

5-2007

Evaluating the Impacts of Accelerated Incident Clearance Tools and Strategies by Harnessing the Power of Microscopic Traffic Simulation

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EVALUATING THE IMPACTS OF ACCELERATED INCIDENT
CLEARANCE TOOLS AND STRATEGIES BY HARNESSING THE POWER
OF MICROSCOPIC TRAFFIC SIMULATION

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Civil Engineering

by
Ryan Fries
May 2007

Accepted by:
Dr. Mashrur Chowdhury, Committee Chair
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ABSTRACT

Traffic incidents cause Americans delay, waste fuel, cause injuries, and create toxic emissions. Transportation professionals have implemented a variety of tools to manage these impacts and researchers have studied their effectiveness, illustrating a wide range between different tools and locations. To improve this state of knowledge, this dissertation sought to 1) identify prominent and effective incident management strategies, 2) model six selected incident management strategies within five highway corridors in South Carolina, and 3) apply benefit-cost analysis to evaluate the impact of various combinations of these strategies.

To meet these objectives, the author evaluated published literature of the selected strategies, administered a nationwide survey of these strategies, conducted traffic simulation, and performed benefit-cost analysis. The literature review guided the author to fill gaps in knowledge regarding the effectiveness and expense of identified strategies. The nationwide survey identified effective incident management tools, the extent of their adoption, and their common problems. The author then applied PARAMICS traffic simulation software to evaluate the impact of six tools at five sites on metropolitan interstates throughout South Carolina. Finally, benefit-cost analysis was used to evaluate the benefits against costs at each study site.

The survey provided many insights into both the effectiveness and collaboration within and among traffic incident management agencies and guided

the author in selecting tools for evaluation. While the simulation study found that as the severity and duration of incident increases, so does the potential benefit of incident management tools, the frequency of incidents also produces significant impact on annual benefits.

The benefit-cost analysis indicated that while all the incident management tools evaluated provided more benefits than costs, freeway service patrols and traffic cameras produced the highest return for incidents of varying severity. It was also found more advantageous to select one expensive but efficient incident management technology, rather than engage in the incremental deployment of various systems that might provide redundant benefits. Departments of transportation across the United States see the need to manage incidents more efficiently, consequently this dissertation developed data and analysis to compare benefits with costs to aid decision makers in selecting tools and strategies for future incident management endeavors.

DEDICATION

This dissertation is dedicated to my wife, Celeste Fries, whose undying love and support has made reaching my goals possible. I thank you with all of my heart. You have shown great patience while I spent countless hours during my degree and while writing this document, you are the most important person in my life, and this dissertation represents the completion of this phase in our lives; for these reasons, I dedicate it to you.

ACKNOWLEDGMENTS

I would first like to thank my advisor Dr. Mashrur Chowdhury for his guidance, encouragement, trust, support, and knowledge. I am grateful for his guidance in both my life and my work as I am pursuing a career in academic teaching, which I feel will be much more rewarding. I appreciate his encouragement during both the often long process of academic publication and the job search and interview process. I am grateful for his trust in allowing me to manage a research project as the graduate student leader because of the experience this has given me and the lessons I have learned. Next, I appreciate Dr. Chowdhury's support through nominations for fellowships and awards, and his wealth of knowledge that he often used to guide me through this program. For all of these reasons, I deeply appreciate his impact in my life and education.

The members of my committee also deserve a special acknowledgement. Dr. Wayne Sarasua was the first person who encouraged me to join the Clemson family. He was always able to keep the classroom an interesting place to learn and constantly challenged me, making me realize how rewarding academia can be. Dr. Jennifer Ogle helped me with both my coursework and my dissertation research. I appreciate the many opportunities she has given me including being a guest grader and a guest lecturer in her classes, but particularly the references she has given me in my job search. Dr. Anne Dunning also deserves special thanks for helping me more clearly communicate my ideas. I especially

appreciate all of the guidance and encouragement she has given me in the interview process and during my job search.

I would also like to give a special thanks to my parents Jane and Nick Fries, my sister Danielle, my grandmother Julia Fries, and my mother and father in-law Jean and George Raymond for all of their continued encouragement throughout my graduate work. This encouragement has allowed me to set high goals and achieve them and I am deeply grateful.

Last, but not least, I would like to acknowledge my fellow students who shared many hours conducting research in the field and in the lab. These include Yongchang Ma, Liz Stephen, Carol Hamlin, Yan Zhou, Imran Inamdar, and Parth Bhafsa. Thanks for your friendship and hard work.

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NOMENCLATURE

ADAS – Advance Driver Assistance Systems

AIMSUN – Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks

API – Application Programming Interface

ATIS – Advanced Traveler Information System

ATMS – Advanced Traffic Management System

AVENUE - Advanced & Visual Evaluator for road Networks in Urban areas

AVL – Automatic Vehicle Location

ARDS - Automated Debris Recovery Systems

CAD – Computer Aided Dispatch

CBD – Central Business District

CCTV - Closed Circuit Television

CHART – Coordinated Highway Action Response Team

CO – Carbon monoxide

COMET - COrridor ManagEment Team

COMPASS – COMPUter Assisted Surveillance System

CORSIM – COrridor SIMulation

DOT – Department of Transportation

DVU – Driver Vehicle Unit

Nomenclature (Continued)

EMS – Emergency Medical Services

FHWA – Federal Highway Administration

FIRST - Freeway Incident Response Safety Team

GETRAM – Generic Environment for TRaffic Analysis and Modeling

GIS – Geographical Informational Systems

GPS – Global Positioning System

HAR – Highway Advisory Radio

Hazmat – Hazardous material

HC – Hydrocarbons

HEROS - Highway Emergency Response Operators (Georgia NaviGator System)

HOV – High Occupancy Vehicle

ILD – Inductive Loop Detector

INTRAS – INTegrated TRAffic Simulator

ITS – Intelligent Transportation Systems

MAP – Motorist Assistance Patrol

MITSIMLab – Microscopic SIMulation Laboratory

MMDI – Metropolitan Model Deployment Initiative

MOE – Measure of Effectiveness

NCHRP - National Cooperative Highway Research Program

NO_x – Nitrous Oxides

OD - Origin Destination

Nomenclature (Continued)

PARAMICS – PARallel MICRo-Simulation

PATH – Partners for Advanced Transit and Highways

PDO – Property Damage Only

PM – Particulate Matter

QRS-Quick Response System

RHODES – Real-time Hierarchical Distributed Effective System

ROW – Right of Way

S2P – Shape to PARAMICS

SCATS – Sydney Coordinated Adaptive Traffic System

SCOOT – Split, cycle, Offset Optimization Technique

SHP – State highway patrol

SITRAS - Simulation of Intelligent

TIMS - Traffic Information Management Center

TRAnsport Systems

TMC – Traffic Management Center

TPSIM - Toll Plaza SIMulation model

VIP – Video Image Processing

VISSIM – VISual traffic SIMulation

VMS – Variable Message Signs

WATSIM – Wide Area Traffic SIMulation

WIM – Weigh-in-motion

CHAPTER ONE

INTRODUCTION

Traffic congestion on American highways is a major problem as it wastes time and fuel while increasing emissions and the risk of secondary crashes (Derr & Ray, 2004; Mathew et al, 1999). Despite widespread awareness of the problem, congestion is worsening (Cambridge, 2004). Most American roadways (approximately 60 percent) are already congested and drivers spend more time traveling than ever before (Schrank & Lomax, 2005). Reducing congestion could greatly improve the quality of life and economy in the United States.

There are two main types of congestion, recurring and nonrecurring. Recurring congestion, which usually occurs during morning and evening peak periods, is caused by vehicle demand nearing or exceeding the roadway capacity. While this type of congestion is routine, nonrecurring congestion involves events that can not be predicted, including vehicle crashes and stalls, debris in the roadway, severe weather, and short-term construction. Of these, traffic incidents create a large portion of all non-recurring congestion. Independent studies conducted over multiple years (Ozbay & Kachroo, 1999; Cambridge, 1990; Cambridge, 2004; Schrank & Lomax, 2004) have estimated that traffic incidents account for between 55 and 60 percent of all traffic congestion in the United States, emphasizing the consistently significant role that incidents play in highway congestion.

A wide variety of strategies are used across the United States and identifying effectively perceived strategies helped to steer the selection of strategies for evaluation. No up-to-date knowledge of which strategies are most widely used exists.

Regardless of whether incident management strategies are widely adopted or highly valued, they have not been measured in a way allowing comparison simultaneously between both locations and strategies. Some previous studies included more than one study site and examined only one strategy (Hagen et al., 2005; Khattak et al., 2004; Bertini et al., 2001; Nee & Hallenbeck, 2001; Fenno & Ogden, 1998; Stamatiadis et al., 1998) or only studied one site and evaluated more than one strategy (Park et al., 2005; Wirtz et al., 2005; Der-Horng et al., 2004; Mahmassani et al., 2004; Chu et al., 2004a; Perrin et al., 2004; Dumke & Doyle, 2001; Carter et al., 2000; Birst & Smadi, 2000; Prevedouros, 1999; Hawkins et al., 1999; Abdulhai et al., 1999; ITE, 1997; Henk et al., 1997; Parsons, 1997; Samartin, 1997; HIDO, 1997). Further, due to the differences in methodologies between studies there is no solid basis for comparing the results between studies. While Fenke & Collins (2003) have evaluated two technologies (microwave and acoustic sensors) at two sites (Philadelphia and Pittsburgh, Pennsylvania), the objective of the dissertation broadens the scope of this and other previous incident management studies.

Beyond the effectiveness of strategies, officials selecting incident management strategies to implement should consider their benefits against their monetary costs. Because no previous incident management simulation studies

have used benefit-cost analysis to compare incident management results from five sites within one state, this work expanded the scope of benefit-cost application. While the use of this tool was not new in incident management, its broad application in this research provided a more realistic comparison of technologies than from other previous studies.

This dissertation sought to meet three objectives. 1.) The first objective was to identify incident management strategies widely used and perceived effective to evaluate. 2.) The second objective of this research was to determine performance of those strategies on multiple metropolitan interstate corridors throughout South Carolina by harnessing the power of both microscopic traffic simulation and application programming interfaces. All strategies and study sites will use the same study methods allowing justified comparison. 3.) The third objective of this research was to use the tool of benefit-cost analysis to evaluate the impact of various combinations of incident clearance strategies in five large networks in South Carolina.

To achieve all three objectives of this dissertation, the author evaluated published literature, conducted a nationwide survey, used traffic simulation, and conducted benefit-cost analysis. The literature review, as presented in the second chapter, guided the author to fill appropriate gaps in knowledge. The nationwide survey helped identify effective incident management tools and problems that guided the selection of tools to evaluate with the traffic simulation. The author then used PARAMICS traffic simulation software to evaluate the impact of using incident management tools at five metropolitan interstate sites across the state of

South Carolina. Benefit-cost analysis was used to evaluate benefits against costs for tools used at each study site.

This document provides detailed explanation and discussion of this research. Chapter two, the literature review, presents relevant literature of incident management strategies, simulation studies and benefit-cost analysis to illustrate the state of practice in more detail. Building on this knowledge of the subject area, chapter three discusses the research methodology used to evaluate incident management strategies through the development of several novel simulation applications. Chapters four and five provides the survey results and the simulation results, respectively. Chapter six discusses the findings from the benefit-cost analysis and chapter seven discusses and synthesizes the findings. Chapter eight concludes the dissertation with the author's overall deductions, as well as makes recommendations.

CHAPTER TWO

LITERATURE REVIEW

Incidents cost the United States \$75 billion in lost productivity and wasted 8.4 billion gallons of fuel in 2005 (FHWA, 2000). Even minor traffic incidents significantly impact traffic delay and safety, one study finding an incident blocking one freeway lane of a two-lane, one-way segment, reduced the capacity by 65 percent (Gordon et al., 1996). Another study found that for every minute an incident blocked travel lanes, traffic was slowed four minutes before returning to normal flow (Maze et al., 2005). To manage the impact of traffic incidents, transportation professionals have implemented a variety of tools and strategies.

Chapter two seeks to inform the reader of the evolution and the current state of knowledge in three main areas:

- freeway incident management,
- traffic simulation software, and
- benefit-cost analysis.

Reviewing these areas will improve the reader's understanding of credible incident management strategies and their effectiveness, and to demonstrate the justification for choosing traffic simulation as an evaluation tool and benefit-cost analysis as an impact assessment tool.

Introduction to Tools and Strategies for Freeway Incident Management

The traffic incident management process includes four primary steps: detection, verification, response, and recovery (Pearce & Subramaniam, 1998). While each of these steps is unique, they are also interdependent. In particular, decreasing incident detection times indirectly affects the timeliness of the incident response process (Skabardonis et al., 1998a). For example, if an incident is detected after three minutes instead of ten, the incident responder will travel through less congestion before reaching the incident scene. The recovery time also decreases with shorter detection times.

Transportation professionals use various other tools specifically developed to reduce the impact of traffic incidents. Because more than 90 percent of all crashes are due to human error (Lamm et al., 2005) and human behavior is difficult to control, preventing crashes is difficult. As a result, incident management professionals focus on decreasing the impact of incidents by reducing response and clearance times through legislation, incident sensors and hotlines, information dissemination tools, traffic management coordination systems, freeway service patrols, and crash investigation tools. While much work has been done on collision avoidance systems (Chan, 2005) that prevent incidents, this literature review focuses on the more realistic environment of incident management.

Incident Clearance Law

Recent state efforts have focused on passing and enforcing laws that require prompt clearance of traffic incidents. While some laws require drivers to

clear their own vehicles after minor, property damage only (PDO) incidents, other laws protect responding law enforcement and incident response personnel. 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 defines quick clearance as “the practice of rapidly and safely removing temporary obstructions from the roadway” (Dunn & Latoski, 2003). For this definition, obstructions not only include the vehicles involved in an incident but also any spilled material.

The National Cooperative Highway Research Program (NCHRP) identifies four main categories of quick clearance laws: driver stop laws, driver removal laws, authority removal laws, and authority tow laws (Dunn & Latoski, 2003). Driver stop laws require drivers to leave vehicles at the place where they stopped after the incident until law enforcement officials arrive and document the crash scene. To expedite faster removal of minor incidents, driver removal laws in many states require drivers to move their vehicles from travel lanes prior to the arrival of law enforcement or incident response officials. Driver removal laws are often called “Move-It” or “Steer It, Clear It” laws (Dunn & Latoski, 2003). Both of these laws place responsibility on the vehicle drivers. The states shaded in Figure 1 have implemented driver removal legislation before May 2006.

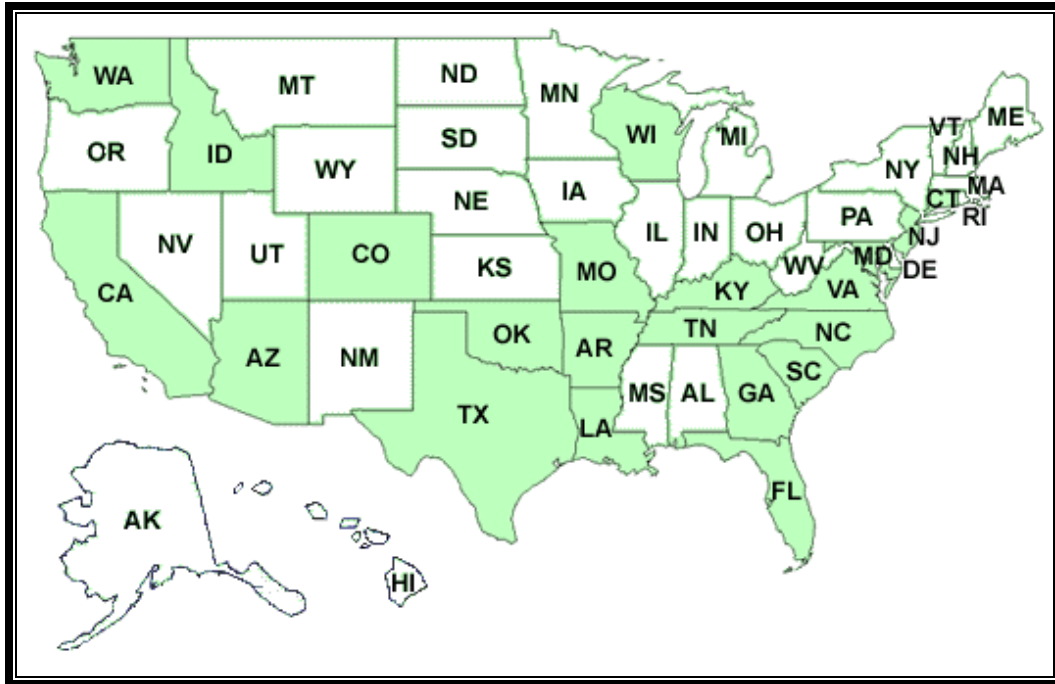


Figure 1. States with driver removal laws
Source: Hamlin et al., 2007

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 (WRAL, 2004). Others find that the effectiveness of these laws is constrained by public knowledge and the understanding of them, which requires effective communication (WRAL, 2004). More findings on the effectiveness of such legislation can encourage other states to implement such legislation.

Authority removal and tow laws place responsibility on the response personnel for quickly moving crash vehicles and their cargos out of the roadway. Causes of increased incident clearance times often include site investigations

seeking to determine the cause of the incident, heavy-duty towing, or spill and cargo cleanup. Historically, many commercial vehicle owners are concerned about the cargo removal, focusing on ensuring salvageable material is handled with care (I-95 Corridor Coalition, 2003). Authority removal and tow laws allow transportation authorities to remove spills and vehicles before the owner has examined the material without threat of repercussion.

Legislations enact quick clearance practices to protect incident responders and to enforce driver involvement in incident clearance. State agencies nationwide have some combination of quick clearance legislation, but the little is known about the effectiveness of these laws.

In addition to laws aimed at removing incidents from travel lanes, other laws focus on protecting responders. Move-Over laws require motorists to either slow down or move over when a police officer or incident responder is on the side of the shoulder with lights on. At least thirty-eight states have passed some form of a Move-Over law (Perdue & Dallas, 2006). While these laws are important for responder safety, the focus of this study was improving the clearance times of crashes.

Incident Detection and Verification Using Traffic Sensors

Traffic sensors are technologies available to provide traffic management personnel with operational data about the conditions along a roadway, are classified into two categories based on location: intrusive sensors are in or under the roadway and non-intrusive sensors beside or above it. While intrusive sensors require the closure of travel lanes for installation, maintenance, and repair, few

non-intrusive sensors do. Regardless of location, sensors monitor traffic characteristics to detect changes caused by traffic incidents.

The most widely used sensors (Chowdhury & Sadek, 2003), the inductive loop sensor, or ILD, uses several coils of wire under or in the road surface, monitoring the inductance, or the ease with which electricity passes through the loop, as vehicles pass. An ILD controller unit interprets the changes in inductance, identifying both stopped and moving vehicles or, in special cases, determining the speeds and vehicle lengths (Burns, 2005).

Two types of non-intrusive sensors include microwave and ultrasonic. Microwave sensors, commonly known as radar, emit microwave signals onto travel lanes, monitoring the reflected signal to interpret the change in its frequency to determine vehicle speed and presence. While radar is popular because it can accurately operate under all weather conditions, ultrasonic sensors are affected by the weather and are not as popular (FHWA, 2003).

Acoustic and infrared, also types of non-intrusive sensors, measure traffic by sound and energy waves, respectively. Specifically, acoustic sensors measure the change in vehicular sound waves to detect presence, speeds, and volumes. While acoustic sensors are unaffected by light and weather conditions, certain locations such as those adjacent to airports or on frontage roads are not suitable. Infrared sensors measure changes in infrared energy to determine vehicle speeds, but their accuracies are impacted by adverse weather (FHWA, 2003).

Closed circuit television cameras (CCTV) are other important non-intrusive sensors frequently used in incident management. While standard cameras can help traffic management verify incidents, computer technology increases the capability of both obtaining information and acting on it quickly. This video image processing (VIP) combines CCTV and computer software to identify vehicles driving along the roadway and to calculate their speeds, with a specified reduction indicating an incident (Chowdhury & Sadek, 2003). Even though weather affects the accuracy of VIP, it remains an invaluable tool for many traffic management agencies worldwide.

Other incident detection tools use motorist interactions with emergency call box systems, incident hotlines and in-vehicle mayday systems. Emergency call boxes (free telephones placed beside the freeway) connect motorists to traffic management personnel for reporting incidents. Research has found these call box systems provide valuable incident detection tools in rural areas. Recently, focus has shifted from call boxes to cellular phone methods.

Programs around the country encourage motorists to report traffic incidents to hotlines, for example *HP and #67, the most widely known number being 911. The value of this tool continues to grow as these networks expand service areas and as cellular technologies improve. Specifically, using geographic information systems (GIS) to locate callers provides incident responders with exact locations, thereby improving response time (FCC, 2006). This practice is highly recommended by the I-95 Corridor Coalition for future deployment under

the name Enhanced Wireless 911 (I-95, 2005). More research is needed on these current and future incident reporting systems to evaluate their effectiveness.

Mayday systems send crash notification and requests for help via satellites to the appropriate emergency response agency. While these systems are not free, they provide users faster incident detection and, therefore, faster response time as well as reducing the traffic delays experienced by other motorists. After detection, to ensure the proper equipment is dispatched to an incident scene, incident verification checks the accuracy of detection and classifies the type of incident. The two most commonly used tools for incident verification, traffic cameras and freeway service patrols, will be discussed in more detail in later sections of this dissertation.

Much research worldwide has focused on determining the impact of the various incident detection and verification tools. In Japan, traffic cameras were installed on the Awaza Curve of the Hanshin Expressway for incident detection in addition to variable message signs to warn drivers of upcoming incidents. After deployment, reduced detection times produced a reduction in information dissemination from 8 minutes to 2 seconds, and resulted in a reduction in the secondary crash rate by 50 percent (HIDO, 1997). On the Gowanus Expressway in Brooklyn, New York, traffic cameras were used to monitor traffic and variable message signs are used to disseminate incident information. The system has reduced incident clearance times from an average of 90 minutes to 31 minutes (Samartin, 1997). Similarly, the COMPASS system in Toronto, Canada, used traffic cameras, loop detectors, and variable message signs to detect incidents and

to disseminate information. The system reduced incident durations from 86 to 30 minutes on average (ITE, 1997). A similar system operating at the Lundby Tunnel in Sweden also used traffic cameras, loop detectors, and variable message signs but included variable speed limit signs. This system reduced the rates of serious crashes, secondary crashes, and overall crashes by 35, 46, and 12 percent, respectively. A comparable system in Germany used the same four technologies, reducing the crash rate by 20 percent (Hawkins, et al., 1999).

Networks of microwave and acoustic sensors were deployed in both Pittsburgh and Philadelphia, Pennsylvania, where the collected data was transmitted in real time to both a national database and to public and private information dissemination services. While many drivers changed their route (68 percent in Pittsburgh and 86 percent in Philadelphia), some changed their travel departure time (47 percent in Pittsburgh and 66 percent in Philadelphia), but few changed their travel mode (6 percent in Pittsburgh and 2 percent in Philadelphia) (Fekpe & Collins, 2003).

The Trailmaster System in Phoenix, Arizona, used road sensors, traffic cameras, variable message signs, ramp meters, and a traffic management center to manage approximately 30 miles of urban freeway. A study found that this system reduced property-damage-only crashes by 25 percent, possible injury crashes by 30 percent, and minor injury crashes by 21 percent (Zimmerman et al., 2000).

The TranStar System in Houston, Texas, integrates variable message signs, a traffic management center, ramp meters, traffic cameras, high occupancy vehicle lanes, freeway service patrols, and regional traffic signal control. In 1997,

a study conducted by Parsons Transportation Group and the Texas Transportation Institute found that this system saved travelers at least five minutes from traffic congestion due to incidents and as much as 30 minutes (for larger incidents) in travel time. Lifting high occupancy vehicle lane restrictions due to incident congestion has also been found to save Houston travelers between 13.5 and 27 minutes in travel time during incidents. The ramp metering system was estimated to save users over \$5 million in delay costs per year by adjusting metering rates for incidents, weather, and other events. Further, the Astrodome ATMS, in coordination with the TranStar System, reduced street congestion around the Astrodome by 46 percent (Parsons, 1997). As these results suggest, the TranStar System provides a valuable service to travelers in Houston.

Similarly, the TransGuide System in San Antonio Texas uses variable message signs, dynamic lane assignment, loop detectors, traffic cameras, and an extensive communication network to aid travelers. This system reduced primary crashes (35 percent), bad weather crashes (40 percent), secondary crashes (30 percent), and overall crashes (41 percent) (Henk et al., 1997).

The Metropolitan Model Development Initiative (MMDI) System in San Antonio, Texas, included an advanced traffic management system and an incident management component. A 1999 study showed that these systems reduced total delay by 7.0 percent and the variability of travel time by 2.1 percent (Carter et al., 2000).

In Albuquerque, New Mexico, a construction traffic management center (CTMC) was used during the construction of the “Big I” interchange between I-

25 and I-40. This CTMC integrated traffic cameras (with wireless interfaces) with variable message signs (permanent and portable), and dispatched police, tow trucks, and a freeway service patrol. This integration reduced the average incident clearance time from 45 minutes to just 20 minutes in one year (Dumke & Doyle, 2001).

In-vehicle sensors also have the ability to report incidents. The PuSHMe Mayday System in Washington State allows drivers to send a distress signal to local traffic management. Drivers reported an improved feeling of security on the roadway while using the system (Haselkorn et al., 1997). Other in-vehicle Mayday systems exist in the private sector. While the OnStar system, a GPS-based in-vehicle system, is better known for its navigation capabilities, the system can also automatically alert authorities of the exact location of a crash when airbags deploy (Thompson, 2004).

Vehicle probes also aid traffic management systems in detecting traffic incidents. One study conducted by the BMW Group found that if approximately 10 percent of the vehicles in a road network were probe vehicles, traffic information about 95 percent of the road network could be updated every 10 minutes. This study noted the coordination needed among vehicle manufacturers to implement such a system eventually (Boeckelt et al., 2005). While current technology can deploy probe vehicle data collection infrastructure on the roadside and in vehicles, this deployment has not been achieved in any large scale public application.

State-of-the-art systems using sensors include the Road Weather Information Systems used in Maryland's Coordinated Highways Action Response Team (Petrov & Point-Du-Jour, 2002), Virginia's Smart Road System (Pearce, 2003), Michigan's Remote Traffic Microwave Sensors (FHWA, 2004), Traffic.com's TrafficPulseSM system, and ENSCO's Remote Monitors (Nejikovsky & Keller, 2000). These systems all use sensor-collected traffic data to detect incidents and/or hazardous weather conditions, to distribute precautionary alerts, to dispatch incident response teams, and to assist in real-time traffic management.

Call boxes are another incident detection tool used by many agencies (Dodd, 1996). 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. This study that examined a six-month period, approximated the benefit at \$330,000, or a benefit-cost ratio of 2.76:1 (Kolb et al., 2000).

As these studies of incident detection and verification tools show, most systems use a combination of tools, making it difficult to compare technologies across cities. Further, when technologies are studied separately, they are examined in only one location, making the results difficult to transfer to other cities. A study examining incident detection and verification tools individually and at multiple locations has the potential to provide a better comparison between tools, one that is also more transferable to other cities.

Incident Management Using Information Dissemination and Route Diversions

Once field devices detect an incident, its management requires that information and pertinent data be sent to the proper authorities, using such tools as advanced traveler information systems, advanced traffic management systems, and traffic management centers. An advanced traveler information system (ATIS) provides travelers with real-time information such as route guidance and ride sharing in the form of web broadcasts, highway advisory radios, and/or variable message signs (Iteris, 2005). Web broadcasts include public web sites for the state departments of transportation (DOT) or at private web sites such as traffic.com. Highway advisory radios are public stations that broadcast only when incident information is available. Some systems include signs alongside the highway, recommending drivers to tune to the broadcast when lights are flashing. In addition, variable message signs (VMS), also known as changeable message signs or dynamic message signs, are permanent or portable electronic signs that allow the posting of several different messages specifically information about traffic.

Advanced traffic management systems (ATMS) integrate technology to improve the safety and mobility of travelers. These systems include ramp metering systems, variable speed limit signs, adaptive signal control, or dynamic lane assignment, use information from an ATIS, but do not specifically focus on broadcasting. Ramp meters, traffic signals located at the end of freeway on-ramps, control the flow of vehicles onto the freeway to maintain optimum volume. Whereas fixed ramp-metering systems use predetermined timings,

adaptive systems react to traffic demand on the ramp and freeway in real time. An ATMS overrides typical timings during incidents, improving freeway safety and efficiency.

ATMS also control variable speed limit signs which lower and raise speed limits. During incidents, lowering speed limits improves safety for incident management responders and motorists. Adaptive signal control changes the traffic signal timing in response to changes in short-term demand, such as those caused by incidents. Dynamic lane assignment used by ATMS activates shoulders and reversible lanes during peak hours and incidents. Commonly, dynamic lane assignment displays a red “x” over a travel lane when closed and a green arrow when open. Because peak period traffic is usually heavier in one direction, this management tool provides ATMS a more efficient way to use existing roadway lanes during peak periods and incident.

Traffic management centers (TMCs) refer to the buildings that house parts of either an ATIS or ATMS and link communications with other local agencies involved in traffic incident management such as police, fire, and emergency medical services (EMS). These centers traditionally have a central monitoring room where operators monitor several traffic cameras and sensor outputs to detect traffic incidents. ATIS and ATMS use the communication abilities of a TMC to manage incidents by coordinating the detection, verification, response, and clearance efforts among agencies and devices.

Traffic management personnel also rely on information dissemination and route diversion tools to minimize the impact of traffic incidents. Sharing timely

information with motorists is also a vital ITS component aimed at reducing congestion, delay, and even secondary incidents. Information dissemination tools such as variable message signs and highway advisory radios suggest route diversion options to drivers; however, these devices cannot always provide motorists sufficient information to change travel routes effectively (Intelligent, 2000). Traffic diversion strategies range in complexity from suggesting the use of a freeway auxiliary lane to both retiming signals on an arterial route and using ramp metering. Current incident management operations primarily focus on freeways, and even though arterial signal control is an effective way to manage traffic, very few agencies employ it for traffic management during incidents (Intelligent, 2000).

Variable message signs and highway advisory radios run by state or local transportation agencies provide valuable up-to-date information to travelers. Variable message signs, electronic road signs that allow several messages to be posted, inform drivers of expected driving conditions, for example, congestion, ice, and roadwork. Highway advisory radios broadcast similar traffic and weather information to drivers on a dedicated frequency. Driver reactions to both of these have large impact on traffic congestion and secondary crashes. Integrating variable message signs, highway advisory radios, and an interactive website, the Traffic Incident Management System (TIMS) in Philadelphia, Pennsylvania has reduced secondary incidents by 40 percent and lowered closure time by 55 percent, by suggesting diversion routes to travelers. The TIMS system has also reduced the rate of severe incidents by 8 percent (Taylor, 1997).

A similar advanced traveler information system (ATIS) was evaluated in Seattle, Washington, as part of the national MMDI project in San Antonio, Texas, previously discussed. While the study showed that under normal operations, the system saved only 1.5 percent of delay during the AM peak period and a 2.5 percent of delay during the PM peak period, these figures were much higher when there was inclement weather, traffic incidents, heavy demand, or a combination of these factors. The ATIS system also reduced crashes by 0.6 percent and fatal crashes by 0.4 percent by providing motorists with pertinent travel information, allowing them to avoid congested roads due to incidents. In combination with an ATMS, this system was projected to produce reductions in delay and stops, reduced emissions, and fewer crashes (Wunderlich et al., 1999).

Studies have also examined driver reactions to information dissemination tools and the resulting congestion impact. Drivers in San Antonio, Texas (TransGuide System), reported that while the signs were helpful in choosing safe travel lanes, rerouting was seldom an option chosen (Carter et al., 2000). Other studies conducted across Europe and the United States have found more quantitative measures of driver response to information dissemination tools. For example, independent studies have shown that 30 percent (Chatterjee et al., 2002), 33 percent (Chatterjee & McDonald, 2004), 70 percent (Emmerink et al., 1995), 75 percent (Abdel-aty et al., 1993), and 86 percent (Henk & Kuhn, 2000) of drivers would change their route if they knew incident information. Although these studies show a large variation, one of these determined that the appearance of queues played a major role in a motorist's choice to follow a recommended

diversion route (Chatterjee & McDonald, 2004) suggesting that diversion choices are site and incident specific.

Information dissemination and clear communication within participating agencies also aids incident management. A computer-aided dispatch (CAD) system used by Albuquerque Ambulance in New Mexico gives the exact location of incidents through a map-based system to its emergency personnel. This system also provides route guidance to the scene, improving efficiency between 10 and 15 percent (Taylor, 1997). One highly recommended future technology that helps locate vehicles is wireless enhanced 911 (I-95, 2005). Similar to enhanced 911, this technology provides dispatchers with additional facts about wireless calls such as locations, through the use of GIS (FCC, 2006).

Incident Management Using Multi-Agency Coordination

Agencies frequently involved in incident management include city or county departments of transportation, intelligent transportation systems management, state highway patrols, and emergency medical services. Because these agencies are frequently located in different regions, their coordination is vital in creating an environment where timely incident detection, verification, and clearance occur. Traffic management centers can support the coordination by providing centralized control and information management centers (Dunn & Latoski, 2003).

The I-95 Corridor Coalition has studied multi-agency coordination for responding to traffic incidents, its recommendations include sharing traffic management centers with multiple jurisdictions, particularly law enforcement,

developing multi-jurisdictional incident management protocol to allow smooth management of incidents along jurisdictional borders, increasing cooperation and partnerships between public and private agencies, building agreements with medical agencies involved in traffic incident response, and building creative towing contracts with private stakeholders (I-95, 2005). Coordination between law enforcement and departments of transportation is more common than between EMS and fire or rescue agencies. Unfortunately, this coordination commonly stops after law enforcement arrives at the incident scene. Because traffic cameras can be used for incident verification, law enforcement does not need to be dispatched for all traffic incidents. When law enforcement presence is required, congestion commonly delays the arrival of these vehicles, to address this problem motorcycle units were found to be effective at reaching incidents scenes during these periods of congestion (Intelligent, 2000).

Other recommended tools for coordinating multi agency response include total stations, satellite photographs, and post-incident meetings. Using satellite photographs and total stations, a surveying technique, to locate incidents was found to decrease responder arrival time (Jakobson et al., 1992) and conducting post-incident meetings regularly can evaluate and improve operating procedures (Intelligent, 2000). Total stations is also used by crash investigation personnel to document debris and vehicle locations at a crash scene accurately and quickly. While investigations are required at only major crashes, this technology was found by some to produce significant reductions in investigation time (56 percent) (Agent et al., 1995; Jakobson et al., 1992) and therefore, faster clearance and

shorter delays. Others, however, noted that because this technology allows an increase in the number of data points, the observed investigation times have actually increased (Cooner & Balke, 2000).

With various recommendations from multiple organizations and publications guiding future multi-agency coordination, agreements and operational procedures are constantly changing. However, no studies have evaluated the recent state-of-practice; therefore, usage rates of these strategies are unknown.

Incident Management Using Freeway Service Patrols

Incident response also includes dispatching the proper vehicles and tools to the incident location. Tools used by traffic management personnel include automated vehicle location and computer-aided dispatching, in vehicles frequently known as freeway service patrols. Automatic vehicle location, which uses GPS to locate vehicles and graphically display their location, is commonly combined with computer-aided dispatching (CAD), a technology that uses GPS and database information to dispatch the most appropriate vehicle to each incident. Assigning the closest vehicle and suggesting a less congested and therefore faster route reduces response time.

Freeway service patrols play a valuable role in incident management in many areas of the United States. These vehicles actively seek incidents by patrolling freeway sections with high incident rates to facilitate short response time and to aid in rapid clearance. Freeway service patrol units commonly have tools and supplies to repair minor car problems, such as flat tires or running out of

fuel. These patrols are widely deployed and have been frequently studied throughout the United States, showing extremely positive impact as displayed in Table 1. Motorists have responded favorably to these freeway service patrol programs (Todd, 1997), particularly regarding the timeliness of assistance and the feelings of safety and security derived from uniformed personnel assistance and free services (Intelligent, 2000). Freeway service patrol units now operate in over 61 locations across the United States including those shown in Table 1.

Table 1. Freeway service patrol deployments in the United States

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 Highways 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, Rochester County, Westchester County	Highway Emergency Local Patrol
North Carolina	Charlotte, Greensboro, Haywood County, Raleigh	Incident Management Assistance Patrol
	Winston-Salem	Motorist Assistance Patrol
Ohio	Cincinnati	Samaritan
Oregon	Lincoln City, Lane County	Region 2 Incident Response

Location		Name
State	City	
Pennsylvania	Pittsburg	Penn-Lincoln Parkway Patrol
	Philadelphia	Incident Management Team
Rhode Island	Providence	Samaritan
South Carolina	Columbia, Greenville	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

Sources: (Fenno and Ogden, 1998; Baird et al. 2003; Bertini et al., 2001; Nee and Hallenbeck, 2001; Petty et al., 1996; Perrin et al., 2004)

While many freeway service patrol programs exist in many regions, most of these services (64 percent) are relatively new, beginning after 1990 (Fenno & Ogden, 1998). As shown in Table 1, deployments nationwide are led by California and Texas focusing on freeways in urban areas. Freeway service patrol units in California, service freeways in Fresno, Los Angeles, Oakland, Orange County, Riverside County, Sacramento, San Diego, and San Francisco. Research estimating the impact of the freeway service patrol operating in Los Angeles has concluded that the average incident duration decreased by 40 percent, or

approximately 15 minutes (Skabardonis et al., 1998b). The freeway service patrol in Orange County saved travelers an estimated 31 gallons of fuel per assisted incident and reduced annual emissions by 7.6 tons of hydrocarbons, 19.1 tons of nitrogen oxides, and 77.2 tons of carbon monoxide (Skabardonis et al., 1995). Similarly, the San Francisco freeway service patrol produced a reduction in 320 tons of NO_x, 129 tons of CO emissions, and 13 tons of hydrocarbons annually (USDOT, 1996). While the study in Los Angeles included differing measures of effectiveness than those in Orange County and San Francisco, all of these studies have shown that freeway service patrol programs provide benefit to travelers in California.

The freeway service patrol, originated in Chicago Illinois in 1960, and now operates there under the name of the Chicago Emergency Traffic Patrol (Levinson et al., 2003). The most recent study of this patrol found that the responsibilities of the various responders have been divided according to incident severity. While freeway service patrol units responded to all incidents, incident management teams also aided in the clearance of major incidents. This study found that the program saved travelers a total of approximately 9.5 million vehicle hours of delay annually, 3.9 million hours saved by the freeway service patrol alone (primarily minor incidents) and 5.6 million vehicle hours saved by the incident management teams (Cambridge, 1997). A similar study found that the Highway Emergency Local Patrol (HELP) in Rockland and Westchester Counties, New York, reduced delay by 685,000 vehicle hours per year (Garmen, 2000).

Researchers have also examined the impact of freeway service patrol programs in Atlanta, Georgia, and Denver, Colorado. The freeway service patrol system in Denver reduced the average incident duration by 8.6 to 10.5 minutes and the average delay by 71 to 98 vehicle-hours per incident (Cuciti & Janson, 1995). The Georgia NaviGator System integrates freeway service patrol units (HEROS), information dissemination tools, and a TMC. A 1997 study found that this system reduced incident verification time from 4.2 to 1.1 minutes, response time from 9.5 to 4.7 minutes, and total incident duration from 41 minutes to 26 minutes (USDOT, 2001).

The Coordinated Highway Action Response Team (CHART) program operates a freeway service patrol program in Maryland and adjacent freeways in Washington, D.C. This system is perhaps one of the better studied incident management systems in the US. In 1999, it reduced incident durations from 93 to 42 minutes, reduced annual delay by 23.36 million vehicle hours, and saved 8.6 million gallons of fuel (Chang & Point-Du-Jour, 1999). Including reduced emissions (hydrocarbons, carbon monoxide, and nitrous oxides) with the savings from fuel and delay, the CHART system saved travelers approximately \$25.7 million in 1999.

In 2000, the CHART system reduced incident duration from 77 minutes to 33 minutes, produced a delay savings of 24.24 million vehicle hours of delay, and saved approximately 4.1 million gallons of fuel. Combining these savings with those from estimated environmental impact, the system saved travelers and estimated \$26.7 million in 2000 (Petrov et al., 2002). In the next year, 2001, the

CHART system reduced average incident durations from 51 to 29 minutes generating a benefit of \$402.75 million. The most recent study of this system conducted in 2002 found a reduction in incident durations from 39 to 28 minutes generating a benefit of \$467.97 million, the highest ever reported. As the reduction in average incident duration has dropped since the first study, the number of incidents has conversely rose (from 27,987 in 1999 to 32,814 in 2002), producing an increase in the CHART system net benefit (Chang et al., 2003).

The motorist assistance patrol (MAP) in Massachusetts began in 1995, gradually expanding to patrol 21 routes in 1998. Researchers used the macroscopic traffic simulation model FREQ11 to model the traffic impact and traveler benefits of this service. Examining a representative site and extrapolating the benefits of the MAP program to the other locations, this study concluded that the program was beneficial to Massachusetts travelers with an average benefit-cost ratio of 19:1 (Stamatiadis et al., 1998).

Similar programs can be found in other areas of the country. The Minnesota Highway Helper Program has reduced the duration of stalled vehicles by 8 minutes (Minnesota, 1994) and the Penn-Lincoln Parkway Service Patrol Program in Pennsylvania has significantly reduced incident response and clearance time (Donnell et al., 1999). The freeway service patrols in North Carolina have been studied not for the traditional benefits but to help predict the optimum number of freeway service patrols to deploy in new locations. This study recommended the deployment of freeway service patrol vehicles in both

Asheville and Raleigh, predicting benefits to travelers in North Carolina as well (Khattak et al., 2004).

The freeway service patrol operating in Oregon was evaluated based on archived data, the study finding reductions in incident duration of 30 percent at one site and 15 percent at the other (Bertini et al., 2001). Others have evaluated these programs in Washington and Utah, also reporting benefits. In addition, the freeway service patrols in Seattle and Tacoma, Washington, have improved incident response times between 44 to 77 percent while at the same time detecting more than 50 percent of incidents (Nee and Hallenbeck, 2001). A similar system in the Salt Lake Valley, Utah also coordinated with an ATMS and has reduced average incident durations by approximately 20 minutes, producing a 37 minute decrease in the average incident duration (of two-lane incidents). The popularity of this service has also grown significantly as incident responses have increased from 2,500 in the year 2000 to over 5,000 by 2002 (Perrin et al., 2004).

All of these studies support the findings of a nationwide study of freeway service patrols that surveyed 53 freeway service patrol agencies in 22 US states. This compilation concluded that these programs produced such benefits as better road surveillance, reduced incident duration due to fast detection and reduced response and clearance times, improved traffic control, faster debris removal, faster motorist assistance, reduced impact of planned incidents, and timely condition reporting. Secondary benefits included reduced congestion, emissions, and secondary crashes; fewer abandoned vehicles; improved motorist safety; faster reporting of damages to highway facilities; improved state patrol

operations, and additional real-time traffic information when AVL systems are on freeway service patrol units (Fenno & Ogden, 1998).

These freeway service patrols are effective because they frequently carry the proper equipment and their responders are properly trained. Because units can encounter hazardous materials (hazmat) spills, some agencies have prepared their vehicles with basic hazmat response equipment identify and respond to these types of incidents to more effectively. This ability has allowed freeway service patrol personnel to manage minor hazmat spills faster and to coordinate with other responding agencies such as medical, police, and fire. Further, establishing standards for fluid and uncommon debris removal by freeway service patrol programs might improve the clearance time (I-95, 2005). Additionally, because freeway service patrol units have traditionally performed the role of first verification, the Georgia DOT trained traffic incident response personnel in Atlanta to identify traffic incidents accurately. This training improved incident management on Atlanta's highways, saved motorists hundreds of hours of delay, and reduced damages from environmental spills (Intelligent, 2000). Providing incentives to hazmat contractors for timely and efficient incident clearance minimizes costs while maintaining peak performance (I-95, 2005).

The *Incident Management Handbook* published by the Federal Highway Administration discusses several new techniques and technologies available to benefit incident clearance including recovery vehicles. Some recovery vehicles equipped with rotating cranes, are designed to upright or remove overturned trucks quickly, reducing the number and duration of lane closures. Another

innovative vehicle, the Automated Debris Recovery Systems (ADRS), can remove large roadway debris at speeds up to 30 mph without stopping or requiring the operators to exit the vehicle. However, these vehicles are expensive and their operating costs exceed those normal wreckers. While ARDS vehicles can conduct routine road maintenance when not responding to incident reports, drivers of both types of these recovery vehicles require additional training to operate them (PB Farradyne, 2000). While their benefits are easily identified, there is no known research about the cost effectiveness of these tools.

Incident Management Using Existing Traffic Management Tools

The same tools that can be used for mitigating both recurring and nonrecurring congestion include high occupancy vehicle (HOV) lane, transit-only lanes, congestion pricing, signal coordination, and adaptive signal control. HOV lanes on freeways in most cities are restricted to those drivers sharing rides with at least one other person. This tool has the ability to reduce the number of vehicles on freeways by almost half, reducing recurring congestion. The availability of HOV lanes in urban areas provides a valuable tool for relieving non-recurring congestion caused by incidents by briefly lifting HOV restrictions reduce the incident-induced congestion, thereby reducing freeway delay (Parsons, 1997).

Transit-only lanes are reserved solely for transit vehicles, for example busses, resulting in a less-congested route. In addition, this type of lane improves the reliability of transit, encouraging more ridership, and thus further reducing congestion. The research in this areas has primarily examined the use of these

lanes and their impact on transit (Al-Mudhaffar & Bang, 2006; Hu et al., 2004; Luh, 2001), none evaluating their use in incident management.

Because in many locations traffic congestion occurs only during the morning and evening commuting hours, or peak periods, transportation engineers also encourage drivers to travel during off-peak periods. One technique to encourage this behavior is to charge larger tolls during peak periods than during off-peak periods, a practice referred to as congestion pricing. While several studies have examined the effectiveness of different toll strategies on the behavior of commuters (Millar et al, 2003; Mosseri et al., 2004b; Al-Deek et al., 2005a; Al-Deek et al., 2005b; Ozbay et al., 2006a) again, none study their effectiveness in incident management.

Signal coordination aims to keep vehicles moving through a corridor, such as a main street in downtown, by providing a communication link between signals, coordinating the green lights in a specific direction at a particular time. To ensure vehicles progress through a corridor with the least amount of delay, the timing and phasing of signal systems are adjusted, changing the amount of red and green time that each approach receives.

While coordinated signal systems improve traffic flow from recurring congestion, adaptive signal control has the added benefit of optimizing traffic flow during nonrecurring congestion. Furthermore, this type of control is not limited to one street; rather, it can change traffic signals throughout a network based on overall demand. Using such software as the Sydney Coordinated Adaptive Traffic System (SCATS); the Split, Cycle, Offset Optimization

Technique (SCOOT); and Real-time Hierarchical Distributed Effective System (RHODES), traffic signals can adapt to the changing traffic demands. Several researchers have studied the impact of these systems under recurring and non-recurring congestion (Li & Prevedouros, 2004; Barcel et al., 2003), all finding positive impact on traffic delay including reducing delay of rerouted vehicles.

Impact of Incident Management

Management of incidents effectively reduces traffic delay, thereby reducing emissions, fuel consumption, and the risk of secondary crashes. Many studies have estimated the impact of incident management strategies with overwhelmingly positive findings. Examples found freeway service patrols have saved between 9.5 million (Cambridge, 1997) and 23.4 million (Chang & Point-Du-Jour, 1999) hours of delay per year, and an ATMS system has saved 700 hours of vehicular delay per incident (Henk et al., 1997). This reduction in delay provided Americans faster commutes to work and more time with family and at social activities.

Ecological Savings

While automobiles emit various compounds, four are of particular interest due to their toxic nature to humans, the environment, or both: carbon monoxide, nitrous oxide, particulate matter, and hydrocarbons. Carbon monoxide (CO), a colorless odorless toxin, produced by burning fossil fuels such as gasoline, contributes to the formation ground-level ozone, also a toxin. Nitrous oxides (NO_x) are a main component in forming ozone and acid rain, while contributing

to global warming. Automobiles produce approximately 55 percent of all nitrous oxides and leave a reddish-brown layer over urban areas (EPA, 2006). Particulate matter (PM), small particles and droplets of pollution in the air, is another frequently studied vehicle emission. Certain PM is visible, such as soot from diesel in heavy vehicles, causing major health problems when inhaled (EPA, 2006). Finally, vehicles emit hydrocarbons (HC), combustible gasses, by not completely burning fuel. Pollution from HC contributes to global warming and causes negative health effects (EPA, 2006).

Previous studies have found the impact that incident management has on emissions. A study in Orange County, California, found that a freeway service patrol program reduced the annual emissions by 7.6 tons of HC, 19.1 tons of NO_x, and 77.2 tons of CO and a study of a freeway service patrol in San Francisco, California, found reductions of 12.9 tons of HC, 321.1 tons of NO_x, and 129.6 tons of CO annually (USDOT, 1996).

Fuel Savings

Estimated fuel savings from incident management tools and strategies vary widely depending on the strategies used, the existing traffic congestion, and the study methodology. The current fossil-fuel-driven transportation marketplace further exaggerates the impact of traffic incidents by wasting limited non-renewable resources and producing substantial emissions. Studies found that a freeway service patrol saved 31 gallons per incident in California (Skabardonis et al., 1995) and that an ATMS system saved 2,600 gallons per incident in Texas (Henk et al., 1997).

Traffic Safety

Researchers have also measured the impact of incident management programs on the safety of motorists and incident responders. Traffic incidents often cause secondary crashes due to the large speed differentials that separate vehicles at the edges of the congestion. Secondary incidents occur within two hours after and within two miles of the initial incident location (Chang et al., 2003). Frequently, secondary incidents cause more serious injuries and damages than the primary incidents (USF, 2005). Further, the risk of occurrence increases with the duration of the primary incident. Specifically, each additional minute of incident duration increases the probability of a secondary incident by 2.8 percent (Karlaftis et al., 1999). While vehicles traveling through congestion caused by incidents are more at-risk for secondary incidents, incident response personnel also share risks. In 2001, 34 incident responders in America were killed when struck by other vehicles (Sullivan, 2002). Limiting the exposure of unprotected incident responders to highway vehicles reduces their job safety risks and is accomplished by reducing incident duration; decreasing incident durations can, therefore, improve safety for the traveling public and incident responders alike.

While many incident management strategies exist, not all have been studied in terms of their effectiveness. The most frequently studied strategy has been the freeway service patrol. Studies have shown a large difference in the benefits of incident management tools across the US and even between neighboring cities. While some incident management systems record detailed performance metrics, most systems do not and rely on traffic simulation software to

predict the impact of such management. The following subsection discusses the various simulation software available and previous applications.

Traffic Simulation Studies

Two commonly used tools for evaluating incident management strategies are traffic simulation and before and after studies. Simulation software attempts to mimic the operation of a transportation system. Some simulation software view transportation systems one vehicle at a time (microscopic), while others choose a more global approach (macroscopic). Software developers have extensively studied vehicle and driver behavior. Simulation software developers used the findings from these studies to represent driver and vehicle behavior through mathematical equations and computer programming. The mathematical equations represent how closely drivers follow each other, accelerate and decelerate, and choose gaps for changing lanes. Macroscopic simulation software uses mathematical equations to specify how fast vehicles will travel under each level of congestion using the traditional speed-flow-density relationship.

Before and after studies use the operation statistics from incident management tools to find their impact. Data availability and inaccuracy problems are commonly associated with this operational data (Nee and Hallenbeck, 2001). Before and after analysis has used rough capacity estimates based on number of lanes blocked, to predict the delays (Nee and Hallenbeck, 2001). Because delay estimates impact the prediction of fuel, emissions, and secondary crashes, before and after studies have the possibility of vastly over or underestimating impact.

Many researchers have chosen traffic simulation to study incident management impact. Some tools and strategies studied with simulation include total stations for crash investigation (Agent et al., 1995; Jacobson et al., 1992), advanced traffic management systems (ATMS) (Carter et al., 2000; Birst & Smadi, 2000; Der-Horng et al., 2004; Henk et al., 1997), route diversion (Rippeon et al., 1999; Prevedouros, 1999), freeway service patrols (Short, 2004; Latoski et al., 1999; Stamatiadis et al., 1997), information dissemination (Ng et al., 2006), and traffic management centers (Mahmassani et al., 2004; Park et al., 2005). Most of these studies only consider one city and some do not analyze significant sample sizes to account for the stochastic nature of most simulation software. Many of the older studies used very limited simulation tools and formal calibration and validation procedures have only recently come into focus (Liu et al., 2006). There has never been a statewide study of incident management; especially none that modeled several incident management strategies realistically and consistently.

Traffic simulation software allows for the study of complex transportation systems in a laboratory instead of in the field (Chowdhury & Sadek, 2003). This characteristic is particularly valuable when studying traffic crashes and other random incidents as field study of these events requires significant investments in time and resource. The simulation models discussed in this section are mathematical and run with the aid of computers. Transportation planners and engineers have used this type of traffic simulation as an effective planning tool because it (May, 1990)

- Allows faster, cheaper, and more flexible testing of designs
- Allows the safe study of hazardous environments, such as traffic crashes
- Allows real-time vehicle interactions especially in microscopic models, thereby providing timely results.

However, these simulations have drawbacks in that they (May, 1990; Leeds, 1997)

- Require time and money for purchase and training
- Require thorough data collection, calibration, and validation for accurate results
- Produce unreliable emissions estimates in some cases
- Pose large challenges in accurately modeling safety
- Produce “black box” results that require experienced professionals to analyze
- Are influenced heavily by user-defined measures of effectiveness

A thorough data collection process and careful calibration and validation, combined with a full understanding of the simulation software, will overcome most of these disadvantages. Choosing the most appropriate software for a study can also help. Because a plethora of simulation software exist, background information is essential in selecting the most appropriate one.

Traffic simulation software are classified as either microscopic, macroscopic, or mesoscopic (Chowdhury & Sadek, 2003; Boxill et al., 2000). These classifications are based on the level of detail with which the software

models driver behavior. Software that concentrate on traffic flow characteristics such as volume and density, not individual drivers, are macroscopic, while software that consider the interactions between individual drivers and their vehicles are microscopic. Those software that consider both to some degree are mesoscopic. Although microscopic simulation provides more detailed results, these models also require greater computing abilities than macroscopic.

Other defining characteristics of simulation software are the randomness of the underlying mathematical models, or algorithms. Because daily traffic is inherently variable, some simulation models also employ stochastic algorithms to represent traffic conditions more closely. Simulation models using these algorithms vary traffic release times, volumes, driver characteristics, and vehicle types within a range centered around a user-specified mean. This random distribution of vehicles, drivers, and volumes at every instant while maintaining an average provides a more realistic representation of traffic. For example, if a stochastic traffic simulation model is specified to release 100 vehicles per hour onto a certain road, the first ten minutes might release 5 vehicles, the next several, 12, 25, 9, 29, and 20 vehicles, varying the volumes over time while meeting the specified hourly average.

To minimize computing requirements, some early traffic simulation models, termed deterministic, employed only averages. Using the preceeding example of volume release, a deterministic model specified to release 100 vehicles per hour onto a certain road, the model would generate approximately 10 vehicles every six minutes so that the traffic volume would remain constant

throughout the hour. Recent advances in computer technologies allow more complicated modeling techniques (stochastic) without degradation of computer processing time. Examples of traffic simulation software and their associated classifications and characteristics are shown in Table 2. This table does not represent a comprehensive list of available simulation software; rather it seeks to display several of the more popular software used.

Table 2. Simulation software characteristics

Software	Classification	Characteristic
AIMSUN	Microscopic	Stochastic
AVENUE	Microscopic	Deterministic
CORSIM	Microscopic	Stochastic
DYNAMIT	Mesoscopic	Stochastic
FREQ	Macroscopic	Deterministic
INTEGRATION	Microscopic	Stochastic
INTRAS	Microscopic	Stochastic
METROPOLIS	Mesoscopic	Stochastic
MITSIMLab	Microscopic	Stochastic
PARAMICS	Microscopic	Stochastic
Sim Traffic	Microscopic	Stochastic
SITRAS	Microscopic	Stochastic
SYNCHRO	Macroscopic	Stochastic
VISSIM	Microscopic	Stochastic
WATSIM	Microscopic	Stochastic
XXEXQ	Macroscopic	Deterministic

Choosing a Simulation Software

After thoroughly understanding the different types of simulation models, the next step in a simulation study is choosing the most appropriate software for the specific project. A study in 1999 compared the software CORSIM, FREQ, and INTEGRATION in their ability to model both congested and uncongested freeways accurately, concluding that while all accurately represented the latter

condition, results were inconsistent for congested freeways (Middelton & Cooner, 1999). A second study published in 2000, broadened the scope, evaluating more than 80 traffic simulation software for their abilities to model intelligent transportation systems (ITS) technologies accurately (Boxill et al., 2000). While this study rated the software INTEGRATION and CORSIM the most useful, the researchers predicted that with additional development and calibration, AIMSUN and PARAMICS would surpass them. Table 3 shows more details of these research findings.

Table 3: Simulation software ratings.

ITS Features Modeled	AIMSUN 2	CONTRAM	CORFLO	CORSIM	FLEXYT II	HUTSIM	INTEGRATION	PARAMICS	VISSIM
Traffic devices	Y	N	N	N	N	N	Y	Y	Y
Traffic device	Y	N	N	N	N	N	Y	Y	Y
Traffic calming	N	N	N	N	Y	Y	Y	Y	Y
Driver behavior	Y	N	N	Y	Y	N	Y	Y	Y
Vehicle interaction	Y	N	N	Y	Y	N	Y	Y	N
Congestion pricing	N	N	N	N	N	Y	N	Y	N
Incident	Y	N	Y	Y	Y	Y	Y	Y	Y
Queue spillback	Y	N	N	Y	Y	Y	Y	Y	Y
Ramp metering	Y	N	N	Y	Y	Y	Y	Y	Y
Coordinated traffic	Y	Y	N	Y	Y	Y	Y	Y	Y
Adaptive traffic	Y	Y	N	Y	Y	Y	Y	Y	Y
Interface w/other ITS	Y	N	N	N	N	N	N	N	N
Network conditions	Y	N	N	N	N	Y	N	Y	Y

Source: Boxill et al., 2000

A more specific study also published in 2000 compared CORSIM and VISSIM for application on congested arterial road networks, both being found appropriate for this application (Bloomberg & Dale, 2000). Extending this study to include PARAMICS, and SimTraffic, multiple studies evaluate these four in 2001 for graphical presentation of the traffic simulation and for performance while modeling moderate volume arterial routes. VISSIM was found to be the

model with the best graphical presentation (Barrios et al., 2001) while CORSIM and SimTraffic were determined to be equally suited for modeling arterials with moderate volumes (Trueblood, 2001).

Two additional studies in 2002 compared CORSIM, PARAMICS, and VISSIM (Nam et al., 2002; Choa et al., 2002), focusing on ease-of-use, calibration results, and software capabilities. The results of one study rated PARAMICS software highest in all of these areas, concluding that it produced the best results for traffic incident applications (Nam et al., 2002). Another found that PARAMICS and VISSIM reflected actual conditions more closely than CORSIM, providing distinct advantages due to the availability of a 3-D interface (Choa et al., 2002).

Also in 2002, three other studies evaluated the software VISSIM, CORSIM, and SimTraffic. While VISSIM was found to be the most powerful, it was also rated the least user-friendly. CORSIM, cited as the one having undergone the most revisions was found to be the most widely used software (Kaseko, 2002), producing the most constant traffic volumes, even though the model was stochastic (Tian et al., 2002). Researchers also concluded that SimTraffic was the most straightforward and easy-to-use of the three (Kaseko, 2002).

In the next year, 2003, a study evaluated CORSIM, INTEGRATION, MITSIMLab, PARAMICS, VISSIM, and WATSIM, finding all models equal for accurately simulating freeways and signalized intersections (Bloomberg et al., 2003). Next, in 2004, researchers evaluated CORSIM, SimTraffic, and AIMSUN

for their ease of model building, data and computing requirements, relevance of output options, and flexibility. While each model varied in data requirements, all provided satisfactory representations of traffic operations (Jones et al., 2004). Similarly, Brockfeld et al. evaluated the car-following models used in ten simulation software, including PARAMICS and MitSim, finding no single model was the best as all produced between 12 and 17 percent error in vehicle headways, defined as the time between consecutive vehicles (2004). Ranjitkar et al. compared vehicle speeds and headways approximated by six simulation models against those collected from a test track (2004). Their findings showed that while speeds were only 4 to 5 percent different, the headways produced by the simulation software varied between 12 and 13 percent different, supporting the findings of Brockfield et al. regarding vehicle headway error.

As this brief history of traffic simulation evaluation shows, software are rapidly improving as all recently examined are similarly proficient in modeling real world traffic conditions. This improvement and the shift toward microscopic stochastic models is likely due to improvements in computing abilities. The only significant difference between recently evaluated models appears to be the presence of a three-dimensional viewing option. While this feature is not always needed, it is a valuable tool for presenting findings to decision makers and the public. Researchers should carefully evaluate the need for this function, among the many other options, before choosing the most appropriate traffic simulation software for any project.

Model Building, Calibrating, and Validation

After choosing the most appropriate simulation software for a project, several steps, common to all software, are required to develop an accurate model. Because traffic simulation aims to represent the vehicle interactions of a real road network, extensive time and data are needed to ensure this goal is reached. A standard approach for the process builds, calibrates, and then validates a model (Dowling, et al., 2004). Building a simulation model entails creating a network of links and nodes where the links represent the uniform segments of the roadway and the nodes denote a change such as an intersection or an increase/decrease in the number of lanes. Other terms used building a traffic simulation network include gateways, restrictions, and sensors. Gateways, the areas where vehicles enter and/or exit the road network, generate traffic according to user-specified volumes, releasing it in either a stochastic or a deterministic manner. Restrictions limit the type, number, or speed of vehicles on certain links, for example prohibiting trucks in the left lane. Sensors function similarly to loop detectors by identifying the presence of vehicles, this allowing traffic signals to respond appropriately to traffic demands within the model.

Model calibration and validation are frequently areas of study, and as a result, many techniques are available and considered sound. Initial studies using PARAMICS (version 1.5) examined the I-405 freeway in Orange County, California, to examine the impact of the ATMS testbed. The model calibration method was based on freeway volumes. Driver behavior characteristics such as driver aggressiveness and awareness were found to influence the traffic behavior

highly in the model. This study calibrated the model by adjusting mean headway and mean reaction time. Validation compared the observed and simulated loop detector volumes along the freeway, concluding that this version of PARAMICS was an excellent shell with high performance and scalability. The most important advantage that the software offered was its application programming interface (API), allowing the customization of the software (Abdulhai et al., 1999).

A similar study, again focusing on the ATMS testbed in California, also used PARAMICS to simulate traffic on the I-5 freeway in Orange County. While this research employed genetic algorithms to aid in calibration, the two primary variables used to calibrate and validate the model were again the mean reaction time and the mean headway (Lee et al., 2001).

In the next year, PARAMICS was used to simulate the impact of ramp meters on I-680 adjacent to the San Francisco Bay Bridge. This study used link speeds, vehicle throughput, and density contour maps as measures of effectiveness to guide calibration, adjusting the mean headway and mean reaction time to match the observed and simulated (Gardes et al., 2002).

Instead of PARAMICS, a study in calibrated a simulation model in Minneapolis, Minnesota, calibrated a simulation model in AIMSUN using a three step process. Researchers first matched the observed and simulated freeway volumes, then used speed contour graphs to compare the observed and simulated average speeds. Finally, the third step involves using a model-specific, qualitative, measure of effectiveness for calibration. During the calibration

process, this study adjusted a dozen parameters, among them mean reaction time and maximum speed (Hourdakis et al., 2003).

Several publications in 2004 focused on the need to calibrate and validate microscopic simulation models accurately. While Toledo et al. presented an excellent calibration framework for vehicle demands in an origin-destination matrix, this work was aimed at networks where multiple routes were available (2004). Ni et al. developed a unique approach for validating traffic simulation models that included statistical techniques for goodness-of-fit and graphical techniques for visually comparing simulation to the real world (2004). Bayarri et al. suggested Bayesian methodology for assessing the uncertainties in stochastic microscopic traffic simulation software (2004), while Schultz and Rilett suggested analyzing genetic algorithms (2004) and Zhang and Owen explored the use of vehicle trajectory plots and headway distributions during model validation (2004).

Most recently in 2006, Lui et al. recommended calibrating PARAMICS simulation models by using origin-destination (OD) matrix adjustment, route choice variables, mean headway, signposting, and adjusting mean reaction time. This study proposed a new streamlined process for simulation calibration to reduce time requirements and repetition. Their process shows that capacity; demand including pattern matrix, OD estimation, and dynamic matrix; and fine tuning are all areas of adjustment until the measures of effectiveness are satisfied as shown in Figure 2.

As these studies indicate, adjusting mean headway and mean reaction time are the most effective methods for calibrating PARAMICS and other simulation

models. In addition, many studies have incorporated traffic volumes, speeds, travel times, and queues as quantitative measures in this process. The choice of these parameters is determined steered by data availability and anticipated model use and output.

After deciding which parameters to examine and which factors to adjust during calibration, the question arises of when to stop calibration. Some suggest that calibration errors of up to 10 percent are acceptable (Brockfeld et al., 2004).

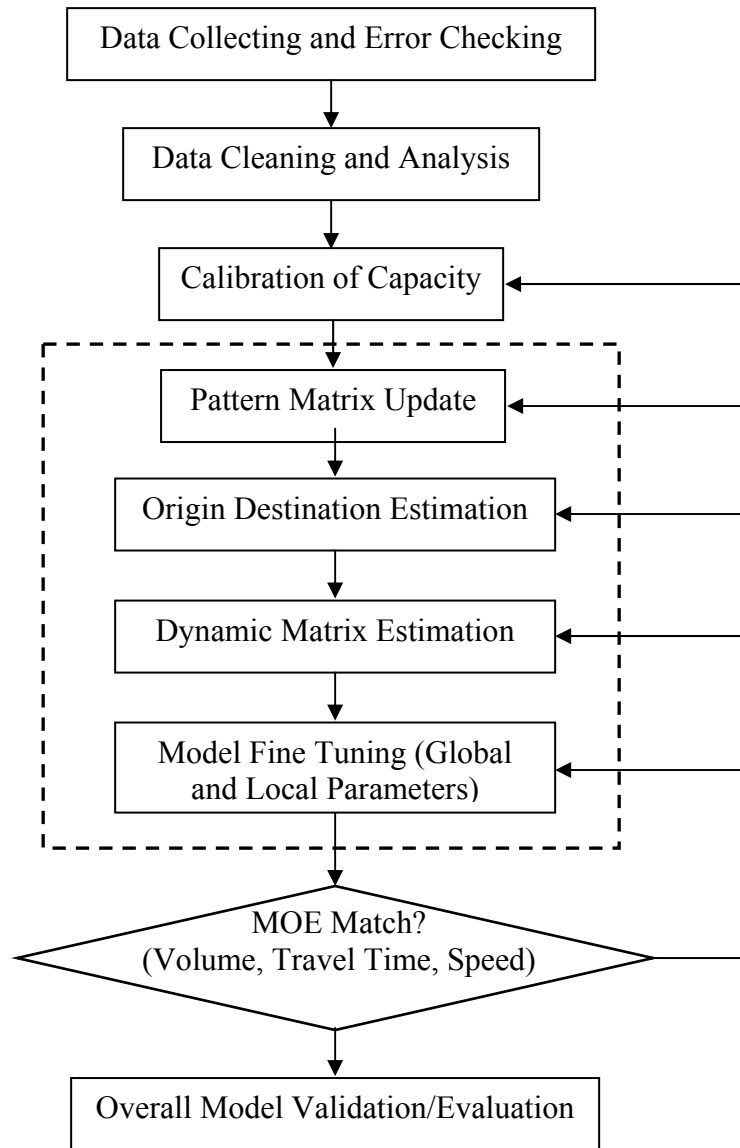


Figure 2. Example calibration process
Source: Liu et al., 2006

Traditional Simulation Studies

After a simulation model has been built, calibrated, and validated, the next step is simulating the desired scenarios. Traffic simulation began in the 1950s (Pursula, 1999) focusing on modeling car-following behavior using mathematic equations for the past 50 years (Chandler et al, 1958; Newell, 1961; Burnham et al., 1974; Gipps, 1981; Kikuchi & Chakroborty, 1992; Hidas, 1998; McDonald et al., 1998; Van Zuylen et al., 2006). The improvements resulting from this research in addition to those in computing ability make older simulation studies outdated with respect to current traffic volumes and accuracy.

Therefore, the following three subsections limit their review of traffic simulation applications from the mid-nineties to 2006, grouped into three basic categories. Traditional simulation studies include examinations of tools traditionally used in transportation engineering including traffic circles and public transit. The next section, novel simulation studies, reviews previous studies that have extended simulation software through programming to model unique scenarios such as ramp metering and automated highway systems. Finally, the incident management simulation subsection reviews previous work examining the impact of incident management tools including route diversion and freeway service patrols.

While recent simulation studies have given significant attention to modeling ITS technologies, traditional traffic operational scenarios such as congestion management, access management, traffic calming, traffic circles, and route choices have also been the focus of recent research. One of the traditional

topics of traffic simulation has been congestion mitigation. Several studies developed a simulation software specifically for this application. Fritzsche developed software in 1994 to examine the impact of different congestion mitigation measures, followed by the development of AVENUE (Advanced & Visual Evaluator for road Networks in Urban arEas) to simulate traffic interactions in urban signalized intersections (Horiguchi et al., 1996). Initial results for the software METROPOLIS were published in 1997, evaluating another tool for urban network traffic simulation (De Palma et al., 1997). Most recently, researchers used the previously developed software WATSIM to simulate I-4 in Orlando, Florida, analyzing the resulting model for aiding in decision-making and evaluation of the congestion improvements from various different measures (Radwan & Ramasamy, 2005).

Traffic simulation has also been used to model the impact of access management and interchange reconfiguration. Specifically, CORSIM was used to evaluate the impact of various left turn restriction strategies and the associated alternatives along a corridor in Ohio. This study compared the delays from two alternatives, the first, direct left turns from driveways and the second, restricting direct left turns and providing u-turns alternatives (Chowdhury et al., 2005). A study using Synchro and Netsim software modeled the impact of proposed access management along a major arterial in San Antonio, Texas, its results aiding in decision making to improve safety along the route (Shadewald & Prem, 2004). Interchange configuration was researched using CORSIM to simulate the

operation of a new freeway between I-10 and I-110 in Pensacola, Florida (Luh, 2001).

Traffic calming measures and traffic circles have been modeled using PARAMICS software. One study measured the impact of traffic calming measures along SR-20 around Clear Lake, California, (Gardes, 2006) while another examined unconventional traffic circles (complex and oval) in New Jersey (Ozbay et al., 2006b).

In addition, studies have focused on simulating the impact on driver route choice of different demands and speeds on existing and planned roadways. For example, a study published in 1998 developed traffic simulation software investigating demand distribution using delay based link cost (Gawron, 1998). In 2002, the model SITRAS (Simulation of Intelligent TRANsport Systems) was evaluated, the results indicating that it produced realistic speed-flow characteristics only when lane changes were forced (Hidas, 2002).

Novel Simulation Studies

More recent simulation studies have focused on less traditional, or novel, transportation engineering solutions. In particular, much research has been published on the simulated impact of ITS, including inductive loop detectors, variable message signs, weigh-in-motion systems, ramp metering, electronic tolling, signalized intersections, safety, tunnels, public transit, multimodal networks, automated highway systems, and evacuation operations. Loop detectors were simulated using the software MITSIM (MICROscopic Traffic SIMulator) in a 1996 study modeling driver behavior based on lane changing, car

following, and traffic event algorithms in response to advanced traffic control monitoring (Yang & Koutsoploulus, 1996).

Variable message signs and weigh-in-motion systems were evaluated for safety impact using a simulation model developed in 2001 (Saka & Glassco, 2001); the former was further studied two years later for rerouting traffic and preventing congestion at highway rail intersections using CORSIM (Mirchandani & Ramesh, 2003). In addition, researchers have simulated driver response to variable message signs to examine optimal distribution of traffic volumes across a road network. Specifically, this study focused on the impact of real-time information dissemination in a congested road network in New Jersey using PARAMICS and its interfacing abilities (API) (Ozbay & Bartın, 2004).

Ramp metering, another technology frequently studied using traffic simulation, was evaluated in conjunction with freeway service patrols and variable message signs using AIMSUN2 (Kanchi et al., 2002). A 2004 study used PARAMICS software to evaluate different ramp metering algorithms (ALINEA, BOTTLENECK, and ZONE) on I-405 in California (Chu et al., 2004b). In the same year, researchers used both QRS-II and PARAMICS to study the effectiveness of a ramp metering system on US-45 in Milwaukee, Wisconsin, finding the latter more accurately provided results (Horowitz et al., 2004). In 2006, researchers applied VISSIM to study traffic responsive ramp metering along I-210 in Pasadena, California (Sun & Horowitz, 2006) and most recently, researchers have developed simulation software to determine ramp metering and signal timing in real time (Dailey & Wall, 2006).

Simulation tools have also been employed to evaluate the impact of toll plazas, including new electronic toll technologies such as EZ-Pass. Studies have used PARAMICS to examine driver reactions to toll pricing strategies, modeling drivers along a toll facility in central Florida and along the adjacent SR 417 (Al-Deek et al., 2005a). Also using PARAMICS, researchers developed a Toll Plaza SIMulation model (TPSIM), to evaluate toll plaza operations on the Orlando-Orange County Expressway in Florida, finding it to be better than other available software (Al-Deek et al., 2005b). Similarly, using the PARAMICS API, researchers modeled traffic on the Sydney Harbor Bridge, simulating peak volumes as high as 13,500 vehicles while allowing the simulation of dynamic lane assignment and toll plazas simultaneously (Millar et al, 2003).

Evaluating the impact of coordinated signal systems has also been an area of study using traffic simulation. Using PARAMICS software, researchers have studied traffic operations at the Orlando airport, including 50 signalized intersections, 7 fire-stations and 66 zones, to evaluate emergency evacuation capabilities (Mollaghasemi and Abdel-Aty, 2003). In the next year, others developed simulation software to evaluate traffic adaptive control systems for oversaturated intersections (Li & Prevedouros, 2004). Similarly, the impact of coordinated signals adjacent the Vielha tunnel in Europe was examined to reduce safety risks for truck platoons. The analysis used the simulation software GETRAM, a microscopic software based on AIMSUN (Barcel et al., 2003). Another tunnel project that used PARAMICS to model the Lane Cove Tunnel Project in Sydney to identify a number of problems related to the initial tunnel

road design finding that the software accurately indicated the long queue lengths. Predicting that they were due to sustained upgrades, the researchers recommended the addition of a climbing lane (Millar et al, 2003).

Evaluating the impact of public transit using shared right of way (fully or partially) has also been the subject of previous simulation studies. CORSIM was used to model a proposed 14-mile section of the Central Florida Light Rail Transit System in Orlando, Florida, to determine its impact on existing traffic operation (Luh, 2001). A similar study evaluated the operation of a proposed bus transit system including dedicated transit lanes on Chaoyangmen-Fuchengment Street in Beijing, China. This study, which used PARAMICS, evaluated the feasibility of one-way streets as well (Hu et al., 2004). Most recently, a study used TRANSYT to evaluate the impact of coordinating signals and providing signal priority to busses in Kungsholmen, Sweden (Al-Mudhaffar & Bang, 2006).

A dense network of urban intersections including multimodal applications along the Ocean Parkway in Brooklyn, New York, used VISSIM to simulate the impact of adjusting signal timing and phasing (Mosseri et al., 2004a). VISSIM was also used to model a multimodal network including transit-only lanes, toll plazas (high speed electronic, and a reconfigured standard plaza), and high occupancy lanes along the Lincoln Tunnel corridor (Mosseri et al., 2004b).

Researchers in 1998 simulated interactions of an intelligent vehicle highway system, currently termed an automated highway system, in real time. This study developed a unique macroscopic simulation platform to demonstrate the feasibility of traffic simulation software for real-time use. After developing

an 18-mile freeway network that modeled more than two million vehicles, a two-hour simulation required 2.35 minutes on a single computer. When researchers used parallel computing, a computing technique that divides that processing work between two or more computers, the same network was simulated in only 5.3 seconds, demonstrating the feasibility of traffic simulation for real-time applications in IVHS (Chronopoulos & Johnston, 1998).

Recent terrorist attacks worldwide have prompted simulation studies of evacuation operations. One study using CORSIM examined emergency response strategies for Birmingham, Alabama, to develop and refine disaster response plans (Sisiopiku et al., 2004). Similarly, emergency evacuation plans were evaluated for Los Alamos National Laboratory, New Mexico, using the software MITSIMLab (Jha et al., 2004b).

Other recent novel simulation studies have focused on larger networks. The MASTER system studied several thousand kilometers of freeway in real-time using a gas kinetic traffic equation in a macroscopic simulation platform. This equation predicts traffic speeds based on congestion and average observed vehicle spacing. This study found an accurate reflection of observed shockwaves between congested and uncongested traffic states (Helbing et al., 2001). Three years later, a study successfully simulated the entire Des Moines, Iowa, metropolitan area using the microscopic simulation software MITSIM, finding that the ability of transportation professionals to use microscopic simulation software was no longer constrained by computing power (Jha et al., 2004a). A similar study used PARAMICS to simulate the central business district of Beijing,

China, to determine the impact of transit-only lanes and one-way streets on congestion and traffic flow (Hu et al., 2004).

While this recent success in modeling large networks using microscopic simulation software is significant, researchers do not always require high levels of detail on the entire simulation network. As a result, several researchers have developed hybrid models that allow a varying degree of detail across a network (Yang & Morgan, 2006; Ziliaskopoulos et al., 2006, Burghout et al., 2005, Horowitz, 2004).

Incident Management Simulation Studies

As congestion across the nation continues to grow, many researchers have used traffic simulation to study the impact of non-recurring congestion, such as traffic incidents. In particular, studies have included total stations, traffic cameras, route diversion, real-time information, freeway service patrols, variable message signs with a traffic management center, advanced traffic management systems, advanced traffic management information systems, changing signal timings, advanced driver assistance systems, and incident impact prediction systems.

In 1992, researchers examined the effectiveness of using total stations to collect crash site information, thus decreasing incident clearance time in Washington State. Traditionally, investigators have used the coordinate method where a tape measure in the center of the crash scene is used to determine the location of all pertinent items, such as skid marks and gouges in the road. More recently, total stations, a surveying technology, is used identify the location of all

pertinent items. In this method, one investigator places a base station at a location from which the entire crash scene is visible, where another investigator places a rod topped with a prism above each location to be measured. The base station records the distance, the angle, and a name for each location. Because the prism is on a rod, the crash investigation can continue even in the presence of vehicles, allowing for some restoration of traffic flow prior its completion.

Using total stations instead of the coordinate method increased the number of location measurements taken per hour by 21 and reduced crash investigation an average of sixty minutes. This reduction in investigation time, simulated using the software FREWAY, predicted that using total stations saved more than 7,000 vehicle hours of delay compared to the traditional coordinated incident investigation method (Jacobson et al., 1992)

In 1997, researchers used the software CORFLOW (a precursor of CORSIM) to model the delay savings of the TransGuide System in San Antonio, Texas. Studies of traffic camera video tapes revealed that the system reduced response time by 20 percent. The simulation of this data produced a delay savings of more than 700 vehicle hours and 2,600 gallons of fuel per incident. This improvement translates to approximately \$1.65 million in annual delay savings (Henk et al., 1997).

In 1999, a study using the software CORSIM examined the impact of route diversion in response to a traffic incident on I-95 in Virginia. This study identified which traffic volumes on the freeway and adjacent arterial route (US 1) were beneficial to diversion during a traffic incident (Rippeon et al., 1999). A

subsequent study published in 2005 examined the effectiveness of route diversion among other strategies, along a freeway outside of Chicago, Illinois (Wirtz et al, 2005)

A second study in 1999 examined the impact of an incident management program including real-time information from variable message signs and highway advisory radios for rerouting travelers around an incident. Researchers used the software INTEGRATION to simulate these scenarios on the Moanalua and H-1 freeway corridor in Honolulu, Hawaii. The simulated incident blocked one lane for 40 minutes and remained in the shoulder for an additional 20. Working with the assumption that 15 percent of drivers would choose another route due to the incident without real-time information, this study determined that 40 percent would reroute with guidance from the incident management program. Specifically, the incident management program saved approximately 185 vehicle hours per incident (Prevedouros, 1999).

Another study compared the impact of real-time traveler information systems, adaptive ramp metering, arterial management, and combinations of these. This research used PARAMICS to apply these strategies to the I-405 and adjacent CA-133 corridor in Irvine, California, finding that while real-time traveler information provided the largest benefit as a single tool, combining several increased benefits further. The benefits were determined by measuring vehicle hours traveled, the average mainline travel speed, and the time percentage of the on-ramp queue spill back to local streets (Chu et al., 2004a). Most recently,

the impact of real-time traffic information was examined on the route choice of heavy vehicle using PARAMICS (Ng et al., 2006).

A 1997 study measured the impact of the Massachusetts Motorist Assistance Program using the microscopic simulation software FREQ11. Researchers evaluated the delay, fuel consumption, carbon monoxide, hydrocarbons, and nitrous oxides finding the program highly beneficial to motorists (Stamatiadis et al, 1997). The Hoosier Helper freeway service patrol in Indiana was simulated using the program XXEXQ, chosen instead of INTEGRATION or INTRAS because of data availability constraints. This study simulated eight scenarios representing freeway service patrols during day-only operations and six scenarios representing 24-hour operation. The study estimated that the freeway service patrol benefited travelers by reducing delay, by \$1.2 million per year for day-only service and \$3.7 million per year for 24-hour operation (Latoski et al., 1999). A similar study examined the Freeway Incident Response Safety Team (FIRST) operated by the Minnesota DOT using the software CORSIM (Short, 2004).

The San Antonio, Texas, TransGuide system was examined using INTEGRATION to simulate variable message signs and traffic management centers. Researchers assumed that diversion information was posted on variable message signs one minute after a traffic incident and that ten percent of drivers would react to the suggested route guidance. The TransGuide system reduced delay to all travelers by 5.7 percent, reduced the rate of secondary crashes by 2.8 percent, and reduced fuel usage by 1.2 percent (Carter et al., 2000).

Traffic management centers provide many different functions around the county and world, and their benefits have also been evaluated by simulation tools. Researchers evaluated Dynasmart-X, a mesoscopic traffic simulation software, a real-time decision support tool in a traffic management center using a center in Irvine, California. This study concluded that Dynasmart-X had the required capability and speed to provide decision support regarding traffic management options to traffic management center operators (Mahmassani et al., 2004).

A similar study examined the feasibility of microscopic simulation to identify vehicles traveling between traffic cameras linked to a traffic management center. This study used PARAMICS, finding that this the software had the capability to re-identify vehicles based on the acceptable error of a traffic management center operator (Park et al., 2005).

An advanced traffic management system was evaluated in one of the first major studies using the PARAMICS (version 1.5) microscopic simulator. Researchers examined the I-405 freeway in Orange County, California, to determine the impact of the system and the ability of the software to model existing conditions accurately, calibrating the model based on freeway volumes. The findings revealed software problems with the release of vehicles and their allocation between travel lanes (Abdulhai et al., 1999).

The study of an advanced traffic management system in Fargo, North Dakota, simulated using INTEGRATION, is unique because it focuses on a small- to medium-sized city with approximately 166,000 residents. The proposed advanced traffic management center employed variable message signs and

adaptive signal controls similar to SCOOT on freeways and arterial routes. Researchers examined four incident scenarios at one location finding an eight percent reduction in network travel times and an eight percent increase in the average vehicle speeds using only variable message signs. When the advanced traffic management center used both variable message signs and adaptive signal control, travel times were reduced by 18 percent and speeds increased by 21 percent. These results illustrate that advanced traffic management systems could provide significant benefits, even when deployed in small- to medium-size metropolitan areas (Birst & Smadi, 2000). More recently in 2004, an advanced traffic management information system was evaluated using PARAMICS. Researchers used various short-term traffic flow scenarios and evaluated the systems' ability to collect traffic data in real-time data (Lee et al., 2004).

The impact of changing signal timings in response to mid-block incidents with signals at each adjacent intersection was simulated using PARAMICS. The findings set the groundwork for network-wide incident responsive traffic control to alleviate incident-induced congestion (Sheu et al., 2003). Other areas of simulation study involve driver assistance systems including those in vehicle as recent work has developed a simulation that models advanced driver assistance systems aimed at reducing incidents and improving safety (Lundgren & Tapani, 2006). Lastly, researchers at the University of Maryland, College Park, developed simulation software that uses historical data from the impact of previous incidents along I-270 to predict the queue lengths and average speeds of other incidents. While this work does not address one specific management

strategy, it provides information that can lead to better management of incidents (Zou et al., 2003).

PARAMICS Simulation Software

PARAMICS, frequently used for simulation in traffic studies as seen in the preceding research, stands PARallel MICRo-Simulation and is a UNIX-based stochastic, microscopic simulation platform developed in the Edinburgh Parallel Computing Center in Scotland (Quadstone, 2000). Similar to other microscopic simulation software, it is founded on car following theory and because it is inherently stochastic, it uses distributions for such driver-vehicle characteristics as acceleration, deceleration, reaction time, and aggressiveness. As each vehicle enters the simulation network, PARAMICS assigns characteristics randomly per these distributions. Based on these randomly, the reactions of each driver-vehicle unit are determined by mathematical equations that model reactions to stimulus such as deciding when to begin slowing down when approaching a red light or when to brake to maintain following distance (Hawas, 2002). These characteristics influence driver choice regarding free flow speeds and gap acceptance with the former influencing the travel speeds of vehicles on uncongested road sections and the latter influences the driver's choice for lane changing and turning maneuvers (Oketch and Carrick, 2005).

To route vehicles to their destinations, PARAMICS uses a dynamic approach, assigning vehicles based on minimum cost. This cost is determined from the sum of the walking time from parking lots (T), the driving distance along routes (D), and tolls (P). The following function shows how PARAMICS

determines the cost of each possible route before selecting the least expensive one.

$$Cost = a * T + b * D + c * P$$

where

a = time coefficient in minutes,

b = distance coefficient in minutes per km

c = toll coefficient in minutes per monetary cost

The important capabilities of PARAMICS include modeling loop sensors, variable message signs, and any other ITS technology added through an application programming interface (API). This API allows PARAMICS to interface with other software and modify decisions made by individual DVUs, all vehicles, or even the road restrictions. Another advantage of PARAMICS is its ability to import road data in a geographical information systems (GIS) format. The Shape-to-PARAMICS (S2P) tool, developed by the University of California, converts GIS road networks into PARAMICS network files, simplifying the network creation task when this data is available. The availability of a three-dimensional display has also helped the wide acceptance of PARAMICS as a traffic simulation platform (Millar et al., 2003).

PARAMICS is a widely used traffic simulation software around the world, particularly for simulating ITS applications. It provides greater capabilities and more detailed car-following behaviors than similar traffic simulation software (Church & Noronha, 2003). Lastly, because of its flexible API, PARAMICS can integrate with other software and simulate special cases such as toll plazas (Ozbay

et al., 2006a). These qualities make PARAMICS a good choice for modeling incident management.

Benefit-cost Analysis of Incidents

Transportation systems, as public assets, require justification for large expenditures such as adding freeway lanes or transit stops. Incident management facilities and tools are no different. Because congestion is worsening, the focus of traffic management officials has shifted towards reducing non-recurring congestion through incident management strategies, tools, and communications. To implement and expand these systems, many agencies have studied the impact of their existing and proposed programs with various methods, the most common of which is benefit-cost analysis. The basic foundation of benefit-cost analysis is that projects are worth implementing if their benefits outweigh their costs. This requires all measures be converted into monetary units.

Benefit-Cost Analysis Process and Theory

Identifying and properly measuring the societal impact of changes in a transportation system requires an in-depth understanding of impact analysis. Several impact analysis techniques exist today, all founded on the concepts of microeconomics. These concepts focus on the change of societal value in certain objects when there is a surplus (Boardman et al., 2006). For example, travelers will value an additional freeway lane more when the existing lanes are congested than when the existing lanes still have available capacity. Relating this example to incident management, travelers will value the services of a freeway service

patrol more, if incidents occur more frequently. However, having more freeway service patrols requires having less of another, such as flowers along the freeway. It is therefore paramount to calculate the benefits and costs during impact analysis accurately to ensure the limited resources of incident management agencies are allocated properly.

Many incident management programs aim to reduce delays to motorists and improve travel times. Timesavings can be classified and valued according to where the time could have been spent. These categories include the following (Layard & Glaister, 2005):

- 1) Subsistence tasks (eating, sleeping, etc)
- 2) Household activities (shopping, cleaning, childcare)
- 3) Paid activities (work or education)
- 4) Social activities (recreation, leisure)

One tool traditionally used for impact analysis is benefit-cost analysis. The basic principle of this technique is if the value of the benefits are greater than the costs, then a project is beneficial. Many pitfalls exist that practitioners must carefully avoid to ensure accurate representation of all costs and benefits. Benefit-cost analysis is a frequently used tool in transportation projects, likely because most transportation projects rely on public funding and provide public benefits. The benefits of incident management projects usually include reduced traffic delay, emissions, fuel consumption, and improved safety. Traffic delay is usually given in vehicle hours of delay, meaning total of delays on each vehicle and traffic simulation is a popular tool for estimating delays.

While benefit-cost analysis has been used by many other incident management studies (Hagen et al., 2005; USDOT, 2001; Latoski et al., 1999; Stamatiadis et al., 1998; COMSIS, 1997; Cuciti & Janson, 1995), these have either evaluated the impact of one incident management tool at more than one city, or more than one tool and at only one city.

Two primary types of benefit-cost analysis exist, *ex ante*, aiding in decisions for future projects, and *ex post*, evaluating already completed projects. Both of these share the objective of providing information that will allow a more efficient disbursement of societal resources and both involve the following steps (Boardman et al., 2006):

1. Identify alternative projects
2. Determine the benefits and the costs of interest to the stakeholders
3. Calculate the impact and select the measures of effectiveness
4. Predict the impact throughout the project life
5. Convert the impact into monetary value
6. Convert the monetary value to current ones
7. Calculate the net value of each alternative in current monetary value
8. Conduct sensitivity analysis
9. Recommend an alternative

It is important to recognize that there are many caveats to using benefit-cost analysis, primarily due to the conversion of qualitative values into monetary ones. Several of the common issues in terms of transportation projects are listed below (Frank, 2000):

- It is often difficult to choose the factors influenced by a project. While it is clear that rerouting traffic around a crash scene can improve delay, it is not clear whether this rerouted traffic will choose to stop for shopping or eating, benefiting nearby businesses, due to the route diversion.
- Non-linear additive benefits and costs are often difficult to represent properly as well. Because the addition of each new freeway service patrol unit will likely have a different impact than the previous, the additional benefit for this service is not linear. Similarly, the addition of each new freeway service patrol has a different cost from the previous due to economies of scale (Frank, 2000). Another example of non-linear additive costs is the value of time. For instance, the first half hour of delay might be valued differently from the next half hour because some drivers might value the first as recreational time (watching the news after work) but value the next half hour as subsistence time such as eating a meal (Layard & Glaister, 2005). These non-linear benefit-cost relationships frequently create difficulty in studies seeking to determine optimum deployment.
- Another important item to understand is that ranking alternatives is not always feasible. If two alternatives are not clearly comparable, comparisons with other alternatives will usually meet most maximization requirements. For example, if a traffic management agency uses radar to detect incidents and traffic cameras to verify them, it is not reasonable to compare the effectiveness of these two technologies. Instead, knowing

that a deploying another freeway service patrol has a higher benefit-cost ratio than deploying additional radar and traffic camera units will provide the required information to make optimum future deployment decisions.

- It is similarly important to identify sources of personal choice constraints in the analysis process. For example, when evaluating the impact of a route diversion strategy reducing the impact of an incident, a required diversion will remove the personal choice of drivers wishing to remaining on the freeway. While this example seems rather trivial, if the diversion route travels through an objectionable part of town, drivers may experience unforeseen distress.
- Willingness to pay for transportation varies between drivers. Some drivers would rather travel in heavy congestion on a public highway than travel faster on an adjacent toll road. While the cost of fuel from idling might be greater than the cost of the toll, the driver's salary might be based on hours, not miles (Frank, 2000). Further, motorists often underestimate the costs of their journey because of a perception of fixed travel costs when in reality they are not (Bruzellius, 1979).
- Travel reliability is also a valuable commodity. Because punctuality is valued highly in our society, an unreliable transportation system will cause travelers to waste large amounts of time to ensure their punctuality. Further, these values impact public transit, freight, and personal vehicles at different costs (Layard & Glaister, 2005).

- Another important issue to recognize is the potential change in the mode of transportation. The impact of incidents and their management on one, might influence travelers' choice of another, therefore, influencing the supply of both (Kay et al, 1989).
- Because this study examines services in a developed, wealthy country, environmental impact will be a significant factor. Without a thorough understanding of the study environment, it is difficult to value the impact of different pollutants accurately. It is similarly difficult to determine the impact (and value thereof) of large trends such as global warming (Frank, 2000).

While it is not reasonable to account for all of these issues, a careful review and selection of the pertinent characteristics should support each study's proper use of benefit-cost analysis (Frank, 2000).

Previous work determining the impact of incident management

Many previous works have examined the impact of incident management tools using benefit-cost ratios. While several studies have evaluated a combination of tools such as the NaviGator system in Atlanta, Georgia; the TransGuide system in Sand Antonio, Texas; and the CHART Program across Maryland, more studies have investigated freeway service patrols at such places as Colorado, Massachusetts, Indiana, Washington State, Oregon, and Florida. In 1997, the Georgia NaviGator system was evaluated for benefits and costs. This System, which includes traffic cameras, freeway service patrols, variable message

signs, and a traffic management center, was found to produce a reduction in delay that generated a benefit-cost ratio of 2.3:1 in 1997 (USDOT, 2001).

The TransGuide System in San Antonio, Texas, reduced crashes by 35 percent, secondary crashes by 30 percent, and the incident response time by 20 percent. These reductions saved approximately 700 vehicle hours and 2,600 gallons of fuel per incident, translating into \$1.65 million annually (Parsons, 1997). The TranStar System in Houston produces an annual benefit of \$8.4 million from reduced delay. While these studies estimate impact, their analyses do not include important factors such as environmental impact and do not compare the savings to costs in all cases.

The initial evaluation of the CHART program estimated a benefit/cost ratio of 5.6:1 (COMSIS, 1997). Most of the benefits resulted from the five percent decrease in delay (2 million vehicle hours per year) associated with reduced incident clearance time. The several follow-up studies conducted found delay cost savings of 25.7 million dollars in 1999 and 26.7 million dollars in 2000 (Petrov et al., 2002). While the CHART system is one of the more frequently analyzed freeway service patrols, the reports do not always compare the benefits and costs in a universally applicable ratio.

One of the earlier works examining the benefits and costs of incident management studied the Courtesy Patrol Program in Denver, Colorado. This study assumed the value of time at \$10 per hour and the cost of tow operators between \$29 and \$38 per hour. Overall, the study estimated the system produced a benefit-cost ratio from 10.5:1 to 16.9:1 (Cuciti & Janson, 1995). A second

study measured the impact of the Massachusetts Motorist Assistance Program as presented in the simulation section of this chapter. The various patrols that the Massachusetts Program operates have generated benefit-cost ratios from 3:1 to 58:1. The program average benefit-cost was estimated at 19:1 in 1998 (Stamatiadis et al., 1998). While the latter included delay, fuel consumption, carbon monoxide, hydrocarbons, and nitrous oxides, the former included only delay.

The Hoosier Helper freeway service patrol program in Indiana was the subject of a 1999 benefit-cost study. As discussed previously, the delay estimates in this study were found using traffic simulation. For determining the reduction in secondary crashes, this study referenced work by Karlaftis et al. (1998). The study of this patrol varied the percentages of trucks and the value of crashed vehicles to produce a range of benefit-cost ratios for the program, finding an average of 4.71:1 for operation during the daytime only and an average of 13.28:1 for 24-hour operation (Latoski et al., 1999).

A similar study examined a freeway service patrol in the Puget Sound area of Washington State in 2001. This study included approximately 65 miles of urban freeway and six months of freeway service patrol records in the impact analysis. The analysis which analyzed both qualitative and quantitative measures, primarily focused on delay reduction, using data collected from computer-aided dispatching databases and rough capacity limitation factors and volumes rather than simulation. Further, the analysis did not include emissions or secondary incidents as impact. The freeway service patrol decreased the average response

time by 61 percent, producing an annual cost savings of more than \$200,000. While benefits of delay reduction were determined, a formal benefit-cost analysis was not conducted (Nee and Hallenbeck, 2001).

More recently, the impact of the COMET (COrridor ManagEment Team) freeway service patrol program in Portland, Oregon, was evaluated, in 2004. The study used data collected from patrols, loop sensor data, and an extensive crash database to quantify delay impact. This study did not identify the impact on emissions or secondary crashes; on incident detection benefits, public relations (including a better sense of safety and security for drivers), quick HAZMAT cleanup preventing environmental; and on infrastructure damage, maintenance monitoring, and monitor construction cones and signage to maintain a safe environment for workers. While this study could not fully conclude that the system produced positive benefits, it offered other support, finding that if the duration of each incident on freeways in the Portland, Oregon, metro region were increased by one, five, or ten minutes from the actual incident delay, total cost per incident would have increased to three percent, 15 percent and 28 percent, respectively. These costs were based on actual delay and estimated fuel consumption (Bertini et al., 2004). This study did not estimate environmental impact from emissions and did not conduct a formal benefit-costs analysis.

The Florida Road Ranger freeway service patrol system was estimated to have benefit-cost ratios ranging from 2.3:1 to 41.5:1 in different districts. The average benefit-cost was 25.8:1 for the entire Road Ranger program. This study estimated the vehicle delay and fuel costs but omitted emissions (Hagen et al.,

2005). Because many studies investigated the benefit-cost ratio for freeway service patrols, Fenno and Ogden combined these findings in a 1996 study as displayed in Table 4:

Table 4. Benefits of freeway service patrols in the U.S

Location	Patrol Name	Year Performed	B/C Ratings
Charlotte, NC	Incident Management Assistance Patrol	1993	3:1 to 7:1
Chicago, IL	Emergency Traffic Patrol	1990	17:1
Dallas, TX	Courtesy Patrol	1995	3.3:1 to 36.2:1
Denver, CO	Mile High Courtesy Patrol	1996	10.5:1 to 16.5:1
Detroit, MI	Freeway Courtesy Patrol	1995	14:1
Fresno, CA	Freeway Service Patrol	1995	12.5:1
Florida	Road Ranger	2005	25.8:1
Hayward, CA	Freeway Service Patrol	1998	5:1
Houston, TX	Motorist Assistance Program	1994	6.6:1 to 23.3:1
Illinois	Hoosier Helper	1999	13.3:1
Los Angeles, CA	Metro Freeway Service Patrol	1993	11:1
Maryland	CHART	1996	5.6:1
Massachusetts	MAP	1998	3:1 to 58:1
Minneapolis, MN	Highway Helper, Freeway Incident Response Safety Team	1995 2004	2:1 15.8:1
New York & Westchester Co., NY	Highway Emergency Local Patrol	1995	23.5:1
Norfolk, VA	Safety Service Patrol	1995	2:1 to 2.5:1
Oakland, CA	Freeway Service Patrol	1991	3.5:1
Orange Co., CA	Freeway Service Patrol	1995	3:1
Riverside Co., CA	Freeway Service Patrol	1995	3:1
Sacramento, CA	Freeway Service Patrol	1995	5.5:1

Source: (Fenno & Ogden, 1998)

As these findings show, a significant variability in the benefit-cost ratios of freeway service patrols exists across the country. Even within a state, such as within Massachusetts, these values vary significantly. Figure 3 displays a frequency plot of the studies in Table 1, indicating that while the range of findings is wide, the majority of the studies found benefit-cost ratios between approximately 2:1 to 20:1.

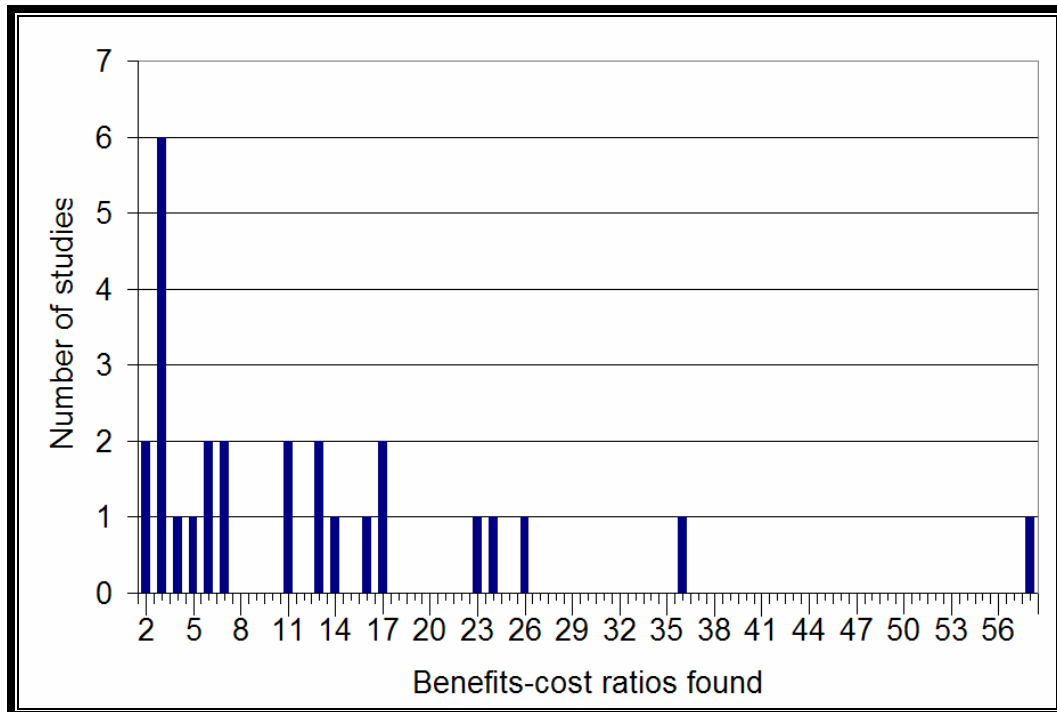


Figure 3. Frequency of benefit-cost ratios

Summary of Literature Review

While the state of the practice of incident management includes various technologies and strategies, there is no universally accepted group of adopted technologies. Many studies have evaluated different technologies and strategies, but few (Fekpe & Collins, 2003) have studied the same combination of tools in more than one city. For this reason, comparing the effectiveness of different technologies and strategies between cities is difficult. Additionally, due to the different methodologies used in each study, it is difficult to compare like tools in different cities. Research is needed to identify which incident management strategies and tools were most widely used and, of these, which were found the most effective.

Simulation studies have examined the impact of incident management by including either more than one urban area or more than one incident management tool, but none evaluated both. Traffic simulation tools have also been used for unique, applications that require the use of application programming interfaces to produce desired traffic operations. Few studies have involved these novel applications in incident management simulations, and no study has included more than one application. Therefore, the full potential of traffic simulation and associated programming tools has not been used to model incident management.

Benefit-cost analysis has been extensively used in the transportation field and more recently, in incident management as well. As a result, other studies have already solved many of the problems related to this analytical method and have built widespread trust of the results. While studies have used this tool to

analyze incident management impact, none have examined five large networks within one state, nor have any examined more than a few different technologies or strategies.

CHAPTER THREE

METHODOLOGY

This study adopted four different methods to attain the research objectives. After first completing a detailed literature review to gain information on state-of-the-art practices in incident management, a nationwide survey polling four types of agencies in all fifty states, the District of Columbia, and Puerto Rico was distributed, compiled, and analyzed. Third, simulation models were created to identify the impact of various incident management strategies; and finally, a benefit-cost analysis was conducted to estimate the comparative benefits of these strategies.

Survey

The research team developed and distributed both a web-based and a paper survey for incident management agencies across the United States and its associated territories. This survey sought to identify the extent of use and the utility of selected technologies, communication methods, and strategies. Specifically, it aimed to find the state of the practice in incident management in the United States. The survey targeted four types of incident management agencies or offices within each state using questionnaires specifically designed for each department. These agencies, which were determined through discussion

with officials from the Federal Highway Administration and the South Carolina Department of Transportation, included:

- administration in state departments of transportation (DOTs);
- officials involved specifically with intelligent transportation systems (ITS), commonly within each state DOT;
- responders in emergency medical services (EMS), and;
- officers in state highway patrols (SHP).

The full identified population of these agencies was invited to participate. The purpose of the survey was to obtain the current state of practice within the United States. Primary themes of the questions related to the implementation of incident management programs, the effectiveness of various elements of these programs, and the extent of institutional collaboration contributing to the programs.

While several survey questions were universal to surveys, unique questions sought to capture an in-depth view of each agency. For example, while all agencies were asked whether their programs were comprehensive or effective, unique questions asked DOTs about funding constraints, ITS offices about technologies, SHPs about freeway coverage area, and EMS about coordination. Copies of each survey can be found in Appendix A.

Simulation

The incident management tools and strategies found to be most widely used and most effective based on the survey responses were then evaluated through simulation. The steps involved site selection, software selection, model

building, model calibration and validation, and simulation of the various strategies selected.

Site Selection

The research team coordinated with the South Carolina DOT project steering committee to select five study sites throughout the state of South Carolina based on incident rates, data availability, and traffic volumes. These sites, all along interstate highways in metropolitan areas, are indicated with circles in Figure 4.

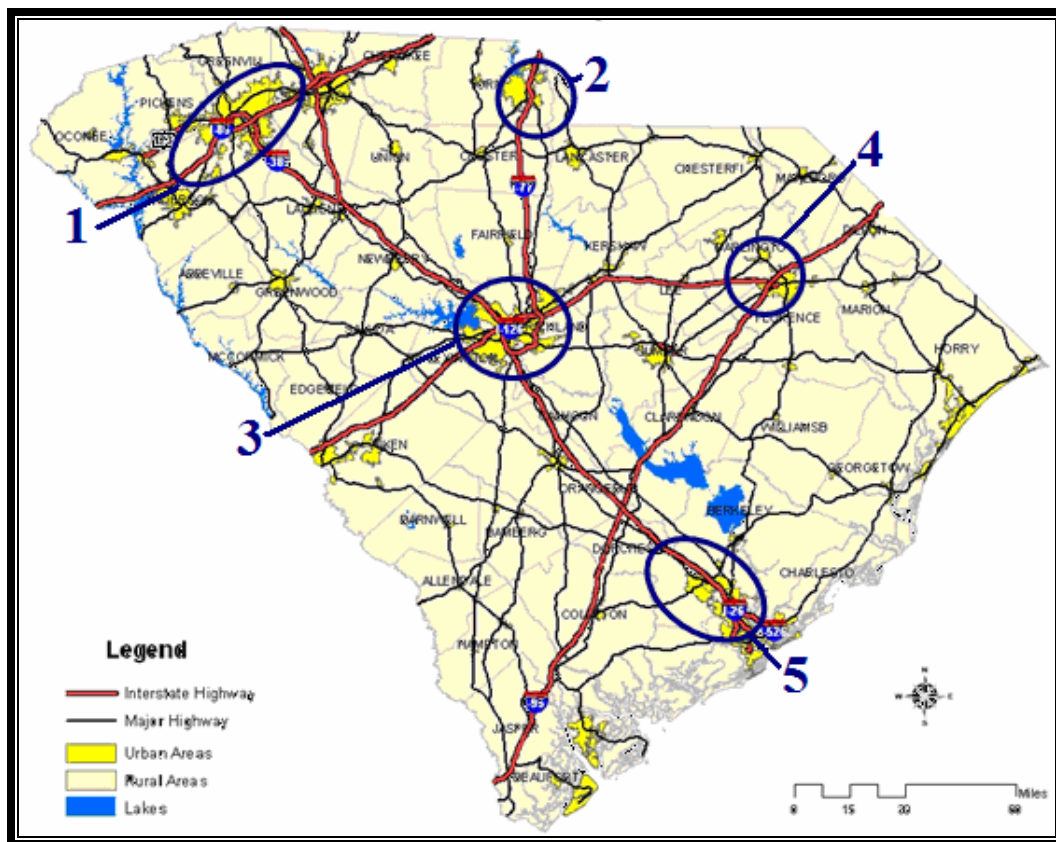


Figure 4. Five simulation study sites

1. The Greenville County site was located along I-85 and included approximately eleven miles of freeway and eight interchanges. While Greenville County was home to approximately 417,000 residents in 2006 (US Census, 2007), it is also located between Charlotte, North Carolina and Atlanta, Georgia.
2. The York County site, along I-77, included approximately five miles of freeway and three interchanges. Although York county was home to approximately 199,000 residents (2006), the adjacent city of Charlotte, North Carolina, with approximately 611,000 residents (2005), significantly impacted traffic at this site (US Census, 2007).
3. The Richland County site was located along I-20, just north of the city of Columbia with a population of approximately 117,000 in 2005 (US Census, 2007), and included approximately twelve miles of freeway and ten interchanges .
4. East of Columbia, the Florence County site along I-95, included approximately seven miles of freeway and three interchanges. This county had approximately 131,000 residents in 2006 (US Census, 2007).
5. The Charleston site, in the lower right of Figure 4, was in Charleston and Berkeley Counties and included approximately eleven miles of freeway and seven interchanges. These two

counties had populations of approximately 332,000 and 152,000 in 2006, respectively (US Census, 2007).

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 metropolitan area in the state, providing a solid basis for estimating impact of freeway incident management.

Software Selection

After the research team and the steering committee finalized the study sites, the research team began building traffic simulation models of each. This type of modeling was chosen as the evaluation tool based on the advantages presented in the literature review, the experience of the research team, and the anticipated challenges of collecting incident impacts in the field. Past research has found that transportation planners and engineers have used simulation as an effective planning tool because it (May, 1990):

- allows faster, cheaper, and more flexible testing of designs
- allows the safe study of hazardous environments, such as traffic crashes
- allows real-time vehicle interactions especially in microscopic models, thereby providing timely results.

Additionally, the research team had experience with traffic simulation modeling and basic computer programming. Finally, it was not feasible to collect data in

the field due to the location of the five sites and the infrequent and random occurrence of incidents.

While some studies (May, 1990; Leeds, 1997) have cited disadvantages to using traffic simulation software, properly selecting the best software for the study, as reviewed above, and understanding of the simulation software, accomplished through training sessions, can overcome some of these disadvantages. Properly building, calibrating, and validating the simulation model, as discussed in the proceeding subsections, will overcome most of the other disadvantages (May, 1990; Leeds, 1997) found.

Because the ability to model freeways and traffic incidents accurately was a requirement for this project, initially CORSIM, VISSIM, and PARAMICS were tentatively selected for evaluation. While many current simulation software programs were found similarly accurate (Brockfield et al., 2004; Ranjitkar et al., 2004; Jones et al., 2004; Bloomberg et al., 2003), further research revealed that VISSIM and PARAMICS could model traffic conditions more accurately than CORSIM (Choa et al., 2002). Further, PARAMICS was found better than both VISSIM and CORSIM in ease-of-use, calibration results, and software capability (Nam et al., 2002). While ease-of-use and calibration results represented important advantages, PARAMICS' programming interface would also allow the evaluation of unique situations that often arise in incident management. Other important features included a three-dimensional display, which would be useful for marketing results to decision makers and practitioners, and the ability to record delay and fuel use for each vehicle. The research team determined that

PARAMICS best fit the research team's skills and the project requirements. For these reasons, this microscopic simulation software was chosen for this study.

Model Building Process

Next, the South Carolina Department of Natural Resources' (SCDNR) online database was referenced to obtain information on all freeways in South Carolina formatted as a geographical information systems (GIS) map based on the site selection process previously outlined. From this map the desired freeway and arterial segments were selected. These segments were then saved into a shape file format, one commonly used in GIS as it represents road segments to the proper scale.

To expedite model building, the research team then used the Shape to PARAMICS (S2P) tool developed by the California Department of Transportation (Church & Noronha, 2003). This tool converts shape files directly into PARAMICS road networks, reading the link properties and retaining the numbers of lanes and speed limits. In this manner, all overpasses and other geometric features were represented to scale as well. Scaled aerial photographs from the South Carolina Department of Natural Resources and other online sources were overlaid onto the PARAMICS road network to aid the author in the placement of curves, particularly at interchange ramps. Planning sheets of the freeways at each site, provided by the South Carolina Department of Transportation, verified the number of lanes on the aerial photos and provided information about the grades along the freeway. The author collected the

remaining information including signage, presence of incident detection devices, and turn restrictions during multiple site visits to each study location.

The author then input the traffic signals, speed limits of interchange ramps, and truck percentages into each simulation network. Traffic signal timing and phasing information was collected from the South Carolina Department of Transportation, from local jurisdictions such as the City of Greenville, or through observation during site visits as were speed limits, truck percentages, travel times, and queue lengths.

After the models were built, the next step was applying the proper traffic volumes. PARAMICS required volumes in the form of an origin-destination matrix specifying how many vehicles were traveling between each entrance to and exit from the simulation network. This method of specifying demand allowed familiar drivers to choose alternate routes if congestion caused delay. Table 5 displays the characteristics of each simulation network including length, number of interchanges, and number of origins and destinations traffic used.

Table 5. 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

To develop an origin-destination matrix that would accurately reflect the traffic volumes along the freeway and at each interchange, planning models were requested from local planning organizations at each site and traffic count data was requested from the South Carolina Department of Transportation. The planning models were supplied in different software formats; primarily (three sites) in TRANPLAN format and a few (one site) in TransCAD format. The research team converted all of the planning models into TransCAD format because of its capabilities and availability. Because planning authorities would not release their model for the fifth study site, along I-20 near Columbia, due to embedded sensitive material, the author collected volume data at that site during site visits.

Planning models included a much larger region than the simulation networks required, therefore, each was edited to combine like-zones, where zones used the same entrances to and exits from the freeway. Where options existed, such as choosing one interchange when traveling north and another when traveling south, zones were kept separate and aggregated manually to reflect these decisions. This process produced an origin-destination matrix with the same number and location of zones as the simulation model contained.

In some cases, volume data between different sources conflicted, primarily due to varying collection years. In these cases, volumes collected during site visits were considered the most reliable, followed by the most recent volume counted by the South Carolina Department of Transportation and lastly, planning model volume estimations. Because these traffic volumes were specified at select

points along the freeway and the simulation model required an origin-destination format, an iterative process was used to develop a matrix that satisfied all point conditions from the South Carolina Department of Transportation and from site visits.

Because some origin-destination matrices contained more than 800 cells and needed to satisfy more than 100 constraints, a program was developed using the software Matlab to expedite the development of origin-destination matrices from the various data sources. The goal of the Matlab program was to satisfy all volume constraints within five percent, ensuring the appropriate volume on each link. To meet this goal, the research team developed a function named “frmto” specifying a range of origins and destinations that a volume of traffic could travel to and from. Equations 1 and 2 show an example of the software inputs:

$$\text{frmto} = [2,3,4,5,0,0,0,0,0,0]; \quad (\text{Equation 1})$$

$$\text{volume} = 28900; \quad (\text{Equation 2})$$

The first two inputs in the “frmto” equation, two and three, specified the range of zones from which the 28,900 vehicles could start. The second two inputs, four and five, specified the range of zones where the vehicles could end. For the function to specify a single zone as either an origin or a destination, the number was repeated. The last six inputs, zeros, were used only in special cases such as when zones were skipped. For example, to specify that a certain number of vehicles began traveling from zones one, two, or four, the first two inputs would

specify the range from one to four and one of the last six inputs would remove three from that range. Equations 1 and 2 exemplify that 28,900 vehicles traveled from zones 2 or 3 to zones 4 or 5.

After the Matlab program output a matrix, Microsoft Excel was used to verify that the volume constraints were satisfied. When certain volumes did not satisfy the constraints, an iterative process manually adjusted the matrix until the volumes met all of the constraints within five percent and the total network volume was within one percent of the required.

Model Calibration and Validation

To ensure that the simulation model accurately reflected traffic conditions, the calibration and validation steps edited simulated driver behavior characteristics. The calibration step compared the volume and freeway travel times observed in the field to those generated by the simulation model. After the origin-destination matrices were developed, loop detectors were placed along key links in the simulation model to ensure that it produced the specified volumes. The overall simulated traffic volumes were within one percent of the observed, and the highest individual volume error was no more than ten percent, with most less than five. After the observed and simulated travel times were compared, the mean target headway and mean driver reaction time were adjusted until, after several iterations, the travel times differed by no more than five percent (less than one percent in most sites). Those two factors were chosen because they were found to impact the model most heavily during calibration (Hourdakis et al., 2003; Gardes et al., 2002; Lee et al., 2001; Abdulhai et al., 1999).

The validation process compared queue lengths and animation from the simulation to the queues and the videotaped traffic interactions observed during site visits with few significant differences. Because officials at South Carolina traffic management centers have observed these traffic networks every day, their approval of the animations was also used to validate the models. As this discussion indicates, the process of building, calibrating, and validating these five networks required significant time and effort.

Simulating Traffic Incident Scenarios

After the simulation models were built, calibrated, and validated, the author sought to simulate the selected incident scenarios. To measure the impacts most realistically, a crash history of the previous three years (2002-2005) was examined to determine high crash locations at each site. The two most frequent crash locations were identified within the three larger sites (Greenville, Charleston, and Richland) and only the most frequent crash location was identified within the smaller sites (Florence and York). Table 6 displays the number and location of crashes that determined the selection of the locations for simulating crashes.

Table 6. Three-year crash history of study sites (2002-2005)

Site by County	Total Crashes Analyzed	Location of Most Crashes		Location of 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

Through literature review, survey response analysis, and discussions with the South Carolina DOT project steering committee, six incident management strategies or tools were chosen for evaluation. Table 7 shows these and the steps in the incident management process that they address.

Table 7. Incident clearance strategies

Strategy or Tool	Detection	Verification	Response	Clearance	Traffic Management
Speed monitoring incident sensors	X				
Traffic cameras	X	X			
Freeway service patrols	X	X	X	X	
Steer-it clear-it law marketing				X	
Route diversion					X
Multiple strategies	X	X	X	X	

The framework developed for this research was comprised of four components: traffic simulation, incident generation, emissions estimation, and incident clearance scenario. The traffic simulation model was built, calibrated, and validated in PARAMICS Modeler, and the other components connected to the traffic simulation through the interface provided by PARAMICS Programmer. After incorporating the functionality and information from each module, the characteristics of each incident scenario were modeled in the traffic simulation software. The impact generation module used emission information generated from the software MOBILE6 to calculate the rates for different vehicle types. MOBILE6 is a software developed for the United States Environmental Protection Agency that predicts emission and fuel use rates for different types of vehicles in different environments. For this study, the author used the average

temperature at each site during the month of July, which represented the worst-case for vehicular emissions. The types of emissions will be discussed in more detail in the section titled, “Benefit-Cost Analysis”. Figure 5 shows the entire simulation process and how the various program modules interacted to create each incident management scenario.

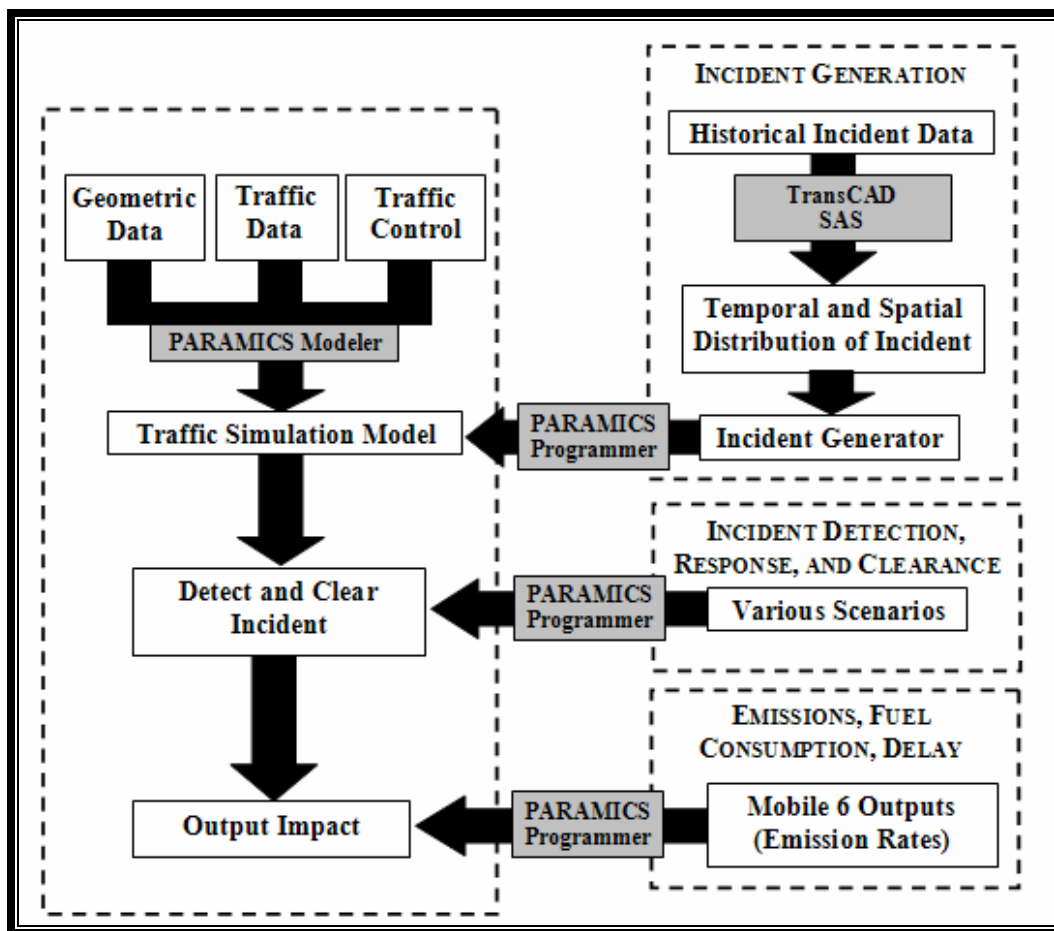


Figure 5. Procedure for simulating traffic incidents

Simulating the Impact of Detecting Incidents Using Traffic Sensors

To simulate the impact of detecting incidents using traffic sensors, an algorithm was developed that interfaced with the PARAMICS application programming interface. The process of generating, detecting, verifying, and clearing is displayed in Figure 6. The algorithm began by randomly creating an incident within one quarter of a mile around the high crash location to ensure a realistic spatial variation of incidents.

Next, the algorithm determined the detection time by choosing from a distribution. The expert opinion of officials at the Columbia Traffic Management Center indicated that traffic sensor detection times ranged from approximately one to five minutes. Based on that range, the algorithm would choose a detection time from a normal distribution with a mean of three minutes and a standard deviation of one minute, providing a 95-percent confidence interval of detection times between one and five minutes.

After the algorithm determined a detection time, the verification, response, and clearance times were determined. For verification, the research team assumed the use of traffic cameras. Similarly, the expert opinion of the Greenville Traffic Management Center indicated that traffic cameras usually verify incidents within 30 to 90 seconds of detection. To determine the verification time, the algorithm selected a time from a normal distribution with a mean of 60 seconds and a standard deviation of 15 seconds that similarly specified a 95- percent confidence interval between 30 and 90 seconds.

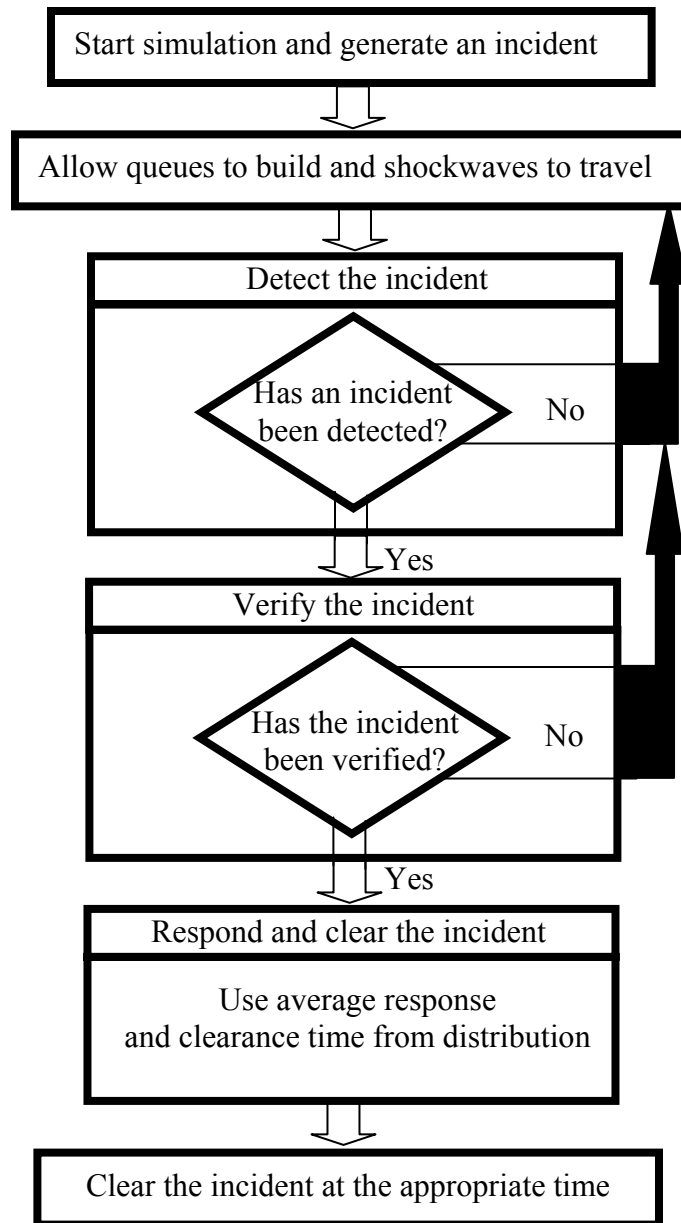


Figure 6. Traffic sensor incident detection process

In response to an incident, officials are dispatched to the scene. To simulate this process, 9.5 minutes was used to represent the average time it would take responders to arrive on-scene, based on national-average arrival times (Dunn & Latoski, 2003). These arrival times were used because no data existed for incident arrivals in South Carolina. To determine an appropriate incident clearance time, data were analyzed to determine the average clearance time for incidents in South Carolina. Because more severe incidents take longer to clear, three severities of incidents was used, based on criteria used by the South Carolina Department of Transportation. These average incident clearance times found are shown in Table 8. To isolate the impact of the detection and verification tools, the same incident response (9.5 minutes) and clearance (Table 8) times were used for the base scenario and the traffic sensor detection scenario.

Table 8. Historical incident clearance by severity

Severity	Minor (Blocks 1 lane)	Moderate (Blocks 2 lanes)	Major (Blocks all lanes)
Historical Duration	8-15 minutes	30-50 minutes	120-150 minutes

The simulated incident detection using traffic sensors with subsequent verification using traffic cameras was compared to base scenarios representing no such use of technologies. The research team used a combined detection and verification time of 20 minutes (Ozbay & Bartın, 2003; Skabardonis et al., 1998b; Nam & Mannering, 2000; Stamatiadis et al., 1997) to represent the base scenario.

Simulating the Impact of Detecting Incidents Using Traffic Cameras

To simulate incidents detected and verified by traffic cameras, a second algorithm was built following a process similar to incident detection with speed sensors. As shown in Figure 7, the algorithm added detection, verification, and clearance times according to different distributions. Again, experts at the Greenville Traffic Management Center suggested a time range between one and five minutes in which incidents have usually been detected by traffic cameras. To simulate this time range, the algorithm would select a detection time from a normal distribution with a mean detection time of 180 seconds and a standard deviation of 61 seconds, corresponding to a 95 percent confidence interval between one and five minutes. The verification time was selected from a normal distribution as presented in the preceding subsection. An arrival time of 9.5 minutes (Dunn & Latoski, 2003) was used to represent the time until the first responders and the incident clearance time was determined based on historical data according to crash severity as shown in Table 8. Because the author sought to isolate the impact of the incident detection and verification processes in this scenario, the results were compared to the same base scenario as previously discussed.

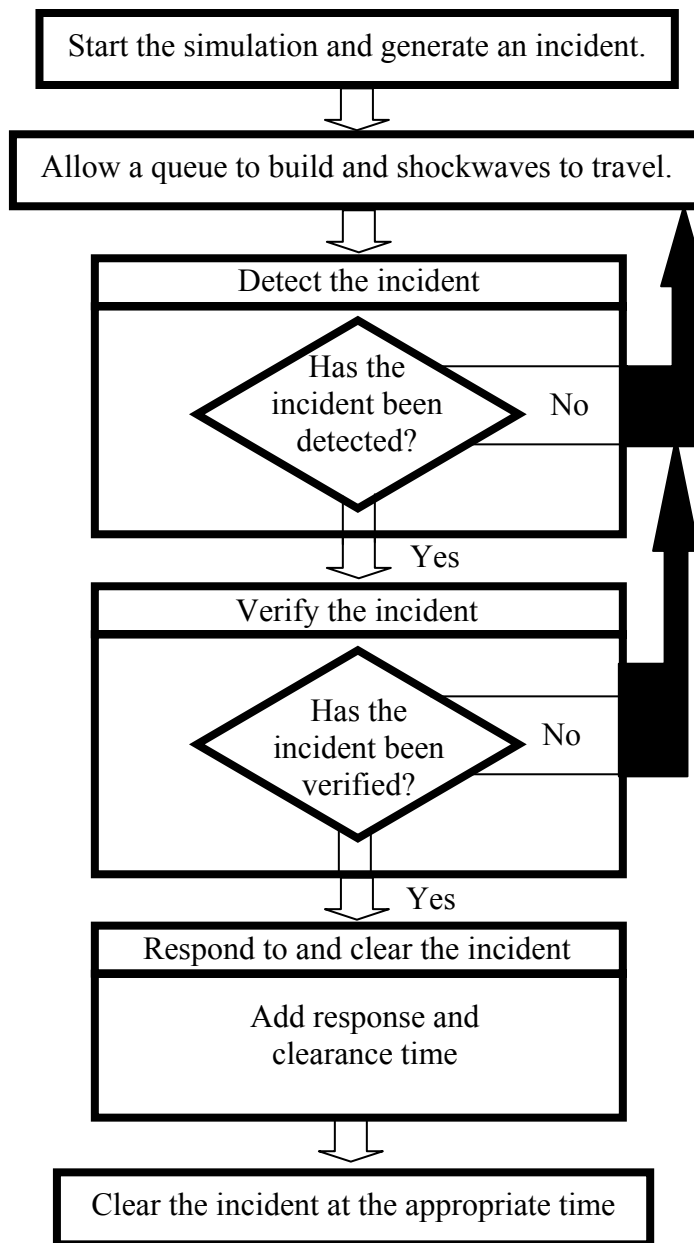


Figure 7. Traffic camera incident detection and verification process

Simulating the Impact of Freeway Service Patrols

To simulate the impact of using freeway service patrols, the author modeled patrol vehicles, assigning them routes that followed the main freeway links. The freeway service patrol vehicles began patrolling at the start of the simulation, turning around when they reached each end of the network. To account for randomness caused by traffic conditions and traffic control devices at the interchanges, a random time variance ranging from one to three minutes was added to each freeway service patrol vehicle when it turned around. These vehicle(s) continued patrolling the network until an incident was detected. The process of simulating freeway service patrol operation is shown in Figure 8.

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 were controlled, the occurrence of the other factors such as location of incidents and assignment of each freeway service patrol (in terms of time entering the network), was 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 ones to determine if increasing the frequency of these vehicles beyond current conditions still provided benefits to travelers. To compare these results against a situation without freeway service patrols, the authors relied on the base scenario previously discussed. The existing and reduced headway evaluated in this study are shown in Table 9.

Table 9. 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

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 offered an expert opinion that incident responders travel at approximately 35 miles per hour along shoulders or emergency lanes. This speed comes with two primary caveats: 1.) if the responder does not arrive in a timely fashion to a severe incident, motorists may exit their vehicles, requiring a slower speed for response vehicles using emergency lanes and 2.) an analysis must verify that bridges do not limit the continuity of emergency lanes. To address the former, the author observed the simulation to ensure responder's timely arrival, which was not a problem at any site. The latter was addressed by observing the shoulder widths upstream from the simulated incident locations. No should limitations were found close enough upstream from these locations, to prevent the freeway service patrols from using it.

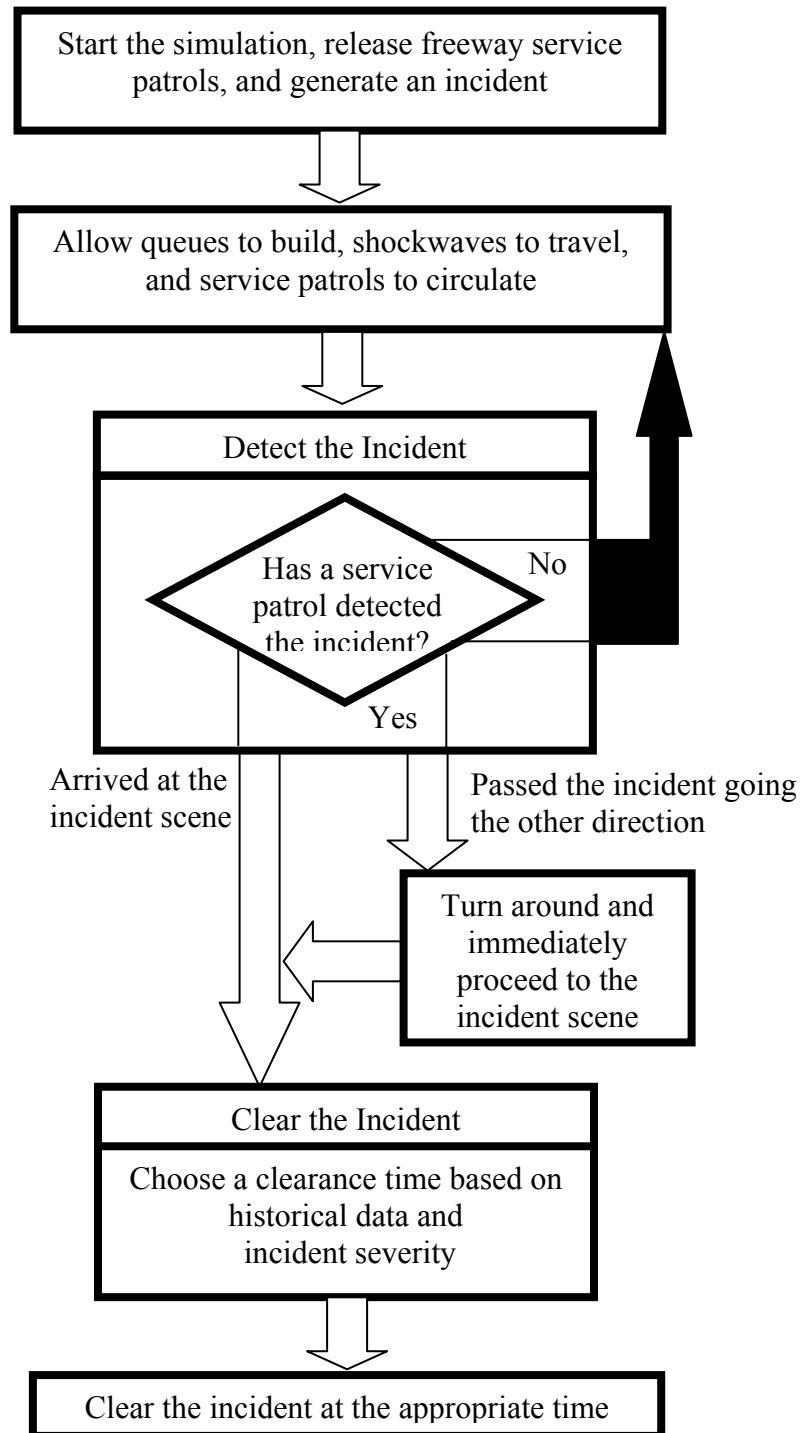


Figure 8. Freeway service patrol simulation

Simulating the Impact of Multiple Strategy Incident Management

Because several incident management strategies are commonly used at once instead of in isolation, this research evaluated the impact of an incident management program including speed sensors, traffic cameras, freeway service patrols, and incident reporting hotlines such as 911 and *HP. An algorithm was developed to simulate this complex environment by allowing different technologies to compete in the detection and verification steps. Once the incidents were detected, the freeway service patrols were notified and instructed to proceed immediately 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 significant role in the duration of the incident.

While the algorithms governing the traffic sensors, traffic cameras, and freeway service patrols operated as previously discussed, incident detection hotlines were unique to this scenario. To simulate incident detection using hotlines, the developed algorithm selected a detection time from a normal distribution with a mean of 2.1 minutes based on call center data for urban areas (Horan et al., 2005) and an assumed standard deviation of one minute.

During the detection step, the algorithm checked if any of the detection times selected from each distribution had occurred, or if a freeway service patrol had arrived. Once the incident was detected, the algorithm recorded the detection time and method, then proceeded to the verification step where traffic cameras and freeway service patrols compete to verify the incident first. Similarly, the

algorithm continually checked if the traffic camera verification time had occurred, or if the freeway service patrol had arrived on-scene. The verification time and method were also recorded; then the algorithm began counting down a clearance time as soon as the freeway service patrol arrived. This process of interactive detection, verification, and response is displayed in Figure 9.

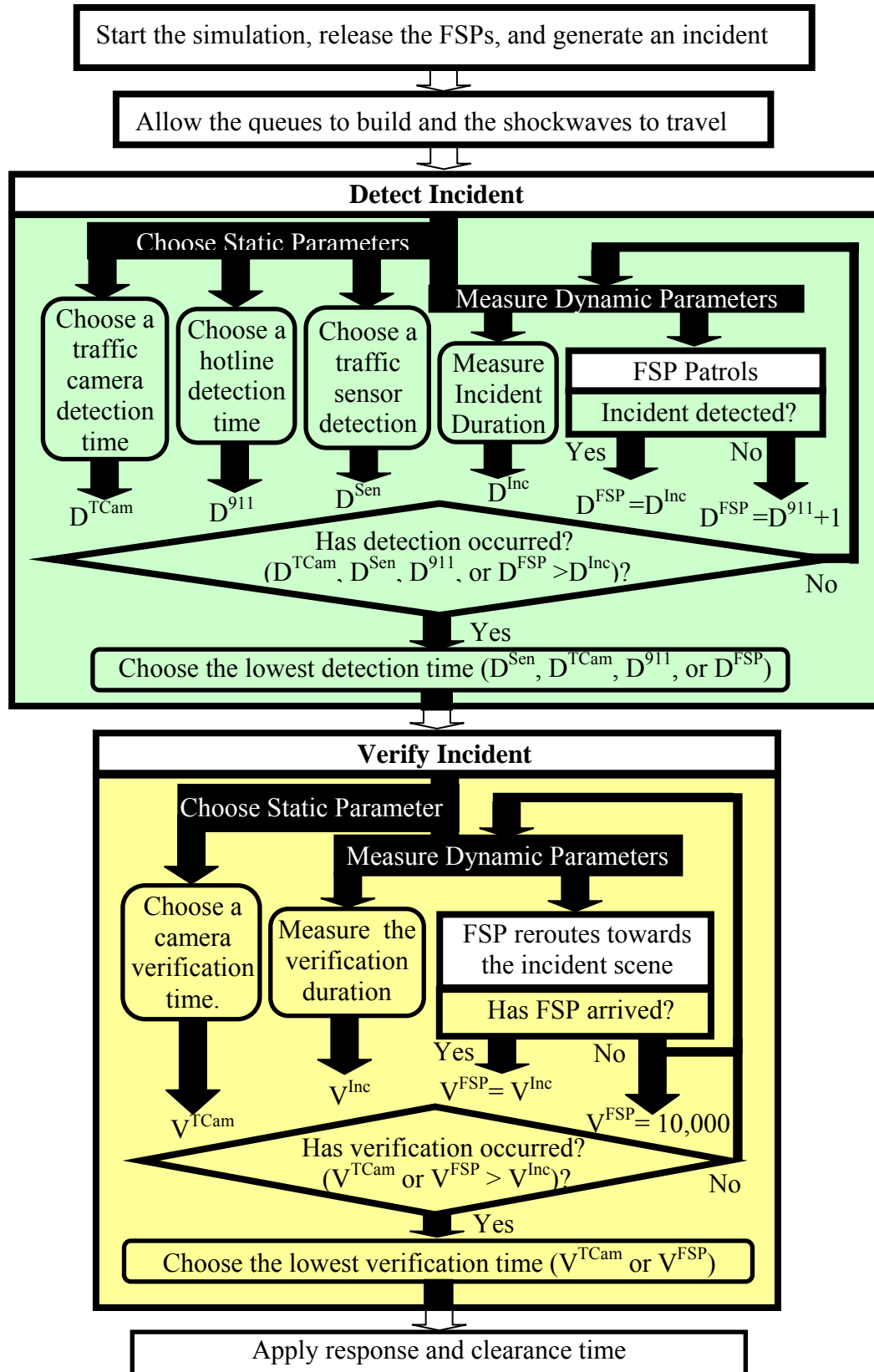


Figure 9. Process for multiple system incident management

Simulating the Impact of Steer-it, Clear-it Legislation

From literature, the research team determined that the steer it, clear it laws usually impacts minor incidents in which drivers can clear their own vehicles without tow assistance (I-95, 2005). Because service patrols and police traditionally arrive in approximately 9.5 minutes, motorists involved in minor incidents aware of the law either need to clear their vehicles before responders arrival, or quickly thereafter. Through discussions with officials at the Greenville Traffic Management Center, a minimum self-clearance time was estimated to be approximately four minutes and the average responder assisted self-clearance time was estimated to be ten minutes. As shown in Figure 10, motorists aware of steer it, clear it legislation clear their minor incidents no faster than two minutes after their occurrence, but if assistance is needed, such as when motorists are stranded in the left lane, then when the first responder arrives, minor incidents should require only approximately one minute to clear the remaining vehicles.

Steer-it, clear-it legislation makes its impact when drivers know about the law and respond to their duty to move vehicles. Simulating the effect of such legislation uses a pre-law base-case scenario in which no drivers move vehicles without assistance. The effect of passing the law and communicating it to drivers can be simulated based on the amount of time drivers might require to move their vehicles from travel lanes under the crash scenarios previously described.

To represent the after-law condition, the researchers created an algorithm to select an incident duration from a normal distribution with a 95 percent confidence interval between 2 and 10.5 minutes. This normal distribution had a

mean of six minutes and a standard deviation of slightly more than two minutes. The incidents where drivers were aware of the law but unable to remove their vehicle without assistance, lasting more than 9.5 minutes, and those where drivers remove their vehicles in under four minutes, rarely occurred because this time was located in the tail of the normal distribution.

To compare the delay impact to similar crashes where no law exists, the base-case scenario, the researchers examined the average clearance time of minor incidents in Greenville, South Carolina. Based on these data and the average police and service patrol arrival rate mentioned previously, the algorithm selected an incident duration from a normal distribution with a 95-percent confidence interval between 10.5 and 19.5 minutes. This distribution used a mean of 15.5 minutes and a standard deviation of just more than 2 minutes, allowing approximately 9.5 minutes for incident responders to arrive (Dunn & Latoski, 2003). This range in clearance times was based on expert opinion from incident management personnel at the Greenville Traffic Management Center. The process of simulating incidents that were candidates for steer-it, clear-it legislation is shown in Figure 10.

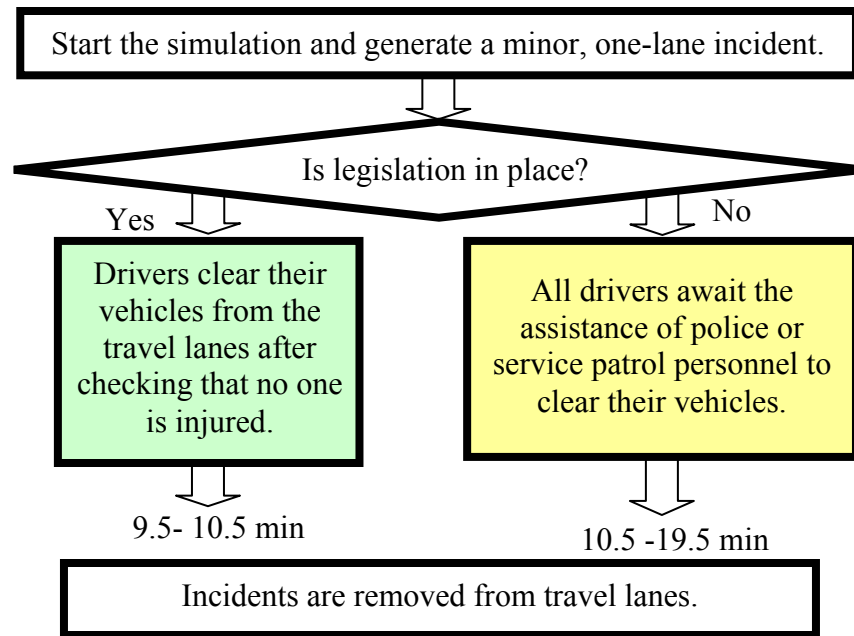


Figure 10. Procedure for steer-it, clear-it legislation simulation

Simulating the Impact of Route Diversion

Through meetings with the South Carolina State Highway Patrol, the research team discovered that incident management authorities in South Carolina consider route diversion as the mitigation option available during the most severe incidents. Because long-duration incidents cause the most severe backups, the author focused route-diversion analysis on the two simulation networks with the longest freeway lengths, Charleston and Greenville. Both of these networks allowed evaluation of the impact of three-hour, all-lane incidents without queues backing up out of the networks. The networks had to contain the incidents or else delay of vehicles queued outside of the networks could not be recorded in PARAMICS. The large networks at Charleston and Greenville contained the

queues of severe incidents within the networks, allowing PARAMICS to capture the full impact of each incident.

At the Greenville site, researchers simulated a route diversion at I-385, the second-most frequent crash location, because it provided a greater length of freeway for queues to build than the Laurens Road incident site, which had been the most frequent crash location. The interchange with I-385 also provided researchers a diversion route that required little network adjustment. Figure 11 shows the multiple locations of the simulated crashes with black squares and the location of the diversion route marked with white dots along the route.

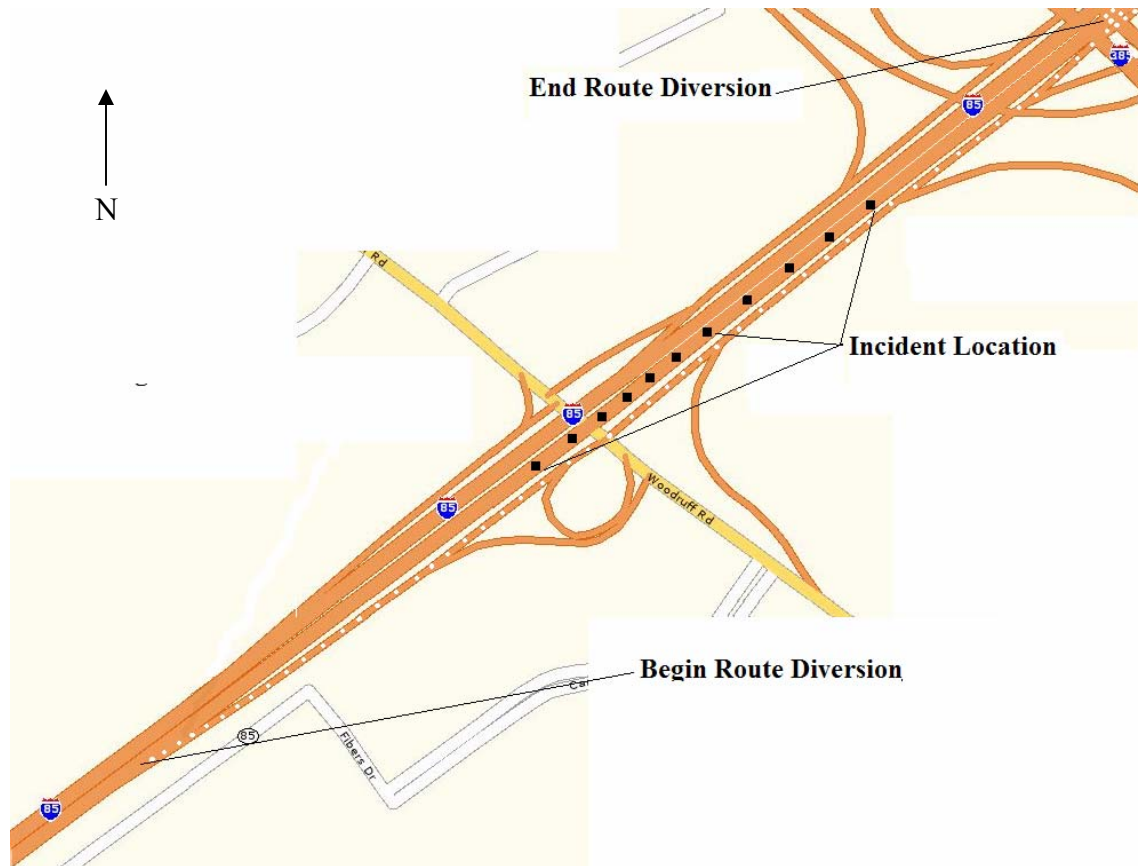


Figure 11. Greenville route diversion

At the Charleston site, the author simulated a route diversion along I-26 at the exit with the most crashes in the network, Ashley Phosphate Road. The South Carolina State Highway Patrol helped the author identify the most feasible alternate route and the number of officers, barriers, vehicles, and time required to implement a route diversion at that location. Because the crash simulated in Greenville for the route diversion scenario had similar route diversion characteristics, this information was easily transferable. Figure 12 shows the route diversion for Charleston with black squares along the multiple incident locations and white dots along the diversion route.



Figure 12. Charleston route diversion

To isolate the impact route diversion, researchers used 20 minutes as the combined incident detection and verification time based on previous research findings (Ozbay & Bartın, 2003; Skabardonis et al., 1998b ; Nam & Mannering, 2000; Stamatiadis et al., 1997), as used in the base-case scenario with no route diversion. As recommended by the South Carolina State Highway Patrol, a route diversion began operation 15 minutes after the incident was detected and verified, allowing time for officers and incident managers to activate variable message

signs, erect barricades, and deploy officers at key locations, such as traffic signals. While the results from the route diversion simulation analyses are site-specific, a sensitivity analysis presented in a later subsection attempted to make these results more transferable to other sites with similar volumes and geometric characteristics by providing a range of possible benefits rather than a single estimate.

Benefit-Cost Analysis

The researchers evaluated many measures of effectiveness for use in the benefit-cost analysis. The four general categories of benefits selected included delay, energy consumption, emissions, and safety. To determine these, the simulation provided ten outputs including vehicle-hours traveled (VHTs), unleaded fuel consumed, diesel fuel consumed, carbon monoxide (CO) produced, nitrous oxides (NO_x) produced, hydrocarbons (HC) produced, particulate matter (PM) produced, volatile organic compounds (VOC) produced, required incident detection and verification time, and vehicle-miles traveled (VMTs). The four general categories used here for costs included service and maintenance, communication, infrastructure, and personnel.

To conduct the benefit-cost analysis, all cost and benefits were converted to annual monetary units. Conversion factors to monetize costs were taken from the USDOT ITS Benefits and Costs Database and the ITS Deployment Analysis System, data frequently given in annual amounts. Benefits were calculated using one or more of the ten simulation outputs, depending on the applicable measure of effectiveness, as seen in Table 10. These measures were taken from recorded historical data and from the various scenario results from the simulation. These

results had to be converted into annual amounts, and to do so, vehicle-miles traveled were used to weight the impact between the simulation networks and their corresponding traffic volumes. For instance, the emission savings from a site with a high traffic volume was thus calculated to have a greater impact on average emissions in the state than emissions savings from a site with light volumes. The specific steps for determining the benefit-cost ratio for each scenario used here is illustrated in Figure 13.

Table 10. Measures of effectiveness

Category	Measure of Effectiveness	Simulation Output Required
Delay	Car	Vehicle hours traveled
	Truck	Vehicle hours traveled
Energy Consumption	Change in fuel use (gallons)	Unleaded fuel consumption
		Diesel fuel consumption
Emissions	Carbon monoxide	Carbon monoxide
	Nitrous oxides	Nitrous oxides
	Hydrocarbons	Hydrocarbons
	Particulate matter	Particulate matter
	Volatile organic compounds	Volatile organic compounds
Safety	Reduction in Fatalities	Detection and verification times
Weighting Factor	Vehicle miles traveled	Vehicle miles traveled

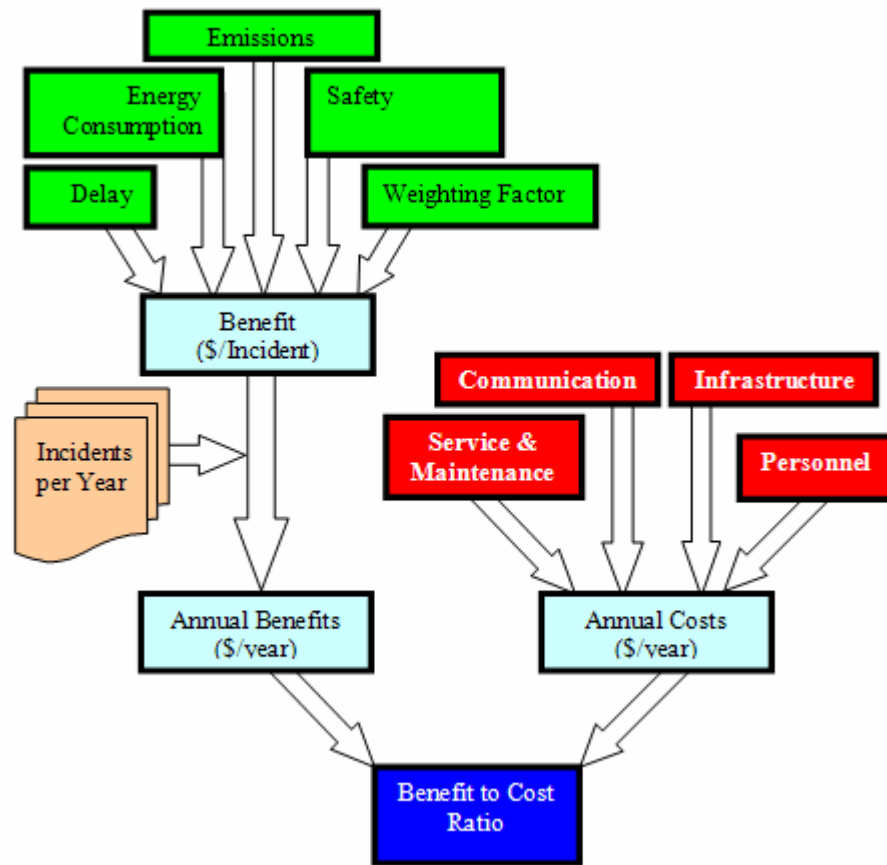


Figure 13. Benefit-cost procedure

Delay Impact

As displayed in Figure 10, the benefits of the various incident management strategies were calculated based on vehicle hours of travel, emissions, fuel consumption, and detection and verification times. The difference between an incident and its corresponding do-nothing scenario were considered the benefit. Delay reduction, considered as the difference in vehicle hours of travel between the incident management and the do-nothing scenarios, was

divided between heavy vehicles and passenger vehicles based on the proportion of the former observed during site visits.

Heavy vehicles which are used primarily for commercial operations, needed to be segregated because commercial travel delay has a higher value than personal travel delay. 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 three percent inflation rate as suggested by IDAS, the resulting values of time were \$13.33 and \$23.48, respectively, in 2006 dollars. Because the simulation software could not differentiate the hours of travel between heavy vehicles and light vehicles, the research team created an average weighted value of time based on the proportion of heavy vehicles specific to each site. Figure 14 shows the process used to determine the financial benefit of reducing delay through incident management in South Carolina.

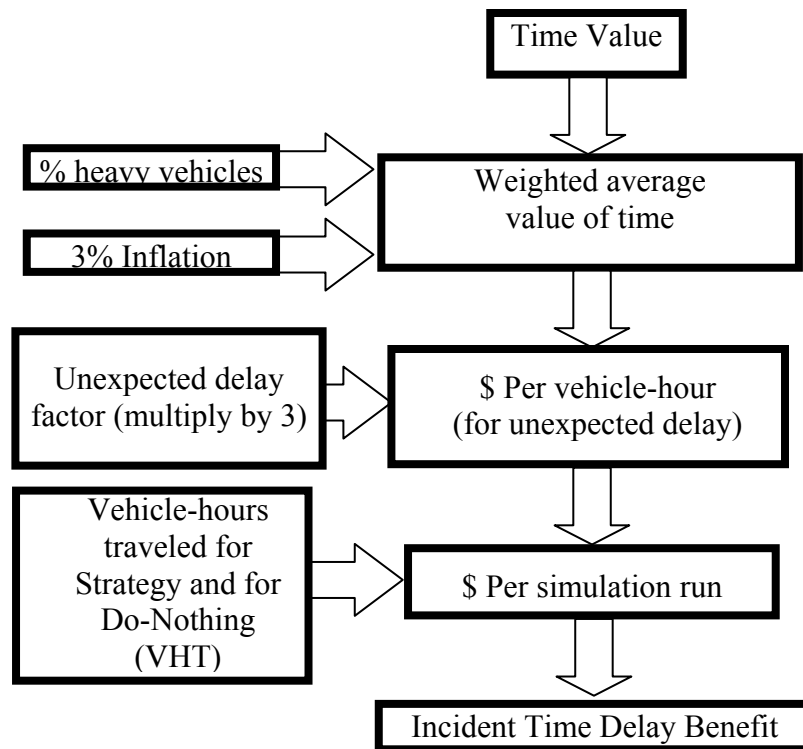


Figure 14. Delay benefits

Emission Impact

The research team relied on the widely-used software Mobile6 to estimate emission rates for the speeds and vehicle types used in the simulations. Three vehicle types, light-duty gasoline vehicles (LDGV), heavy-duty gasoline vehicles (HDGV), and heavy-duty diesel vehicles (HDDV) were used here. The module of PARAMICS used in this study to model the emissions shown in Figure 5 required that all emissions be expressed in rates of either grams or milligrams per seconds.

Mobile6 was run to find the average emission rate for these three types of vehicles for speeds ranging from 2.5 miles per hour, the lower limit of Mobile6

assumed to be idle speed, to 65mph, the upper limit of Mobile6 assumed to be free flow speed. For values lower and higher, PARAMICS Monitor used the closest value. For example, at zero miles per hour, Monitor used the emissions rate from the 2.5 miles per hour category. For vehicles traveling at speeds between those specified in the Monitor files, the software interpolated the emission values. An average vehicle age of nine years was used for all vehicle categories based on national averages (Davis & Diegel, 2002). Emission rates were determined for the five types of pollutants shown in Table 10, for the seventeen types of vehicles, displayed in Table 11, and at eight speeds in ten-mile-per-hour increments between 2.5 and 65 miles per hour. After determining the total emissions from a particular simulation run, these values were converted into dollar values using IDAS documentation for national average emissions costs (McTrans, 2003).

Table 11. Vehicle weight and classifications for emission and fuel calculation

Emission Type	Weight (1,000 lbs)	Mobile6 Vehicle Type	PARAMICS Vehicle Type
Light duty gasoline vehicles	<10	1-6	1-9, 16, 17
Heavy duty gasoline vehicles	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
Heavy duty diesel vehicles	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

Energy Consumption Impact

The consumption rates for fuel were calculated from various sources and input into PARAMICS Monitor in a process similar to that used for the emissions data. More detailed research has been conducted on the fuel consumption rates of light vehicles than for heavy vehicles; as a result, the research team found well-established consumption rates for different light vehicle speeds (Akcelik, 2003). For heavy vehicles, national average fuel consumption rates (Akcelik, 2003; Stodolsky et al., 2000) were applied for each vehicle weight range shown in Table 11, and applying the number of vehicles in each weight range registered in South

Carolina in 2005, a weighted average fuel consumption for the two heavy-duty vehicle types was determined. The weighted average fuel consumption rates were converted to gallons per second at each speed at 5 mile-per-hour increments between 0 and 75 miles per hour for input into PARAMICS Monitor. Gallons per second was chosen because PARAMICS Monitor required rates per second and because all fuel costs were based on gallons. For fuel consumption when vehicles were idling, several sources were referenced to identify the fuel consumption rates for light duty gasoline vehicles (Akcelik, 2003), heavy duty gasoline vehicles (Akcelik, 2003), and heavy duty diesel vehicles (Stodolsky et al., 2000). Fuel consumption rates were calculated at 14 speeds for these three types of vehicles simulated in the models.

Because PARAMICS Monitor could not recognize the difference in fuel types (unleaded or diesel), the research team treated these as two separate categories by specifying that diesel fuel was an emission and only the heavy duty diesel vehicles emit this at a certain rate. Researchers remained aware that this category was not an emission, rather an amount of diesel fuel consumption. After determining the total fuel consumption for a particular simulation run, these values were converted into dollars using average fuel costs for South Carolina (AAA, 2006).

Safety Impact

The impact of incident management on medical response times was also evaluated. Because limited research identifies the impact of response time on the costs of injuries, only the reduction in fatalities was considered. Evanco (1996)

developed the following equation relating the reduction in accident notification time to the reduction in the number of fatalities.

$$\frac{\Delta NF}{NF} = 0.27 * \frac{\Delta ANF}{ANF} \quad (\text{Equation 3})$$

Where, ΔNF represents the reduction in the number of fatalities, NF the total number of fatalities for the time period in question, ΔANF the change in accident notification time with respect to emergency medical responders, and ANF the normal accident notification time. Equation 3 considers accident notification time as between the incident occurrence and the notification of emergency medical response personnel. Because these personnel are commonly notified immediately after the incident verification step, this research considered accident notification time equal to the sum of the detection and verification times. Substituting the accident notification time into Equation 3, the reduction in fatalities due to incident management was predicted using Equation 4.

$$\Delta NF = NF * 0.27 * \frac{(\text{Detection} + \text{Verification})_{\text{Before}} - (\text{Detection} + \text{Verification})_{\text{After}}}{(\text{Detection} + \text{Verification})_{\text{Before}}} \quad (\text{Equation 4})$$

Cost Impact

Because each incident management strategy used different types and values of personnel, equipment, and time, the costs were unique to each.

Determining the costs of radar and camera systems involved both capital (infrastructure) and operating costs, including annual maintenance, repair, communication, and personnel wages. Even though these systems and personnel would often provide benefits other than incident management, such as security monitoring, their costs were considered solely incident management related.

Costs of freeway service patrols were estimated based on the number of freeway patrol units and referencing operating hours. These hourly costs were specific to South Carolina based on the patrols currently operating at all of the study sites. The multiple strategy scenario considered the same costs, including a 911 incident hotline with costs assumed to be shared among other non-freeway incident services. Costs were calculated based on the assumption that the 911-call center required one additional full-time operator to handle traffic-related calls.

Analyzing the costs associated with advertising steer-it, clear-it laws, researchers determined the cost of posting signs and advertising the new law based on multiple sources. The assumed deployment included one sign posted on each side of the interstate, every two miles. The last scenario examined, route diversion, was applied only to the most severe traffic incidents due to its high cost to local agencies. The impact analysis of route diversion included the costs of police unit time, trailer-mounted and static variable message signs, highway advisory radio use, communication between the traffic management center and the signs and radio, and infrastructure. These costs were site-specific to the two locations evaluated.

All of these costs and benefits were converted into annual monetary amounts. Because most of the benefits were per incident, the frequency of incidents for each severity level at each site determined the annual benefit. For instance, if traffic cameras provided a \$1,000 benefit for each incident blocking one lane and these incidents occur 200 times per year, then traffic cameras would benefit motorists at that site \$200,000 per year. Similarly, if costs were incurred by the hour or per patrol unit, these costs were converted into an annual cost based on frequency of a given type of incident.

Sensitivity Analysis

Because the number of crashes changes between years, it is essential to use several years of data when determining the average crash rate. This study examined three years of crash data at each site to determine the average number of crashes. To account for this yearly variation, researchers conducted sensitivity analysis that varied the number of each severity of crash between the percentages shown in Table 12. For example, if a study site had a three-year average annual crash rate of 100, then the lowest benefit would be when only 80 crashes occur, the highest when 90 occur, and the average when 85 do. Because costs of incident management tools are different across the country, the author also conducted sensitivity analysis with respect to costs by using the high and low costs of these tools reported from around the United States.

Table 12. Range of sensitivity analysis

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

Limitations

Several limitations influenced the benefit-cost analysis including evaluating secondary crashes, various emissions, driver stress, and legislative costs; comparing the findings to observed empirical crash data; and transferring findings to other locations. Several parameters that were identified as relevant to evaluating the benefits and costs of incident management were omitted from this study for various reasons.

The researchers examined previous methods used to evaluate the impact of reducing secondary incidents (Karlaftis et al., 1999; Karlaftis et al., 1998). However, two primary factors prevented this research from evaluating the benefits of reducing secondary incidents. Both of the previous studies regarding secondary crash probability were based on data from Minnesota, making it difficult to justify its applicability to South Carolina. A lack of data regarding the rates of secondary crashes in South Carolina further prevented a scientific approach to predicting a reduction in secondary crashes from the incident clearance scenarios evaluated. Discussions with the project steering committee

indicated little interest in the impact from emissions; therefore, carbon dioxide was not evaluated. Further, because driver stress is often a qualitative measure, researchers conservatively decided to assume a negligible impact from this factor.

Two costs considered but not included in the analysis were legislation costs for steer-it, clear-it laws and traffic management center costs for the other six scenarios. While annual legislature costs were available for South Carolina and other states, there existed no scientific way to determine how much time each branch of the legislature spent passing the law. Because South Carolina's traffic management centers are commonly located within existing DOT buildings, overhead cost was assumed to be absorbed into the normal annual operating budget.

One key limitation encountered by other traffic incident simulation studies (Ozbay & Bartın, 2003; Skabardonis et al., 1998b; Nam & Mannering, 2000; Stamatiadis et al., 1997) was the lack of empirical data to validate crash impact predictions. To date, South Carolina has not recorded data from traffic cameras and has recorded loop detector data, but only macroscopically (per hour). A partnership including the research team and any traffic management center in the state could implement a recording system to capture the impact of a traffic incident as discussed in the proposed research plan in Appendix B.

The key transferability limitation exists in the route diversion scenario. While all freeway sections in this research conformed to interstate standards and were, therefore, similar to freeways in other areas of the country, route diversion is a site-specific endeavor. Factors influencing effectiveness include the presence

and knowledge of a route diversion plan, nearby high-capacity roadways, and traffic signals. The results from this scenario should be transferred to other sites only if the geometry and volumes are similar.

Chapter Summary

The research presented in this document used four key tools to improve the state of incident management knowledge including a literature review, a nationwide multi-agency survey, traffic simulation, and benefit-cost analysis. The literature review was presented in chapter two and the survey included four key types of incident management agencies across the US. The traffic simulation portion examined five freeway sites across the state of South Carolina and used programming tools to interface with the PARAMICS simulation model to mimic six incident management scenarios. Benefit-cost analysis compared the benefits found from traffic simulation to the associated costs. Together, these tools provided an updated and a more comprehensive view of incident management building on the work of previous studies.

CHAPTER FOUR

SURVEY ANALYSIS FINDINGS

Traffic congestion on American highways wastes time and fuel while increasing emissions and the risk of secondary crashes (Derr, 2004; Barth et al., 1999). Recognizing the need for and benefit of incident management programs will only take highway agencies halfway to the solution. Agencies must further determine the most appropriate combination of technology and organizational practices needed to create the best balance of investment in incident management programs. Choosing the proper technologies and concepts for an incident management program is vital to maximizing benefits. A successful incident management program includes focus on three items:

- **Technologies** are often site-specific and some technologies are specific to types of incidents. In modern incident management practice, intelligent transportation systems (ITS) allows quicker identification of incidents through traffic sensors, faster response through coordination support, and faster recovery through the use of real-time information dissemination of alternate routes (FHWA, 1999). Few agencies can afford to invest in all available technologies; therefore, program managers need some indication of past experience regarding which technologies bring the most improvement in

incident response.

- **Communication** is a main factor in achieving effective coordination between partnering agencies. Successful incident management programs require coordination between various agencies and therefore require a guided selection of communication methods. Communicating the results of incident management to the public, decision makers, or to an agency's own employees has different constraints.
- **Strategies** provide the focus needed for effective incident management. Beyond understanding what technologies are available and how to interact within and between agencies, incident management programs need action strategies. Incident management strategies must account for institutional issues such as multiple jurisdictions and a variety of agencies involved with handling incidents. The strategies need to integrate technology with this complex institutional environment to create a pragmatic and efficient real-time solution.

This chapter identifies commonly implemented technologies, communication methods, and strategies within incident management programs across the United States by briefly reviewing past program experience previously identified in the literature, from chapter two, then through analysis of a nationwide survey conducted by the Clemson University Transportation Systems Team. The survey analysis describes the frequency and utility of the three key

incident management features listed above. Identifying synergies between stakeholders' experience has helped identify common problems to overcome and opportunities that exist for successful incident management programs.

Methodology Review

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 application and the 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. To view the surveys, refer to appendix A.

The survey was completed in December 2005 with 57 agencies responding. DOTs and SHPs had a much better response rate than the other agencies pooled, as shown in Figure 15.

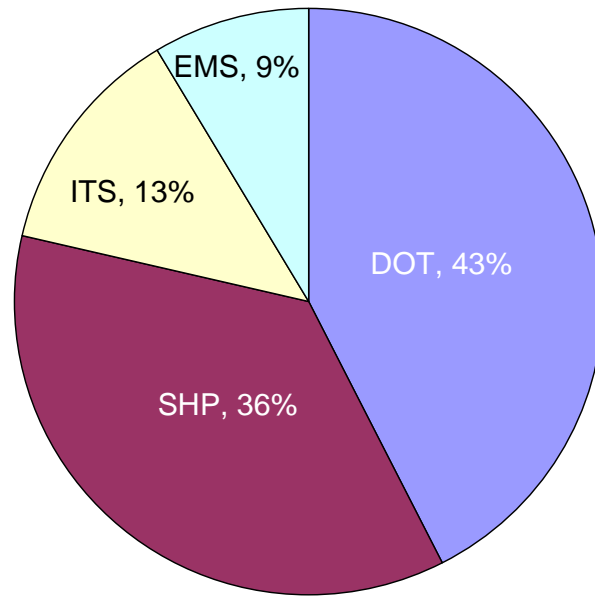


Figure 15. Respondent distribution

The research team received responses from at least one agency stakeholder department in each of 36 states. Figure 16 shows the responding states. There was a low response rate from states in the central south of the country. The hurricane season of fall 2005, including Hurricane Katrina, might have caused the low response rate in these states.

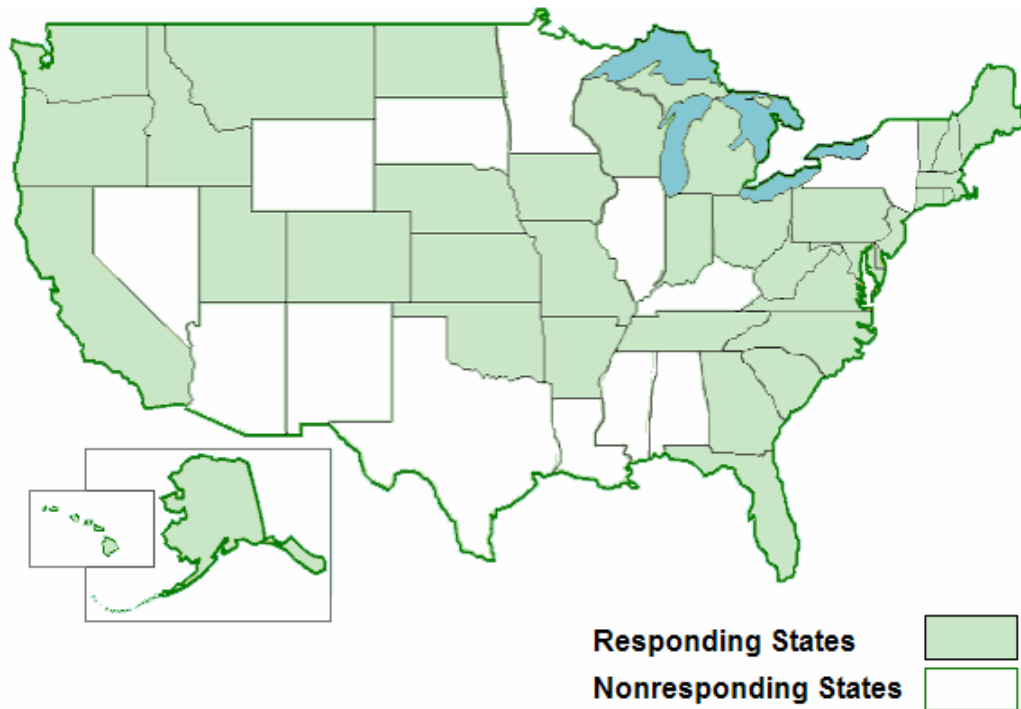


Figure 16. States responding to the incident management survey

Reviewing current incident clearance methods and technologies leaves several thoughts unaddressed. Although incident detection and verification technologies are independently found effective, little is known about how effective combinations of technologies are in real-world applications. Similarly, the application of clearance strategies, information dissemination methods, and investigative technologies might benefit from updated estimates of effectiveness in today's traffic environment. Alternate route diversion strategies are excellent tools to guide traffic around freeway incidents, but there is no information available on how widespread these strategies are used.

Other unanswered questions relate to the number and type of agencies involved with incident management. Identifying the agencies commonly included in successful incident management programs will provide existing and proposed programs a direction to grow and change. For agencies to respond decisively, clear definitions should be accepted by all participating agencies. There are various textbook definitions of a traffic “incident”, but little is known about how practitioners define it in their jurisdictions. The proceeding analysis section aims to address these remaining questions to improve the incident management industry.

Analysis of Survey Responses

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.

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” (FHWA, 2000). To assess definitions in practice, the survey asked all agencies to define a traffic incident (question one for DOTs and two for others), as displayed in Appendix A. The DOTs, ITS offices, and SHP respondents would agree that an incident disrupts the normal flow of traffic. The

SHP and 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).

Incident Prevalence by Type

To form a complete picture of incident management, it is important to understand the types of incidents to which agencies have frequently responded. DOTs responding to question two 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. ITS respondents rated single vehicle crashes the most prevalent incident type followed by weather-related debris, such as snow or ice, on the roadway, per question three. Multi-vehicle crashes and abandoned/ disabled vehicles were not rated by any ITS respondents. Responding state highway patrols to question three 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 the differing definitions of incidents among agencies.

The prevalence of secondary incidents, as asked in question three to DOTs and question four to others, was found similarly variable across agencies. Survey analysis identified collisions as the most common secondary incidents for DOTs and EMS responders and secondary incident and disabled vehicles for responding SHP and ITS agencies. Although difference exist in which incident type was the most prevalent, the analysis clearly identified the top candidates.

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 17) when responding to questions five and six, respectively. Of the agencies that rated their incident management program as both comprehensive and effective, half included only DOTs and SHPs in their incident clearance teams and one third included private companies as well. Two thirds of the better-rated agencies rated their programs equally comprehensive and effective. Several agencies perceived themselves as somewhat effective in both comprehensiveness and effectiveness. All of these agencies included DOT and SHP in their incident clearance patrol. One third of these respondents included DOT, SHP, EMS, and private companies.

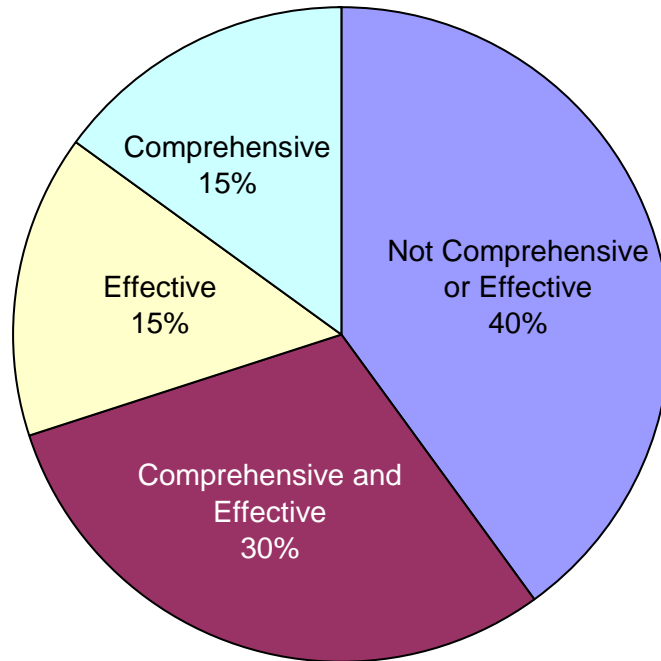


Figure 17. Self-ratings of DOT incident management programs

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, therefore; the more agencies involved in the incident management program, the less effective or comprehensive DOTs perceive them. This 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 are included due to rural landform, or if rural landform is 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 statement 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.

Evaluating the state highway patrol answers to the same effectiveness and comprehensiveness questions, numbers 15 and 16 in that survey, revealed similar trends in that the most common answer was that agencies' incident management programs were neither comprehensive nor effective (47 percent). Again, the second most frequent answer was both comprehensive and effective. While the departments of transportation responses separated these categories by ten percent, state highway patrol responses revealed a difference of only six percent. As shown in Figure 18, while no state highway patrol agencies rated themselves as only comprehensive, 12 percent of respondents rated their incident management programs as only effective.

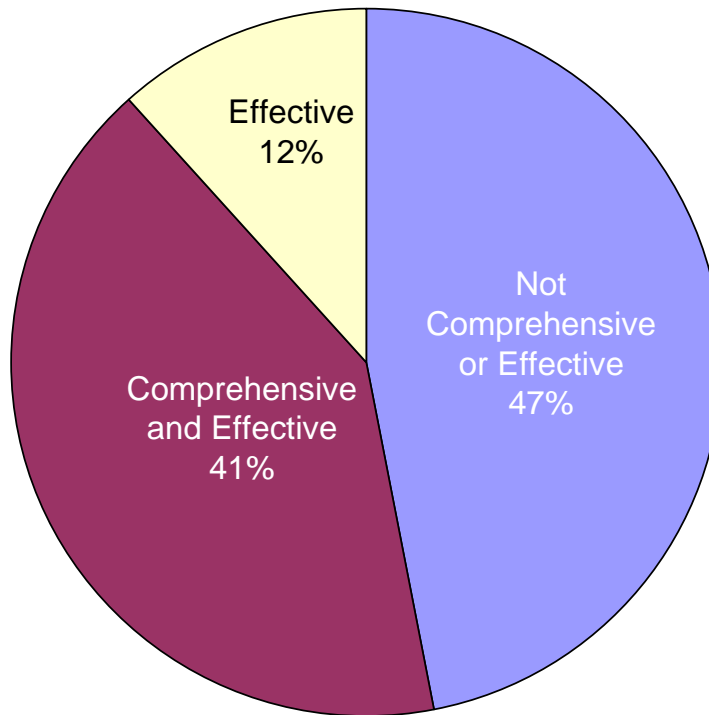


Figure 18. Self-ratings of SHP incident management programs

Findings from intelligent transportation systems officials answering effectiveness and comprehensiveness questions, numbers 12 and 13, revealed the lowest percentage reporting their incident management programs were neither effective nor comprehensive (33 percent). This respondent group also reported a high percentage of comprehensive and effective incident management programs at 50 percent, as shown in Figure 19. Responses from emergency medical services personnel revealed that all agencies felt their programs were effective and similarly, 50 percent reported their programs were comprehensive and effective.

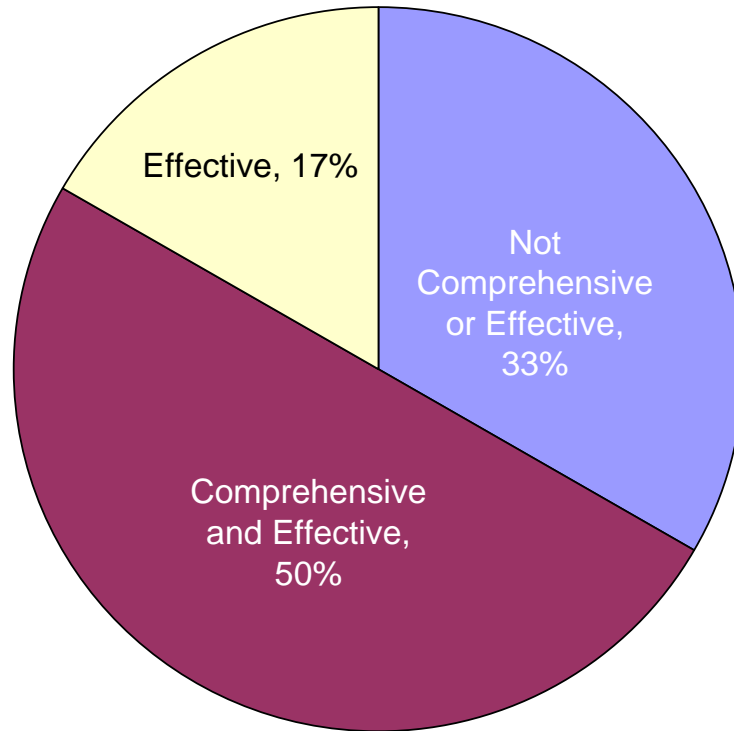


Figure 19. Self-ratings of ITS incident management programs

While differences were found between these agencies, only 15 percent of one agency type, the DOT, reported comprehensive incident management systems that were not effective, hinting that a system must first be effective, and then improve comprehensiveness. While not more than 50 percent of any agency group reported their programs were comprehensive and effective, providing justification for further research of incident management best practices, not more than 47 percent of any agency group reported neither comprehensive nor effective exhibiting that more than half of agencies are either effective, comprehensive, or both.

Equipment and ITS Technologies Deployed and Planned 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 were found to rely on five key devices per the answers to question five. These devices included variable message signs, automated incident sensors, highway advisory radios, traffic cameras, and traffic management centers. All responding ITS agencies used variable message signs and highway advisory radios. Further, all respondents either had or planed 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 (question 17). High false-alarm rates and labor requirements are likely causes of this rating (FHWA, 2000). The distribution of the use and plans of the other heavily used devices is shown in Figure 20. More agencies plan to implement a TMC before they plan to invest in field equipment to support the TMC.

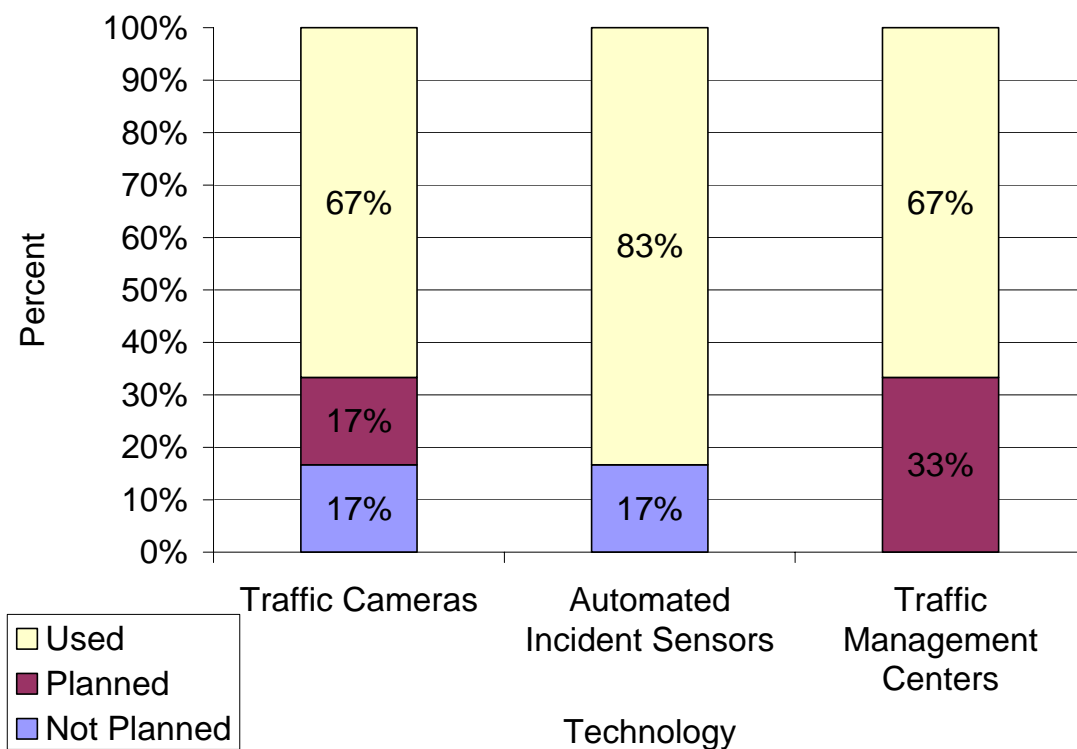


Figure 20. ITS technology existing and planned use

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 categories. 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.

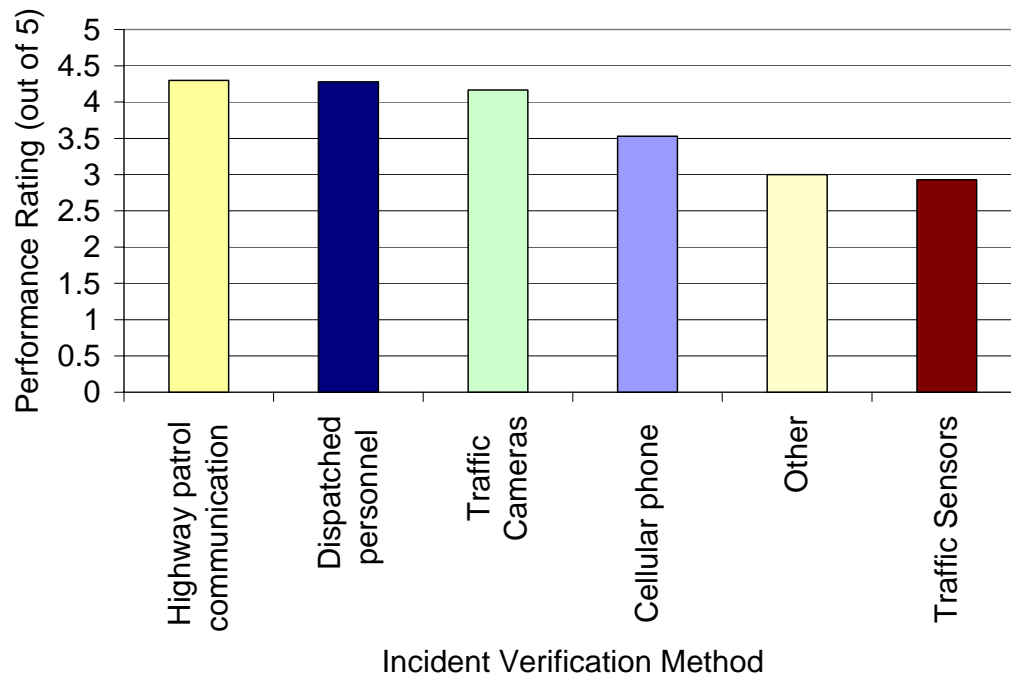


Figure 21. Performance of incident detection methods

The survey questioned DOTs more specifically about technology use for each step in incident clearance. As displayed in Figure 21, respondents rated traffic cameras, cellular phones, and highway patrol communication as the top three tools in incident detection, in response to question 13. All DOTs that rated their programs higher in collaboration and effectiveness made use of these top three incident detection methods.

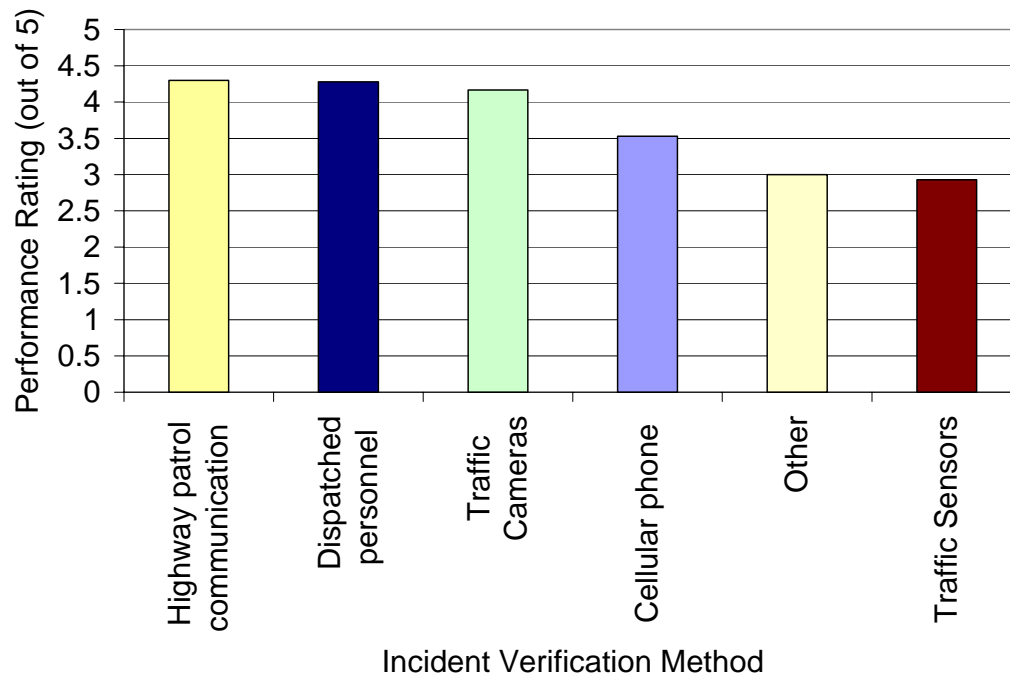


Figure 22. Performance of incident verification methods

While technology might improve performance in incident detection, the survey found that DOTs still relied on human interaction heavily, for incident verification (question 14), as illustrated in Figure 22. 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.

After polling agencies regarding incident detection and verification methods, the focus turned to incident clearance. The clearance of major (non-

hazardous) incidents by DOTs was reported to rely most heavily on dump trucks, sweepers, and heavy-duty tow trucks, by responses to question 16. 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 agency that rated their program poorly 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 to question nine indicated 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, providing no significant trends. The data collected were only available to limited agencies (question 10).

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, such as accurately evaluating the benefits of existing systems, these findings left plenty of room for industry improvement.

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 indicated that 80 percent of ITS offices used variable message signs to disseminate information during an incidents and another 15 percent planned to. As previously presented, 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 comprehensive 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, per responses to question seven.

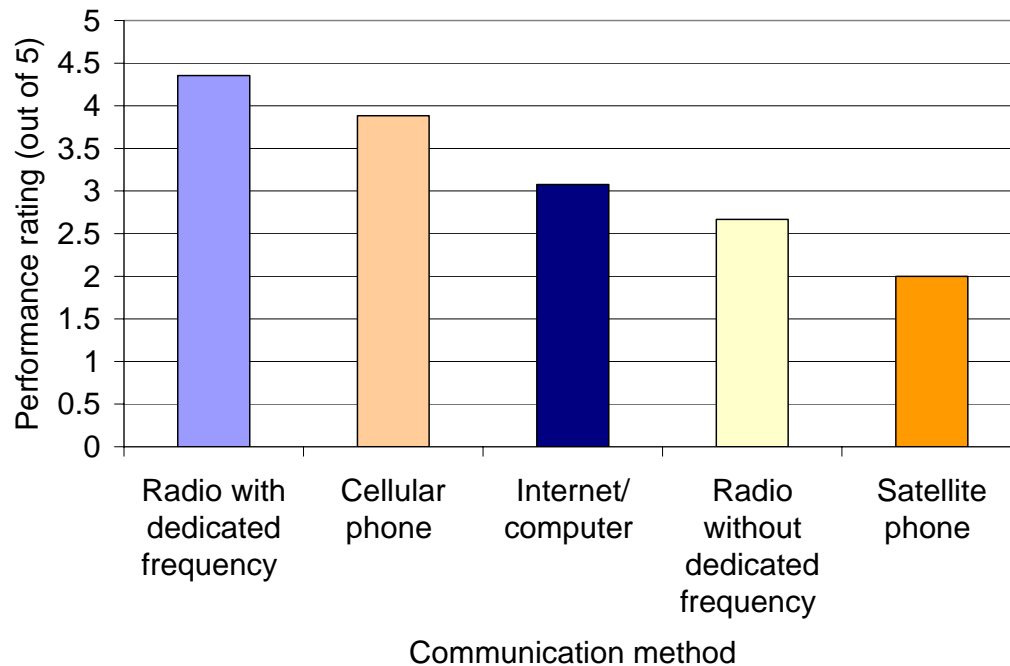


Figure 23. Performance ratings of communication methods

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 (question 15) that rated their programs as collaborative 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. These findings support the performance ratings of all DOTs, as shown in Figure 23.

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.

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 questions 32 and 33 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.

State Highway Patrol Information Sources

The survey responses illustrated that the general public has been the largest source (56 percent) to SHP's incident detection and verification in the United States (question 7). 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 with question eight. A scale of one to five was used, with five being the best. The responding agencies rated total stations, crash reconstruction 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 using question nine. 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.

Successful Emergency Medical Services

Traffic incidents often involve the response of EMS, so the survey poled these agencies to determine their typical roles (question 10), perceived effectiveness in incident response (question 12), and best practices (questions seven and nine). EMS respondents rated their incident clearance programs on a scale of one to five, with five being the highest. Results supported EMS respondents' had 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 (question 13). Agencies that implemented a new or changed strategy reported the same or better collaboration between agencies as those that did not. Because there are no dramatic differenced 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.

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 (question 18) were lack of coordination between agencies, lack of funding, and lack of public awareness, as displayed in Figure 24. 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.

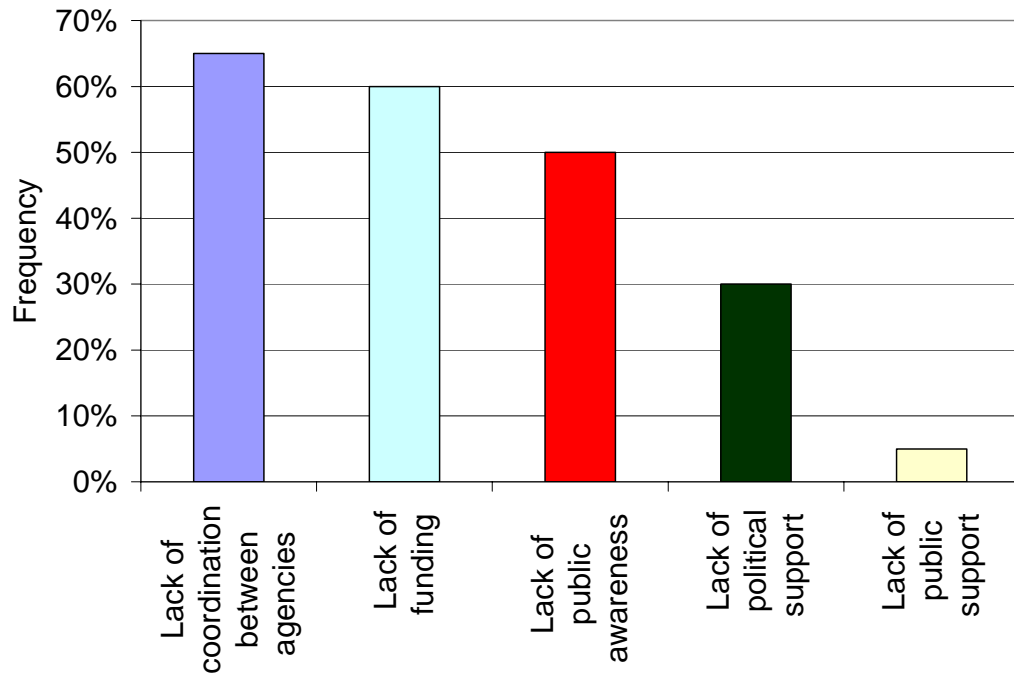


Figure 24. Obstacles to incident management programs

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.

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 conduct 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 found 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 reported 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 for 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.

Anticipated Use

The survey responses summarized in this chapter will be useful for departments of transportation, traffic management centers, emergency medical services, state highway patrols, decision makers and community leaders, and others involved in incident management. Respondents raised many common needs, such as interagency cooperation. These needs should be considered before implementing a new incident management program in order to plan for

cooperation and to perform before-and-after studies measuring the full impact of new or changed programs. Similarly, successful experiences reported by the respondents for this research can aid in project selection for new ever-evolving incident management agencies.

Conclusions of Survey Analysis

This chapter 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. Based on agencies included in presently comprehensive and effective incident management programs, 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 traffic cameras, dispatched personnel, and highway patrols the most successful. Usage patterns hint that efficient and comprehensive programs have dump trucks, sweepers, and heavy-duty tow trucks for incident clearance. Air-cushioned recovery systems and cranes were only used by agencies that considered their use of technologies efficient and comprehensive. This finding could suggest the recovery systems are not critical to skeletal incident management or that truly efficient incident management requires these tools.

The incident management industry is also widely using alternate routing of traffic, because all responding agencies have or plan to have variable message signs, highway advisory radio, and alternate route plans. Responses indicate that

the two most planned technologies include CAD and TMCs, which will also aid in implementing alternate routes.

Responses to data archiving questions indicate that the industry has strong footing with road sensor data. The incident management industry must branch out 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 of communicating between incident clearance agencies are telephones and the Internet. Therefore, there are few applications of newer technologies for communication within and between incident management agencies.

Agencies responded that total stations, crash recreation software, and interviews with witnesses are the most effective tools for incident investigation. Other incident-investigation-related responses found wide deployments of ineffective technologies and no plans for some effectively rated technologies. 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 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 tools, and communication methods to the public and to decision makers.

CHAPTER FIVE

SIMULATION RESULTS

Based on the survey findings, this study chose the following incident management strategies to simulate their impact on traffic delays, fuel use, emissions, and fatalities.

- Traffic sensors
- Traffic cameras
- Freeway service patrols
- Multiple strategies
- State legislation
- Route diversion

Incident Management Using Traffic Sensors

Transportation agencies often use radar sensors and loop detectors to monitor vehicular speed for incident detection. Other examples of sensors, specifically optical and video, are commonly combined with computer software to detect incidents automatically. As the process of evaluating loop detectors and radar sensors shown in Figure 6 indicates, incident durations were determined by selecting the detection and verification times from normal distributions, then adding the response and clearance times. The results of this simulation show reductions in delay, fuel, and fatality shown in Figure 25 and the reductions in

emission shown in Figure 26. This data is based only on incidents blocking two or three lanes because sensors were found ineffective in detecting minor incidents, those blocking one lane.

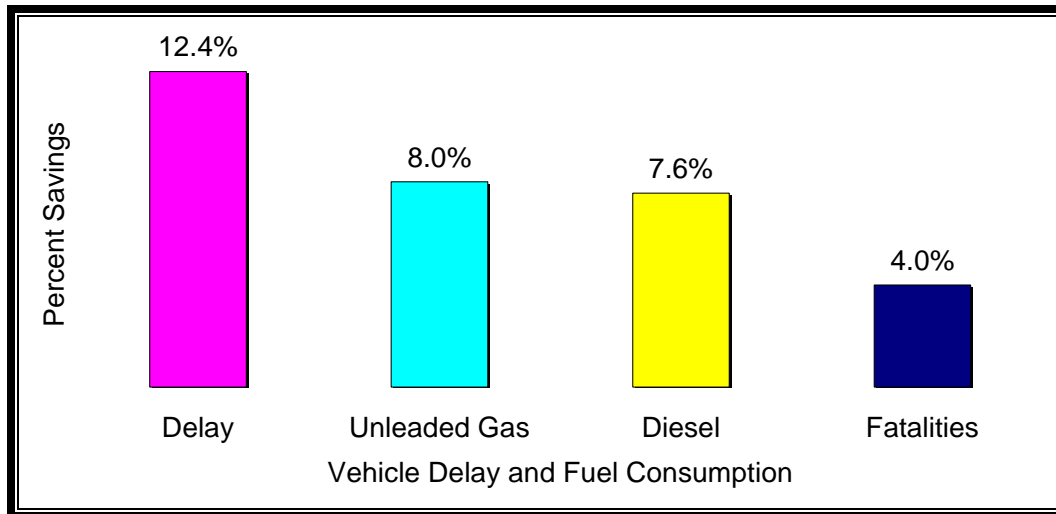
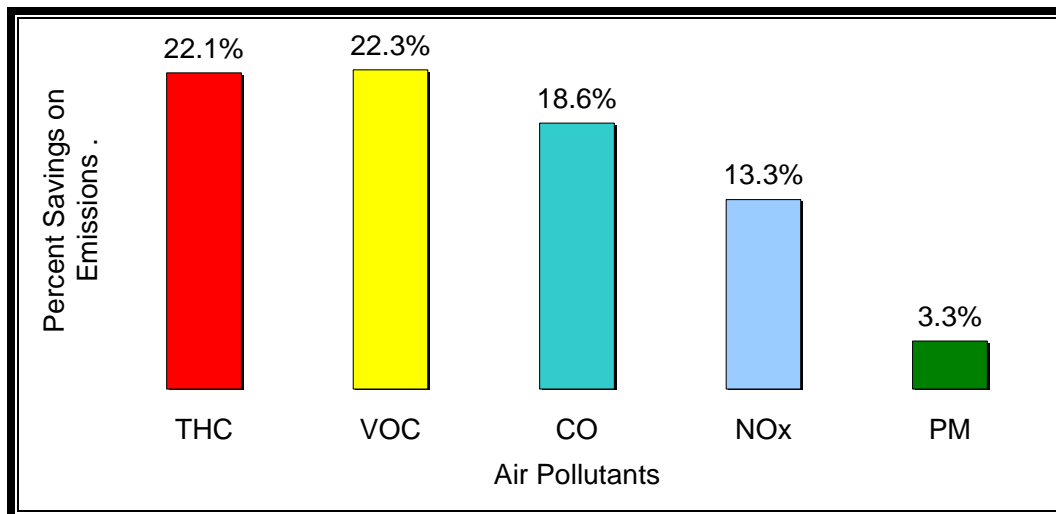


Figure 25. Percentage savings using traffic sensors



THC=total hydrocarbons ■ VOC=volatile organic compounds ■ CO=carbon monoxide
 NOx=nitrous oxides ■ PM=particulate matter

Figure 26. Percentage savings on air pollution using traffic sensors

As Figure 27 shows, the fiscal benefit of these reductions with respect to the incident severity at an urban South Carolina freeway site is approximately three million dollars annually when traffic sensors are used to detect all incidents blocking two lanes and approximately four million dollars annually for those blocking three lanes. Because the number of crashes and the costs of traffic sensors vary each year, this study included a sensitivity analysis. The squares in Figure 27 represent the average annual benefit based on average crash rates at each study site and the line represents the possible range in annual benefit, both using three years of crash history data to ensure the sample was large enough to predict the mean crash rate accurately. Because the benefit per incident was greater for incidents blocking three lanes than for two, the annual number of those incidents more heavily impacted the range of predicted benefits. For example, managing one additional incident blocking three lanes in a year will produce approximately \$200,000 in benefit, compared to only \$27,000 for incidents blocking two lanes.

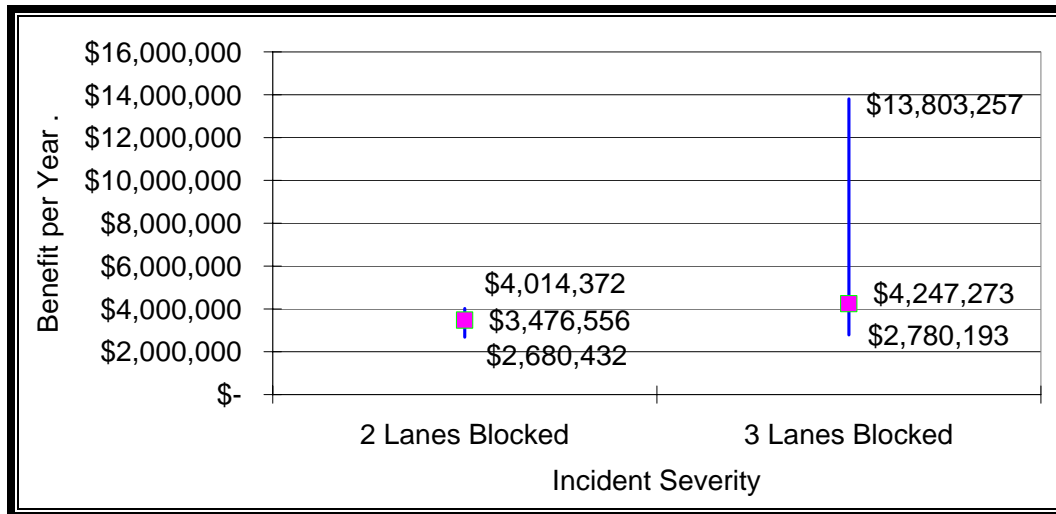


Figure 27. Annual benefit of traffic sensors for incident detection

The three measures of effectiveness that produced the most significant impact on the benefits of two-lane incidents were savings in vehicular delay, unleaded gasoline usage, and carbon monoxide emissions. In addition to three measures of effectiveness, diesel fuel and nitrous oxide savings were also significant contributors to the benefits of three-lane incidents.

Incident Detection and Verification Using Traffic Cameras

Due to the human element, incident detection using traffic cameras does not have as large of a risk of false detection as traffic sensors. As Figure 7 shows, evaluating these impacts uses a similar process as that of traffic sensors. The percent savings on delay, fuel consumption, fatalities, and pollution for each incident using traffic cameras is shown in Figures 28 and 29. Because traffic cameras were evaluated for their impact on all three severities of incidents while

traffic sensors were only evaluated for the two most severe, the percent reductions for traffic cameras were less than those found for traffic sensors.

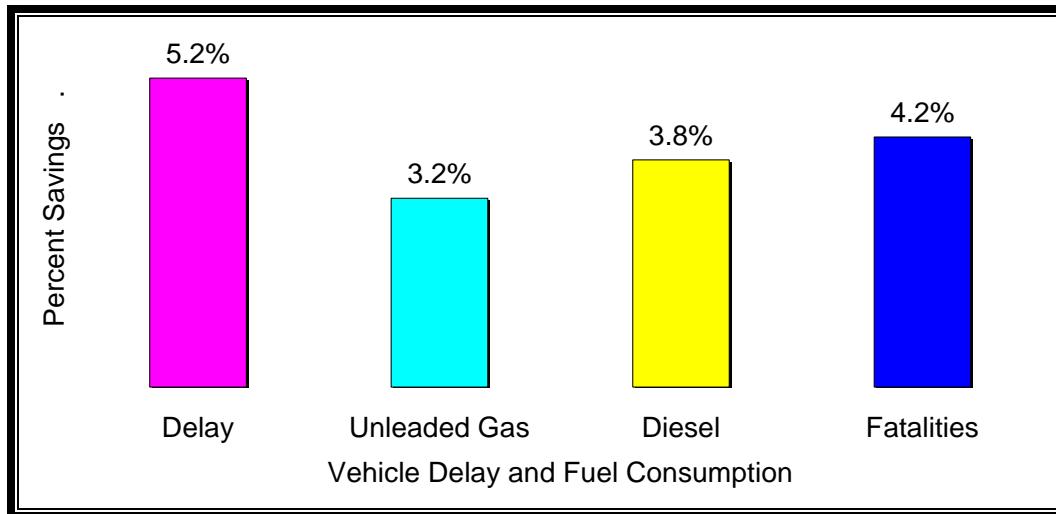
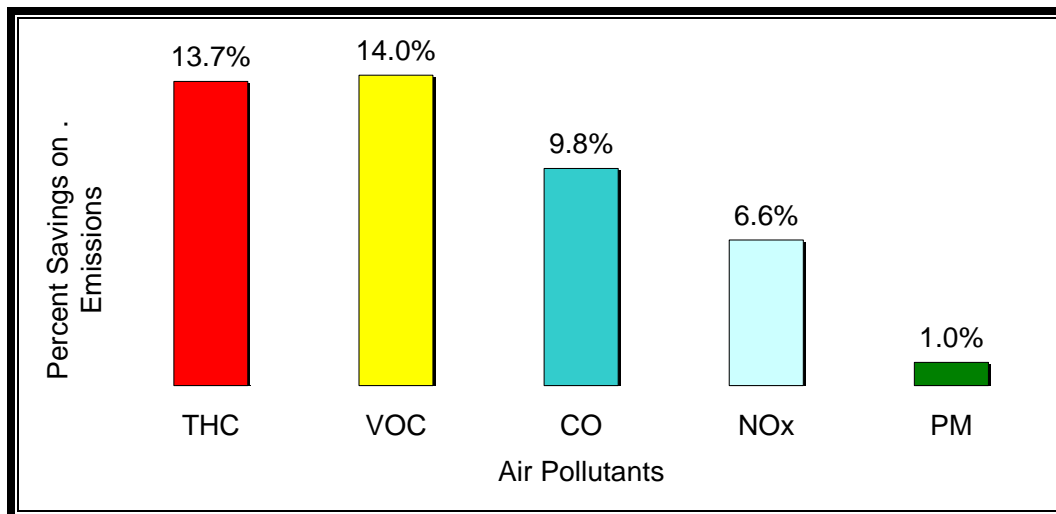


Figure 28. Percentage savings using traffic cameras



THC=total hydrocarbons ■ VOC=volatile organic compounds ■ CO=carbon monoxide
 NOx=nitrous oxides ■ PM=particulate matter

Figure 29. Percentage savings on pollution using traffic cameras

Figure 30 shows the annual range of benefits found for using a traffic camera system for incident detection and verification on urban freeway sections in a South Carolina city. The varying frequencies of each crash severity played a significant role in the annual benefits. While the per-incident benefits increased with the incident severity resulting in approximately \$6,000 for one-lane, \$40,000 for two-lanes, and \$84,000 for three-lanes, incidents blocking two lanes produced the most annual benefit due to their combination of per-incident benefit and frequency.

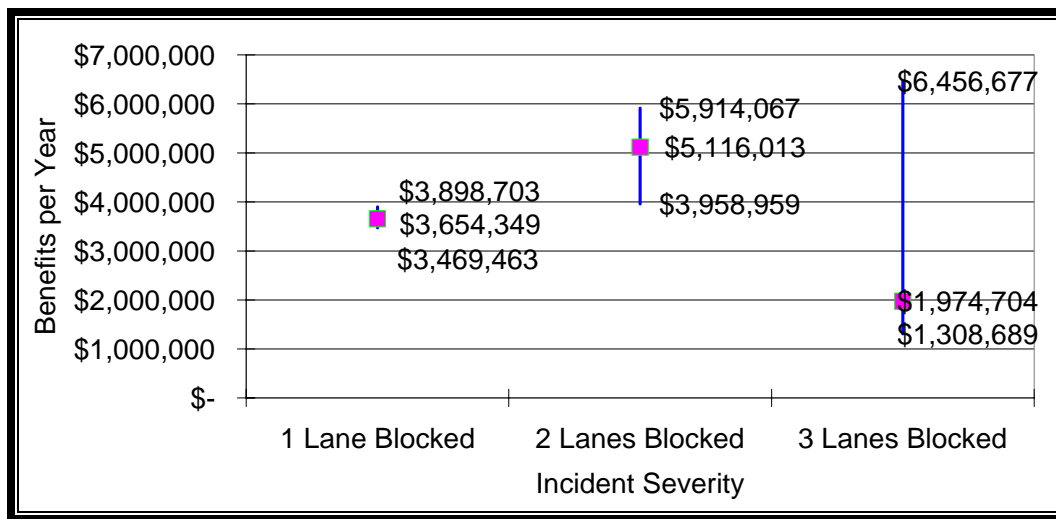


Figure 30. Annual benefits using traffic cameras

Incident Detection, Verification, and Response Using Freeway Service Patrol

The researchers evaluated the impact of using freeway service patrols through the process shown in Figure 8. Incidents blocking three lanes were not

evaluated for this scenario because patrols do not possess the required equipment to clear and manage that severe an incident. Figure 31 displays the percent savings for delay, fuel consumption, and fatalities, and Figure 32 shows the percent reduction in emissions produced by using the existing headways of South Carolina freeway service patrols.

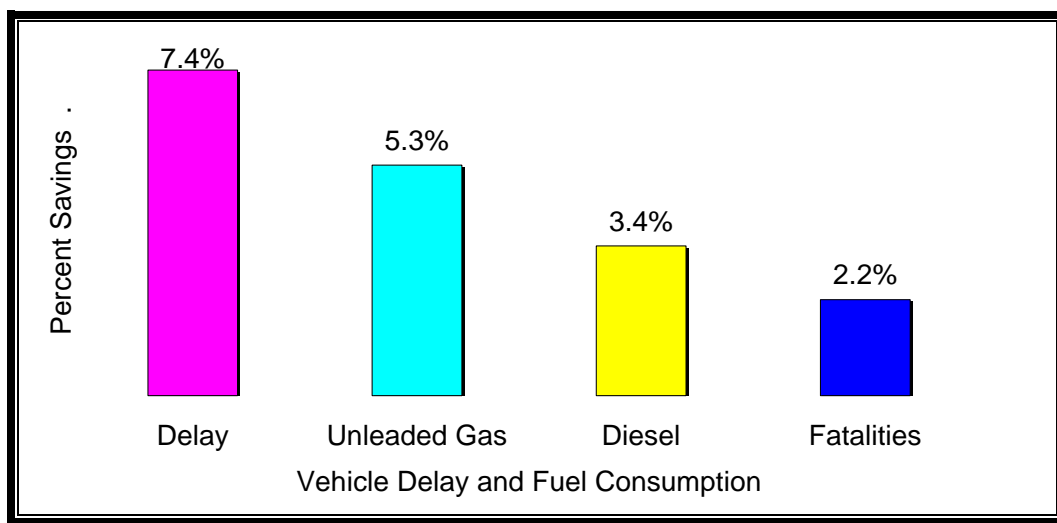
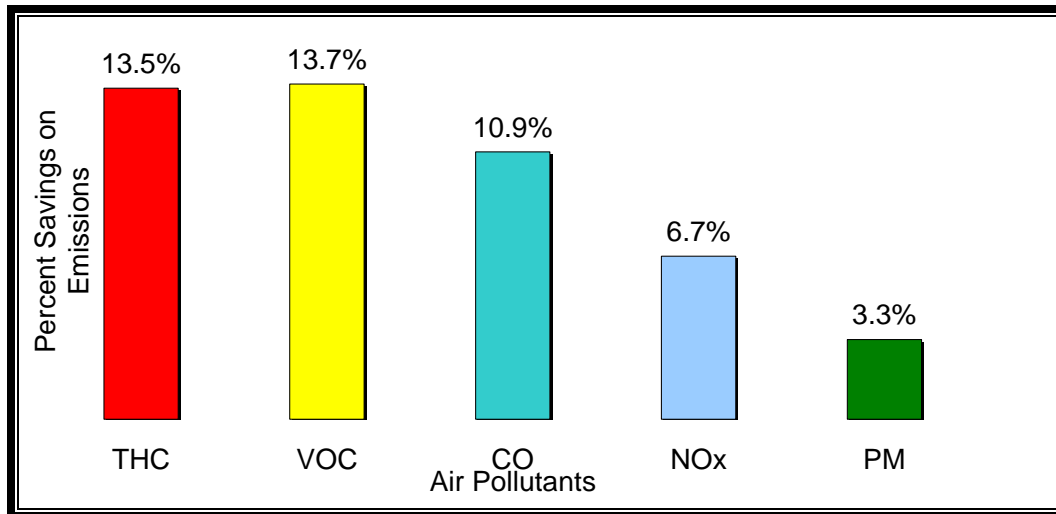


Figure 31. Percentage savings using freeway service patrols



THC=total hydrocarbons ■ VOC=volatile organic compounds ■ CO=carbon monoxide

NOx=nitrous oxides ■ PM=particulate matter

Figure 32. Percentage savings on pollution using freeway service patrols

Researchers compared the benefits of freeway service patrols operating at existing headways with patrols operating with reduced headways as shown in Figure 9. Sites with existing headways of 45 minutes or less were reduced by two thirds to between 15 and 5 minutes, and the site with an existing headway of one hour was reduced by three quarters to 15 minutes. Figure 33, showing the per-incident benefits of the proposed reductions in headways compared to the benefits of the existing headways, indicates that no significant additional benefit was achieved by the reduction in headway; therefore, no further research was conducted on these reduced headways.

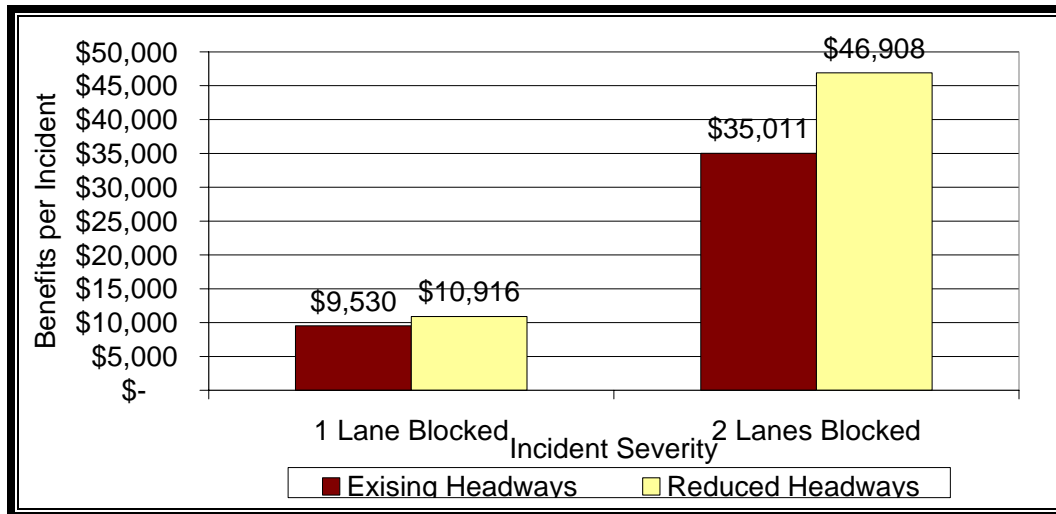


Figure 33. Benefits of existing and reduced freeway service patrol headways

As Figure 34 showing the average annual benefits of freeway service patrols on South Carolina freeways indicates the benefit was more for each incident blocking two lanes than for those blocking one. The sensitivity analysis produced less variation in the annual benefits of incidents blocking one lane than those blocking two because of the difference in per-incident benefits. The frequency of incidents caused the highest annual benefit to result from managing incidents blocking one lane.

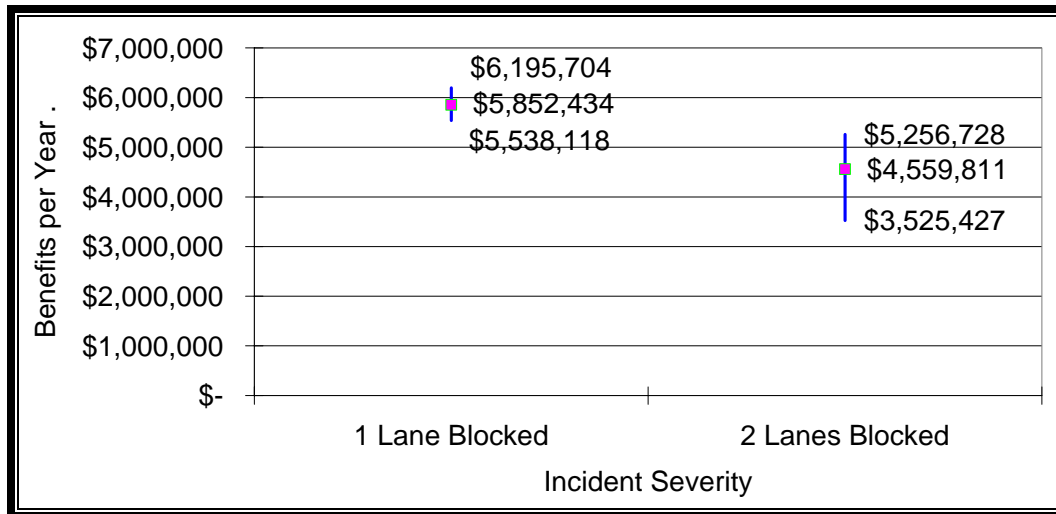


Figure 34. Annual benefit of freeway service patrols

Incident Detection, Verification, and Response Using Multiple Strategies

Because incident management tools are seldom used alone, this study also examined the impact of using multiple tools in coordination as displayed in Figure 9. Figures 35 and 36 present the reductions in delay, fuel consumption, fatalities, and emissions produced by the multiple strategy scenario, including traffic sensors, traffic cameras, incident reporting hotlines such as 911 and *HP, and freeway service patrols.

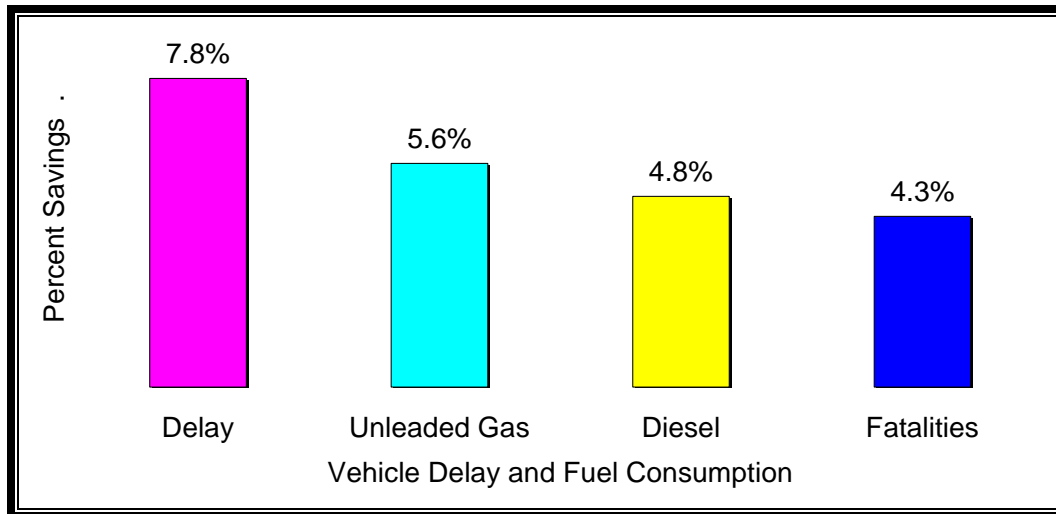
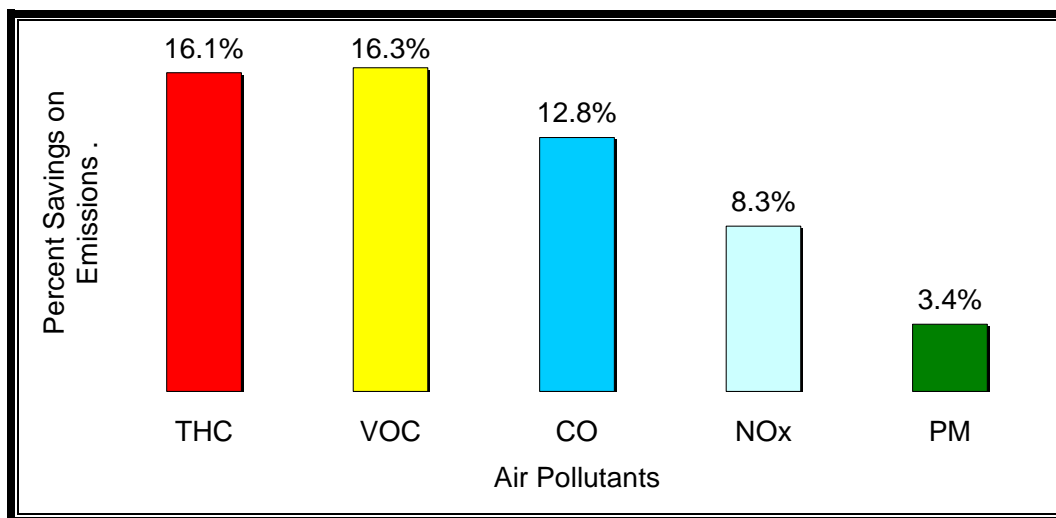


Figure 35. Percentage savings using multiple strategies



THC=total hydrocarbons ■ VOC=volatile organic compounds ■ CO=carbon monoxide
 NOx=nitrous oxides ■ PM=particulate matter

Figure 36. Percentage reduction of pollution using multiple strategies

Figure 37 displays the average and the range of annual benefits with respect to incident severity. While the benefits of managing incidents blocking three lanes, approximately \$68,000, were significantly higher than for less severe incidents, approximately \$49,000 for two-lane incidents and \$10,000 for one-lane incidents, the frequency of incidents more significantly impacted the annual benefits than the per-incident benefit values. The annual benefits of incident management using multiple strategies were, therefore, more heavily impacted by less severe, but more frequent incidents.

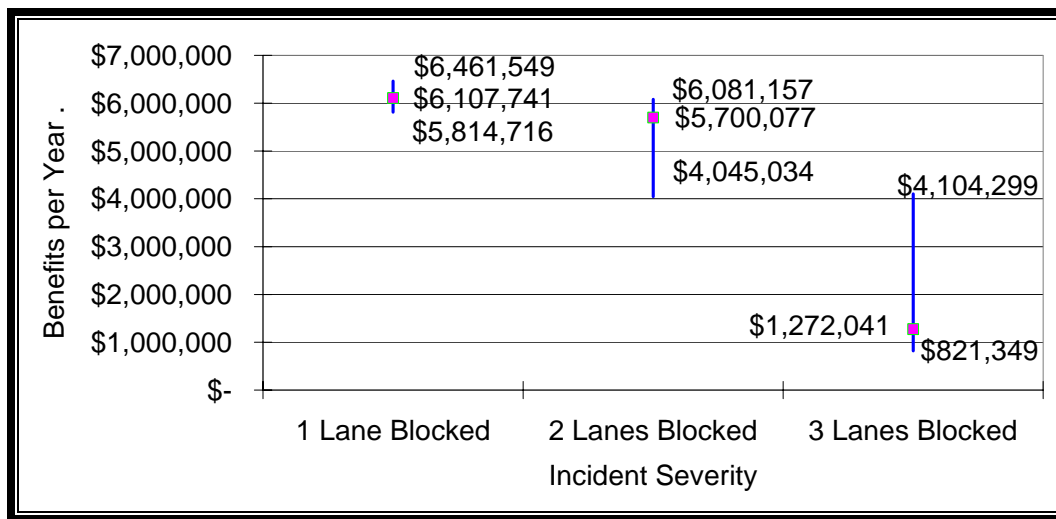


Figure 37. Annual benefits for the integrated application of multiple strategies

While the reduction in fatalities was considered at each study site, it was considered only in scenarios reducing the incident response time, these including traffic sensors, traffic cameras, freeway service patrols, and the comprehensive

strategy. Because the route diversion and state legislation scenarios did not improve detection and verification times, these scenarios did not improve the emergency medical response times, and, therefore, no reduction in fatalities was predicted.

Minor Incident Clearance Using State Legislation

This scenario aimed to evaluate legislation, such as South Carolina's recent Steer-it, Clear-it Law, requiring drivers involved in minor crashes where there are no injuries, to remove their vehicle from the travel lanes prior to the arrival of police or service vehicles. The evaluation process is shown in Figure 10 in chapter three.

Figure 38 displays the percent savings in fuel use and delay for incident clearance legislation, and Figure 39 shows the percent reduction in emissions. For this scenario, the number of freeway lanes and the existing traffic volumes at each study site significantly affected the impact of minor incidents. Specifically, study sites with more lanes and less traffic volume were not as heavily impacted by these minor incidents as sites with fewer lanes and higher volumes.

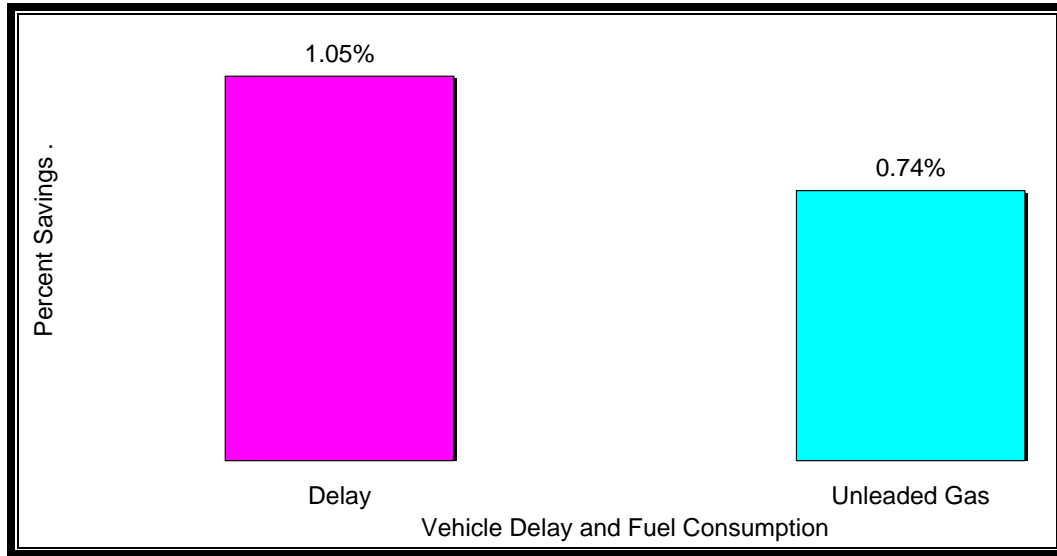
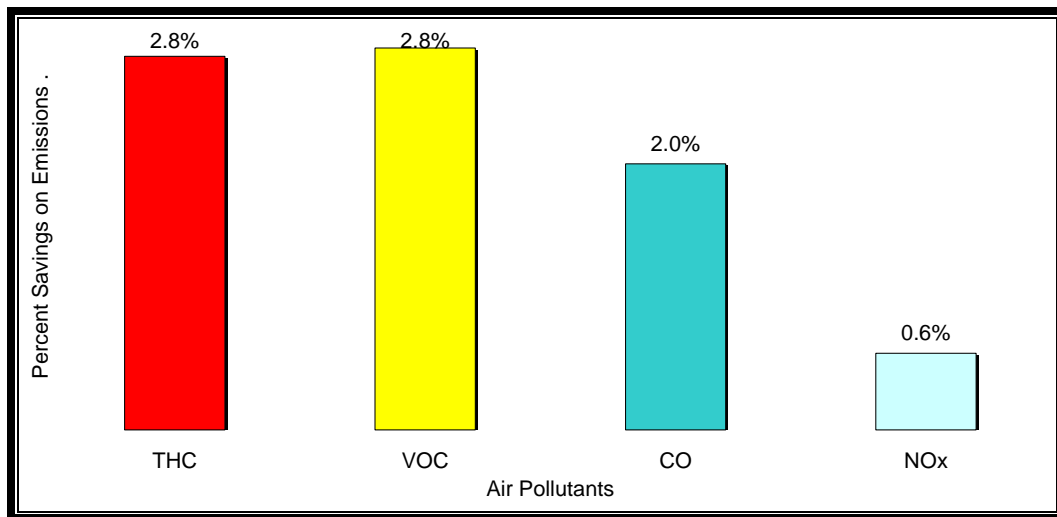


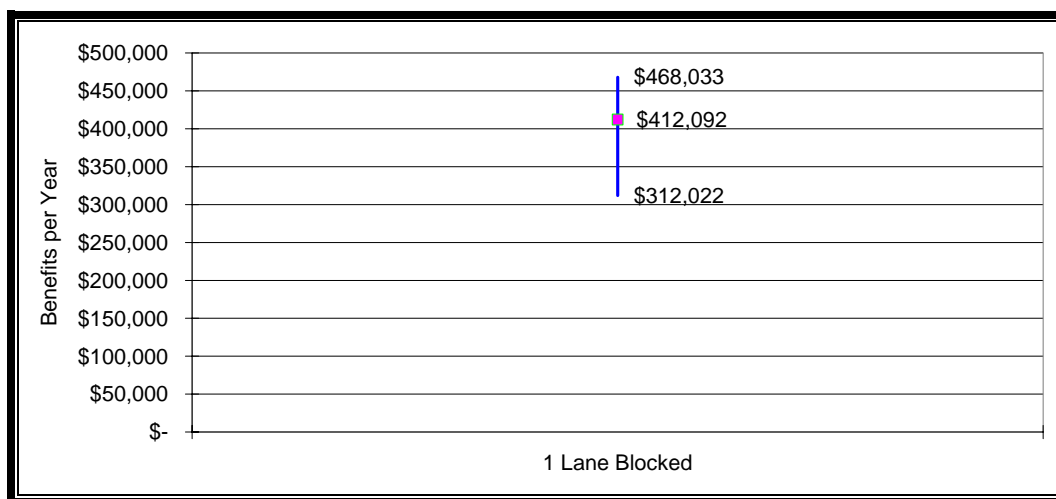
Figure 38. Percentage savings using steer-it, clear-it laws



THC=total hydrocarbons ■ VOC=volatile organic compounds ■ CO=carbon monoxide
 NOx=nitrous oxides ■ PM=particulate matter

Figure 39. Percentage savings on pollution using steer-it, clear-it laws

Figure 40 shows that annual benefits total more than \$400,000 per urban area freeway section, if all drivers are aware of and comply with the steer-it, clear-it laws. While it is unlikely that 100 percent of drivers will be aware of this new law and obey it, the large annual benefit provides justification for an aggressive advertisement campaign to approach the predicted benefit levels, especially because the range of benefits shows that even with partial compliance, this law can provide significant benefits to motorists.



Fi
Figure 40. Annual benefit of steer-it, clear-it compliance

Major Incident Traffic Management Using Route Diversion

Route diversions are time and personnel-intensive efforts usually adopted to minimize traffic impacts for severe incidents. This study examined the impact of route diversions using the process shown in Figure 11 at high crash locations at

both the Charleston and Greenville sites. Both diversions provided motorists with significant benefits. Figures 41 and 42 show the percent reduction of delay, fuel consumption, and emissions. While the largest percent reductions were in the emission categories, particularly total hydrocarbons and volatile organic compounds, the most valuable monetary benefit was from the reduction in delay.

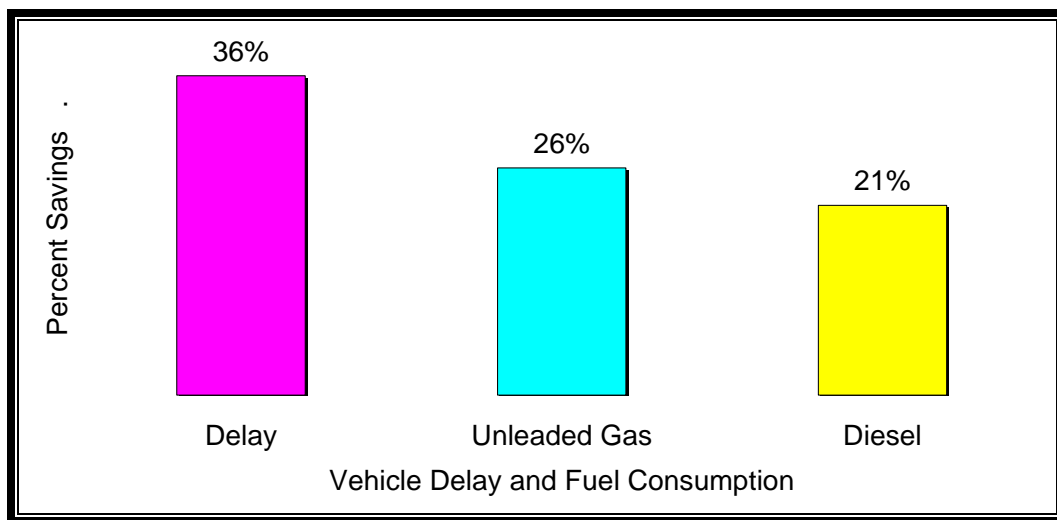
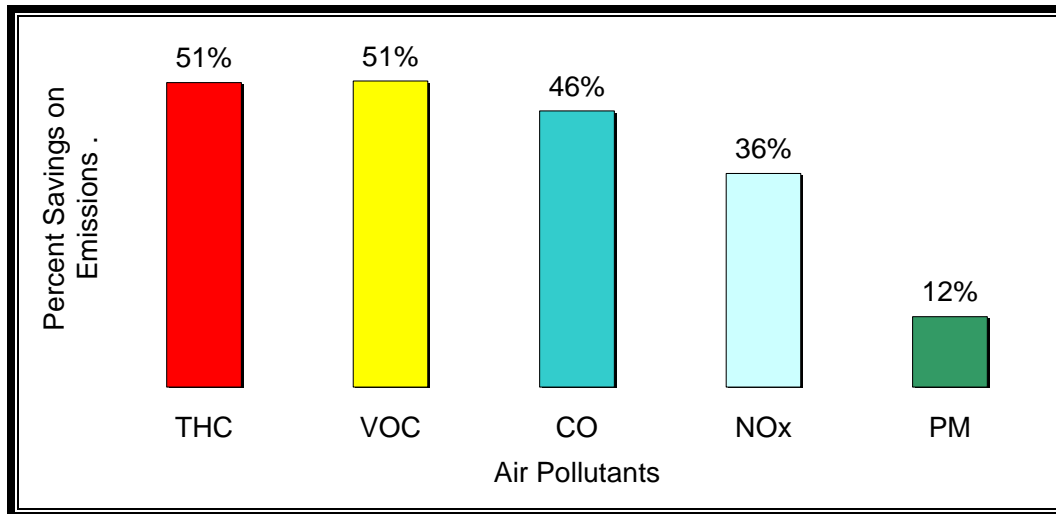


Figure 41. Percentage savings on using route diversion



THC=total hydrocarbons ■ VOC=volatile organic compounds ■ CO=carbon monoxide
 NOx=nitrous oxides ■ PM=particulate matter

Figure 42. Percentage savings on pollution using route diversion

Figure 43 shows the range of annual benefits if a route diversion is available and used for each incident blocking three lanes. Because the benefit value of using route diversion at each incident is large, the number of those incidents in a year significantly influences the annual benefit.

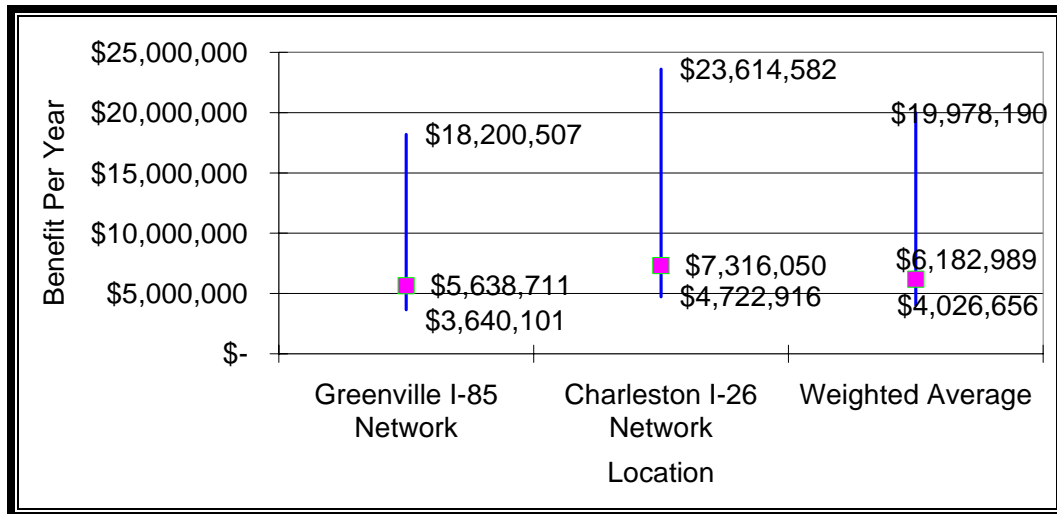


Figure 43. Annual benefit for route diversion

Concluding Remarks on Simulation Results

Overall, as the severity and, therefore, duration of incidents increase, so does the potential for incident management tools to provide benefit to motorists. Annual benefits ranged from approximately \$400,000 for obeying steer-it, clear-it laws to approximately \$6,200,000 for operating route diversions as displayed in Table 13. The multiple strategy scenarios provided more benefits per incident than the individual use of traffic sensors, traffic cameras, or freeway service patrols, illustrating the advantage of combining these technologies.

Table 13: Scenario benefits

	Benefit Per Incident (\$)			Average Annual Benefit (Thousand \$)		
	Number of Lanes Blocked					
Treatment	One-Lane	Two-Lane	Three-Lane	One-Lane	Two-Lane	Three-Lane
Traffic Sensors	-	27,000	200,000	-	3,477	4,247
Traffic Cameras	6,000	40,000	84,000	3,654	5,116	1,975
Freeway Service Patrols	10,000	35,000	-	5,852	4,560	-
Multiple Strategies	10,000	49,000	68,000	6,107	5,700	1,272
Steer-it, Clear-it Law	760	-	-	412	-	-
Route Diversion	-	-	314,000	-	-	6,183

CHAPTER SIX

BENEFIT-COST ANALYSIS RESULTS

Because identifying trends that cause changes in incident management benefits only provides a partial description of the true impact, it is essential to compare these benefits to the associated costs of each incident management program. To conduct a comprehensive evaluation of the benefit-cost ratio of various incident management strategies, sensitivity analysis was used to produce a possible range of these ratios. As discussed in the preceding chapter, the researchers varied the number of incidents per year to account for the annual variations and to examine their impact on the estimated benefits. Again, the following incident management strategies will be reviewed:

- Traffic sensors
- Traffic cameras
- Freeway service patrols
- Multiple strategies
- State legislation
- Route diversion

Incident Detection Using Traffic Sensors

Because many agencies have implemented traffic sensors in incident detection, in conjunction with some form of an incident verification method, this

scenario assumes the use of traffic cameras. Costs for traffic sensors, such as radar units, were found by taking an average of the manufacturers' price for typical units and then adding installation costs. Costs for traffic camera systems included the cameras themselves, installation, cabinets to protect them, electrical services, and an encoder and decoder for each camera. Additionally, the costs included the installation of each traffic camera on a tower, communication from the cameras to the traffic management center, the video wall displaying the camera images, and the traffic management center operators, technicians, and managers. Communications costs included capital, installation, and maintenance for fiber optic and in-ground conduit. Operators were assumed capable of monitoring a video wall including a simultaneous display of many camera images, and only one maintenance technician was needed per site. All of these costs were found in the US Department of Transportation ITS benefits and costs online database (USDOT, 2006) and from IDAS (Intelligent, 2003) database and are displayed in Table 14.

The yearly cost of each element was calculated and converted to the current value (2006) based on a 3 percent inflation rate (USDOT, 2006) and its estimated lifetime. The salvage value of each element was assumed negligible, and the cost of the traffic management center labor included salary, benefits, and job supplies. For large sites such as Greenville, Charleston, and Columbia, two operators, one technician, and one manager were assumed for the operation of the traffic management center. For smaller sites, such as York and Florence counties, only one full-time operator was assumed for the traffic management center. The

costs reflected traffic sensors and cameras 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 freeway network.

Table 14. 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 sensor)	10	2003	3.8	4.0	0.2	0.4
Conduit design and installation	20	2005	50.0	75.0	3.0	3.0
Fiber optic cable installation	20	2005	20.0	52.0	1.0	2.5
CCTV video camera	10	2005	9.0	19.0	1.0	2.3
CCTV video camera tower	20	2005	4.0	12.0		
Video wall inside TMC	10	2003	48.0	87.0	3.0	4.0
TMC operator labor		2001			40.0	50.0
TMC technician labor		2001			60.0	75.0
TMC manager Labor		2001			120.0	150.0

*O&M stands for operation and maintenance

To determine the benefits, the outputs from the simulation were paired with their associated monetary value. Delay was valued as \$44.03 per hour, a weighted average between the value of passenger car and heavy vehicle delay (USDOT, 2006). Fuel was valued per gallon at \$2.845 for unleaded and \$2.186 for diesel in 2005 (AAA, 2006). The value of emissions were converted into

dollars per ton in 2005 dollars and were \$2,355.63 for total hydrocarbons, \$2,117.63 for volatile organic compounds, \$5,383.29 for carbon monoxide, \$5,164.58 for nitrous oxides, \$4,235.25 for particulate matter. The value of a life was estimated at \$977,000 in the year 2000 (Blincoe et al., 2002). Using an inflation rate of three percent as specified by IDAS, the 2006 value of a fatality saved in the US is shown in Equation 5:

$$Present_value = \$977,000 * (1 + 0.03)^{6years} = \$1,166,600 \quad (\text{Equation 5})$$

As previously discussed, the reduction in fatalities was found only for scenarios reducing the detection or verification times, for example those including traffic sensors, traffic cameras, freeway service patrols, and the multiple strategies scenario. The value of the benefit categories is shown in Table 15.

Table 15. Value of benefit measures of effectiveness

MOE	Delay	Fuel		Emissions					Fatality
		Unleaded	Diesel	THC	VOC	CO	NOx	PM	
Units	\$/veh. - Hr.	\$/gal.		Thousand \$/ton					Million \$/life saved
Value	44.03	2.85	2.19	2.36	2.12	5.38	5.60	4.24	1.17

Table 16 shows the benefit-cost ratios for detecting incidents with traffic sensors. These values represent the return of the traffic sensor strategy for costs ranging from high, average, and low and the benefits remaining average. As shown, if the costs range between those found elsewhere in the United States and the benefits remain average, the average, weighted statewide benefit-cost ratio ranges from approximately 8:1 to 12:1.

Table 16. Benefit-cost ratios for traffic sensors with sensitivity to costs

B/C Ratio		Greenville	Charleston	Columbia	York	Florence	Average
Variation with costs	Mean	14.04	10.46	4.70	7.48	25.37	9.49
	High	12.14	9.11	2.60	2.11	8.28	7.64
	Low	18.40	13.81	4.16	3.31	13.45	11.81

Table 17 displays the range of benefit-cost ratios when the costs remain average and the benefits vary by changing the number of incidents per year between the values shown in Table 12. The column labeled “Average” was again, weighted based on the vehicle-miles traveled at each site. This sensitivity analysis revealed that if the costs remain at average and the number of annual incidents varies, the benefit-cost ratio ranges between approximately 7:1 and 19:1.

As shown in Tables 16 and 17, the benefit-cost ratios vary more with a change in the number of incidents than with a change in the costs.

Table 17. Benefit-cost ratios for traffic sensors with sensitivity to benefits

B/C Ratio		Greenville	Charleston	Columbia	York	Florence	Average
Variation with benefits	Mean	14.04	10.46	4.70	7.48	25.37	9.49
	High	31.86	17.28	9.71	8.14	28.45	19.13
	Low	9.83	7.69	3.34	7.89	27.44	6.78

Incident Detection and Verification Using Traffic Cameras

Agencies that use traffic cameras for incident detection and verification require personnel to monitor the traffic conditions to detect incidents. The cost of using traffic cameras to detect and verify incident was similar to the cost of using other traffic sensors. Specifically, the traffic camera scenario requires twice the number of operators, but does not require any other traffic sensors. The elements used during this scenario and their associated costs are shown in Table 18 and the value of the benefits items from the simulation are shown in Table 13 in the preceding section.

Table 18. Cost of incident management elements for traffic cameras

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	3.0
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	4.0
TMC operator labor	-	2001	-	-	40	50.0
TMC technician labor	-	2001	-	-	60	75.0
TMC manager labor	-	2001	-	-	120	150.0

*O&M stands for operation and maintenance

Table 19 shows the benefit-cost ratios for mean, high, and low costs for elements used for this scenario. Similar to

Table 16, this table uses the average annual benefit and varies the costs based on other comparable systems across the United States while the column titled Average refers to a weighted average of all study sites. The benefit-cost ratios ranges between approximately 11:1 and 16:1.

Table 19. Benefit-cost ratios for traffic cameras with sensitivity to costs

B/C Ratio		Greenville	Charleston	Columbia	York	Florence	Average
Variation with costs	Mean	18.97	5.83	11.56	7.06	16.59	12.53
	High	17.60	5.41	10.73	6.55	15.39	10.65
	Low	20.58	6.33	12.54	7.66	17.99	15.70

Table 20 shows the benefit-cost ratios for the traffic camera scenario when the costs are average and the number of annual incidents determines the amount of benefit. This scenario produces a range of ratios between approximately 11:1 and 17:1. The difference in benefit-cost ratios between Tables 19 and 20 does not vary as much as between Tables 16 and 17, meaning traffic camera benefit-cost ratio was less variable. Further, these tables illustrate the traffic camera scenario provided more return per dollar spent than the traffic sensor scenario.

Table 20. Benefit-cost ratios of traffic cameras with sensitivity to benefits

B/C Ratio		Greenville	Charleston	Columbia	York	Florence	Average
Variation with benefits	Mean	18.97	5.83	11.56	7.06	16.59	12.53
	High	27.57	7.53	15.08	7.60	17.89	17.07
	Low	15.64	4.71	11.28	6.89	16.64	11.21

Incident Detection, Verification, and Response Using Freeway Service Patrols

Costs for operating freeway service patrols included labor, communications and vehicles. To determine labor costs, annual salary values for each type of employee were used, assuming one manager per program, one maintenance technician per two service vehicles, and one operator per vehicle. The communications costs included one wireless phone per operator. The values of these items were found in the USDOT ITS Benefits and Costs Database (USDOT, 2006).

Table 21 shows the costs associated with operating freeway service patrols. Each site operated a different number of patrols during the PM peak period; thus, costs were unique to each site. To determine the patrol costs, capital costs, yearly maintenance costs, and a ten-year life span per vehicle were included. Other costs included communications and labor. To determine labor costs, annual salary values for each type of employee were used, assuming one manager per program, one maintenance technician per two service vehicles, and

one operator per vehicle. The communications costs included one wireless phone per operator. The values of these items were found in the USDOT ITS Benefits and Costs Database (USDOT, 2006). Again, the benefits were determined using the simulation output and the values from Table 13.

Table 21. 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	1.00	2.0
Wireless communications	-	2003	-	-	0.12	0.2
FSP operator labor	-	2001	-	-	40.00	50.0
FSP technician labor	-	2001	-	-	60.00	75.0
FSP manager labor	-	2001	-	-	120.00	150.0

*O&M stands for operation and maintenance

The benefit-cost ratios for operating existing freeway service patrols in South Carolina with average benefits, and varying the costs are shown in Table 21. The high and low correspond to the high and lost costs presented in Table 19. The two sites with the lowest benefit-cost ratios operated the shortest and the longest headways. Reducing the headways of freeway service patrols at the site with the longest ones, Columbia, and reducing the headways at the site with the shortest ones, York County, might increase the benefit-cost ratios closer to those

found in other sites. The average benefit to cost ratios vary between approximately 11:1 and 14:1.

Table 22. Benefit-cost ratios for freeway service patrols with sensitivity to costs

B/C Ratio		Greenville	Charleston	Columbia	York	Florence	Average
Variation with costs	Mean	22.50	15.59	3.17	6.01	13.18	11.64
	High	20.87	14.46	2.94	5.57	12.22	11.35
	Low	24.40	16.91	3.44	6.51	14.29	14.26

Table 22 shows the benefit-cost ratios when the costs are held at the average and the annual number of crashes varies, thus changing the amount of annual benefit. These findings indicate that for every dollar invested, freeway service patrols provide an average of between 11 and 13 dollars of benefits to motorists when the number of incidents per year changes.

Table 23. Benefit-cost ratios for freeway service patrols with sensitivity to
benefits

B/C Ratio		Greenville	Charleston	Columbia	York	Florence	Average
Variation with benefits	Mean	22.50	15.59	3.17	6.01	13.18	11.64
	High	25.20	17.00	2.93	6.45	14.10	12.62
	Low	19.42	15.29	5.05	6.16	13.99	11.60

Incident Detection, Verification, and Response Using Multiple Strategies

This method of incident management takes into account the combination of incident management strategies that were previously studied, including traffic cameras, traffic sensors, and freeway service patrols, as well as one additional strategy, traffic incident hotlines. While the costs of the previous scenarios were applied in a similar manner as before, the cost of the traffic incident hotlines was assumed to include one additional operator at an existing call center, such as a 911 call center. The costs of each of these items are displayed in Table 24 and the benefits were determined using simulation output and the values shown in Table 13.

Table 24. 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	-	-	-	-	30.00	40.0
Traffic sensor (e.g. radar sensor)	10	2003	3.8	4.0	0.20	0.4
Conduit design and installation	20	2005	50.0	75.0	3.00	3.0
Fiber optic cable installation	20	2005	20.0	52.0	1.00	2.5
CCTV video camera	10	2005	9.0	19.0	1.00	2.3
CCTV video camera tower	20	2005	4.0	12.0	-	-
Video wall inside TMC	10	2003	48.0	87.0	3.00	4.0
TMC operator labor	-	2001	-	-	40.00	50.0
TMC technician labor	-	2001	-	-	60.00	75.0
TMC manager labor	-	2001	-	-	120.00	150.0
Service patrol vehicles	10	2005	50.0	75.0	1.00	2.0
Wireless communications	-	2003	-	-	0.12	0.2
FSP operator labor	-	2001	-	-	40.00	50.0
FSP technician labor	-	2001	-	-	60.00	75.0
FSP manager labor	-	2001	-	-	120.00	150.0

*O&M stands for operation and maintenance

Table 24 shows the range of benefit-cost ratios when the low and high costs are used with the average benefits. Similar to previous tables, the column labeled Average shows a weighted average based on vehicle-miles traveled at

each site. The high, mean, and low correspond to the costs shown in Table 24. The benefit-cost ratios range between approximately 6:1 and 9:1 when the costs vary and the benefits remain at average.

Table 25. Benefit-cost of multiple strategies with sensitivity to costs

B/C Ratio		Greenville	Charleston	Columbia	York	Florence	Average
Variation with costs	Mean	11.53	8.41	4.88	4.23	7.73	7.41
	High	8.00	5.78	3.37	3.61	6.10	5.86
	Low	13.61	9.88	5.85	6.02	10.55	8.59

Table 26 shows the benefit-cost ratios when the average costs remained constant and the number of incidents vary each year. These findings suggest that using multiple strategies for incident management returns approximately seven dollars for every one invested. Comparing Tables 25 and 26 suggests that the number of crashes per year impact the benefit-cost ratio more heavily than changes in the costs of implementation and operation. While using multiple strategies provides more benefits to motorists than other strategies, as shown in chapter four, this scenario requires larger investments than a single strategy, thus producing smaller returns on each dollar invested.

Table 26. Benefit-cost ratios of multiple strategies with sensitivity to benefits

B/C Ratio		Greenville	Charleston	Columbia	York	Florence	Average
Variation with benefits	Mean	11.53	8.41	4.88	4.23	7.73	7.41
	High	14.69	12.03	6.90	4.71	8.66	9.56
	Low	9.64	7.35	4.71	4.12	7.65	6.71

Minor Incident Clearance Using State Legislation

Determining the costs of quick clearance legislation such as the Steer it, Clear it Law in South Carolina involved advertising costs to make drivers aware of this policy change. The costs were estimated by considering signage and billboard advertisements along the freeway and radio and television commercials. These signs were assumed purchased and installed along the freeways every two miles in each direction of travel. These costs included capital, maintenance, and installation for the sign and associated breakaway mounting post. The cost of the billboard advertisements were determined from local merchants in South Carolina and included designing and producing the graphics and renting one billboard at each site for one year.

The costs for both the radio and the television commercials assumed that the SCDOT would produce its own commercial, considerably lowering costs. The cost for radio advertisement assumed a 60-second commercial airing once per week for one year, and the cost for the television commercial was based on a

statewide advertisement airing once a day for one week. The cost estimations for both of these media were based on the average costs found during market research of various advertising companies, radio, and television stations. While the costs for this scenario are less transportation-oriented than the other scenarios, it was less expensive than the other strategies. These costs are shown in Table 27.

Table 27. Costs of advertising steer-it, clear-it laws

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	35.00	40.00	-	-
Freeway billboard advertisement	-	2006	0.08	0.60	0.08	0.17
Radio advertisement	-	2006	-	-	0.20	0.22
TV advertisement	-	2006	-	-	15.00	16.00
Installation labor	-	2006	0.18	0.22	-	-

*O&M stands for operation and maintenance

The benefits were determined using the simulation output and the values displayed in Table 13. Because this scenario did not reduce the incident detection and verification times, emergency medical responders did not arrive on-scene faster; thus, reduction in fatalities was not used in determining the benefits. Table 28 shows the benefit-cost ratios corresponding to the high, low, and average costs displayed in Table 27 compared to average benefits. Benefit-cost ratios ranged

from approximately 20:1 to 22:1. The York County site showed the lowest return because fewer crashes occurred there than at the other sites, producing less benefit and a lower benefit-cost ratio. These results assume all drivers are aware of and comply with steer-it, clear-it laws.

Table 28. Benefit-cost ratios for steer-it, clear-it laws with sensitivity to costs

B/C Ratio		Greenville	Charleston	Columbia	York	Florence	Average
Variation with costs	Mean	57.22	45.16	35.57	2.01	41.46	21.58
	High	51.74	40.83	31.92	1.91	38.71	20.16
	Low	58.41	46.09	36.35	2.04	42.08	21.90

Table 29 shows the range of benefit-cost ratios produced when the annual number of crashes changes and the costs are average. As this table shows, the average benefit-cost ratio ranged from approximately 16:1 to 24:1, again suggesting that the number of incidents per year is a significant factor influencing the return of investments in this scenario.

Table 29. Benefit-cost ratios for steer-it, clear-it laws with sensitivity to benefits

B/C Ratio		Greenville	Charleston	Columbia	York	Florence	Average
Variation with benefits	Mean	57.22	45.16	35.57	2.01	41.46	21.58
	High	65.00	51.31	40.40	2.28	47.00	24.45
	Low	43.33	34.20	26.94	1.52	31.33	16.30

Because drivers require time to learn about and comply with the new law and the costs of advertisement will also decrease with time, it is expected that the benefit-cost ratio found in this study is higher than initial returns and lower than future returns.

Major Incident Traffic Management with Route Diversion

For major incidents blocking the entire roadway, it is sometimes necessary to divert traffic away from the freeway completely, requiring the use of additional communication methods including variable message signs and highway advisory radios to advise drivers of this situation. Diversion operations also require highway patrol units at the incident scene to direct traffic, as well as a traffic management center operator to assist.

The costs of this scenario included the use of one highway advisory radio system; one large stationary variable message sign; one portable, trailer-mounted variable message sign; the communications for the radio and signs; and the labor

of highway patrol and traffic management personnel. The costs of highway advisory radio, variable message signs, and the communication were found from the ITS Benefit-Cost Database (USDOT, 2006). The number of officers differed between the sites because the Charleston one required the manual operation of a traffic signal while Greenville did not. The hourly labor costs for the officers was obtained from the South Carolina State Highway Patrol and those for the traffic management center operators were obtained from the ITS Benefit-Cost Database (USDOT, 2006). Table 30 shows the costs of these elements.

Table 30: 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	15.0	35	0.6	1.0
Highway advisory radio Sign	20	2005	5.0	9	0.3	0.3
Wireless communications	10	2005	-	-	0.1	0.2
Variable message sign	20	2005	47.0	117	2.3	6.0
Variable message sign tower	10	2003	25.0	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

Again, because this scenario did not reduce the incident detection or verification times, fatalities were not considered in determining the benefits. The benefits, including delay, fuel use, and emissions, were determined by their output from the simulation and their values as shown in Table 13.

Table 31 shows the benefit-cost ratios for each site when the costs vary from the high to low estimates as shown in Table 30 and the benefits remain average. Route diversion returned an average of between approximately 43 and 84 dollars for every dollar spent.

Table 31. Benefit-cost ratios for route diversion with sensitivity to costs

B/C Ratio		Greenville	Charleston	Average
Variation with costs	Mean	46.98	61.08	54.66
	High	37.68	48.96	43.82
	Low	71.91	93.71	83.77

Table 32 shows the benefit-cost ratios for both sites when the number of severe crashes varied and the costs remained average. The benefit-cost ratios ranged from approximately 39:1 to 135:1, indicating that the number of crashes has a larger impact on the return than a change in the costs.

Table 32: Benefit-cost ratios for route diversions with sensitivity to benefits

B/C Ratio		Greenville	Charleston	Average
Variation with benefits	Mean	46.98	61.08	54.66
	Low	33.86	43.75	39.26
	High	120.41	146.81	135.21

Route diversions showed the most significant benefit-cost ratio of all scenarios studied, but was also the most location-specific. While the two locations simulated corresponded to the highest crash locations at each site, a crash one mile before or after the simulated location would probably produce a completely different impact. This difference is due to availability of a feasible diversion route, the availability of a formalized diversion plan, the presence of signalized intersections along the diversion route, and the existing volumes along the diversion route, among others.

Chapter Summary

Overall, each scenario evaluated showed positive return for investment. This fully-positive outcome is neither surprising nor suspicious given that the incident management strategies tested had been selected based on favorable reviews from the nationwide survey of practitioners. The results illustrated the significance of incident frequency for determining annual benefits of incident management tools and that using several redundant tools, for example, the multiple strategies scenario, significantly reduces the benefit-cost ratio. As displayed in Table 33, the two highest benefit-cost ratios were for steer-it, clear-it

and the route diversion scenarios. The significant return from steer-it, clear-it laws suggests needed investment in advertisement and enforcement. While the benefit-cost ratio was highest for the route diversion scenario, this scenario revealed site-specific results and should only be applied to locations where alternate routes are available and during severe incidents.

Table 33: Summary of benefit-cost ratios

Scenario	Benefit-Cost Ratio
Traffic sensors	9:1
Traffic cameras	13:1
Freeway service patrols	12:1
Multiple strategies	7:1
Steer-it, clear-it laws	22:1
Route diversion	55:1

CHAPTER SEVEN

INTEGRATION AND DISCUSSION OF RESULTS

State departments of transportation across the United States have recognized the need to manage incidents efficiently. Sound information about the benefits of incident management programs can aid in successfully lobbying for increased incident management funding. To address this issue, this dissertation:

- 1) identified potential incident management strategies. Because little had been known about how practitioners perceive the effectiveness of a wide variety of such strategies currently in use across the United States, a nationwide survey was designed and distributed.

- 2) estimated the impact of incident management strategies in South Carolina by integrating microscopic traffic simulation and application programming interfaces, broadening the scope of previous incident management studies.

- 3) applied benefit-cost analysis to evaluate the impact of various combinations of incident management strategies simulated on five large networks in South Carolina.

Identification of Incident Management Strategies

Addressing the first objective, the literature review, identifying technologies and strategies and their impact in combination with the survey, found that the most successful means of incident verification involved traffic cameras, cellular phones, and first responder personnel dispatched to the incidents, such as highway patrol law enforcement, and fire units. The results of the survey of usage patterns suggests that efficient and comprehensive incident management and clearance programs maintain fleets of both heavy and light duty dump trucks and sweepers for incident clearance, and that air-cushioned recovery systems and cranes were used only by agencies that considered their use of technologies efficient and comprehensive.

The survey also suggested that the incident management industry is using alternate routing of traffic; currently all responding agencies either possess or intend to purchase variable message sign, highway advisory radio, and alternate route plans. Responses indicate that the two technologies most frequently planned for deployment include computer-aided dispatching and traffic management centers, both of which also aid in alternative route implementation.

Responses to survey questions regarding the use of data archiving strongly indicated that the both state DOTs and smaller transportation agencies strongly rely on road sensor data. Because of this reliance, the incident management industry must expand the nature and type of archived data, their length of storage time, and their availability to different agencies, all of which will help remove constraints regarding the communication of benefits to decision makers and the

public and the archived data will aid in future planning and evaluation. Common methods of communicating incident clearance information to decision makers have been only marginally effective, however; because agency-specific methods have been rated much higher, uniquely developed communication strategies based on specific institutional scenarios are likely more effective for reaching decision makers.

Survey responses also indicated that the most effective methodologies for investigating incidents were the use of total stations, crash recreation software, and witness interviews. There has been little previous research evaluating the usefulness of ITS technologies in the complex organizational and operational systems used by incident management programs. The apparent inconsistency of deployment between agencies that rated their programs efficient and those that did not, emphasizes the need to publicize this material and develop a national guide that moves beyond the scope of the current traffic incident management handbook. This guide should primarily focusing on coordinating activities between agencies, detailing the proper methods for using incident management tools, and using the most efficient means of communicating these methods to both the public and decision makers.

Integration of Simulation and Application Programming Interfaces

The second objective of this dissertation concentrated on broadening the scope of contemporary incident management studies by the evaluation of six incident management strategies on five freeway corridors in South Carolina through the innovative application of both microscopic traffic simulation and

application programming interfaces. The integration of traffic simulation and application programming interface tools allow for the evaluation of traffic sensors, traffic cameras, freeway service patrols, a multiple strategy scenario, state legislation, and route diversion for incident management in terms of measured in delay, fuel consumption, safety, and emissions.

While it was determined that the use of traffic sensors to detect incidents provided benefits to motorists, the use of traffic cameras and freeway service patrols both provided significantly more annual benefits. The multiple strategy incident management scenario provided a larger benefit than traffic sensors and cameras, or service patrols in isolation.

Two special cases were examined, the first case study involving minor incidents where motorists complied with steer-it, clear-it laws, and the second involving severe incidents requiring route diversions. Evaluations of these scenarios revealed that steer-it, clear-it laws provided smaller benefits per incident than all other scenarios analyzed because the incidents remained on travel lanes for a limited time, and blocked only one lane. Because minor incidents occur much more frequently than severe ones, the impact of this law can provide significant annual benefits if advertised by the DOT and obeyed by the motorists.

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

Benefit-Cost of Incident Management Strategies

Results from the benefit-cost analysis conducted by evaluating the impact of various combinations of incident clearance strategies indicated that freeway service patrols produce approximately \$12 of benefit for every dollar invested. While traffic cameras to detect and verify incidents produced \$13 in benefits for each dollar invested, using traffic sensors to detect incidents and traffic cameras to verify incidents produced \$9. Even though the scenario using multiple strategies to manage incidents produced a high benefit compared to these three strategies, it only produced approximately \$7 of benefit for each dollar invested because of the capital investment required by the operation of several different systems.

If all citizens were aware of and obeyed the law, the benefit-cost analysis resulted in high returns for the steer-it, clear-it scenario (22:1). While a 100 percent compliance rate to law is unrealistic, these results justify investment in an aggressive statewide advertisement and enforcement campaign to promote compliance to realize the anticipated benefits. Producing the highest benefit-cost ratio, the route diversion strategy evaluated produced approximately \$55 of benefit for every dollar invested. While route diversion is site-specific and alternative routes are not available at all crash locations, this return justifies future investments in the planning and execution of route diversion strategies.

Although all incident management tools evaluated for use in South Carolina provided benefits, freeway service patrols and traffic cameras were found to have the highest return for management of all severities of incidents.

The results of this research revealed that it was more advantageous to select an expensive but efficient incident management technology than to use several systems combined and incrementally deployed, such as in the multiple strategy scenario. If properly obeyed, steer-it, clear-it laws can be of great benefit to the traveling public. However, explaining it to US motorists requires capital outlays for advertisement and enforcement programs. Similarly, the route diversion scenario provided an enormous return-on-investment, justifying the investment necessary for further planning and training.

CHAPTER EIGHT

CONCLUSIONS

This research has advanced the state of knowledge in incident management both in terms of practice in the field and the theory. Primary contributions of this work include a unique perspective of incident management practices and a comparative research approach that provides new directions for future research.

In terms of specific tools, while the survey results indicated that current automated incident detection tools are not the most effective, the simulation study found these tools provide a positive return on investment. This survey response illustrated that there might not be adequate communication between incident management system professionals responsible for incident detection and decision makers selecting tools for deployment, indicating a need to share benefit and costs information among incident management stakeholders. Further, as indicated by the nationwide survey findings, there is a need for simplicity and direct assignment of responsibility to operate an effective incident management program.

Overall, the simulation study found one incident management tool would operate more efficiently than several different ones because multiple tools might provide redundant benefits. In particular, it is better to operate multi-function tools that are able to perform several of the steps in the incident management

process or other external functions, such as freeway service patrols and traffic cameras performing security functions as well as traffic management. Freeway service patrols and traffic cameras were found to be the most widely deployed and highly rated by practitioners based on the nationwide survey. They also had the highest benefit-cost ratio for tools managing all severities of incidents from the benefit-cost study. For severe incidents, the route diversion strategy was found effective, supporting the survey findings that all agencies that deemed themselves effective had up-to-date route diversion plans and all others planned to.

Research results support widespread implementation of incident management tools in metropolitan areas. Appendix C provides guidelines that can accelerate both the efficiency of implementing and operating strategies for mitigating, managing and resolving traffic incidents on American roadways.

Several pressing issues have yet to be addressed in the area of incident management research. Because safety is a high priority in all engineering practices, future research endeavors in managing major and minor traffic incidents must identify measures to reduce secondary crashes, beginning with data archiving of secondary crash occurrences. In addition, data archiving of traffic impact due to incidents can provide empirical data with which to validate research results from simulation analysis.

As the influence of cellular phones continues to grow and a nation-wide 511 program gains momentum, incident detection through hotlines requires further study to determine the place and purpose of such systems in incident management. In particular, because incident detection from cellular phone calls

still requires the use of other tools for verifying location, global positioning systems on cellular phones have the potential to change this relation significantly.

Because this research has shown that the frequency of incidents is a significant factor in the benefits of a given incident management strategy, research is needed to identify the correct technology for different frequencies of crash severities. Because route diversion, specifically for severe incidents, showed site-specific results in this study, future research is needed to identify the key site characteristics, such as the presence of traffic signals on diversion routes, that impact the effectiveness of route diversion.

Future research should also build from this study by including the analysis of multiple tools, evaluating effectiveness at different locations, using more measures of effectiveness, and using stochastic algorithms and software to capture the true nature of traffic incidents more accurately. Research in these areas will result in continuing improvement and evolution of incident management practices, benefiting Americans by reducing travel time, fuel consumption, pollution, and fatalities.

APPENDICES

Appendix A: Incident Management Survey Questions

DOT Survey

Questionnaire # _____

Clemson's Highway Incident Clearance and Management Survey for State Department of Transportations

Clemson University is conducting a survey of relevant agencies associated with highway incident clearance and management in order to obtain the current state of practice within the United States. This survey is one component of a research study funded by the South Carolina Department of Transportation to provide decision makers with the costs and benefits of accelerated incident clearance strategies. This survey will take between 15 and 25 minutes to complete, and is intended to gather information about your individual agency's incident management framework, accelerated incident clearance strategies, and the benefits and costs associated with these strategies. It consists of six sections including:

- 1.0 Incidents
- 2.0 Agencies and Collaboration
- 3.0 Jurisdiction Legislation and Regulation

4.0 Technology

5.0 Incident Clearance Program

6.0 Benefits and Costs associated with incident clearance

Please be assured that names of individual respondents will remain confidential, although states or agencies might be identified in our results. If you would like to receive a copy of our survey findings, please provide your e-mail address. Thank you for contributing to this important study aimed at improving incident clearance, your time and effort will help to make our highways operate in a safer and more efficient manner.

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Section 1.0 Incidents

1 How does your state define an incident?

2 Please rate the prevalence of the following types of incidents within your state, with 1 being least prevalent and 5 being most prevalent.

	Least Prevalent 1	2	Somewhat Prevalent 3	4	Most Prevalent 5
Q4a Single vehicle crash	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Q4b Disabled/Abandoned vehicle	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Q4c Multi-vehicle crash	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Q4d Hazardous material spill	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Q4e Debris on roadway	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Q4f Weather-related debris on roadway	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

3 Please rate the prevalence of the following types of secondary incidents that occur within your state, with 1 being least prevalent and 5 being most prevalent.

	Least Prevalent 1	2	Somewhat Prevalent 3	4	Most Prevalent 5
Collision	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Disabled vehicle	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

Section 2.0 Agencies and Collaboration

4 What agencies comprise the incident clearance patrol in your state?

- ☐ ₁ State DOT
 - ☐ ₂ Emergency Management Services
 - ☐ ₃ State Highway Patrol
 - ☐ ₄ Private Company
 - ☐ ₅ Other
-

5 Within your state, how would you rate the comprehensiveness of collaboration programs that are responsible for incident management and clearance, with 5 being very comprehensive and 1 being least comprehensive?

	Least 1	2	Somew hat 3	4	Most 5
Comprehensiveness of collaboration	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅

6 Within your state, how would you rate the effectiveness of collaboration programs that are responsible for incident management and clearance, with 5 being very effective and 1 being least effective?

	Least 1	2	Somew hat 3	4	Most 5
Effectiveness of collaboration	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅

Section 3.0 Jurisdiction Legislation and Regulation

7 Does your jurisdiction have a 'quick clearance' law which requires drivers of motor vehicles who are involved in a property-damage-only crash to move their damaged vehicle from travel lanes, to other locations such as the shoulder?

- ☐ ₁ Unknown if legislation exists
 - ☐ ₂ No existing or proposed legislation
 - ☐ ₃ Bill currently proposed
 - ☐ ₄ Yes, please provide year enacted:
-

8 Does your state have a 'move-it' law which requires incident clearance patrols (state DOT) to move vehicles that are involved in property-damage-only crashes to other locations such as the shoulder?

- ☐ ₁ Unknown if legislation exists
 - ☐ ₂ No existing or proposed legislation
 - ☐ ₃ Bill currently proposed
 - ☐ ₄ Yes, please provide year enacted
-

9 What other legislation within your jurisdiction is aimed at facilitating incident clearance?

10 Has a study been completed that evaluated "Quick clearance" and "Move it" legislations?

- ☐ ₁ Yes
- ☐ ₂ No
- ☐ ₃ Unknown

11 Who conducted the study, and what were the findings?

12 Does your state have legislation that protects incident responders from liability when moving vehicles involved in an incident?

- ☐ ₁ Yes
- ☐ ₂ No
- ☐ ₃ Unknown

Section 4.0 Technology

13 How are incidents detected and identified within your state? Rate the performance of the technology with 1 being the worst and 5 being the best. If your agency doesn't currently utilize the technology but is planning to implement it, please check "Technology Planned."

	Worst 1	2	Neutral 3	4	Best 5	Techno logy Planne d
Traffic cameras	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Automated incident detection (sensors)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Highway patrol communication	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Cellular phone	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Call Box	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

14 Once an incident is detected, how is this incident verified? Rate the performance of the technology/method with 1 being the worst and 5 being the best. If your agency doesn't currently utilize the technology but is planning to implement it, please check "Technology Planned."

	Worst 1	2	Neutral 3	4	Best 5	Techno logy Planne d
Traffic cameras	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Automated incident detection (sensors)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Highway patrol communication	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Cellular phone	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Call Box	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
By air	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Dispatched personnel	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

15 How is communication accomplished between incident responders? Check all that apply, and rate the performance of the technology with 1 being the worst and 5 being the best. If your agency doesn't currently utilize the technology but is planning to implement it, please check "Technology Planned."

	Worst 1	2	Neutral 3	4	Best 5	Techno logy Planne d
Cellular phone	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Internet/computer	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Radio with dedicated frequency	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Radio without dedicated frequency	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Satellite phone	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

16 What equipment is available to your jurisdiction to facilitate the clearance of a major, non-hazardous incident? Check all that apply.

- ☐ ₀₁ Heavy-duty tow truck
 - ☐ ₀₂ Sweeper
 - ☐ ₀₃ Empty box trailer
 - ☐ ₀₄ Air cushion recovery
 - ☐ ₀₅ Crane
 - ☐ ₀₆ Debris recovery vehicle
 - ☐ ₀₇ Empty tanker truck
 - ☐ ₀₈ Empty box trailer
 - ☐ ₀₉ Empty livestock trailer
 - ☐ ₁₀ Dump truck
 - ☐ ₁₁ Other
-

Section 5.0 Incident Clearance Program

17 What are the components of your incident clearance strategies? Please select all that apply.

	Implem ented	Planne d	Not Planne d	No longer used
Route diversion	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄
Notifications through variable message signs	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄
Collaborative agreements giving multiple agencies authority to move vehicles from the right-of-way	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄
Major equipment for vehicle removal	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄
Agreement with towing companies	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄
Collaborative agreements for information sharing	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄
Other	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄

18 What problems have you encountered with implementation? Check all that apply.

- ☐₁ Lack of political support
 - ☐₂ Lack of public awareness
 - ☐₃ Lack of coordination between agencies
 - ☐₄ Lack of public support
 - ☐₅ Lack of funding
 - ☐₆ Other
-

19 What specific responder training was needed to perform these strategies?

Section 6.0 Incident Clearance Program Benefit-Cost Analysis

20 Has a study of the benefits and costs associated with your incident strategy/program been conducted?

- ☐₁ Yes
- ☐₂ No
- ☐₃ Unknown

21 If your agency conducted a study, who conducted the study and what were the findings?

22 If you did conduct a study on the benefits and costs associated with your incident strategy/program, what problems did you encounter during your study?

Check all that apply.

- ☐₁ Lack of data
 - ☐₂ Lack of political support
 - ☐₃ Lack of organizational cooperation
 - ☐₄ Other
-

23 When looking at the benefits and costs associated with incident clearance, what tools were used to evaluate the performance of accelerated incident clearance strategies?

- ☐₁ Traffic simulation/model
 - ☐₂ Analytical tools
 - ☐₃ Field data
 - ☐₄ Other
-

24 What benefits has your jurisdiction received due to an incident clearance program? Check all that apply.

- ☐₁ Reduction in secondary incidents
 - ☐₂ Reduction in vehicle clearance time
 - ☐₃ Reduction in travel time
 - ☐₄ Environmental benefits
 - ☐₅ Other
-

25 What costs, either qualitative or quantitative, are associated with your incident clearance plan?

26 What other aspects of your strategy do you wish you could study but did not have the adequate capacity/resources to do so?

27 How well do you like the results that your incident management program is providing, with 1 being not satisfied and 5 being very satisfied.

	Not Satisfied 1	2	Neutral 3	4	Very Satisfied 5	Not Sure
Satisfaction with incident management program	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆

28 If you are not satisfied, what could be done to improve the program?

29 Has your department instituted a new incident management/clearance program/strategy or upgraded a current program/strategy aimed at increasing collaboration between relevant agencies within the last five years?

- ☐ ₁ Yes
- ☐ ₂ No
- ☐ ₃ Unknown

30 Please rate how well collaboration has worked between your agency and other relevant agencies before and after the creation of an incident clearance and management program, with 5 being productive and 1 being unproductive.

a) Collaboration *before* the incident management program

	Unproductive 1	2	3	4	Productive 5
State Highway Patrol	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Emergency Management Services	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Traffic Management/Control Center	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

b) Collaboration after the incident management program

	Unproductive 1	2	3	4	Productive 5
State Highway Patrol	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Emergency Management Services	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Traffic Management/Control Center	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

31 Please indicate the level of improvement according to the following performance measures because the implementation of incident clearance programs, with 1 being the least and 5 being the most.

	Least 1	2	Somew hat 3	4	Most 5
Response time	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Traffic backup	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Incident clearance time	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Incident detection time	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Agency coordination	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

32 How is information (benefits and costs) of your incident clearance plan communicated to decision makers? Please rate the effectiveness of each form of communication with 1 being least effective and 5 being most

	Least 1	2	Somew hat 3	4	Most 5
Personal communication	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Electronically (Internet, e-mail, etc.)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Print (brochure, newsletter, magazine, etc.)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

33 How is information (benefits and costs) of your incident clearance plan communicated to the general public? Select by rating the effectiveness of each form of communication with 1 being least effective and 5 being most effective.

	Not Satisfied 1	2	Neutral 3	4	Very Satisfied 5	Not Sure
Personal communication	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Electronically (Television, Internet, e-mail, etc.)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Print (brochure, newsletter, magazine, etc.)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Public meetings	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

34 Please include any additional information/data that you believe is valuable in accessing the benefits and costs of incident clearance.

Please give us any comments, suggestions, or additional information you feel will help this study.

Thank you for your time and your responses. Please fill out the information below.

Name _____

Job title _____

Agency _____

Mailing address _____

Phone number _____

Facsimile number _____

E-mail address _____

ITS Survey

Clemson University's Highway Incident Clearance and Management Survey for Intelligent Transportation Systems Management

Clemson University is conducting a survey of relevant agencies associated with highway incident clearance and management in order to obtain the current state of practice within the United States. This survey is one component of a research study funded by the South Carolina Department of Transportation to provide decision makers with the costs and benefits of accelerated incident clearance strategies. This survey which will take between 5 and 10 minutes, is intended to gather information about your individual agency's incident management framework, accelerated incident clearance strategies, and the benefits and costs associated with these strategies. It consists of three sections including:

- 1.0 Incidents
- 2.0 Technology
- 3.0 Agencies and Collaboration

Please be assured that names of individual respondents will remain confidential, although states or agencies might be identified in our results. If you would like to receive a copy of our survey findings, please provide your e-mail address. Thank you for contributing to this important study aimed at improving incident clearance, your time and effort will help to make our highways operate in a safer and more efficient manner.

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Section 1.0 Incidents

1 Please define your jurisdiction. Include all city and county names along with major highways. _____

2 How does your jurisdiction define an incident?

3 Please rate the prevalence of the following types of incidents within your state, with 1 being least prevalent and 5 being most prevalent.

	Not Satisf ied 1	2	Neutr al 3	4	Very Satisf ied 5	Not Sure
Single vehicle crash	<input type="checkbox"/> 01	<input type="checkbox"/> 02	<input type="checkbox"/> 03	<input type="checkbox"/> 04	<input type="checkbox"/> 05	<input type="checkbox"/> 06
Disabled/Abandoned vehicle	<input type="checkbox"/> 01	<input type="checkbox"/> 02	<input type="checkbox"/> 03	<input type="checkbox"/> 04	<input type="checkbox"/> 05	<input type="checkbox"/> 06
Multi-vehicle crash	<input type="checkbox"/> 01	<input type="checkbox"/> 02	<input type="checkbox"/> 03	<input type="checkbox"/> 04	<input type="checkbox"/> 05	<input type="checkbox"/> 06
Hazardous material spill	<input type="checkbox"/> 01	<input type="checkbox"/> 02	<input type="checkbox"/> 03	<input type="checkbox"/> 04	<input type="checkbox"/> 05	<input type="checkbox"/> 06
Debris on roadway	<input type="checkbox"/> 01	<input type="checkbox"/> 02	<input type="checkbox"/> 03	<input type="checkbox"/> 04	<input type="checkbox"/> 05	<input type="checkbox"/> 06
Weather-related debris on roadway	<input type="checkbox"/> 01	<input type="checkbox"/> 02	<input type="checkbox"/> 03	<input type="checkbox"/> 04	<input type="checkbox"/> 05	<input type="checkbox"/> 06

4 Please rate the prevalence of the following types of secondary incidents that occur within your state, with 1 being least prevalent and 5 being most prevalent.

	Not Satisf ied 1	2	Neutr al 3	4	Very Satisf ied 5	Not Sure
Collision	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Disabled vehicle	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

Section 2.0 Technology

5 What type of intelligent transportation systems (ITS) infrastructure does your jurisdiction use to handle incident management? Check all that apply.

	Imple ment ed	Plann ed	Not plann ed	No longe r used
Traffic cameras	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4
Variable message signs	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4
Computer aided dispatch (CAD)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4
Automated incident sensors	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4
Traffic Management Center	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4
Automated vehicle locators (AVL)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4
Highway Advisor Radio (HAR)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4
Dynamic lane designation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4

6 Does your agency have a route diversion/alternate route plan?

- ☐ 1 Yes
- ☐ 2 No
- ☐ 3 Unknown

7 If your agency does have a route diversion/alternate route plan, please rate the effectiveness of the following route diversion tools used by your agency, with 1 being very ineffective and 5 being very effective.

	Very ineffe ctive 1	2	3	4	Very effect ive 5	Not Appli cable
Ramp metering	<input type="checkbox"/> 001	<input type="checkbox"/> 002	<input type="checkbox"/> 003	<input type="checkbox"/> 004	<input type="checkbox"/> 005	<input type="checkbox"/> 006
Variable message sign alerts	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	001	002	003	004	005	006
Arterial signal control	<input type="checkbox"/> 001	<input type="checkbox"/> 002	<input type="checkbox"/> 003	<input type="checkbox"/> 004	<input type="checkbox"/> 005	<input type="checkbox"/> 006
Highway Advisory Radio (HAR) alerts	<input type="checkbox"/> 001	<input type="checkbox"/> 002	<input type="checkbox"/> 003	<input type="checkbox"/> 004	<input type="checkbox"/> 005	<input type="checkbox"/> 006
Lane closure systems	<input type="checkbox"/> 001	<input type="checkbox"/> 002	<input type="checkbox"/> 003	<input type="checkbox"/> 004	<input type="checkbox"/> 005	<input type="checkbox"/> 006
Other	<input type="checkbox"/> 001	<input type="checkbox"/> 002	<input type="checkbox"/> 003	<input type="checkbox"/> 004	<input type="checkbox"/> 005	<input type="checkbox"/> 006

8 Once an incident is detected and verified, how is this information disseminated to relevant agencies? Check all that apply.

- ☐ 1 Land line telephone
- ☐ 2 Electronically (e-mail)
- ☐ 3 Computer aided dispatch
- ☐ 4 Dedicated frequency radio
- ☐ 5 Radio without dedicated frequency
- ☐ 6 Other

9 Please indicate what kind of data your agency keeps on record and how long it is stored.

	0-30 Days	31-60 Days	61-90 Days	More than 90 Days	Not Kept
Phone calls	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Video recordings	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Sensor readings	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

10 Please indicate which of the following agencies/organizations have access to data that are collected and stored by your agency. Check all that apply.

- ☐ 1 Department of Transportation
 - ☐ 2 Emergency Management Services
 - ☐ 3 State Highway Patrol
 - ☐ 4 Department of Public Safety
 - ☐ 5 State Division of Motor Vehicles
 - ☐ 6 News media
 - ☐ 7 General public
 - ☐ 8 Other
-

Section 3.0 Agency Collaboration

11 What is your agency's role in incident clearance and management?

12 Within your state, how would you rate the comprehensiveness of collaboration programs that are responsible for incident management and clearance, with 5 being very comprehensive and 1 being least comprehensive?

	Not Satisfied 1	2	Neutr al 3	4	Very Satisfied 5	Not Sure
Comprehensiveness of collaboration	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

13 Within your state, how would you rate the effectiveness of collaboration programs that are responsible for incident management and clearance, with 5 being very effective and 1 being least effective?

	Not Satisfied 1	2	Neutr al 3	4	Very Satisfied 5	Not Sure
Effectiveness of collaboration	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

14 Has your department instituted a new incident management/clearance program/strategy or upgraded a current program/strategy aimed at increasing collaboration between relevant agencies within the last five years?

- ☐ 1 Yes
- ☐ 2 No
- ☐ 3 Unknown

5 For the questions below, please rate how well collaboration has worked between your agency and other relevant agencies before and after the creation of an incident clearance and management program, with 5 being productive and 1 being unproductive.

a) Collaboration before the incident management program

	Unpr oduct ive 1	2	3	4	Prod uctiv e 5
State Highway Patrol	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
State Department of Transportation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Emergency Management Services	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

b) Collaboration after the incident management program

	Unproductive 1	2	3	4	Productive 5
State Highway Patrol	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
State Department of Transportation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Emergency Management Services	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

16 Please give us any comments, suggestions, or additional information you feel will help this study.

17 Thank you for your time and your responses. Please fill out the information below.

Name _____

Job title _____

Agency _____

Mailing address _____

Phone number _____

Facsimile number _____

E-mail address _____

State Highway Patrol Survey

Clemson's Highway Incident Clearance and Management Survey for State Highway Patrols.

Clemson University is conducting a survey of relevant agencies associated with highway incident clearance and management in order to obtain the current state of practice within the United States. This survey is one component of a research study funded by the South Carolina Department of Transportation to provide decision makers with the costs and benefits of accelerated incident clearance strategies. This survey will take between 5 and 10 minutes, and is intended to gather information about your individual agency's incident management framework, accelerated incident clearance strategies, and the benefits and costs associated with these strategies. It consists of three sections including:

- 1.0 Incidents
- 2.0 Equipment and Preparedness
- 3.0 Agency Collaboration

Please be assured that names of individual respondents will remain confidential, although states or agencies might be identified in our results. If you would like to receive a copy of our survey findings, please provide your e-mail address. Thank you for contributing to this important study aimed at improving incident clearance, your time and effort will help to make our highways operate in a safer and more efficient manner.

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Section 1.0 Incidents

1 Please define your jurisdiction. Include all city and county names along with major highways. _____

2 How does your jurisdiction define an incident?

3 Please rate the prevalence of the following types of incidents within your state, with 1 being least prevalent and 5 being most prevalent.

	Not Satisfied 1	2	Neutr al 3	4	Very Satisfied 5	Not Sure
Single vehicle crash	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Disabled/Abandoned vehicle	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Multi-vehicle crash	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Hazardous material spill	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Debris on roadway	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Weather-related debris on roadway	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

4 Please rate the prevalence of the following types of secondary incidents that occur within your state, with 1 being least prevalent and 5 being most prevalent.

	Not Satisf ied 1	2	Neutr al 3	4	Very Satisf ied 5	Not Sure
Collision	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Disabled vehicle	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

Section 2.0 Equipment and Preparedness

5 Do accident investigation posts/offices exist along freeways/highways within your jurisdiction?

- ☐ 1 Yes
- ☐ 2 No
- ☐ 3 Unknown

6 If yes, how many posts/offices exist?

Number of Posts/offices _____

Miles of freeway covered _____

7 Please estimate what percentage each of the following methods contribute to

incident detection and verification. NOTE: Column must total 100%.

Video equipment	_____
General public	_____
Department of Transportation	_____
Emergency Management Services	_____
Field Observation	_____
Traffic Management Center	_____
Other	_____

8 Please rate the performance of the following incident investigation technologies/methods used in your jurisdiction. Check all that apply, and rate the performance of the technology/method with 1 being the worst and 5 being the best. If your agency doesn't currently utilize the technology/method check "Not used." If your agency is planning to implement the technology, please check "Technology/method planned."

	Worst 1	2	3	4	Best 5	Not used	Technology/ method planned	Not Sure
Photography	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8
Video equipment	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8
Data recording equipment	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8
Total stations	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8
Bystander interviews	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8
Global Positioning Systems (GPS)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8
Multi-disciplinary investigation teams	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8
Accident re-creation software	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8
Interviews with involved motorists/passengers	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8

9 Please estimate the percentage that each of the following technologies/methods contribute to your total incident investigation effort. NOTE: Please try to have column total 100%.

Photography _____
 Video equipment _____
 Data recording equipment _____
 Total stations _____
 Bystander interviews _____
 Global Positioning Systems (GPS) _____
 Multi-disciplinary investigation teams _____
 Accident re-creation software _____
 Interviews with involved motorists/passengers _____
 Other _____

10 How well do you feel that your agency is equipped to handle highway incidents (including proper training, needed infrastructure and resources, proper management, etc.), with 1 being least prepared to 5 being most prepared.

	Least prepa red 1	2	3	4	Most prepa red 5
Agency preparedness	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

11 What do you believe should be done to handle highway incident management better?

12 Does your agency have an incident management manual?

- ☐ 1 Yes
- ☐ 2 No
- ☐ 3 Unknown

13 Do troopers in your jurisdiction have in their possession a layman's terms manual in order to facilitate on-site incident clearance and management, especially pertaining to incidents involving hazardous materials?

- ☐ 1 Yes
- ☐ 2 No
- ☐ 3 Unknown

Section 3.0 Agency Collaboration

14 What is your agency's role in incident clearance and management?

15 Within your state, how would you rate the comprehensiveness of collaboration programs that are responsible for incident management and clearance, with 5 being very comprehensive and 1 being least comprehensive?

	Not Satisf ied 1	2	Neutr al 3	4	Very Satisf ied 5	Not Sure
Comprehensiv eness of collaboration	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

16 Within your state, how would you rate the effectiveness of collaboration programs that are responsible for incident management and clearance, with 5 being very effective and 1 being least effective?

	Not Satisf ied 1	2	Neutr al 3	4	Very Satisf ied 5	Not Sure
Effectiveness of collaboration	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

17 Has your department instituted a new incident management/clearance program/strategy or upgraded a current program/strategy aimed at increasing collaboration between relevant agencies within the last five years?

- ☐ 1 Yes
- ☐ 2 No
- ☐ 3 Unknown

18 For the questions below, please rate how well collaboration has worked between your agency and other relevant agencies before and after the creation of an incident clearance and management program, with 5 being productive and 1 being unproductive.

a) Collaboration *before* the incident mangement program

	Unproductive 1	2	3	4	Productive 5
Emergency Management Services	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
State Department of Transportation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Traffic Management/Control Center	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

b) Collaboration *after* the incident management program

	Unproductive 1	2	3	4	Productive 5
Emergency Management Services	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
State Department of Transportation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Traffic Management/Control Center	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

19 Please indicate the level of improvement according to the following performance measures because the implementation of incident clearance programs, with 1 being the least and 5 being the most.

	Least 1	2	3	4	Most 5	Not measured
Incident detection time	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Response time	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Clearance time	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Agency collaboration	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Secondary incidents	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

20 Please give us any comments, suggestions, or additional information you feel will help this study.

Thank you for your time and your responses. Please fill out the information below.

Name _____

Job

title _____

Agency _____

Mailing address _____

Phone number _____

Facsimile number _____

E-mail address _____

Emergency Management Services Survey

Clemson University's Highway Incident Clearance and Management Survey for Emergency Management Services

Clemson University is conducting a survey of relevant agencies associated with highway incident clearance and management in order to obtain the current state of practice within the United States. This survey is one component of a research study funded by the South Carolina Department of Transportation to provide decision makers with the costs and benefits of accelerated incident clearance strategies. This survey will take between 5 and 10 minutes, and is intended to gather information about your individual agency's incident management framework, accelerated incident clearance strategies, and the benefits and costs associated with these strategies. It consists of six sections including:

- 1.0 Incidents
- 2.0 Agencies and Collaboration
- 3.0 Jurisdiction Legislation and Regulation
- 4.0 Technology
- 5.0 Incident Clearance Program
- 6.0 Benefits and Costs associated with incident clearance

Please be assured that names of individual respondents will remain confidential, although states or agencies might be identified in our results. If you would like to

receive a copy of our survey findings, please provide your e-mail address. Thank you for contributing to this important study aimed at improving incident clearance, your time and effort will help to make our highways operate in a safer and more efficient manner.

Principal investigator:

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Section 1.0 Incidents

1 Please define your jurisdiction. Include all city and county names along with major highways. _____

2 How does your jurisdiction define an incident?

3 Please rate the prevalence of the following types of incidents within your state, with 1 being least prevalent and 5 being most prevalent.

	Not Satisfied 1	2	Neutral 3	4	Very Satisfied 5	Not Sure
Single vehicle crash	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Disabled/Abandoned vehicle	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Multi-vehicle crash	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Hazardous material spill	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Debris on roadway	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Weather-related debris on roadway	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

4 Please rate the prevalence of the following types of secondary incidents that occur within your state, with 1 being least prevalent and 5 being most prevalent.

	Not Satisfied 1	2	Neutral 3	4	Very Satisfied 5	Not Sure
Collision	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Disabled vehicle	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

Section 2.0 Equipment and Preparedness

5 Please rate how much each of the following contribute to incident detection and verification, with 1 being the least and 5 being the most

	Least 1	2	3	4	Most 5
General public	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Department of Transportation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
State Highway Patrol	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Field observation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Traffic Management Center	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

6 How well do you feel that your agency is properly equipped to handle highway incidents (including proper training, needed infrastructure and resources, proper management, etc.) with 1 being least prepared to 5 being most prepared.

	Not Satisfied 1	2	Neutr al 3	4	Very Satisfied 5	Not Sure
EMS preparedness	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

7 What do you believe should be done to handle highway incident management better?

8 Please rate how time-effective your emergency management service is, that is, do you think the amount of time needed to coordinate other relevant agencies (fire, police, hazardous material team, etc.) is at a minimum, with 1 being very time-ineffective and 5 being very time-effective.

	Very ineffective 1	2	3	4	Very effective 5	Unknown
Time effectiveness	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

9 If you rated your service at least partially ineffective in the previous question, why do you feel coordination time is too long, and what would you suggest to improve it?

Section 3.0 Agency Collaboration

10 What is your agency's role in incident clearance and management?

11 Within your state, how would you rate the comprehensiveness of collaboration programs that are responsible for incident management and clearance, with 5 being very comprehensive and 1 being least comprehensive?

	Not Satisfied 1	2	Neutr al 3	4	Very Satisfied 5	Not Sure
Comprehensiveness of collaboration	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

12 Within your state, how would you rate the effectiveness of collaboration programs that are responsible for incident management and clearance, with 5 being very effective and 1 being least effective?

	Not Satisfied 1	2	Neutr al 3	4	Very Satisfied 5	Not Sure
Effectiveness of collaboration	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6

13 Has your department instituted a new incident management/clearance program/strategy or upgraded a current program/strategy aimed at increasing collaboration between relevant agencies within the last five years?

- ☐ 1 Yes
- ☐ 2 No
- ☐ 3 Unknown

14 For the questions below, please rate how well collaboration has worked between your agency and other relevant agencies before and after the creation of an incident clearance and management program, with 5 being productive and 1 being unproductive.

a) Collaboration before the incident management program

	Unproductive 1	2	3	4	Productive 5
State Highway patrol	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
State Department of Transportation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Traffic Management/Control Center	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

b) Collaboration after the incident management program

	Unproductive 1	2	3	4	Productive 5
State Highway patrol	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
State Department of Transportation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Traffic Management/Control Center	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
Other	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

15 Please give us any comments, suggestions, or additional information you feel will help this study.

Thank you for your time and your responses. Please fill out the information below.

Name_____

Job title_____

Agency_____

Mailing address_____

Phone number_____

Facsimile number_____

E-mail address_____

Appendix B: Empirical Crash Data Collection Proposal

South Carolina's traffic management centers operate traffic cameras, loop detectors, and side-fire radar to measure traffic parameters such as speed and flow. Unfortunately, all detectors do not record these data in detail (less than once an hour). Particularly, traffic cameras in the state do not record images due to liability and data archiving concerns, which is similar to other agencies around the country as found by our nation-wide survey. Loop detectors on interstates focus on recording hourly volumes for estimation of average daily traffic. The location of both traffic cameras and loop detectors with respect to an incident will significantly affect the ability to detect incidents and record traffic impact.

To collect the traffic impact of a freeway incident, this section proposes a simple process that can be adopted by the South Carolina traffic management centers. The proposed data collection tool will be traffic cameras because they are one of the most densely deployed devices along urban interstates in the state and they record detailed data. The proposed research will attach three video recorders, either computer or video cassette, to the feeds from three selected monitors in the traffic management center. Researchers will work with operators at the traffic management center to develop a procedure for capturing the incident with only three traffic cameras, three monitor screens, and three recorders. Initially, the research team can test a procedure whereas the traffic management center operator writes down when an incident is detected, then starts the first

monitor-recorder unit taping the traffic flow at the incident scene. Next, depending on the location of the next upstream traffic camera, the second monitor-recorder unit can begin taping the growth of the queue. If the recorded incident is severe, a third monitor-recorder unit might be used to record the flow in the center of the congested section. Other information that needs to be recorded by traffic management center officials includes the verification time and the incident duration.

After an incident has been successfully recorded, the same time and location must be recorded under normal traffic conditions to establish a baseline to compare the incident impact against. Video image processing tools such as those in Autoscope software, will be used to count vehicle flow and speed. Measures of effectiveness include incident duration, detection time, verification time, and average vehicle speeds.

The observed measures of effectiveness will be compared to those from the simulation study. If the observed incident occurs at a different location than previously simulated or closes a different number of lanes, more simulation runs might be required to verify the simulated vehicle speeds match the observed under incident conditions. The detection, verification, and response method chosen in the field should also match the strategy simulated.

Many challenges exist to successfully collecting empirical crash data. Due to the random nature of incidents, it may require several trials before successfully recording an incident in the manner proposed. Operators at traffic management centers also have duties such as dispatching police and medical

personnel that are more important than beginning to record an incident, therefore; it is hypothesized that minor incidents are more likely to be successfully recorded than more severe ones. While vehicle hours of delay was found to be the most significant impact of incident management, recording empirical delay data requires several assumptions that can significantly bias the data. Emissions and fuel use are similarly difficult to accurately observe without major assumptions. For this reason, delay, emissions, and fuel use are not included in the proposed measures of effectiveness.

Because it is generally accepted that simulation software produces between approximately 12 and 17 percent error (Brockfeld et al., 2004; Ranjitkar et al., 2004), the model can be considered validated if falling within 15 percent of the observed incident duration, detection time, verification time, and average vehicle speeds.

Appendix C: Implementation Strategy

Before beginning this process, the strategies all parties involved must clearly understand the strategies to be used, especially by the stakeholders directly responsible for freeway operations, which is usually the state Department 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, it is advisable that the Department of Transportation host a partnership meeting for all agencies involved in incident management. Involving these parties as much as possible in the earliest stages of planning will be 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. Reaching these goals will require some extent of effort by each stakeholder, and thus objectives for each goal need to 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 departments of transportation must conduct an in-

depth assessment on their own programs. This phase will help the agency identify existing problems with incident management faced by each stakeholder, and point them towards potential areas for improvement.

Incident management programs must involve coordination between all the respective agencies. For example, in South Carolina the SC DOT 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.

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 will 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 to the road user. 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 leads to 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 for implementation. These alternatives 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. Utilizing the collected data, the results should 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. Self-assessment can be performed to identify possible changes or updates needed, as well as documentation of the progress made so 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:

Detectors

Many agencies have implemented radar 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 CCTV 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 for good traffic management.

Agency Coordination

Critical agencies that should be involved in implementation of radar units in the incident management system for a particular network include the DOT and local or state TMC. Personnel from these offices 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 radar 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.

Policy Changes

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

Technology

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.

Funding Sources

Resource sharing described in Section 6.3.4 can be adapted to acquire detectors. In addition, the Federal CMAQ (as it improves air quality as found this research) or safety funds (as it reduces secondary crashes) can be used to acquire these systems for greater coverage. In addition to initial funding, the agency must find funds for maintaining the system.

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.

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.

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 keeping track of 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. Incorporation of these parties into the planning stages of implementation will be an important step in effectively utilizing traffic camera's capabilities for incident management.

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.

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.

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.

Freeway Service Patrols

The potential for freeway service patrols to enhance traffic operating conditions is seemingly limitless, from the view of both incident clearance histories and documentation of their effectiveness, and from the public. Many surveys have sought to gain knowledge of public opinion on this type of

assistance, and the results have been overwhelmingly positive. What's more, benefit-cost analyses indicated 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.

Agency/Stakeholder Coordination

Agencies involved in Freeway Service Patrol operations and communications will include the state DOTs 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.

Policy Changes

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

Technology Needs

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

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 could 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 that are less pressured to handle traffic situations, and are thus free to perform law enforcement duties as a result of FSP programs. Another source of funding may be partnerships with private companies, who can advertise their services on their vehicles in exchanges of supporting the cost of operation and upkeep.

Incident Quick Clearance Legislation

Quick clearance legislation such as South Carolina's Steer-it, 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 have travel lanes cleared as quickly as possible in the event of an incident that blocks a lane 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 growth and increasing 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.

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, these personnel must be made aware of the potential impact of reduced incident durations.

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. Such policy changes may make it 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 after their individual evaluation of the scene.

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, because many drivers hold fast to the belief that law enforcement assistance is needed in every situation. After 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.

Funding Sources

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

Route Diversion

For major incidents blocking the entire freeway, it may be necessary to divert traffic to secondary routes to reduce overall incident delay for road users. Implementing such a plan requires the use of additional communication methods to drivers, including variable message signs and highway advisory radio (HAR). Utilizing such strategies can maximize the effectiveness of diversion routes by

informing drivers of the incident characteristics encountered, permitting drivers to decide if they wish follow the detour or find less congested routes.

Agency Coordination:

Both HAR and variable message sign 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 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.

Policy Changes

The incident management stakeholders need to identify alternate routes for each anticipated incident locations on freeways. Highway patrol 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.

Technology

HAR and variable message sign 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.

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 develop these alternate routes. Funding for HAR and variable message sign systems can be provided through other traffic safety and congestion mitigation programs, and emergency operations because they supply reports to a broad network of travelers regarding Amber Alerts and daily freeway congestion.

Data Archiving System for Incident Management Planning

SCDOT currently has four Traffic Management Centers. These centers should be able to formally archive collect and archive traffic data in a database, including during and after an incident. 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 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 project.

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