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NATIONAL CENTER FOR TRANSPORTATION SYSTEMS PRODUCTIVITY AND MANAGEMENT

Optimizing EMS Through Intelligent Transportation System (ITS) Technologies

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ABSTRACT

Emergency service (EMS, fire, and police) operations can benefit from the integration of Intelligent Transportation Systems (ITS) technologies into the transportation system infrastructure and the emergency vehicles themselves. From simple emergency notification systems to sophisticated dynamic routing algorithms for expedited incident response, ITS technologies provide capabilities to improve the efficiency of emergency operations. This study analyzed the potential for ITS to optimize response and transport times for emergency vehicles and mitigate non-recurrent incident induced congestion. Using public safety records, historical travel time data, and simulation models the study team analyzed a number of candidate technologies and scenarios to estimate the benefits to emergency operations. Specific scenarios analyzed the potential benefits of optimizing vehicle dispatch to minimize response and transport times and minimizing overall response times in order to reduce secondary congestion. The study examined the use of historical and real-time traffic data to select the optimum unit in emergency vehicle dispatch and found that while the use of real-time traffic data benefits emergency vehicle dispatch, much of the same benefit can be achieved by using historical traffic data which can be purchased more cheaply and does not require an ongoing service provider. Using Interstate 65 in the Birmingham region as a study corridor, it was estimated that even small reductions in overall incident response could result in significant reductions in incident-induced congestion.

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1. INTRODUCTION

Emergency service (EMS, fire, and police) operations can benefit from the integration of Intelligent Transportation Systems (ITS) technologies into the transportation system infrastructure and the emergency vehicles themselves. From emergency notification systems to sophisticated dynamic routing algorithms for expedited incident response, ITS technologies can provide capabilities to improve the efficiency of emergency operations. This study analyzed the potential for ITS to optimize response and transport times for emergency vehicles and mitigate non-recurrent incident induced congestion. Using public safety records, historical travel time data, and simulation models the study team analyzed several candidate technologies and scenarios to estimate the benefits to emergency operations.

Specific scenarios analyzed included the following:

- Technologies to automate the reporting of incidents and improve the accuracy of location data;
- Technologies to correctly identify the types if vehicles involved in a traffic incident so that the correct equipment can be dispatched;
- Using different types of travel time data (planning models, historical travel time data, and real-time travel time data) to select the appropriate emergency response units and provide optimum routing;
- Evaluating the impacts of response time reductions on incident induced congestion.

1.1. Emergency Response Phases

A typical emergency response can be broken into the following phases shown in Figure 1:

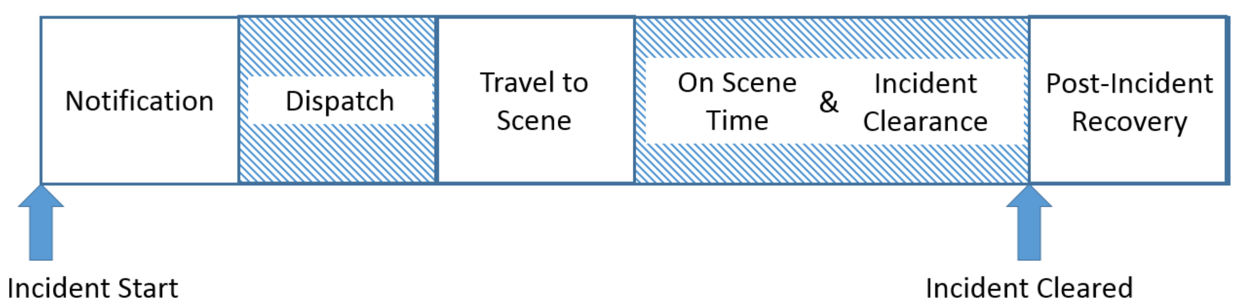

Figure 1. Typical phases of an emergency response event.

Incident Notification – The period between the occurrence of the emergency incident and the receipt of notification by the emergency response agency, typically a 911 PSAP (public safety access point) center. In the example of a vehicular crash, the notification period would be the time from when the incident occurred to the time the nature and location of the incident is communicated to the emergency response agency.

Dispatch – The period begins after the notification of the emergency response agency and includes the decision of what types of units to send, the selection of the optimum unit, and the notification of the actual responding unit (police, fire, or EMS).

Travel to Scene – The time period following dispatch during which the emergency response units mobilize and travel to the incident scene.

On Scene Time and Incident Clearance – The time spent by the emergency response unit at the scene of the incident. This can include medical treatment, patient evacuation, police reporting, and vehicle clearance.

Post-Incident Recovery – In the case of vehicular incidents, the time period required for traffic flows and speeds to return to normal levels for the given time of day.

The length of emergency response times has been shown to have impacts on patient outcomes as well as significant impacts to those not directly involved in the incident in the form of traffic congestion. Both impacts carry significant societal costs, so there are incentives to minimize all phases of an emergency response phases from dispatch through patient transport and incident clearance.

1.2. Impacts of Emergency Response Times on Patient Outcomes

The impact of EMS response times on patient outcomes has been studied previously. Studies of hospital records have found that the majority of trauma deaths occur within the first 1-2 hours after the trauma occurs. *(61,63,65)* This knowledge has led to the concept of the "golden hour" after trauma occurs, during which the faster a patient can begin to receive medical attention (either from an EMT or in a hospital) the better the patient outcome is likely to be. Patients who suffer trauma appear to benefit most from reduced EMS response times, which allow emergency medical treatment to begin sooner, while lesser benefits result from reduced transport times to the hospital. Feero *(65)* studied the outcomes of severe trauma incidents in Portland, Oregon and found that total response times (from notification through transport of the patient to the hospital) were on average 10 minutes shorter for survivors than they were for non-surviving patients. The same study found that the average times for emergency services to arrive on the scene were significantly shorter for surviving patients than for non-survivors. Another study has estimated that the risk of death for severe trauma patients increases by approximately 5% for each additional minute required to bring the patient to the hospital. *(67)* The literature has generally found that the benefits of shorter response times are much smaller for non-trauma patients.

1.3. Impacts of Emergency Response Times on Congestion

It has been estimated that as much as 50% of all roadway congestion is non-recurrent, resulting from crashes, construction, weather, and other causes. As much as half of non-recurrent congestion may be the direct result of vehicle crashes. In these cases, the time required for emergency services to arrive on scene, treat and transport the injured, and clear the crash scene has a direct impact on the magnitude and duration of the resulting congestion. Studies have shown a direct correlation between incident severity and the magnitude of the resulting congestion, with the time required to clear the crash vehicles the critical component. Analysis of Birmingham congestion has found that a single crash can more than double total vehicle delay on an already congested highway during peak conditions. Numerous studies have demonstrated the benefits of incident detection and clearance programs that have been implemented across the U.S. Although many jurisdictions have incident detection programs in place on major highways and interstates, they are less commonly deployed in smaller cities or on major and minor arterials. Also, the integration of emergency medical and fire services into the planning and operations process is also not always complete. There remain opportunities to reduce secondary congestion through improved incident response.

1.4. Opportunities to Reduce Emergency Response Times

The study team analyzed a month of records for emergency response units (police, fire, and medical) in Jefferson and Shelby Counties in Alabama. The units in these records were responding to all types of incidents, including both vehicular and non-vehicular emergencies. The notification period is difficult to quantify because time of incident occurrence is typically not be recorded or cannot be determined, however, the response times for the dispatch through transport of patients to the hospital are recorded.

An analysis of over 7500 separate emergency responses yielded average lengths for the primary response phases, as shown in Figure 2. The data indicate that the actual dispatch process (once notification is received) is typically performed very quickly. In fact, dispatch orders were conveyed to emergency units in less than 1 minute in almost all cases. Travel time to scene, time spent on scene, and times to transport patients to hospitals (where applicable) were significantly longer. The data suggest that if response times are to be reduced, the greatest opportunities lie in 4 areas: incident detection and notification, selection of the most appropriate unit to respond, travel to the scene, and transport of patients to the hospital. Furthermore, as will be discussed in subsequent sections, there is a link between incident detection and notification and travel times to the scene, as the accuracy of reports related to incident location and description can affect the types of units dispatched and the ability of responding units to find the location quickly.

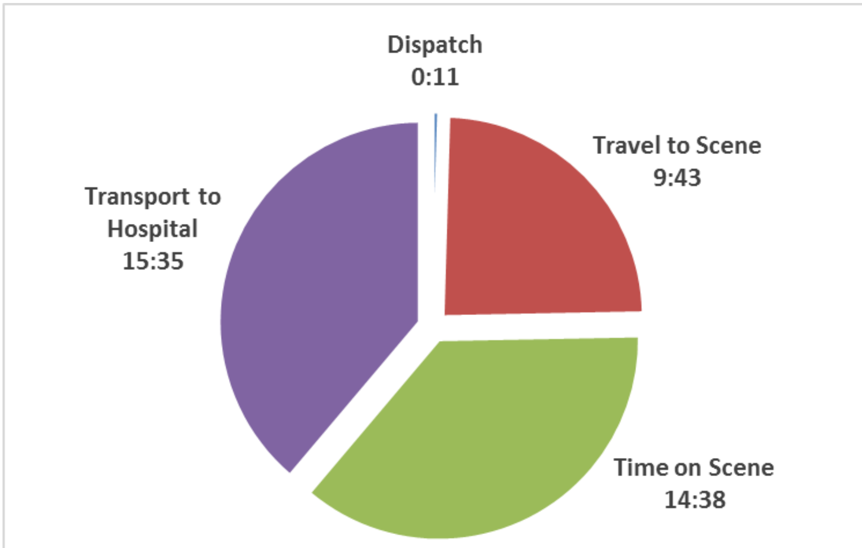

Figure 2. Average times for emergency response phases (Jefferson and Shelby Cos., AL)

It is important, however, that any discussion of the potential application of ITS technologies to emergency response start with a review of the emergency response process and an examination of needs identified by people within the EMS community. This study is not intended to identify technologies in search of problems, rather it seeks to identify common problems as indicated by EMS personnel and determine whether existing or emerging ITS technologies can have a positive impact.

1.4.1. Survey of Emergency Responders

This study built on previous research performed at UAB related to emergency response, traffic congestion, and the problems frequently encountered by EMS professionals. Researchers performed two surveys of Alabama EMS professionals: one with first responders (i.e., those professionals in the field) *(61)* and the other with EMS dispatchers *(68)*. The emergency responder survey authored by McGwin et al., identified factors that professionals in the field felt adversely affect response times. Among the findings:

- Inaccurate reporting of incidents, particularly the locations of vehicle crashes, is one of the most common causes of delay in traveling to the incident scene, as emergency units often have difficulty finding incidents when the locations have been misreported. 80% of responders surveyed said that they sometimes or often receive inaccurate location information.
- Median barriers can make it difficult to access crashes on major highways, forcing emergency units to travel past the incident to the next exit in order to turn around and return. While on-board GPS units generally have accurate street maps, their databases typically do not contain the locations of emergency median openings and therefore may not produce optimum routing.
- In-vehicle signal pre-emption devices are effective but not as widely deployed as responders would like.
- First responders are often not made aware of planned construction and maintenance activities in their area.
- Many responders felt that emergency dispatchers did not always relay information to them correctly or failed to provide all information available.

1.4.2. Survey of Emergency Dispatchers

A second study by Sullivan and Sisiopiku *(68)* surveyed emergency dispatch centers across the state of Alabama to obtain feedback on the emergency response process and the impact that factors such as incident reporting and traffic congestion have on response times. Some of the key findings were:

- Poor incident location information was the most commonly cited reason for response delays. These location inaccuracies resulted from several sources: inaccurate incident reports from callers, errors resulting from cell phone location systems, and a lack of accurate location data from callers using voice over internet provider phone service (VOIP).
- Only 33% of urban dispatchers and 31% of rural dispatchers agreed with the statement that traffic congestion is a “significant problem that impacts response times”. Even when only dispatchers who worked during peak traffic periods were counted, those numbers rose only to 38% and 37% respectively.
- 90% of dispatchers surveyed believed that traffic congestion only “sometimes” or “rarely” affected emergency response times.

- There was a disconnect between emergency dispatchers and emergency responders regarding their views on the impact of traffic congestion. While 40% of first responders statewide felt that congestion *frequently* impacts response times, only 10% of dispatchers did.

- None of the dispatchers who responded to the survey reported having real-time traffic information available to them in the dispatch center. This may account for the differing views of congestion compared to the emergency responders.

The results of the responder and dispatcher surveys indicate the most promising areas to reduce emergency response times:

Incident Notification

- Improving incident location information
- Providing more accurate information on the nature of the incident, such as number of persons involved, severity of injuries, types of vehicles involved. This would allow the correct number and types of emergency units to be dispatched.

Emergency Dispatch

- Incorporating traffic and construction information into the dispatch process, so that the optimum unit is dispatched.

Travel to Scene and hospital (when applicable)

- Incorporate improved route guidance information on the location of median and barrier openings to allow emergency units to take more direct paths to an incident.
- Deploy advanced signal pre-emption systems on approach routes to key hospitals and trauma centers.

1.5. Organization of the Report

The remainder of this report is organized as follows. Section 2 presents a summary of a literature review related to the use of ITS technologies and emergency response. Section 3 presents a summary of key ITS technologies and their potential benefits to reducing emergency response times. Section 4 discusses the impacts that improved emergency response times can have on reducing secondary congestion resulting from incidents. Section 5 presents conclusions and recommendations.

2. LITERATURE REVIEW

Every year in the United States, there are several hundred severe weather incidents, complex multi-vehicle crashes, potential security incidents, and highway hazardous material incidents that require emergency response and/or evacuation (*32*). The U.S. transportation system must be prepared for any eventuality. Responders must reach the scene, victims must evacuate the danger zone, and clearance and recovery resources must access the incident site in a timely manner. During transportation-related emergencies, the use of ITS technologies can result in improved and timely management of resources. ITS technologies provide *Emergency Medical Services* (EMS) agencies with the ability to communicate and coordinate operations and resources in real time. This report investigates the relevant *Intelligent Transportation Systems* (ITS) technologies for benefits, costs, lessons learned, impacts, and/or interoperability considerations.

2.1. Introduction

EMS is a system that provides out-of-hospital emergency medical care, transport to definitive care, and other medical transport to patients with illnesses and/or injuries that prevent the patient from transporting themselves (*23*). EMS functions include detection, reporting, response, on-scene care, care in transit, and transfer to definitive care (*24*). From a Transportation Engineering perspective, these EMS functions could be grouped in four operational areas, namely:

- Incident detection and reporting
- Deployment and dispatch
- Information dissemination
- Pre-hospital health care services.

ITS taxonomy includes two program areas that support EMS operations, that are “Emergency Management” and “Traffic Incident Management” (*18*). These ITS program areas house several function sections that are being served by ITS technologies relevant EMS operations. These technologies support the data collection required for effective coordination of changing transportation system conditions and allow for the real-time implementation of operational and logistical strategies in tandem with EMS operations (*11*). The Relevant ITS technologies grouped by EMS operational areas, are (*14, 33, 35*):

- **Incident detection and reporting**
  - Incident Detection Systems
  - Wireless Enhanced 9-1-1
  - Roadside Call Boxes
  - Automated Collision Notification

EMS deployment and dispatch

Computer Aided Dispatch / Automated Vehicle Location
Response Management
Emergency Vehicle Signal Preemption
Response Routing

Information dissemination

Dynamic Message Signs
Highway Advisory Radio

Pre-hospital health care services

Telemedicine

The following sections present and investigates these ITS technologies to determine the benefits, lessons learned, limitations, and/or interoperability considerations.

2.2. Incident Detection Systems

Incident detection systems consists of two main components, namely: data collection and data processing components (*28*). Data collection refers to the detectors, sensors, or surveillance technologies that are used to obtain traffic flow data. Data processing refers to the algorithms used for detecting and classifying incidents through analyzing the traffic patterns then reporting the occurrence, severity, and location of an incident to the proper responders. Such systems depend on a variety of surveillance and detection technologies that can help detect incidents quickly, including inductive loop or acoustic roadway detectors, and camera systems providing frequent still images or full-motion video (*33*).

Incident detection systems have various reported benefits, which include operations staff satisfaction, savings in delay costs, and improvement in response times. For example, In Pennsylvania, Pittsburgh-TMC staff in indicated that a real-time traffic information system used to monitor traffic density and congestion was useful and helped improve coverage for incident management (*20*). In New Jersey, NJDOT reported estimated savings of $100,000 per incident in user delay costs as a result of enhancing incident management efficiency by using I-95 Corridor Coalition's Vehicle Probe Project data (*15*). In Ontario, Canada, the traffic management system for Highway 401 in Metropolitan Toronto consisted of CCTV cameras and loop detectors for monitoring highways and determining traffic speed, volume, and density, which reduced average incident duration from 86 minutes to 30 minutes per incident (*34*). In Monroe County, NY, DOT operators were able to validate incidents within 4 minutes of conclusion, indicating a reduction of 50% to 80% saving between 5 and 12 minutes per incident (*5*).

Despite the obvious benefits of incident detection systems, it should be realized that such systems incorporate initial and on-going investments to maintain a management center, roadside equipment, and communications. Table 1 illustrates representative costs of implementing incident detection systems.

Table 1: Representative costs of Incident Detection Systems (*20*)

Item	Item Description	Cost Range
1	Transportation Management Center	
1.1	Software for Incident Detection	\$83,000 - \$101,000
1.2	Labor for Incident Detection (annually)	\$751,000 - \$917,000
2	Roadside Detection (each)	
2.1	Inductive Loops on Corridor	\$3,000 - \$8,000
2.2	Remote Traffic Microwave Sensor on Corridor	\$9,000 - \$13,000
2.3	CCTV Video Camera	\$9,000 - \$19,000
3	Roadside Telecommunications (per mi)	
3.1	Conduit Design and Installation	\$50,000 - \$75,000
3.2	Fiber Optic Cable Installation	\$20,000 - \$52,000

2.2.1. Wireless Enhanced 9-1-1

Wireless Enhanced 9-1-1 (WE-911) is a technology that is used to implement the “Emergency Notification and Personal Security” ITS User Service by providing the ability of transportation system users to notify appropriate emergency response personnel regarding the need for assistance due to emergency incidents (*36*). Information provided to emergency response personnel via WE-911 help incident/emergency management system personnel identify incidents quickly and dispatch proper response team(s) efficiently Since October 2001, The *Federal Communications Commission* (FCC) has mandated wireless carriers to provide *Public Safety Answering Points* (PSAPs) with *Automatic Location Identification* (ALI) for each WE-911 call with an accuracy radius of 125 meters or better. This will enable immediate response to emergencies because automatic location data will be displayed within seconds on the dispatcher’s computer mapping terminal for all WE-911 calls.

Bailey and Scott (*4*) summarized the lessons learned from the deployment of WE-911 in New York State. The study emphasized that technology is not the major barrier to the deployment. In addition, the study concluded that the primary requirement is getting stakeholders together and agreeing on an implementation strategy. To do that the study suggested three-step procedure for implementing WE-911 as follows:

1. Identify the key stakeholders
2. Get the stakeholders engaged
3. Keep the stakeholders engaged

Finally, the study identified the need to develop and clearly define the role of an advisory committee, carefully time public education, establish strong media relations, remain flexible enough to adapt to changing situations, seek routine input from outside observers, and secure the support of an expert in legislative affairs.

The findings of Bailey and Scott (*4*) were further emphasized by a study that was performed by the National Emergency Number Association (*22*), as that study concluded that effective implementation of WE-911 requires cooperation between agencies of the federal government (e.g. the FCC and DOT), state governments (primarily state wireless coordinators, where they exist), local governments (especially county 9-1-1 coordinators), and the private sector.

In another study, Boyd (*6*) summarized and interpreted the results of two *Field Operational Tests* (FOTs) that included emergency notification and response system components. The findings of that study supplied several technical lessons about the function of the emergency systems. The most important technical lesson was the benefits of integrating GPS technology in the system, which can be achieved with the proper application of readily available technology.

2.2.2. Roadside Call Boxes

Roadside call boxes are battery-powered, solar-charged roadside cellular telephones. Roadside call boxes are easy to spot, with their bright yellow box on an aluminum post with a royal blue identifying sign, and are conveniently located next to highways and freeways (*39*). A professional call answering center answers the call box calls, transfers them to the appropriate public safety assistance such as law enforcement, EMS, and fire control to be dispatched when needed. With the proliferation of cell phones, roadside call box feasibility was questioned; however, they proved to be more reliable than cell phones.

A study evaluated the Georgia Call Box Pilot Project that involved installation and monitoring of 147 cellular/solar powered call boxes in rural areas of interstate I-185 (*16*). The study was performed by surveying motorist and emergency dispatch personnel satisfaction. Emergency center managers believed call boxes provided a valuable service in areas on I-185 where motorists were unwilling to stop and assist, and in areas where cell phone signals were limited. Moreover, 97 percent of public respondents felt that call boxes on rural interstates in Georgia were a good idea given that 64 percent of them owned cellular phones. The cost to install the call boxes, connect them to an emergency call center, and provide agency training was estimated at $911,873 with a cost to benefit ratio of 2.76 (*17*).

2.2.3. Automated Collision Notification

Automated Collision Notification (ACN) systems use vehicle-mounted sensors and wireless communication to automatically determine that a collision has taken place and notify emergency response personnel of the incident. ACN systems provide various information on the detected incident including vehicle location, collision characteristics, and may be some medical information regarding motorists on board detected vehicle. Depending on the ACN system architecture it may provide the capability to establish a voice link between the vehicle and emergency response personnel, estimates of crash severity, and the probability of serious injury (*2*). Figure 3 illustrates a typical ACN system architecture with all possible capabilities.

Figure 3: Typical ACN System Architecture (*2*)

A FOT was conducted in Erie County, NY to evaluate the County ACN system. Key performance indicators were reducing incident notification and response times for vehicular accidents in rural and suburban areas (*2*). In order to evaluate the impact of ACN, incident notification and emergency response times were tracked for vehicles with and without ACN systems. Significant conclusions from that FOT were not drawn because of the unavailability of EMS response times. The average incident notification time for vehicles equipped with ACN was less than 1 minute and in some cases was as long as 2 minutes. The average incident notification time for vehicles without ACN was approximately 3 minutes, and in some cases was as long as 9 to 46 minutes.

Insufficient cellular coverage, damage to ACN equipment during collision, vehicle battery low, and temporary disconnection of telephone equipment at dispatch center were the primary factors where ACN did not function as expected. In addition, faulty accelerometer mount installations, and intermittent vehicle power supply failures induced false notifications for non-crash events during the FOT. To overcome the issue of false notifications and to assist in identifying crashes with disabling injuries, the William Lehman Injury Research Center in Miami, FL and BMW developed an algorithm called *URGENCY* using US national collision statistics and BMW internal data (*31*). *URGENCY* enables the transmission of the earliest and best possible information to the PSAPs.

However, EMS personnel highly appreciate ACN systems as indicated by a study that was performed by an expert panel that was elected by the *Center for Disease Control* (CDC). That expert panel recommended establishing a national system to collect and analyze ACN and injury data (*21*). The panel also recommended that ACN should be integrated as much as possible into current national data systems (National Accident Sampling System, National Emergency Medical Services Information System, and National Trauma Data Bank).

The FOT of Erie County, NY included an estimate of the ACN Costs (*2*). These costs were estimated for dispatch center and in-vehicle systems. Table 2 details these costs in 1997 discounted US Dollars.

Table 2: ACN Cost Estimate

Item	Item Description	Amount
1	**Dispatch center**	
1.1	Capital costs	23,300
1.2	Equipment development costs	152,400
1.3	Equipment installation costs	5,600
1.4	Training costs	5,000
1.5	Repair and maintenance costs	15,000
2	**In-vehicle systems unit costs**	
2.1	In-Vehicle module	549
2.2	In-Vehicle communications	446
2.3	In-vehicle module development costs	1,412,811
2.4	Installation of in-vehicle system	70
2.5	Maintenance and repair costs	129,000

2.3. Computer Aided Dispatch / Automated Vehicle Location

Computer Aided Dispatch assisted with *Automated Vehicle Location* (CAD-AVL) systems assist emergency dispatchers in locating and assigning appropriate responders to incidents that occur throughout a response area, including those that occur on the transportation system (*33*). The main component of CAD-AVL systems is a comprehensive software that effectively manages single or multi-jurisdictional dispatching activities for law enforcement, fire, and EMS. The CAD software seamlessly integrates GIS mapping, mobile computing, and records management to provide the information and communication essential to accelerating and improving emergency response (*25*). The main advantages of implementing CAD-AVL systems are:

1. ***Accelerated response times:*** CAD-AVL features like automatic address verification, real-time GPS unit locations, and dynamic unit recommendations allow call takers and dispatchers make critical decisions quickly thus reducing response times significantly.

2. ***Increased first responder safety:*** CAD-AVL systems provide real-time information such as preplans, hazards, and warrants to dispatchers and field personnel, which increases the level of safety for emergency responders.

3. ***Location information and advanced mapping:*** CAD-AVL systems utilize GIS maps that provide valuable information that improves tactical analysis and enhances situational awareness and preparation of emergency responders.

The benefits of CAD-AVL systems deployment in Albuquerque, NM were assessed, and an increase in *Albuquerque Ambulance* efficiency by 10 to 15 percent was reported as a result of using a map-based CAD-AVL system which allows the dispatch to send ambulances the exact location of an emergency and guidance on how to get there (*44*). However, the costs of such systems vary according to the system scope and technologies used. A study on the Richmond Smart Traffic Center / Virginia State Police CAD integration project reported a total amount of $249,200 during 2003 – 2004 for system development (*37*), on the other hand, a similar project in Minnesota cost just over $1.5 million (*10*).

Lessons learned from CAD-AVL FOTs help States proactively identify issues that may affect deployment cost, schedule, and technical performance. Utah DOT experience in integrating a Transportation Management Center with CAD-AVL systems concluded that duplicate data entries should be eliminated, redundant communications paths are always an advantage, information sharing is a key factor for success, and schedule coordination is a key for efficiency due to existence of multiple stakeholders (*27*). In addition, Virginia DOT experience indicates that CAD-AVL project goals should be balanced against the constraints and capabilities of project stakeholders (*37*).

2.4. Response Management

Response Management refers to coordination among transportation and emergency services professionals and their respective agencies to minimize the adverse system-wide effects of incidents and to optimize the use of limited resources (*42*). From the perspective of highway transportation, the most apparent need for coordination is with law enforcement, due to shared responsibilities for highway safety, traffic regulation, and response to traffic incidents. Response management includes the tracking of emergency vehicle fleets using automated vehicle location (AVL) and two-way communications between emergency vehicles and dispatchers. Integration with traffic and transit management systems enables emergency response information to be shared between various agencies and travelers (*34*).

Survey responses from key professionals in five states indicated that the realized benefits of Response Management from transportation professionals' perspective include (i) reduced time to restore normal traffic conditions following an incident, (ii) improved incident response times, and (iii) improved accuracy and timeliness of information provided to motorists and the public. While emergency service professionals indicated the benefits would be (iv) improved scene and responder safety, (v) reduced impact of major disasters, terrorist attacks, or other large-scale events, and (vi) reduced frequency and severity of hazardous material releases. (*42*)
Houston TranStar is a success story of Response Management. It is a formal partnership among the principal transportation and emergency management agencies in Harris County, including: Texas Department of Transportation, Metropolitan Transit Authority of Harris County (METRO), Harris County, and the City of Houston. Since its establishment in 1993, Houston TranStar provided multi-agency operations and management of the region's transportation system. Its estimated benefits are 30 minute time savings per freeway incident with total annual estimated delay savings of 572,095 vehicle-hours. It has an estimated annual economic value of these savings of USD 8,440,000. (*13*)

2.4.1. Emergency Vehicle Signal Preemption

Emergency vehicles operating in higher congestion levels are at higher risk for involvement in crashes and are subject to unpredictable delays in reaching the scene of a fire or crash. Crashes involving emergency vehicles are significantly problematic nationwide. The national traffic fatality rates for emergency medical service personnel, police officers, and firefighters have been estimated to be 2.5 to 4.8 times the national average among all occupations (*40*). *Emergency Vehicle Signal Preemption* (EVSP) systems are designed to override the regular control of traffic lights at signalized intersections in such manner to give emergency response vehicles a green light on their approach to the intersection while providing a red light to other approaches (*19*). There are many EVSP technologies including light-based, infrared-based, sound-based, and radio-based emitter/detector systems.

Several studies showed that EVSP systems have the following benefits:

1. **Improved response time:** A radio-based, GPS EVSP system reduced the average response times by five to seven minutes on the busy corridor of DeRenne Avenue in Savannah, Georgia (*12*). Another EVSP system in Houston, Texas reduced emergency vehicle travel time by 16 to 23 percent (*34*).
2. **Improved safety and reduced liability:** Pre-and post-EVSP safety impact analysis in St. Paul, Minnesota showed a decrease in emergency vehicle crashes from 8 to 3.3 per year (*19*).
3. **Cost savings in fire/rescue and EMS planning:** Improved response time and safety can translate into cost savings for the community.

Concerns about the impacts of EVSP on other traffic were studied using the CORSIM traffic simulation model to evaluate the effectiveness of EVSP and its impacts (*7*). The study consisted of three coordinated intersections on Route 7 in Virginia. Results showed that the impact on other traffic is statistically significant; however, it is minimal with a 2.4 percent increase in average travel time when priority is requested.

As for interoperability which is a key consideration in the selection of a particular EVSP technology, stakeholders need to identify the functional requirements of their own system and the requirement to support other neighboring jurisdictions as part of larger emergency response networks and mutual aid agreements. Table 3 shows the impact of interoperability conditions on the usability of various EVSP technology options.

Table 3: Impact of Interoperability Conditions on the Usability of EVSP Technologies (*19*)

Level of Interoperability	Light or Infrared Strobe Activated	Siren Activated	Radio Activated
Emergency Response Route	Yes, equip all participants	Yes	Yes, equip all participants
Mutual Aid Agreement	Yes, equip all participants	Yes	No
Transit Signal Priority	Yes, equip all participants	No	Yes, equip all participants
Regional Medical Center	Yes, equip all participants	Yes	Yes, equip all participants

2.4.2. Response Routing

Mobility on the routes leading from responding agencies to the incident scene and from the incident scene to the closest hospital is a key factor to timeliness of emergency response. Traffic congestion and lengthy delays may prevent the delivery of care to the injured and may force emergency response personnel into dangerous situations to avoid delays. *Response Routing* systems assist responders in identifying the quickest safe route to incident locations. Advanced systems may incorporate information on current traffic congestion, allowing responders to avoid traffic delays. *Response Routing* is not a standalone technology, it is rather dependent on other ITS technologies such as Automatic Vehicle Location (AVL), Computer Aided Dispatch (CAD), Route Guidance, and telecommunications technologies. (*26, 32, 34*)

As explained earlier, an ambulance provider in Albuquerque, New Mexico reported increased efficiency by 10 to 15 percent using AVL/CAD based *Response Routing* to improve route guidance (*34*). In addition, *Response Routing* proved to be beneficial in Police pursuits. StarChase is a suspect tracking system deployed in several Police agencies that assists police pursuits by letting technology take over (*43*). StarChase has a GPS projectile that is propelled from the front end of the police car and makes contact with a suspect that is fleeing from arrest. The GPS module sticks to the suspect vehicle and transmits coordinates back to dispatch. Response Routing personnel track the vehicle that is fleeing police, and provide the police officer in charge with exact location and safest routes until he/she is ready to engage that suspect and effectively make a traffic stop without harming innocent people. Such system could be beneficial for EMS *Response Routing*, where airborne responders utilize the system to track vehicles or persons involved in an incident and are in a state of constant moving (as an example, being thrown off a bridge into a river).

A key challenge to the success of *Response Routing* Systems is thorough and effective communications between the partners in the system. Key elements in communications include a thorough knowledge of each partner’s roles and responsibilities, understanding each partner’s capabilities/limitations, and managing expectations. (*29*)

2.4.3. Dynamic Message Signs

Dynamic Message Signs (DMS) are roadside systems that many traffic incident management agencies use to notify travelers of traffic incidents on both freeways and arterial streets (*20*). DMS are used alongside other technologies to communicate traffic conditions, incident-related information, and recommended rerouting strategies to motorists (*41*). Recent statistics indicated that 79 percent of traffic incident management agencies in the US 108 largest metropolitan areas disseminate traffic incident information on freeways using DMS (*20*).

WSDOT deployed DMS every half-mile over a 7.5 mile stretch of I-5 in Seattle, WA which reduced collisions by 65-75 percent (*46*). Analysis of DMS based integrated corridor management systems in Dallas, TX; San Diego, CA; and Minneapolis, MN found out that such systems produce more benefits at higher levels of travel demand and during nonrecurring congestion with the majority of benefits accruing under incident related conditions. That system had an estimated benefit-cost ratio of 22:1 over ten years (*1*) with costs ranging from $48,000 to $119,000 for roadside equipment (*20*).

Georgia DOT *NaviGAtor* system represents a success story of DMS usage (*45*). By implementing that system, traffic information is collected through an array of closed circuit television cameras and vehicle detection system cameras that cover about 155 (as of 2006) centerline miles of Atlanta's freeway system. These data are used to populate a real-time GIS map to depict the current conditions on the freeway system and to provide traffic information to DMSs that are strategically placed throughout the system to alert travelers of incidents in their travel route so that they may take an alternate route, if possible. In addition, there was a 70 percent reduction in secondary crashes, 6.83 million gallons annual reduction in fuel consumption, and significant contribution to decreased emissions (2,457 tons less Carbon monoxide, 186 tons less hydrocarbons, and 262 tons less Nitrous oxides), all as a result of implementing the *NaviGAtor* system.

Several ITS projects in the city of San Antonio, TX were evaluated (*8*). The evaluation report detailed benefits regarding the implementation of an incident management program with DMS along a freeway corridor. Through modeling efforts, that study investigated the impacts of integrating DMS with incident management. Results indicate that implementation of the integrated DMS and incident management result in a 2.8 percent decrease in crashes for freeways and 2.0 percent decrease in crashes for arterials. Moreover, focus group participants indicated that DMS were a reliable source of traffic information.

2.4.4. Highway Advisory Radio

Highway Advisory Radio (HAR) allows organizations operating ITS to share information concerning ongoing incidents with road users via radio frequency to help mitigate the traffic impacts of an incident (*26*). HAR is one of the widely used technologies for incident-related information dissemination as recent statistics indicate that nearly 46 percent of traffic incident management agencies use it to do so (*20*). HAR is deployed by means of licensed low-power

AM radio stations set up by local DOTs to provide bulletins to motorists and other travelers regarding traffic and other delays. Relayed information may go beyond the advisory role towards instructing motorists to re-route in order to assist EMS in accessing or departing an incident site.

In Honolulu, HI simulation was used to assess the impact of using motorist information technologies on incident-related traffic congestion (*30*). The study results indicated 40 percent decrease in incident-related delay due to implementing HAR and using it to inform the motorists of incident-related traffic conditions and diversion routes. In Brooklyn, NY implementing HAR within an incident management system as part of the Gowanus Expressway/Prospect Expressway rehabilitation project resulted in one hour reduction (66%) for incident clearing time (*38*). As for the costs, HAR roadside subsystem costs range from $15,000 to $35,000 (*20*).

2.5. Telemedicine

Telemedicine is the use of telecommunications for medical diagnosis and patient care. Telecommunication technology allows for the provision of medical services to incident sites or while the injured motorist is in transit to hospital. Telemedicine communication link usually involves fiber optics, satellite connections, and other sophisticated peripheral equipment and software. Telemedicine areas are (*9*):

1. ***Remote sensing*** which involves the transmission of patient information from the incident site to hospital. This includes electrocardiographic (ECG) and digital x-ray data.
2. ***Collaborative real-time patient management*** which represents the most innovative category of telemedicine which allows a remote practitioner to observe and discuss symptoms with an injured motorist or EMS personnel using two-way workstations that produce quality digital motion pictures across long distances.

San Antonio Metropolitan Model Deployment Initiative deployed “LifeLink” a project solely devoted to improving emergency services (*8*). “LifeLink” is a unique project that allows doctors in the hospital emergency room to communicate with EMS personnel via video and voice teleconferencing. “LifeLink” was evaluated and showed reduced emergency treatment costs, improved patient survivability and recovery, reduced litigation and claims, and reduced delay and secondary crashes.

Regardless of the evident benefits of Telemedicine, there are some impediments to its deployment including issues raised by videoconferencing credentialing, liability, cross-state licensing, referral practices, patient consent, and reimbursement. In addition, the startup costs of building a telemedicine suite represent a challenge to state and local stakeholders. (*8, 9*)

2.6. Summary

Several ITS technologies exist that can and does assist emergency service professionals. These systems if coordinated and planned properly can also enhance the leveraging of funds to ensure all stakeholders who can benefit from these systems share in not only the initial capital cost of these systems, but also system operating and maintenance costs. The delivery of emergency services to community can be enhanced by the use of such ITS technologies that have proven to be beneficial to EMS operations in terms of faster response, safer routing, enhanced incident management, cost savings for emergency agencies and the public, improved incident detection and verification, safer and faster clearance of incidents, and increased prevention of secondary incidents. Despite the realized benefits, successful support of ITS for EMS operations is highly dependent on the level of cooperation between agencies, interoperability between neighboring States and jurisdictions, and funding availability.

3. EVALUATION OF ITS TECHNOLOGIES TO IMPROVE EMERGENCY RESPONSE

Based on surveys of first responders and dispatchers and analysis of incident logs from the Jefferson and Shelby County EMS services, this study focused on ITS technologies with the potential to address the key phases of the emergency response timeline which the dispatchers and responders felt resulted in the most delays, namely: the incident notification period, the selection of the optimum unit to dispatch, and travel to/from the incident scene. For the notification phase, technologies were examined that could improve the accuracy of incident location information and details about the incident (i.e., number and severity of injuries). For the dispatch phase, the analysis focused on the impact of incorporating historical and/or real-time traffic data into the dispatch process and what benefits each has. For the travel and transport phases the analysis focused on technologies that could minimize travel times to and from the incident scene. Each phase is discussed in detail in the following sections.

3.1. Incident Notification

The problems most commonly cited by Alabama first responders and dispatchers in the UAB surveys were inaccurate location data and inaccurate descriptions of the nature of the incidents as reported to 911 centers by callers. A survey of Alabama first responders conducted by McGwin found that 18% felt inaccurate location data was a frequent problem. In interviews conducted with Alabama dispatch personnel and EMS managers, inaccurate location was cited as a frequent problem for vehicular incidents, particularly on interstates where people reporting an incident often incorrectly report direction, mile post, or exit. The two technologies with the greatest potential to address these issues in the Birmingham region are automated crash notification (ACN) and video surveillance.

Automated Crash Notification

ACN systems have been demonstrated to reduce notification times and provide accurate crash location data to emergency response agencies. On-board systems such as On-Star can send an automated crash notification when there is an airbag deployment or when deceleration (ΔV) exceeds specified threshold values. The magnitude of the ΔV can in many cases provide some indication of the severity of injuries to be expected. Advanced ACN systems (AACN) can provide even more detail on the vehicle change in direction and acceleration during the event, number of occupants, and whether seatbelts were in use. The information can allow 911 centers to dispatch additional medical units and even alert helicopter units when the expected injury severity is high.

Because the exact time of occurrence is not available for most incidents, it is difficult to quantify the time elapsed from when an incident occurred to when that incident was reported to a PSAP center, but data from automated crash notification systems (ACN) can provide a general idea when compared to the times at which the first phone call reports came in. McGwin *(62)* found that the median times for On-Star automated crash reports to reach the Birmingham Regional Emergency Medical Service System (BREMSS) ranged from 1 minute 30 seconds to 1 minute 45 seconds after crash occurrence. The median times after that for the first phone reports to reach the PSAP centers were 1:11 for urban incidents and 1:18 for rural incidents. It indicates median times for conventional incident notification by phone of between 2:40 and 3:00 in the Birmingham region.

Typical reductions in notification times that ACN can provide have been measured between 1:00 and 3:00 minutes in urban areas and 2:00 to 6:00 minutes in rural areas. The experience in the Birmingham region has been consistent with these findings. What impact these time savings will have on patient outcomes has been open for debate. Some models have suggested the widespread deployment of ACN systems will ultimately have only limited impacts on patient outcomes. This is due to several reasons, including the fact that the majority of traffic incidents do not involve severe injuries, notification times are generally under 4 minutes in urban areas even without ACN, and overall notification time is generally short in relation to the other phases incident response, particularly the times required to travel to the scene or to the hospital. In short, ACN may provide the greatest health benefits to those most severely injured or in rural areas where low traffic volumes would lead to longer reporting times for incidents involving incapacitating injuries.

The health benefits, however, are only one aspect of how ACN can benefit emergency response. Just as important for first responders and dispatchers is the accuracy of the location information provided, even in minor incidents or those not involving serious injuries. The GPS unit in an ACN system can automatically report the location of an incident and previous direction of travel with great accuracy. Automatic location information provided for 911 calls received over landlines is generally good, however, location data received from mobile phones can vary in accuracy. In 2014, approximately 70% of 911 calls were made using cell phones and in many jurisdictions less than half of cell phone calls to 911 resulted in the direct transmission of location data from the phone to the PSAP center. The Federal Communications Commission has set targets for improved cell phone location transmission to 911 centers, with at least 80% of calls covered by 2021, but inaccurate cell location information will likely remain an issue beyond that time.

While ACN systems have the potential to improve location information, they will ultimately rely on sufficient market penetration in private and commercial vehicles to have an impact. As more automated and connected vehicles enter the vehicle fleet it is likely that incident location issues will decrease, but this will depend on market acceptance more than any policy decisions by public agencies.

Video Detection and Verification

Many cities use sensor networks and incident detection algorithms to reduce the time to detect traffic incidents. While these can be effective, many small and mid-sized cities lack the resources to install and maintain extensive systems. For the Birmingham region and the state as a whole, the most promising technologies to reduce notification time and improve the accuracy of incident location data appear to be the combination of video surveillance and service patrols. Experience in other states has found that the combination of service patrols and video detection can reduce response times from 10%-20%, reduce total traffic incident duration by up to 12%-36%, and reduce lane blockage times by up to 25%. These reductions in response times also have been found to reduce the number of secondary crashes by 30%-50% according to FHWA figures. The costs of video detection systems are discussed in Section 2. The potential benefits of these time reductions for the Birmingham region are discussed in Section 4.

3.2. Impacts of Traffic Data on Vehicle Dispatch Choice and Response Times

Traffic incidents are among the major causes of traffic congestion and contribute to about 50 percent of total congestion delays *(47,49)*. Emergency management vehicles are important components of traffic incidents and emergency management systems. The response time of emergency vehicles, such as fire rescue, tow trucks, and police, are critical to the success of incident and emergency management. Emergency vehicle routing is a strategy that has the potential to reduce emergency vehicle response times.

3.2.1. Background

Emergency vehicle route selection depends on the availability of travel time information. In the absence of field measurements of travel time, travel time information can be obtained from travel forecasting models calibrated for the region. A simple travel time estimation method that is commonly used in these models is to utilize volume-delay functions, such as the Bureau of Public Roads (BPR) curve *(49,50)*, to estimate travel times based on free-flow speeds, demands, and capacities. Different levels of traffic simulation modeling can also been used to produce better estimates of travel times compared to demand forecasting model, with better consideration of traffic flow dynamics. Camille et al. *(51)* used VISTA, a simulation-based dynamic traffic assignment (DTA) model, to estimate travel times under incident conditions. The results confirmed that an effective traveler information system has the potential to ease the networkwide impacts of incidents. Huang and Pan *(52)* combined Geographic Information System (GIS), traffic simulation, and optimization methods to produce optimized incident responses. In their study, dynamic traffic information derived from micro-simulation models was imported to the GIS environment and combined with an optimization model. The case study results indicate that the proposed method can significantly reduce the response time of emergency vehicles.

Rich traffic data are increasingly becoming available with the rapid deployment of Intelligent Transportation System (ITS), including traffic data collected by point traffic detectors, vehicle identification technologies, automatic vehicle location (AVL) technologies, and data provided by private vendors such as INRIX, HERE, TOMTOM, and so on. The availability of real-world travel time data leads to a better understanding of network congestion, and thus can allow better routing of emergency vehicles to reach incident scenes.

There is a need to quantify the benefits of using traffic data collected by the ITS technologies for emergency vehicle route selection and to determine the value that this data can provide in this regard. This study will investigate this issue by conducting a comparison between the performances of emergency vehicle routing based on three different sources of data. The first is based on travel times estimated by regional travel forecasting models, representing routing scenarios with a minimal amount of available real-world data. The second is based on average travel times obtained from archived travel time datasets provided by a private sector travel time provider. The third is based on travel time data provided by the same private sector provider for the specific incident day to emulate routing based on real-time information.

3.2.2. Methodology

In this study, the required travel time data for each emergency vehicle routing strategy was first collected and processed. The optimal emergency vehicle route was then obtained using the ArcGIS Network Analyst (ArcGIS NA) function based on these travel times, and the performances of the resulting routes were compared. This section presents a detailed description of the approach used for the purpose of this study.

3.2.2a. Travel Time Estimation

The selection of the best route for emergency vehicles requires travel time estimates for all possible routes, from emergency management stations to incident locations. As mentioned earlier, three alternative sources are used in this study to obtain travel time estimates, as described below.

3.2.2b. Travel time estimates from the regional travel demand model

In travel demand models, vehicle trips are assigned to the network, and the resulting travel times for each link are estimated based on volume-delay relationships. The case study used in this paper is for a sub-network located in South Florida. The commonly used relationship in Florida regional travel forecasting models is the Bureau of Public Road (BPR) function, which relates the travel time to the link volume/capacity ratio as follows:

$$TT = FFT[1 + \alpha(\frac{v}{c})^{\beta}] \tag{47}$$

Where TT is the calculated travel time, FFT is free-flow travel time, v is volume, c is capacity, and α and β are model coefficients. In this study, the link travel times from the Southeast Regional Planning Model (SERPM) were utilized to support the first strategy to identify the optimal routes for emergency vehicles. As stated earlier, this represents a strategy that requires additional minimal real-world data.

3.2.2c. Archived travel time data

In this study, one year of traffic data from a private sector information provider (INRIX) was collected for the period between July 1, 2010 and June 30, 2011. The collected INRIX data include the measurements of speed and travel time for predefined segments aggregated at 5 minute interval. The average values of historical travel times, for the same time period and on the same day of the week as the incident day, are used in the second emergency vehicle routing strategy to represent routing based on archived ITS data.

3.2.2d. Real-time travel time data

The third emergency vehicle routing strategy investigated in this study is the utilization of travel time information collected in real time to calculate the best routes on-line. This is emulated in this study by using the INRIX travel time measurements for the exact time of the incident occurrence. For example, when selecting a response route for an incident that occurred on August 10, 2010 at 4:30 pm, the INRIX travel time in the same time period on that day is used as input to the optimal route selection step for emergency vehicles in the GIS environment.

3.2.2e. Travel Time Data Processing and Merging

After an initial examination of the collected INRIX data, it turns out that the INRIX data only covers a subset of the roadway links coded in the regional demand model SERPEM. The SERPM network for the case study is comprised of 14,165 links, and the INRIX data covers only 2,730 links. Roadway links such as ramps and less traveled streets are not included in the INRIX travel time database. As all of the link travel times are needed to build optimal emergency vehicle routes, the missing travel times that are not covered by the INRIX data are imputed in this study using the travel time estimates from the travel demand model.

3.2.2f. Emergency Vehicle Route Selection

Once the travel times for all of the study links are obtained, the Closest Facility solver, one of several routing solvers within the ArcGIS Network Analyst (ArcGIS NA), was used to search the optimal paths with the shortest response time for emergency vehicles. ArcGIS NA enables users to conduct a network-based spatial analysis, including routing, travel directions, closest facility, and service area analysis. Dynamic characteristics of the network, such as turn restrictions, speed limits, height restrictions, and traffic conditions at different times of the day can be modeled in ArcGIS NA.

In ArcGIS NA, the network is modeled as nodes (where roadway segments join, start or end) and links that connect these nodes. Each link is assigned an associated cost such as travel time. The Closest Facility routing solver within the ArcGIS NA finds the paths through a set of stops (including the origin, destination and intermediate nodes) with the minimum costs, based on the well-known Dijkstra's algorithm *(53)*. The classic Dijkstra's algorithm solves single-origin shortest path problem over a directionless and nonnegative weighted network. The classical Dijkstra's algorithm is further modified in ArcGIS NA for directional transportation networks with roadway constraints such as turning restrictions.

3.2.3. **Assessment of the Benefits of Using ITS Data**

A case study was used to assess the effectiveness of including ITS data in emergency vehicle route selections. The corridor that is covered by the emergency management system in the case study is Interstate 95 (I-95) in Miami, Florida. Figure 4 shows the location of the I-95 corridor and its surrounding network. Ten incidents that occurred along the I-95 corridor were used in this case study, including three incidents that occurred in the AM peak hours of weekdays, three incidents in the PM peak hours of weekdays and four incidents during the off-peak periods, as summarized in Table 4. To facilitate the discussion of the analysis results in the next section, each incident is given a short name, such as AM1, PM1 and MID1 as shown in the first column of Table 4. The locations of the incidents are shown in Figure 4. Three types of incident response agencies were considered in this study: police, towing company, and fire & rescue. A total number of 17 police stations, 10 towing companies, and 31 fire & rescue stations are located within the study area, based on the information provided by the traffic management center. The locations of these stations are also indicated in Figure 4. These station locations were input to the ArcGIS NA model.

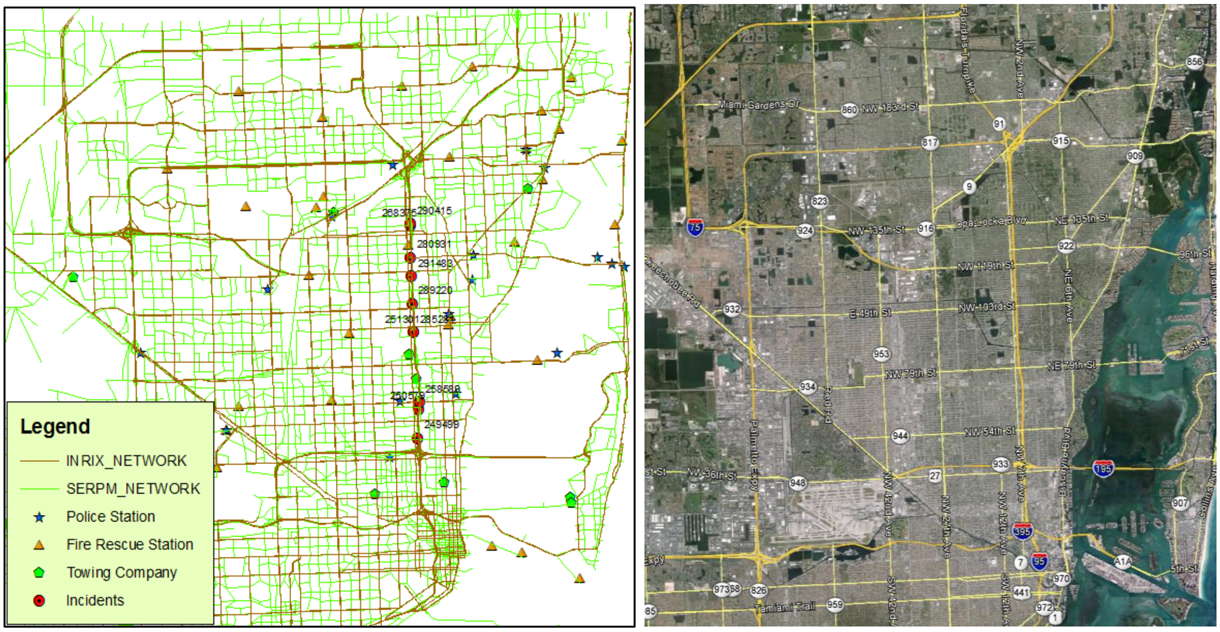

Figure 4. Locations of Study Corridor and Emergency Response Agencies

Table 4. Description of Selected Incidents

Index	Event ID	Day of Week	Period	Direction	Duration (min)	Blockage
AM1	280931	Tue	AM	NB	84	One of four lanes blocked
AM2	251301	Wed	AM	SB	97	Three of five lanes blocked
AM3	289220	Fri	AM	SB	64	One of five lanes blocked
MID1	249499	Sat	Off-peak	SB	170	Four of five lanes blocked
MID2	258589	Thu	Off-peak	NB	79	Two of four lanes blocked
MID3	250579	Wed	Off-peak	NB	50	Two of four lanes blocked
MID4	290415	Mon	Off-peak	NB	62	Two of four lanes blocked
PM1	291483	Tue	PM	NB	45	One of five lanes blocked

Index	Event ID	Day of Week	Period	Direction	Duration (min)	Blockage
PM2	285281	Mon	PM	NB	76	One of two lanes blocked
PM3	268375	Fri	PM	NB	99	One of two lanes blocked

Three strategies were investigated for each incident, which correspond to different levels of ITS data availability for emergency vehicle routing, as described earlier.

- **Strategy 1:** Emergency vehicle routing based on travel times from the regional travel forecasting model (the SERPM model).
- **Strategy 2:** Emergency vehicle routing based on archived ITS data. For this strategy, the historical INRIX data are calculated following the procedure described in the previous section.
- **Strategy 3:** Emergency vehicle routing based on real-time ITS data. It is assumed that for this strategy, INRIX travel time information is available in real time to emergency response agencies through various traveler information systems.

3.2.4. **Analysis and Results**

The performance of the three route selections strategies were analyzed and compared, in terms of the resulting emergency vehicle response route and time. The examination of the resulting routes from different strategies reveals that the same response route originated from the same response station is selected in most of the cases. However, in few cases, the identified optimal response routes are originated from different stations with different response routes, as shown in Figure 5. Also in few cases, different routes are selected from the same station by different strategies. The emergency vehicle response time is defined as the travel time that the emergency vehicle travels from its station to the incident site. As stated earlier, for strategy 2 and strategy

3, the INRIX data had to be supplemented with travel time estimates from the regional demand model. INRIX travel times for the same day that the incident occurred is used in Strategy 3 to emulate the use of real-time data. The results of Strategy 3 are used as the base for the comparison.

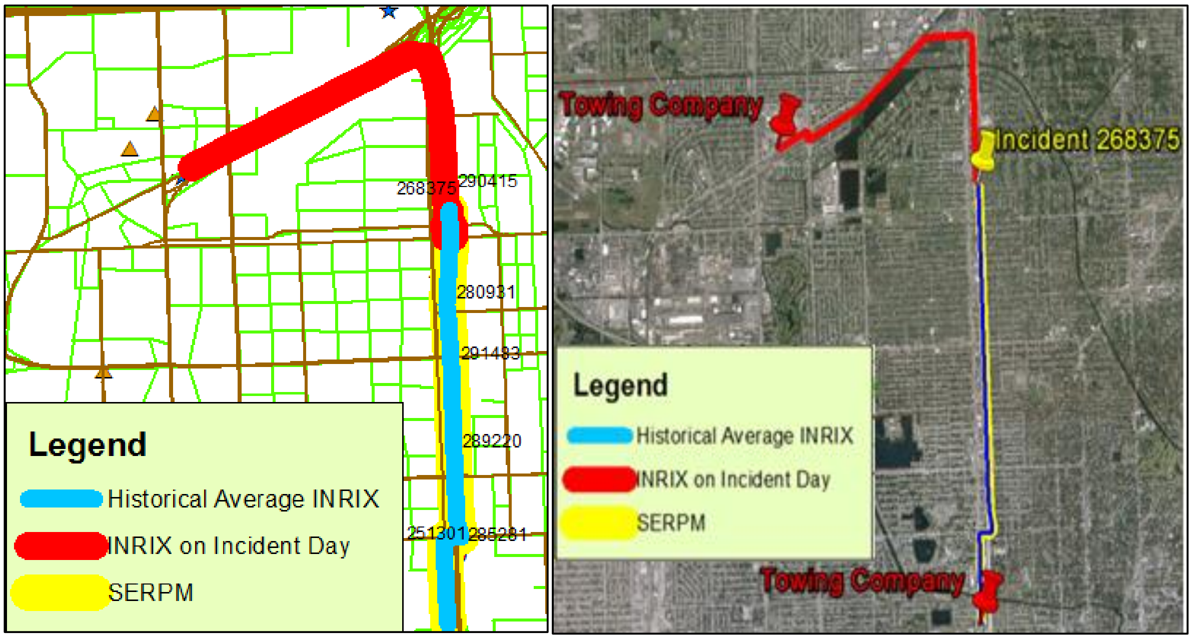

Figure 5. Example of Response Routes with Different Response Stations.

3.2.5. Emergency Vehicle Response Route Comparison

A total of 30 response routes and response station combination were found for the ten incidents and the three types of response agencies. Table 5 summarizes the emergency vehicle response route comparison results. As shown in Table 2, 23 out of the 30 response routes generated from Strategy 1 are the same as the routes obtained from Strategy 3. This number increases to 27 for Strategy 2. This indicates that the emergency response routes estimated from the historical travel time data are closer to the routes estimated from real-time travel time data, compared to those routes derived from the regional travel forecasting model. Also, as seen in Table 5, of the seven different routes resulting from Strategy 1 that are different from those selected by Strategy 3, three begin at the same response station but take different routes, and the remaining four begin at different response stations. Compared to Strategy 3, Strategy 2 produces three different routes, one of which begins at the same response station, and the other two routes begin at different stations.

Table 5. Comparison of Emergency Vehicle Response Routes

<table>
<tr><th rowspan="3">Strategy</th><th colspan="3">Strategy 3: Baseline (Real-time data)</th></tr>
<tr><th rowspan="2">Same Route</th><th colspan="2">Different Route</th></tr>
<tr><th>Generated from Same Station</th><th>Generated from Different Station</th></tr>
<tr><td>Strategy 1 (Demand model data)</td><td>23</td><td>3</td><td>4</td></tr>
<tr><td>Strategy 2 (Historical travel time data)</td><td>27</td><td>1</td><td>2</td></tr>
</table>

3.2.5a. Emergency Vehicle Response Time Comparison

Two comparisons were conducted in this study when assessing the emergency vehicle response times for the three routing strategies. The first comparison, referred to as Comparison 1, was based on the travel times estimated and used for each strategy. The second comparison of the routes from the three strategies, referred to as Comparison 2, was based on travel times estimated using INRIX data for the incident day under consideration. These two comparisons are meant to assess different aspects of the route selection. The first comparison is meant to find the difference in travel times estimated by different methods for the same selected routes. Thus, the comparison was only done for the incidents where all three routings identified the same routes. The second comparison is meant to show how different the route travel times actually are based on “ground truth” data, which are the incident day travel times, as used in Strategy 3. Comparison 2 was made one time for all 30 routes and one time only for the specific routes selected for Strategies 1 and 2 that are different from those for Strategy 3, which are seven and three routes, respectively.

Figures 6 to 8 present the results for the first comparison (using the same source of travel times used in the route selection) for the three response agencies: fire & rescue, towing company, and police, respectively. Note that the results in these figures are sorted by time of day, and the baseline strategy for the comparison is Strategy 3, that is, the strategy that emulates real-time travel times. As shown in Figures 6 to 8, for the same selected routes, the emergency vehicle response times as estimated based on historical average INRIX travel times are quite similar to the estimates based on real-time INRIX data. It can be also seen from these figures that the times based on the SERPM model in Comparison 1 are slightly different than the INRIX estimates during the AM and PM peak periods. However, there is up to one and a half times of overestimation during the midday period, which is a high percentage.

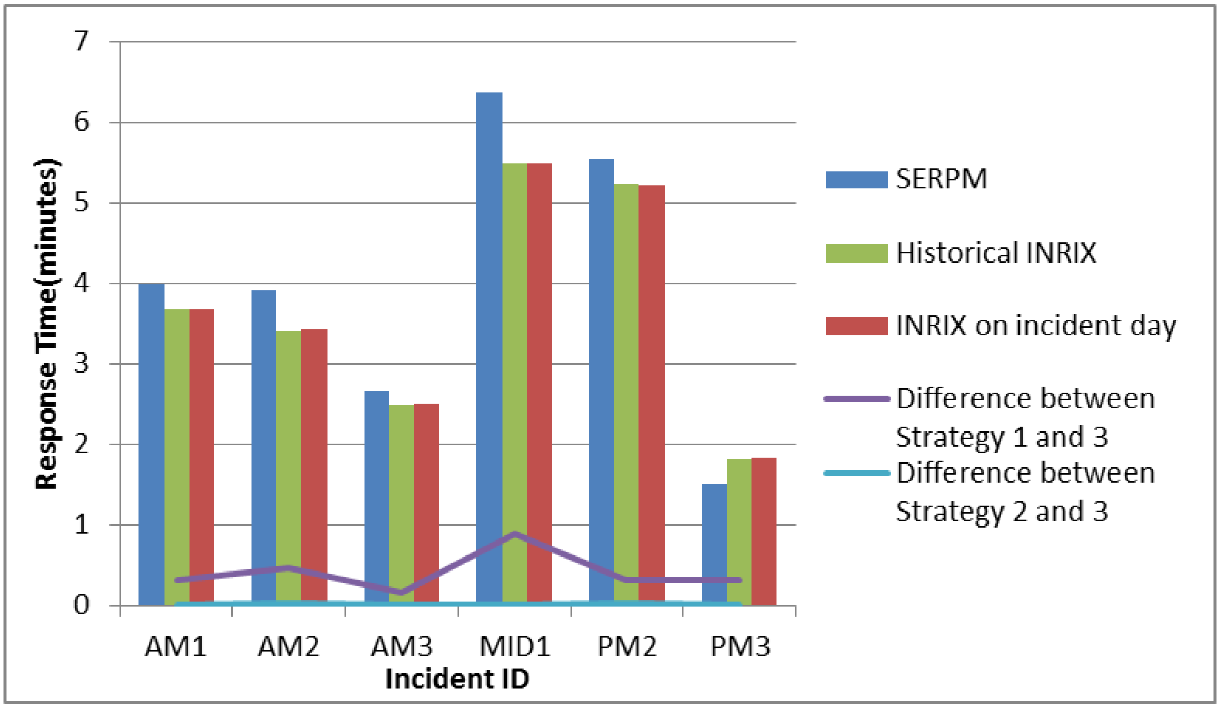

Figure 6. Response Time for Fire Rescue According to Comparison 1

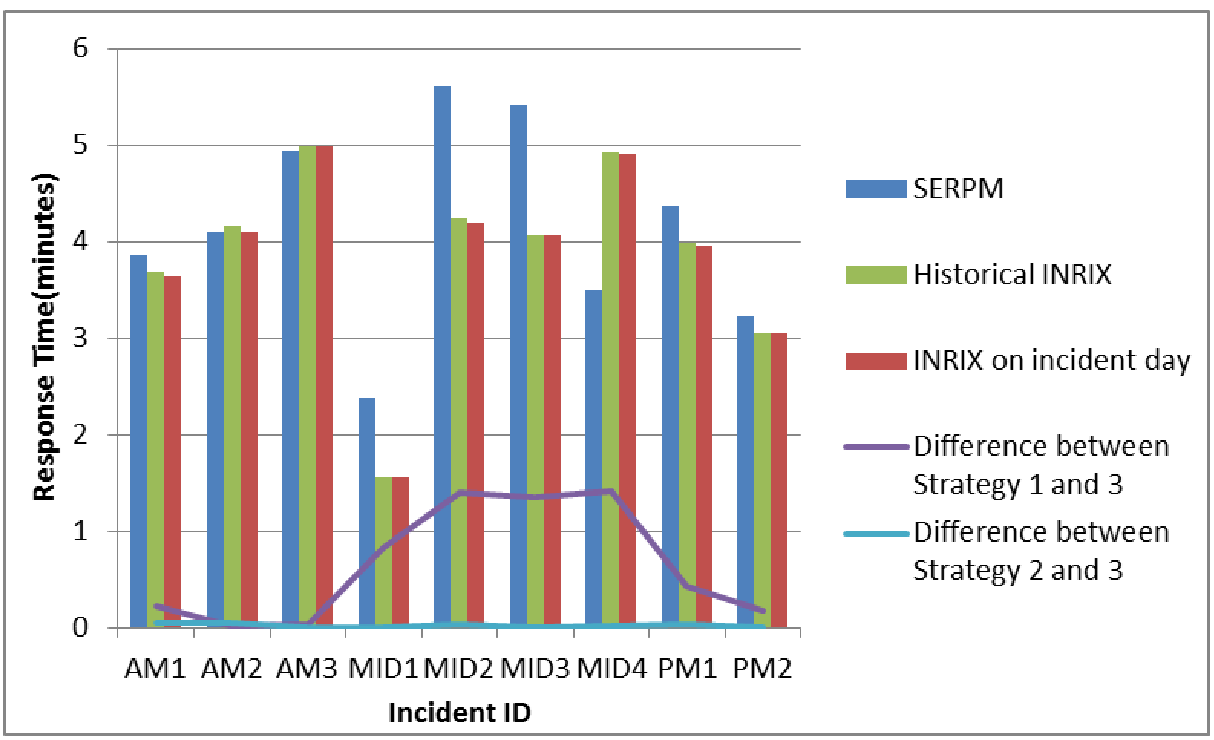

Figure 7. Response Time for Towing Vehicle According to Comparison 1

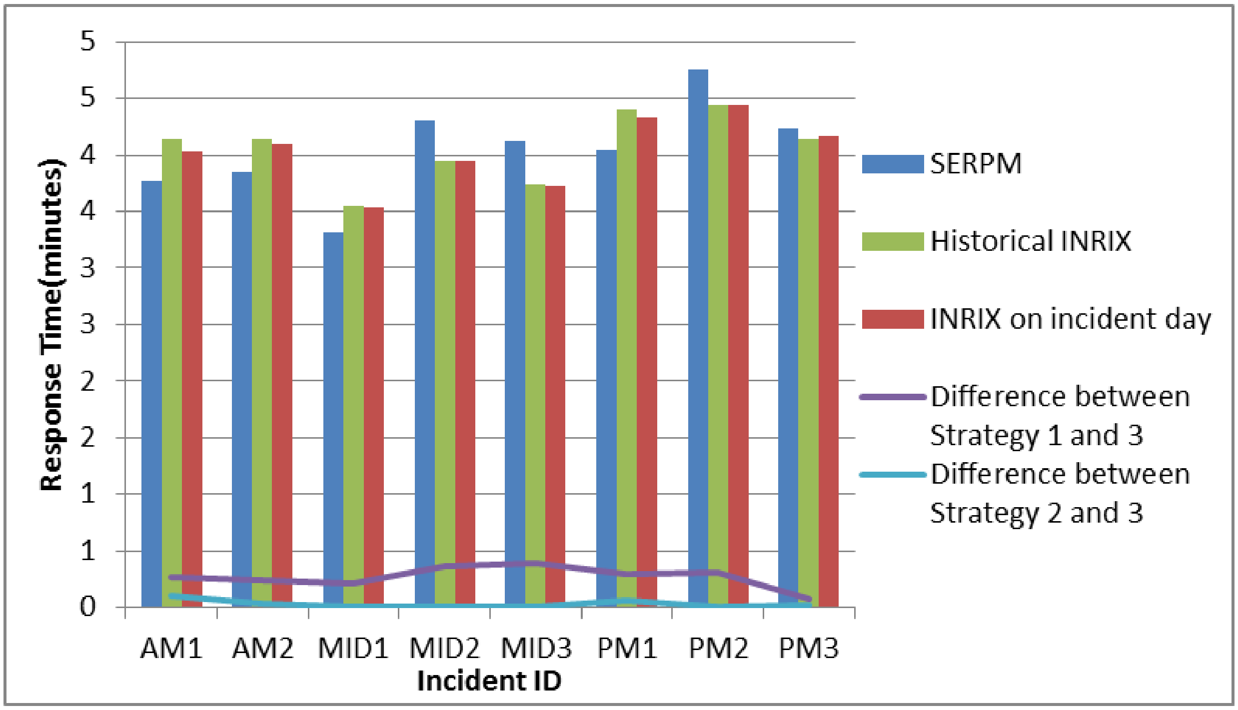

Figure 8. Response Time for Police According to Comparison 1

The second comparison (Comparison 2) results are presented in Figures 9 to 11. In this analysis, all of the response times are calculated using the INRIX travel time on incident days. It is seen from Figures 9 to 11 that the response times for most incidents are the same, particularly for those incidents occurring in the AM and PM peaks. This is because the routes for the majority of incidents identified by all three strategies are the same. As listed in Table 5, only seven of the incidents had different routes for Strategy 1, compared to Strategy 3, and only three incidents had different routes for Strategy 2, compared to Strategy 3. When comparing the travel times only for the routes that are different between the strategies, the results show a larger difference in the response times. Figure 12 shows the difference in the travel times only for the incidents that had different routes between Strategies 1 and 3. Figure 13 shows the difference in the travel times only for the incidents that had different routes between Strategies 2 and 3. From the results in Figures 12 and 13, it is noted that there can be a significant difference between the route travel times when comparing the results of strategies 2 and 3 (up to 1.5 minutes or 42 % in the case of the differences between Strategies 1 and 3 and up to 0.2 minutes or 2.5 % in the case of the differences between Strategies 2 and 3).

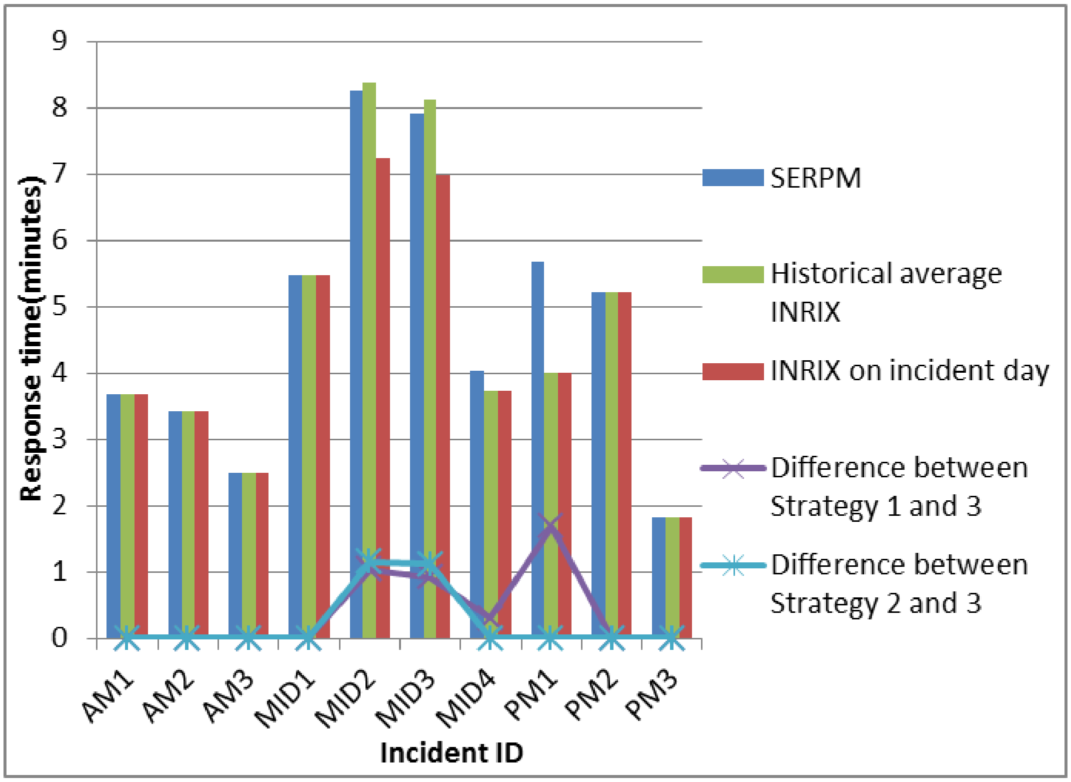

Figure 9. Comparison 2 of Response Time for Fire & Rescue

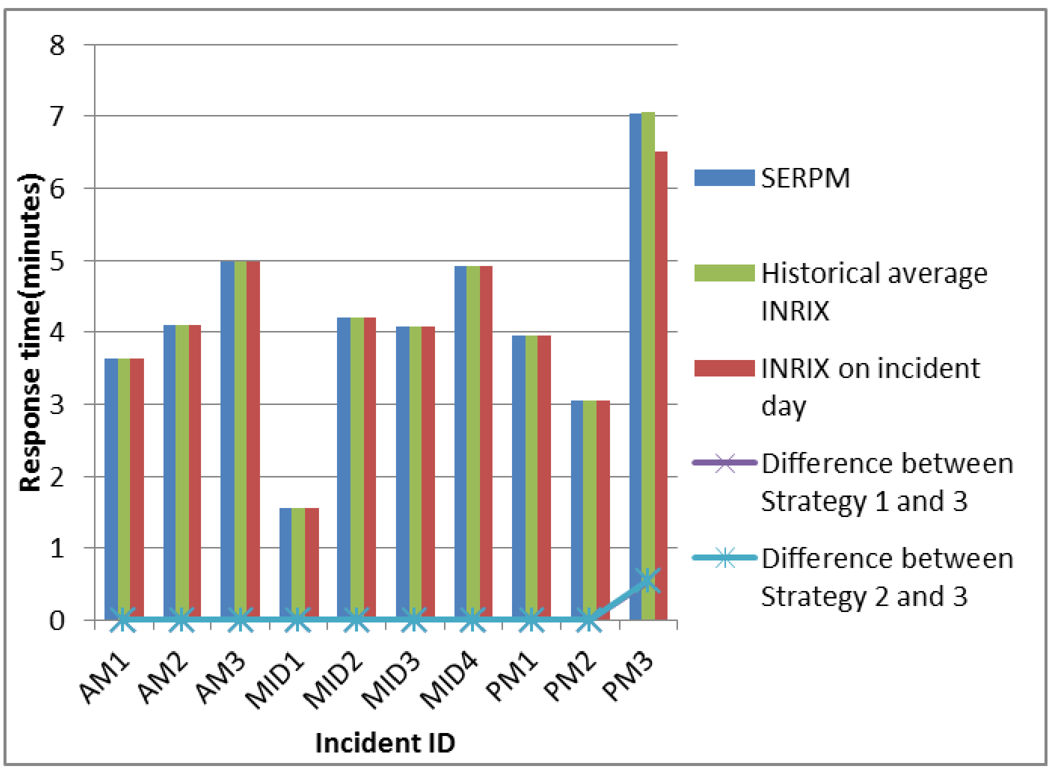

Figure 10. Comparison 2 of Response Time for Towing Company

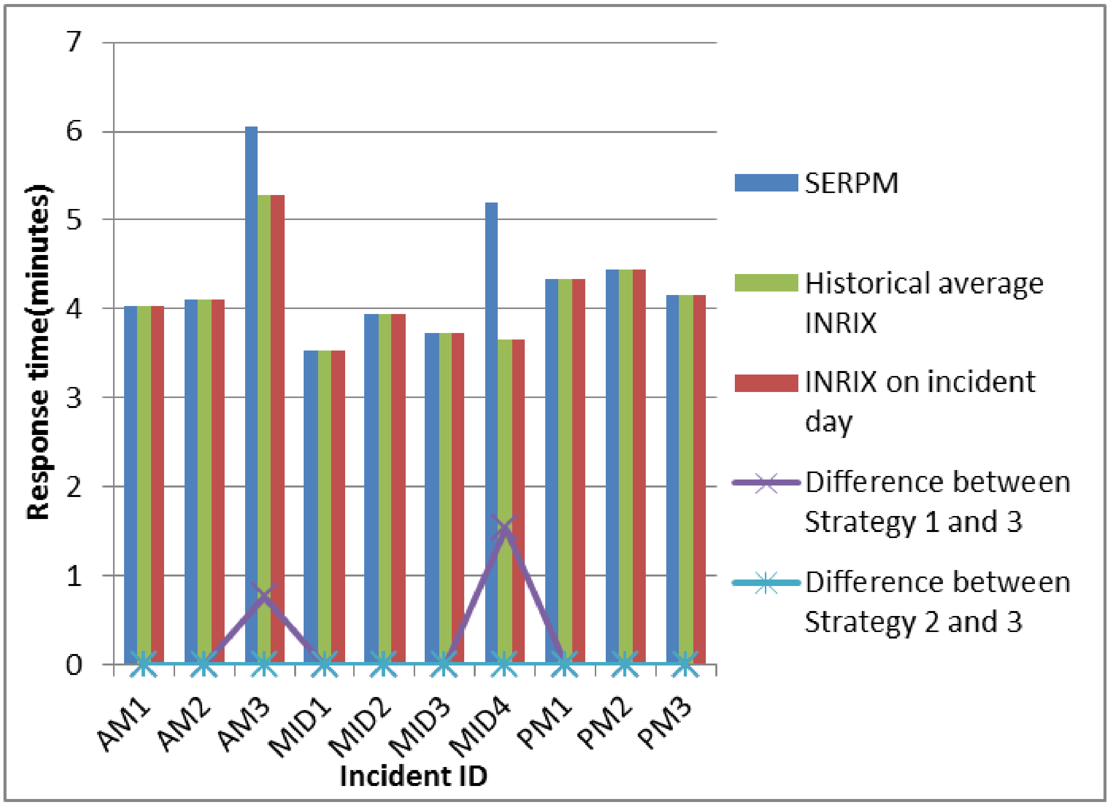

Figure 11. Comparison 2 of Response Time for Police

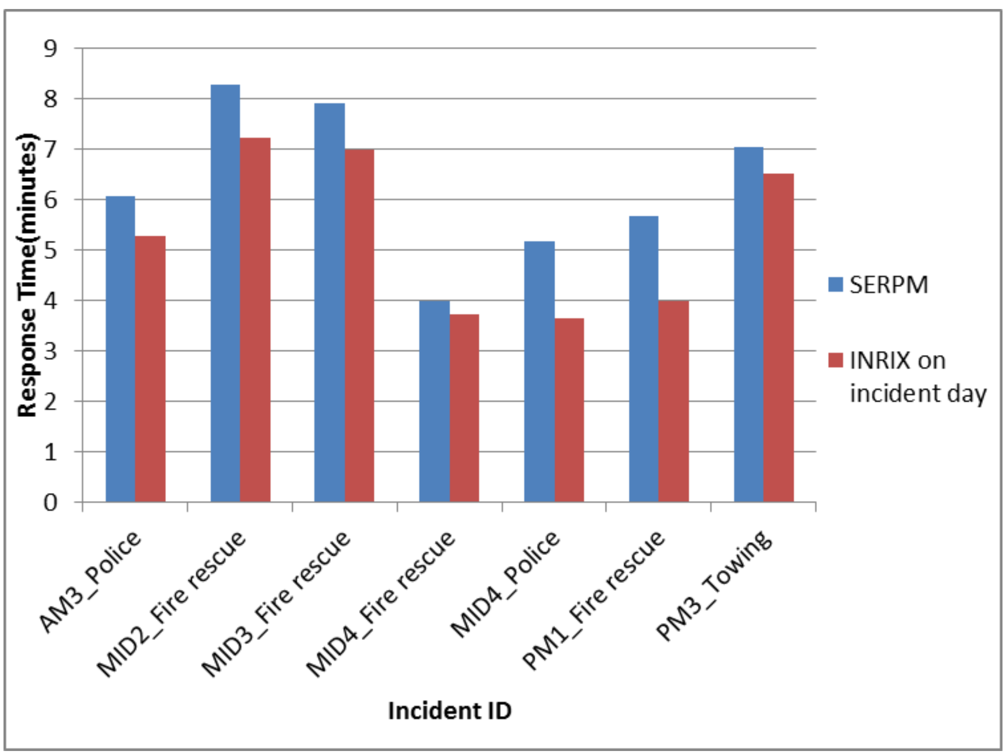

Figure 12. Comparison 2 of Different Response Routes between Scenarios 1 and 3

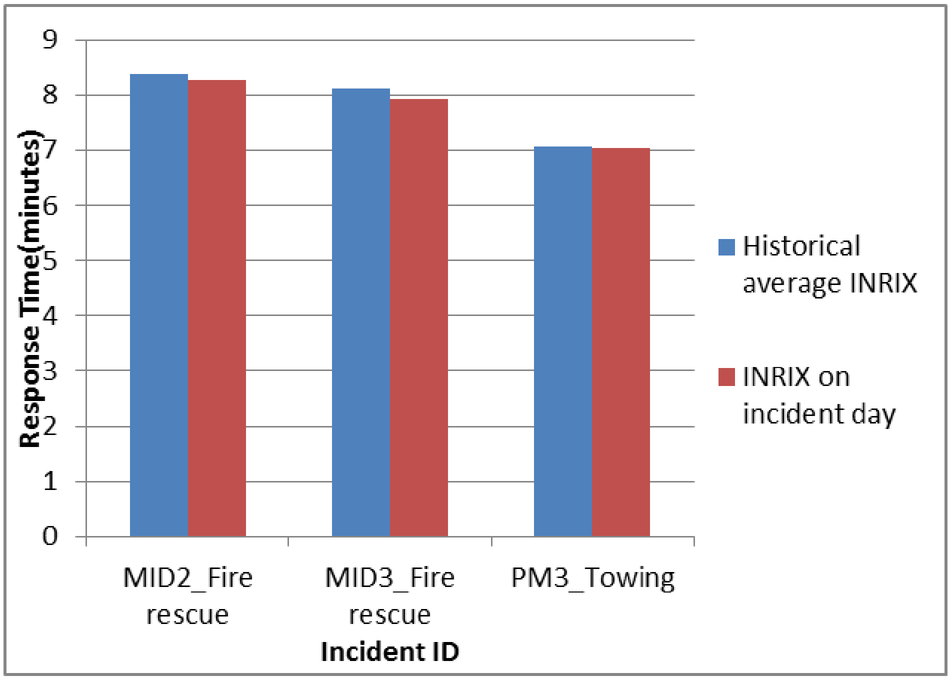

Figure 13. Comparison 2 of Different Response Routes between Scenarios 2 and 3

3.2.6. Conclusions – Unit Selection and Routing

In this study, a comparison was made of the use of various sources of travel time information in emergency vehicle route selection. An assessment of the effectiveness of these routing strategies was made by examining the estimated response routes and response times of the fire and rescue, towing, and police vehicles.

Based on the results of the case study used in this paper, it can be seen that for the majority of incidents, the routing based on all three data sources results in selecting the same routes, and thus in the same response times. However, the travel times from the travel forecasting model appear to overestimate the travel times by one to two minutes (which is 20% - 30% of the total response times), compared to the other two data sources, especially during the off-peak periods. There were no significant differences in the estimations of the travel times of the routes based on the historical data and real-time data for the case study incidents. The response times for the incidents, in which different routes were selected when using travel forecasting data instead of real-world measurements, could be 18.7% higher. Still only few of the optimized routes were different when using different travel time sources. This may reflect the smaller variations in the travel times between days in the data. Better data sources are expected to better detect these variations between days. The data obtained from the private sector provider was for the years 2010 and 2011. It has been stated by the provider that the quality of travel time estimation on arterials has improved significantly since then with the increase of probe vehicle sample size used as the basis for travel time estimation. Thus, newer real-world data with larger variations in travel times may show even more significant variations in the selected routes and thus the response times.

3.3. Emergency Response – Travel Time to Scene and Hospital

The survey of first responders conducted by McGwin *(61)* found that 40% believe traffic congestion frequently impacts response times. 40% also responded that they have had to request another unit be sent due to excessive delays from traffic congestion. Emergency response logs for October 2012 reveal that median times required for units to travel to an incident scene double during the morning peak hours and increase significantly during the PM peak period as well (Figure 14). A similar pattern can be seen when response times are broken down by urban and rural calls (Figure 15). Travel times to scene are typically longer for rural areas due to dispersed populations and greater distances to be covered by response units, however during the AM and PM peak periods travel times to scene are longer in urban areas.

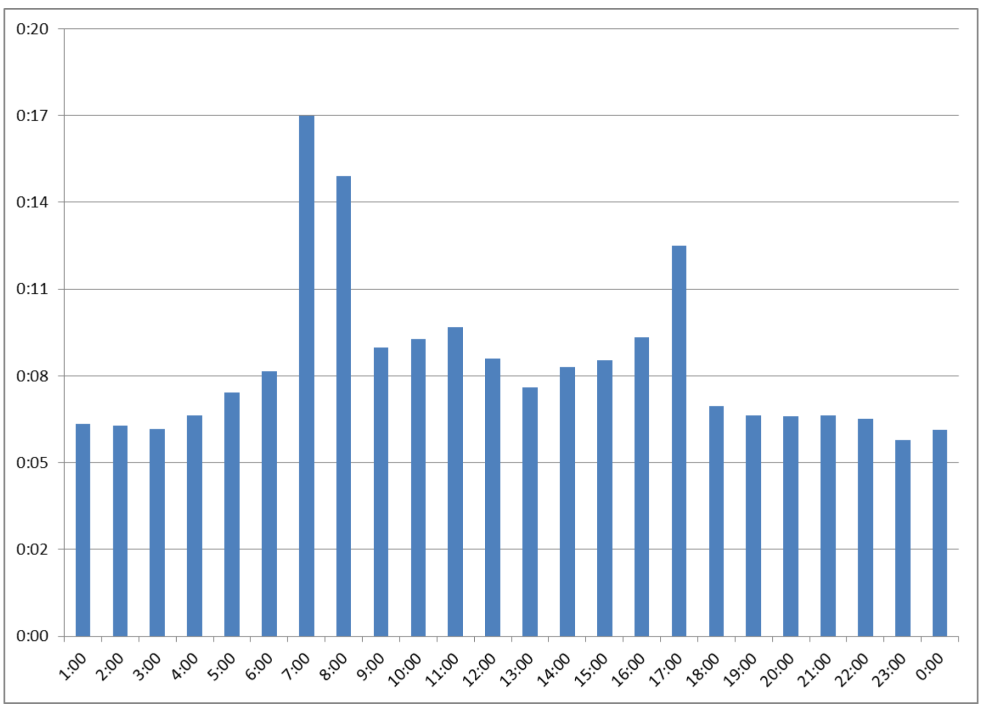

Figure 14. Median travel time to scene time by time of day (Jefferson and Shelby Cos., AL)

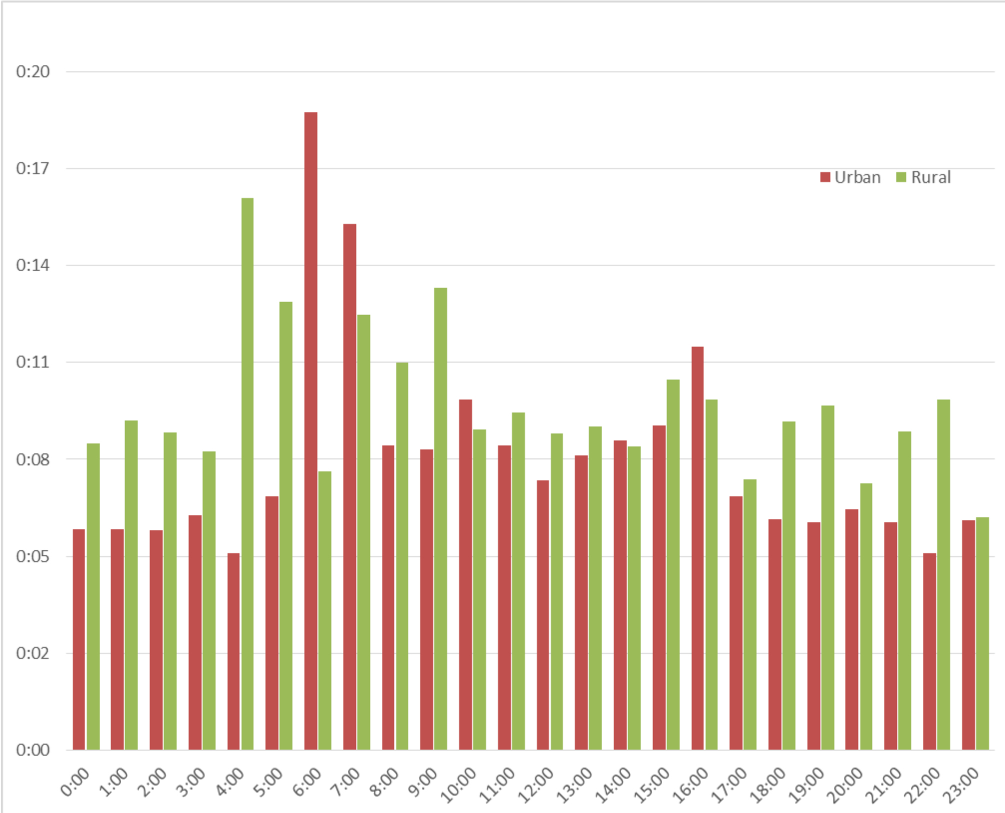

Figure 15. Median time to travel to scene, urban vs. rural (Jefferson and Shelby Cos., AL)

Similar patterns can be seen in the data for transport times to the hospital. The average time for patient transport to the hospital (15:35) was 58% longer than the average travel time to scene (9:43), as would be expected since response units are typically dispatched according to proximity to the incident but must travel to a limited number of hospitals that tend to be closer to urban centers. The data suggest that meaningful time savings can be achieved during the travel to scene and patient transport phases.

In-vehicle GPS systems with real-time traffic are available to emergency units and can provide optimum routing to the driver, however as the unit nears the hospital it becomes constrained by fewer available approach routes. 80% of Alabama first responders surveyed stated that they find emergency vehicle pre-emption (EVP) at traffic signals to be an effective means to reduce travel times, but that they are not as widely deployed as they would wish. Given the investment required for EVP, it make most sense to give priority to signal systems on major approach routes to hospitals.

Conventional EVP systems, and the types currently in the vicinity of Birmingham hospitals, activate each traffic signal in sequence as the emergency vehicle approaches. Studies have shown these types of systems can reduce travel times for emergency vehicles by up to 25%. However, under congested conditions the effectiveness of EVP can diminish. The emergency vehicle can create a “snowplow” effect in heavy traffic that reduces the effectiveness of signal pre-emption systems. An alternative type of pre-emption activates an entire signal system in a timing pattern that clears the path for the emergency vehicle as it approaches. The system would have pre-programmed signal timing plans that could be activated either by a driver or by a control center at the request of a driver. This type of system can operate effectively over short systems of a few signals, where it can be assumed that an emergency vehicle will pass through each signal in sequence, but operation becomes more difficult over larger systems where the entry point of the emergency vehicle is unknown. Such a system must be able to account for entry of an emergency vehicle at any point in the system and activate only those signals in the system remaining on its path. The study examined the effectiveness of such a system compared to a conventional EVP system on a test corridor in Birmingham.

The U.S. Highway 280 corridor east of Birmingham was chosen as a test corridor because it is a heavily congested arterial that serves as the primary access to a large population center southeast of Birmingham. Emergency vehicles traveling from this area to any of the major hospitals downtown must use this route. It was modeled using CORSIM to evaluate different pre-emption schemes. CORSIM 6.3 software was selected for this modeling due to its advanced capabilities to model the behavior of emergency vehicles using lights and sirens and different levels of aggressiveness in driving practices.

The study corridor spanned over 9 miles and included 26 signalized intersections. While long, it is the route that emergency vehicles from this area would need to travel in order to reach downtown Birmingham, the location of the only level one trauma center in the region. The corridor experiences congestion during many portions of the day but the westbound congestion into downtown is most pronounced during the AM peak period (7:00-8:00 AM). The AM peak hour was chosen for the simulation period.

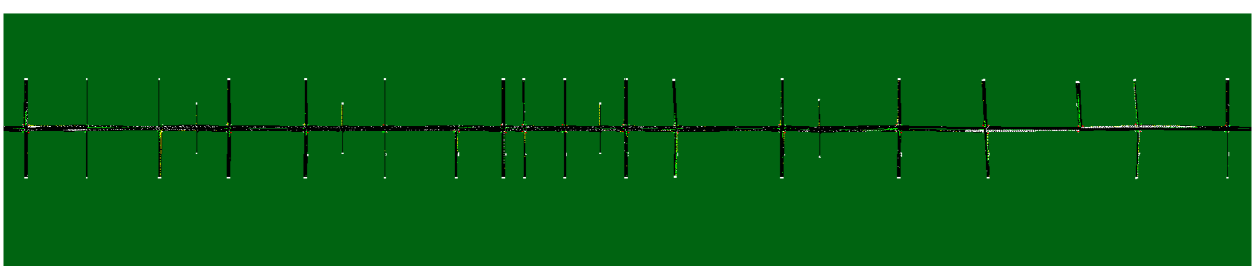

Figure 16. Portion of the U.S. Highway 280 CORSIM network

Three scenarios were modeled during the AM peak hour: an emergency vehicle traveling the corridor using conventional lights and sirens, an emergency vehicle traveling the corridor using lights and sirens and convention EVP, and an emergency vehicle traveling the corridor with lights and sirens and using an advanced path clearing system pre-emption.

CORSIM 6.3 allows parameters such as pre-emption detection distance and driver behavior parameters to be coded into the model. In this case, detection distances were assumed to be 1200 feet and moderate driver aggressiveness factors chosen. Some driver behaviors, such as driving in opposing travel lanes, were prohibited because US 280 is median divided and traffic volumes are generally heavy. An optimized timing plan was developed for the third scenario. The simulations indicated that during peak periods, conventional EVP reduced travel times through the corridor by 11% over lights and sirens alone. The activation of a path clearing pre-emption system could reduce travel times through the corridor by up to an additional 6%. One limitation of this simulation was that it only considered emergency vehicles traveling from end to end and did not consider intermediate entry or exit into the system. However, it indicates that the use of path clearing timing plans could reduce travel times in the case of severe trauma. It is likely the system could operate under conventional EVP during off-peak periods or in cases of non-severe medical conditions. System activation could be limited to severe medical conditions as it has a disruptive impact on traffic moving in the opposite direction or from side streets.

4. IMPACTS OF REDUCED RESPONSE TIMES ON TRAFFIC CONGESTION

4.1. Impact of Incident Clearance Time on Congestion

On a system-wide scale, congestion resulting from vehicle crashes or other incidents can account for 25% or more of all roadway congestion. Technologies and procedures that can reduce the time it takes to clear an incident can therefore have significant impacts on congestion and delay. The magnitude of congestion resulting from any individual roadway incident of course depends on a number of factors: the number of lanes blocked and the number of lanes available, prevailing traffic volumes, incident duration, and route diversion capabilities among others.

This study sought to examine the impacts of incident clearance times on a section of interstate in the Birmingham, AL area. We looked at I-65 in Jefferson and Shelby Counties for one month (April) in 2016. The goal was to determine the total amount of crash and incident-related congestion on that segment of interstate during the month and what the theoretical reductions could be achieved if incidents could be cleared a certain percentage more quickly.

Incident 1 – April 1, 2016 (I-65 NB), Property Damage Only

Travel time data for I-65 was available at 5-minute intervals for the entire month of April 2016. Using a standard normal deviate algorithm developed for the analysis, the data were analyzed to identify instances where travel speeds dropped significantly below normal levels for any given time of day. Deviations from historic norms for any given time period were plotted and reviewed in order to identify significant traffic incidents. Incidents were then checked against the Alabama CARE crash database to correlate the disturbance with a known crash report.

An example incident occurred on April 8, 2016 in the northbound lanes of I-65 near milepost 252. The incident was a crash involving two pickup truck/SUV type vehicles (vehicle 1 rear-ended vehicle 2). No injuries were reported and there was no transport of persons to the hospital. The exact number of lanes blocked could not be determined from the accident records, but the congestion plot for the affected highway links based on the travel time data is shown in Figure 17. The incident is estimated to have occurred at about 3:45 PM. Police records indicate that emergency responders arrived on scene after approximately 10 minutes. Within 15 minutes of the crash occurrence abnormal congestion was already being experienced several miles to the south. After 60 minutes, crash related congestion was detected over 5 miles to the south on I-65 as well as on adjacent segments of I-459.

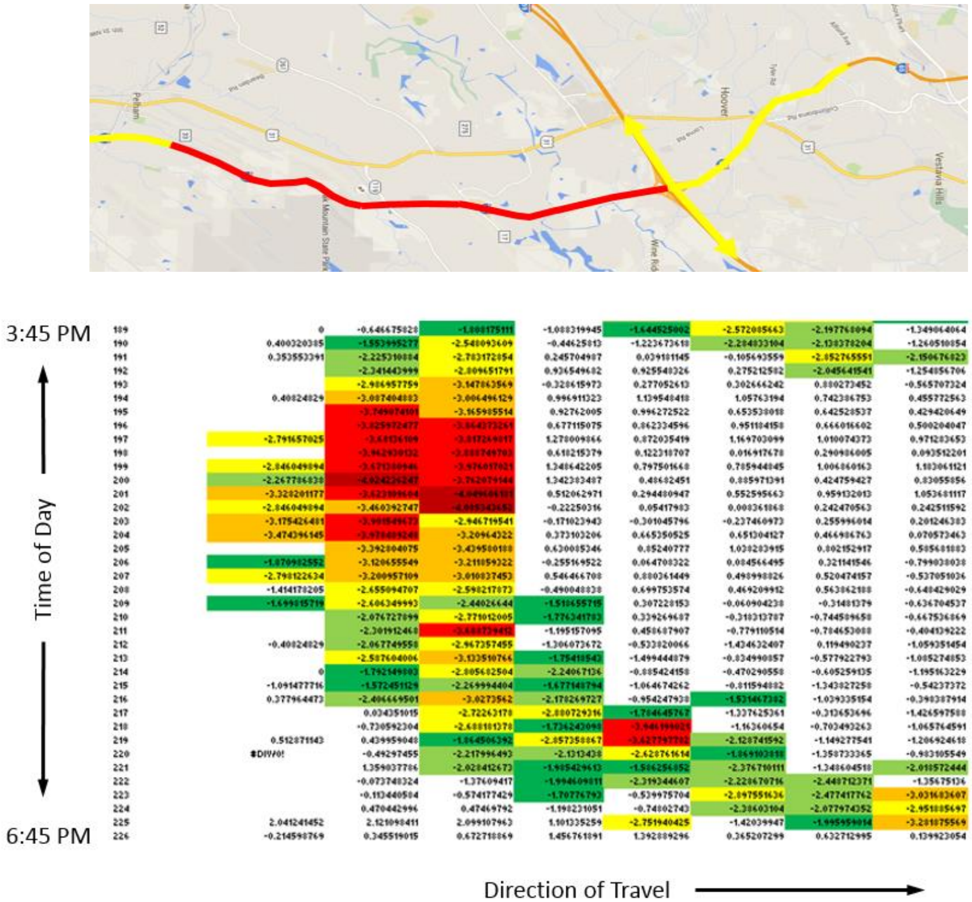

Figure 17. Incident 1 Congestion on Affected Segments (I-65 NB)

Travel speed data and police records indicate that emergency crews began removing the vehicles from the scene at approximately T+80 minutes and that the scene was completely cleared at T+100 minutes. At this point congestion began to “spill forward” to segments of I-65 north of the crash scene as queued traffic was released. Abnormal congestion was detected on interstate segments north of the crash scene for the next 80 minutes, with the last traces of crash related congestion being detected 180 hours after the initial incident took place.

Total vehicle-hours of delay caused by the crash were estimated by using the travel speed data and comparing it to historical speed data for the same links. Total crash-related congestion on interstate segments alone was estimated to be 2620 vehicle-hours. This is greater than the amount of vehicle delay that occurs over these same segments during the PM peak period, representing a more than doubling of total vehicle delay. This is also almost certainly an underestimate of total delay caused by this crash as it does not take into account delays on secondary roads near interchanges and additional delay on other routes created by diverting vehicles.

A plot of 5-minute vehicle delay and cumulative vehicle delay for Incident 1 is presented in Figure 18. The crash clearance point is shown at T+100, as well as estimated delay curves for crash clearance times 15, 30, and 45 minutes earlier. In this case, it is estimated that earlier incident management would have reduced total vehicle delays by the amounts shown in Table 7. In this example, reducing the total response and on-scene time from 100 minutes to 70 minutes would have reduced total vehicle delay by approximately 29%. This time reduction could be achieved through any combination of reductions in notification time, time to scene, and time on scene.

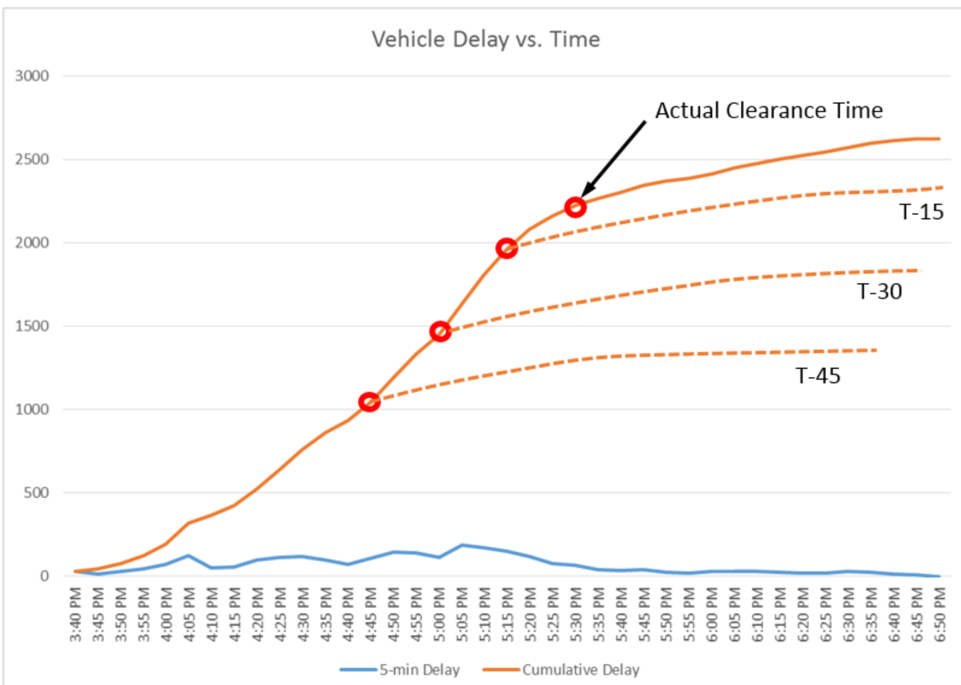

Figure 18. Estimated Vehicle Delay for Earlier Clearance Times (Incident 1)

Table 7. Estimated Delay Reductions for Earlier Clearance Times (Incident 1)

Clearance Time Reduction (min)	Total Delay (v-hr)	Delay Reduction (v-hr)
0 (actual)	2620	-
15	2350	270 (10.3%)
30	1850	770 (29.0%)
45	1400	1220 (46.5%)

Incident 2 – April 8, 2016 (I-65 SB), Personal Injury and Secondary Crash

The second incident occurred at 7:00 AM near mile post 254 in the southbound lanes of I-65. The two vehicle crash involved an incapacitating injury with one person being transported to the hospital. EMS logs indicate that police arrived on the scene within 5 minutes of accident occurrence and an ambulance arrived within approximately 15 minutes. Though the crash occurred during the morning peak period, the segment of I-65 SB where the incident occurred does not normally experience congestion during that time. Congestion levels for affected segments of I-65 SB are shown in Figure 19.

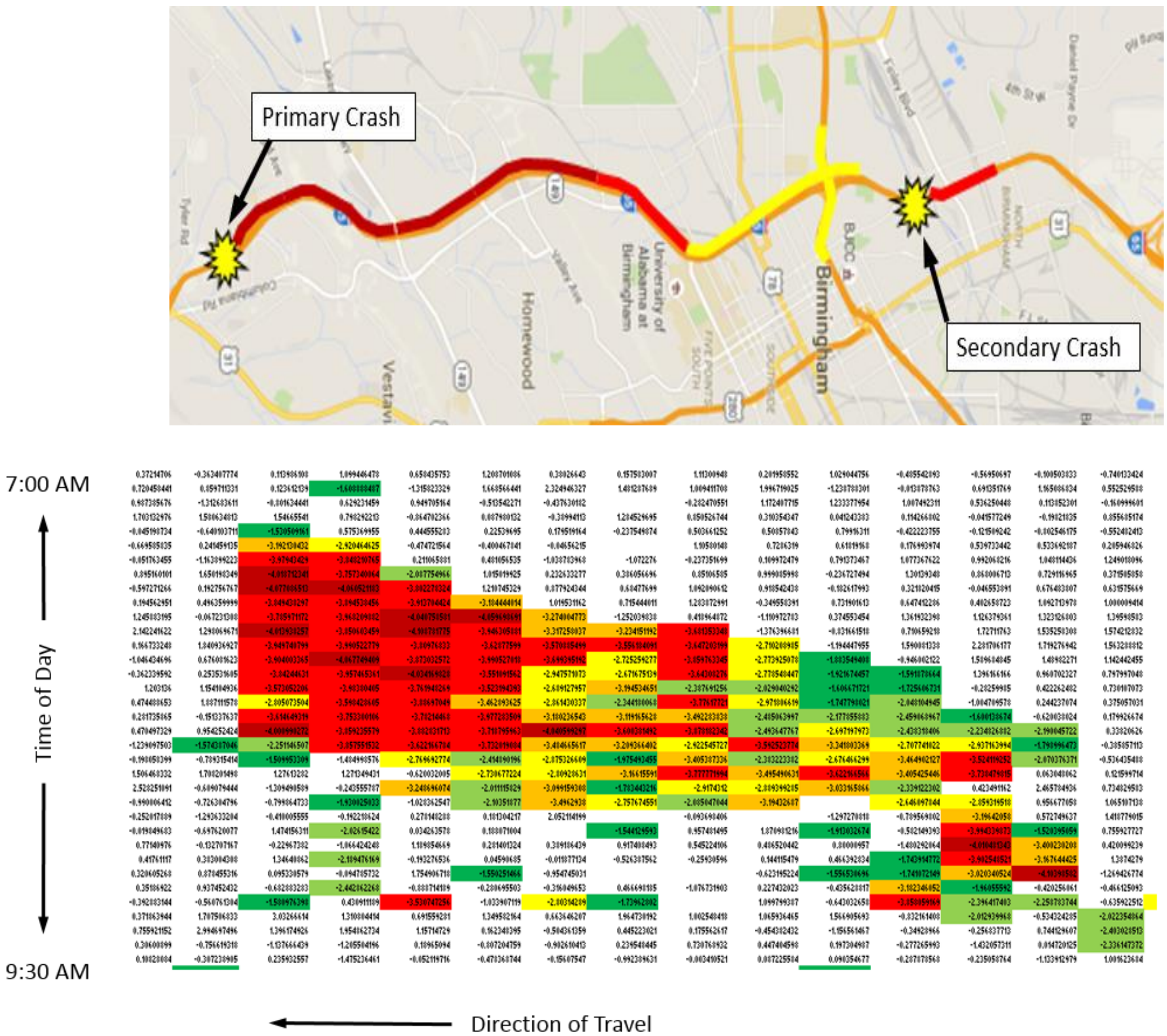

Figure 19. Incident 2 Congestion on Affected Segments (I-65 SB)

The incident is estimated to have occurred at 7:00 AM. The number of lanes closed could not be determined from records but within 60 minutes of crash occurrence congestion was detected nearly 8 miles upstream, stretching back to the I-20/59 interchange and onto adjoining segments of I-20/59. EMS records and speed data indicate that the accident was cleared at approximately T+75 minutes, at which point congestion was detected north of the I-20/59 interchange as far back as Finley Blvd. At T+90 minutes the congestion was still dispersing along the vehicle queue.

At T+105 minutes a secondary crash occurred at the back of the congestion queue near milepost 262. This was a two vehicle, property damage only crash in which one vehicle rear-ended another. By T+115 minutes the queue from the secondary crash extended north of Finley Blvd. The secondary crash was cleared at T+135 minutes and all congestion had dissipated by T+150 minutes. Total vehicle delay resulting from the primary and secondary crashes was computed based on measured vehicle speeds and historical speed data for the affected segments using the same standard normal deviate approach and is shown in Figure 20.

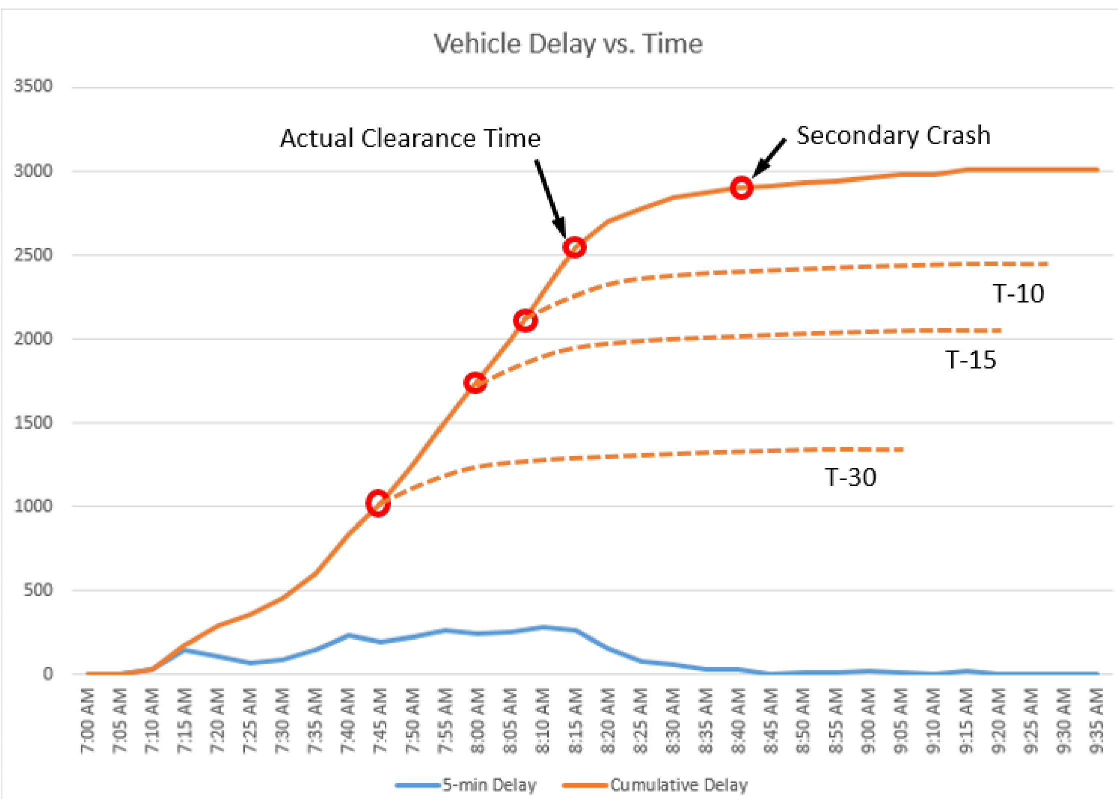

Figure 20. Estimated Vehicle Delay for Earlier Clearance Times (Incident 2)

Table 8. Estimated Delay Reductions for Earlier Clearance Times (Incident 2)

Clearance Time Reduction (min)	Total Delay (v-hr)	Delay Reduction (v-hr)
0 (actual)	2997	-
10	2470	527 (18%)
15	2050	947 (31%)
30	1380	1220 (46%)

Estimated reductions in incident induced delays are shown in Table 8 for 10, 15, and 30 minute intervals. A reduction in the total time from incident occurrence to incident clear of just 10 minutes would have resulted in a reduction in total vehicle delay of 18%. A reduction of 15 minutes would have resulted in a total reduction in vehicle delay of over 30%. Either reduction likely would have eliminated the secondary crash that occurred at T+105 minutes. The two incidents illustrate that for highway incidents which occur either during peak periods or result in substantial lane blockages even small reductions in the total response and on-scene time can have significant impacts to motorists caught in the resulting congestion.

Using similar methodology, we reviewed traffic data for the entire month of April 2016 for I-65 in Jefferson and Shelby Counties. We identified major traffic incidents that occurred during the AM and PM peak periods, since these were most likely to result in significant congestion. A summary of key incidents are summarized in Tables 9 and 10.

Table 9. Major Emergency Incidents – I-65 Northbound, April 2016.

Date	Peak Period	Severity	Duration (hrs)	Delay (veh-hr)
4/1	PM	High	3.00	2622
4/4	AM	Med	1.50	894
4/5	AM	Med	1.75	1614
4/7	AM	High	2.00	2644
4/8	PM	High	2.25	3010
4/11	PM	High	2.00	2405
4/11	AM	Low	2.00	448
4/18	AM	Low	0.75	39
4/20	AM	Low	0.75	640
4/22	PM	Med	1.25	457
4/26	AM	Med	1.00	346
			Sum	**16268**

Table 10. Major Emergency Incidents – I-65 Southbound, April 2016.

Date	Peak Period	Severity	Duration (hrs)	Delay (veh-hr)
4/1	AM	Med	1.50	1197
4/1	PM	High	1.50	2679
4/5	PM	Low	1.00	430
4/6	PM	High	1.50	2706
4/8	AM	High	3.00	3031
4/8	PM	Med	1.25	569
4/11	AM	Med	1.50	387
4/13	AM	Low	0.75	150
4/13	PM	Med	0.75	728
4/15	PM	Med	1.00	279
4/18	PM	High	1.25	3098
4/19	AM	Med	0.75	758
4/20	PM	Med	1.5	620
4/22	AM	Low	1.5	368
4/22	PM	High	0.75	3258
			Sum	**20744**

A total of 61,260 veh-hrs of non-recurrent delay were estimated for I-65 during the month of April 2015. Of this delay, 52% was directly related to the incidents listed in the tables above. The remaining non-recurrent delay was due to weather, construction, and minor roadway incidents. Examining the incidents above we estimated the reduction in congestion delay that would have resulted if total incident response times had been reduced by just 5 minutes, 10 minutes, and 15 minutes. This includes the entire emergency response time from notification to clearing the scene.

It was estimated that reducing total emergency response time by just 5 minutes at each of these 26 incidents would have reduced crash related delays by 9-11%, or by nearly 4,000 vehicle-hours for the month of April. Reducing overall response times by 10 minutes at each of the 26 incidents would have reduced overall incident related delays by 7200 vehicle-hours during April. Reducing emergency response times by 15 minutes at each of these incidents would have eliminated over 11,000 vehicle hours of delay. It would also have prevented several secondary crashes.

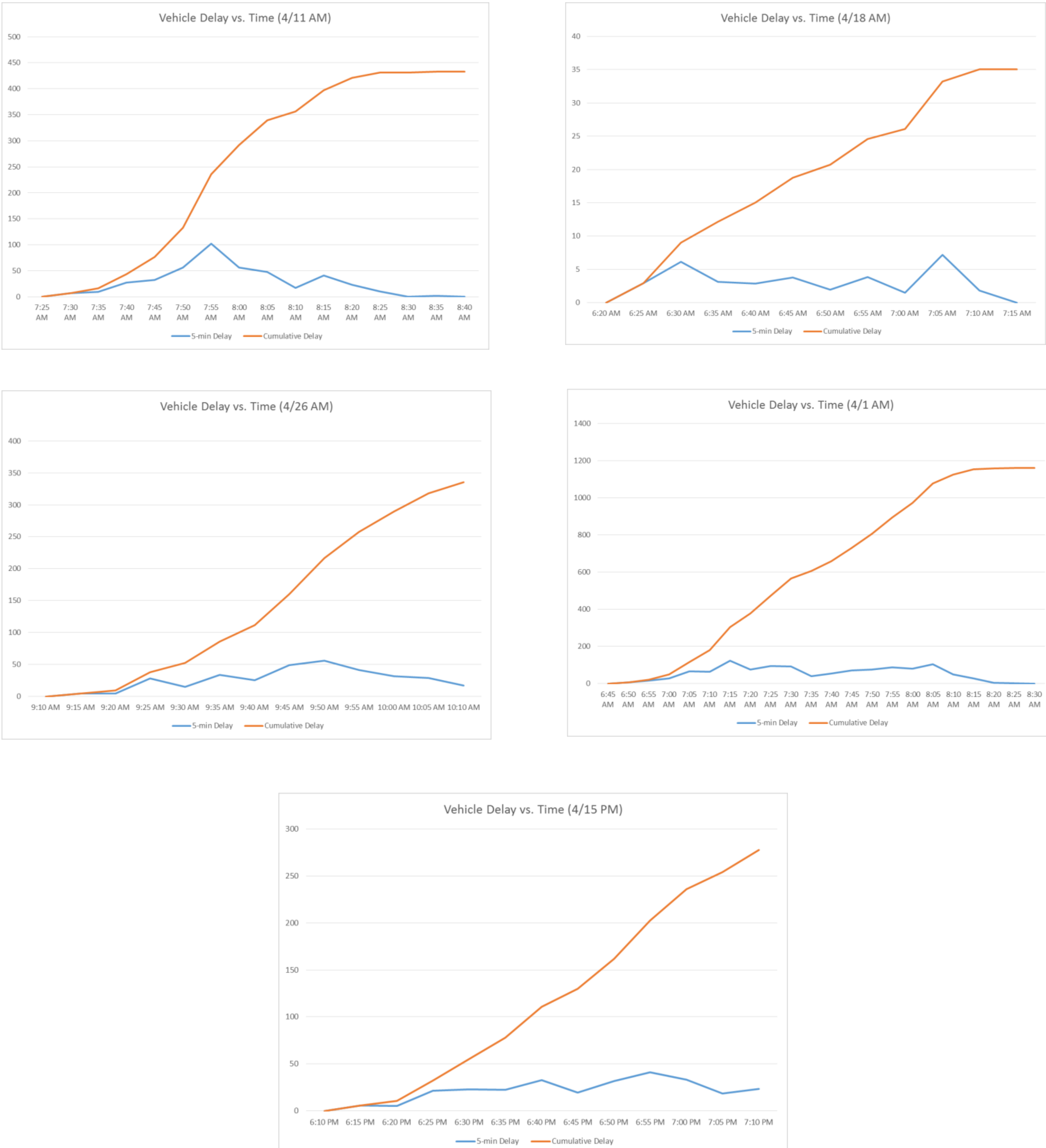

Figure 21. Cumulative delay estimates for selected traffic incidents on I-65.

The delay estimates listed above were for the most serious incidents identified through analysis of travel time data. The 26 incidents listed contributed to over half of all non-recurrent delay experienced on that portion of I-65 during that month. They represent, however, only a small percentage of total incidents that occur during a typical month. We obtained one month of service patrol logs from the Alabama DOT for this same segment of I-65 in Birmingham. The Alabama service patrol responded to a total of 1039 service calls along this stretch of I-65 during the month of April 2012. Of those, 126 incidents involved a lane closure while the remainder involved responding to incidents on the shoulder or away from the travel lanes.

Table 11. Average Duration of Traffic Incidents (minutes) on I-65 (April 2012)

Number of Lanes Blocked		
1	**2**	**3**
26.7	38.5	53.2

The times in Table 11 represent only the times that the service patrol was on scene and do not include notification, dispatch, or travel times to scene. They also encompass the full range of lane blockage incidents that can occur, from debris in the roadway blocking a single lane and requiring a “clearance” time of only a few minutes, to vehicle crashes blocking multiple lanes and having clearance times exceeding one hour. Nonetheless, these numbers indicate that even for single lane blockages the duration can be significant and thus the potential for reductions in delay is also significant.

5. CONCLUSIONS AND RECOMMENDATIONS

The study built on previous work performed at UAB related to emergency response and the potential benefits of ITS technologies. Interviews and surveys of first responders and emergency dispatchers in the State of Alabama identified several of priority areas where they felt emergency response could be improved. These areas specifically related to improving the accuracy of incident reporting and incident location information, incorporating traffic information into the dispatch process, and making better use of available signal pre-emption technologies. While ITS technologies have been employed to significant degrees in many cities, much of Alabama, and specifically rural areas, have little ITS technology deployed to address these concerns. Added to these was the congestion management goal of reducing overall response times in order to minimize resulting congestion.

The study looked at records for both traffic and non-traffic related incidents. The accuracy of incident location information was cited as a significant issue for both types. The Birmingham region has a fairly comprehensive video camera system deployed on its interstate routes and on a few state highways. Like many small to medium sized metropolitan areas, however, deployment of cameras is limited beyond these primary routes. Reviews of programs in other states indicates that expanding the coverage of the video surveillance system would be the most effective way to confirm the accuracy of traffic incident reports and incident locations. Analysis of Birmingham traffic data indicates that even relatively small reductions in total incident response time achieved through the use of video surveillance would likely result in significant reductions of total vehicle delay.

When surveyed, the majority of emergency dispatchers said that they did not consider traffic conditions when selecting a unit to dispatch. This study evaluated the effectiveness of using three different types of traffic data in the dispatching process: planning model travel times, historical travel time data, and real-time travel time data. Our analysis found that in the majority of cases all three data sources resulted in the same unit selection and recommended routing to the incident. In a small portion of the cases, the historical and real-time traffic data did yield improved unit selection and improved routing. For the incidents evaluated for this study, the historical and real-time travel time data did not yield any differences in unit selection or recommended routing to the scene. Using real-time travel time data is obviously preferable for dispatching agencies to use, even if it provides a benefit for only a small number of cases, however, in rural areas or for agencies with limited budgets, historical travel time data can be purchased far more cheaply and will yield the same benefits as real-time data in most cases.

To evaluate the impact that ITS technologies could have on secondary congestion, we used historical travel time data for Interstate 65 in Birmingham to analyze major emergency incidents over a one month period. Our analysis found that shortening total incident response by just 5 minutes would reduce total incident-related delay by approximately 10%. Reducing total response time (from dispatch to clearance) at major incidents by 15 minutes would reduce associated vehicle delays by over 30%. It is not specified which combination of technologies will achieve these savings. In most cases, emergency response agencies will need to select those technologies that address their environment and needs. The findings indicated that on average each minute of total response that could be eliminated would result in a 2-3% reduction in total incident induced delay.

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