hours traveled (VHTs), fuel consumption, and emissions. Herein, the research teams used VMTs as the weighting factors to calculate the average benefits for the five study sites with respect to traffic volumes. Along with value of vehicle delay, cost of fuel and emissions, the difference in VHTs, fuel consumption and emissions between with and without incident management strategies were directly used to determine the monetary savings per incident for different strategy at each site. The costs of incident management tools were also divided into four categories including service and maintenance, communication, infrastructure, and personnel. While the costs of incident management tools were easily converted to yearly amounts, benefits were with respect to the incident scenario and incident histories in South

Carolina were examined to convert the findings into annual benefits, as shown in Figure 12, where benefit to cost ratio equals to annual benefits / annual cost.

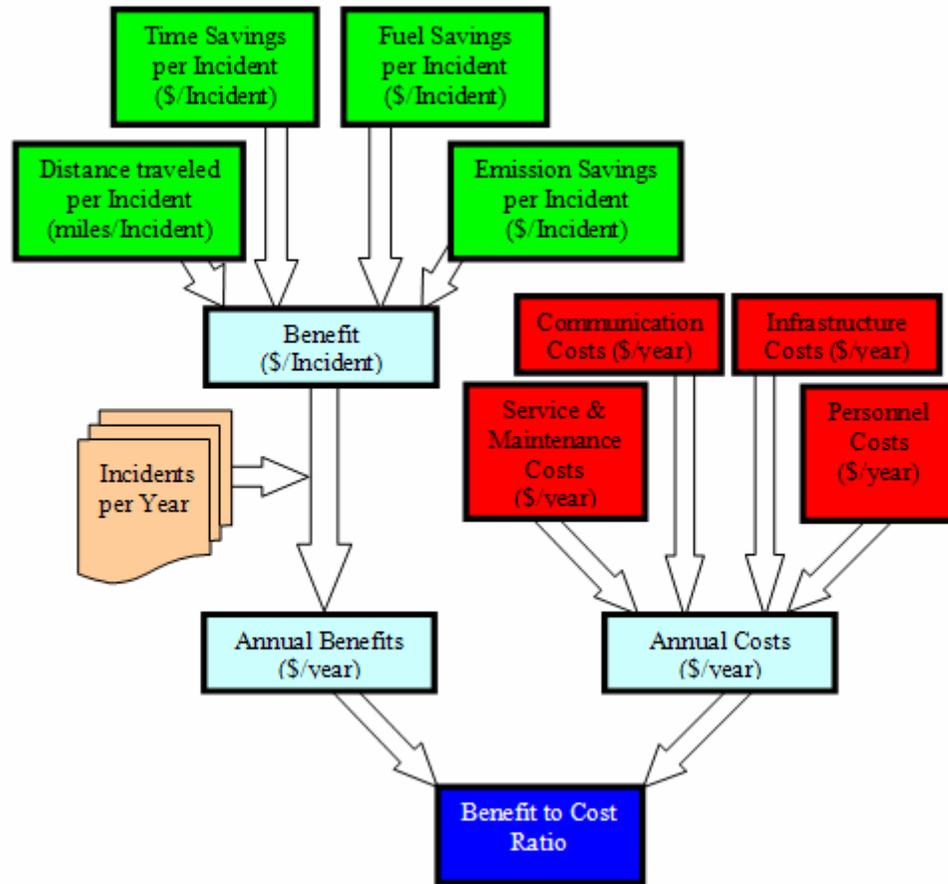


Figure 12: Benefit-Cost Procedure

Benefits were calculated using one or more of these outputs, depending on the applicable measure of effectiveness, as seen in Table 7. Vehicle miles traveled was shown in Figure 12 but not Table 7 because it was used to properly weight the impacts between simulation networks with significantly different traffic volumes. For instance, the emission savings rate from a site with a heavy traffic volume will have a greater impact than an emission savings rate from a site with light volumes.

Table 7: Measures of Effectiveness

Category	MOE	Simulation Output Required
Delay	Car	VHT
	Truck	VHT
Energy Consumption	Change in fuel use (gallons)	Fuel Consumption
Air Pollution	CO	CO
	NOX	NOX
	HC	HC
	PM	PM
	VOC	VOC

The benefits of the various incident management strategies were calculated based on VHTs, fuel consumption, and emission outputs. The difference between an incident and its corresponding do nothing scenario were considered the benefit. The difference in VHT was considered incident induced delay and was further split between heavy vehicles and passenger vehicles based on observed proportion of heavy vehicles. This split was necessary because delay is calculated differently for heavy vehicles than for passenger cars.

Referencing the ITS Deployment Analysis System (IDAS) database, costs for expected hourly delays were found to be \$9.63 for passenger vehicles and \$16.96 for heavy vehicles (in 1995 dollars). After applying a 3% inflation rate, the resulting values of time were \$13.33 and \$23.48, respectively (in 2006 dollars). The research team created an average weighted value of time based on the proportion of light vehicles and heavy vehicles. Since the proportion of heavy vehicles varied between sites, a different value was used for each site. Figure 13 shows the process used to determine the monetary benefit of reducing delay through incident management in South Carolina.

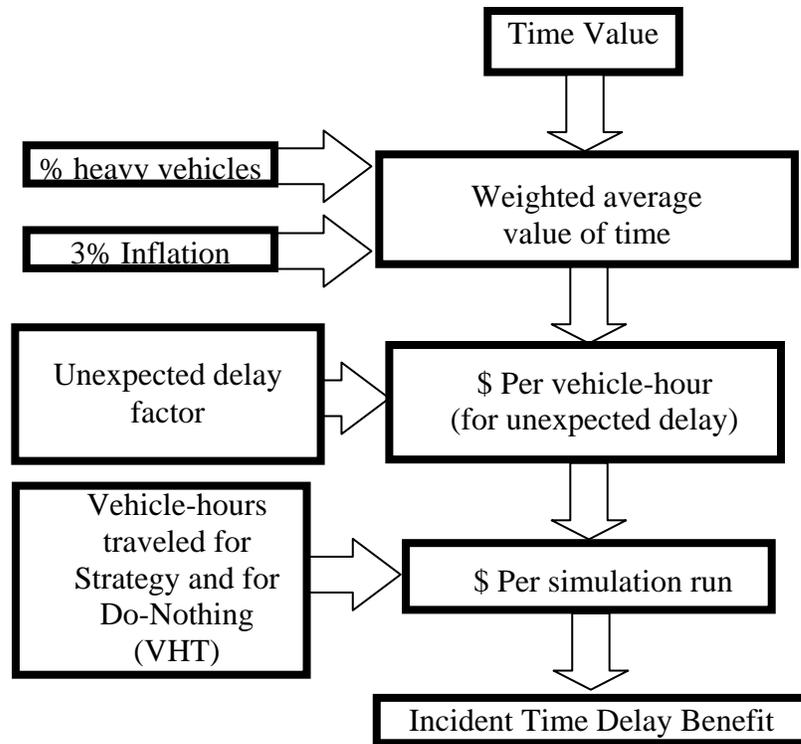


Figure 13: Delay Benefits

The research team relied on Mobile6, software developed for the US Environmental Protection Agency, to find emission rates for the simulations. The part of PARAMICS that models the emissions is named Monitor and requires that all emissions and fuel consumption be expressed in a rate of either grams per seconds per vehicle or milligrams per second per vehicle. Different rates are provided for different speeds for each vehicle type. The research team used three vehicle types, light duty gasoline vehicles, heavy duty gasoline vehicles, and heavy duty diesel vehicles.

Table 8: Vehicle Weight and Classifications for Emission and Fuel Calculation

Emission Type	Weight (1,000 lbs)	Mobile6 Vehicle Type	PARAMICS Vehicle Type
LDDV	<10	1-6	1-9, 16, 17
HDGV	10-14	7	11, 12, 15
	14-16	8	11, 12, 15
	16-19.5	9	11, 12, 15
	19.5-26	10	11, 12, 15
HDDV	10-14	17	13, 14
	14-16	18	13, 14
	16-19.5	19	13, 14
	19.5-26	20	13, 14
	26-33	21	13, 14
	33-60	22	13, 14
	>60	23	13, 14

Using the categories displayed in Table 8, Mobile6 was used to estimate the average emission rate of each of the three categories (light duty gas vehicle (LDGV), heavy duty gas vehicle (HDGV), and heavy duty diesel vehicle (HDDV)) for speeds ranging from 2.5mph (the lower limit of Mobile6, assumed idle speed) to 65mph (the upper limit of Mobile6, assumed as free flow speed). For values lower and higher, PARAMICS Monitor would use the closest value (i.e. at 0 mph, PARAMICS would use the emissions value for 2.5mph). PARAMICS Monitor interpolated emission values for vehicles in between the speed / emission rate values given. An average vehicle age of 9 years old was used for all categories (29). Overall, emission rates were determined for five types of pollutants as shown in Table 7, for seventeen different types of vehicles (Table 8), and at 8 different speeds from 2.5mph through 65mph.

The consumption rates for fuel were calculated from various other sources (29-32). More detailed research has been conducted on the fuel consumption rate of light vehicles than that of heavy vehicles and the research team found well established consumption rates for different light vehicle speeds. Using fuel consumption rates for each vehicle weight range and the number of vehicles in each weight range registered in South Carolina (33), weighted average fuel consumption for the two heavy duty vehicle types was determined. The weighed average fuel consumption rates were converted to a rate of gallons per second at each speed (5 mph increment) for input into PARAMICS. This unit was chosen because PARAMICS Monitor required rates per second and costs for fuel were in gallons.

The special case for fuel consumption was idling. Several sources were referenced to identify the fuel consumption rates for LDGV (30), HDGV (30), and HDDV (31). Fuel consumption rates were calculated at 14 different speeds for three different types of vehicles simulated in the models (LDGV, HDGV, & HDDV).

After determining the total emissions and fuel consumption in a particular run, these values were converted into dollar values using IDAS documentation for national average emissions costs (32) and average fuel costs for South Carolina (33). Adding the monetary benefits due to savings on delay, emissions and fuel consumption yielded the total annual benefits of particular incident management strategy in 2006 dollar.

Since each incident management strategy used different types and values of personnel, equipment, and time, the costs were unique to each. The formula to calculate the cost of various incident management strategies is as follows:

$$\text{Annual cost} = \sum_{i=1}^p \left(C_i \frac{d(1+d)^{n_i}}{(1+d)^{n_i} - 1} + O_i \right)$$

Where C_i is the capitalized cost of tool i ; O_i is the annual operational cost; d is the discount rate; n_i is the life years of tool i ; 1,2, ..., p represent different tools.

Analyzing the costs of the steer-it clear-it law, researchers found the cost of posting signs and advertising the new law. We assumed one sign was posted one each side of the interstate every five miles. Costs of freeway service patrols were estimated on number of freeway service patrol units and applying that to the exiting and proposed operating hours. These costs were specific to South Carolina since freeway service patrols currently operate in all five study networks.

Determining the costs of traffic sensors and camera systems was notably more complicated. Although these systems were already in place, capital (infrastructure) costs as well as operating costs were considered, including annual maintenance, repair, communication costs, and personnel wages. Because these systems and personnel often provide benefits other than incident management, such as security monitoring, their costs are shared by other services as well.

Route diversions were only applied in the most severe traffic incidents due to their costs to local agencies. Impact analysis of route diversion included costs of police units, VMS and HAR use, and communication and infrastructure costs.

Similarly, the cost of 911 systems was assumed shared among other non-freeway incident services. Costs for traffic incident management were calculated based on the assumption that the 911 call center would require one additional operator to handle traffic-related calls.

All of these costs and benefits were converted into annual monetary figures. If the benefits were per incident, then the frequency of that type of incident at each site determined the annual benefit. If costs were per hour, or patrol unit, then the hourly operations per year, per unit, determined the annual costs.

Researchers examined methods to evaluate the impacts of reducing secondary incidents, particularly in 34 and 35. Two major factors prevented this research from evaluating the benefits of reducing secondary incidents. Both of the studies regarding secondary crash probability were based on data in another state and it is difficult to justify its applicability to South Carolina. A lack of data regarding the rates of secondary crashes in South Carolina further prevented a sound approach to predicting a reduction in secondary crashes from accelerated incident clearance.

Since the number of incidents varies each year, the researchers conducted a sensitivity analysis. Historical incident data showed that 85 percent of all incidents blocked one lane, 13 percent blocked two lanes, and only 2 percent blocked three lanes. For the sensitivity analysis, researchers examined the impact of reducing the percentage of one-lane incidents to 80 percent and increasing to 90 percent. Similarly, for two-lane incidents, researchers examined the impact of varying the distribution of crashes from 10 to 15 percent. The percentage of three-lane incidents was varied from one percent to five percent. These percentages as shown in Table 9 produced a range of benefits that more realistically portrays the random nature of incidents. Since the historical rate of incidents cleared in less than 10 minutes included 53 percent of all crashes, researchers varied the crashes between 40 and 60 percent of all crashes occurring at each site for the “Steer-it Clear-it” strategy.

Table 9: Crash Severity Distribution

	Average	Sensitivity	
		High	Low
1 Lane Blocked	85%	90%	80%
2 Lanes Blocked	13%	15%	10%
3 Lanes Blocked	2%	5%	1%

5.0 Results

The following section presents the findings from this study.

5.1 Survey

The research team developed and distributed a web-based and paper survey for incident management agencies across the United States and its associated territories. The survey posed questions to identify the extent of use and usefulness of certain technologies, communication methods, and strategies. Survey questions uniquely targeted state departments of transportation (DOTs), officials involved specifically with intelligent transportation systems (ITS) in each DOT, emergency medical services (EMS), and state highway patrol (SHP), in an attempt to capture the most in-depth view of the state of the practice in incident management. The survey was completed in December 2005 with 57 agencies responding. State highway patrols had a much better response rate than the other agencies poled. The research team received responses from at least one agency stakeholder department in each of 36 states. Figure 14 shows the responding states. There was a low response rate from states in the central south of the country. The fierce hurricane season of fall 2005, particularly Hurricane Katrina, might have caused the low response rate in these states. Survey respondents provided valuable insight to the state of incident management practice. In this section the findings are presented by topic to provide an industry wide perspective of current practice.

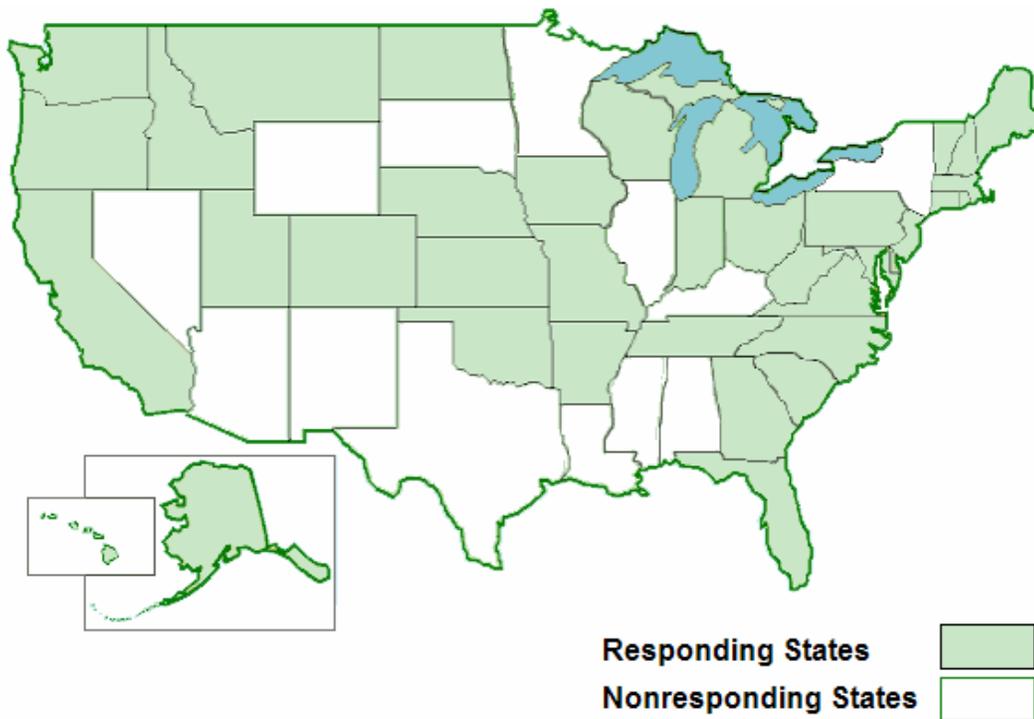


Figure 14: Responding States

5.1.1 Definitions of an Incident

As previously mentioned, there are many definitions of a traffic incident. One fairly comprehensive definition states that an incident “refers to any event that degrades safety and slows traffic, including disabled vehicles, crashes, maintenance activities, adverse weather conditions, special events, and debris on the roadway” (9). To assess definitions in practice, the survey asked all agencies to define a traffic incident. The Departments of Transportation (DOTs), Intelligent Transportation Systems (ITS) offices, and State Highway Patrol (SHP) respondents would agree that an incident disrupts the normal flow of traffic. The SHP and Emergency Medical Services (EMS) would agree that an incident is anything that requires police response. Combining the most frequently used phrases from all respondents, a new definition is presented:

A traffic incident is any non-recurring event, natural or man-made, that disrupts the normal flow of traffic and requires police response.

Some less common responses in incident definitions included “threatening safety” (according to DOTs and EMS), “increased travel time” (according to DOTs), and phrases that included a duration for incident classification, such as “greater than 30 minutes” (from an ITS department).

5.1.2. Incident Prevalence by Type

To form a complete picture of incident management, it is important to understand the types of incidents agencies have frequently responded. Responding DOTs identified the most prevalent incident types as multi-vehicle crashes, single vehicle crashes, and abandoned/disabled vehicles, respectively. Interestingly, respondents from the ITS field had a slightly

different perspective. Respondents in the ITS field rated single vehicle crashes the most prevalent incident type followed by weather-related debris on the roadway. Multi-vehicle crashes and abandoned/ disabled vehicles were not rated by any ITS respondents. Responding state highway patrols indicated a combination of the above agencies' responses by rating single vehicle crashes, multiple-vehicle crashes, and disabled/ abandoned vehicles as the most prevalent incidents in their jurisdictions. These results hint to differing definitions of incidents among agencies.

Secondary incidents were similarly variable across agencies. Survey analysis identified collisions as the most common secondary incidents for DOTs. Responding SHP agencies rated collisions as a much more prevalent secondary incident than disabled vehicles. Disabled vehicles and collisions were rated similarly by responding ITS agencies. Although difference exist in which incident type was the most prevalent, the analysis clearly identified the top candidates.

5.1.3. Agencies Included in Successful Programs

To identify the current multi-agency practice of incident management, DOTs were asked which other agencies participated in incident management in their states and were asked to rate their incident management programs in comprehensiveness and effectiveness. Only 30 percent of state DOT respondents rated their incident management and clearance programs as both comprehensive and effective (Figure 15). Of the agencies that rated their incident management program as both comprehensive and effective, half included only DOT and SHP in their incident clearance teams and one third included private companies also. Two thirds of the better rated agencies rated their programs equally comprehensive and effective. Several agencies rated themselves as somewhat effective in both comprehensiveness and effectiveness. All of these agencies include DOT and SHP in their incident clearance patrol. One third of these respondents included DOT, SHP, EMS, and private companies.

The DOT respondents who rated themselves as somewhat effective or worse in both comprehensiveness and effectiveness of their incident clearance programs included more agencies than the above. This response suggests that responsibilities need to be clearly defined in incident management programs that include multiple agencies. Poorly rated agencies were the only ones to include local law enforcement in the incident clearance programs. It is unclear if local law enforcement agencies were included due to rural land form, or if rural land form was a cause of the poor ratings. In either case, *the survey findings point to simplicity and direct assignment of responsibility as a means to achieve a more effective and comprehensive incident clearance program.* The agencies rated as somewhat effective or worse in both comprehensiveness and effectiveness support this finding by rating their programs slightly more comprehensive than effective. Direct assignment of responsibility among a small group of agencies appears to improve comprehensiveness better than including more agencies with specific expertise.

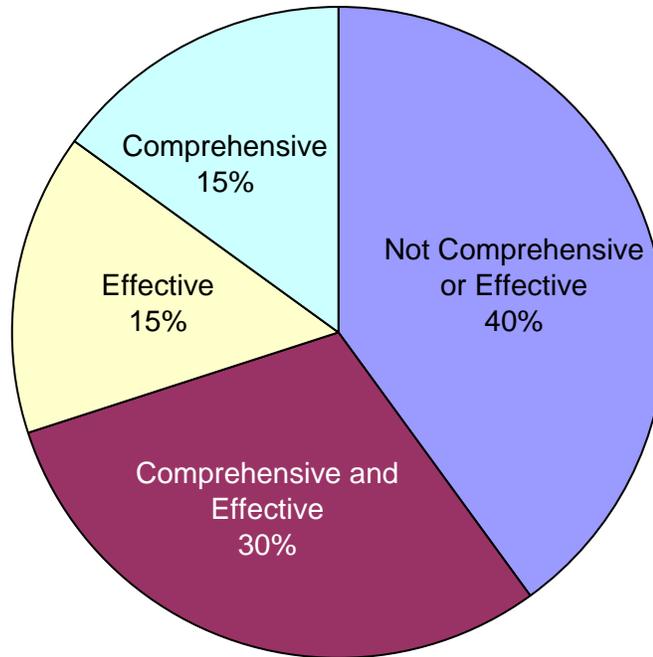


Figure 15: Comprehensiveness and Effectiveness of Incident Management Programs

5.1.4. Equipment and Technologies for Incident Management

Possessing the right tools for the job can improve performance in almost any situation. Well-informed incident management agencies can use funds more effectively by purchasing effective technologies and equipment. ITS agencies responding to the survey relied on five main devices. The devices include variable message signs, automated incident sensors, highway advisory radios, traffic cameras, and traffic management centers. All responding agencies used variable message signs and highway advisory radios. Further, all respondents either had or planned to have computer aided dispatching (CAD) and a traffic management center (TMC). The survey also found that no respondents had plans for dynamic lane designation projects. This finding is surprising due to the known safety and capacity improvements of reversible lanes. Responding DOTs rated automated incident detection as one of the worst performing device for both incident detection and verification. High false-alarm rates and labor requirements are likely causes of this rating (9). The distribution of the use and plans of the other heavily-used devices is shown in Figure 16. More agencies plan to implement a TMC before they plan to invest in field equipment to support the TMC.

Less-defined patterns existed for automated vehicle location (AVL) and 511 information systems. While one third of respondents noted plans for AVL, the remaining agencies were divided between the “implemented” and the “not planned” sides of the spectrum. The survey also identified that while several agencies employed 511, there was no clear evidence as to whether or not it has helped incident management. This result might be due to the relative youth of the 511 service in the United States.

The survey questioned DOTs more specifically about technology use for each step in incident clearance. Respondents rated traffic cameras, cellular phones, and highway patrol communication as the top three tools in incident detection, respectively. All DOTs that rated their programs higher in collaboration and effectiveness made use of these top three incident detection methods. While technology might improve performance in incident detection, the survey found that DOTs still relied on human interaction heavily, for incident verification.

Respondents rated highway patrol communication, dispatched personnel, and traffic cameras as the respective top three performing methods for incident verification. All but one of the agencies rated as highly effective and collaborative used all of the top three verification methods. Call boxes rated the lowest performance of all methods for detection and verification. These results are likely due to the prevalence of cellular phones today.

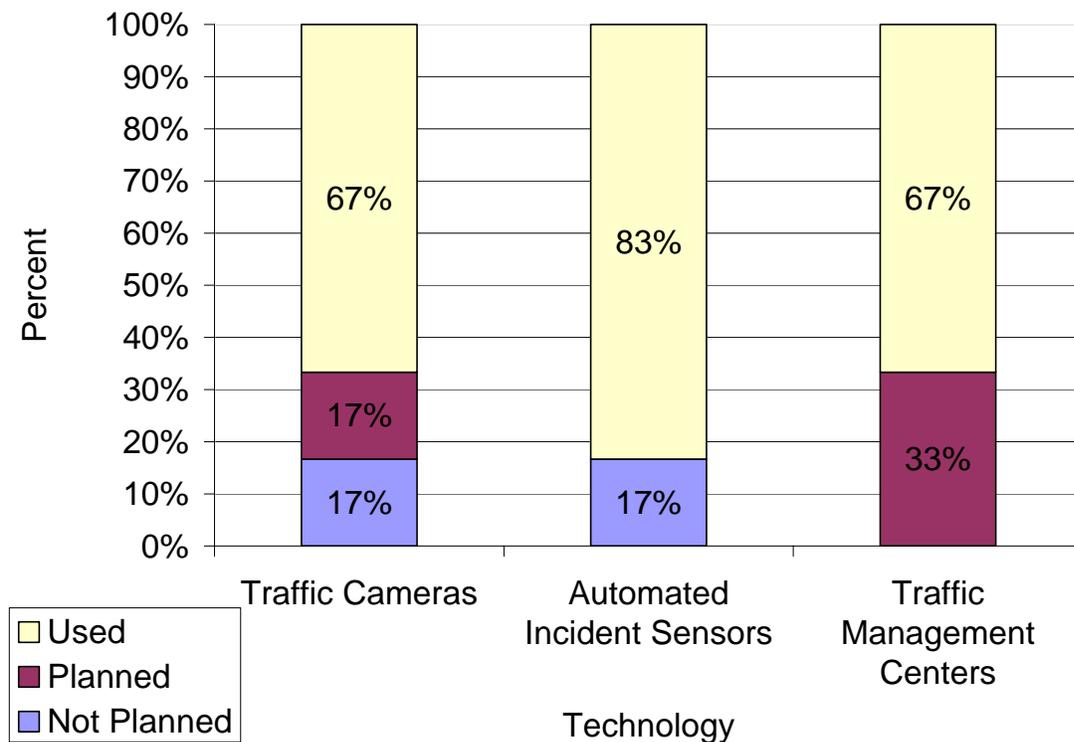


Figure 16: ITS technology existing and planned use

After polling agencies regarding incident detection and verification methods, the focus turned to incident clearance. The clearance of major (non-hazardous) incidents through DOTs was reported to rely most heavily on dump trucks, sweepers, and heavy duty tow trucks. All DOTs with a self-reportedly effective and comprehensive program possessed dump trucks, almost all had sweepers (83 percent), and most had heavy duty tow trucks (67 percent). Further, half of these highly-rated agencies used air-cushioned recovery systems and cranes, while almost no poorly rated agencies did. This information supported the premise that DOTs must own the right equipment and technology for the job in order to have an effective and comprehensive incident management program.

Data archiving of collected ITS data can provide valuable information for improving and publicizing the benefits of an incident management program. Responses from ITS agencies showed that highway sensor data was the only consistently stored data. Most responding agencies storing these data (75 percent) did so for more than ninety days. Phone and video data were stored for varying lengths of time and showed no significant trends. The data collected were only available to limited agencies. Respondents revealed that 83 percent of agencies made stored data available to the DOTs and 33 percent of agencies made stored data available to the public. Because data sharing and archiving is useful for future planning and evaluation, these findings left plenty of room for industry improvement.

5.1.5. Information Dissemination and Communications

Incidents with different severities require varying clearance times and varying levels of information dissemination. Incidents with long expected durations require a more intensive information dissemination effort. Although longer incidents occur less frequently, they cost more to road users and traffic control personnel. Improving information dissemination by choosing successful technologies might produce the greatest benefits during long-lasting incidents.

Survey respondents showed that 80 percent of DOTs used variable message signs to disseminate information during an incidents and another 15 percent planned to. As presented previously, all respondents either had or planned to have highway advisory radio also. Information dissemination for incident management often involves alternate routes. All ITS agencies that rated their incident management programs as effective and collaborative also rated their current alternate route plans effective. Effective alternate routes were not always available, however; all responding ITS agencies either had, or planned to have alternate route plans in the next five years.

Communication with and between incident responders is also important to incident management. Radios with dedicated frequencies and cellular phones appeared most frequently as technologies used by responding DOTs that rated their programs as effective and comprehensive. Responding ITS departments with reportedly comprehensive and effective programs all relied on landline telephones, and 67 percent relied on Internet communication to disseminate information to appropriate agencies.

Information dissemination, which depends on solid information and data collection, is a costly venture. Information sharing between agencies can greatly increase comprehensiveness of data collection while maintaining costs of current data collection operations. Seventy five percent of responding DOTs implemented or planned information sharing agreements, which suggested that the DOTs recognized the potential for cost savings with this strategy.

5.1.6. Methods of Communication to the Public

Successfully lobbying for incident management funding can start with solid communication to both the general public and to decision makers. The survey respondents answered several questions regarding the communication methods used to publicize the benefits of incident clearance. Respondents from DOTs rated personal communication, electronic methods, and print methods nearly equal and all somewhat effective for publicizing benefits and costs to decision makers. Two DOTs offered their own methods with much higher ratings. These methods include holding staff meetings and giving presentations to the media and first responders.

Responding DOTs felt that electronic methods (such as television, Internet, and email) were effective in communicating incident management benefits and costs to the public. Print methods were a close second while personal communication and public meetings were perceived as somewhat effective for communicating incident management benefits to the public.

5.1.7. State Highway Patrol Information Sources

The survey portrayed the general public has been the largest source (56 percent) to state highway patrol's (SHP) incident detection and verification in the United States. Respondents rated field observation (29 percent) and video monitoring (13 percent) as two other important contributing factors to incident detection and verification

The survey also polled SHPs regarding the performance of incident investigation technologies. A scale of one to five was used, with five being the best. The responding agencies rated total stations, crash re-creation software, and interviews with involved motorists/passengers as the best performing incident investigation technologies, ranking 4.1, 3.9, and 3.9 respectively. Few agencies used global positions systems (GPS) and those that did rated its performance poorly with a ranking of 2.4. Despite this poor performance, the number of respondents that use GPS will double after reported current GPS deployment plans are implemented. While multidisciplinary investigation teams rated well in performance for incident investigation with a score of 3.7, few agencies (nine percent) used this technique and no responding agencies planned to start. Further investigation into the benefits of this technique and cost effective methods of implementing it might help incident investigation for state highway patrols in the future.

State highway patrol agencies were also surveyed regarding their usage rates of incident investigation technologies. Responding SHPs rated interviews with involved motorists/passengers, total stations, and photography as the three most commonly used techniques in crash investigations with ratings of 27, 16, and 16 percent, respectively. Two of the best performing technologies were also two of the most used. Crash reconstruction software is usually only used for more severe crashes, while photography is used at many more types of incidents. Photography is understandably among the top three most used technologies instead of crash reconstruction software.

5.1.8. Successful Emergency Medical Services

Traffic incidents often involve the response of emergency medical service (EMS) so the survey polled these agencies to determine their typical roles, perceived effectiveness in incident response, and best practices. EMS respondents rated their incident clearance programs on a scale of one to five, with five being the highest. Results showed EMS respondents' confidence in their state's incident clearance programs' effectiveness and collaboration with other agencies with an average rating of 3.8 of 5.0 for effectiveness and 4.5 of 5.0 for collaboration. It is interesting that only half of the responding agencies had upgraded or changed their incident clearance strategies in the past five years. Agencies that implemented a new or changed strategy showed the same or better collaboration between agencies as those that did not. Because there are no dramatic differences in collaboration after agencies implemented new or changed strategies, perhaps advanced technologies for dispatching, incident and emergency vehicle location, and improved hospital communication might be more appropriate improvements.

Several suggestions were given to improve overall performance at incident management scenes. These comments focused on developing new plans or legislation that improves the chain of command through the direct assignment of responsibility at a crash sites and supports previously discussed findings from DOT surveys.

5.1.9. Obstacles for Incident Clearance Programs

Identifying problems with incident clearance strategies is the first step in finding effective strategies to mitigate or solve them in the future. The three most prominent problems encountered in incident clearance strategies by DOTs were lack of coordination between agencies (65 percent), lack of funding (60 percent), and lack of public awareness (50 percent). Lack of funding and public awareness appeared to be widespread between all incident clearance programs. It is likely these factors are linked for two reasons. The first reason considers that a lack of funding might eliminate the ability to include before-and-after study in the project budget. Without solid information it is not possible to advertise the effectiveness of an incident

clearance program to the general public or to decision makers. The second reason takes into account that a lack of funding can also prevent advertising of incident clearance information even if such information is available.

Another problem reported to be encountered by many incident management agencies was liability. Moving vehicles involved in incidents can create liability or make liability difficult to assign. Two primary forms of legislation regarding moving vehicles exist: quick clearance laws assign responsibility to the drivers and move-it laws require incident responders to clear travel lanes of vehicles. The survey found 55 percent of the respondents reported existing or proposed legislation requiring quick clearance of property-damage-only (PDO) incidents by drivers. Legislation allowing incident responders to move PDO incident in the same manner is slower to arrive. Only 33 percent of respondents had move-it legislation, requiring incident managers to move property-damage-only incidents out of right of way.

A final problem encountered by incident management agencies was a lack of impact or benefit data. Only 15 percent of the respondents indicated that a benefit-cost study had been done to evaluate their incident management programs. This finding supports the thought that limited data is available for communication with the general public and decision makers. All studies reported suffering from a lack of data and respondents indicated a need to study a distribution of situations, e.g. incidents lasting varying lengths of time, rather than just average incident duration. Before-and-after studies are often difficult because, as discussed above, limited data are recorded, less are saved for a long time, and even less are available to multiple agencies.

5.1.10. Synergy and Differences between Agency Responses

Synergies provide validation that certain methods, processes and issues are common to all agencies. Differences provide insights on either what unique resources or problems are present in an agency or agencies and how certain implementation alternatives can create a successful incident management programs perceived as highly collaborative and efficient.

All responding DOTs suffered from lack of information regarding the benefits of incident management and a lack of funding. Agencies that had not conducted benefit-cost analysis or before-and-after studies did not have the information required to market an incident management program successfully. Respondents who had conducted studies showed positive benefit-cost ratios for incident management. However, the respondents noted that data availability issues had diminished levels of trust in the studies. Lack of information has permeated the DOTs. Survey responses indicated that studies performed had not attained enough information, finished studies were not trusted, and agencies without studies had no information to advertise. The industry needs benefit cost studies based on sound methods and validated data to effectively communicate with the general public and decision makers as well as evaluate their program for future upgrades.

Incident management agencies showed strong synergy for effective use of traffic cameras, variable message signs, and highway advisory radios. Differences existed in methods of inter-agency communication used and the employment of benefit-cost studies.

Another important synergy found was the need for training of incident responders, especially first responders. Special training also should be provided in handling hazardous materials. Some survey respondents reported that useful time has been wasted after incidents involving hazardous materials because responders were not familiar with the materials or unaware of the handling procedures.

5.1.11. Survey Conclusions

The survey responses summarized in this report will be useful for departments of transportation, traffic management centers, emergency management services, state highway patrols, decision makers and community leaders, and others involved in incident management. Respondents raised many common needs, such as interagency cooperation and periodic evaluation of the program. These needs should be considered in order to plan for an effective incident management program.

This survey offers many insights into effectiveness and collaboration within and among traffic incident management agencies. This first of such insights provides incident management agencies across the country with an industry-created definition of an incident for better consistency. Agencies who rated their incident management programs being comprehensive and effective have a consensus that simplicity and direct assignment of responsibility are the keys to success. Successful technologies for incident detection include traffic cameras, cellular telephones, and highway patrols. For incident verification, the survey found that traffic cameras, dispatched personnel, and highway patrols have been most successful. The survey also found that efficient and comprehensive programs have dump trucks, sweepers, and heavy-duty tow trucks for incident clearance. Air-cushioned recovery systems and cranes have also been used by few agencies with a comprehensive incident management program.

The incident management industry is also widely using alternate routing of traffic. All responding agencies have or plan to have VMS, HAR, and alternate route plans. Responses show that the two most planned technologies for incident management include CAD and TMCs, which will also aid in implementing alternate routes.

Responses to data archiving questions show that the industry has strong footing with collecting road sensor data. The incident management industry must have a formal policy in the type of data archived, length of storage, and the availability to different agencies. This need is apparent by the number of data sharing agreements planned but not implemented. Improving these three factors will stop constraining the communication of benefits to decision makers and the public, and archived data will help future planning and evaluation. Common methods of communicating incident clearance information to decision makers are considered only somewhat effective and agency-specific methods are rated much higher; therefore uniquely developed communication strategies based on specific institutional scenarios are likely the best way to reach decision makers in each locality or state.

While reaching decision makers is currently difficult, contacting the public and other agencies is much easier. Agencies rated electronic methods, such as television, the Internet, and email, as the best methods of reaching the public. The highest-rated methods of communicating with incident clearance field personnel are radios with a dedicated frequency and cellular telephones. The highest-rated methods for communicating between incident clearance agencies are telephones and the Internet. Agencies responded that total stations, crash recreation software, and interviews with witnesses are the most effective tools for incident investigation.

Overall, little research has been done to evaluate the usefulness of ITS technologies in the complex organizational and operational systems used by incident management programs. The apparent deployment inconsistencies, in terms of incident management strategies and tools, between agencies that rated their programs efficient and those that did not, have emphasized the need for publication of this material to guide the industry toward effective technologies, communications methods, and incident clearance strategies. It appears that a national guide should be developed, beyond the scope of the traffic incident handbook, focusing on the institutional coordination, incident management strategies and tools, and communication methods to the public and to decision makers.

5.2 Simulation Results

5.2.1 Incident Detection with Traffic Sensors

5.2.1.1 Statewide View

The SCDOT uses radar and loop detectors to monitor traffic condition to detect incidents. Other types of detectors such as optical and video sensor have also been applied for automatic incident detection in many states. The effects of such automatic incident detection system are simulated and analyzed. Figure 17 and Figure 18 shows the results of the simulation analysis in terms of percentage savings in delay and fuel consumption, and air pollution, respectively, for using traffic sensors in detecting incidents.

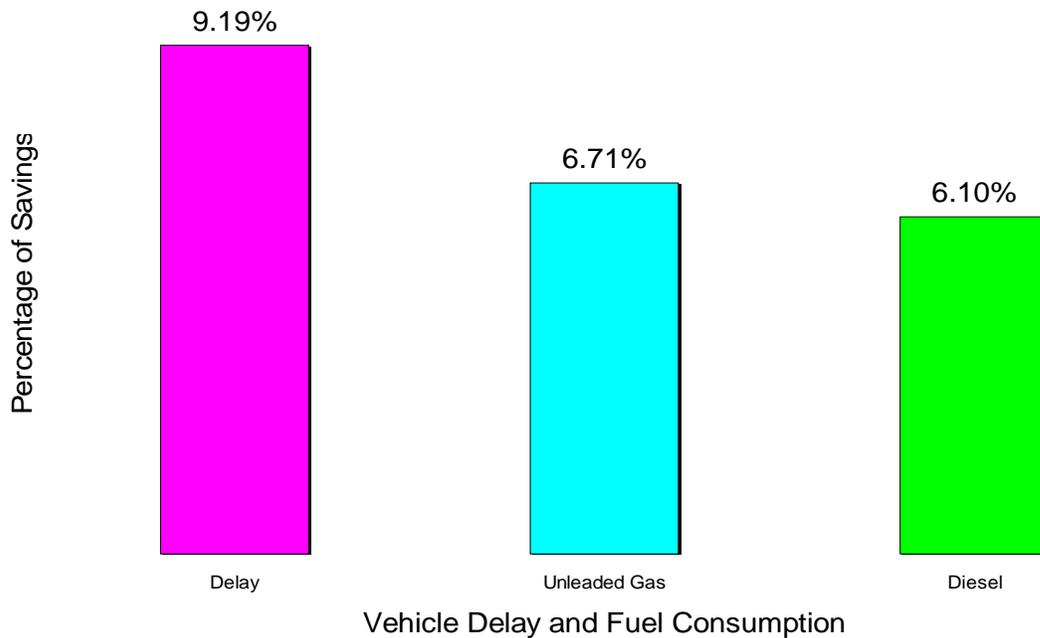


Figure 17: Percent savings on delay and fuel consumption for using traffic sensors

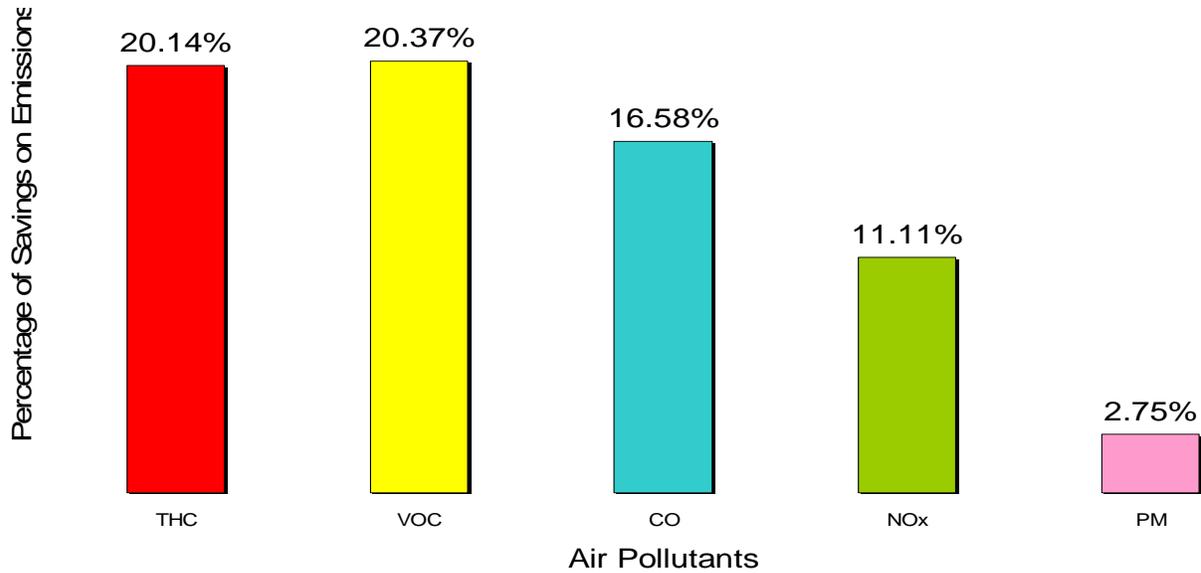


Figure 18: Percent savings on air pollution for using traffic sensors

5.2.1.2 Ranges of Benefits

As Figure 19 shows, traffic sensors detecting incidents while placed at half-mile spacing in an urban freeway site benefit South Carolinians approximately 3.4 million dollars annually for incidents blocking two lanes and approximately 1.9 million dollars annually for incidents blocking three lanes. Because the number of crashes varies each year this study included sensitivity analysis as discussed in section 4.3. The squares in Figure 19 represent the annual benefit based on a three-year average crash rate in each study site and the line represents the range in annual benefit. Savings in vehicle-delay, unleaded gasoline usage, and carbon monoxide were the major contributors to the benefits of using traffic sensor to detect incidents blocking two lanes and three lanes.

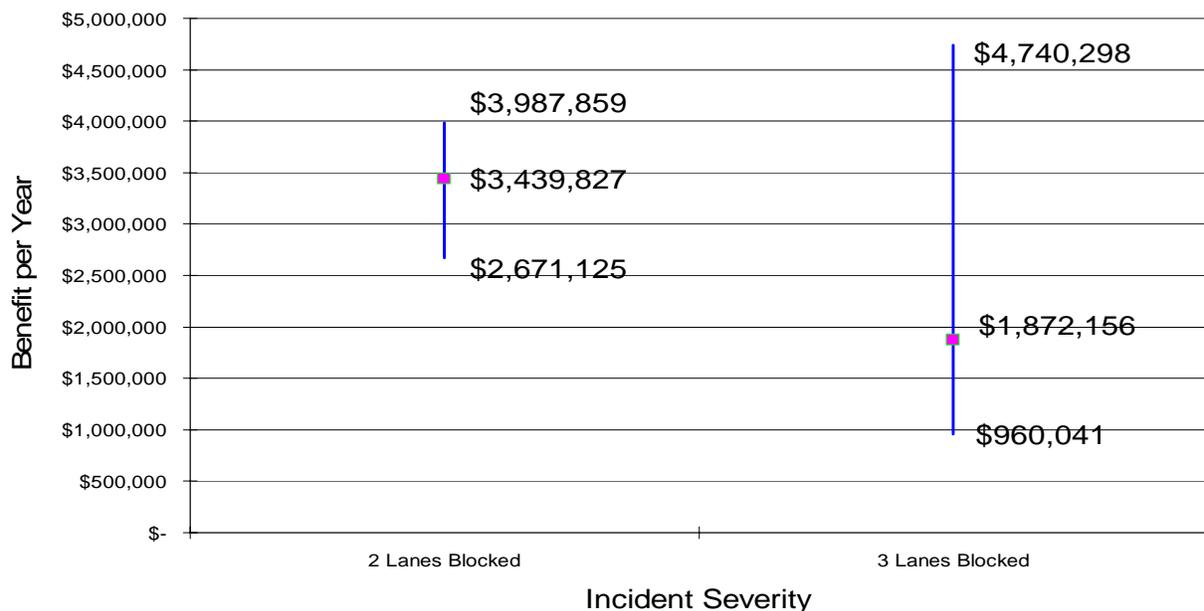


Figure 19: Annual Benefit of traffic sensors for incident detection

5.2.2 Incident Detection and Verification Using Traffic Cameras

5.2.2.1 Statewide View

Figure 20 shows percent savings on delay and fuel consumption for detecting and verifying incidents using traffic cameras. Figure 21 shows percent savings on pollution for detecting and verifying incidents using traffic cameras.

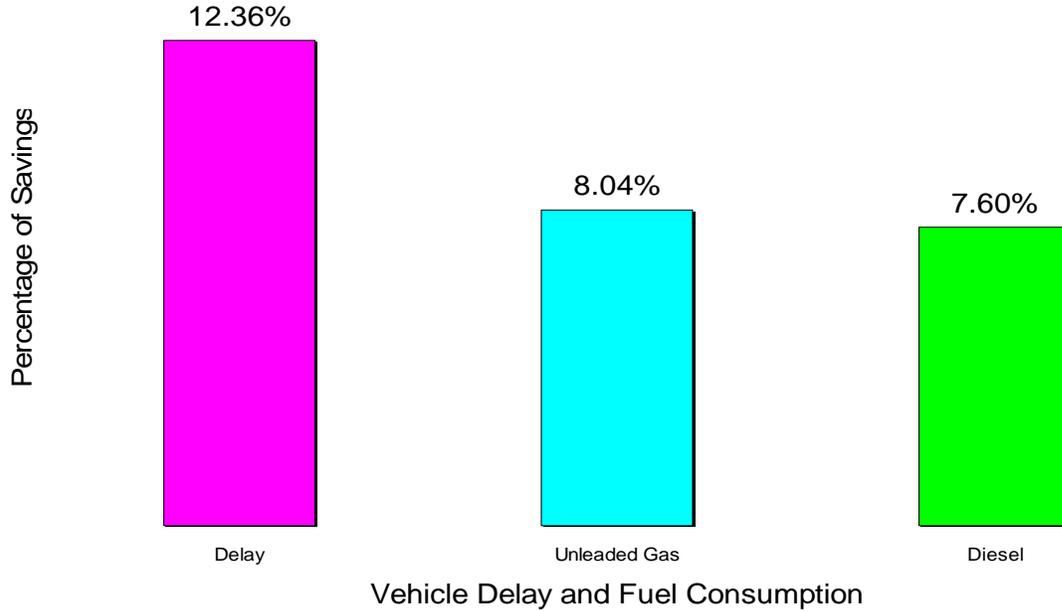


Figure 20: Percent Savings using traffic cameras for incident detection and verification

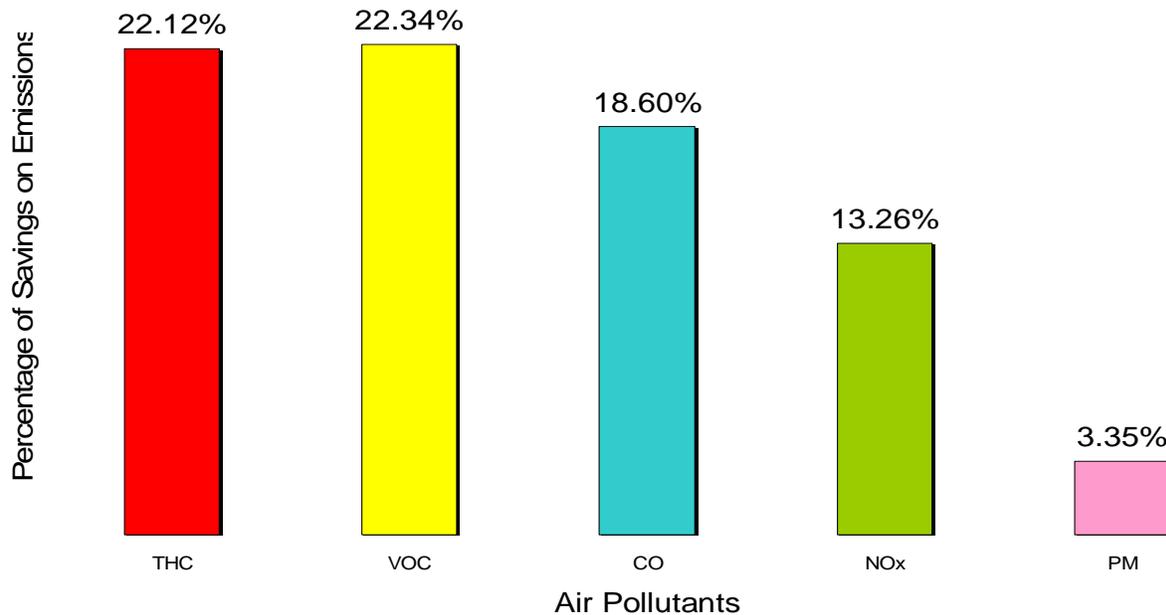


Figure 21: Percent savings on pollution using traffic cameras

5.2.2.2 Ranges of Benefits

The distribution crashes by number of lanes blocked played an important role in the annual benefits related to incident detection and verification using traffic cameras. Figure 22 shows the annual benefits for an average urban freeway section in a South Carolina city for using traffic camera systems for incident detection and verification. Although detecting and verifying each one-lane incident with traffic cameras provided much less benefit than more severe incidents, the high frequency of these types of incidents produced an average annual benefit comparable to the other two incident types examined.

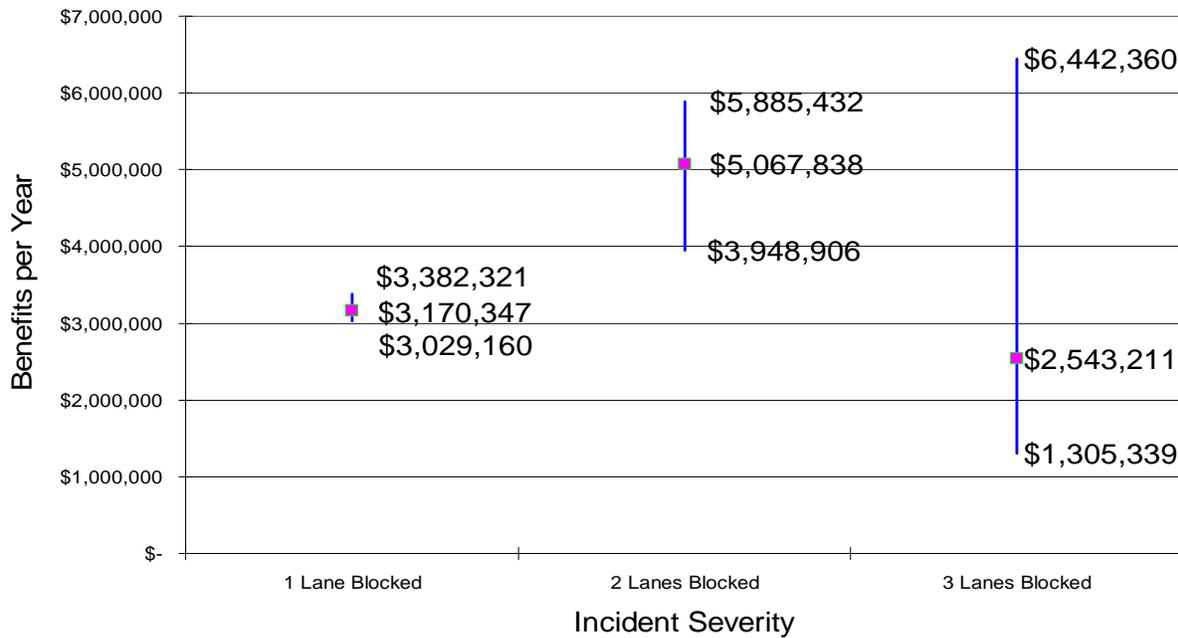


Figure 22: Annual benefits using traffic camera

5.2.3 Incident Detection, Verification, & Response Using Freeway Service Patrol

5.2.3.1 Statewide View

Researchers first evaluated the headways currently used for the freeway service patrols at each site. Figure 23 displays the percent savings in fuel use and traffic delay and Figure 24 shows the percent reduction in various air pollutants, for using freeway service patrols in incident detection, verification and response.

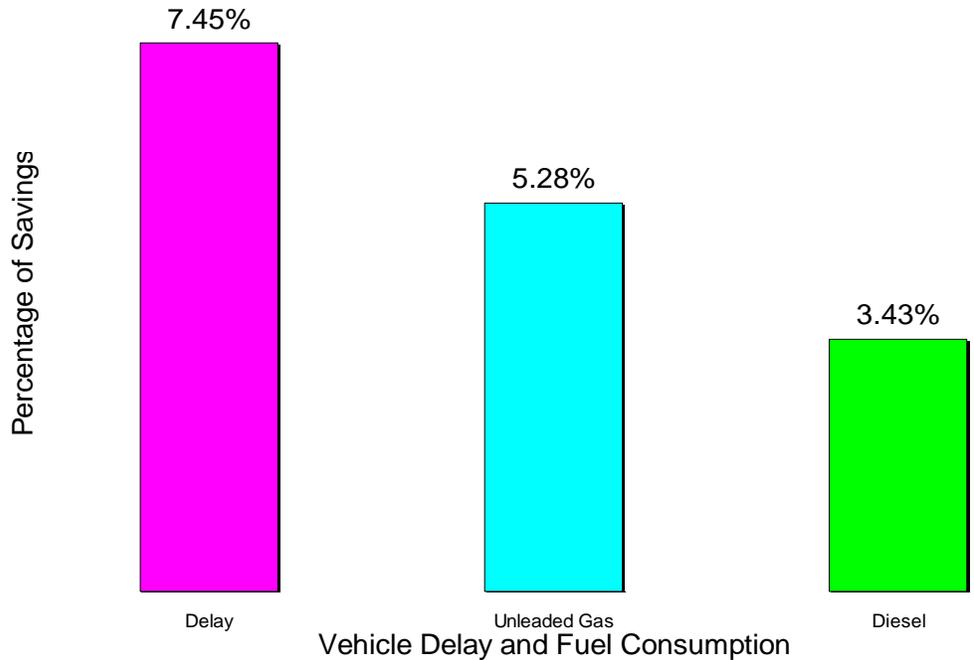


Figure 23: Percent savings using freeway service patrols

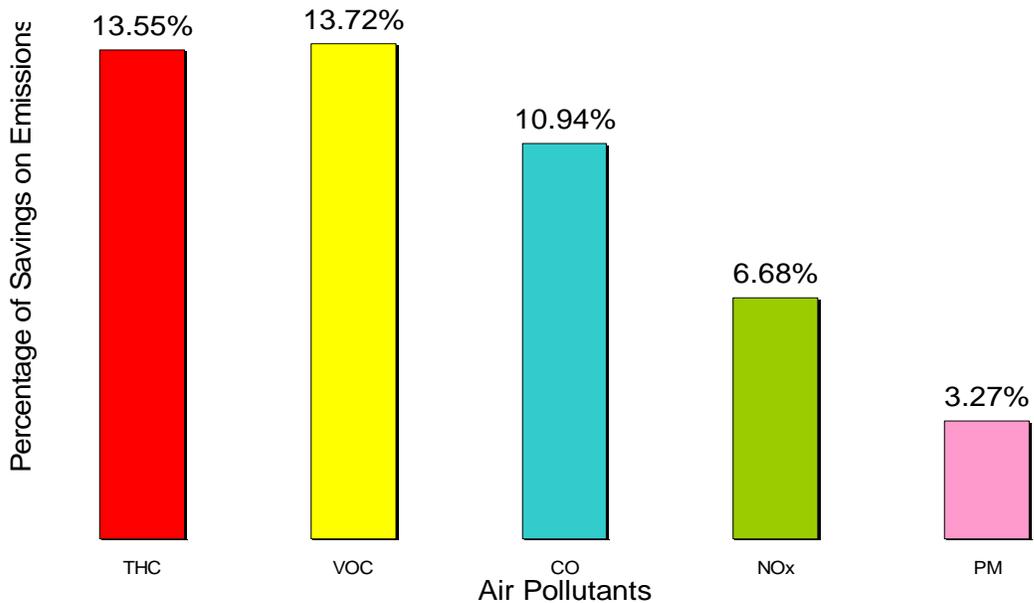


Figure 24: Percent savings on pollution using freeway service patrols

Researchers compared the benefits of existing freeway service patrol headways with the benefits of reducing the headways. The sites with existing headways of 45 minutes or less were reduced by one third (to between 15 to 5 minutes) and the site with an existing headway of one hour was reduced by one quarter to 15 minutes. Figure 25 shows the benefits of the proposed reductions in headways compared to the benefits of the existing headways per incident, indicating that little additional benefit was achieved by a significant reduction in headway.

A study evaluating a Congestion Mitigation and Air Quality Improvement Program (CMAQ) examined the impacts of a freeway service patrol in San Francisco, California. This study found reductions of 32 kg/day in hydrocarbons, a reduction of 322 kg/day in carbon monoxide, and a reduction of 798 kg/day in nitrous oxides (36). Comparing the results found from this study to those from others supports the findings on hydrocarbons and carbon monoxide reductions, while results in the nitrous oxide emissions differed.

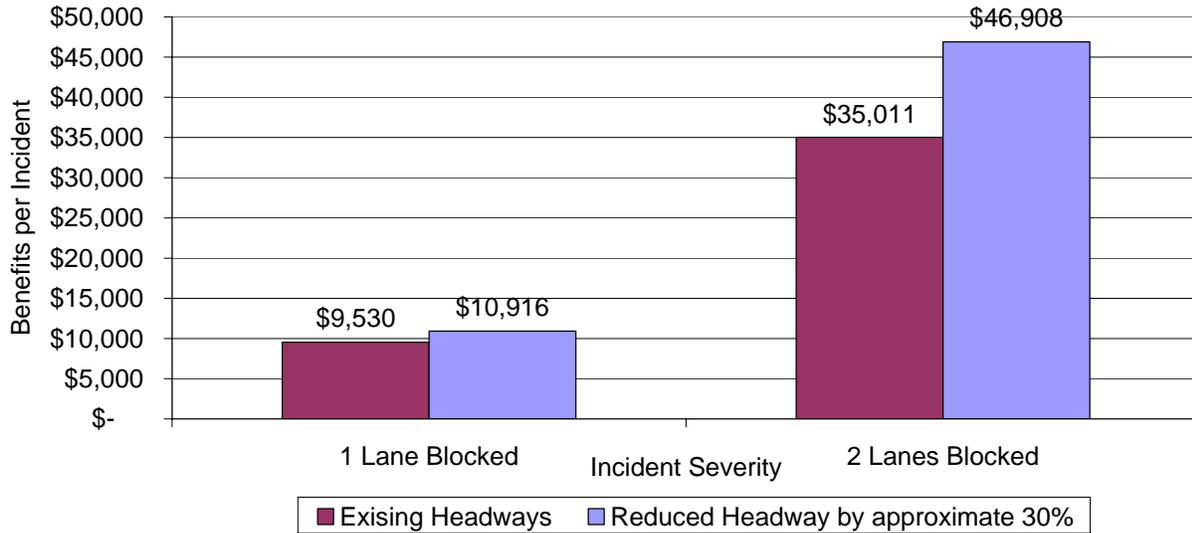


Figure 25: Benefits of existing and reduced freeway service patrol headways

5.2.3.2 Ranges of Benefits

Figure 26 shows that while the benefit of freeway service patrol was much more for each incident blocking two lanes, the higher frequency of incidents blocking one lane caused the annual benefit to be greater for incidents only blocking one lane.



Figure 26: Annual benefit of freeway service patrols

5.2.4 Incident Detection, Verification, & Response Using Multiple Strategies

5.2.4.1 Statewide View

Since incident management tools are seldom used alone, this study also examined the impacts of using multiple tools including traffic sensors, traffic camera, incident reporting hotlines, and freeway service patrols. The results are shown in Figure 27 and Figure 28.

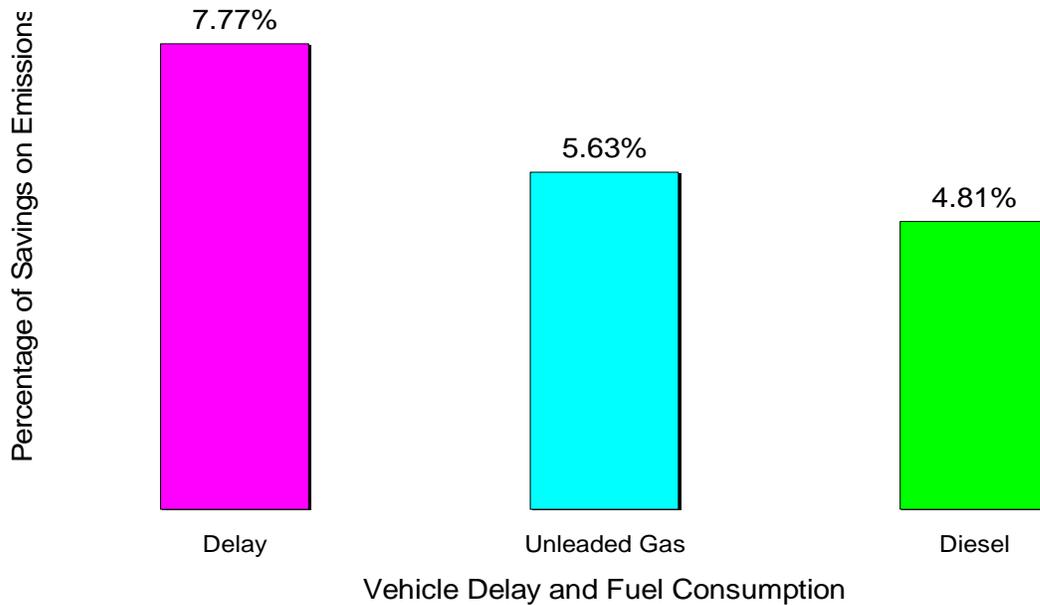


Figure 27: Percent savings using multiple strategies

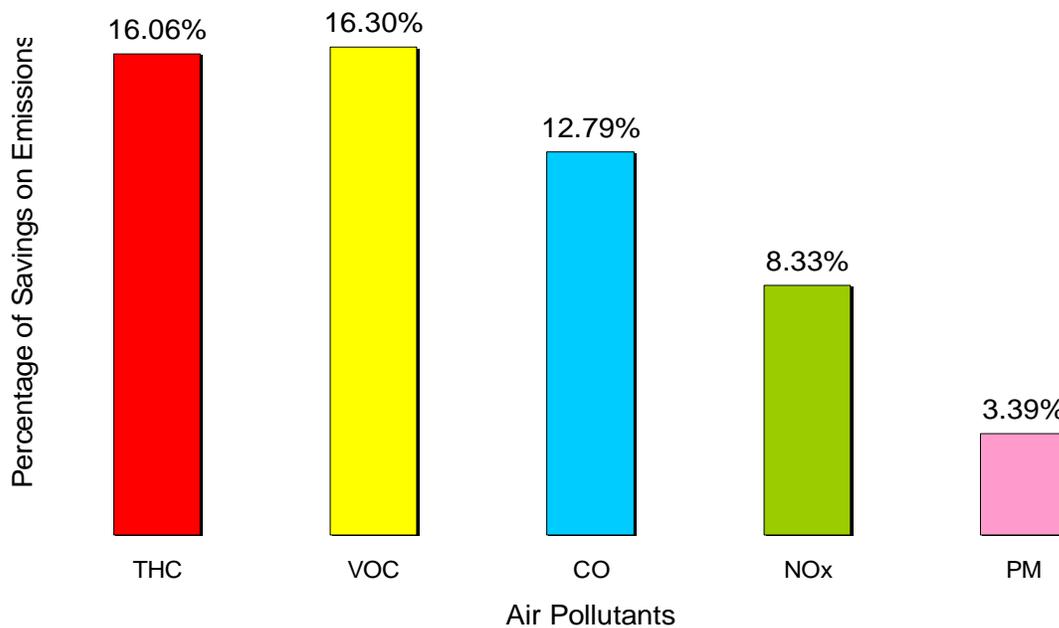


Figure 28: Percent savings on pollution using multiple strategies

5.2.4.2 Ranges of Benefits

While the benefits of managing three-lane incidents with multiple strategies were significantly higher than for less severe incidents, the frequency of one- and two-lane incidents outweighs these benefits as shown in Figure 29. The annual benefits of incident management using multiple strategies were more heavily impacted by less severe, but more frequent incidents.

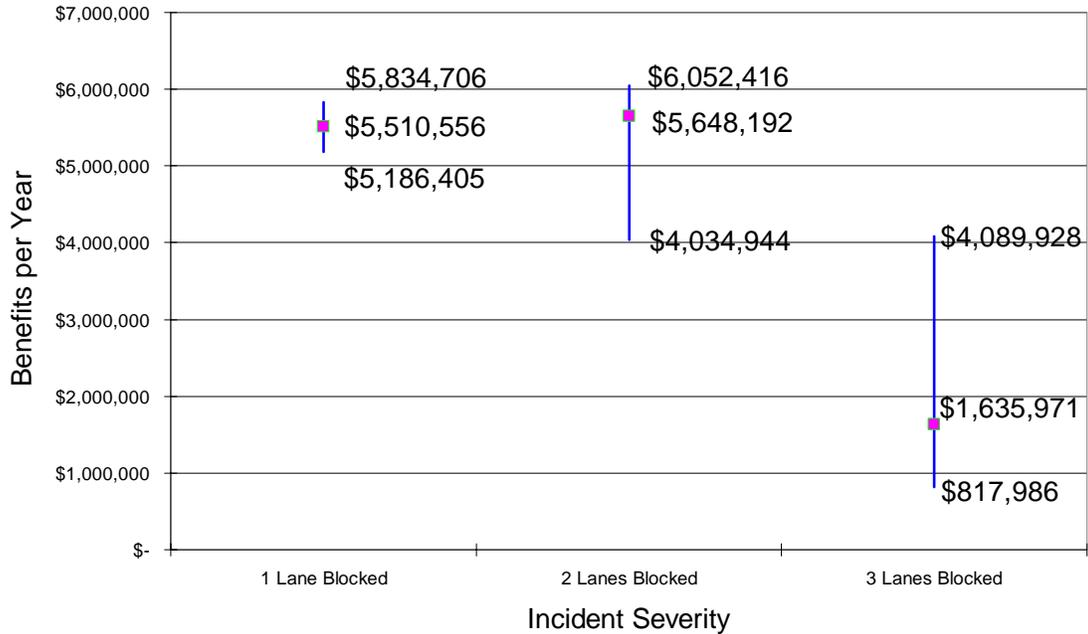


Figure 29: Annual benefits for integrated application of the multiple strategies

5.2.5 Minor Incident Clearance with State Legislation

This scenario aimed to evaluate legislation, such as South Carolina’s recent ‘Steer-it Clear-it’ law, that require drivers involved in minor crashes where no one is injured, to remove their vehicle from travel lanes prior to the arrival of police or service vehicles.

5.2.5.1 Statewide View

The number of lanes on the freeway and the existing traffic volumes also significantly affected the impact that minor incidents generate on the freeway network. Figure 30 displays the percent savings in delay and fuel use and Figure 31 shows the percent reduction in pollution, assuming all drivers are aware of and comply with the “Steer-it Clear-it” law. Figure 32 shows that annual benefits reach over four hundred thousand dollars per urban area freeway section, if all drivers are aware of and comply with the “Steer-it Clear-it” law.

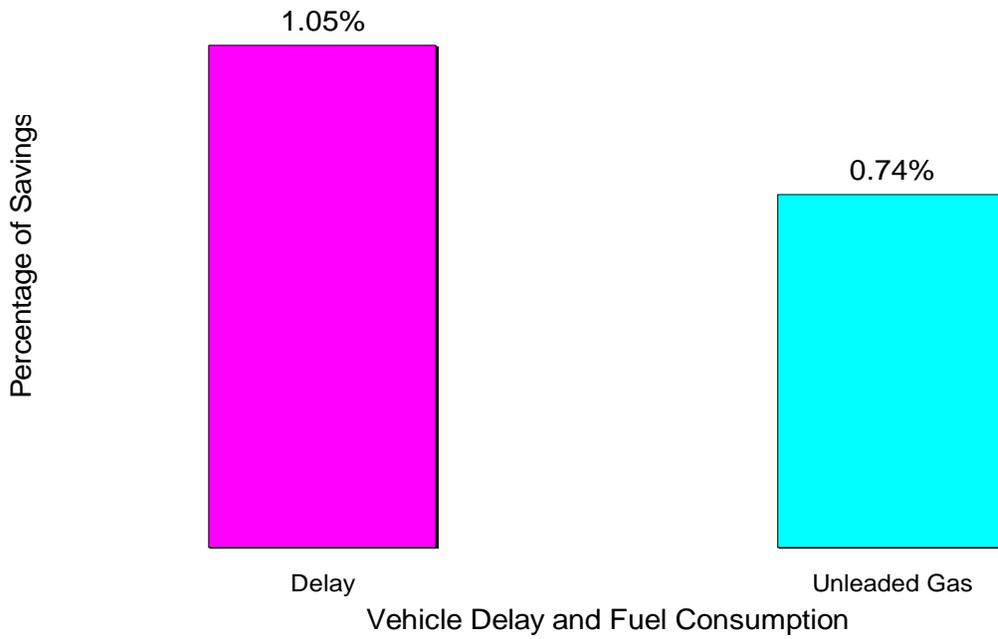


Figure 30: Percent savings using "Steer-it Clear-it" law

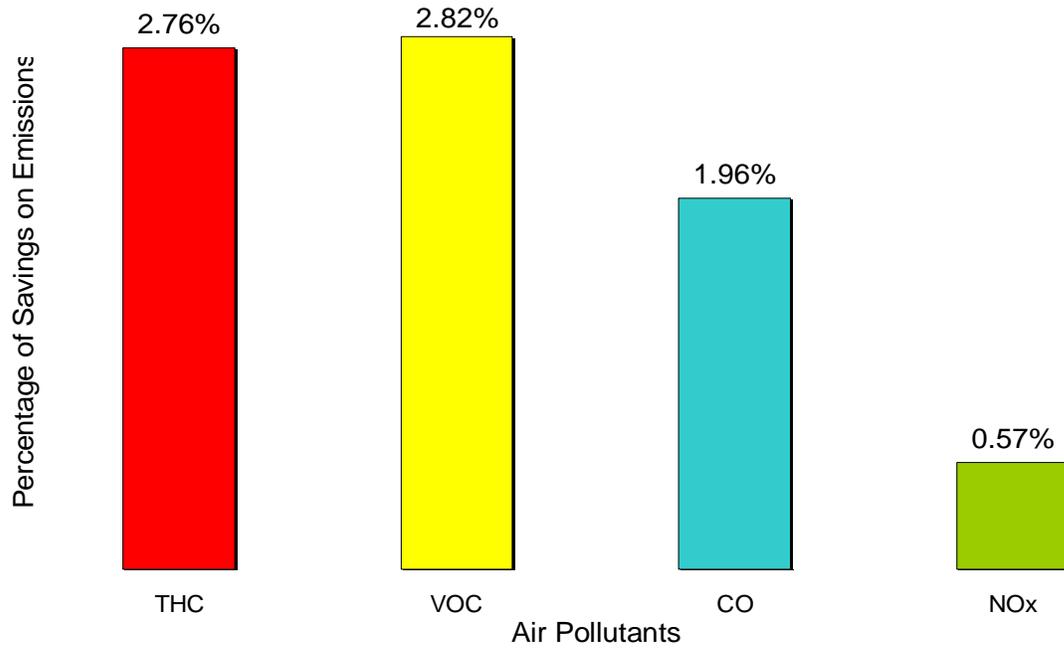


Figure 31: Percent savings on pollution using "Steer-it Clear-it" law

5.2.5.2 Ranges of Benefits

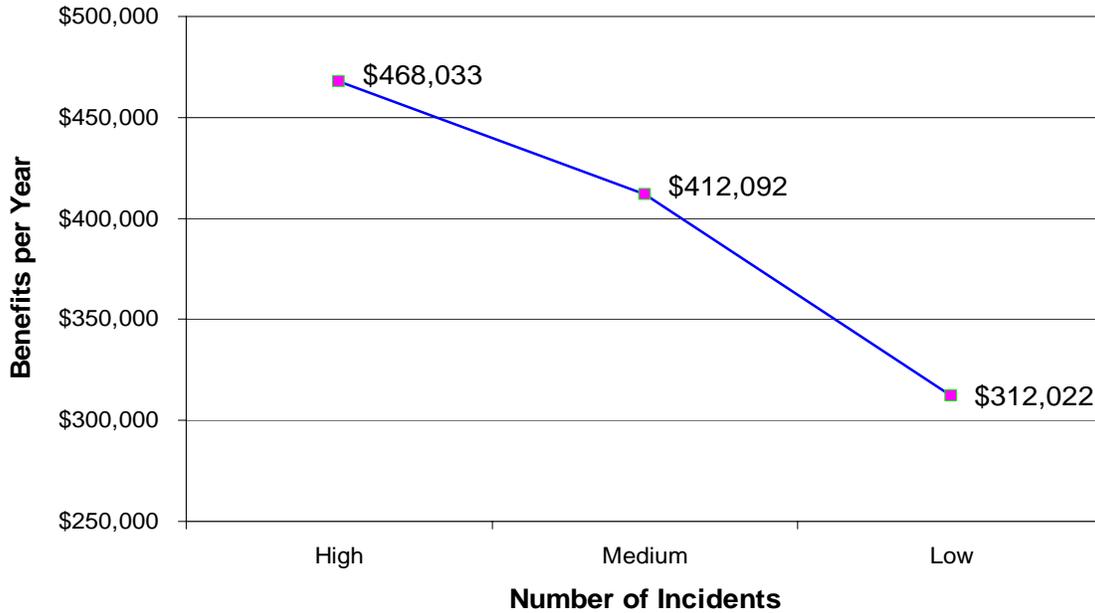


Figure 32: Annual benefit of "Steer-it Clear-it" Law Compliance

5.2.6 Major Incident Traffic Management with Route Diversion

5.2.6.1 Statewide View

Route diversions are time and personnel-intensive efforts used for more severe incidents. This study examined the impact of route diversions at high crash locations in both Charleston and Greenville. Both diversions provided motorists with large benefits as shown in Figure 33 and Figure 34.

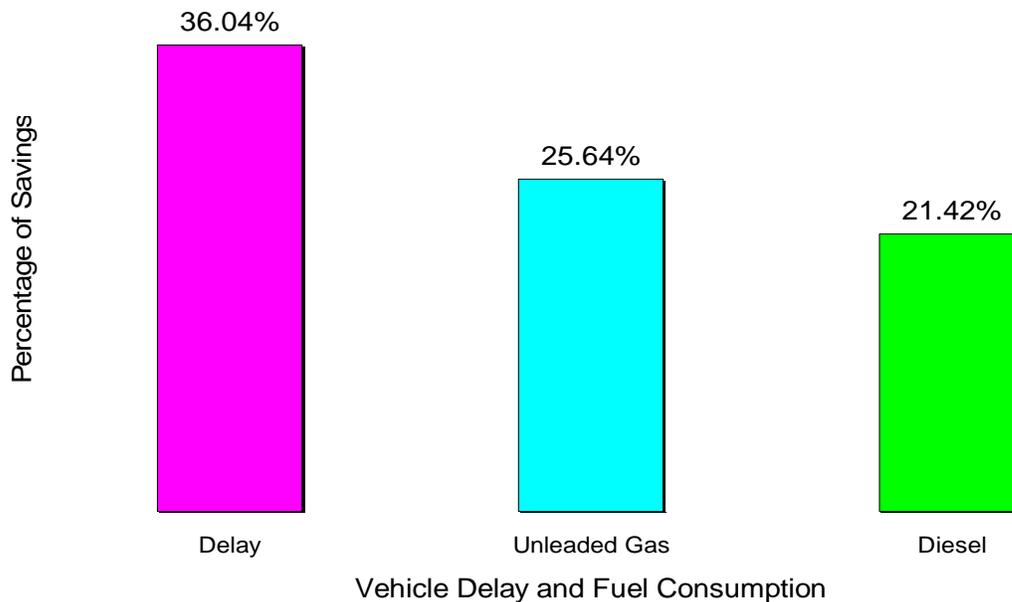


Figure 33: Percent savings on using route diversion

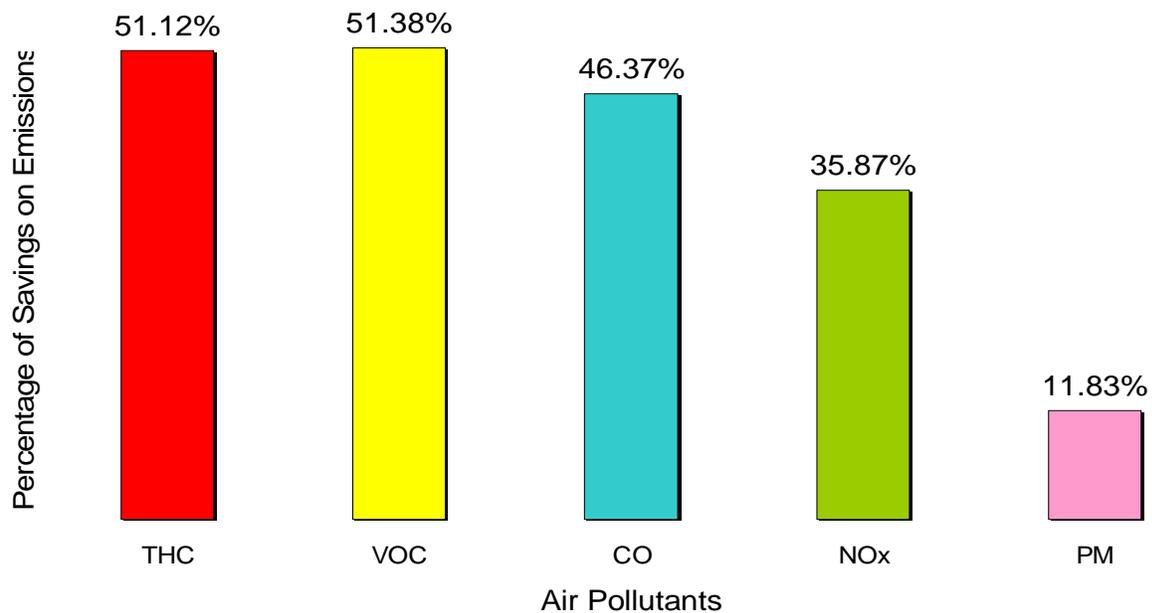


Figure 34: Percent savings on pollution using route diversion

5.2.6.2 Ranges of Benefits

Figure 35 shows the range of annual benefits if a route diversion is available and used for each incident blocking three lanes. Since the benefit value of each three-lane incident is large, the number of those incidents in a year significantly influences the annual benefit.

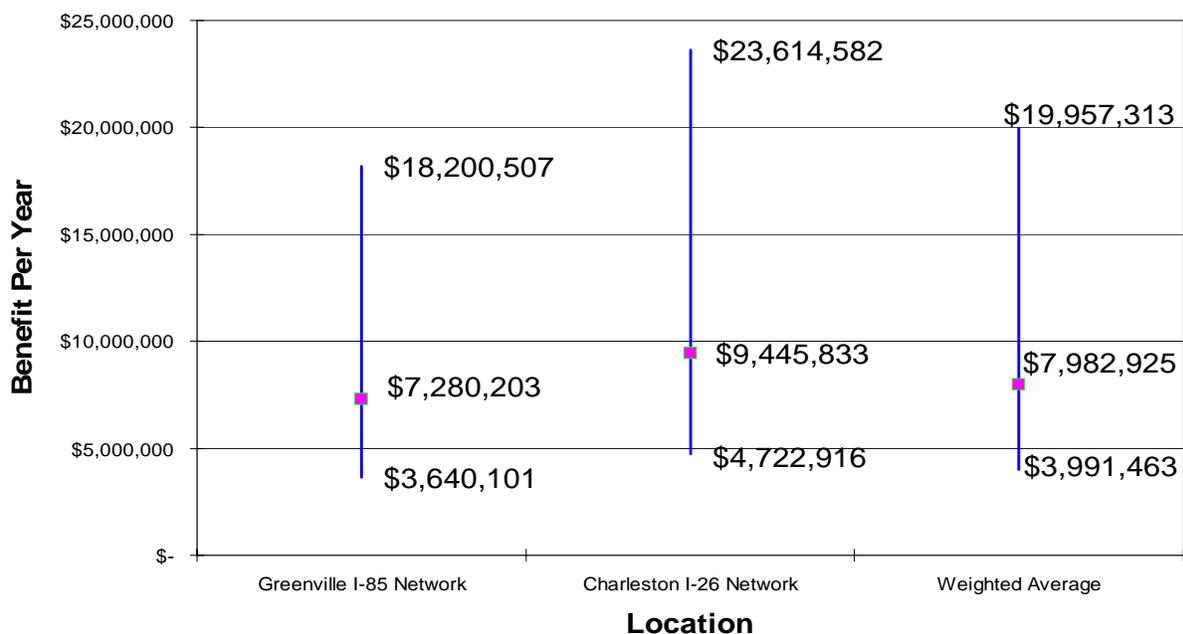


Figure 35: Annual benefit for route diversion

5.2.7 Concluding Remarks on Simulation Results

Overall, as the severity and therefore duration of incident increases, so does the potential for incident management tools to provide benefit to motorists. Benefits per incident ranged from

\$760, obeying the “Steer-it Clear-it” law, to \$310,000, operating a route diversion. The integrated application of multiple strategies provided more benefits than individual use traffic sensors, traffic cameras, or freeway service patrols, showing an advantage of incorporating multiple strategies in terms of savings on delay, emissions and fuel consumption.

5.3 Benefit-Cost Analysis Results

While analyzing the benefits is important for identifying trends and estimating incident management impacts, it is essential to compare the benefits to the costs associated with operating incident management programs. The following subsections present the results of the benefit-cost analysis.

In order to conduct a comprehensive evaluation of benefit-cost ratio of various incident management strategies, sensitivity studies were performed to give a broad view of the range of the possible range of benefit-cost ratio. First, the researchers varied the cost of various components of the incident management strategies to account for the variability in cost. The high, low and average values of benefit-cost ratio with respect to variation in cost correspond to high, low and average cost of incident management strategies. Then, the researchers varied the number of incidents blocking one, two and three lanes to account for the year-to-year variations of number of incidents and examine their impact on the estimated benefits of the various incident management strategies. The high, low and average values of benefit-cost ratio with respect to variation in benefits correspond to high, low and average number of the incidents per year.

5.3.1 Incident Detection Using Traffic Sensors

Many agencies have implemented traffic sensors for use in incident detection. Traffic sensors are often used in conjunction with some form of an incident verification method such as traffic cameras. Costs for traffic sensors such as radar units were found by taking an average of manufacturers’ pricing for typical units, and adding installation costs. Costs for traffic cameras included the cameras themselves, installation, cabinets to protect the cameras, electrical services, and an encoder and decoder for each camera, as given in the ITS unit cost online database (37). Additionally, each traffic camera would be installed on a traffic camera tower, the cost of which was also found in the same database. Other costs included communication from the cameras to the TMC, the video wall displaying camera images, and TMC operators, technicians, and managers. Communications costs included installation and maintenance costs of fiber optic and in-ground conduit. Operators were assumed to be capable of monitoring many camera images simultaneously, and only one maintenance technician was needed per site.

Table 10 shows the cost elements for traffic sensors and the values listed there come from IDAS (32) database and FHWA ITS unit cost online database (37). The yearly cost of each element was calculated and converted to current value according to a three percent inflation rate (32), the years between the cost estimate year in the database and present, and its predicted lifetime. The salvage value of each element was assumed negligible and the cost of Traffic Management Center labor included salary, benefits, and job supplies. For large sites such as Greenville, Charleston and Columbia, 2 operators, 1 technician, and 1 manager were assumed in the TMC. For smaller sites, which include York and Florence, only one full time operator was assumed in the TMC cost calculation. Traffic sensors and traffic cameras were placed every half mile on each side of the freeway and the total cost of the system was estimated according to unit cost and the size of each network. The values in Table 10 represent the costs range of the strategy from high to low as given in the ITS unit cost online database (37).

Table 10: Cost of Incident Management Elements for Traffic Sensor

Element	Lifetime (years)	Estimated Year	Capital Cost (\$K)		O&M Cost (\$K/year)	
			Low	High	Low	High
Traffic Sensor (e.g. radar detector)	10	2003	3.8	4.0	0.2	0.4
Conduit Design and Installation	20	2005	50	75	3	3
Fiber Optic Cable Installation	20	2005	20	52	1	2.5
TMC Operator Labor		2001			40	50
TMC Technician Labor		2001			60	75
TMC Manager Labor		2001			120	150

Table 11 shows the benefit to cost ratios for detecting incidents with traffic sensors. The column labeled “Average” provides an average benefit-cost ratio of the five sites weighted by the number of incidents in each network.

Table 11: Benefit to Cost Ratios for Traffic Sensors with Sensitivity to Costs

		Greenville	Charleston	Columbia	York	Florence	Average
Variation with Costs	Mean	9.06:1	9.32:1	4.33:1	2.85:1	5.32:1	6.54:1
	High	7.90:1	8.13:1	3.67:1	2.45:1	4.51:1	5.63:1
	Low	11.97:1	12.32:1	5.88:1	5.16:1	7.60:1	8.76:1

Table 12 shows how number of incidents affects the benefit to cost ratios. The benefits range was determined by the number of each type of crash per year as presented in section 4.3 and compared to the average cost from Table 10. The column labeled “Average” was weighted by each site’s vehicle miles traveled. The sensitivity analysis revealed that the lowest benefit to cost ratio was 4.50:1 and the highest benefit to cost ratio was 10.23:1.

Table 12: Benefit to Cost Ratios for Traffic Sensors With Sensitivity to Benefits

		Greenville	Charleston	Columbia	York	Florence	Average
Variation with Benefits	Mean	9.06:1	9.32:1	4.33:1	2.85:1	5.32:1	6.54:1
	High	14.07:1	12.79:1	7.43:1	5.99:1	8.91:1	10.23:1
	Low	6.25:1	6.77:1	2.85:1	1.65:1	3.53:1	4.50:1

As shown in Table 11 and Table 12, the benefit to cost ratios varies more with a change in the number of incidents than with a change in the costs. Therefore, a return on traffic sensors detecting incidents is heavily impacted by the number of times they are used per year. The expected average benefit to cost ratio with average number of crashes and average costs is 6.54:1.

5.3.2 Incident Detection and Verification Using Traffic Cameras

Some agencies use traffic cameras for incident detection as well, setting aside a certain number of personnel to continually monitor video of traffic conditions. The traffic camera scenario requires twice the number of operators as the previous, but does not require any other traffic sensors to complete the detection and verification tasks. The elements used during this scenario are shown in Table 13 below.

Table 13: Cost of Incident Management Elements for Traffic Camera Incident Detection

Element	Lifetime (years)	Estimated Year	Capital Cost (\$K)		O&M Cost (\$K/year)	
			Low	High	Low	High
Conduit Design and Installation	20	2005	50	75	3	3
Fiber Optic Cable Installation	20	2005	20	52	1	2.5
CCTV Video Camera	10	2005	9	19	1	2.3
CCTV Video Camera Tower	20	2005	4	12		
Video Wall inside TMC	10	2003	48	87	3	4
TMC Operator Labor		2001			40	50
TMC Technician Labor		2001			60	75
TMC Manager Labor		2001			120	150

Table 14 shows the benefit to cost ratios for average, high, and low costs for elements used during incident detection and verification with traffic cameras. The column titled “Average” shows a weighted average of all study sites, based on number of incidents at each site.

Table 14: Benefit to Cost Ratios for Traffic Cameras With Sensitivity to Costs

		Greenville	Charleston	Columbia	York	Florence	Average
Variation with Costs	Mean	19.46:1	5.63:1	11.30:1	8.14:1	18.52:1	12.47:1
	High Cost	17.23:1	4.99:1	9.96:1	7.23:1	16.16:1	11.01:1
	Low Cost	25.29:1	7.32:1	14.72:1	10.57:1	24.19:1	16.23:1

Table 15 shows the benefit to cost ratios for using traffic cameras to detect and verify freeway incidents ranged between 9.91:1 and 16.61:1 with respect to different number of incidents per year. The average benefit to cost ratio is 12:47:1.

Table 15: Benefit to Cost Ratios of Traffic Cameras with Sensitivity to Benefits

		Greenville	Charleston	Columbia	York	Florence	Average
Variation with Benefits	Mean	19.46:1	5.63:1	11.30:1	8.14:1	18.52:1	12.47:1
	High	27.26:1	7.22:1	14.49:1	11.92:1	23.38:1	16.61:1
	Low	14.62:1	4.29:1	9.47:1	6.29:1	15.66:1	9.91:1

5.3.3 Incident Detection, Verification, & Response Using Freeway Service Patrols

Table 16 shows the costs associated with operating freeway service patrols. Each site operated different number of freeway service patrols during the AM and PM peak period so total costs were unique to each site. For service patrol vehicle costs, the ITS unit cost online database lists a range of low and high values for both capital costs and yearly maintenance costs per vehicle, each with a lifespan of 10 years. An average of this range was determined to be the best approximation of both capital and maintenance costs. The resulting capital cost of a selected tool was then converted to a yearly cost according to the lifespan of that tool, which was added to the yearly maintenance cost. The database also lists the year in which this information was last updated, which was 2003 for service vehicles, and so the total yearly cost was adjusted for inflation to determine yearly costs in 2006 dollars. The per-vehicle yearly cost was multiplied by

the number of service vehicles required to maintain the time headways at each site. The headways reflect the average time between consecutive service vehicles.

The remaining costs involved labor and communications. It was estimated there would be one manager per program, that one maintenance technician would be assigned to two service vehicles, and that one operator would be assigned to each vehicle. The communications costs were assumed to include one wireless phone per operator, so the number of operators was multiplied by the average of the high and low usage costs found in the database. Refer to Table 6 for the freeway service patrol headways at each study site.

Table 16: Cost of Incident Management Elements Used for Freeway Service Patrols

Element	Lifetime (years)	Estimated Year	Capital Cost (\$K)		O&M Cost (\$K/year)	
			Low	High	Low	High
Service Patrol Vehicles	10	2005	50	75	1	2
Wireless Communications		2003			0.12	0.2
FSP Operator Labor		2001			40	50
FSP Technician Labor		2001			60	75
FSP Manager Labor		2001			120	150

Table 17 shows the benefit to cost ratios for operating freeway service patrols in South Carolina using existing headways. The high and low correspond to the high and low costs as shown in Table 16.

Table 17: Benefit to Cost Ratios for Freeway Service Patrols With Sensitivity to Costs

		Greenville	Charleston	Columbia	York	Florence	Average
Variation with Costs	Mean	22.12:1	15.40:1	2.89:1	5.65:1	13.05:1	11.37:1
	High	22.02:1	15.36:1	2.88:1	5.62:1	12.99:1	11.31:1
	Low	27.66:1	19.25:1	3.62:1	7.07:1	16.32:1	14.21:1

Table 18 shows the benefit to cost ratios for operating freeway service patrols by varying the number of crashes per year. The findings indicate that for every dollar invested, freeway service patrols provide approximately \$11 of expected benefits to South Carolina, on average.

Table 18: Benefit to Cost Ratios for Freeway Service Patrols With Sensitivity to Benefits

		Greenville	Charleston	Columbia	York	Florence	Average
Variation with Benefits	Mean	22.12:1	15.40:1	2.89:1	5.65:1	13.05:1	11.37:1
	High	24.94:1	16.87:1	2.65:1	6.12:1	14.00:1	12.40:1
	Low	18.07:1	13.47:1	3.48:1	5.08:1	11.94:1	10.04:1

5.3.4 Incident Detection, Verification, & Response Using Multiple Strategies

The multiple strategy scenario of incident management took into account a combination of incident management strategies that were previously studied separately, as well as one additional strategy. The strategies used previously included traffic cameras, traffic sensors, and freeway service patrols. The yearly costs for each of these strategies were considered for the total cost of the multiple strategy method. In addition, this method considered traffic incident

hotlines, which other state departments of transportation regard as one of the fastest methods of incident detection. For the traffic incident hotlines, it was assumed that one additional operator would be stationed at the call center and would be responsible for all the traffic incident related calls.

Table 19 presents the costs of each item considered in the integrated application of multiple strategies. All of the items were used in previous strategies except the emergency operator for the incident hotline.

Table 19 Cost of Incident Management Elements for Multiple Strategies

Element	Lifetime (years)	Estimated Year	Capital Cost (\$K)		O&M Cost (\$K/year)	
			Low	High	Low	High
Hotline Operator Labor		2001			30	40
Traffic Sensor (e.g. radar detector)	10	2003	3.8	4.0	0.2	0.4
Conduit Design and Installation	20	2005	50	75	3	3
Fiber Optic Cable Installation	20	2005	20	52	1	2.5
CCTV Video Camera	10	2005	9	19	1	2.3
CCTV Video Camera Tower	20	2005	4	12		
Video Wall inside TMC	10	2003	48	87	3	4
TMC Operator Labor		2001			40	50
TMC Technician Labor		2001			60	75
TMC Manager Labor		2001			120	150
Service Patrol Vehicles	10	2005	50	75	1	2
Wireless Communications		2003			0.12	0.2
FSP Operator Labor		2001			40	50
FSP Technician Labor		2001			60	75
FSP Manager Labor		2001			120	150

Table 20 shows the range of benefit to cost ratios when the low and high costs are compared to average benefits. As with the previous tables, the column labeled Average displays a weighted average based on vehicle miles traveled in each site.

Table 20: Benefit to Cost of Multiple Strategies with Sensitivity to Costs

		Greenville	Charleston	Columbia	York	Florence	Average
Variation with Costs	Mean	11.53:1	8.56:1	4.79:1	5.10:1	8.86:1	7.71:1
	High	8.57:1	5.96:1	3.40:1	4.78:1	6.34:1	5.86:1
	Low	12.47:1	8.71:1	5.05:1	6.52:1	11.43:1	8.59:1

While using multiple strategies provides better benefits, it also requires larger investments than using only one strategy. Table 21 shows that using multiple strategies for incident management returned approximately \$8 for every dollar invested. The average, high, and low correspond to the number of crashes per year.

Table 21: Benefit to Cost Ratios of Multiple Strategies With Sensitivity to Benefits

		Greenville	Charleston	Columbia	York	Florence	Average
Variation with Benefits	Mean	11.53:1	8.56:1	4.79:1	5.10:1	8.86:1	7.71:1
	High	14.35:1	11.65:1	6.41:1	7.26:1	11.41:1	10.08:1
	Low	9.13:1	6.76:1	4.02:1	4.06:1	7.47:1	6.25:1

5.3.5 Minor Incident Clearance with State Legislation

Determining the costs of quick clearance legislation, such as the Steer It and Clear It law in South Carolina, involved calculating implementation costs as well as advertising costs to make drivers aware of this policy change. Advertising costs were estimated by considering signage and billboard advertisements on the freeway as well as radio and TV commercials. The radio advertisement would be a 60-second commercial run once per week of the first year of the law, while the TV spot cost corresponds to statewide advertisement for one week. The cost estimations for both of these media types were found by researching various advertising companies, and radio and TV stations.

Billboard signage on the freeway was considered as well, and values for this sign were determined by finding the cost involved in producing the image as well as rental of the billboard for one year. Other signs specific to the law would also have to be produced. The costs of these signs were found by estimating capital and maintenance costs for both the sign and the breakaway post, as well as costs of labor for installation. The costs for advertising a new law was less expensive than the investments required by the other strategies studied. The cost included in the evaluation of benefit to cost ration of “Steer-it Clear-it” law are shown in Table 22.

Table 22: Costs of Advertising “Steer-it Clear-it” Legislation

Element	Lifetime (years)	Estimated Year	Capital Cost (\$K)		O&M Cost (\$K/year)	
			Low	High	Low	High
Freeway signage	10	2006	0.18	0.22	0.03	0.05
Break-away posts	10	2006	35	40		
Freeway billboard advertisement		2006	0.08	0.60	0.08	0.17
Radio advertisement		2006			0.20	0.22
TV advertisement		2006			15	16
Installation labor		2006	0.18	0.22		

Table 23 shows the benefit to cost ratios that correspond to the high, low, and average costs. The average return for all sites examined was \$22 for each dollar invested. The York site showed the lowest return because fewer crashes occurred there than other sites, producing less benefit and a lower benefit to cost ratio.

Table 23: Benefit to Cost Ratios for “Steer-it Clear-it” Legislation With Sensitivity to Costs

		Greenville	Charleston	Columbia	York	Florence	Average
Variation with Costs	Mean	57.22:1	45.16:1	35.57:1	2.01:1	41.46:1	21.58:1
	High	51.74:1	40.83:1	31.92:1	1.91:1	38.71:1	20.16:1
	Low	58.41:1	46.09:1	36.35:1	2.04:1	42.08:1	21.90:1

It is important to realize that these results assume that all drivers are aware of and comply with the “Steer-it Clear-it” law. While drivers will take time to learn about and comply with the new law, the costs of advertisement will also decrease with time. Therefore, it is expected that the benefit to cost ratio found in this study is higher than initial returns and lower than future returns. Table 24 shows the range of benefit to cost ratios when the number of crashes changes.

Table 24: Benefit to Cost Ratios for “Steer-it Clear-it” Legislation With Sensitivity to Benefits

		Greenville	Charleston	Columbia	York	Florence	Average
Variation with Benefits	Mean	57.22:1	45.16:1	35.57:1	2.01:1	41.46:1	21.58:1
	High	65.00:1	51.31:1	40.40:1	2.28:1	47.00:1	24.45:1
	Low	43.33:1	34.20:1	26.94:1	1.52:1	31.33:1	16.30:1

5.3.6 Major Incident Traffic Management with Route Diversion

This section shows the results of the benefit to cost and sensitivity analysis for the route diversion scenarios. For major incidents that block the entire freeway, it is sometimes necessary to divert traffic away from the freeway completely, which can require the use of additional communication methods to drivers, which includes variable message signs (VMS) and highway advisory radio (HAR). Diversion operations also require highway patrol units deployed on the scene to direct traffic, as well as a TMC operator to help manage the overall operation from their location at the TMC.

Costs of HAR were available within the ITS Benefit Cost Database online. One HAR system was assumed to be in place for each site. It was also assumed that one large stationary VMS and two portable VMS would be used in each operation. Communications for both HAR and VMS would be needed and these costs were found in the ITS Benefit Cost database as well. The cost of both highway patrol and TMC personnel were calculated by multiplying an average wage per person by the number of units needed per hour of diversion, and then multiplying this hourly cost by the number of hours per operation.

Table 25 shows the elements considered in the route diversion. The number of officers changed between the sites because the Charleston site required the manual operation of a traffic signal and the Greenville site did not. The costs for other elements were obtained from IDAS (32) and remained the same for both analyses.

Table 25: Costs of Incident Management Elements Used for Route Diversion

Element	Lifetime (years)	Estimated Year	Capital Cost (\$K)		O&M Cost (\$K/year)	
			Low	High	Low	High
Highway Advisory Radio	20	2005	15	35	0.6	1.0
Highway Advisory Radio Sign	20	2005	5	9	0.3	0.3
Wireless Communications	10	2005			0.1	0.2
Variable Message Sign	20	2005	47	117	2.3	6.0
Variable Message Sign Tower	10	2003	25	120	3.0	4.0
Portable Sign	14	2005	18.3	24	0.6	1.8
TMC Operator Labor		2006			\$35/hour	\$45/hour
Police Officer Labor		2006			\$35/hour	\$45/hour

Table 26 shows the benefit to cost ratios for each site when the costs vary from the high to low estimates. On average, route diversion returned \$55 for every dollar spent.

Table 26: Benefit to Cost Ratios for Route Diversion with Sensitivity to Costs

		Greenville	Charleston	Average
Variation with Costs	Mean	46.98:1	61.08:1	54.66:1
	High	37.68:1	48.96:1	43.82:1
	Low	71.91:1	93.71:1	83.77:1

Route diversions showed the largest benefit to cost ratio of all scenarios studied. Table 27 shows the benefit to cost ratios for each site when the number of crashes was varied. While network delay was captured, a significant factor to recognize is that the simulation networks were built with the focus of capturing freeway impacts; therefore, arterial streets were not constructed far from the interchanges. During route diversions, increased arterial congestion, particularly in the Charleston network, may cause unforeseen delays to non-freeway motorists.

Table 27: Benefit to Cost Ratios for Route Diversions With Sensitivity to Benefits

		Greenville	Charleston	Average
Variation with Benefits	Mean	46.98:1	61.08:1	54.66:1
	High	120.41:1	146.81:1	135.21:1
	Low	33.86:1	43.75:1	39.26:1

6.0 Implementation Strategy Summary

The implementation of freeway incident clearance strategies that this research encompasses will require substantial development and preparation. The goal of this implementation strategy, presented in Appendix B, is to summarize the most important steps in implementing these strategies, and to identify possible sources of opportunities and concerns within the implementation process.

The incident management strategies evaluated in this research provide significant benefits as compared to the cost. The two most important strategies for implementing this plan are coordination and funding of responsible agencies. In some instances, policy changes and the technology selection may also support the success of these strategies when implemented. Developing and following regional and a statewide ITS architecture aid in the coordination process. Initial and long term maintenance funding should also be considered since maintenance and its associated costs are an important financial issue. Securing these funding early on will help sustain these strategies. A crucial part of an incident management implementation plan also involves providing a means of assessing the system to determine if any changes are needed. See Appendix B for a detailed discussion on the implementation strategy.

7.0 Concluding Remarks

State departments across the US have recognized the need to manage incidents more efficiently. Successfully lobbying for increased incident management funding is often damaged by a lack of sound information about the benefits of incident management programs. This study

sought to improve the state of knowledge about incident management in South Carolina and across the US by reviewing published literature, conducting a nation-wide survey of incident management agencies, and estimating the benefits of incident management in South Carolina using traffic simulation and benefit-cost analysis.

The first objective of this research, identifying the current state-of-the-practice for accelerated incident clearance, was satisfied by thoroughly reviewing published literature from other studies of incident management across the US and conducting a nation-wide survey. The literature review identified which technologies, strategies, and organizations to poll in the survey and also identified several gaps in knowledge.

7.1 Survey Findings

Successful technologies for incident detection include traffic cameras, cellular telephones, and highway patrols. For incident verification, the survey found traffic cameras, dispatched personnel, and highway patrols are the most successful. The survey also revealed that efficient and comprehensive incident management programs have dump trucks, sweepers, air-cushioned recovery systems, cranes and heavy-duty tow trucks for incident clearance.

All responding agencies have or plan to have VMS, HAR, and alternate routing options. Responses show that the two most planned technologies include CAD and TMCs, which will also aid in implementing alternate routes.

Respondents felt it is important to archive traffic data collected through TMC, which can be used for future planning and evaluation. The incident management industry should plan for the type of data to be archived, length of storage, and the availability of archived data to different agencies. This need is apparent by the number of data sharing agreements planned but not implemented.

Common methods of communicating incident clearance information to decision makers are considered only somewhat effective and agency-specific methods are rated much higher; therefore uniquely developed communication strategies based on specific institutional scenarios are likely the best way to reach decision makers in each locality or state.

While reaching decision makers is sometimes difficult, contacting the public and other agencies is much easier. Agencies rated electronic methods, such as television, the Internet, and email, as the best methods of reaching the public. The highest-rated methods of communicating with incident clearance field personnel are radios with a dedicated frequency and cellular telephones. The highest-rated methods of communicating between incident clearance agencies are telephones and the Internet.

Agencies responded that total stations, crash recreation software, and interviews with witnesses are the most effective tools for incident investigation. Overall, little research has been done to evaluate the usefulness of ITS technologies in the complex organizational and operational systems used by incident management programs. Survey respondents have emphasized the need for publication of an incident management professional practice manual to guide the industry toward effective technologies, standards related to communication between stakeholders, and operations and maintenance requirements/issues. It appears that a national guide should be developed, beyond the scope of the traffic incident management handbook, focusing on the institutional coordination, incident management tools, and communication methods to the public and to decision makers.

7.2 Incidents in South Carolina

The next objective of this research, identify the different levels of incidents, in terms of number of lanes blocked and distribution of crashes by different severity level, on S.C.

interstates, was met through coordination with incident management personnel in regional traffic management centers and analyzing crash databases. The research team used the levels of incidents to guide the simulation portions of the project. Similarly, the objective of identifying solution strategies was met through the guidance from the project steering committee, which helped the research team to select key strategies for evaluation.

7.3 Traffic Simulation

To meet the objective of estimating the impacts of incident management strategies, the research team used the traffic simulation tool PARAMICS. The simulation outputs included delay, fuel consumption, and emissions. While detecting incidents using traffic sensors provided large benefits to motorists, using traffic cameras provides significantly more benefits for all incidents analyzed. Freeway service patrols showed larger benefits than traffic cameras for incidents involving one-lane blocked, but not for incidents involving two-lanes blocked. The multiple tool incident management strategy, which included an integrated application of traffic sensors, traffic cameras, telephone calls reporting incidents and freeway service patrols, provided more benefits in all incidents involving different severity levels.

The two special cases examined, are first, very minor incidents under compliance with the “Steer-it Clear-it” law, and second, very severe incidents that require a route diversion. The “Steer-it Clear-it” law provided smaller per-incident benefits than other scenarios analyzed because the incidents remained on travel lanes for a limited time, and the limited number of lanes blocked. Since minor incidents occur much more frequently than severe ones, the impact of this law can provide very significant annual benefits if advertised by stakeholder agencies and complied by the drivers.

The route diversions produced the largest benefits of all scenarios analyzed because these incidents were the most severe even though route diversions require more resources than other scenarios. If route diversion plans and alternate routes are available for all high-crash locations along freeways, significant benefits can be provided to motorists if route diversion is used during severe incidents.

7.4 Benefit-Cost Analysis

To meet the objective of analyzing the impacts of the incident management scenarios, the research team conducted a benefit-cost analysis. Results from the benefit-cost analysis indicated that freeway service patrols produce \$11 of benefit for every dollar invested. Using traffic cameras to detect and verify incidents produced \$12 of benefit for each dollar invested. Using traffic sensors to detect incidents and traffic cameras to verify incidents produced \$7 for every dollar invested. While the scenario using multiple strategies to manage incidents produced a high benefit compared to these previous strategies, it only produces \$8 for each dollar invested because it requires investment in several systems.

The benefit-cost analysis showed very high returns for the “Steer-it Clear-it” and the route diversion scenarios. The “Steer-it Clear-it” scenario produced approximately \$22 for each dollar invested if all citizens were aware of and obeyed the law. While a 100 percent compliance rate is unrealistic, these results justify investment in an aggressive advertisement and enforcement campaign statewide. The route diversions evaluated produced approximately \$55 for every dollar invested. While route diversion option is not available at all crash locations, these results justify future investments in route diversion planning.

7.5 Summary

While all incident management tools evaluated for use in South Carolina provided benefits, freeway service patrols and traffic cameras showed the highest return for management of all levels of incidents. In terms of strategies, the “Steer-it Clear-it” law can provide great benefits to motorists if obeyed, requiring advertisement by SCDOT and compliance by motorists. Similarly, the route diversion strategy provided enormous return on investment providing justification for further planning and training.

To meet the next objectives of providing implementation guidelines and educational materials, the research team has developed an implementation plan, a brochure, and a voice embedded presentation. The implementation plan is presented in Appendix B. The electronic brochure and a voice embedded presentation developed as a result of this study are presented separately from this report.

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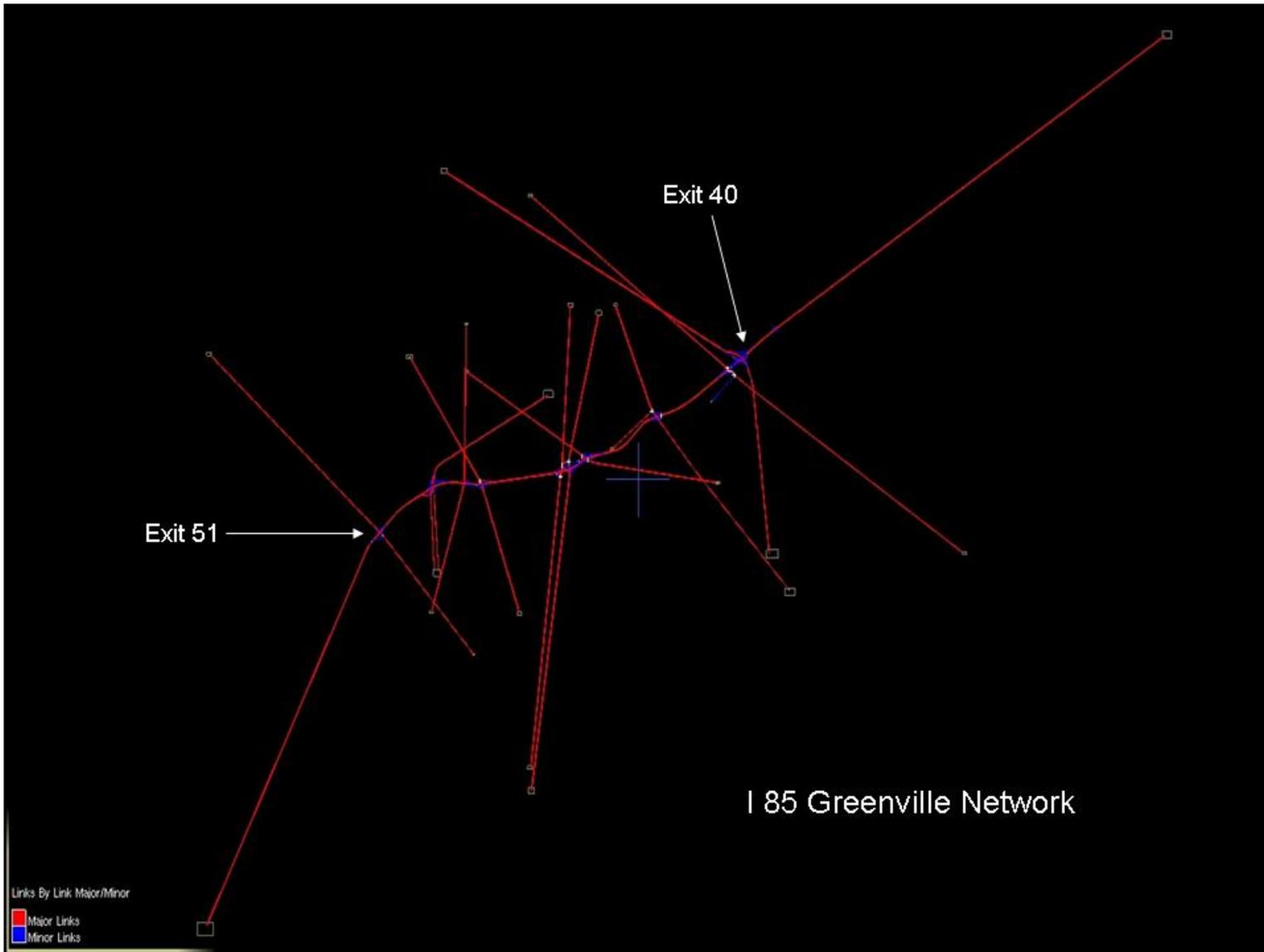
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9.0 Appendix A: Simulation Network Information



Simulation output for Greenville, South Carolina

Strategy: Freeway Service Patrol

Lanes Blocked	Vehicle Miles of Travel (VMT)	Vehicle Hours of Travel (VHT)	Fuel-Gas gal	Fuel-Diesel gal	Total Hydrocarbons (THC) g	Volatile Organic Compounds (VOC) g	Carbon Monoxide (CO) g	Nitrous Oxide (NOX) g	Particulate Matter (PM) g
Existing 30 min headway									
1	822906.7	14005.48	7726.314	3765.47	59930.29	54661.15	531378.5	248763.8	50571.85
2	1185299	20841.99	11370.71	5572.57	96209.19	87995.49	823855.2	375695.4	73803.14
Proposed 10 min headway									
1	823380.4	13974.61	7732.868	3754.10	58714.59	53515.67	525128.0	247305.8	50591.81
2	1187216	20612.46	11280.94	5503.94	92663.48	84669.28	80282.3	368505.1	73413.45

Strategy: Traffic Camera

Lanes Blocked	Vehicle Miles of Travel (VMT)	Vehicle Hours of Travel (VHT)	Fuel-Gas gal	Fuel-Diesel gal	Total Hydrocarbons (THC) g	Volatile Organic Compounds (VOC) g	Carbon Monoxide (CO) g	Nitrous Oxide (NOX) g	Particulate Matter (PM) g
1	825613	14050.04	7789.50	3735.16	58991.70	53751.79	528715.1	246894.1	50564.07
2	1182319	20637.59	11289.82	5514.08	93112.22	85093.38	805913.0	370610.1	73318.01
3	1714312	50735.68	23231.45	10483.96	466958.74	433868.84	3107951.8	962271.3	120677.43

Strategy: Traffic Sensor

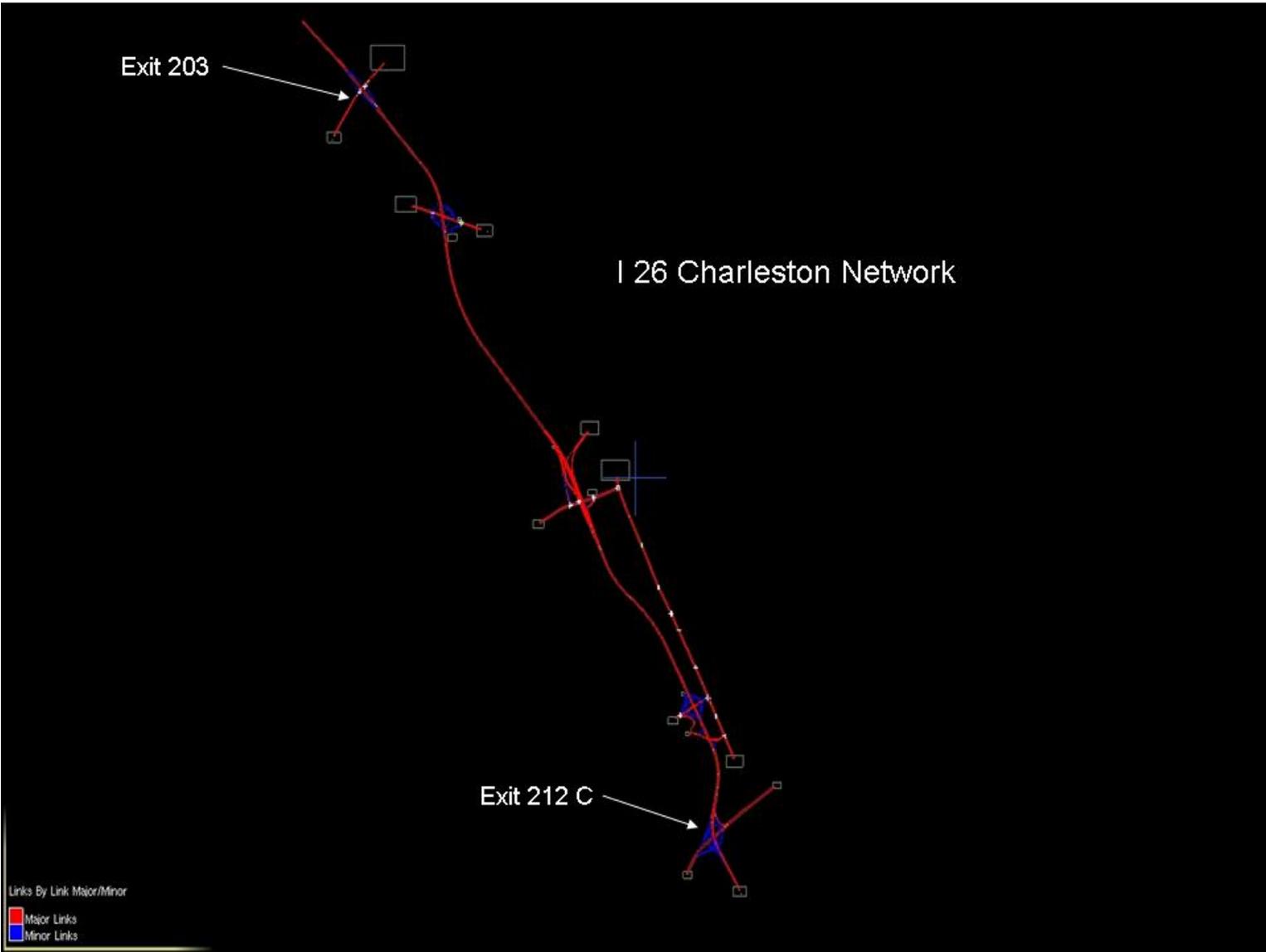
Lanes Blocked	Vehicle Miles of Travel (VMT)	Vehicle Hours of Travel (VHT)	Fuel-Gas gal	Fuel-Diesel gal	Total Hydrocarbons (THC) g	Volatile Organic Compounds (VOC) g	Carbon Monoxide (CO) g	Nitrous Oxide (NOX) g	Particulate Matter (PM) g
2	1142636	22995.98	11885.85	5796.72	139082.59	121528.51	1064518.2	430845.25	73285.82
3	1715196	62884.63	24328.20	11159.25	527582.48	490697.73	3460008.9	1053565.84	123422.16

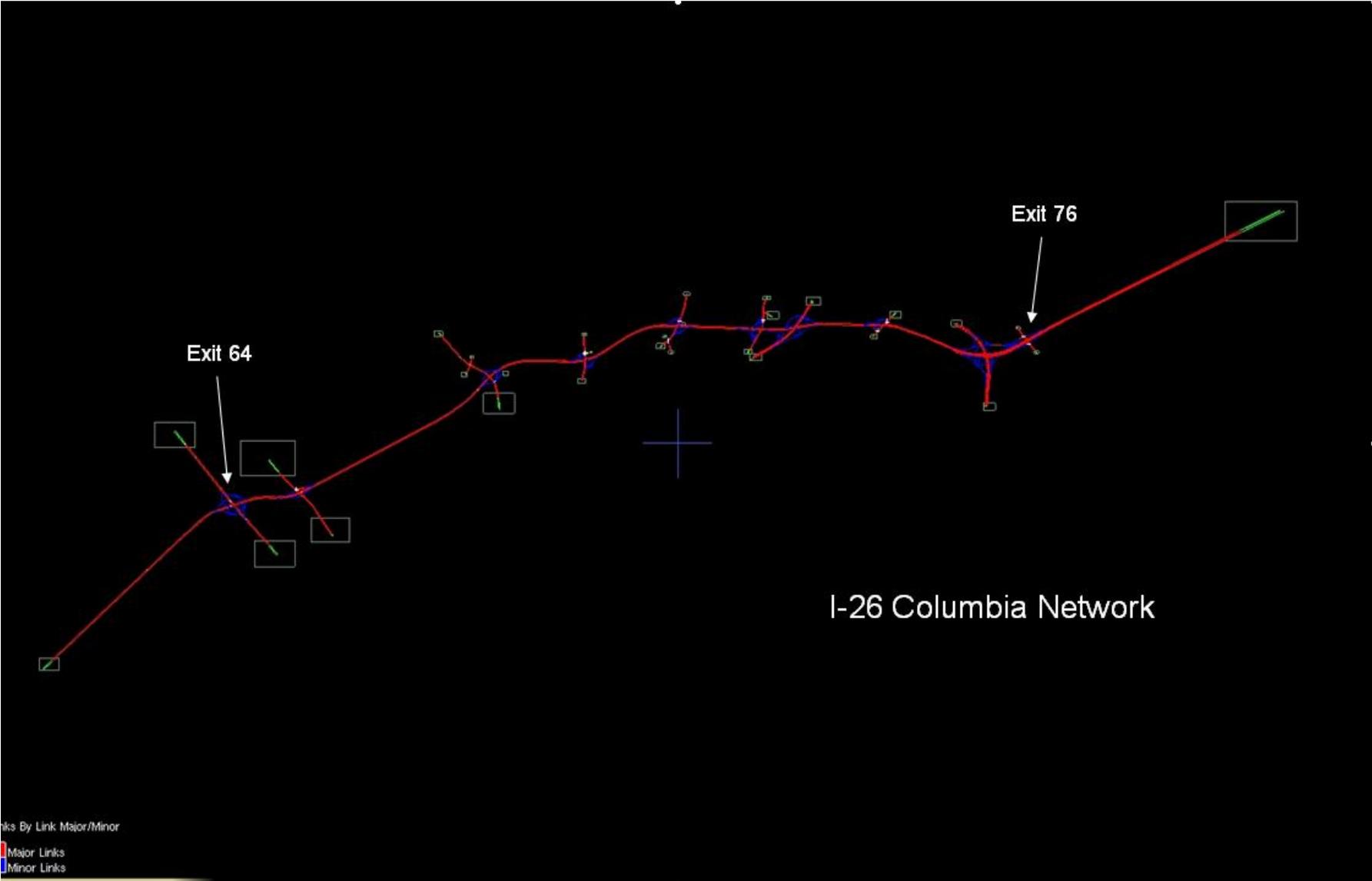
Strategy: Multiple Strategies

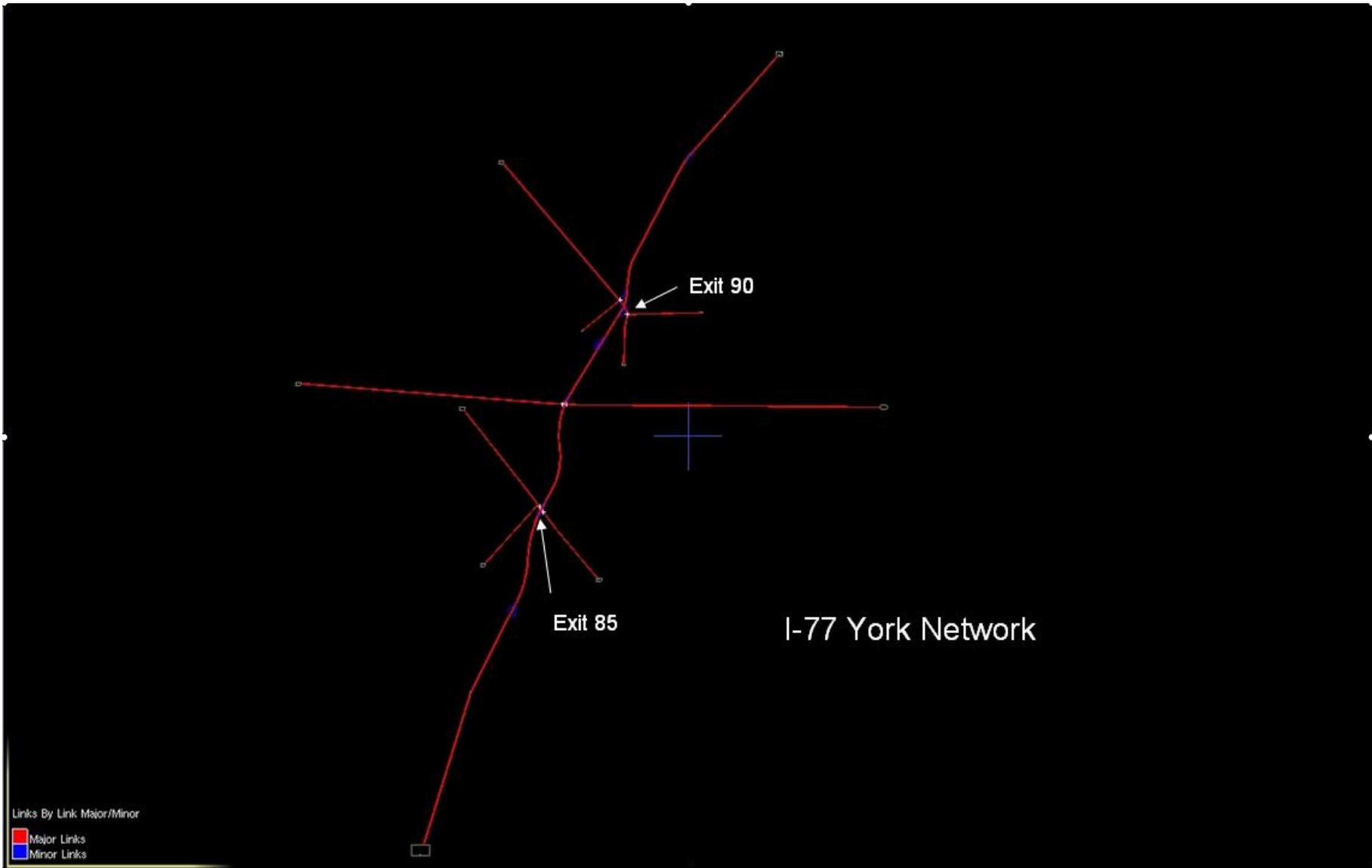
Lanes Blocked	Vehicle Miles of Travel (VMT)	Vehicle Hours of Travel (VHT)	Fuel-Gas gal	Fuel-Diesel gal	Total Hydrocarbons (THC) g	Volatile Organic Compounds (VOC) g	Carbon Monoxide (CO) g	Nitrous Oxide (NOX) g	Particulate Matter (PM) g
1	821725	13966.66	7731.7	3778.609	59019.52	53810.73	526464.6	248663.6	50697.99
2	1185389	20466.89	11271.47	5453.144	90537.63	82678.44	790867.9	364463.5	73126.96
3	1622759	62980.49	26774	12138.45	681343.9	634715.1	4337513	1252293	126305.6

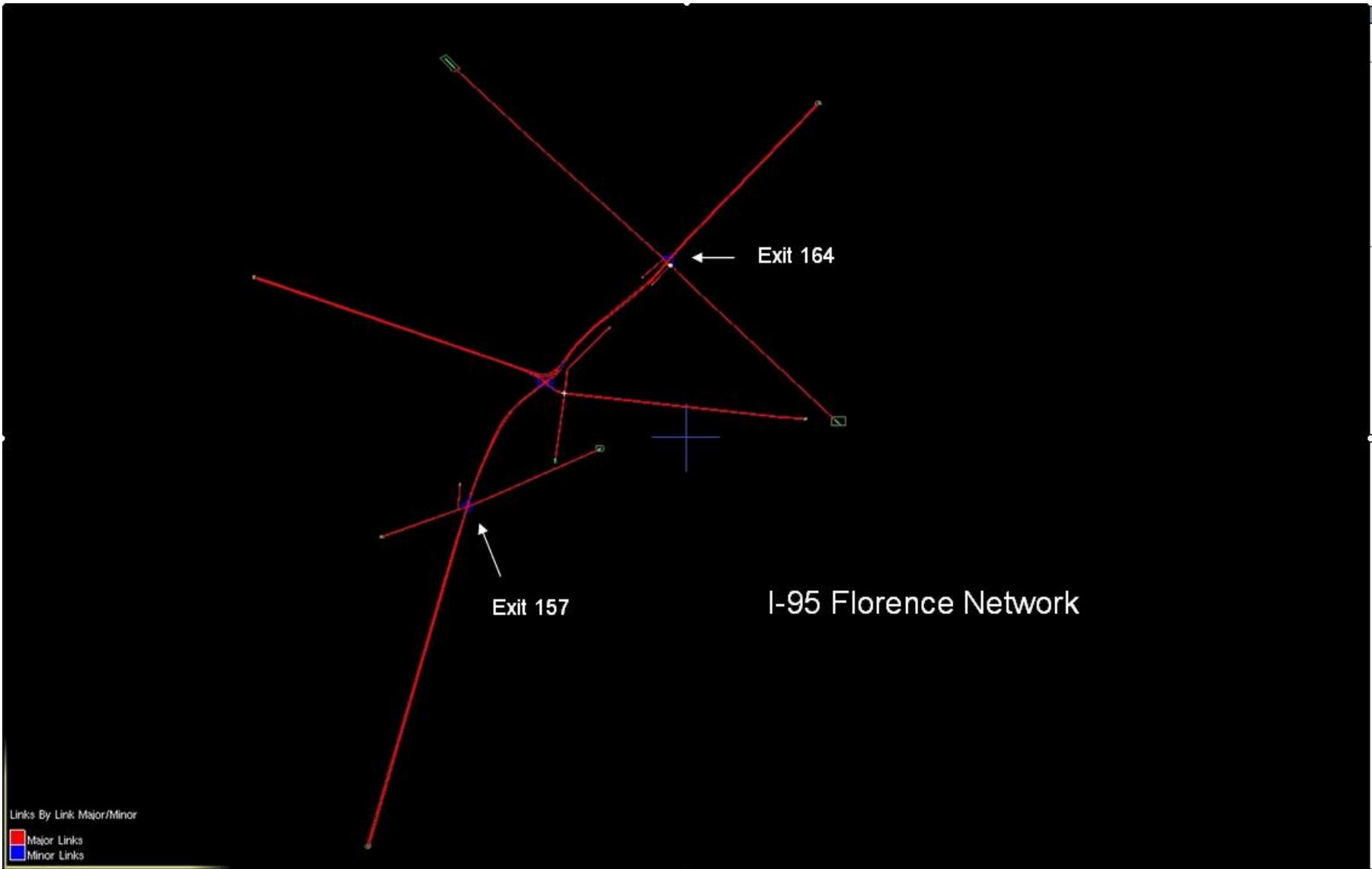
Strategy: Diversion

Lanes Blocked	Vehicle Hours of Travel (VHT)	Fuel-Gas gal	Fuel-Diesel gal	Total Hydrocarbons (THC) g	Volatile Organic Compounds (VOC) g	Carbon Monoxide (CO) g	Nitrous Oxide (NOX) g	Particulate Matter (PM) g
3	36598.69	18456.31	1685475.85	248427.40	229503.77	1823661.34	671508.15	109361.27









10.0 Appendix B: Implementation Strategy

Before beginning the process of implementing an effective incident management program, all parties involved must clearly understand the strategies to be used, especially those stakeholders directly responsible for freeway operations, which are usually State Departments of Transportation. The first planning phase is best for addressing potential issues or problems if all parties are clear as to the strategy, and if all stakeholders are included in this early stage. To reach a consensus for moving forward in the implementation process, the Department of Transportation should host a partnership meeting for all agencies involved in incident management. Involving these parties as much as possible in the earliest stages of planning is essential to achieving successful implementation of incident management, regardless of the strategies chosen for deployment.

Within this stakeholder consensus, goals for the overall operation should be established. These can be relatively broad statements of policies or ideals suggested by the incident management program. Because reaching these goals will require some extent of effort by each stakeholder, objectives for each must be identified. Objectives should be more specific than the defined goals, and be translatable into measurable criteria. This “performance measures” criteria will provide a quantifiable means of evaluating the system so that an accurate representation of the system’s performance will be obtained.

One of the first phases for any implementation plan must always include an evaluation of the existing system. For the incident management strategies studied in this research, state transportation departments must conduct an in-depth assessment of their own program. This phase will help the agency identify existing problems with incident management faced by each stakeholder, and direct them towards potential areas for improvement.

Incident management programs must involve coordination between all the respective agencies. For example, in South Carolina, the SCDOT must coordinate with the State Highway Patrol as well as local EMS providers to ensure that each agency handles the appropriate responsibilities. Each stakeholder must have a defined set of roles and responsibilities for the overall system to manage incidents. The National ITS Architecture is a suitable starting point for defining both these roles as well as the interfaces between agencies. At the very least, the National ITS Architecture can provide a framework for beginning the effort of assigning tasks to each agency. It is also a major part of any implementation process, as it sets standards for communications for all traffic operational components and involved agencies.

Hosting monthly meetings is an effective method for keeping all agencies involved. These meetings, in which successes and problems are discussed, helps agencies continue to support the regional incident management plan without losing focus. More importantly, because the staffs who deal with incident management at each agency often change over time, these meetings will familiarize new staff with on-going efforts to ensure long-term commitment of both specific and multiple agencies to a multi-year effort incident management effort.

Regulations for collecting traffic information and communicating that data must be standardized to ensure that all users have access to the same data set and can track traffic conditions as needed based on this data. Developing a set of standards for both the data collection and the communications processes will help to ensure interoperability of the different incident management agencies.

In addition to agency coordination, each of the incident clearance strategies researched in this study require financial investments. These investments exist in terms of both capital costs and life-cycle maintenance costs. This plan provides a list of possible funding opportunities that go beyond the scope of sources that are normally considered. Traditionally, highway funding comes from fuel taxes. However, as vehicles become more fuel efficient, revenue from these taxes decreases or remains constant, while the number of vehicles increases and congestion soars. The results of such congestion will result in an eventual need for increased capacity and methods of dealing with delay, such as the incident management strategies discussed in this report. Therefore, the need for non-traditional means of supporting highway-related projects becomes ever more apparent. These projects, although ultimately beneficial, will require significant financial funding at the outset, and additional funding throughout the life of the project. Therefore, the sources of this funding must be considered in the initial planning stages of implementation.

After outlining the scope of each strategy, agencies must evaluate the most cost-effective alternatives to determine the best course of action. These alternative strategies should include legislative changes, technology upgrades, financial investments, and long-term maintenance needs and associated costs. Within the alternative evaluation, study should also focus on the best delivery methods of the program that will contribute to minimal overall life-cycle cost and maintenance needs.

A crucial part of an incident management implementation plan is to provide a method for assessing the system, and constant re-evaluation to determine the appropriate changes. The first step in creating this evaluation methodology is to determine the best sources of quality data with which to assess the system. This may require investing in software that provides the transportation agency with the tools needed to maintain the data archiving required in this step. This collected data can then be used to analyze the system. This analysis will require the use of the performance measures identified in the earlier planning stages. Measuring performance in this manner lends a level of confidence to the evaluation process in that the agency can verify its objectivity and have accountability to the stakeholders involved. The results of measuring performance will then become part of the data archiving process. A set of realistic and quantifiable criteria has to be identified. For example, overall accident response time can be used a realistic and quantifiable criterion for assessing performance. Self-assessment can be performed to identify possible changes or updates needed, as well as documentation of the progress made thus far. The following section presents discussions on how those incident management strategies with high benefit-to-cost ratios could be widely implemented on South Carolina highways.

10.1 Traffic Monitoring Devices

Many agencies have implemented traffic monitoring devices or sensors for use in incident detection, developing an algorithm that notifies TMC personnel in the case of an incident. These algorithms track traffic characteristics such as average speeds; when these measures drop below some threshold value, the TMC is notified. Used in conjunction with traffic cameras for verification, these units can be highly effective for initial detection. They also help personnel to be more efficient at monitoring the network. Because personnel need only scan camera images when traffic sensors detect traffic incidents, they would have more time to accomplish other tasks for necessary traffic management.

10.1.1 Agency Coordination

Critical agencies that should be involved in implementation of sensor units in the incident management system for a particular network include the DOT and local or state TMC. Personnel from these offices who are concerned with the day-to-day operations of this system should be included in planning the system. Operating requirements that the particular agency sets forth need to be considered in the initial stages of implementation,

but minimal coverage would likely be the first step in implementing sensor systems. After such a program has been in place for a period of time, the system flaws and inadequacies can be identified and additional coverage or alternative means of monitoring traffic conditions can be developed. Evaluation of the minimal system would be important for an appropriate implementation plan to be completed.

10.1.2 Policy Changes

Sensor detection, a potentially viable incident management strategy, does not require a good deal of legislation to regulate its operations.

10.1.3 Technology

The SCDOT use both radar and loop detectors for incident management. The SCDOT may investigate other detectors, such as optical, acoustic and video detectors and evaluate their efficacy and cost in order to identify the best technology for the invested funds. Data communication alternatives between field devices to traffic management centers that could potentially reduce the existing and future costs should be evaluated.

10.1.4 Funding Sources

Resource sharing described in Section 10.2.4 can be adapted to acquire traffic sensors. In addition, the Federal CMAQ (as it improves air quality as found this research) funds can be used to acquire these systems for greater coverage. In addition to initial funding, the agency must find funds for maintaining the system.

10.2 Traffic Cameras

Agencies across the country utilize traffic cameras for incident verification on a regular basis. Traffic management center (TMC) personnel monitor video feeds from different areas of the network to monitor traffic conditions, and often use the video for specifying the type or severity of an incident that has been detected by other means. Some agencies use traffic cameras for incident detection as well, setting aside a certain number of personnel to continually monitor video. Many DOTs have found greater efficiency in the use of automated sensors to monitor traffic speeds and rely on traffic cameras to examine the area of the incident to determine appropriate response actions. One effective method for reducing incident clearance times is to have an officer from the state police in the TMC. In most cases, he/ she can get a visual image of an accident at the TMC and allow the on-site crews to go ahead with the incident clearance operations without having to wait for the arrival of the state police to the scene. This approach, however, might not only require an effective interagency coordination but also some policy changes.

Some agencies have implemented web feeds to broadcast traffic information from traffic cameras images to the public. For example, South Carolina's DOT website has an area dedicated to traffic cameras, regularly updated with images from each of the cameras positioned on freeways throughout the state. The public can view up-to-date conditions at specified points, which can help them make travel plans using the latest traffic conditions.

10.2.1 Agency Coordination

Agencies involved in traffic camera implementation could include the state DOT as well as law enforcement agencies wishing to use video data for monitoring security. Although most video cameras used in traffic monitoring do not have the capability for very detailed images of traffic, such as for recording license plate numbers, certain cameras could be dedicated for this purpose if the agency requested it. Other organizations usually included in such efforts are the media outlets, which often keep track of traffic information for broadcast to their viewers. Incorporating these assets into the planning stages of

implementation will be an important step in effectively utilizing traffic camera's capabilities for incident management.

10.2.2 Policy Changes

Regulating traffic camera video images would involve defining at first the scope of the data collected. For example, if the cameras are used in traffic management, license plate data would not be part of the collected data, and therefore should not be available to personnel monitoring the images. Thus, regulating the placement of cameras and the resolution of images would be a part of implementing this type of system.

10.2.3. Technology

Traffic cameras are continually being upgraded to include more technologies for agencies wishing to use video feeds for traffic and incident management. Data can be transmitted through fiber-optic lines, allowing for large processing capacity. Additionally, advancements in data transfer capabilities create opportunities for more widespread use of traffic camera systems. The National ITS Architecture and ITS standards provide key descriptions of the communication standards for this data exchange.

10.2.4 Funding Sources

Financial support for traffic cameras will likely require additional funding beyond the traditional fuel tax dollars. Resource sharing is also an excellent way to fund these systems. Resource-sharing initiatives between public and private agencies are gaining popularity with public agencies looking for additional funds for deploying technology in support of their incident management plans. For example, under these initiatives public agencies may provide right-of-way to a private agency to install landline communication systems or communication towers for wireless communications. In return, the public agency receives the right to use the same communication channels without charge while also receiving traffic camera or detector systems. These opportunities should be studied during the initial organizing of the traffic camera deployment plan so that life-cycle costs can be supported throughout the life of the program.

10.3 Freeway Service Patrols

The potential for freeway service patrols to enhance traffic operating conditions is seemingly limitless from the view of previous studies that documented their effectiveness, and from the public opinions. Many surveys have sought to gain knowledge of public opinion on this type of assistance, and the results have been overwhelmingly positive. Further, benefit cost analyses showed that this incident management strategy is very cost-effective.

This research studied the effects of having additional Freeway Service Patrol units operating in the network. Current practice in South Carolina consists of a designated number of Freeway Service Patrol vehicles patrolling a specified portion of interstate, usually near major metropolitan areas. Typical headways between these vehicles during peak hour traffic are usually close to 30 minutes, meaning that the number of units operating at this time of day allow for one freeway service patrol vehicle to pass by an arbitrary point along the route every 30 minutes. This study found that reducing the existing headways provided additional benefits in delay savings, and reductions in energy consumptions and air pollutions. However, this would require additional financial investments and operating costs, but could prove worthwhile because of the benefits to the road users and traffic operations. Another important area of concern is the network coverage of freeway service patrols. While it is not possible to provide full coverage, it is important to cover most of the heavily used routes in a given region. This goal might not be achieved immediately due to budget and other constraints. However, an incremental approach which increases the network-wide coverage can be adopted.

10.3.1 Agency/Stakeholder Coordination

Agencies involved in Freeway Service Patrol operations and communications will include the state department of transportation (DOT) as the lead agency. In addition, Freeway Service Patrol operators must have open communication lines with both the emergency management center and the state highway patrol.

The traveling public is a major stakeholder for freeway service patrols. Agencies responsible for freeway service patrol systems must ensure proper communications to the public about the existence of the patrol and the services they provide in order to maximize their effectiveness. Information that the public must be made aware of includes the portion of freeway on which a unit operates, hours of operation, and contact information, usually in terms of a designated phone number that directs calls to the freeway service patrol dispatch personnel.

10.3.2 Policy Changes

Stakeholders may adjust the service policies of the freeway services patrols, if necessary, to provide greater benefits to the traveling public.

10.3.3 Technology Needs

Existing freeway service patrols may be upgraded with technology to provide additional capabilities such as detecting hazardous materials or re-routing these vehicles in real-time.

10.3.4 Funding Sources

Though the success of freeway service patrols leads to the belief that state officials will support such systems without much opposition, most state DOTs and state governments currently lack the funding to implement them. Therefore, innovative means of financing such projects is crucial to effectively operating these helpful programs. The most effective means of getting the attention of legislators who can direct funds toward these programs is to emphasize the positive public opinion of freeway service patrols, and thus persuade lawmakers that funding them will be received well by voters. To accomplish this task, DOTs can enlist outside agencies to perform surveys to determine the public's inclination regarding the implementation of Freeway Service Patrol programs.

Resource sharing between highway patrol agencies and DOTs is another funding possibility. Traditionally, state troopers or police personnel are dispatched when an incident occurs. These personnel are diverted from more important law enforcement duties that pose a more critical threat than minor traffic incidents such as assisting stranded motorists. Freeway service patrols, on the other hand, can be trained to handle such incidents, and thus lighten the load for highway patrol officers. Therefore, as a potential funding source, DOTs can consider resource sharing with highway patrol agencies, where freeway service patrol programs can make the highway patrols less pressured to handle traffic situations, and are thus free to perform law enforcement duties. Another source of funding may be partnerships with private companies, who can advertise their services on freeway service patrol vehicles in exchanges of supporting the cost of operation and upkeep.

10.4 Incident Quick Clearance Legislation

Quick clearance legislation such as South Carolina's "Steer it and Clear It" law requires drivers involved in minor crashes to remove their vehicles from the crash area if no injuries have occurred. The desired effect of this law is to clear travel lanes as quickly as possible in the event of an incident that blocks lanes on the freeway. The traditional response to these types of minor crashes has been to wait for responders, usually the highway patrol, to arrive on the scene and complete an accident report before moving the vehicle(s) off the

roadway. However, as metropolitan areas across the country continue to experience both growth and increase congestion, this method of dealing with incidents causes more problems than necessary. Therefore, many states have passed (or are planning to pass) laws requiring that those drivers are able to move their vehicle after an incident must do so immediately. This action could rapidly clear travel lanes so that traffic flow could quickly return to normal.

10.4.1 Agency/Stakeholder Coordination

Major stakeholders that must be involved in implementing driver removal legislation include decision makers responsible for passing and sustaining such laws. To obtain their support, they must be made aware of the potential impacts of reduced incident durations due to the legislation.

10.4.2 Policy Changes

The public must not focus on this law at the expense of ignoring safety issues. Such a focus could challenge implementation if not properly defined and communicated to the public. Without such well advertised policy, it will be difficult for the average traveler to determine the level of severity required for an incident to be considered minor, and what actions they must take based upon their individual evaluation of the scene.

10.4.3 Technology Needs

The researchers did not identify any specific needs for the establishment of technological advances as part of implementing driver removal quick clearance legislation. Nonetheless, there is a need for increasing public awareness of such laws, since many drivers hold fast to the belief that law enforcement assistance is needed in every situation. Upon educating the public that this process can be performed outside of the travel way, and not adjacent to the exact crash location, gains can be made towards creating expedited crash clearance techniques. To promote awareness of this legislation, signs can be (and often are) placed along the interstate stating the basic implications of the law, in a format easily understood by drivers. Such messages can designate the type of crash in which driver removal laws apply, and specify the appropriate actions for the driver to take. Other means of spreading information about these laws could include media features, newspaper articles and/or public service announcements. Agencies should evaluate which of these methods would be the most effective for the particular area involved.

10.4.4 Funding Sources

Funding is not a significant issue because the required funds for implementing quick clearance legislation concerns only promoting awareness of the law and such costs are minor. Therefore, a small amount of money must be set aside for highway projects to enhance driver awareness of the legislation. Such an awareness program can include radio advertisements, signage, billboards, and/or TV commercials.

10.5 Route Diversion

For major incidents blocking the entire freeway, it may be necessary to divert traffic to secondary routes to reduce overall network wide incident delay for road users. Implementing such a plan requires the use of additional communication methods to drivers, including variable message signs (VMS) and highway advisory radio (HAR). Utilizing such strategies can maximize the effectiveness of diversion routes by informing drivers of the severity the incident and its anticipated impact on their travel, permitting drivers to decide if they wish to follow the detour or find less congested routes.

10.5.1 Agency Coordination

Both HAR and VMS will require additional system input from emergency response agencies and/or traffic management centers. Communications to drivers must allow for appropriate response times and options

on alternatives, which require full cooperation between stakeholder agencies to provide the most up-to-date information to the traveling public. Coordinating between agencies is the most effective way to establish the lines of communication before a situation arises. There are also various private non-profit entities such as the Cross County Transportation Management Agency (TMA) in Camden New Jersey that provide real-time information to commuters who are registered to their distributions lists <http://www.transportationchoices.com/>. List of other TMAs in New Jersey can be found at <http://www.gmtma.org/statetmas.html>.

10.5.1 Policy Changes

The incident management stakeholders must identify alternate routes for each anticipated incident locations on freeways. Highway patrols personnel responsible for diverting traffic must be made aware of these routes and have plans in place to deploy in a timely manner when such situations arise.

10.5.3 Technology

HAR and VMS can notify motorists of the alternate routes. A direct communication between the freeway and arterial management systems will facilitate real time modification of signal timing on alternate routes to accommodate the additional diverted traffic. There are also various new technologies that can facilitate the dissemination of diversion information to the motorists. (a,b) These include cell phone messages (pager messages) and e-mails. Most of the states have paper diversion maps along with other information that they use to decide about the diversion routes. However, these paper maps and other vital information such as the names and numbers of the people to be contacted in the event of a diversion tend to get obsolete quickly. Updating these paper maps have also proven to be inefficient and time consuming. One way to address this issue is to have electronic diversion decision support tools that can be run using a relatively cheap laptop computer. This kind of computer based portable diversion decision making systems have been or are being implemented by several researchers.

10.5.4 Funding Sources

Resources are needed to identify suitable alternate routes and off-line traffic simulation may help identify such routes. DOT can use researching funding to hire universities or other research entities to identify these alternate routes. Funding for HAR and VMS systems can be provided through other traffic safety, congestion mitigation and emergency operations programs, because they supply information to a broad network of travelers regarding Amber Alerts and daily freeway congestion among others.

10.6 Data Archiving System for Incident Management Planning

SCDOT Traffic Management Centers should be able to formally collect and archive traffic data in a database, including during and after an incident. One method of collecting such data is to equip freeway service patrol personnel with hand-held data collection devices that can be used to quickly enter incident-specific data, such as type of incidents, response and clearance time, and duration of incidents. This would ensure timely and accurate collection of valuable accident data. For example, NJDOT is using a similar hand-held system to collect incident data. Such a formal data collection system can make the data easily accessible for use in incident management planning, analysis and evaluation. Real-time data produce excellent data for future

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operational planning. Archives data can be used to develop planning decisions based on long-term travel trends, the effects of operational adjustments and developing predictive capabilities. Private agencies or academic institutions, via professional services contracts, can be used to develop these systems. Revenue sources from federal and state sources can fund this type of projects.

Printing Costs

Total Printing Costs	\$450.00
Total Number of Documents	50
Cost per Unit	\$9